PostgreSQL Programmer’s Guide

The PostgreSQL Development Team

Edited by

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Summary

Postgres, developed originally in the UC Berkeley Computer Science Department, pioneered many of the object-relational concepts now becoming available in some commercial databases. It provides SQL92/SQL3 language support, transaction integrity, and type extensibility. PostgreSQL is a public-domain, open source descendant of this original Berkeley code.

Chapter 1. Introduction

This document is the programmer's manual for the PostgreSQL database management system, originally developed at the University of California at Berkeley. PostgreSQL is based on Postgres release 4.2. The Postgres project, led by Professor Michael Stonebraker, has been sponsored by the Defense Advanced Research Projects Agency (DARPA), the Army Research Office (ARO), the National Science Foundation (NSF), and ESL, Inc.

The first part of this manual explains the Postgres approach to extensibility and describe how users can extend Postgres by adding user-defined types, operators, aggregates, and both query language and programming language functions. After a discussion of the Postgres rule system, we discuss the trigger and SPI interfaces. The manual concludes with a detailed description of the programming interfaces and support libraries for various languages.

We assume proficiency with UNIX and C programming.

Resources

This manual set is organized into several parts:

Tutorial

  An introduction for new users. Does not cover advanced features.

User's Guide

  General information for users, including available commands and data types.

Programmer's Guide

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

Administrator's Guide

  Installation and management information. List of supported machines.

Developer's Guide

  Information for Postgres developers. This is intended for those who are contributing to the Postgres project; application development information should appear in the Programmer's Guide. Currently included in the Programmer's Guide.

Reference Manual

  Detailed reference information on command syntax. Currently included in the User's Guide.

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

man pages

  The man pages have general information on command syntax.

FAQs

  The Frequently Asked Questions (FAQ) documents address both general issues and some platform-specific issues.

READMEs

  README files are available for some contributed packages.

Web Site

The Postgres web site has some information not appearing in the distribution. There is a mhonarc catalog of mailing list traffic which is a rich resource for many topics.

Mailing Lists

The Postgres Questions mailing list is a good place to have user questions answered. Other mailing lists are available; consult the web page for details.

Yourself!

Postgres is an open source product. As such, it depends on the user community for ongoing support. As you begin to use Postgres, 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 it. 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 Postgres Documentation mailing list is the place to get going.

Terminology

In the following documentation, site may be interpreted as the host machine on which Postgres is installed. Since it is possible to install more than one set of Postgres databases on a single host, this term more precisely denotes any particular set of installed Postgres binaries and databases.

The Postgres superuser is the user named postgres who owns the Postgres binaries and database files. As the database superuser, all protection mechanisms may be bypassed and any data accessed arbitrarily. In addition, the Postgres superuser is allowed to execute some support programs which are generally not available to all users. Note that the Postgres superuser is not the same as the Unix superuser (which will be referred to as root). The superuser should have a non-zero user identifier (UID) for security reasons.

The database administrator or DBA, is the person who is responsible for installing Postgres with mechanisms to enforce a security policy for a site. The DBA can add new users by the method described below and maintain a set of template databases for use by createdb.

The postmaster is the process that acts as a clearing-house for requests to the Postgres system. Frontend applications connect to the postmaster, which keeps tracks of any system errors and communication between the backend processes. The postmaster can take several command-line arguments to tune its behavior. However, supplying arguments is necessary only if you intend to run multiple sites or a non-default site.

The Postgres backend (the actual executable program postgres) may be executed directly from the user shell by the Postgres super-user (with the database name as an argument). However, doing this bypasses the shared buffer pool and lock table associated with a postmaster/site, therefore this is not recommended in a multiuser site.

Notation

... or /usr/local/pgsql/ at the front of a file name is used to represent the path to the Postgres superuser's home directory.

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.

In examples, parentheses ((and)) are used to group boolean expressions. | is the boolean operator OR.

Examples will show commands executed from various accounts and programs. Commands executed from the root account will be preceeded with > . Commands executed from the Postgres superuser account will be preceeded with % , while commands executed from an unprivileged user's account will be preceeded with $. SQL commands will be preceeded with => or will have no leading prompt, depending on the context.

> Note: At the time of writing (Postgres v6.4) the notation for flagging commands is not universally consistant throughout the documentation set. Please report problems to the Documentation Mailing List.

Y2K Statement

> Author: Written by Thomas Lockhart on 1998-10-22.

The PostgreSQL Global Development Team provides the Postgres software code tree as a public service, without warranty and without liability for it's behavior or performance. However, at the time of writing:

- The author of this statement, a volunteer on the Postgres support team since November, 1996, is not aware of any problems in the Postgres code base related to time transitions around Jan 1, 2000 (Y2K).
- The author of this statement is not aware of any reports of Y2K problems uncovered in regression testing or in other field use of recent or current versions of Postgres. We might have expected to hear about problems if they existed, given the installed base and the active participation of users on the support mailing lists.
- To the best of the author's knowledge, the assumptions Postgres makes about dates specified with a two-digit year are documented in the current User's Guide in the chapter on data types. For two-digit years, the significant transition year is 1970, not 2000; i.e. 70-01-01 is interpreted as 1970-01-01 , whereas 69-01-01 is interpreted as 2069-01-01 .
- Any Y2K problems in the underlying OS related to obtaining "the current time" may propagate into apparent Y2K problems in Postgres.

Refer to The Gnu Project and The Perl Institute for further discussion of Y2K issues, particularly as it relates to open source, no fee software.

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Chapter 2. Architecture

Postgres Architectural Concepts

Before we continue, you should understand the basic Postgres system architecture. Understanding how the parts of Postgres interact will make the next chapter somewhat clearer. In database jargon, Postgres uses a simple "process per-user" client/server model. A Postgres session consists of the following cooperating UNIX processes (programs):

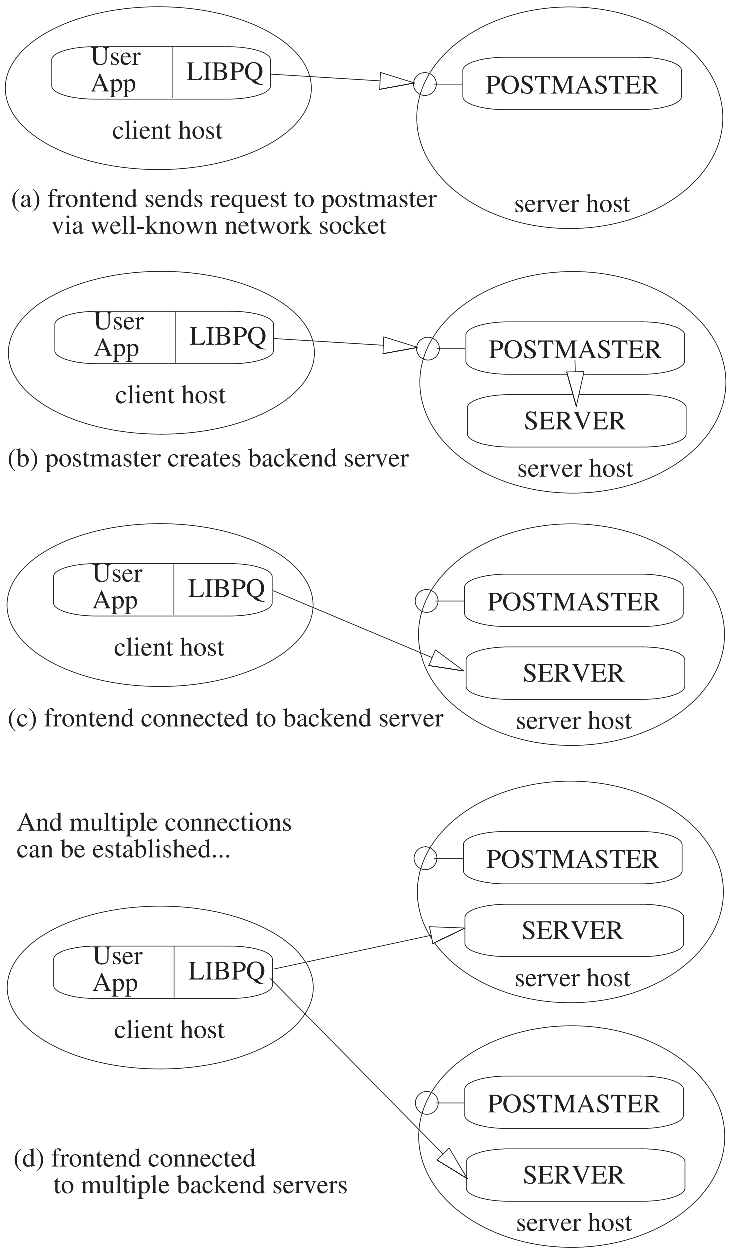
A supervisory daemon process (postmaster),

the user's frontend application (e.g., the psql program), and

the 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 an installation or site. Frontend applications that wish to access a given database within an installation make calls to the library. The library sends user requests over the network to the postmaster (*How a connection is established*(a)), which in turn starts a new backend server process (*How a connection is established*(b)) and connects the frontend process to the new server (*How a connection is established*(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 requests, whereas frontend and backend processes come and go. The libpq library allows a single frontend to make multiple connections to backend processes. However, the frontend application is still a single-threaded process. Multithreaded frontend/backend connections are not currently supported in libpq. 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 filename) on the database server machine. You should also be aware that the postmaster and postgres servers run with the user-id of the Postgres "superuser." Note that the Postgres superuser does not have to be a special user (e.g., a user named "postgres"), although many systems are installed that way. Furthermore, the Postgres superuser should definitely not be the UNIX superuser, "root"! In any case, all files relating to a database should belong to this Postgres superuser.

Figure 2-1. How a connection is established



Chapter 3. Extending SQL: An Overview

In the sections that follow, we will discuss how you can extend the Postgres SQL query language by adding:

functions
types
operators
aggregates

How Extensibility Works

Postgres 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 classes, like any other, but the DBMS stores its internal bookkeeping in them. One key difference between Postgres and standard relational systems is that Postgres 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 classes can be modified by the user, and since Postgres bases its internal operation on these classes, this means that Postgres 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.

Postgres 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 compiled .o file or shared library) that implements a new type or function and Postgres will load it as required. Code written in SQL are even more trivial to add to the server. This ability to modify its operation "on the fly" makes Postgres uniquely suited for rapid prototyping of new applications and storage structures.

The Postgres Type System

The Postgres 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"; Postgres 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 class. EMP is an example of a composite type.

Postgres stores these types in only one way (within the file that stores all instances of the class) but the user can "look inside" at the attributes of these types from the query language and optimize their retrieval by (for example) defining indices on the attributes. Postgres 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 below.

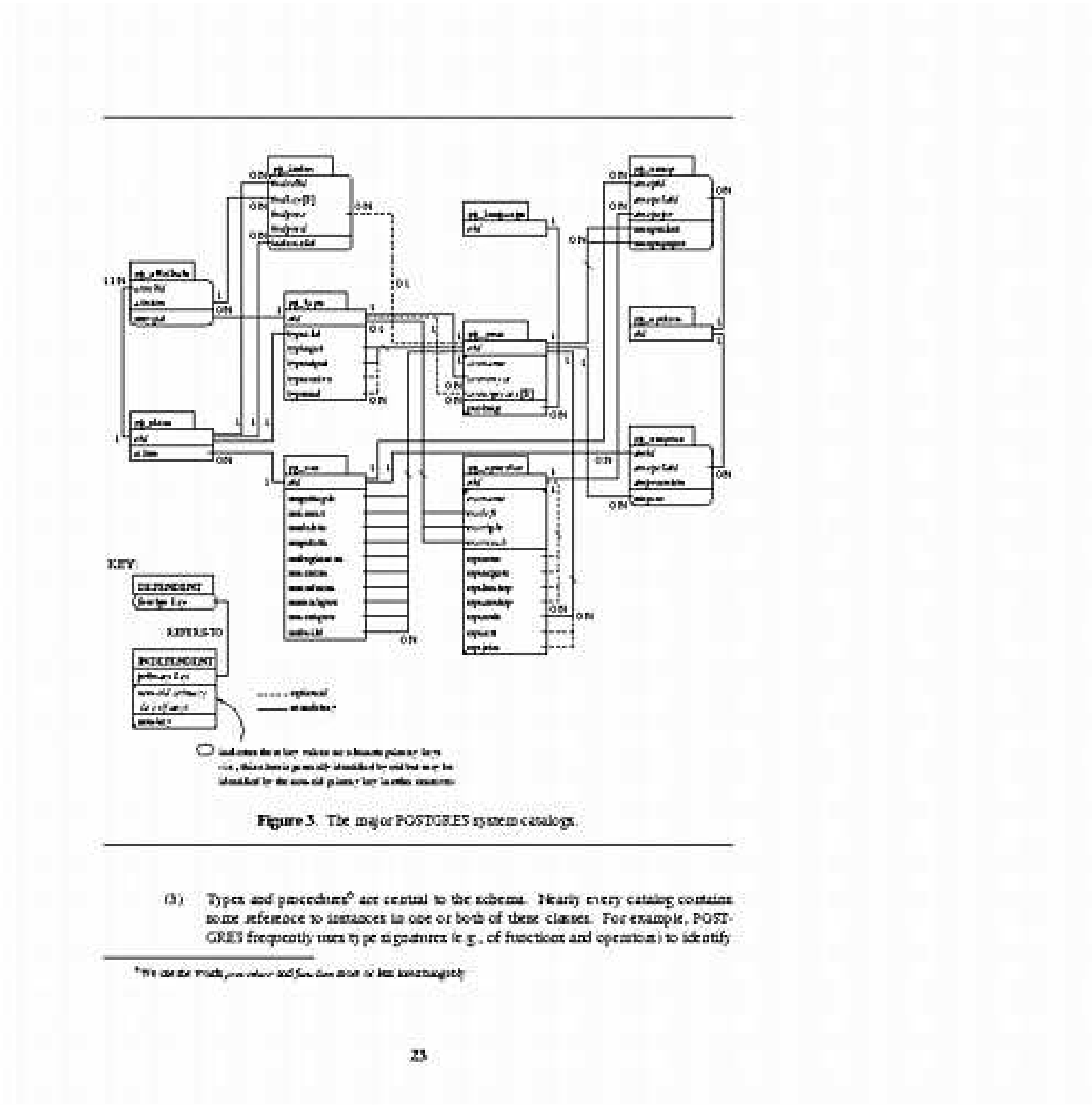
About the Postgres System Catalogs

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 classes 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 3-1. Postgres System Catalogs

Catalog Name	Description
pg_database	databases
pg_class	classes
pg_attribute	class attributes
pg_index	secondary indices
pg_proc	procedures (both C and SQL)
pg_type	types (both base and complex)
pg_operator	operators
pg_aggregate	aggregates and aggregate functions
pg_am	access methods
pg_amop	access method operators
pg_amproc	access method support functions
pg_opclass	access method operator classes

Figure 3-1. The major Postgres system catalogs



The Reference Manual gives a more detailed explanation of these catalogs and their attributes. However, *The major Postgres system catalogs* shows the major entities and their relationships in the system catalogs. (Attributes 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 attributes used in the queries form foreign keys in other classes.

Many different features (classes, attributes, 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 interchangably.

Nearly every catalog contains some reference to instances in one or both of these classes. For example, Postgres frequently uses type signatures (e.g., of functions and operators) to identify unique instances of other catalogs.

There are many attributes and relationships that have obvious meanings, but there are many (particularly those that have to do with access methods) that do not. The relationships between pg_am, pg_amop, pg_amproc, pg_operator and pg_opclass are particularly hard to understand and will be described in depth (in the section on interfacing types and operators to indices) after we have discussed basic extensions.

Chapter 4. Extending SQL: Functions

As it turns out, part of defining a new type is the definition of functions that describe its behavior. Consequently, while it is possible to define a new function without defining a new type, the reverse is not true. We therefore describe how to add new functions to Postgres before describing how to add new types. Postgres SQL provides two types of functions: query language functions (functions written in SQL and programming language functions (functions written in a compiled programming language such as C.) Either kind of function can take a base type, a composite type or some combination as arguments (parameters). In addition, both kinds of functions can return a base type or a composite type. It's easier to define SQL functions, so we'll start with those. Examples in this section can also be found in funcs.sql and C-code/funcs.c.

Query Language (SQL) Functions

SQL Functions on Base Types

The simplest possible SQL function has no arguments and simply returns a base type, such as int4:

```
CREATE FUNCTION one() RETURNS int4
 AS 'SELECT 1 as RESULT' LANGUAGE 'sql';

SELECT one() AS answer;

     +-------+
     |answer |
     +-------+
     |1      |
     +-------+
```

Notice that we defined a target list for the function (with the name RESULT), but the target list of the query that invoked the function overrode the function's target list. Hence, the result is labelled answer instead of one.

It's 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(int4, int4) RETURNS int4
 AS 'SELECT $1 + $2;' LANGUAGE 'sql';

SELECT add_em(1, 2) AS answer;

     +-------+
     |answer |
     +-------+
     |3      |
     +-------+
```

SQL Functions on Composite Types

When specifying functions with arguments of composite types (such as EMP), 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, take the function double_salary that computes what your salary would be if it were doubled.

```
CREATE FUNCTION double_salary(EMP) RETURNS int4
 AS 'SELECT $1.salary * 2 AS salary;' LANGUAGE 'sql';
```

```
SELECT name, double_salary(EMP) AS dream
 FROM EMP
 WHERE EMP.dept = 'toy';

     +-----+-------+
     |name | dream |
     +-----+-------+
     |Sam  | 2400  |
     +-----+-------+
```

Notice the use of the syntax $1.salary. Before launching into the subject of functions that return composite types, we must first introduce the function notation for projecting attributes. The simple way to explain this is that we can usually use the notation attribute(class) and class.attribute interchangably.

```
--
-- 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       |
     +----------+
```

As we shall see, however, this is not always the case. This function notation is important when we want to use a function that returns a single instance. We do this by assembling the entire instance within the function, attribute by attribute. This is an example of a function that returns a single EMP instance:

```
CREATE FUNCTION new_emp() RETURNS EMP
 AS 'SELECT \'None\'::text AS name,
  1000 AS salary,
  25 AS age,
  \'none\'::text AS dept;'
  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. Defining a function like this can be tricky. Some of the more important caveats are as follows:

The target list order must be exactly the same as that in which the attributes appear in the CREATE TABLE statement (or when you execute a .* query).

You must typecast the expressions (using ::) very carefully or you will see the following error:

```
            WARN::function declared to return type EMP does not
retrieve (EMP.*)
```

When calling a function that returns an instance, we cannot retrieve the entire instance. We must either project an attribute out of the instance or pass the entire instance into another function.

```
SELECT name(new_emp()) AS nobody;

        +-------+
        |nobody |
        +-------+
        |None   |
        +-------+
```

The reason why, in general, we must use the function syntax for projecting attributes of function return values is that the parser just doesn't understand the other (dot) syntax for projection when combined with function calls.

```
SELECT new_emp().name AS nobody;
WARN:parser: syntax error at or near "."
```

Any collection of commands in the SQL query language can be packaged together and defined as a function. The commands can include updates (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 returntype.

```
CREATE FUNCTION clean_EMP () RETURNS int4
 AS 'DELETE FROM EMP WHERE EMP.salary <= 0;
SELECT 1 AS ignore_this'
 LANGUAGE 'sql';

SELECT clean_EMP();

     +--+
     |x |
     +--+
     |1 |
     +--+
```

Programming Language Functions

Programming Language Functions on Base Types

Internally, Postgres 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 Postgres can operate on it. That is, Postgres 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 (even if your computer supports by-value types of other sizes). Postgres itself only passes integer types by value. 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 (though not on most personal computers). A reasonable implementation of the int4 type on UNIX machines might be:

```
/* 4-byte integer, passed by value */
typedef int int4;
```

On the other hand, fixed-length types of any size may be passed by-reference. For example, here is a sample implementation of a Postgres type:

```
/* 16-byte structure, passed by reference */
typedef struct {
    char data[16];
} char16;
```

Only pointers to such types can be used when passing them in and out of Postgres functions. 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 is not long enough to hold all possible strings -- it's impossible to declare such a structure in C. When manipulating variable-length types, we must be careful to allocate the correct amount of memory and initialize the length field. 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;
memmove(destination->data, buffer, 40);
...
```

Now that we've gone over all of the possible structures for base types, we can show some examples of real functions. Suppose funcs.c look like:

```
#include <string.h>
#include "postgres.h"
int
add_one(int arg)
{
    return(arg + 1);
}
text *
concat_text(text *arg1, text *arg2)
{
    int32 new_text_size = VARSIZE(arg1) + VARSIZE(arg2) -
VARHDRSZ;
    text *new_text = (text *) palloc(new_text_size);

    memset((void *) new_text, 0, new_text_size);
    VARSIZE(new_text) = new_text_size;
    strncpy(VARDATA(new_text), VARDATA(arg1),
VARSIZE(arg1)-VARHDRSZ);
    strncat(VARDATA(new_text), VARDATA(arg2),
VARSIZE(arg2)-VARHDRSZ);
    return (new_text);
}
text *
copytext(text *t)
{
    /*
     * VARSIZE is the total size of the struct in bytes.
     */
    text *new_t = (text *) palloc(VARSIZE(t));
    memset(new_t, 0, VARSIZE(t));
    VARSIZE(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);
}
```

On OSF/1 we would type:

```
CREATE FUNCTION add_one(int4) RETURNS int4
     AS 'PGROOT/tutorial/obj/funcs.so' LANGUAGE 'c';
```

```
CREATE FUNCTION concat_text(text, text) RETURNS text
     AS 'PGROOT/tutorial/obj/funcs.so' LANGUAGE 'c';

CREATE FUNCTION copytext(text) RETURNS text
     AS 'PGROOT/tutorial/obj/funcs.so' LANGUAGE 'c';
```

On other systems, we might have to make the filename end in .sl (to indicate that it's a shared library).

Programming Language Functions on Composite Types

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, Postgres provides a procedural interface for accessing fields of composite types from C. As Postgres processes a set of instances, each instance 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 "libpq-fe.h" /* for TUPLE */
bool
c_overpaid(TUPLE t,/* the current instance of EMP */
           int4 limit)
{
    bool isnull = false;
    int4 salary;
    salary = (int4) GetAttributeByName(t, "salary", &isnull);
    if (isnull)
        return (false);
    return(salary > limit);
}
```

GetAttributeByName is the Postgres system function that returns attributes out of the current instance. It has three arguments: the argument of type TUPLE passed into the function, the name of the desired attribute, and a return parameter that describes whether the attribute is null. GetAttributeByName will align data properly so you can cast its return value to the desired type. For example, if you have an attribute name which is of the type name, the GetAttributeByName call would look like:

```
char *str;
...
str = (char *) GetAttributeByName(t, "name", &isnull)
```

The following query lets Postgres know about the c_overpaid function:

```
* CREATE FUNCTION c_overpaid(EMP, int4) RETURNS bool
     AS 'PGROOT/tutorial/obj/funcs.so' LANGUAGE 'c';
```

While there are ways to construct new instances or modify existing instances from within a C function, these are far too complex to discuss in this manual.

Caveats

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 and the malloc memory manager) before trying to write C functions for use with Postgres. While it may be possible to load functions written in languages other than C into Postgres, 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:

Most of the header (include) files for Postgres should already be installed in PGROOT/include (see Figure 2). You should always include

```
-I$PGROOT/include
```

on your cc command lines. Sometimes, you may find that you require header files that are in the server source itself (i.e., you need a file we neglected to install in include). In those cases you may need to add one or more of

```
-I$PGROOT/src/backend
-I$PGROOT/src/backend/include
-I$PGROOT/src/backend/port/<PORTNAME>
-I$PGROOT/src/backend/obj
```

(where <PORTNAME> is the name of the port, e.g., alpha or sparc).

When allocating memory, use the Postgres 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 Postgres types are declared in postgres.h, so it’s a good idea to always include that file as well. Including postgres.h will also include elog.h and palloc.h for you.

Compiling and loading your object code so that it can be dynamically loaded into Postgres always requires special flags. See Appendix A for a detailed explanation of how to do it for your particular operating system.

Chapter 5. Extending SQL: Types

As previously mentioned, there are two kinds of types in Postgres: base types (defined in a programming language) and composite types (instances). Examples in this section up to interfacing indices can be found in complex.sql and complex.c. Composite examples are in funcs.sql.

User-Defined Types

Functions Needed for a User-Defined Type

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-delimited 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 delimited character string. Suppose we want to define a complex type which represents complex numbers. Naturally, we 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. These 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!

```
Complex *
complex_in(char *str)
{
    double x, y;
    Complex *result;
    if (sscanf(str, " ( %lf , %lf )", &x, &y) != 2) {
        elog(WARN, "complex_in: error in parsing
        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(opaque)
   RETURNS complex
   AS 'PGROOT/tutorial/obj/complex.so'
   LANGUAGE 'c';

CREATE FUNCTION complex_out(opaque)
   RETURNS opaque
   AS 'PGROOT/tutorial/obj/complex.so'
   LANGUAGE 'c';

CREATE TYPE complex (
   internallength = 16,
   input = complex_in,
   output = complex_out
);
```

As discussed earlier, Postgres fully supports arrays of base types. Additionally, Postgres supports arrays of user-defined types as well. When you define a type, Postgres 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.

Large Objects

The types discussed to this point are all "small" objects -- that is, they are smaller than 8KB in size.

> Note: 1024 longwords == 8192 bytes. In fact, the type must be considerably smaller than 8192 bytes, since the Postgres tuple and page overhead must also fit into this 8KB limitation. The actual value that fits depends on the machine architecture.

If you require a larger type for something like a document retrieval system or for storing bitmaps, you will need to use the Postgres large object interface.

Chapter 6. Extending SQL: Operators

Postgres supports left unary, right unary and binary operators. Operators can be overloaded, or re-used with different numbers and types of arguments. If there is an ambiguous situation and the system cannot determine the correct operator to use, it will return an error and you may have to typecast the left and/or right operands to help it understand which operator you meant to use. To create an operator for adding two complex numbers can be done as follows. First we need to create a function to add the new types. Then, we can create the operator with the function.

```
CREATE FUNCTION complex_add(complex, complex)
   RETURNS complex
   AS '$PWD/obj/complex.so'
   LANGUAGE 'c';

CREATE OPERATOR + (
   leftarg = complex,
   rightarg = complex,
   procedure = complex_add,
   commutator = +
);
```

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). If we give the system enough type information, it can automatically figure out which operators to use.

```
SELECT (a + b) AS c FROM test_complex;

+----------------+
|c               |
+----------------+
|(5.2,6.05)      |
+----------------+
|(133.42,144.95) |
+----------------+
```

Chapter 7. Extending SQL: Aggregates

Aggregates in Postgres are expressed in terms of state transition functions. That is, an aggregate can be defined in terms of state that is modified whenever an instance is processed. Some state functions look at a particular value in the instance when computing the new state (sfunc1 in the create aggregate syntax) while others only keep track of their own internal state (sfunc2). If we define an aggregate that uses only sfunc1, we define an aggregate that computes a running function of the attribute values from each instance. "Sum" is an example of this kind of aggregate. "Sum" starts at zero and always adds the current instance's value to its running total. We will use the int4pl that is built into Postgres to perform this addition.

```
CREATE AGGREGATE complex_sum (
     sfunc1 = complex_add,
     basetype = complex,
     stype1 = complex,
     initcond1 = '(0,0)'
  );

SELECT complex_sum(a) FROM test_complex;

+------------+
|complex_sum |
+------------+
|(34,53.9)   |
+------------+
```

If we define only sfunc2, we are specifying an aggregate that computes a running function that is independent of the attribute values from each instance. "Count" is the most common example of this kind of aggregate. "Count" starts at zero and adds one to its running total for each instance, ignoring the instance value. Here, we use the built-in int4inc routine to do the work for us. This routine increments (adds one to) its argument.

```
 CREATE AGGREGATE my_count (sfunc2 = int4inc, -- add one
    basetype = int4, stype2 = int4,
    initcond2 = '0'
);

 SELECT my_count(*) as emp_count from EMP;

 +----------+
 |emp_count |
 +----------+
 |5         |
 +----------+
```

"Average" is an example of an aggregate that requires both a function to compute the running sum and a function to compute the running count. When all of the instances have been processed, the final answer for the aggregate is the running sum divided by the running count. We use the int4pl and int4inc routines we used before as well as the Postgres integer division routine, int4div, to compute the division of the sum by the count.

```
CREATE AGGREGATE my_average (sfunc1 = int4pl, --  sum
                        basetype = int4,
                        stype1 = int4,
                        sfunc2 = int4inc, -- count
                        stype2 = int4,
                            finalfunc = int4div, -- division
                        initcond1 = '0',
                        initcond2 = '0')
```

```
SELECT my_average(salary) as emp_average FROM EMP;

+------------+
|emp_average |
+------------+
|1640        |
+------------+
```

Chapter 8. The Postgres Rule System

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 Postgres rule system can be found in [*Stonebraker et al, ACM, 1990*].

Some other database systems define active database rules. These are usually stored procedures and triggers and are implemented in Postgres 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 optimizer for 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 [*Ong and Goh, 1990*] as well as [*Stonebraker et al, ACM, 1990*].

What is a Querytree?

To understand how the rule system works it is necessary to know when it is invoked and what it's input and results are.

The rule system is located between the query parser and the optimizer. It takes the output of the parser, one querytree, and the rewrite rules from the pg_rewrite catalog, which are querytrees too with some extra information, and creates zero or many querytrees as result. So it's 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 querytree? It is an internal representation of an SQL statement where the single parts that built it are stored separately. These querytrees are visible when starting the Postgres backend with debuglevel 4 and typing queries into the interactive backend interface. The rule actions in the pg_rewrite system catalog are also stored as querytrees. They are not formatted like the debug output, but they contain exactly the same information.

Reading a querytree 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 targetlist, water and coffee powder in a rangetable and all the buttons in a qualification expression. Since SQL representations of querytrees 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.

The Parts of a Querytree

When reading the SQL representations of the querytrees in this document it is necessary to be able to identify the parts the statement is broken into when it is in the querytree structure. The parts of a querytree are

the commandtype

: This is a simple value telling which command (SELECT, INSERT, UPDATE, DELETE) produced the parsetree.

the rangetable

: The rangtable is a list of relations that are used in the query. In a SELECT statement that are the relations given after the FROM keyword.

: Every rangetable entry identifies a table or view and tells by which name it is called in the other parts of the query. In the querytree the rangetable 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 rangetables of rules have been merged in. The examples in this document will not have this situation.

the resultrelation

This is an index into the rangetable 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 resultrelation is the table (or view!) where the changes take effect.

the targetlist

The targetlist 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).

DELETE queries don't need a targetlist because they don't produce any result. In fact the optimizer will add a special entry to the empty targetlist. But this is after the rule system and will be discussed later. For the rule system the targetlist is empty.

In INSERT queries the targetlist describes the new rows that should go into the resultrelation. Missing columns of the resultrelation will be added by the optimizer with a constant NULL expression. It are the expressions in the VALUES clause or the ones from the SELECT clause on INSERT ... SELECT.

On UPDATE queries, it describes the new rows that should replace the old ones. Here now the optimizer will add missing columns by inserting expressions that put the values from the old rows into the new one. And it will add the special entry like for DELETE too. It are the expressions from the SET attribute = expression part of the query.

Every entry in the targetlist contains an expression that can be a constant value, a variable pointing to an attribute of one of the relations in the rangetable, a parameter or an expression tree made of function calls, constants, variables, operators etc.

the qualification

The queries qualification is an expression much like one of those contained in the targetlist 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 others

The other parts of the querytree like the ORDER BY clause arent 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. GROUP BY is a special thing when it appears in a view definition and still needs to be documented.

Views and the Rule System

Implementation of Views in Postgres

Views in Postgres are implemented using the rule system. In fact there is absolutely 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 "_RETmyview" 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 Postgres system catalogs is exactly the same as it is for a table. So for the query parsers, there is absolutely no difference between a table and a view. They are the same thing - relations. That is the important one for now.

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 parsetree in place instead of creating a new one. So SELECT rules are described first.

Currently, there could be only one action and it must be a 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 example 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 on 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 descripitons 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 queries rangetable. The rule has no rule qualification (discussed in 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 rules action has a qualification.

The rules action is one querytree that is an exact 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 querytree) 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 parsetree

```
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 rangetable and checks if there are rules in pg_rewrite for any relation. When processing the rangetable entry for shoelace (the only one up to now) it finds the rule '_RETshoelace' with the parsetree

```
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. The first step in rewriting is merging the two rangetables. The resulting parsetree then reads

```
SELECT shoelace.sl_name, shoelace.sl_avail,
       shoelace.sl_color, shoelace.sl_len,
       shoelace.sl_unit, shoelace.sl_len_cm
  FROM shoelace shoelace, shoelace *OLD*,
       shoelace *NEW*, shoelace_data s,
       unit u;
```

In step 2 it adds the qualification from the rule action to the parsetree resulting in

```
SELECT shoelace.sl_name, shoelace.sl_avail,
       shoelace.sl_color, shoelace.sl_len,
       shoelace.sl_unit, shoelace.sl_len_cm
  FROM shoelace shoelace, shoelace *OLD*,
       shoelace *NEW*, shoelace_data s,
       unit u
 WHERE bpchareq(s.sl_unit, u.un_name);
```

And in step 3 it replaces all the variables in the parsetree, that reference the rangetable entry (the one for shoelace that is currently processed) by the corresponding targetlist expressions from the rule action. This results in the final query

```
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 shoelace, shoelace *OLD*,
       shoelace *NEW*, shoelace_data s,
       unit u
 WHERE bpchareq(s.sl_unit, u.un_name);
```

Turning this back into a real SQL statement a human user would type reads

```
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;
```

That was the first rule applied. While this was done, the rangetable has grown. So the rule system continues checking the range table entries. The next one is number 2 (shoelace *OLD*). Relation shoelace has a rule, but this rangetable entry isn't referenced in any of the variables of the parsetree, so it is ignored. Since all the remaining rangetable entries either have no rules in pg_rewrite or aren't referenced, it reaches the end of the rangetable. Rewriting is complete and the above is the final result given into the optimizer. The optimizer ignores the extra rangetable entries that aren't referenced by variables in the parsetree and the plan produced by the planner/optimizer would be exactly the same as if Al had typed the above SELECT query instead of the view selection.

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 theach him how 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 parsetree

```
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 that one for the shoe_ready relation and it results in the parsetree

```
SELECT rsh.shoename, rsh.sh_avail,
       rsl.sl_name, rsl.sl_avail,
       min(rsh.sh_avail, rsl.sl_avail) AS total_avail
  FROM shoe_ready shoe_ready, shoe_ready *OLD*,
       shoe_ready *NEW*, shoe rsh,
       shoelace rsl
 WHERE int4ge(min(rsh.sh_avail, rsl.sl_avail), 2)
   AND (bpchareq(rsl.sl_color, rsh.slcolor)
        AND float8ge(rsl.sl_len_cm, rsh.slminlen_cm)
        AND float8le(rsl.sl_len_cm, rsh.slmaxlen_cm)
       );
```

In reality the AND clauses in the qualification will be operator nodes of type AND with a left and right expression. But that makes it lesser readable as it already is, and there are more rules to apply. So I only put them into some parantheses to group them into logical units in the order they where added and we continue with the rule for relation shoe as it is the next rangetable entry that is referenced and has a rule. The result of applying it is

```
SELECT sh.shoename, sh.sh_avail,
       rsl.sl_name, rsl.sl_avail,
       min(sh.sh_avail, rsl.sl_avail) AS total_avail,
  FROM shoe_ready shoe_ready, shoe_ready *OLD*,
       shoe_ready *NEW*, shoe rsh,
       shoelace rsl, shoe *OLD*,
       shoe *NEW*, shoe_data sh,
       unit un
 WHERE (int4ge(min(sh.sh_avail, rsl.sl_avail), 2)
        AND (bpchareq(rsl.sl_color, sh.slcolor)
             AND float8ge(rsl.sl_len_cm,
                          float8mul(sh.slminlen, un.un_fact))
             AND float8le(rsl.sl_len_cm,
                          float8mul(sh.slmaxlen, un.un_fact))
            )
       )
   AND bpchareq(sh.slunit, un.un_name);
```

And finally we apply the already well known rule for shoelace (this time on a parsetree that is a little more complex) and get

```
SELECT sh.shoename, sh.sh_avail,
       s.sl_name, s.sl_avail,
       min(sh.sh_avail, s.sl_avail) AS total_avail
  FROM shoe_ready shoe_ready, shoe_ready *OLD*,
       shoe_ready *NEW*, shoe rsh,
       shoelace rsl, shoe *OLD*,
       shoe *NEW*, shoe_data sh,
       unit un, shoelace *OLD*,
       shoelace *NEW*, shoelace_data s,
       unit u
 WHERE (    (int4ge(min(sh.sh_avail, s.sl_avail), 2)
             AND (bpchareq(s.sl_color, sh.slcolor)
                  AND float8ge(float8mul(s.sl_len, u.un_fact),
                               float8mul(sh.slminlen, un.un_fact))
                  AND float8le(float8mul(s.sl_len, u.un_fact),
                               float8mul(sh.slmaxlen, un.un_fact))
                 )
            )
        AND bpchareq(sh.slunit, un.un_name)
       )
   AND bpchareq(s.sl_unit, u.un_name);
```

Again we reduce it to a real SQL statement that is equivalent to the final output of the rule system:

```
SELECT sh.shoename, sh.sh_avail,
       s.sl_name, s.sl_avail,
       min(sh.sh_avail, s.sl_avail) AS total_avail
  FROM shoe_data sh, shoelace_data s, unit u, unit un
 WHERE min(sh.sh_avail, s.sl_avail) >= 2
   AND s.sl_color = sh.slcolor
   AND s.sl_len * u.un_fact >= sh.slminlen * un.un_fact
   AND s.sl_len * u.un_fact <= sh.slmaxlen * un.un_fact
   AND sh.sl_unit = un.un_name
   AND s.sl_unit = u.un_name;
```

Recursive processing of rules rewrote one SELECT from a view into a parsetree, that is equivalent to exactly that what Al had to type if there would be no views at all.

> Note: There is currently no recursion stopping mechanism for view rules in the rule system (only for the other 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 on the first CREATE VIEW, the second relation does not exist and thus the first view cannot select from the second.

View Rules in Non-SELECT Statements

Two details of the parsetree aren't touched in the description of view rules above. These are the commandtype and the resultrelation. In fact, view rules don't need these informations.

There are only a few differences between a parsetree for a SELECT and one for any other command. Obviously they have another commandtype and this time the resultrelation points to the rangetable entry where the result should go. Anything else is absolutely the same. So having two tables t1 and t2 with attributes a and b, the parsetrees 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 rangetables contain entries for the tables t1 and t2.

The targetlists contain one variable that points to attribute b of the rangetable entry for table t2.

The qualification expressions compare the attributes a of both ranges for equality.

The consequence is, that both parsetrees 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 targetlist by the optimizer and the final parsetree 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 parsetree) that this is an UPDATE, and he knows that this result should go into table t1. But which of the 666 rows that are there has to be replaced by the new row? The plan executed is a join with a qualification that potentially could produce any number of rows between 0 and 666 in unknown order.

To resolve this problem, another entry is added to the targetlist in UPDATE and DELETE statements. The current tuple ID (ctid). This is a system attribute with a special feature. It contains the block and position in the block for the row. Knowing the table, the ctid can be used to find one specific row in a 1.5GB sized table containing millions of rows by fetching one single data block. After adding the ctid to the targetlist, the final result set could be defined as

```
SELECT t1.a, t2.b, t1.ctid FROM t1, t2 WHERE t1.a = t2.a;
```

Now another detail of Postgres 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 commited the vacuum cleaner can really move it out.

Knowing that all, we can simply apply view rules in absolutely the same way to any command. There is no difference.

The Power of Views in Postgres

The above demonstrates how the rule system incorporates view definitions into the original parsetree. In the second example a simple SELECT from one view created a final parsetree that is a join of 4 tables (unit is used twice with different names).

Benefits

The benefit of implementing views with the rule system is, that the optimizer 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 parsetree. And this is still the situation when the original query is already a join over views. Now the optimizer has to decide which is the best path to execute the query. The more information the optimizer has, the better this decision can be. And the rule system as implemented in Postgres ensures, that this is all information available about the query up to now.

Concerns

There was a long time where the Postgres rule system was considered broken. The use of rules was not recommended and the only part working where view rules. And also these view rules made problems because the rule system wasn't able to apply them properly on other statements than a SELECT (for example an UPDATE that used data from a view didn't work).

During that time, development moved on and many features where added to the parser and optimizer. The rule system got more and more out of sync with their capabilities and it became harder and harder to start fixing it. Thus, noone did.

For 6.4, someone locked the door, took a deep breath and shuffled that damned thing up. What came out was a rule system with the capabilities described in this document. But there are still some constructs not handled and some where it fails due to things that are currently not supported by the Postgres query optimizer.

- Views with aggregate columns have bad problems. Aggregate expressions in qualifications must be used in subselects. Currently it is not possible to do a join of two views, each having an aggregate column, and compare the two aggregate values in the qualification. In the meantime it is possible to put these aggregate expressions into functions with the appropriate arguments and use them in the view definition.
- Views of unions are currently not supported. Well it's easy to rewrite a simple SELECT into a union. But it is a little difficult if the view is part of a join doing an update.
- ORDER BY clauses in view definitions aren't supported.
- DISTINCT isn't supported in view definitions.

There is no good reason why the optimizer should not handle parsetree constructs that the parser could never produce due to limitations in the SQL syntax. The author hopes that these items disappear in the future.

Implementation Side Effects

Using the described rule system to implement views has a funny side effect. The following does not seem to work:

```
al_bundy=> INSERT INTO shoe (shoename, sh_avail, slcolor)
al_bundy->     VALUES ('sh5', 0, 'black');
INSERT 20128 1
al_bundy=> SELECT shoename, sh_avail, slcolor FROM shoe_data;
shoename  |sh_avail|slcolor
----------+--------+----------
sh1       |       2|black
sh3       |       4|brown
sh2       |       0|black
sh4       |       3|brown
(4 rows)
```

The interesting thing is that the return code for INSERT gave us an object ID and told that 1 row has been inserted. But it doesn't appear in shoe_data. Looking into the database directory we can see, that the database file for the view relation shoe seems now to have a data block. And that is definitely the case.

We can also issue a DELETE and if it does not have a qualification, it tells us that rows have been deleted and the next vacuum run will reset the file to zero size.

The reason for that behaviour is, that the parsetree for the INSERT does not reference the shoe relation in any variable. The targetlist contains only constant values. So there is no rule to apply and it goes down unchanged into execution and the row is inserted. And so for the DELETE.

To change this we can define rules that modify the behaviour of non-SELECT queries. This is the topic of the next section.

Rules on INSERT, UPDATE and DELETE

Differences to 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 parsetree in place. Instead they create zero or many new parsetrees and can throw away the original one.

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 commandtype of a parsetree are equal to the object and event given in the CREATE RULE command. For update rules, the rule system creates a list of parsetrees. Initially the parsetree 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 parsetrees for a one-action rule.

No qualification and not INSTEAD:

: The parsetree from the rule action where the original parsetrees qualification has been added.

No qualification but INSTEAD:

: The parsetree from the rule action where the original parsetrees qualification has been added.

Qualification given and not INSTEAD:

: The parsetree from the rule action where the rule qualification and the original parsetrees qualification have been added.

Qualification given and INSTEAD:

The parsetree from the rule action where the rule qualification and the original parsetrees qualification have been added.

The original parsetree where the negated rule qualification has been added.

Finally, if the rule is not INSTEAD, the unchanged original parsetree is added to the list. Since only qualified INSTEAD rules already add the original parsetree, we end up with a total maximum of two parsetrees for a rule with one action.

The parsetrees generated from rule actions are thrown into the rewrite system again and maybe more rules get applied resulting in more or less parsetrees. So the parsetrees in the rule actions must have either another commandtype or another resultrelation. Otherwise this recursive process will end up in a loop. There is a compiled in recursion limit of currently 10 iterations. If after 10 iterations there are still update rules to apply the rule system assumes a loop over multiple rule definitions and aborts the transaction.

The parsetrees found in the actions of the pg_rewrite system catalog are only templates. Since they can reference the rangetable entries for NEW and OLD, some substitutions have to be made before they can be used. For any reference to NEW, the targetlist of the original query is searched for a corresponding entry. If found, that entries expression is placed into the reference. Otherwise NEW means the same as OLD. Any reference to OLD is replaced by a reference to the rangetable entry which is the resultrelation.

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 writes us entries every time and UPDATE is performed on shoelace_data.

```
CREATE TABLE shoelace_log (
    sl_name    char(10),      -- shoelace changed
    sl_avail   integer,       -- new available value
    log_who    name,          -- who did it
    log_when   datetime       -- 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,
                                    getpgusername(),
                                    'now'::text
                                );
```

One interesting detail is the casting of 'now' in the rules INSERT action to type text. Without that, the parser would see at CREATE RULE time, that the target type in shoelace_log is a datetime and tries to make a constant from it - with success. So a constant datetime value would be stored in the rule action and all log entries would have the time of the CREATE RULE statement. Not exactly what we want. The casting causes that the parser constructs a datetime('now'::text) from it and this will be evaluated when the rule is executed.

Now Al does

```
al_bundy=> UPDATE shoelace_data SET sl_avail = 6
al_bundy->     WHERE sl_name = 'sl7';
```

and we look at the logtable.

```
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 parsetree (this time the parts of the original parsetree 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 SELECT
       *NEW*.sl_name, *NEW*.sl_avail,
       getpgusername(), datetime('now'::text)
  FROM shoelace_data *NEW*, shoelace_data *OLD*,
       shoelace_log shoelace_log;
```

Don’t trust the output of the pg_rules system view. It specially handles the situation that there are only references to NEW and OLD in the INSERT and outputs the VALUES format of INSERT. In fact there is no difference between an INSERT ... VALUES and an INSERT ... SELECT on parsetree level. They both have rangetables, targetlists and maybe qualifications etc. The optimizer later decides, if to create an execution plan of type result, seqscan, indexscan, join or whatever for that parsetree. If there are no references to rangetable entries leftin the parsetree , it becomes a result execution plan (the INSERT ... VALUES version). The rule action above can truely result in both variants.

The rule is a qualified non-INSTEAD rule, so the rule system has to return two parsetrees. The modified rule action and the original parsetree. In the first step the rangetable of the original query is incorporated into the rules action parsetree. This results in

```
INSERT INTO shoelace_log SELECT
       *NEW*.sl_name, *NEW*.sl_avai,
       getpgusername(), datetime('now'::text)
  FROM shoelace_data shoelace_data, shoelace_data *NEW*,
       shoelace_data *OLD*, shoelace_log shoelace_log;
```

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 SELECT
       *NEW*.sl_name, *NEW*.sl_avai,
       getpgusername(), datetime('now'::text)
  FROM shoelace_data shoelace_data, shoelace_data *NEW*,
       shoelace_data *OLD*, shoelace_log shoelace_log
 WHERE int4ne(*NEW*.sl_avail, *OLD*.sl_avail);
```

In step 3 the original parsetrees qualification is added, restricting the resultset further to only the rows touched by the original parsetree.

```
INSERT INTO shoelace_log SELECT
       *NEW*.sl_name, *NEW*.sl_avai,
       getpgusername(), datetime('now'::text)
  FROM shoelace_data shoelace_data, shoelace_data *NEW*,
       shoelace_data *OLD*, shoelace_log shoelace_log
 WHERE int4ne(*NEW*.sl_avail, *OLD*.sl_avail)
   AND bpchareq(shoelace_data.sl_name, 'sl7');
```

Step 4 substitutes NEW references by the targetlist entries from the original parsetree or with the matching variable references from the result relation.

```
INSERT INTO shoelace_log SELECT
       shoelace_data.sl_name, 6,
       getpgusername(), datetime('now'::text)
  FROM shoelace_data shoelace_data, shoelace_data *NEW*,
       shoelace_data *OLD*, shoelace_log shoelace_log
 WHERE int4ne(6, *OLD*.sl_avail)
   AND bpchareq(shoelace_data.sl_name, 'sl7');
```

Step 5 replaces OLD references into resultrelation references.

```
INSERT INTO shoelace_log SELECT
       shoelace_data.sl_name, 6,
       getpgusername(), datetime('now'::text)
  FROM shoelace_data shoelace_data, shoelace_data *NEW*,
       shoelace_data *OLD*, shoelace_log shoelace_log
 WHERE int4ne(6, shoelace_data.sl_avail)
   AND bpchareq(shoelace_data.sl_name, 'sl7');
```

That's it. So reduced to the max the return from the rule system is a list of two parsetrees that are the same as the statements:

```
INSERT INTO shoelace_log SELECT
       shoelace_data.sl_name, 6,
       getpgusername(), 'now'
  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 subtitutions and the qualifications added ensure, that if the original query would be an

```
UPDATE shoelace_data SET sl_color = 'green'
 WHERE sl_name = 'sl7';
```

No log entry would get written because due to the fact that this time the original parsetree does not contain a targetlist entry for sl_avail, NEW.sl_avail will get replaced by shoelace_data.sl_avail resulting in the extra query

```
INSERT INTO shoelace_log SELECT
       shoelace_data.sl_name, shoelace_data.sl_avail,
       getpgusername(), 'now'
  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. Since the is no difference on parsetree level between an INSERT ... SELECT, and an INSERT ... VALUES, 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 parsetrees qualification is different and that results in the extra parsetree

```
INSERT INTO shoelace_log SELECT
       shoelace_data.sl_name, 0,
       getpgusername(), 'now'
  FROM shoelace_data
 WHERE 0 != shoelace_data.sl_avail
   AND shoelace_data.sl_color = 'black';
```

This parsetree will surely insert three new log entries. And that's absolutely correct.

It is important, that the original parsetree is executed last. The Postgres "traffic cop" does a command counter increment between the execution of the two parsetrees so the second one can see changes made by the first. 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.

Cooperation with Views

A simple way to protect view relations from the mentioned possibility that someone can INSERT, UPDATE and DELETE invisible data on them is to let those parsetrees 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 parsetrees 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.

> Note: This fact might irritate frontend applications because absolutely nothing happened on the database and thus, the backend will not return anything for the query. Not even a PGRES_EMPTY_QUERY or so will be available in libpq. In psql, nothing happens. This might change in the future.

A more sophisticated way to use the rule system is to create rules that rewrite the parsetree 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 partlist. 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 partlist and one with a special trick. The create commands for anything 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 that what's on the part list. We take a quick look at the current data,

```
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
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 it's description will be the last in this document (but not the last example :-). First there was the parsers 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 parsetree is trashed. Note that this query sill uses the view shoelace But the rule system isn't finished with this loop so it continues and applies the rule '_RETshoelace' 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 what produces the extra parsetree

```
    INSERT INTO shoelace_log SELECT
           s.sl_name,
           int4pl(s.sl_avail, shoelace_arrive.arr_quant),
           getpgusername(),
           datetime('now'::text)
      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 parsetrees. So we end up with two final parsetrees that are equal to the SQL statements

```
    INSERT INTO shoelace_log SELECT
           s.sl_name,
           s.sl_avail + shoelace_arrive.arr_quant,
           getpgusername(),
           'now'
      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 rangetable where it could definitely be reduced to one. The optimizer 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 rangetable 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 Postgres rule system and it's 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);
```

It's 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 debt Al before we can throw 'em away, but that's another problem. The pink entry we delete. To make it a little harder for Postgres, 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);
```

Voila:

```
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 parsetree 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.

Rules and Permissions

Due to rewriting of queries by the Postgres 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 Postgres rule system changes the behaviour of the default access control system. Relations that are used due to rules get checked during the rewrite against the permissions of the relation owner, the rule is defined on. 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 still performed, so nobody than 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 successfull. 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.

Rules versus Triggers

Many things that can be done using triggers can also be implemented using the Postgres 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 parsetree 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 indices setup, the optimizer 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 optimizer 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 indices. And it depends on the overall size of the software table if the rule will still be faster in the seqscan 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 Nestloop over two IndexScan's. 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 are cases on UPDATE where it depends on the change of an attribute if an action should be performed or not. In Postgres version 6.4, the attribute specification for rule events is disabled (it will have it's 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 allways, even if the attribute of interest cannot change at all because it does not appear in the targetlist 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 it's actions will only be done when a specific attribute is updated is hidden in it's 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 it's decision. The rule system will know it by looking up the targetlist and will suppress the additional query completely if the attribute isn't touched. So the rule, qualified or not, will only do it's scan's if there ever could be something to do.

Rules will only be significant slower than triggers if their actions result in large and bad qualified joins, a situation where the optimizer 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 9. Interfacing Extensions To Indices

The procedures described thus far let you define a new type, 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 or its operators.

Look back at *The major Postgres system catalogs*. The right half shows the catalogs that we must modify in order to tell Postgres how to use a user-defined type and/or user-defined operators with an index (i.e., pg_am, pg_amop, pg_amproc and pg_opclass). Unfortunately, there is no simple command to do this. We will demonstrate how to modify these catalogs through a running example: a new operator class for the B-tree access method that sorts integers in ascending absolute value order.

The pg_am class contains one instance for every user defined access method. Support for the heap access method is built into Postgres, but every other access method is described here. The schema is

Table 9-1. Index Schema

Attribute	Description
amname	name of the access method
amowner	object id of the owner's instance in pg_user
amkind	not used at present, but set to 'o' as a place holder
amstrategies	number of strategies for this access method (see below)
amsupport	number of support routines for this access method (see below)
amgettuple aminsert ...	procedure identifiers for interface routines to the access method. For example, regproc ids for opening, closing, and getting instances from the access method appear here.

The object ID of the instance in pg_am is used as a foreign key in lots of other classes. You don't need to add a new instance to this class; all you're interested in is the object ID of the access method instance you want to extend:

```
SELECT oid FROM pg_am WHERE amname = 'btree';

         +----+
         |oid |
         +----+
         |403 |
         +----+
```

The amstrategies attribute exists to standardize comparisons across data types. For example, B-trees impose a strict ordering on keys, lesser to greater. Since Postgres allows the user to define operators, Postgres cannot look at the name of an operator (eg, ">" or "<") and tell what kind of comparison it is. In fact, some access methods don't impose any ordering at all. For example, R-trees express a rectangle-containment relationship, whereas a hashed data structure expresses only bitwise similarity based on the value of a hash function. Postgres needs some consistent way of taking a qualification in your query, looking at the operator and then deciding if a usable index exists. This implies that Postgres needs to know, for example, that the "<=" and ">" operators partition a B-tree. Postgres uses strategies to express these relationships between operators and the way they can be used to scan indices.

Defining a new set of strategies is beyond the scope of this discussion, but we'll explain how B-tree strategies work because you'll need to know that to add a new operator class. In the pg_am class, the amstrategies attribute is the number of strategies defined for this access method. For B-trees, this number is 5. These strategies correspond to

Table 9-2. B-tree Strategies

Operation	Index
less than	1
less than or equal	2
equal	3
greater than or equal	4
greater than	5

The idea is that you'll need to add procedures corresponding to the comparisons above to the pg_amop relation (see below). The access method code can use these strategy numbers, regardless of data type, to figure out how to partition the B-tree, compute selectivity, and so on. Don't worry about the details of adding procedures yet; just understand that there must be a set of these procedures for int2, int4, oid, and every other data type on which a B-tree can operate. Sometimes, strategies aren't enough information for the system to figure out how to use an index. Some access methods require other 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 user qualifications in SQL queries; they are administrative routines used by the access methods, internally.

In order to manage diverse support routines consistently across all Postgres access methods, pg_am includes an attribute called amsupport. This attribute records the number of support routines used by an access method. For B-trees, this number is one -- the routine to take two keys and return -1, 0, or +1, depending on whether the first key is less than, equal to, or greater than the second.

> Note: Strictly speaking, this routine can return a negative number (< 0), 0, or a non-zero positive number (> 0).

The amstrategies entry in pg_am is just the number of strategies defined for the access method in question. The procedures for less than, less equal, and so on don't appear in pg_am. Similarly, amsupport is just the number of support routines required by the access method. The actual routines are listed elsewhere.

The next class of interest is pg_opclass. This class exists only to associate a name with an oid. In pg_amop, every B-tree operator class has a set of procedures, one through five, above. Some existing opclasses are int2_ops, int4_ops, and oid_ops. You need to add an instance with your opclass name (for example, complex_abs_ops) to pg_opclass. The oid of this instance is a foreign key in other classes.

```
INSERT INTO pg_opclass (opcname) VALUES ('complex_abs_ops');
```

```
SELECT oid, opcname
    FROM pg_opclass
    WHERE opcname = 'complex_abs_ops';

         +------+--------------+
         |oid   | opcname      |
         +------+--------------+
         |17314 | int4_abs_ops |
         +------+--------------+
```

Note that the oid for your pg_opclass instance will be different! You should substitute your value for 17314 wherever it appears in this discussion.

So now we have an access method and an operator class. We still need a set of operators; the procedure for defining operators was discussed earlier in this manual. For the complex_abs_ops operator class on Btrees, the operators we require are:

```
        absolute value less-than
        absolute value less-than-or-equal
        absolute value equal
        absolute value greater-than-or-equal
        absolute value greater-than
```

```
Suppose the code that implements the functions defined is stored in the
file PGROOT/src/tutorial/complex.c
```

Part of the code look like this: (note that we will only show the equality operator for the rest of the examples. The other four operators are very similar. Refer to complex.c or complex.sql for the details.)

```
#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);
         }
```

There are a couple of important things that are happening below.

First, note that operators for less-than, less-than-or equal, equal, greater-than-or-equal, and greater-than for int4 are being defined. All of these operators are already defined for int4 under the names <, <=, =, >=, and >. The new operators behave differently, of course. In order to guarantee that Postgres uses these new operators rather than the old ones, they need to be named differently from the old ones. This is a key point: you can overload operators in Postgres, but only if the operator isn't already defined for the argument types. That is, if you have < defined for (int4, int4), you can't define it again. Postgres does not check this when you define your operator, so be careful. To avoid this problem, odd names will be used for the operators. If you get this wrong, the access methods are likely to crash when you try to do scans.

The other important point is that all the operator functions return Boolean values. The access methods rely on this fact. (On the other hand, the support function returns whatever the particular access method expects -- in this case, a signed integer.) The final routine in the file is the "support routine" mentioned when we discussed the amsupport attribute of the pg_am class. We will use this later on. For now, ignore it.

```
CREATE FUNCTION complex_abs_eq(complex, complex)
              RETURNS bool
              AS 'PGROOT/tutorial/obj/complex.so'
              LANGUAGE 'c';
```

Now define the operators that use them. As noted, the operator names must be unique among all operators that take two int4 operands. In order to see if the operator names listed below are taken, we can do a query on pg_operator:

```
/*
 * this query uses the regular expression operator (~)
 * to find three-character operator names that end in
 * the character &
 */
SELECT *
 FROM pg_operator
 WHERE oprname ~ '^..&$'::text;
```

to see if your name is taken for the types you want. The important things here are the procedure (which are the C functions defined above) and the restriction and join selectivity functions. You should just use the ones used below--note that there are different such functions for the less-than, equal, and greater-than cases. These must be supplied, or the access method will crash when it tries to use the operator. You should copy the names for restrict and join, but use the procedure names you defined in the last step.

```
CREATE OPERATOR = (
     leftarg = complex, rightarg = complex,
     procedure = complex_abs_eq,
     restrict = eqsel, join = eqjoinsel
         )
```

Notice that five operators corresponding to less, less equal, equal, greater, and greater equal are defined.

We're just about finished. the last thing we need to do is to update the pg_amop relation. To do this, we need the following attributes:

Table 9-3. pg_amproc Schema

Attribute	Description
amopid	the oid of the pg_am instance for B-tree (== 403, see above)
amopclaid	the oid of the pg_opclass instance for int4_abs_ops (== whatever you got instead of 17314, see above)
amopopr	the oids of the operators for the opclass (which we'll get in just a minute)
amopselect, amopnpages	cost functions

The cost functions are used by the query optimizer to decide whether or not to use a given index in a scan. Fortunately, these already exist. The two functions we'll use are btreesel, which estimates the selectivity of the B-tree, and btreenpage, which estimates the number of pages a search will touch in the tree.

So we need the oids of the operators we just defined. We'll look up the names of all the operators that take two int4s, and pick ours out:

```
SELECT o.oid AS opoid, o.oprname
 INTO TABLE complex_ops_tmp
 FROM pg_operator o, pg_type t
 WHERE o.oprleft = t.oid and o.oprright = t.oid
  and t.typname = 'complex';
```

```
+------+---------+
|oid   | oprname |
+------+---------+
|17321 | <       |
+------+---------+
|17322 | <=      |
+------+---------+
|17323 |  =      |
+------+---------+
|17324 | >=      |
+------+---------+
|17325 | >       |
+------+---------+
```

(Again, some of your oid numbers will almost certainly be different.) The operators we are interested in are those with oids 17321 through 17325. The values you get will probably be different, and you should substitute them for the values below. We can look at the operator names and pick out the ones we just added.

Now we're ready to update pg_amop with our new operator class. The most important thing in this entire discussion is that the operators are ordered, from less equal through greater equal, in pg_amop. We add the instances we need:

```
INSERT INTO pg_amop (amopid, amopclaid,
 amopopr, amopstrategy,
 amopselect, amopnpages)
SELECT am.oid, opcl.oid, c.opoid, 3,
 'btreesel'::regproc, 'btreenpage'::regproc
FROM pg_am am, pg_opclass opcl, complex_ops_tmp c
WHERE amname = 'btree'
 and opcname = 'complex_abs_ops'
 and c.oprname = '=';
```

Note the order: "less than" is 1, "less than or equal" is 2, "equal" is 3, "greater than or equal" is 4, and "greater than" is 5.

The last step (finally!) is registration of the "support routine" previously described in our discussion of pg_am. The oid of this support routine is stored in the pg_amproc class, keyed by the access method oid and the operator class oid. First, we need to register the function in Postgres (recall that we put the C code that implements this routine in the bottom of the file in which we implemented the operator routines):

```
CREATE FUNCTION int4_abs_cmp(int4, int4)
 RETURNS int4
 AS 'PGROOT/tutorial/obj/complex.so'
 LANGUAGE 'c';

SELECT oid, proname FROM pg_proc
 WHERE prname = 'int4_abs_cmp';

     +------+--------------+
     |oid   | proname      |
     +------+--------------+
     |17328 | int4_abs_cmp |
     +------+--------------+
```

(Again, your oid number will probably be different and you should substitute the value you see for the value below.) Recalling that the B-tree instance's oid is 403 and that of int4_abs_ops is 17314, we can add the new instance as follows:

```
INSERT INTO pg_amproc (amid, amopclaid, amproc, amprocnum)
 VALUES ('403'::oid, -- btree oid
 '17314'::oid,       --  pg_opclass tuple
 '17328'::oid,       -- new pg_proc oid
 '1'::int2);
```

Chapter 10. GiST Indices

The information about GIST is at http://GiST.CS.Berkeley.EDU:8000/gist/ with more on different indexing and sorting schemes at http://s2k-ftp.CS.Berkeley.EDU:8000/personal/jmh/ And there is more interesting reading at the Berkely database site at http://epoch.cs.berkeley.edu:8000/.

> Author: This extraction from an e-mail sent by Eugene Selkov Jr. contains good information on GiST. Hopefully we will learn more in the future and update this information. - thomas 1998-03-01

Well, I can't say I quite understand what's going on, but at least I (almost) succeeded in porting GiST examples to linux. The GiST access method is already in the postgres tree (src/backend/access/gist).

Examples at Berkeley come with an overview of the methods and demonstrate spatial index mechanisms for 2D boxes, polygons, integer intervals and text (see also GiST at Berkeley). In the box example, we are supposed to see a performance gain when using the GiST index; it did work for me but I do not have a reasonably large collection of boxes to check that. Other examples also worked, except polygons: I got an error doing

```
test=> create index pix on polytmp
test-> using gist (p:box gist_poly_ops) with (islossy);
ERROR:  cannot open pix
```

```
(PostgreSQL 6.3              Sun Feb  1 14:57:30 EST 1998)
```

I could not get sense of this error message; it appears to be something we'd rather ask the developers about (see also Note 4 below). What I would suggest here is that someone of you linux guys (linux==gcc?) fetch the original sources quoted above and apply my patch (see attachment) and tell us what you feel about it. Looks cool to me, but I would not like to hold it up while there are so many competent people around.

A few notes on the sources:

1. I failed to make use of the original (HPUX) Makefile and rearranged the Makefile from the ancient postgres95 tutorial to do the job. I tried to keep it generic, but I am a very poor makefile writer -- just did some monkey work. Sorry about that, but I guess it is now a little more portable that the original makefile.

2. I built the example sources right under pgsql/src (just extracted the tar file there). The aforementioned Makefile assumes it is one level below pgsql/src (in our case, in pgsql/src/pggist).

3. The changes I made to the *.c files were all about #include's, function prototypes and typecasting. Other than that, I just threw away a bunch of unused vars and added a couple parentheses to please gcc. I hope I did not screw up too much :)

4. There is a comment in polyproc.sql:

```
-- -- there's a memory leak in rtree poly_ops!!
-- -- create index pix2 on polytmp using rtree (p poly_ops);
```

Roger that!! I thought it could be related to a number of Postgres versions back and tried the query. My system went nuts and I had to shoot down the postmaster in about ten minutes.

I will continue to look into GiST for a while, but I would also appreciate more examples of R-tree usage.

Chapter 11. Procedural Languages

Beginning with the release of version 6.3, Postgres supports the definition of procedural languages. In the case of a function or trigger procedure defined in a procedural language, the database has no builtin knowlege how to interpret the functions source text. Instead, the calls are passed into a handler that knows the details of the language. The handler itself is a special programming language function compiled into a shared object and loaded on demand.

Installing Procedural Languages

Procedure 11.1. Procedural Language Installation

A procedural language is installed in the database in three steps.

1. **The shared object for the language handler must be compiled and installed. By default the handler for PL/pgSQL is built and installed into the database library directory. If Tcl/Tk support is configured in, the handler for PL/Tcl is also built and installed in the same location.**

   Writing a handler for a new procedural language (PL) is outside the scope of this manual.

2. **The handler must be declared with the command**

   ```
   CREATE FUNCTION handler_function_name () RETURNS OPAQUE AS
       'path-to-shared-object' LANGUAGE 'C';
   ```

   The special return type of OPAQUE tells the database, that this function does not return one of the defined base- or composite 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
       LANCOMPILER 'description';
   ```

   The optional keyword TRUSTED tells if ordinary database users that have no superuser privileges can use this language to create functions and trigger procedures. Since PL functions are executed inside the database backend it should only be used for languages that don't gain access to database backends internals or the filesystem. The languages PL/pgSQL and PL/Tcl are known to be trusted.

Procedure 11.2. Example

1. **The following command tells the database where to find the shared object for the PL/pgSQL languages call handler function.**

   ```
   CREATE FUNCTION plpgsql_call_handler () RETURNS OPAQUE AS
       '/usr/local/pgsql/lib/plpgsql.so' LANGUAGE 'C';
   ```

2. **The command**

   ```
   CREATE TRUSTED PROCEDURAL LANGUAGE 'plpgsql'
       HANDLER plpgsql_call_handler
       LANCOMPILER 'PL/pgSQL';
   ```

   then defines that the previously declared call handler function should be invoked for functions and trigger procedures where the language attribute is 'plpgsql'.

PL handler functions have a special call interface that is different from regular C language functions. One of the arguments given to the handler is the object ID in the pg_proc tables entry for the function that should be executed. The handler examines various system catalogs to analyze the functions call arguments and it's return data type. The source text of the functions body is found in the prosrc attribute of pg_proc. Due to this, in contrast to C language functions, PL functions can be overloaded like SQL language functions. There can be multiple different PL functions having the same function name, as long as the call arguments differ.

Procedural languages defined in the template1 database are automatically defined in all subsequently created databases. So the database administrator can decide which languages are available by default.

PL/pgSQL

PL/pgSQL is a loadable procedural language for the Postgres database system.

This package was originally written by Jan Wieck.

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 functions source text and produces an internal binary instruction tree on the first time, the function is called by a backend. The produced bytecode is identified in the call handler by the object ID of the function. This ensures, that changing a function by a DROP/CREATE sequence will take effect without establishing a new database connection.

For all expressions and SQL statements used in the function, the PL/pgSQL bytecode interpreter creates a prepared execution plan using the SPI managers SPI_prepare() and SPI_saveplan() functions. This is done the first time, the individual statement is processed in the PL/pgSQL function. Thus, a function with conditional code that contains many statements for which execution plans would be required, will only prepare and save those plans that are really used during the entire lifetime of the database connection.

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 indices.

Description

Structure of PL/pgSQL

The PL/pgSQL language is case insensitive. All keywords and identifiers can be used in mixed upper- and lowercase.

PL/pgSQL is a block oriented language. A block is defined as

```
[<<label>>]
[DECLARE
    declarations]
BEGIN
    statements
END;
```

There can be any number of subblocks in the statement section of a block. Subblocks can be used to hide variables from outside a block 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.

It is important not to misunderstand the meaning of BEGIN/END for grouping statements in PL/pgSQL and the database commands for transaction control. Functions and trigger procedures cannot start or commit transactions and Postgres does not have nested transactions.

Comments

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 occurence 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 '*/'.

Declarations

All variables, rows and records used in a block or it's subblocks must be declared in the declarations section of a block except for the loop variable of a FOR loop iterating over a range of integer values. Parameters given to a PL/pgSQL function are automatically declared with the usual identifiers $n. The declarations have the following syntax:

name [CONSTANT] type [NOT NULL] [DEFAULT | := value];

> Declares a variable of the specified base type. If the variable is declared as CONSTANT, the value cannot be changed. If NOT NULL is specified, an assignment of a NULL value results in a runtime error. Since the default value of all variables is the SQL NULL value, all variables declared as NOT NULL must also have a default value specified.
>
> The default value is evaluated ever time the function is called. So assigning 'now' to a variable of type datetime causes the variable to have the time of the actual function call, not when the function was precompiled into it's bytecode.

name class%ROWTYPE;

> Declares a row with the structure of the given class. Class must be an existing table- or viewname of the database. The fields of the row are accessed in the dot notation. Parameters to a function can be composite types (complete table rows). In that case, the corresponding identifier $n will be a rowtype, but it must be aliased using the ALIAS command described below. Only the user attributes of a table row are accessible in the row, no Oid or other system attributes (hence the row could be from a view and view rows don't have useful system attributes).
>
> The fields of the rowtype inherit the tables fieldsizes or precision for char() etc. data types.

name RECORD;

> Records are similar to rowtypes, but they have no predefined structure. They are used in selections and FOR loops to hold one actual database row from a SELECT operation. One and the same record can be used in different selections. Accessing a record or an attempt

to assign a value to a record field when there is no actual row in it results in a runtime error.

The NEW and OLD rows in a trigger are given to the procedure as records. This is necessary because in Postgres one and the same trigger procedure can handle trigger events for different tables.

name ALIAS FOR $n;

For better readability of the code it is possible to define an alias for a positional parameter to a function.

This aliasing is required for composite types given as arguments to a function. The dot notation $1.salary as in SQL functions is not allowed in PL/pgSQL.

RENAME oldname TO newname;

Change the name of a variable, record or row. This is useful if NEW or OLD should be referenced by another name inside a trigger procedure.

Data Types

The type of a varible can be any of the existing basetypes of the database. type in the declarations section above is defined as:

Postgres-basetype

variable%TYPE

class.field%TYPE

variable is the name of a variable, previously declared in the same function, that is visible at this point.

class is the name of an existing table or view where field is the name of an attribute.

Using the class.field%TYPE causes PL/pgSQL to lookup the attributes definitions at the first call to the funciton during the lifetime of a backend. Have a table with a char(20) attribute and some PL/pgSQL functions that deal with it’s content in local variables. Now someone decides that char(20) isn’t enough, dumps the table, drops it, recreates it now with the attribute in question defined as char(40) and restores the data. Ha - he forgot about the funcitons. The computations inside them will truncate the values to 20 characters. But if they are defined using the class.field%TYPE declarations, they will automagically handle the size change or if the new table schema defines the attribute as text type.

Expressions

All expressions used in PL/pgSQL statements are processed using the backends executor. Expressions which appear to contain constants may in fact require run-time evaluation (e.g. ’now’ for the datetime 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, occurences of variable identifiers are substituted by parameters and the actual values from the variables are passed to the executor in the parameter array. All expressions used in a PL/pgSQL function are only prepared and saved once.

The type checking done by the Postgres main parser has some side effects to the interpretation of constant values. In detail there is a difference between what the two functions

```
CREATE FUNCTION logfunc1 (text) RETURNS datetime AS '
    DECLARE
        logtxt ALIAS FOR $1;
    BEGIN
        INSERT INTO logtable VALUES (logtxt, ''now'');
        RETURN ''now'';
    END;
' LANGUAGE 'plpgsql';
```

and

```
CREATE FUNCTION logfunc2 (text) RETURNS datetime AS '
    DECLARE
        logtxt ALIAS FOR $1;
        curtime datetime;
    BEGIN
        curtime := ''now'';
        INSERT INTO logtable VALUES (logtxt, curtime);
        RETURN curtime;
    END;
' LANGUAGE 'plpgsql';
```

do. In the case of logfunc1(), the Postgres main parser knows when preparing the plan for the INSERT, that the string 'now' should be interpreted as datetime 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 Postgres main parser does not know what type 'now' should become and therefor it returns a datatype of text containing the string 'now'. During the assignment to the local variable curtime, the PL/pgSQL interpreter casts this string to the datetime type by calling the text_out() and datetime_in() functions for the conversion.

This type checking done by the Postgres main parser got implemented after PL/pgSQL was nearly done. It is a difference between 6.3 and 6.4 and affects all functions using the prepared plan feature of the SPI manager. Using a local variable in the above manner is currently the only way in PL/pgSQL to get those values interpreted correctly.

If record fields are used in expressions or statements, the data types of fields should not change between calls of one and the same expression. Keep this in mind when writing trigger procedures that handle events for more than one table.

Statements

Anything not understood by the PL/pgSQL parser as specified below will be put into a query and sent down to the database engine to execute. The resulting query should not return any data.

Assignment

An assignment of a value to a variable or row/record field is written as

```
identifier := expression;
```

If the expressions result data type doesn't match the variables data type, or the variable has a size/precision that is known (as for char(20)), the result value will be implicitly casted by the PL/pgSQL bytecode interpreter using the result types output- and the variables type input-functions. Note that this could potentially result in runtime errors generated by the types input functions.

An assignment of a complete selection into a record or row can be done by

```
SELECT expressions INTO target FROM ...;
```

target can be a record, a row variable or a comma separated list of variables and record-/row-fields.

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 runtime error occurs. The FROM keyword can be followed by any valid qualification, grouping, sorting etc. that can be given for a SELECT statement.

There is a special variable named FOUND of type bool that can be used immediately after a SELECT INTO to check if an assignment had success.

```
SELECT * INTO myrec FROM EMP WHERE empname = myname;
IF NOT FOUND THEN
    RAISE EXCEPTION ''employee % not found'', myname;
END IF;
```

If the selection returns multiple rows, only the first is moved into the target fields. All others are silently discarded.

Calling another function

All functions defined in a Prostgres database return a value. Thus, the normal way to call a function is to execute a SELECT query or doing an assignment (resulting in a PL/pgSQL internal SELECT). But there are cases where someone isn't interested int the functions result.

```
PERFORM query
```

executes a 'SELECT query' over the SPI manager and discards the result. Identifiers like local variables are still substituted into parameters.

Returning from the function

```
RETURN expression
```

The function terminates and the value of expression will be returned to the upper executor. The return value of a function cannot be undefined. If control reaches the end of the toplevel block of the function without hitting a RETURN statement, a runtime error will occur.

The expressions result will be automatically casted into the functions return type as described for assignments.

Aborting and messages

As indicated in the above examples there is a RAISE statement that can throw messages into the Postgres elog mechanism.

```
RAISE level ''format'' [, identifier [...]];
```

Inside the format, % is used as a placeholder for the subsequent comma-separated identifiers. Possible levels are DEBUG (silently suppressed in production running databases), NOTICE (written into the database log and forwarded to the client application) and EXCEPTION (written into the database log and aborting the transaction).

Conditionals

```
IF expression THEN
    statements
[ELSE
    statements]
END IF;
```

The expression must return a value that at least can be casted into a boolean type.

Loops

There are multiple types of loops.

```
[<<label>>]
LOOP
    statements
END LOOP;
```

An unconditional loop that must be terminated explicitly by an EXIT statement. The optional label can be used by EXIT statements of nested loops to specify which level of nesting should be terminated.

```
[<<label>>]
WHILE expression LOOP
    statements
END LOOP;
```

A conditional loop that is executed as long as the evaluation of expression is true.

```
[<<label>>]
FOR name IN [ REVERSE ] expression .. expression LOOP
    statements
END LOOP;
```

A loop that iterates over a range of integer values. The variable name is automatically created as type integer and exists only inside the loop. The two expressions giving the lower and upper bound of the range are evaluated only when entering the loop. The iteration step is always 1.

```
[<<label>>]
FOR record | row IN select_clause LOOP
    statements
END LOOP;
```

The record or row is assigned all the rows resulting from the select clause and the statements executed for each. If the loop is terminated with an EXIT statement, the last assigned row is still accessible after the loop.

```
EXIT [ label ] [ WHEN expression ];
```

If no label 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 an upper level of nested loop blocks. Then the named loop or block is terminated and control continues with the statement after the loops/blocks corresponding END.

Trigger Procedures

PL/pgSQL can be used to define trigger procedures. They are created with the usual CREATE FUNCTION command as a function with no arguments and a return type of OPAQUE.

There are some Postgres specific details in functions used as trigger procedures.

First they have some special variables created automatically in the toplevel blocks declaration section. They are

NEW

Datatype RECORD; variable holding the new database row on INSERT/UPDATE operations on ROW level triggers.

OLD

Datatype RECORD; variable holding the old database row on UPDATE/DELETE operations on ROW level triggers.

TG_NAME

Datatype name; variable that contains the name of the trigger actually fired.

TG_WHEN

Datatype text; a string of either ’BEFORE’ or ’AFTER’ depending on the triggers definition.

TG_LEVEL

Datatype text; a string of either ’ROW’ or ’STATEMENT’ depending on the triggers definition.

TG_OP

Datatype text; a string of ’INSERT’, ’UPDATE’ or ’DELETE’ telling for which operation the trigger is actually fired.

TG_RELID

Datatype oid; the object ID of the table that caused the trigger invocation.

TG_RELNAME

Datatype name; the name of the table that caused the trigger invocation.

TG_NARGS

Datatype integer; the number of arguments given to the trigger procedure in the CREATE TRIGGER statement.

TG_ARGV[]

Datatype 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.

Second they must return either NULL or a record/row containing exactly the structure of the table the trigger was fired for. Triggers fired AFTER might always return a NULL value with no effect. Triggers fired BEFORE signal the trigger manager to skip the operation for this actual row when returning NULL. Otherwise, the returned record/row replaces the inserted/updated row in the operation. It is possible to replace single values directly in NEW and return that or to build a complete new record/row to return.

Exceptions

Postgres 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 mainloop 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’s 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. And even if, at this point the information, that the transaction is aborted, is already sent to the client application, so resuming operation does not make any sense.

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 DEBUG level log messages telling in which function and where (line number and type of statement) this happened.

Examples

Here are only a few functions to demonstrate how easy PL/pgSQL functions can be written. For more complex examples the programmer might look at the regression test for PL/pgSQL.

One painful detail of writing functions in PL/pgSQL is the handling of single quotes. The functions source text on 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 qoutes as in the examples below should be used. Any solution for this in future versions of Postgres will be upward compatible.

Some Simple PL/pgSQL Functions

The following two PL/pgSQL functions are identical to their counterparts from the C language function discussion.

```
CREATE FUNCTION add_one (int4) RETURNS int4 AS '
    BEGIN
        RETURN $1 + 1;
    END;
' LANGUAGE 'plpgsql';
```

```
CREATE FUNCTION concat_text (text, text) RETURNS text AS '
    BEGIN
        RETURN $1 || $2;
    END;
' LANGUAGE 'plpgsql';
```

PL/pgSQL Function on Composite Type

Again it is the PL/pgSQL equivalent to the example from The C functions.

```
CREATE FUNCTION c_overpaid (EMP, int4) RETURNS bool 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';
```

PL/pgSQL Trigger Procedure

This trigger ensures, that any time a row is inserted or updated in the table, the current username and time are stamped into the row. And it ensures that an employees name is given and that the salary is a positive value.

```
CREATE TABLE emp (
    empname text,
    salary int4,
    last_date datetime,
    last_user name);

CREATE FUNCTION emp_stamp () RETURNS OPAQUE 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 := getpgusername();
        RETURN NEW;
    END;
' LANGUAGE 'plpgsql';

CREATE TRIGGER emp_stamp BEFORE INSERT OR UPDATE ON emp
    FOR EACH ROW EXECUTE PROCEDURE emp_stamp();
```

PL/Tcl

PL/Tcl is a loadable procedural language for the Postgres database system that enables the Tcl language to be used to create functions and trigger-procedures.

This package was originally written by Jan Wieck.

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 over SPI and to raise messages via elog(). There is no way to access internals of the database backend or gaining OS-level access under the permissions of the Postgres user ID like in C. Thus, any unprivileged database user may be permitted to use this language.

The other, internal given, restriction is, that Tcl procedures cannot be used to create input-/output-functions for new data types.

The shared object for the PL/Tcl call handler is automatically built and installed in the Postgres library directory if the Tcl/Tk support is specified in the configuration step of the installation procedure.

Description

Postgres Functions and Tcl Procedure Names

In Postgres, one and the same function name can be used for different functions as long as the number of arguments or their types differ. This would collide with Tcl procedure names. To offer the same flexibility in PL/Tcl, the internal Tcl procedure names contain the object ID of the procedures pg_proc row as part of their name. Thus, different argtype versions of the same Postgres function are different for Tcl too.

Defining Functions in PL/Tcl

To create a function in the PL/Tcl language, use the known syntax

```
CREATE FUNCTION funcname (argument-types) RETURNS returntype AS ’
    # PL/Tcl function body
’ LANGUAGE ’pltcl’;
```

When calling this function in a query, the arguments are given as variables $1 ... $n to the Tcl procedure body. So a little max function returning the higher of two int4 values would be created as:

```
CREATE FUNCTION tcl_max (int4, int4) RETURNS int4 AS ’
    if {$1 > $2} {return $1}
    return $2
’ LANGUAGE ’pltcl’;
```

Composite type arguments are given to the procedure as Tcl arrays. The element names in the array are the attribute names of the composite type. If an attribute in the actual 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 Postgres 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’;
```

Global Data in PL/Tcl

Sometimes (especially when using the SPI functions described later) it is useful to have some global status data that is held between two calls to a procedure. All PL/Tcl procedures executed in one backend share the same safe Tcl interpreter. To help protecting PL/Tcl procedures from side effects, an array is made available to each procedure via the upvar command. The global name of this variable is the procedures internal name and the local name is GD.

Trigger Procedures in PL/Tcl

Trigger procedures are defined in Postgres as functions without arguments and a return type of opaque. And so are they in the PL/Tcl language.

The informations from the trigger manager are given 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 tables field names prefixed with an empty list element. So looking up an element name in the list with the lsearch Tcl command returns the same positive number starting from 1 as the fields are numbered in the pg_attribute system catalog.

$TG_when

The string BEFORE or AFTER depending on the event of the trigger call.

$TG_level

The string ROW or STATEMENT depending on the event of the trigger call.

$TG_op

The string INSERT, UPDATE or DELETE depending on the event of the trigger call.

$NEW

An array containing the values of the new table row on INSERT/UPDATE actions, or empty on DELETE.

$OLD

An array containing the values of the old table row on UPDATE/DELETE actions, or empty on INSERT.

$GD

The global status data array as described above.

$args

A Tcl list of the arguments to the procedure as given in the CREATE TRIGGER statement. The arguments are also accessible as $1 ... $n in the procedure body.

The return value from a trigger procedure is 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 normal operation (INSERT/UPDATE/DELETE) that fired this trigger will take place. Obviously, SKIP tells the trigger manager to silently suppress the operation. The list from 'array get' tells PL/Tcl to return a modified row to the trigger manager that will be inserted instead of the one given in $NEW (INSERT/UPDATE only). Needless to say that all this is only meaningful when the trigger is BEFORE and FOR EACH ROW.

Here's a little example trigger procedure that forces an integer value in a table to keep track of the # of updates that are performed on the row. For new row's inserted, the value is initialized to 0 and then incremented on every update operation:

```
CREATE FUNCTION trigfunc_modcount() RETURNS OPAQUE 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 int4, modcnt int4, desc text);

CREATE TRIGGER trig_mytab_modcount BEFORE INSERT OR UPDATE ON mytab
    FOR EACH ROW EXECUTE PROCEDURE trigfunc_modcount('modcnt');
```

Database Access from PL/Tcl

The following commands are available to access the database from the body of a PL/Tcl procedure:

elog level msg

Fire a log message. Possible levels are NOTICE, WARN, ERROR, FATAL, DEBUG and NOIND like for the elog() C function.

quote string

Duplicates all occurences of single quote and backslash characters. It should be used when variables are used in the query string given to spi_exec or spi_prepare (not for the value list on spi_execp). 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"
```

what would cause a parse error during spi_exec or spi_prepare. It should contain

```
"SELECT 'doesn''t' AS ret"
```

and has to be written as

```
"SELECT '[ quote $val ]' AS ret"
```

spi_exec ?-count n? ?-array name? query ?loop-body?

Call parser/planner/optimizer/executor for query. The optional -count value tells spi_exec the maximum number of rows to be processed by the query.

If the query is a SELECT statement and the optional loop-body (a body of Tcl commands like in a foreach statement) is given, it is evaluated for each row selected and behaves like expected on continue/break. The values of selected fields are put into variables named as the column names. So a

```
spi_exec "SELECT count(*) AS cnt FROM pg_proc"
```

will set the variable $cnt to the number of rows in the pg_proc system catalog. If the option -array is given, the column values are stored in the associative array named 'name' indexed by the column name instead of individual variables.

```
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. The return value of spi_exec is the number of rows affected by query as found in the global variable SPI_processed.

spi_prepare query typelist

Prepares AND SAVES a query plan for later execution. It is a bit different from the C level SPI_prepare in that the plan is automatically copied to the toplevel memory context. Thus, there is currently no way of preparing a plan without saving it.

If the query references arguments, the type names must be given as a Tcl list. The return value from spi_prepare is a query ID to be used in subsequent calls to spi_execp. See spi_execp for a sample.

spi_exec ?-count n? ?-array name? ?-nulls str? query ?valuelist? ?loop-body?

Execute a prepared plan from spi_prepare with variable substitution. The optional -count value tells spi_execp the maximum number of rows to be processed by the query.

The optional value for -nulls is a string of spaces and 'n' characters telling spi_execp which of the values are NULL's. If given, it must have exactly the length of the number of values.

The queryid is the ID returned by the spi_prepare call.

If there was a typelist given to spi_prepare, a Tcl list of values of exactly the same length must be given to spi_execp after the query. If the type list on spi_prepare was empty, this argument must be omitted.

If the query is a SELECT statement, the same as described for spi_exec happens for the loop-body and the variables for the fields selected.

Here's an example for a PL/Tcl function using a prepared plan:

```
    CREATE FUNCTION t1_count(int4, int4) RETURNS int4 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" \\
                    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 in the query creating the function, since the main parser processes backslashes too on CREATE FUNCTION. Inside the query string given to spi_prepare should really be dollar signs to mark the parameter positions and to not let $1 be substituted by the value given in the first function call.

Modules and the unknown command

PL/Tcl has a special support for things often used. It recognizes two magic tables, pltcl_modules and pltcl_modfuncs. If these exist, the module 'unknown' is loaded into the interpreter right after creation. Whenever an unknown Tcl procedure is called, the unknown proc is asked to check if the procedure is defined in one of the modules. If this is true, the module is loaded on demand. To enable this behavior, the PL/Tcl call handler must be compiled with -DPLTCL_UNKNOWN_SUPPORT set.

There are support scripts to maintain these tables in the modules subdirectory of the PL/Tcl source including the source for the unknown module that must get installed initially.

Chapter 12. Linking Dynamically-Loaded Functions

After you have created and registered a user-defined function, your work is essentially done. Postgres, however, must load the object code (e.g., a .o file, or a shared library) that implements your function. As previously mentioned, Postgres loads your code at runtime, as required. In order to allow your code to be dynamically loaded, you may have to compile and link-edit it in a special way. This section briefly describes how to perform the compilation and link-editing required before you can load your user-defined functions into a running Postgres server. Note that this process has changed as of Version 4.2.

> Tip: The old Postgres dynamic loading mechanism required in-depth knowledge in terms of executable format, placement and alignment of executable instructions within memory, etc. on the part of the person writing the dynamic loader. Such loaders tended to be slow and buggy. As of Version 4.2, the Postgres dynamic loading mechanism has been rewritten to use the dynamic loading mechanism provided by the operating system. This approach is generally faster, more reliable and more portable than our previous dynamic loading mechanism. The reason for this is that nearly all modern versions of UNIX use a dynamic loading mechanism to implement shared libraries and must therefore provide a fast and reliable mechanism. On the other hand, the object file must be postprocessed a bit before it can be loaded into Postgres. We hope that the large increase in speed and reliability will make up for the slight decrease in convenience.

You should expect to read (and reread, and re-reread) the manual pages for the C compiler, cc(1), and the link editor, ld(1), if you have specific questions. In addition, the regression test suites in the directory PGROOT/src/regress contain several working examples of this process. If you copy what these tests do, you should not have any problems. The following terminology will be used below:

Dynamic loading is what Postgres does to an object file. The object file is copied into the running Postgres server and the functions and variables within the file are made available to the functions within the Postgres process. Postgres does this using the dynamic loading mechanism provided by the operating system.

Loading and link editing is what you do to an object file in order to produce another kind of object file (e.g., an executable program or a shared library). You perform this using the link editing program, ld(1).

The following general restrictions and notes also apply to the discussion below:

Paths given to the create function command must be absolute paths (i.e., start with "/") that refer to directories visible on the machine on which the Postgres server is running.

> Tip: Relative paths do in fact work, but are relative to the directory where the database resides (which is generally invisible to the frontend application). Obviously, it makes no sense to make the path relative to the directory in which the user started the frontend application, since the server could be running on a completely different machine!

The Postgres user must be able to traverse the path given to the create function command and be able to read the object file. This is because the Postgres server runs as the Postgres user, not as the user who starts up the frontend process. (Making the file or a higher-level directory unreadable and/or unexecutable by the "postgres" user is an extremely common mistake.)

Symbol names defined within object files must not conflict with each other or with symbols defined in Postgres.

The GNU C compiler usually does not provide the special options that are required to use the operating system's dynamic loader interface. In such cases, the C compiler that comes with the operating system must be used.

ULTRIX

It is very easy to build dynamically-loaded object files under ULTRIX. ULTRIX does not have any shared library mechanism and hence does not place any restrictions on the dynamic loader interface. On the other hand, we had to (re)write a non-portable dynamic loader ourselves and could not use true shared libraries. Under ULTRIX, the only restriction is that you must produce each object file with the option -G 0. (Notice that that's the numeral ‘‘0’’ and not the letter ‘‘O’’). For example,

```
# simple ULTRIX example
% cc -G 0 -c foo.c
```

produces an object file called foo.o that can then be dynamically loaded into Postgres. No additional loading or link-editing must be performed.

DEC OSF/1

Under DEC OSF/1, you can take any simple object file and produce a shared object file by running the ld command over it with the correct options. The commands to do this look like:

```
# simple DEC OSF/1 example
% cc -c foo.c
% ld -shared -expect_unresolved ’*’ -o foo.so foo.o
```

The resulting shared object file can then be loaded into Postgres. When specifying the object file name to the create function command, one must give it the name of the shared object file (ending in .so) rather than the simple object file.

> Tip: Actually, Postgres does not care what you name the file as long as it is a shared object file. If you prefer to name your shared object files with the extension .o, this is fine with Postgres so long as you make sure that the correct file name is given to the create function command. In other words, you must simply be consistent. However, from a pragmatic point of view, we discourage this practice because you will undoubtedly confuse yourself with regards to which files have been made into shared object files and which have not. For example, it's very hard to write Makefiles to do the link-editing automatically if both the object file and the shared object file end in .o!

If the file you specify is not a shared object, the backend will hang!

SunOS 4.x, Solaris 2.x and HP-UX

Under SunOS 4.x, Solaris 2.x and HP-UX, the simple object file must be created by compiling the source file with special compiler flags and a shared library must be produced. The necessary steps with HP-UX are as follows. The +z flag to the HP-UX C compiler produces so-called "Position Independent Code" (PIC) and the +u flag removes some alignment restrictions that the PA-RISC architecture normally enforces. The object file must be turned into a shared library using the HP-UX link editor with the -b option. This sounds complicated but is actually very simple, since the commands to do it are just:

```
# simple HP-UX example
% cc +z +u -c foo.c
```

```
% ld -b -o foo.sl foo.o
```

As with the .so files mentioned in the last subsection, the create function command must be told which file is the correct file to load (i.e., you must give it the location of the shared library, or .sl file). Under SunOS 4.x, the commands look like:

```
# simple SunOS 4.x example
% cc -PIC -c foo.c
% ld -dc -dp -Bdynamic -o foo.so foo.o
```

and the equivalent lines under Solaris 2.x are:

```
# simple Solaris 2.x example
% cc -K PIC -c foo.c
% ld -G -Bdynamic -o foo.so foo.o
```

or

```
# simple Solaris 2.x example
% gcc -fPIC -c foo.c
% ld -G -Bdynamic -o foo.so foo.o
```

When linking shared libraries, you may have to specify some additional shared libraries (typically system libraries, such as the C and math libraries) on your ld command line.

Chapter 13. Triggers

The current version of Postgres has various client interfaces such as Perl, Tcl, Python and C, as well as two new Procedural Languages (PL). It is also possible to call C functions as trigger actions. 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.

Trigger Creation

If a trigger event occurs, the trigger manager (called by the Executor) initializes the global structure TriggerData *CurrentTriggerData (described below) and calls the trigger function to handle the event.

The trigger function must be created before the trigger is created as a function taking no arguments and returns opaque.

The syntax for creating triggers is as follows:

```
CREATE TRIGGER <trigger name> <BEFORE|AFTER> <INSERT|DELETE|UPDATE>
    ON <relation name> FOR EACH <ROW|STATEMENT>
    EXECUTE PROCEDURE <procedure name> (<function args>);
```

The name of the trigger is used if you ever have to delete the trigger. It is used as an argument to the DROP TRIGGER command.

The next word determines whether the function is called before or after the event.

The next element of the command determines on what event(s) will trigger the function. Multiple events can be specified separated by OR.

The relation name determines which table the event applies to.

The FOR EACH statement determines whether the trigger is fired for each affected row or before (or after) the entire statement has completed.

The procedure name is the C function called.

The args are passed to the function in the CurrentTriggerData structure. The purpose of passing arguments to the function is to allow different triggers with similar requirements to call the same function.

Also, function may be used for triggering different relations (these functions are named as "general trigger functions").

As example of using both features above, there could be a general function that takes as its arguments two field names and puts the current user in one and the current timestamp in the other. This allows triggers to be written on INSERT events to automatically track creation of records in a transaction table for example. It could also be used as a "last updated" function if used in an UPDATE event.

Trigger functions return HeapTuple to the calling Executor. This is ignored for triggers fired after an INSERT, DELETE or UPDATE operation but it allows BEFORE triggers to: - return NULL to skip the operation for the current tuple (and so the tuple will not be inserted/updated/deleted); - return a pointer to another tuple (INSERT and UPDATE only) which will be inserted (as the new version of the updated tuple if UPDATE) instead of original tuple.

Note, that there is no initialization performed by the CREATE TRIGGER handler. This will be changed in the future. Also, if more than one trigger is defined for the same event on the same relation, the order of trigger firing is unpredictable. This may be changed in the future.

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 explicit limitation on the number of cascade levels.

If a trigger is fired by INSERT and inserts a new tuple in the same relation then this trigger will be fired again. Currently, there is nothing provided for synchronization (etc) of these cases but this may change. At the moment, there is function funny_dup17() in the regress tests which uses some techniques to stop recursion (cascading) on itself...

Interaction with the Trigger Manager

As mentioned above, when function is called by the trigger manager, structure TriggerData *CurrentTriggerData is NOT NULL and initialized. So it is better to check CurrentTriggerData against being NULL at the start and set it to NULL just after fetching the information to prevent calls to a trigger function not from the trigger manager.

struct TriggerData is defined in src/include/commands/trigger.h:

```
typedef struct TriggerData
{
        TriggerEvent    tg_event;
        Relation        tg_relation;
        HeapTuple       tg_trigtuple;
        HeapTuple       tg_newtuple;
        Trigger         *tg_trigger;
} TriggerData;

tg_event
   describes event for which the function is called. You may use the
   following macros to examine tg_event:

   TRIGGER_FIRED_BEFORE(event) returns TRUE if trigger fired BEFORE;
   TRIGGER_FIRED_AFTER(event) returns TRUE if trigger fired AFTER;
   TRIGGER_FIRED_FOR_ROW(event) returns TRUE if trigger fired for
                             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 pointer to structure describing the triggered relation. Look at
   src/include/utils/rel.h for details about this structure.  The most
   interest 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 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 src/include/utils/rel.h:

typedef struct Trigger
{
        char            *tgname;
        Oid             tgfoid;
        func_ptr        tgfunc;
        int16           tgtype;
        int16           tgnargs;
        int16           tgattr[8];
        char            **tgargs;
} Trigger;

   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.
```

Visibility of Data Changes

Postgres 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 which 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!

Examples

There are more complex examples in 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 NULL 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 */
```

```
HeapTuple               trigf(void);

HeapTuple
trigf()
{
        TupleDesc       tupdesc;
        HeapTuple       rettuple;
        char            *when;
        bool            checknull = false;
        bool            isnull;
        int             ret, i;

        if (!CurrentTriggerData)
                elog(WARN, "trigf: triggers are not initialized");

        /* tuple to return to Executor */
        if (TRIGGER_FIRED_BY_UPDATE(CurrentTriggerData->tg_event))
                rettuple = CurrentTriggerData->tg_newtuple;
        else
                rettuple = CurrentTriggerData->tg_trigtuple;

        /* check for NULLs ? */
        if (!TRIGGER_FIRED_BY_DELETE(CurrentTriggerData->tg_event) &&
                TRIGGER_FIRED_BEFORE(CurrentTriggerData->tg_event))
                checknull = true;

        if (TRIGGER_FIRED_BEFORE(CurrentTriggerData->tg_event))
                when = "before";
        else
                when = "after ";

        tupdesc = CurrentTriggerData->tg_relation->rd_att;
        CurrentTriggerData = NULL;

        /* Connect to SPI manager */
        if ((ret = SPI_connect()) < 0)
                elog(WARN, "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(WARN, "trigf (fired %s): SPI_exec returned %d",
when, ret);

        i = 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)
        {
                i = SPI_getbinval(rettuple, tupdesc, 1, &isnull);
                if (isnull)
                        rettuple = NULL;
        }

        return (rettuple);
}
```

Now, compile and create table ttest (x int4); create function trigf () returns opaque as '...path_to_so' language 'c';

```
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);
NOTICE: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);
NOTICE:trigf (fired before): there are 0 tuples in ttest
NOTICE: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;
NOTICE:trigf (fired before): there are 1 tuples in ttest
NOTICE: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;
NOTICE:trigf (fired before): there are 2 tuples in ttest
UPDATE 0
vac=> update ttest set x = 4 where x = 2;
NOTICE:trigf (fired before): there are 2 tuples in ttest
NOTICE:trigf (fired after ): there are 2 tuples in ttest
UPDATE 1
vac=> select * from ttest;
x
-
1
4
(2 rows)

vac=> delete from ttest;
NOTICE:trigf (fired before): there are 2 tuples in ttest
NOTICE:trigf (fired after ): there are 1 tuples in ttest
NOTICE:trigf (fired before): there are 1 tuples in ttest
NOTICE: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 14. Server Programming Interface

The Server Programming Interface (SPI) gives users the ability to run SQL queries inside user-defined C functions. The available Procedural Languages (PL) give an alternate means to access these capabilities..

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.

SPI procedures are always called by some (upper) Executor and the SPI manager uses the Executor to run your queries. Other procedures may be called by the Executor running queries from your procedure.

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 be changed in future versions.

Other restrictions are the inability to execute BEGIN, END and ABORT (transaction control statements) and cursor operations. 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.

Interface Functions

SPI_connect

Name

SPI_connect   Connects your procedure to the SPI manager.

```
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 to the Postgres backend. You should call this function if you will need to execute queries. Some utility SPI functions may be called from un-connected procedures.

You may get SPI_ERROR_CONNECT error if SPI_connect is called from an already connected procedure - e.g. if you directly call one procedure from another connected one. Actually, while the child procedure will be able to use SPI, your parent procedure will not be able to continue to use SPI after the child returns (if SPI_finish is called by the child). It's bad practice.

Usage

XXX thomas 1997-12-24

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.

```
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 Postgres backend. You should call this function after completing operations through the SPI manager.

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! Note that you can safely skip the call to SPI_finish if you abort the transaction (via elog(ERROR)).

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.

```
SPI_exec(query, tcount)
```

Inputs

*char *query*

String containing query plan

int tcount

Maximum number of tuples to return

Outputs

int

```
SPI_OK_EXEC if properly disconnected
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. For example,

```
SPI_exec ("insert into table select * from table", 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 many 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 returned and SPI_processed > 0 then you may use global pointer SPITupleTable *SPI_tuptable to access the selected tuples: Also NOTE, that SPI_finish frees and makes all SPITupleTables unusable! (See Memory management).

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).

Algorithm

SPI_exec 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_prepare

Name

SPI_prepare   Connects your procedure to the SPI manager.

```
SPI_prepare(query, nargs, argtypes)
```

Inputs

query

    Query string

nargs

    Number of input parameters ($1 ... $nargs - as in
    SQL-functions)

argtypes

    Pointer list of type OIDs to input arguments

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

nargs is number of parameters ($1 ... $nargs - as in SQL-functions), and nargs may be 0 only if there is not any $1 in query.

Execution of prepared execution plans is sometimes much faster so this feature may be useful if the same query will be executed many times.

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. See SPI_saveplan.

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_saveplan

Name

SPI_saveplan   Saves a passed plan

```
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 Postgres 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 consequent 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.

SPI_execp

Name

SPI_execp   Executes a plan from SPI_saveplan

```
SPI_execp(plan,
values,
nulls,
tcount)
```

Inputs

*void *plan*

Execution plan

*Datum *values*

Actual parameter values

*char *nulls*

Array describing what parameters get NULLs

```
'n' indicates NULL allowed
' ' indicates NULL not allowed
```

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 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 Postgres 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 a work arround, there is the ability to reuse prepared plans in the consequent invocations of your procedure in the current session. Use SPI_execp to execute this saved plan.

Usage

If nulls is NULL then SPI_execp assumes that all values (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.

Interface Support Functions

All functions described below may be used by connected and unconnected procedures.

SPI_copytuple

Name

SPI_copytuple   Makes copy of tuple in upper Executor context

```
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. See the section on Memory Management.

Usage

TBD

SPI_modifytuple

Name

SPI_modifytuple   Modifies tuple of relation

```
SPI_modifytuple(rel, tuple , nattrs
, attnum , Values , Nulls)
```

Inputs

Relation rel

HeapTuple tuple

Input tuple to be modified

int nattrs

Number of attribute numbers in attnum

*int * attnum*

Array of numbers of the attributes which are to be changed

*Datum * Values*

New values for the attributes specified

*char * Nulls*

Which attributes 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 Modifies a tuple in upper Executor context. See the section on Memory Management.

Usage

If successful, a pointer to the new tuple is returned. The new tuple is allocated in upper Executor context (see Memory management). Passed tuple is not changed.

SPI_fnumber

Name

SPI_fnumber   Finds the attribute number for specified attribute

```
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.

SPI_fname

Name

SPI_fname   Finds the attribute name for the specified attribute

```
SPI_fname(tupdesc, fname)
```

Inputs

TupleDesc tupdesc

Input tuple description

*char * 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.

SPI_getvalue

Name

SPI_getvalue   Returns the string value of the specified attribute

`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

Allocates memory as required by the value.

SPI_getbinval

Name

SPI_getbinval   Returns the binary value of the specified attribute

```
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 binary value of the specified attribute.

Usage

Attribute numbers are 1 based.

Algorithm

Does not allocate new space for the binary value.

SPI_gettype

Name

SPI_gettype   Returns the type name of the specified attribute

```
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.

Usage

Attribute numbers are 1 based.

Algorithm

Does not allocate new space for the binary value.

SPI_gettypeid

Name

SPI_gettypeid   Returns the type OID of the specified attribute

```
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.

Algorithm

TBD

SPI_getrelname

Name

SPI_getrelname   Returns the name of the specified relation

```
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.

Usage

TBD

Algorithm

Copies the relation name into new storage.

SPI_palloc

Name

SPI_palloc — Allocates memory in upper Executor context

```
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. See section on memory management.

Usage

TBD

SPI_repalloc

Name

SPI_repalloc   Re-allocates memory in upper Executor context

```
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. See section on memory management.

Usage

TBD

SPI_pfree

Name

SPI_pfree   Frees memory from upper Executor context

```
SPI_pfree(pointer)
```

Inputs

*void * pointer*

    Pointer to existing storage

Outputs

```
None
```

Description

SPI_pfree frees memory in upper Executor context. See section on memory management.

Usage

TBD

Memory Management

Server allocates memory in memory contexts in such way that allocations made in one context may be freed by context destruction without affecting allocations made in other contexts. All allocations (via palloc, etc) are made in the context which are chosen as current one. You'll get unpredictable results if you'll try to free (or reallocate) memory allocated not in current context.

Creation and switching between memory contexts are subject of SPI manager memory management.

SPI procedures deal with two memory contexts: upper Executor memory context and procedure memory context (if connected).

Before a procedure is connected to the SPI manager, current memory context is upper Executor context so all allocation made by the procedure itself via palloc/repalloc or by SPI utility functions before connecting to SPI are made in this context.

After SPI_connect is called current context is the procedure's one. All allocations made via palloc/repalloc or by SPI utility functions (except for SPI_copytuple, SPI_modifytuple, SPI_palloc and SPI_repalloc) 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!

If you want to return something to the upper Executor then you have to allocate memory for this in the upper context!

SPI has no ability to automatically free allocations in the upper Executor context!

SPI automatically frees memory allocated during execution of a query when this query is done!

Visibility of Data Changes

Postgres 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.

Changes made by query Q are visible by queries which are started after query Q, no matter whether they are started inside Q (during the execution of Q) or after Q is done.

Examples

This example of SPI usage demonstrates the visibility rule. There are more complex examples in 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)
```

```
{
        int ret;
        int proc = 0;

        SPI_connect();

        ret = SPI_exec(textout(sql), cnt);

        proc = SPI_processed;
        /*
         * If this is SELECT and some tuple(s) fetched -
         * returns tuples to the caller via elog (NOTICE).
         */
        if ( ret == SPI_OK_SELECT && SPI_processed > 0 )
        {
                TupleDesc tupdesc = SPI_tuptable->tupdesc;
                SPITupleTable *tuptable = SPI_tuptable;
                char buf[8192];
                int i;

                for (ret = 0; ret < proc; ret++)
                {
                        HeapTuple tuple = tuptable->vals[ret];

                        for (i = 1, buf[0] = 0; i <= tupdesc->natts;
i++)
                                sprintf(buf + strlen (buf), " %s%s",
                                        SPI_getvalue(tuple, tupdesc,
i),
                                        (i == tupdesc->natts) ? " " : "
|");
                        elog (NOTICE, "EXECQ: %s", buf);
                }
        }

        SPI_finish();

        return (proc);
}
```

Now, compile and create the function:

```
create function execq (text, int4) returns int4 as '...path_to_so'
language 'c';

vac=> select execq('create table a (x int4)', 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);
NOTICE:EXECQ:  0 <<< inserted by execq

NOTICE: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);
NOTICE:EXECQ:  0
```

```
NOTICE:EXECQ:  1

NOTICE: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);
NOTICE: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;
NOTICE:EXECQ:  1
NOTICE:EXECQ:  2
NOTICE:EXECQ:  1
NOTICE:EXECQ:  2
NOTICE: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
```

Chapter 15. Large Objects

In Postgres, data values are stored in tuples and individual tuples cannot span data pages. Since the size of a data page is 8192 bytes, the upper limit on the size of a data value is relatively low. To support the storage of larger atomic values, Postgres provides a large object interface. This interface provides file oriented access to user data that has been declared to be a large type. This section describes the implementation and the programmatic and query language interfaces to Postgres large object data.

Historical Note

Originally, Postgres 4.2 supported three standard implementations of large objects: as files external to Postgres, as UNIX files managed by Postgres, and as data stored within the Postgres database. It causes considerable confusion among users. As a result, we only support large objects as data stored within the Postgres database in PostgreSQL. Even though is is slower to access, it provides stricter data integrity. For historical reasons, this storage scheme is referred to as Inversion large objects. (We will use Inversion and large objects interchangeably to mean the same thing in this section.)

Inversion Large Objects

The Inversion 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.

Large Object Interfaces

The facilities Postgres 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. The interface is the same for dynamically-loaded C functions as well as for native routines. The Postgres 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. Postgres provides a set of routines that support opening, reading, writing, closing, and seeking on large objects.

Creating a Large Object

The routine

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

creates a new large object. The mode is a bitmask describing several different attributes of the new object. The symbolic constants listed here are defined in PGROOT/src/backend/libpq/libpq-fs.h The access type (read, write, or both) is controlled by

OR ing together the bits INV_READ and INV_WRITE. If the large object should be archived -- that is, if historical versions of it should be moved periodically to a special archive relation -- then the INV_ARCHIVE bit should be set. The low-order sixteen bits of mask are the storage manager number on which the large object should reside. For sites other than Berkeley, these bits should always be zero. The commands below create an (Inversion) large object:

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

Importing a Large Object

To import a UNIX file as a large object, call

```
Oid lo_import(PGconn *conn, text *filename)
```

The filename argument specifies the UNIX pathname of the file to be imported as a large object.

Exporting a Large Object

To export a large object into UNIX file, call

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

The lobjId argument specifies the Oid of the large object to export and the filename argument specifies the UNIX pathname of the file.

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 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.

Writing Data to a Large Object

The routine

```
int lo_write(PGconn *conn, int fd, char *buf, int 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.

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 .i whence are SEEK_SET SEEK_CUR and SEEK_END.

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.

Built in registered 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';
```

Accessing Large Objects from LIBPQ

Below 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 readers benefit. This program can be found in ../src/test/examples 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.

Sample Program

```
/*--------------------------------------------------------------
          *
          * testlo.c--
          *    test using large objects with libpq
          *
          * Copyright (c) 1994, Regents of the University of California
          *
          *
          * IDENTIFICATION
          *    /usr/local/devel/pglite/cvs/src/doc/manual.me,v 1.16
1995/09/01 23:55:00 jolly Exp
          *
          *--------------------------------------------------------------
---
          */
         #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;
            }
            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;
            }
            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 16. `libpq`

libpq is the C application programmer's interface to Postgres. libpq is a set of library routines that allow client programs to pass queries to the Postgres backend server and to receive the results of these queries. libpq is also the underlying engine for several other Postgres application interfaces, including libpq++ (C++), libpgtcl (Tcl), perl5, 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/regress
../src/test/examples
../src/bin/psql
```

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

Database Connection Functions

The following routines deal with making a connection to a Postgres 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.

PQsetdbLogin Makes a new connection to a backend.

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

If any argument is NULL, then the corresponding environment variable (see "Environment Variables" section) is checked. If the environment variable is also not set, then hardwired defaults are used. The return value is a pointer to an abstract struct representing the connection to the backend.

PQsetdb Makes a new connection to a backend.

```
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.

PQconnectdb Makes a new connection to a backend.

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

This routine opens a new database connection using parameters taken from a string. Unlike PQsetdbLogin(), the parameter set can be extended without changing the function signature, so use of this routine is encouraged for new 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 a null value or a value containing spaces, surround it with single quotes, eg, keyword = 'a value'. Single quotes within the value must be written as \'. Spaces around the equal sign are optional.) The currently recognized parameter keywords are:

host -- host to connect to. If a non-zero-length string is specified, TCP/IP communication is used. Without a host name, libpq will connect using a local Unix domain socket.

port -- port number to connect to at the server host, or socket filename extension for Unix-domain connections.

dbname -- database name.

user -- user name for authentication.

password -- password used if the backend demands password authentication.

authtype -- authorization type. (No longer used, since the backend now chooses how to authenticate users. libpq still accepts and ignores this keyword for backward compatibility.)

options -- trace/debug options to send to backend.

tty -- file or tty for optional debug output from backend.

Like PQsetdbLogin, PQconnectdb uses environment variables or built-in default values for unspecified options.

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 value */
                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 options - don't
                                      create a field by default */
                int     dispsize;  /* Field size in characters for
dialog */
        };
```

Returns the address of the connection options structure. 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.

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 postmaster, using all the same parameters previously used. This may be useful for error recovery if a working connection is lost.

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 Postgres 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(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(PGconn *conn)
```

PQpass Returns the password of the connection.

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

PQhost Returns the server host name of the connection.

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

PQport Returns the port of the connection.

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

PQtty Returns the debug tty of the connection.

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

PQoptions Returns the backend options used in the connection.

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

PQstatus Returns the status of the connection. The status can be CONNECTION_OK or CONNECTION_BAD.

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

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.

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

```
char *PQerrorMessage(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(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!

Query 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.

PQexec Submit a query to Postgres 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 query 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 query 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 Postgres release 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 query. PQresultStatus can return one of the following values:

```
PGRES_EMPTY_QUERY,
PGRES_COMMAND_OK,       /* the query was a command returning no data
*/
PGRES_TUPLES_OK,        /* the query successfully returned tuples */
PGRES_COPY_OUT,         /* Copy Out (from server) data transfer
started */
PGRES_COPY_IN,          /* Copy In (to server) data transfer started
*/
PGRES_BAD_RESPONSE,     /* an unexpected response was received */
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 tuples returned by the query. Note that a SELECT that happens to retrieve zero tuples still shows PGRES_TUPLES_OK. PGRES_COMMAND_OK is for commands that can never return tuples.

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

```
const char *PQresultErrorMessage(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.

PQntuples Returns the number of tuples (instances) in the query result.

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

PQnfields Returns the number of fields (attributes) in each tuple of the query result.

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

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

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

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

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

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

PQfnumber Returns the field (attribute) index associated with the given field name.

```
int PQfnumber(PGresult *res,
              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(PGresult *res,
            int field_num);
```

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

```
int PQfsize(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.

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

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

PQgetvalue Returns a single field (attribute) value of one tuple of a PGresult. Tuple and field indices start at 0.

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

For most queries, the value returned by PQgetvalue is a null-terminated ASCII string representation of the attribute value. But if PQbinaryTuples() is TRUE, 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.

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

```
int PQgetlength(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 ASCII-represented values, this size has little to do with the binary size reported by PQfsize.

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

```
int PQgetisnull(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.)

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.

```
const 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.

PQoidStatus Returns a string with the object id of the tuple inserted, if the SQL command was an INSERT. Otherwise, returns an empty string.

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

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

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

struct _PQprintOpt
        {
                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 */
        };
```

This function is intended to replace PQprintTuples(), which is now obsolete. The psql program uses PQprint() to display query results.

PQprintTuples Prints out all the tuples and, optionally, the attribute names to the specified output stream.

```
void PQprintTuples(PGresult* res,
                   FILE* fout,      /* output stream */
                   int printAttName,/* print attribute names or not*/
                   int terseOutput, /* delimiter bars or not?*/
                   int width);      /* width of column, variable
width if 0*/
```

PQdisplayTuples Prints out all the tuples and, optionally, the attribute names to the specified output stream.

```
void PQdisplayTuples(PGresult* res,
                     FILE* fout,           /* output stream */
                     int fillAlign,        /* space fill to align
columns */
                     const char *fieldSep, /* field separator */
                     int printHeader,      /* display headers? */
```

```
                     int quiet);           /* suppress print of row
count at end */
```

PQdisplayTuples() was intended to supersede PQprintTuples(), and is in turn superseded by PQprint().

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 errorMessage is copied into the PGresult. Note that PQclear should eventually be called on the object, just as with a PGresult returned by libpq itself.

Asynchronous Query Processing

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

PQexec waits for the query 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 query. (It can be done from a signal handler, but not otherwise.)

PQexec can return only one PGresult structure. If the submitted query 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.

PQsendQuery Submit a query to Postgres without waiting for the result(s). TRUE is returned if the query was successfully dispatched, FALSE 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 query results. PQsendQuery may not be called again (on the same connection) until PQgetResult has returned NULL, indicating that the query 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 query is done. (If called when no query 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 query 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 query 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(2) 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 TRUE if a query is busy, that is, PQgetResult would block waiting for input. A FALSE 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.

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(PGconn *conn);
```

PQsocket should be used to obtain the backend socket descriptor in preparation for executing select(2). This allows an application to wait for either backend responses or other conditions. If the result of select(2) 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.

A typical frontend using these functions will have a main loop that uses select(2) 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. It can also call PQnotifies to detect NOTIFY messages (see "Asynchronous Notification", below). An example is given in the sample programs section.

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

PQrequestCancel Request that Postgres abandon processing of the current query.

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

The return value is TRUE if the cancel request was successfully dispatched, FALSE 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 query will terminate early and return an error result. If the cancellation fails (say because the backend was already done processing the query), then there will be no visible result at all.

Note that if the current query 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 query.

Fast Path

Postgres 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,
               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 resultStatus should be checked before the result is used. The caller is responsible for freeing the PGresult with PQclear when it is no longer needed.

Asynchronous Notification

Postgres 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 queries. 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[NAMEDATALEN];       /* 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 Postgres 6.4 and later, the be_pid is the notifying backend's, whereas in earlier versions it was always your own backend's PID.

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(2) to wait for backend data to arrive, thereby using no CPU power unless there is something to do. Note that this will work OK whether you use PQsendQuery/PQgetResult or plain old PQexec for queries. 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.

Functions Associated with the COPY Command

The COPY command in Postgres 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(3), this routine copies up to length-1 characters into string. It is like gets(3), however, in that it converts the terminating newline into a null character. PQgetline returns EOF at EOF, 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/psql.c contains 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,
              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 Syncs 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 query. 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 char16, d float8)");
PQexec(conn, "copy foo from stdin");
PQputline(conn, "3<TAB>hello world<TAB>4.5\n");
PQputline(conn,"4<TAB>goodbye world<TAB>7.11\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 query string.

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)
```

libpq Control Functions

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

```
void PQsetNoticeProcessor (PGconn * conn,
        void (*noticeProcessor) (void * arg, const char * message),
        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.

User Authentication Functions

The frontend/backend authentication process is handled by PQconnectdb without any further intervention. The authentication method is now determined entirely by the DBA (see pga_hba.conf(5)). The following routines no longer have any effect and should not be used.

fe_getauthname Returns a pointer to static space containing whatever name the user has authenticated. Use of this routine in place of calls to getenv(3) or getpwuid(3) by applications is highly recommended, as it is entirely possible that the authenticated user name is not the same as value of the USER environment variable or the user's entry in /etc/passwd.

```
char *fe_getauthname(char* errorMessage)
```

fe_setauthsvc Specifies that libpq should use authentication service name rather than its compiled-in default. This value is typically taken from a command-line switch.

```
void fe_setauthsvc(char *name,
                   char* errorMessage)
```

Any error messages from the authentication attempts are returned in the errorMessage argument.

Environment Variables

The following environment variables can be used to select default connection parameter values, which will be used by PQconnectdb or PQsetdbLogin if no value is directly specified by the calling code. These are useful to avoid hard-coding database names into simple application programs.

PGHOST sets the default server name. If a non-zero-length string is specified, TCP/IP communication is used. Without a host name, libpq will connect using a local Unix domain socket.

PGPORT sets the default port or local Unix domain socket file extension for communicating with the Postgres backend.

PGDATABASE sets the default Postgres database name.

PGUSER sets the username used to connect to the database and for authentication.

PGPASSWORD sets the password used if the backend demands password authentication.

PGREALM sets the Kerberos realm to use with Postgres, if it is different from the local realm. If PGREALM is set, Postgres 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 runtime options for the Postgres backend.

PGTTY sets the file or tty on which debugging messages from the backend server are displayed.

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

PGDATESTYLE sets the default style of date/time representation.

PGTZ sets the default time zone.

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

PGGEQO sets the default mode for the genetic optimizer.

PGRPLANS sets the default mode to allow or disable right-sided plans in the optimizer.

PGCOSTHEAP sets the default cost for heap searches for the optimizer.

PGCOSTINDEX sets the default cost for indexed searches for the optimizer.

PGQUERY_LIMIT sets the maximum number of rows returned by a query.

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

Caveats

The query buffer is 8192 bytes long, and queries over that length will be rejected.

Sample Programs

Sample Program 1

```
/*
 * testlibpq.c Test the C version of Libpq, the Postgres 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 (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 instances from the pg_database, the system catalog of
     * databases
     */
    res = PQexec(conn, "DECLARE mycursor CURSOR FOR select * from
pg_database");
    if (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 (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 instances */
    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); */
}
```

Sample Program 2

```
/*
 * testlibpq2.c Test of the asynchronous notification interface
 *
 * 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];
 *
 * Then start up this program After the program has begun, 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 (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);

}
```

Sample Program 3

```
/*
 * testlibpq3.c Test the C version of Libpq, the Postgres frontend
 * library. tests the binary cursor interface
 *
 *
 *
 * populate a database by doing the following:
 *
 * CREATE TABLE test1 (i int4, d float4, p polygon);
 *
 * INSERT INTO test1 values (1, 3.567, '(3.0, 4.0, 1.0,
 * 2.0)'::polygon);
 *
 * INSERT INTO test1 values (2, 89.05, '(4.0, 3.0, 2.0,
 * 1.0)'::polygon);
 *
 * 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 (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 instances from the pg_database, the system catalog of
     * databases
     */
    res = PQexec(conn, "DECLARE mycursor BINARY CURSOR FOR select *
from test1");
    if (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 (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);

}
```

Chapter 17. libpq C++ Binding

libpq++ is the C++ API to Postgres. libpq++ is a set of classes which allow client programs to connect to the Postgres backend server. These connections come in two forms: a Database Class and a Large Object class.

The Database Class is intended for manipulating a database. You can send all sorts of SQL queries to the Postgres backend server and retrieve the responses of the server.

The Large Object Class is intended for manipulating a large object in a database. Although a Large Object instance can send normal queries to the Postgres backend server it is only intended for simple queries that do not return any data. A large object should be seen as a file stream. In future it should behave much like the C++ file streams cin, cout and cerr.

This chapter is based on the documentation for the libpq C library. Three short programs are listed at the end of this section as examples of libpq++ programming (though not necessarily of good programming). There are several examples of libpq++ applications in src/libpq++/examples, including the source code for the three examples in this chapter.

Control and Initialization

Environment Variables

The following environment variables can be used to set up default values for an environment and to avoid hard-coding database names into an application program:

> Note: Refer to the *Environment VariablesThe following environment variables can be used to select default connection parameter values, which will be used by PQconnectdb or PQsetdbLogin if no value is directly specified by the calling code. These are useful to avoid hard-coding database names into simple application programs. PGHOST sets the default server name. If a non-zero-length string is specified, TCP/IP communication is used. Without a host name, libpq will connect using a local Unix domain socket.PGPORT sets the default port or local Unix domain socket file extension for communicating with the Postgres backend.PGDATABASE sets the default Postgres database name.PGUSER sets the username used to connect to the database and for authentication.PGPASSWORD sets the password used if the backend demands password authentication.PGREALM sets the Kerberos realm to use with Postgres, if it is different from the local realm. If PGREALM is set, Postgres 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 runtime options for the Postgres backend.PGTTY sets the file or tty on which debugging messages from the backend server are displayed.The following environment variables can be used to specify user-level default behavior for every Postgres session: PGDATESTYLE sets the default style of date/time representation.PGTZ sets the default time zone.The following environment variables can be used to specify default internal behavior for every Postgres session: PGGEQO sets the default mode for the genetic optimizer.PGRPLANS sets the default mode to allow or disable right-sided plans in the optimizer.PGCOSTHEAP sets the default cost for heap searches for the optimizer.PGCOSTINDEX sets the default cost for indexed searches for the optimizer.PGQUERY_LIMIT sets the maximum number of rows returned by a query.Refer to the SET SQL command for information on correct values for these environment variables.* for a complete list of available connection options.

The following environment variables can be used to select default connection parameter values, which will be used by PQconnectdb or PQsetdbLogin if no value is directly specified by the calling code. These are useful to avoid hard-coding database names into simple application programs.

PGHOST sets the default server name. If a non-zero-length string is specified, TCP/IP communication is used. Without a host name, libpq will connect using a local Unix domain socket.

PGPORT sets the default port or local Unix domain socket file extension for communicating with the Postgres backend.

PGDATABASE sets the default Postgres database name.

PGUSER sets the username used to connect to the database and for authentication.

PGPASSWORD sets the password used if the backend demands password authentication.

PGREALM sets the Kerberos realm to use with Postgres, if it is different from the local realm. If PGREALM is set, Postgres 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 runtime options for the Postgres backend.

PGTTY sets the file or tty on which debugging messages from the backend server are displayed.

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

PGDATESTYLE sets the default style of date/time representation.

PGTZ sets the default time zone.

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

PGGEQO sets the default mode for the genetic optimizer.

PGRPLANS sets the default mode to allow or disable right-sided plans in the optimizer.

PGCOSTHEAP sets the default cost for heap searches for the optimizer.

PGCOSTINDEX sets the default cost for indexed searches for the optimizer.

PGQUERY_LIMIT sets the maximum number of rows returned by a query.

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

Database Connection Functions

Database Environment Class: PGenv

The database environment class provides C++ objects for manipulating the above environment variables:

PGenv creates an environment for the running program.

```
PGenv()
PGenv(char* auth, char* host, char* port, char* option, char* tty)
```

The first form of this object's constructor sets up the defaults for the program from the environment variables listed above. The second allows the programmer to hardcode the values into the program. The values of the second form relate directly to the environment variables above.

Database Class: PGdatabase

The database class is a provides C++ objects that have a connection to a backend server. To create such an object one first need the apropriate environment for the backend to access. The following constructors deal with making a connection to a backend server from a C++ program.

PGdatabase makes a new connection to a backend database server.

```
PGdatabase(PGenv *env, char *dbName)
```

After a PGdatabase has been created it should be checked to make sure the connection to the database succeded before sending queries to the object. This can easily be done by retrieving the current status of the PGdatabase object with the status method.

status returns the status of the PGdatabase object.

```
ConnStatus PGdatabase::status()
```

The following values are allowed:

CONNECTION_OK
CONNECTION_BAD

Query Execution Functions

PGdatabase::exec submits a query to Postgres and returns result status. In case of an error PGdatabase::errormessage can be used to get more information on the error.

```
void ExecStatusType PGdatabase::exec(char *query);
```

The following status results can be expected:

PGRES_EMPTY_QUERY
PGRES_COMMAND_OK, if the query was a command
PGRES_TUPLES_OK, if the query successfully returned tuples
PGRES_COPY_OUT
PGRES_COPY_IN
PGRES_BAD_RESPONSE, if an unexpected response was received
PGRES_NONFATAL_ERROR
PGRES_FATAL_ERROR

If the result status is PGRES_TUPLES_OK, then the following routines can be used to retrieve the tuples returned by the query.

PGdatabase::ntuples returns the number of tuples (instances) in the query result.

```
int PGdatabase::ntuples()
```

PGdatabase::nfields returns the number of fields (attributes) in the query result.

```
int PGdatabase::nfields()
```

PGdatabase::fieldname returns the field (attribute) name associated with the given field index. Field indices start at zero.

```
char* PGdatabase::fieldname(int field_index)
```

PGdatabase::fieldnum returns the field (attribute) index associated with the given field name.

```
int PGdatabase::fieldnum(char* field_name)
```

PGdatabase::fieldtype returns the field type of associated with the given field index or name. The integer returned is an internal coding of the type. Field indices start at zero.

```
Oid PGdatabase::fieldtype(int field_index)
```

```
Oid PGdatabase::fieldtype(char* field_name)
```

PGdatabase::fieldsize returns the size in bytes of the field associated with the given field index or name. If the size returned is -1, the field is a variable length field. Field indices start at zero.

```
int2 PGdatabase::fieldsize(int field_index)
int2 PGdatabase::fieldsize(char* field_name)
```

PGdatabase::getvalue returns the field (attribute) value. For most queries, the values returned by PGdatabase::getvalue is a null-terminated ASCII string representation of the attribute value. If the query was a result of a BINARY cursor, then the values returned by PGdatabase::getvalue is the binary representation of the type in the internal format of the backend server. It is the programmer's responsibility to cast and convert the data to the correct C++ type. The value return by PGdatabase::getvalue points to storage that is part of the PGdatabase structure. One must explicitly copy the value into other storage if it is to be used past the next query.

```
char* PGdatabase::getvalue(int tup_num, int field_index)
char* PGdatabase::getvalue(int tup_num, char* field_name)
```

PGdatabase::getlength returns the length of a field (attribute) in bytes. If the field is a struct varlena, the length returned here does not include the size field of the varlena, i.e., it is 4 bytes less.

```
int PGdatabase::getlength(int tup_num, int field_index)
int PGdatabase::getlength(int tup_num, char* field_name)
```

PGdatabase::printtuples prints out all the tuples and, optionally, the attribute names to the specified output stream.

```
void PGdatabase::printtuples(
       FILE* fout,      /* output stream */
       int printAttName,/* print attribute names or not*/
       int terseOutput, /* delimiter bars or not?*/
       int width        /* width of column, variable width if 0*/
       );
```

Asynchronous Notification

Postgres supports asynchronous notification via the LISTEN and NOTIFY commands. A backend registers its interest in a particular semaphore with the LISTEN command. All backends that are listening on a particular named semaphore will be notified asynchronously when a NOTIFY of that name is executed by another 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 the relation.

> Note: In the past, the documentation has associated the names used for asyncronous notification with relations or classes. However, there is in fact no direct linkage of the two concepts in the implementation, and the named semaphore in fact does not need to have a corresponding relation previously defined.

libpq++ applications are notified whenever a connected backend has received an asynchronous notification. However, the communication from the backend to the frontend is not asynchronous. The libpq++ application must poll the backend to see if there is any pending notification information. After the execution of a query, a frontend may call PGdatabase::notifies to see if any notification data is currently available from the backend. PGdatabase::notifies returns the notification from a list of unhandled notifications from the backend. The function eturns NULL if there is no pending notifications from the backend. PGdatabase::notifies behaves like the popping of a stack. Once a notification is returned from PGdatabase::notifies, it is considered handled and will be removed from the list of notifications.

PGdatabase::notifies retrieves pending notifications from the server.

```
PGnotify* PGdatabase::notifies()
```

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

Functions Associated with the COPY Command

The copy command in Postgres 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 full advantage of this capability.

PGdatabase::getline reads a newline-terminated line of characters (transmitted by the backend server) into a buffer string of size length.

```
int PGdatabase::getline(char* string, int length)
```

Like the Unix system routine fgets (3), this routine copies up to length-1 characters into string. It is like gets (3), however, in that it converts the terminating newline into a null character.

PGdatabase::getline returns EOF at end of file, 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 a single period ("."), which indicates that the backend server has finished sending the results of the copy. Therefore, if the application ever expects to receive lines that are more than length-1 characters long, the application must be sure to check the return value of PGdatabase::getline very carefully.

PGdatabase::putline Sends a null-terminated string to the backend server.

```
void PGdatabase::putline(char* string)
```

The application must explicitly send a single period character (".") to indicate to the backend that it has finished sending its data.

PGdatabase::endcopy syncs with the backend.

```
int PGdatabase::endcopy()
```

This function waits until the backend has finished processing the copy. It should either be issued when the last string has been sent to the backend using PGdatabase::putline or when the last string has been received from the backend using PGdatabase::getline. 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 query.

The return value is 0 on successful completion, nonzero otherwise.

As an example:

```
PGdatabase data;
data.exec("create table foo (a int4, b char16, d float8)");
data.exec("copy foo from stdin");
data.putline("3\etHello World\et4.5\en");
data.putline("4\etGoodbye World\et7.11\en");
\&...
data.putline(".\en");
data.endcopy();
```

Caveats

The query buffer is 8192 bytes long, and queries over that length will be silently truncated.

The PGlobj class is largely untested. Use with caution.

Chapter 18. pgtcl

pgtcl is a tcl package for front-end programs to interface with Postgres backends. It makes most of the functionality of libpq available to tcl scripts.

This package was originally written by Jolly Chen.

Commands

Table 18-1. 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_listen	establish a callback for NOTIFY messages
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

These commands are described further on subsequent pages.

The pg_lo* routines are interfaces to the Large Object features of Postgres. 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/END 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/END transaction block.

Examples

Here's a small example of how to use the routines:

```
# 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
}
```

pgtcl Command Reference Information

pg_connect

Name

pg_connect   opens a connection to the backend server

```
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.

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 Postgres 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

XXX thomas 1997-12-24

pg_disconnect

Name

pg_disconnect closes a connection to the backend server

pg_disconnect dbHandle

Inputs

dbHandle

Specifies a valid database handle.

Outputs

None

Description

pg_disconnect closes a connection to the Postgres backend.

pg_conndefaults

Name

pg_conndefaults obtain information about default connection parameters

`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 query string to the backend

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 Postgres 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

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 an empty string.

-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

```
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

resultHandle

the return result is either an error message or a handle for a query result.

Description

pg_select submits a SELECT query to the Postgres 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.

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_listen

Name

pg_listen   sets or changes a callback for asynchronous NOTIFY messages

`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 and not empty, 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 Postgres 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 Postgres 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_lo_creat

Name

pg_lo_creat   create a large object

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, INV_WRITE, and INV_ARCHIVE. The OR delimiter character is "|".

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

pg_lo_open

Name

pg_lo_open   open a large object

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

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

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

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

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

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

pg_lo_unlink conn lobjId

Inputs

conn

Specifies a valid database connection.

lobjId

Identifier for a large object. XXX Is this the same as objOid in other calls?? - thomas 1998-01-11

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 Unix file

pg_lo_import conn filename

Inputs

conn

`Specifies a valid database connection.`

filename

`Unix file name.`

Outputs

```
None XXX Does this return a lobjId? Is that the same as the
objOid in other calls? thomas - 1998-01-11
```

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 Unix file

pg_lo_export conn lobjId filename

Inputs

conn

    Specifies a valid database connection.

lobjId

    Large object identifier. XXX Is this the same as the objOid in other calls?? thomas - 1998-01-11

filename

    Unix file name.

Outputs

`None XXX Does this return a lobjId? Is that the same as the objOid in other calls? thomas - 1998-01-11`

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 19. ecpg - Embedded SQL in C

This describes an embedded SQL in C package for Postgres. It is written by Linus Tolke and Michael Meskes.

> Note: Permission is granted to copy and use in the same way as you are allowed to copy and use the rest of the PostgreSQL.

Why Embedded SQL?

Embedded SQL has some small advantages over other ways to handle SQL queries. It takes care of all the tedious moving of information to and from variables in your C program. Many RDBMS packages support this embedded language.

There is an ANSI-standard describing how the embedded language should work. ecpg was designed to meet this standard as much as possible. So it is possible to port programs with embedded SQL written for other RDBMS packages to Postgres and thus promoting the spirit of free software.

The Concept

You write your program in C with some special SQL things. For declaring variables that can be used in SQL statements you need to put them in a special declare section. You use a special syntax for the SQL queries.

Before compiling you run the file through the embedded SQL C preprocessor and it converts the SQL statements you used to function calls with the variables used as arguments. Both variables that are used as input to the SQL statements and variables that will contain the result are passed.

Then you compile and at link time you link with a special library that contains the functions used. These functions (actually it is mostly one single function) fetches the information from the arguments, performs the SQL query using the ordinary interface (libpq) and puts back the result in the arguments dedicated for output.

Then you run your program and when the control arrives to the SQL statement the SQL statement is performed against the database and you can continue with the result.

How To Use egpc

This section describes how to use the egpc tool.

Preprocessor

The preprocessor is called ecpg. After installation it resides in the Postgres bin/ directory.

Library

The ecpg library is called libecpg.a or libecpg.so. Additionally, the library uses the libpq library for communication to the Postgres server so you will have to link your program with -lecpg -lpq.

The library has some methods that are "hidden" but that could prove very useful sometime.

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 logs its arguments and result.

The most important one (ECPGdo) that is called on all SQL statements except EXEC SQL COMMIT, EXEC SQL ROLLBACK, EXEC SQL CONNECT logs both its expanded string, i.e. the string with all the input variables inserted, and the result from the Postgres 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.

Error handling

To be able to detect errors from the Postgres server you include a line like

```
exec sql include sqlca;
```

in the include section of your file. This will define a struct and a variable with the name sqlca as following:

```
struct sqlca {
    int sqlcode;
    struct {
        int sqlerrml;
        char sqlerrmc[1000];
    } sqlerrm;
} sqlca;
```

If an error occured in the last SQL statement then sqlca.sqlcode will be non-zero. If sqlca.sqlcode is less that 0 then this is some kind of serious error, like the database definition does not match the query given. If it is bigger than 0 then this 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 line 23. where the line is the line number in the source file (actually the file generated by the preprocessor but I hope I can fix this to be the line number in the input file.)

List of errors that can occur:

-1, Unsupported type %s on line %d.

    Does not normally occur. This is a sign that the preprocessor has generated something that the library does not know about. Perhaps you are running incompatible versions of the preprocessor and the library.

-1, Too many arguments line %d.

    The preprocessor has goofed up and generated some incorrect code.

-1, Too few arguments line %d.

    The preprocessor has goofed up and generated some incorrect code.

-1, Error starting transaction line %d.

    Postgres signalled to us that we cannot open the connection.

-1, Postgres error: %s line %d.

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

1, Data not found line %d.

    This is a "normal" error that tells you that what you are quering cannot be found or we have gone through the cursor.

-1, To many matches line %d.

This means that the query has returned several lines. The SELECT you made probably was not unique.

-1, Not correctly formatted int type: %s line %d.

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

-1, Not correctly formatted unsigned type: %s line %d.

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

-1, Not correctly formatted floating point type: %s line %d.

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

-1, Too few arguments line %d.

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

-1, Too many arguments line %d.

This means that Postgres has returned fewer records than we have host variables. Perhaps you have to many host variables in the INTO :var1,:var2-list.

-1, Empty query line %d.

Postgres returned PGRES_EMPTY_QUERY.

-1, Error: %s line %d.

This means that Postgres returned on of the errors PGRES_NONFATAL_ERROR, PGRES_FATAL_ERROR or PGRES_BAD_RESPONSE. Which one and why is explained in the message.

-1, Postgres error line %d.

Postgres returns something that the library does not know how to handle. This is probably because the version of Postgres does not match the version of the ecpg library.

-1, Error committing line %d.

Error during COMMIT. EXEC SQL COMMIT is translated to an end operation in Postgres and that is the operation that could not be performed.

-1, Error rolling back line %d.

Error during ROLLBACK. EXEC SQL ROLLBACK is translated to an abort operation in Postgres and that is the operation that could not be performed.

-1, ECPGconnect: could not open database %s.

The connect to the database did not work.

Limitations

What will never be included and why or what cannot be done with this concept.

oracles single tasking possibility

Oracle version 7.0 on AIX 3 uses the OS-supported locks on the shared memory segments and allows the application designer to link an application in a so called single tasking way. Instead of starting one client process per application process both the database part and the application part is run in the same process. In later versions of oracle this is no longer supported.

This would require a total redesign of the Postgres access model and that effort can not justify the performance gained.

Porting From Other RDBMS Packages

To be written by someone who knows the different RDBMS packages and who actually does port something...

Installation

Since version 0.5 ecpg is distributed together with Postgres. So you should get your precompiler, libraries and header files compiled and installed by default as a part of your installation.

For the Developer

This section is for those who want to develop the ecpg interface. It describes how the things work. The ambition is to make this section contain things for those that want to have a look inside and the section on How to use it should be enough for all normal questions. So, read this before looking at the internals of the ecpg. If you are not interested in how it really works, skip this section.

ToDo List

This version the preprocessor has some flaws:

no restriction to strings only

The PQ interface, and most of all the PQexec function, that is used by the ecpg relies on that the request is built up as a string. In some cases, like when the data contains the null character, this will be a serious problem.

error codes

There should be different error numbers for the different errors instead of just -1 for them all.

library functions

to_date et al.

records

Records or structures have to be defined in the declare section.

missing statements

The following statements are not implemented thus far:

exec sql type

exec sql prepare

exec sql allocate

exec sql free

exec sql whenever sqlwarning

SQLSTATE

message ´no data found´

The error message for "no data" in an exec sql insert select from statement has to be 100.

sqlwanr[6]

sqlwarn[6] should be 'W' if the PRECISION or SCALE value specified in a SET DESCRIPTOR statement will be ignored.

conversion of scripts

To set up a database you need a few scripts with table definitions and other configuration parameters. If you have these scripts for an old database you would like to just apply them to get a Postgres database that works in the same way.

To set up a database you need a few scripts with table definitions and The functionality could be accomplished with some conversion scripts. Speed will never be accomplished in this way. To do this you need a bigger insight in the database construction and the use of the database than could be realised in a script.

The Preprocessor

First four lines are written to the output. Two comments and two include lines necessary for the interface to the library.

Then the preprocessor works in one pass only reading the input file and writing to the output as it goes along. Normally it just echoes everything to the output without looking at it further.

When it comes to an EXEC SQL statements it interviens and changes them depending on what iit is. The EXEC SQL statement can be one of these:

Declare sections

Declare sections begins with

```
exec sql begin declare section;
```

and ends with

```
exec sql end declare section;
```

In the section only variable declarations are allowed. Every variable declare within this section is also entered in a list of variables indexed on their name together with the corresponding type.

The declaration is echoed to the file to make the variable a normal C-variable also.

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;
```

Include statements

An include statement looks like:

```
exec sql include filename;
```

It is converted into

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

Connect statement

A connect statement looks like:

```
exec sql connect 'database';
```

That statement is converted into

```
ECPGconnect("database");
```

Open cursor statement

An open cursor statement looks like:

```
exec sql open cursor;
```

and is ignore and not copied from the output.

Commit statement

A commit statement looks like

```
exec sql commit;
```

and is translated on the output to

```
ECPGcommit(__LINE__);
```

Rollback statement

A rollback statement looks like

```
exec sql rollback;
```

and is translated on the output to

```
ECPGrollback(__LINE__);
```

Other statements

Other SQL statements are other statements that start with exec sql and ends with ;. Everything inbetween is treated as an SQL statement and parsed for variable substitution.

Variable substitution occur when a symbol starts with a colon (:). Then a variable with that name is found among the variables that were previously declared within a declare section and depending on whether or not the SQL statements knows it to be a variable for input or output the pointers to the variables are written to the output to allow for access by the function.

For every variable that is part of the SQL request the function gets another five arguments:

The type as a special symbol
A pointer to the value
The size of the variable if it is a varchar
Number of elements in the array (for array fetches)
The offset to the next element in the array (for array fetches)

Since the array fetches are not implemented yet the two last arguments are not really important. They could perhaps have been left out.

A Complete Example

Here is a complete example describing the output 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:

```
/* These two include files are added by the preprocessor */
#include <ecpgtype.h>
#include <ecpglib.h>
/* exec sql begin declare section */

 int index;
 int result;
/* exec sql end declare section */

...
    ECPGdo(__LINE__, "select res from mytable where index = ;;",
           ECPGt_int,&index,0,0,sizeof(int),
           ECPGt_EOIT,
           ECPGt_int,&result,0,0,sizeof(int),
           ECPGt_EORT );
```

(the indentation in this manual is added for readability and not something that the preprocessor can do.)

The Library

The most important function in the library is the ECPGdo function. It takes a variable amount of arguments. Hopefully we wont run into machines with limits on the amount of variables that can be accepted by a varchar function. This could easily add up to 50 or so arguments.

The arguments are:

A line number

This is a line number for the original line used in error messages only.

A string

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

Input variables

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

ECPGt_EORT

An enum telling that there are no more variables.

All the SQL statements are performed in one transaction unless you issue a commit transaction. This works so that the first transaction or the first after a commit or rollback always begins a transaction.

To be completed: entries describing the other entries.

Chapter 20. ODBC Interface

> Note: Background information originally by Tim Goeke

ODBC (Open Database Connectivity) is an abstract API which allows you to write applications which can interoperate with various RDBMS servers. ODBC provides a product-neutral interface between frontend applications and database servers, allowing a user or developer to write applications which are transportable between servers from different manufacturers..

Background

The ODBC API matches up on the backend to an ODBC-compatible data source. This could be anything from a text file to an Oracle or Postgres RDBMS.

The backend access come from ODBC drivers, or vendor specifc drivers that allow data access. psqlODBC is such a driver, along with others that are available, such as the OpenLink ODBC drivers.

Once you write an ODBC application, you should be able to connect to any back end database, regardless of the vendor, as long as the database schema is the same.

For example. you could have MS SQL Server and Postgres servers which have exactly the same data. Using ODBC, your Windows application would make exactly the same calls and the back end data source would look the same (to the Windows app).

Insight Distributors provides active and ongoing support for the core psqlODBC distribution. They provide a FAQ, ongoing development on the code base, and actively participate on the interfaces mailing list.

Windows Applications

In the real world, differences in drivers and the level of ODBC support lessens the potential of ODBC:

Access, Delphi, and Visual Basic all support ODBC directly.
Under C++, such as Visual C++, you can use the C++ ODBC API.
In Visual C++, you can use the CRecordSet class, which wraps the ODBC API set within an MFC 4.2 class. This is the easiest route if you are doing Windows C++ development under Windows NT.

Writing Applications

If I write an application for Postgres can I write it using ODBC calls to the Postgres server, or is that only when another database program like MS SQL Server or Access needs to access the data?

The ODBC API is the way to go. For Visual C++ coding you can find out more at Microsoft's web site or in your VC++ docs.

Visual Basic and the other RAD tools have Recordset objects that use ODBC directly to access data. Using the data-aware controls, you can quickly link to the ODBC back end database (very quickly).

Playing around with MS Access will help you sort this out. Try using File->Get External Data.

> Tip: You'll have to set up a DSN first.

Unix Installation

ApplixWare has an ODBC database interface supported on at least some platforms. ApplixWare v4.4.1 has been demonstrated under Linux with Postgres v6.4 using the psqlODBC driver contained in the Postgres distribution.

Building the Driver

The first thing to note about the psqlODBC driver (or any ODBC driver) is that there must exist a driver manager on the system where the ODBC driver is to be used. There exists a freeware ODBC driver for Unix called iodbc which can be obtained from various locations on the Net, including at AS200. Instructions for installing iodbc are beyond the scope of this document, but there is a README that can be found inside the iodbc compressed .shar file that should explain how to get it up and running.

Having said that, any driver manager that you can find for your platform should support the psqlODBC driver or any ODBC driver.

The Unix configuration files for psqlODBC have recently been extensively reworked to allow for easy building on supported platforms as well as to allow for support of other Unix platforms in the future. The new configuration and build files for the driver should make it a simple process to build the driver on the supported platforms. Currently these include Linux and FreeBSD but we are hoping other users will contribute the necessary information to quickly expand the number of platforms for which the driver can be built.

There are actually two separate methods to build the driver depending on how you received it and these differences come down to only where and how to run configure and make. The driver can be built in a standalone, client-only installation, or can be built as a part of the main Postgres distribution. The standalone installation is convenient if you have ODBC client applications on multiple, heterogeneous platforms. The integrated installation is convenient when the target client is the same as the server, or when the client and server have similar runtime configurations.

Specifically if you have received the psqlODBC driver as part of the Postgres distribution (from now on referred to as an "integrated" build) then you will configure and make the ODBC driver from the top level source directory of the Postgres distribution along with the rest of its libraries. If you received the driver as a standalone package than you will run configure and make from the directory in which you unpacked the driver source.

Procedure 20.1. Integrated Installation

This installation procedure is appropriate for an integrated installation.

1. **Specify the --with-odbc command-line argument for src/configure:**

   ```
   % ./configure --with-odbc
   % make
   ```

2. **Rebuild the Postgres distribution:**

   ```
   % make install
   ```

Once configured, the ODBC driver will be built and installed into the areas defined for the other components of the Postgres system. The installation-wide ODBC configuration file will be placed into the top directory of the Postgres target tree (POSTGRESDIR). This can be overridden from the make command-line as

```
% make ODBCINST=filename install
```

Procedure 20.2. Pre-v6.4 Integrated Installation

If you have a Postgres installation older than v6.4, you have the original source tree available, and you want to use the newest version of the ODBC driver, then you may want to try this form of installation.

1. **Copy the output tar file to your target system and unpack it into a clean directory.**
2. **From the directory containing the sources, type:**

```
% ./configure
% make
% make POSTGRESDIR=PostgresTopDir install
```

3. **If you would like to install components into different trees, then you can specify various destinations explicitly:**

```
% make BINDIR=bindir  LIBDIR=libdir  HEADERDIR=headerdir
ODBCINST=instfile install
```

Procedure 20.3. Standalone Installation

A standalone installation is not integrated with or built on the normal Postgres distribution. It should be best suited for building the ODBC driver for multiple, heterogeneous clients who do not have a locally-installed Postgres source tree.

The default location for libraries and headers for the standalone installation is /usr/local/lib and /usr/local/include/iodbc, respectively. There is another system wide configuration file that gets installed as /share/odbcinst.ini (if /share exists) or as /etc/odbcinst.ini (if /share does not exist).

> Note: Installation of files into /share or /etc requires system root privileges. Most installation steps for Postgres do not have this requirement, and you can choose another destination which is writable by your non-root Postgres superuser account instead.

1. **The standalone installation distribution can be built from the Postgres distribution or may be obtained from Insight Distributors, the current maintainers of the non-Unix sources.**

   Copy the zip or gzipped tarfile to an empty directory. If using the zip package unzip it with the command

   % unzip −a packagename

   The -a option is necessary to get rid of DOS CR/LF pairs in the source files.

   If you have the gzipped tar package than simply run

   tar −xzf packagename

   a. **To create a tar file for a complete standalone installation from the main Postgres source tree:**

2. **Configure the main Postgres distribution.**
3. **Create the tar file:**

```
% cd interfaces/odbc
% make standalone
```

4. **Copy the output tar file to your target system. Be sure to transfer as a binary file if using ftp.**
5. **Unpack the tar file into a clean directory.**
6. **Configure the standalone installation:**

```
% ./configure
```

The configuration can be done with options:

```
% ./configure --prefix=rootdir --with-odbc=inidir
```

where --prefix installs the libraries and headers in the directories rootdir/lib and rootdir/include/iodbc, and --with-odbc installs odbcinst.ini in the specified directory.

Note that both of these options can also be used from the integrated build but be aware that when used in the integrated build --prefix will also apply to the rest of your Postgres installation. --with-odbc applies only to the configuration file odbcinst.ini.

7. **Compile and link the source code:**

   ```
   % make ODBCINST=instdir
   ```

   You can also override the default location for installation on the 'make' command line. This only applies to the installation of the library and header files. Since the driver needs to know the location of the odbcinst.ini file attempting to override the enviroment variable that specifies its installation directory will probably cause you headaches. It is safest simply to allow the driver to install the odbcinst.ini file in the default directory or the directory you specified on the './configure' command line with --with-odbc.

8. **Install the source code:**

   ```
   % make POSTGRESDIR=targettree install
   ```

   To override the library and header installation directories separately you need to pass the correct installation variables on the make install command line. These variables are LIBDIR, HEADERDIR and ODBCINST. Overriding POSTGRESDIR on the make command line will cause LIBDIR and HEADERDIR to be rooted at the new directory you specify. ODBCINST is independent of POSTGRESDIR.

   Here is how you would specify the various destinations explicitly:

   ```
   % make BINDIR=bindir LIBDIR=libdir HEADERDIR=headerdir install
   ```

   For example, typing

   ```
   % make POSTGRESDIR=/opt/psqlodbc install
   ```

   (after you've used ./configure and make) will cause the libraries and headers to be installed in the directories /opt/psqlodbc/lib and /opt/psqlodbc/include/iodbc respectively.

   The command

   ```
   % make POSTGRESDIR=/opt/psqlodbc HEADERDIR=/usr/local install
   ```

   should cause the libraries to be installed in /opt/psqlodbc/lib and the headers in /usr/local/include/iodbc. If this doesn't work as expected please contact one of the maintainers.

Configuration Files

~/.odbc.ini contains user-specified access information for the psqlODBC driver. The file uses conventions typical for Windows Registry files, but despite this restriction can be made to work.

The .odbc.ini file has three required sections. The first is [ODBC Data Sources] which is a list of arbitrary names and descriptions for each database you wish to access. The second required section is the Data Source Specification and there will be one of these sections for each database. Each section must be labeled with the name given in [ODBC Data Sources] and must contain the following entries:

```
Driver = POSTGRESDIR/lib/libpsqlodbc.so
Database=DatabaseName
Servername=localhost
Port=5432
```

> Tip: Remember that the Postgres database name is usually a single word, without path names of any sort. The Postgres server manages the actual access to the database, and you need only specify the name from the client.

Other entries may be inserted to control the format of the display. The third required section is [ODBC] which must contain the InstallDir keyword and which may contain other options.

Here is an example .odbc.ini file, showing access information for three databases:

```
[ODBC Data Sources]
DataEntry = Read/Write Database
QueryOnly = Read-only Database
Test = Debugging Database
Default = Postgres Stripped

[DataEntry]
ReadOnly = 0
Servername = localhost
Database = Sales

[QueryOnly]
ReadOnly = 1
Servername = localhost
Database = Sales

[Test]
Debug = 1
CommLog = 1
ReadOnly = 0
Servername = localhost
Username = tgl
Password = "no$way"
Port = 5432
Database = test

[Default]
Servername = localhost
Database = tgl
Driver = /opt/postgres/current/lib/libpsqlodbc.so

[ODBC]
InstallDir = /opt/applix/axdata/axshlib
```

ApplixWare

Configuration

ApplixWare must be configured correctly in order for it to be able to access the Postgres ODBC software drivers.

Procedure 20.4. Enabling ApplixWare Database Access

Note that these instructions are for the 4.4.1 release of ApplixWare on Linux. Refer to the Linux Sys Admin on-line book for more detailed information.

1. **You must modify axnet.cnf so that elfodbc can find libodbc.so (the ODBC driver manager) shared library. This library is included with the ApplixWare distribution, but axnet.cnf needs to be modified to point to the correct location.**

   As root, edit the file applixroot/applix/axdata/axnet.cnf.

a. **At the bottom of axnet.cnf, find the line that starts with**

   `#libFor elfodbc /ax/...`

b. **Change line to read**

   ```
   libFor elfodbc applixroot/applix/axdata/axshlib/lib
   ```

   which will tell elfodbc to look in this directory for the ODBC support library. If you have installed applix somewhere else, change the path accordingly.

2. **Create .odbc.ini as described above. You may also want to add the flag**

   ```
   TextAsLongVarchar=0
   ```

   to the database-specific portion of .odbc.ini so that text fields will not be shown as **BLOB.**

Procedure 20.5. Testing ApplixWare ODBC Connections

1. **Bring up Applix Data**
2. **Select the Postgres database of interest.**
   a. **Select Query->Choose Server.**
   b. **Select ODBC, and click Browse. The database you configured in .odbc.ini should be shown. Make sure that the Host: field is empty (if it is not, axnet will try to contact axnet on another machine to look for the database).**
   c. **Select the database in the box that was launched by Browse, then click OK.**
   d. **Enter username and password in the login identification dialog, and click OK.**

   You should see Starting elfodbc server in the lower left corner of the data window. If you get an error dialog box, see the debugging section below.
3. **The 'Ready' message will appear in the lower left corner of the data window. This indicates that you can now enter queries.**
4. **Select a table from Query->Choose tables, and then select Query->Query to access the database. The first 50 or so rows from the table should appear.**

Common Problems

The following messages can appear while trying to make an ODBC connection through Applix Data:

Cannot launch gateway on server

> elfodbc can't find libodbc.so. Check your axnet.cnf.

Error from ODBC Gateway: IM003::[iODBC][Driver Manager]Specified driver could not be loaded

> libodbc.so cannot find the driver listed in .odbc.ini. Verify the settings.

Server: Broken Pipe

> The driver process has terminated due to some other problem. You might not have an up-to-date version of the Postgres ODBC package.

setuid to 256: failed to launch gateway

The September release of ApplixWare v4.4.1 (the first release with official ODBC support under Linux) shows problems when usernames exceed eight (8) characters in length. Problem description ontributed by Steve Campbell.

Author: Contributed by Steve Campbell on 1998-10-20.

The axnet program's security system seems a little suspect. axnet does things on behalf of the user and on a true multiple user system it really should be run with root security (so it can read/write in each user's directory). I would hesitate to recommend this, however, since we have no idea what security holes this creates.

Debugging ApplixWare ODBC Connections

One good tool for debugging connection problems uses the Unix system utility strace.

Procedure 20.6. Debugging with strace

1. **Start applixware.**
2. **Start an strace on the axnet process. For example, if**

   ```
   ps -aucx | grep ax
   ```

   shows

   ```
   cary   10432  0.0  2.6  1740   392  ?  S  Oct  9  0:00 axnet
   cary   27883  0.9 31.0 12692  4596  ?  S   10:24  0:04 axmain
   ```

   Then run

   ```
   strace -f -s 1024 -p 10432
   ```

3. **Check the strace output.**

Note from Cary: Many of the error messages from ApplixWare go to stderr, but I'm not sure where stderr is sent, so strace is the way to find out.

For example, after getting a Cannot launch gateway on server , I ran strace on axnet and got

```
[pid 27947] open("/usr/lib/libodbc.so", O_RDONLY) = -1 ENOENT
    (No such file or directory)
[pid 27947] open("/lib/libodbc.so", O_RDONLY) = -1 ENOENT
    (No such file or directory)
[pid 27947] write(2, "/usr2/applix/axdata/elfodbc:
    can't load library 'libodbc.so'\n", 61) = -1 EIO (I/O error)
```

So what is happening is that applix elfodbc is searching for libodbc.so, but it can't find it. That is why axnet.cnf needed to be changed.

Running the ApplixWare Demo

In order to go through the ApplixWare Data Tutorial, you need to create the sample tables that the Tutorial refers to. The ELF Macro used to create the tables tries to use a NULL condition on many of the database columns, and Postgres does not currently allow this option.

To get around this problem, you can do the following:

Procedure 20.7. Modifying the ApplixWare Demo

1. **Copy /opt/applix/axdata/eng/Demos/sqldemo.am to a local directory.**
2. **Edit this local copy of sqldemo.am:**

   a. **Search for ’null_clause = "NULL"**
   b. **Change this to null_clause = ""**
3. **Start Applix Macro Editor.**
4. **Open the sqldemo.am file from the Macro Editor.**
5. **Select File->Compile and Save.**
6. **Exit Macro Editor.**
7. **Start Applix Data.**
8. **Select *->Run Macro**
9. **Enter the value sqldemo , then click OK.**

   You should see the progress in the status line of the data window (in the lower left corner).
10. **You should now be able to access the demo tables.**

Useful Macros

You can add information about your database login and password to the standard Applix startup macro file. This is an example ~/axhome/macros/login.am file: ======= ApplixWare must be configured correctly in order for it to be able to access the Postgres ODBC software drivers.

Procedure 20.8. Enabling ApplixWare Database Access

Note that these instructions are for the 4.4.1 release of ApplixWare on Linux. Refer to the Linux Sys Admin on-line book for more detailed information.

1. **You must modify axnet.cnf so that elfodbc can find libodbc.so (the ODBC driver manager) shared library. This library is included with the ApplixWare distribution, but axnet.cnf needs to be modified to point to the correct location.**

   As root, edit the file applixroot/applix/axdata/axnet.cnf.

   a. **At the bottom of axnet.cnf, find the line that starts with**

      `#libFor elfodbc /ax/...`

   b. **Change line to read**

      ```
      libFor elfodbc applixroot/applix/axdata/axshlib/lib
      ```

      which will tell elfodbc to look in this directory for the ODBC support library. If you have installed applix somewhere else, change the path accordingly.
2. **Create .odbc.ini as described above. You may also want to add the flag**

   ```
   TextAsLongVarchar=0
   ```

   to the database-specific portion of .odbc.ini so that text fields will not be shown as **BLOB.**

Procedure 20.9. Testing ApplixWare ODBC Connections

1. **Bring up Applix Data**
2. **Select the Postgres database of interest.**

   a. **Select Query->Choose Server.**

   b. **Select ODBC, and click Browse. The database you configured in .odbc.ini should be shown. Make sure that the Host: field is empty (if it is not, axnet will try to contact axnet on another machine to look for the database).**
   c. **Select the database in the box that was launched by Browse, then click OK.**
   d. **Enter username and password in the login identification dialog, and click OK.**

   You should see Starting elfodbc server in the lower left corner of the data window. If you get an error dialog box, see the debugging section below.

3. **The 'Ready' message will appear in the lower left corner of the data window. This indicates that you can now enter queries.**
4. **Select a table from Query->Choose tables, and then select Query->Query to access the database. The first 50 or so rows from the table should appear.**

Common Problems

The following messages can appear while trying to make an ODBC connection through Applix Data:

Cannot launch gateway on server

elfodbc can't find libodbc.so. Check your axnet.cnf.

Error from ODBC Gateway: IM003::[iODBC][Driver Manager]Specified driver could not be loaded

libodbc.so cannot find the driver listed in .odbc.ini. Verify the settings.

Server: Broken Pipe

The driver process has terminated due to some other problem. You might not have an up-to-date version of the Postgres ODBC package.

Debugging ApplixWare ODBC Connections

One good tool for debugging connection problems uses the Unix system utility strace.

Procedure 20.10. Debugging with strace

1. **Start applixware.**
2. **Start an strace on the axnet process. For example, if**

   ```
   ps -aucx | grep ax
   ```

   shows

   ```
   cary   10432  0.0  2.6  1740   392  ?  S  Oct  9  0:00 axnet
   cary   27883  0.9 31.0 12692  4596  ?  S   10:24  0:04 axmain
   ```

   Then run

   ```
   strace -f -s 1024 -p 10432
   ```

3. **Check the strace output.**

Note from Cary: Many of the error messages from ApplixWare go to stderr, but I'm not sure where stderr is sent, so strace is the way to find out.

For example, after getting a Cannot launch gateway on server , I ran strace on axnet and got

```
[pid 27947] open("/usr/lib/libodbc.so", O_RDONLY) = -1 ENOENT
    (No such file or directory)
```

```
[pid 27947] open("/lib/libodbc.so", O_RDONLY) = -1 ENOENT
    (No such file or directory)
[pid 27947] write(2, "/usr2/applix/axdata/elfodbc:
    can't load library 'libodbc.so'\n", 61) = -1 EIO (I/O error)
```

So what is happening is that applix elfodbc is searching for libodbc.so, but it can't find it. That is why axnet.cnf needed to be changed.

Running the ApplixWare Demo

In order to go through the ApplixWare Data Tutorial, you need to create the sample tables that the Tutorial refers to. The ELF Macro used to create the tables tries to use a NULL condition on many of the database columns, and Postgres does not currently allow this option.

To get around this problem, you can do the following:

Procedure 20.11. Modifying the ApplixWare Demo

1. **Copy /opt/applix/axdata/eng/Demos/sqldemo.am to a local directory.**
2. **Edit this local copy of sqldemo.am:**
    a. **Search for 'null_clause = "NULL"**
    b. **Change this to null_clause = ""**
3. **Start Applix Macro Editor.**
4. **Open the sqldemo.am file from the Macro Editor.**
5. **Select File->Compile and Save.**
6. **Exit Macro Editor.**
7. **Start Applix Data.**
8. **Select *->Run Macro**
9. **Enter the value sqldemo , then click OK.**

    You should see the progress in the status line of the data window (in the lower left corner).
10. **You should now be able to access the demo tables.**

Useful Macros

You can add information about your database login and password to the standard Applix startup macro file. This is an example ~/axhome/macros/login.am file:

```
macro login
    set_set_system_var@("sql_username@","tgl")
    set_system_var@("sql_passwd@","no$way")
endmacro
```

Caution

You should be careful about the file protections on any file containing username and password information.

Supported Platforms

psqlODBC has been built and tested on Linux. There have been reports of success with FreeBSD and with Solaris. There are no known restrictions on the basic code for other platforms which already support Postgres.

Chapter 21. JDBC Interface

Author: Written by Peter T. Mount, the 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.

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

Building the JDBC Interface

Compiling the Driver

The driver's source is located in the src/interfaces/jdbc directory of the source tree. To compile simply change directory to that directory, and type:

```
% make
```

Upon completion, you will find the archive postgresql.jar in the current directory. This is the JDBC driver.

> Note: You must use make, not javac, as the driver uses some dynamic loading techniques for performance reasons, and javac cannot cope. The Makefile will generate the jar archive.

Installing the Driver

To use the driver, the jar archive postgresql.jar needs to be included in the CLASSPATH.

Example:

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/jdk1.1.6.

To run the application, I would use:

export CLASSPATH = \ /usr/local/lib/finder.jar:/usr/local/lib/postgresql.jar:. java uk.org.retep.finder.Main

Loading the driver is covered later on in this chapter.

Preparing the Database for JDBC

Because Java can only use TCP/IP connections, the Postgres postmaster must be running with the -i flag.

Also, the pg_hba.conf file must be configured. It's located in the PGDATA directory. In a default installation, this file permits access only by UNIX domain sockets. For the JDBC driver to connect to the same localhost, you need to add something like:

host all 127.0.0.1 255.255.255.255 password

Here access to all databases are possible from the local machine with JDBC.

The JDBC Driver supports trust, ident, password and crypt authentication methods.

Using the Driver

This section 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.

Importing JDBC

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

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

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

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 to the best one to use.

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

```
Class.forName(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, so you will need to catch it if the driver is not available.

This is the most common method to use, but restricts your code to use just Postgres. If your code may access another database in the future, and you don't use our 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=postgresql.Driver example.ImageViewer
```

In this example, the JVM will attempt to load the driver as part of it's initialisation. 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 databases, without recompiling the code. The only thing that would also change is the 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 classpath, or the value in the parameter not being correct.

Connecting to the Database

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

jdbc:postgresql:database

jdbc:postgresql://host/database

jdbc:postgresql://host:port/database

where:

host

The hostname of the server. Defaults to "localhost".

port

The port number the server is listening on. Defaults to the Postgres 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,user,pwd);

Issuing a Query and Processing the Result

Any time you want to issue SQL statements to the database, you require a Statement instance. Once you have a Statement, you can use the executeQuery() method to issue a query. This will return a ResultSet instance, which contains the entire result.

Using the Statement Interface

The following must be considered when using the Statement interface:

You can use a Statement instance as many times as you want. You could create one as soon as you open the connection, and use it for the connections lifetime. You have to remember that only one ResultSet can exist per Statement.

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 the sections covering Threads and Servlets later in this document if you are thinking of using them, as it covers some important points.

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 spec, you should access a field only once. It's safest to stick to this rule, although at the current time, the Postgres 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 with it.

Once you request another query with the Statement used to create a ResultSet, the currently open instance is closed.

An example is as follows:

```
Statement st = db.createStatement();
ResultSet rs = st.executeQuery(select * from mytable);
while(rs.next()) {
    System.out.print(Column 1 returned );
    System.out.println(rs.getString(1));
}
rs.close();
st.close();
```

Performing Updates

To perform an update (or any other SQL statement that does not return a result), you simply use the executeUpdate() method:

```
st.executeUpdate(create table basic (a int2, b int2));
```

Closing the Connection

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

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

Using Large Objects

In Postgres, large objects (also known as blobs) are used to hold data in the database that cannot be stored in a normal SQL table. They are stored as a Table/Index pair, and are refered to from your own tables, by an OID value.

Now, there are you methods of using Large Objects. The first is the standard JDBC way, and is documented here. The other, uses our own extension to the api, which presents the libpq large object API to Java, providing even better access to large objects than the standard. Internally, the driver uses the extension to provide large object support.

In JDBC, the standard way to access them is using the getBinaryStream() method in ResultSet, and setBinaryStream() method in PreparedStatement. These methods make the large object appear as a Java stream, allowing you to use the java.io package, and others, to manipulate the object.

For example, suppose you have a table containing the file name of an image, and a large object containing that image:

```
create table images (imgname name,imgoid oid);
```

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();
```

Now in this example, setBinaryStream transfers a set number of bytes from a stream into a large object, and stores the OID into the field holding a reference to it.

Retrieving an image is even easier (I'm using PreparedStatement here, but Statement can equally be used):

```
PreparedStatement ps = con.prepareStatement(select oid from images
where name=?);
ps.setString(1,myimage.gif);
ResultSet rs = ps.executeQuery();
if(rs!=null) {
    while(rs.next()) {
        InputStream is = rs.getBinaryInputStream(1);
        // use the stream in some way here
        is.close();
    }
    rs.close();
}
ps.close();
```

Now here you can see where the Large Object is retrieved as an InputStream. You'll also notice that we close the stream before processing the next row in the result. This is part of the JDBC Specification, which states that any InputStream returned is closed when ResultSet.next() or ResultSet.close() is called.

Postgres Extensions to the JDBC API

Postgres 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.

Now, as these are facilities unique to us, 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.

```
Accessing the extensions

To access some of the extensions, you need to use some extra methods
in the postgresql.Connection class. In this case, you would need to
case the return value of Driver.getConnection().

For example:

    Connection db = Driver.getConnection(url,user,pass);

    // later on
    Fastpath fp = ((postgresql.Connection)db).getFastpathAPI();

Class postgresql.Connection

java.lang.Object
   |
   +----postgresql.Connection

   public class Connection extends Object implements Connection

These are the extra methods used to gain access to our extensions. I
have not listed the methods defined by java.sql.Connection.

 public Fastpath getFastpathAPI() throws SQLException

          This returns the Fastpath API for the current connection.

          NOTE: This is not part of JDBC, but allows access to
functions on the postgresql backend itself.

          It is primarily used by the LargeObject API

          The best way to use this is as follows:

 import postgresql.fastpath.*;
 ...
 Fastpath fp = ((postgresql.Connection)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 initialising for first time

 public LargeObjectManager getLargeObjectAPI() throws SQLException

          This returns the LargeObject API for the current connection.

          NOTE: This is not part of JDBC, but allows access to
functions on the postgresql backend itself.

          The best way to use this is as follows:

 import postgresql.largeobject.*;
 ...
 LargeObjectManager lo =
((postgresql.Connection)myconn).getLargeObjectAPI();

          where myconn is an open Connection to postgresql.

        Returns:
                LargeObject object that implements the API

        Throws: SQLException
                by LargeObject when initialising 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.

          NOTE: This is not part of JDBC, but an extension.

          The best way to use this is as follows:

 ...
 ((postgresql.Connection)myconn).addDataType("mytype","my.class.name"-
);
 ...

          where myconn is an open Connection to postgresql.

          The handling class must extend postgresql.util.PGobject

        See Also:
                PGobject

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's provided
because the Large Object API uses it.

To use, you need to import the postgresql.fastpath package, using the
line:
     import postgresql.fastpath.*;
```

```
Then, in your code, you need to get a FastPath object:
     Fastpath fp = ((postgresql.Connection)conn).getFastpathAPI();

This will return an instance associated with the database connection
that you can use to issue commands. The casing of Connection to
postgresql.Connection is required, as the getFastpathAPI() is one of
our own methods, not JDBC's.

Once you have a Fastpath instance, you can use the fastpath() methods
to execute a backend function.

Class postgresql.fastpath.Fastpath

java.lang.Object
   |
   +----postgresql.fastpath.Fastpath

   public class Fastpath

   extends Object

   This class implements the Fastpath api.

   This is a means of executing functions imbeded in the postgresql
backend from within a java application.

   It is based around the file src/interfaces/libpq/fe-exec.c

   See Also:
          FastpathFastpathArg, LargeObject

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

        Throws: SQLException
                if a database-access error occurs.

 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
prefered method to call, as function id's can/may change between
versions of the backend. For an example of how this works, refer to
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

        Throws: SQLException
                if name is unknown or if a database-access error
occurs.

        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 lookup 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.

        Parameters:
                name - Function name
                fnid - Function id

 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.

          REMEMBER to close() the resultset after calling this!!

          Implementation note about function name lookups:
```

```
          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 postgresql.LargeObject class performs a query upon it’s
startup, and passes the returned ResultSet to the addFunctions()
method here.

          Once this has been done, the LargeObject api refers to the
functions by name.

          Dont think that manually converting them to the oid’s 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.

        Parameters:
                rs - ResultSet

        Throws: SQLException
                if a database-access error occurs.

        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.

        Parameters:
                name - Function name to lookup

        Returns:
                Function ID for fastpath call

        Throws: SQLException
                is function is unknown.

Class postgresql.fastpath.FastpathArg

java.lang.Object
   |
   +----postgresql.fastpath.FastpathArg

   public class FastpathArg extends Object

   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
postgresql.largeobject package

   See Also:
          Fastpath, LargeObjectManager, LargeObject

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.

        Parameters:
                s - String to store

Geometric Data Types

PostgreSQL has a set of datatypes that can store geometric features
into a table. These range from single points, lines, and polygons.

We support these types in Java with the postgresql.geometric package.

It contains classes that extend the postgresql.util.PGobject class.
Refer to that class for details on how to implement your own data type
handlers.

Class postgresql.geometric.PGbox

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----postgresql.geometric.PGbox

   public class PGbox extends PGobject implements Serializable,
Cloneable

   This represents the box datatype 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
overidden, 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 overidden 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 postgresql.geometric.PGcircle

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----postgresql.geometric.PGcircle

   public class PGcircle extends PGobject implements Serializable,
Cloneable

   This represents postgresql's circle datatype, consisting of a point
and a radius

Variables
```

```
 public PGpoint center

          This is the centre point

public double radius

          This is the radius

Constructors

 public PGcircle(double x,
                 double y,
                 double r)

        Parameters:
               x - coordinate of centre
                y - coordinate of centre
                r - radius of circle

 public PGcircle(PGpoint c,
                 double r)

        Parameters:
                c - PGpoint describing the circle's centre
                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 boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overidden 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 postgresql.geometric.PGline

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----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 circle in PostgreSQL's syntax.

        Throws: SQLException
                on conversion failure

 public PGline()

          reuired 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 boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overidden 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 postgresql.geometric.PGlseg

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----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 circle in PostgreSQL's syntax.
```

```
        Throws: SQLException
                on conversion failure

 public PGlseg()

          reuired 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 boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overidden 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 postgresql.geometric.PGpath

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----postgresql.geometric.PGpath

   public class PGpath extends PGobject implements Serializable,
Cloneable

   This implements a path (a multiple 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 circle 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 boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overidden to allow the object to be cloned

        Overrides:
                clone in class PGobject

 public String getValue()

          This returns the polygon 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 postgresql.geometric.PGpoint

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----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 datatype 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 imbeded 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 boxes are identical
```

```
        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overidden 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 postgresql.geometric.PGpolygon

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----postgresql.geometric.PGpolygon

   public class PGpolygon extends PGobject implements Serializable,
Cloneable

   This implements the polygon datatype 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 circle 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 boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()
```

```
          This must be overidden 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

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 postgresql.largeobject package profides to Java the libpq C
interface's large object API. It consists of two classes,
LargeObjectManager, which deals with creating, opening and deleting
large obejects, and LargeObject which deals with an individual object.

Class postgresql.largeobject.LargeObject

java.lang.Object
   |
   +----postgresql.largeobject.LargeObject

public class LargeObject extends Object

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 getAsciiStream,
getBinaryStream, or getUnicodeStream methods in ResultSet, or
setAsciiStream, setBinaryStream, or setUnicodeStream methods in
PreparedStatement to access Large Objects.

   However, sometimes lower level access to Large Objects are
required, that are not supported by the JDBC specification.

   Refer to postgresql.largeobject.LargeObjectManager on how to gain
access to a Large Object, or how to create one.

   See Also:
          LargeObjectManager

Variables

 public static final int SEEK_SET

          Indicates a seek from the begining 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

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.

    Throws: SQLException
                if a database-access error occurs.

 public byte[] read(int len) throws SQLException

          Reads some data from the object, and return as a byte[]
array

        Parameters:
                len - number of bytes to read

        Returns:
                byte[] array containing data read

        Throws: SQLException
                if a database-access error occurs.

 public void 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

        Throws: SQLException
                if a database-access error occurs.

 public void write(byte buf[]) throws SQLException

          Writes an array to the object


        Parameters:
                buf - array to write

        Throws: SQLException
                if a database-access error occurs.

 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

        Throws: SQLException
                if a database-access error occurs.

 public void seek(int pos,
                  int ref) throws SQLException

          Sets the current position within the object.

          This is similar to the fseek() call in the standard C
library.It allows you to have random access to the large object.

        Parameters:
```

```
                pos - position within object
                ref - Either SEEK_SET, SEEK_CUR or SEEK_END
        Throws: SQLException
                if a database-access error occurs.

 public void seek(int pos) throws SQLException

          Sets the current position within the object.

          This is similar to the fseek() call in the standard C
library.It allows you to have random access to the large object.

        Parameters:
                pos - position within object from begining

        Throws: SQLException
                if a database-access error occurs.

 public int tell() throws SQLException

        Returns:
                the current position within the object

        Throws: SQLException
                if a database-access error occurs.

 public int size() throws SQLException

          This method is inefficient, as the only way to find out the
size of the object is to seek to the end, record the current position,
then return to the original position.

          A better method will be found in the future.

        Returns:
                the size of the large object

        Throws: SQLException
                if a database-access error occurs.

 public InputStream getInputStream() throws SQLException

          Returns an InputStream from this object.

          This InputStream can then be used in any method that
requires an InputStream.

        Throws: SQLException
                if a database-access error occurs.

 public OutputStream getOutputStream() throws SQLException

          Returns an OutputStream to this object

          This OutputStream can then be used in any method that
requires an OutputStream.

        Throws: SQLException
                if a database-access error occurs.

Class postgresql.largeobject.LargeObjectManager

java.lang.Object
   |
   +----postgresql.largeobject.LargeObjectManager

public class LargeObjectManager extends Object

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 postgresql.largeobject.LargeObject is returned, and its
methods then allow access to the object.

This class can only be created by postgresql.Connection

To get access to this class, use the following segment of code:

 import postgresql.largeobject.*;
 Connection  conn;
 LargeObjectManager lobj;
 ... code that opens a connection ...
 lobj = ((postgresql.Connection)myconn).getLargeObjectAPI();

Normally, client code would use the getAsciiStream, getBinaryStream,
or getUnicodeStream methods in ResultSet, or setAsciiStream,
setBinaryStream, or setUnicodeStream methods in PreparedStatement to
access Large Objects.

   However, sometimes lower level access to Large Objects are
required, that are not supported by the JDBC specification.

   Refer to postgresql.largeobject.LargeObject on how to manipulate
the contents of a Large Object.

   See Also:
          LargeObject

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

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).

        Parameters:
                oid - of large object

        Returns:
                LargeObject instance providing access to the object

        Throws: SQLException
                on error

 public LargeObject open(int oid,
                         int mode) throws SQLException

          This opens an existing large object, based on its OID

        Parameters:
                oid - of large object
                mode - mode of open

        Returns:
                LargeObject instance providing access to the object

        Throws: SQLException
```

```
                on error

 public int create() throws SQLException

          This creates a large object, returning its OID.

          It defaults to READWRITE for the new object's attributes.

        Returns:
                oid of new object

        Throws: SQLException
                on error

 public int create(int mode) throws SQLException

          This creates a large object, returning its OID

        Parameters:
                mode - a bitmask describing different attributes of
the
                new object

        Returns:
                oid of new object

        Throws: SQLException
                on error

 public void delete(int oid) throws SQLException

          This deletes a large object.

        Parameters:
                oid - describing object to delete

        Throws: SQLException
                on error

 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.

        Parameters:
                oid - describing object to delete

        Throws: SQLException
                on error

Object Serialisation
PostgreSQL is not a normal SQL Database. It is far more extensible
than most other databases, and does support Object Oriented features
that are unique to it.

One of the consequences of this, is that you can have one table refer
to a row in another table. For example:

test=> create table users (username name,fullname text);
CREATE
test=> create table server (servername name,adminuser users);
CREATE
test=> insert into users values ('peter','Peter Mount');
INSERT 2610132 1
test=> insert into server values ('maidast',2610132::users);
INSERT 2610133 1
test=> select * from users;
username|fullname
--------+--------------
peter   |Peter Mount
```

```
(1 row)

test=> select * from server;
servername|adminuser
----------+---------
maidast   |  2610132
(1 row)
```

Ok, the above example shows that we can use a table name as a field, and the row's oid value is stored in that field.

What does this have to do with Java?

In Java, you can store an object to a Stream as long as it's class implements the java.io.Serializable interface. This process, known as Object Serialization, can be used to store complex objects into the database.

Now, under JDBC, you would have to use a LargeObject to store them. However, you cannot perform queries on those objects.

What the postgresql.util.Serialize class does, is provide a means of storing an object as a table, and to retrieve that object from a table. In most cases, you would not need to access this class direct, but you would use the PreparedStatement.setObject() and ResultSet.getObject() methods. Those methods will check the objects class name against the table's in the database. If a match is found, it assumes that the object is a Serialized object, and retrieves it from that table. As it does so, if the object contains other serialized objects, then it recurses down the tree.

Sound's complicated? In fact, it's simpler than what I wrote - it's just difficult to explain.

The only time you would access this class, is to use the create() methods. These are not used by the driver, but issue one or more "create table" statements to the database, based on a Java Object or Class that you want to serialize.

Oh, one last thing. If your object contains a line like:

```
public int oid;
```

then, when the object is retrieved from the table, it is set to the oid within the table. Then, if the object is modified, and re-serialized, the existing entry is updated.

If the oid variable is not present, then when the object is serialized, it is always inserted into the table, and any existing entry in the table is preserved.

Setting oid to 0 before serialization, will also cause the object to be inserted. This enables an object to be duplicated in the database.

Class postgresql.util.Serialize

```
java.lang.Object
   |
   +----postgresql.util.Serialize
```

public class Serialize extends Object

This class uses PostgreSQL's object oriented features to store Java Objects. It does this by mapping a Java Class name to a table in the database. Each entry in this new table then represents a Serialized instance of this class. As each entry has an OID (Object IDentifier), this OID can be included in another table. This is too complex to show here, and will be documented in the main documents in more detail.

Constructors

```
public Serialize(Connection c,
```

```
                  String type) throws SQLException

        This creates an instance that can be used to serialize
ordeserialize a Java object from a PostgreSQL table.

Methods

 public Object fetch(int oid) throws SQLException

        This fetches an object from a table, given it's OID

        Parameters:
                oid - The oid of the object

        Returns:
                Object relating to oid

        Throws: SQLException
                on error

 public int store(Object o) throws SQLException

        This stores an object into a table, returning it's OID.

        If the object has an int called OID, and it is > 0, then
that value is used for the OID, and the table will be updated. If the
value of OID is 0, then a new row will be created, and the value of
OID will be set in the object. This enables an object's value in the
database to be updateable. If the object has no int called OID, then
the object is stored. However if the object is later retrieved,
amended and stored again, it's new state will be appended to the
table, and will not overwrite the old entries.

        Parameters:
                o - Object to store (must implement Serializable)

        Returns:
                oid of stored object

        Throws: SQLException
                on error

 public static void create(Connection con,
                           Object o) throws SQLException

        This method is not used by the driver, but it creates a
table, given a Serializable Java Object. It should be used before
serializing any objects.

        Parameters:
                c - Connection to database
                o - Object to base table on

        Throws: SQLException
                on error

                   Returns:
                Object relating to oid

        Throws: SQLException
                on error

 public int store(Object o) throws SQLException

        This stores an object into a table, returning it's OID.

        If the object has an int called OID, and it is > 0, then
that value is used for the OID, and the table will be updated. If the
value of OID is 0, then a new row will be created, and the value of
OID will be set in the object. This enables an object's value in the
database to be updateable. If the object has no int called OID, then
the object is stored. However if the object is later retrieved,
```

```
amended and stored again, it’s new state will be appended to the
table, and will not overwrite the old entries.

        Parameters:
                o - Object to store (must implement Serializable)

        Returns:
                oid of stored object

        Throws: SQLException
                on error

 public static void create(Connection con,
                           Object o) throws SQLException

          This method is not used by the driver, but it creates a
table, given a Serializable Java Object. It should be used before
serializing any objects.

        Parameters:
                c - Connection to database
                o - Object to base table on

        Throws: SQLException
                on error

 public static void create(Connection con,
                           Class c) throws SQLException

          This method is not used by the driver, but it creates a
table, given a Serializable Java Object. It should be used before
serializing any objects.

        Parameters:
                c - Connection to database
                o - Class to base table on

        Throws: SQLException
                on error

 public static String toPostgreSQL(String name) throws SQLException

          This converts a Java Class name to a postgresql table, by
          replacing . with _

          Because of this, a Class name may not have _ in the name.

          Another limitation, is that the entire class name (including
          packages) cannot be longer than 31 characters (a limit
forced by PostgreSQL).

        Parameters:
                name - Class name

        Returns:
                PostgreSQL table name

        Throws: SQLException
                on error

 public static String toClassName(String name) throws SQLException

          This converts a postgresql table to a Java Class name, by
          replacing _ with .

        Parameters:
                name - PostgreSQL table name

        Returns:
                Class name

        Throws: SQLException
```

```
                on error

Utility Classes

The postgresql.util package contains classes used by the internals of
the main driver, and the other extensions.

Class postgresql.util.PGmoney

java.lang.Object
   |
   +----postgresql.util.PGobject
           |
           +----postgresql.util.PGmoney

   public class PGmoney extends PGobject implements Serializable,
Cloneable

   This implements a class that handles the PostgreSQL money type

Variables

 public double val

          The value of the field

Constructors

 public PGmoney(double value)

        Parameters:
                value - of field

 public PGmoney(String value) throws SQLException

          This is called mainly from the other geometric types, when a
point is imbeded within their definition.

        Parameters:
                value - Definition of this point in PostgreSQL's
syntax

 public PGmoney()

          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 boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()
```

```
          This must be overidden 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

Class postgresql.util.PGobject

java.lang.Object
   |
   +----postgresql.util.PGobject

   public class PGobject extends Object implements Serializable,
Cloneable

   This class is used to describe data types that are unknown by JDBC
Standard.
    A call to postgresql.Connection permits a class that extends this
class to be associated with a named type. This is how the
postgresql.geometric package operates.
    ResultSet.getObject() will return this class for any type that is
not recognised on having it's own handler. Because of this, any
postgresql data type is supported.

Constructors

 public PGobject()

          This is called by postgresql.Connection.getObject() to
create the object.

Methods

 public final void setType(String type)

          This method sets the type of this object.

          It should not be extended by subclasses, hence its final

        Parameters:
                type - a string describing the type of the object

 public void setValue(String value) throws SQLException

          This method sets the value of this object. It must be
overidden.

        Parameters:
                value - a string representation of the value of the
                object

        Throws: SQLException
                thrown if value is invalid for this type

 public final String getType()

          As this cannot change during the life of the object, it's
final.

        Returns:
                the type name of this object

 public String getValue()

          This must be overidden, to return the value of the object,
```

```
in the form required by postgresql.

        Returns:
                the value of this object

 public boolean equals(Object obj)

          This must be overidden to allow comparisons of objects

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two boxes are identical

        Overrides:
                equals in class Object

 public Object clone()

          This must be overidden to allow the object to be cloned

        Overrides:
                clone in class Object

 public String toString()

          This is defined here, so user code need not overide it.

        Returns:
                the value of this object, in the syntax expected by
postgresql

        Overrides:
                toString in class Object

Class postgresql.util.PGtokenizer

java.lang.Object
   |
   +----postgresql.util.PGtokenizer

   public class PGtokenizer extends Object

   This class is used to tokenize the text output of postgres.

   We could have used StringTokenizer to do this, however, we needed
to handle nesting of '(' ')' '[' ']' '<' and '>' as these are used by
the geometric data types.

   It's mainly used by the geometric classes, but is useful in parsing
any output from custom data types output from postgresql.

   See Also:
          PGbox, PGcircle, PGlseg, PGpath, PGpoint, PGpolygon

Constructors

 public PGtokenizer(String string,
                    char delim)

          Create a tokeniser.

        Parameters:
                string - containing tokens
                delim - single character to split the tokens

Methods

 public int tokenize(String string,
                     char delim)
```

```
          This resets this tokenizer with a new string and/or
delimiter.

        Parameters:
                string - containing tokens
                delim - single character to split the tokens

 public int getSize()

        Returns:
                the number of tokens available

 public String getToken(int n)

        Parameters:
                n - Token number ( 0 ... getSize()-1 )

        Returns:
                The token value

 public PGtokenizer tokenizeToken(int n,
                                  char delim)

          This returns a new tokenizer based on one of our tokens. The
geometric datatypes use this to process nested tokens (usually
PGpoint).

        Parameters:
                n - Token number ( 0 ... getSize()-1 )
                delim - The delimiter to use

        Returns:
                A new instance of PGtokenizer based on the token

 public static String remove(String s,
                             String l,
                             String t)

          This removes the lead/trailing strings from a string

        Parameters:
                s - Source string
                l - Leading string to remove
                t - Trailing string to remove

        Returns:
                String without the lead/trailing strings

 public void remove(String l,
                    String t)

          This removes the lead/trailing strings from all tokens

        Parameters:
                l - Leading string to remove
                t - Trailing string to remove

 public static String removePara(String s)

          Removes ( and ) from the beginning and end of a string

        Parameters:
                s - String to remove from

        Returns:
                String without the ( or )

 public void removePara()

          Removes ( and ) from the beginning and end of all tokens

        Returns:
```

```
                String without the ( or )

 public static String removeBox(String s)

          Removes [ and ] from the beginning and end of a string

        Parameters:
                s - String to remove from

        Returns:
                String without the [ or ]

 public void removeBox()

          Removes [ and ] from the beginning and end of all tokens

        Returns:
                String without the [ or ]

 public static String removeAngle(String s)

          Removes < and > from the beginning and end of a string

        Parameters:
                s - String to remove from

        Returns:
                String without the < or >

 public void removeAngle()

          Removes < and > from the beginning and end of all tokens

        Returns:
                String without the < or >

Class postgresql.util.Serialize

This was documented earlier under Object Serialisation.

Class postgresql.util.UnixCrypt

java.lang.Object
   |
   +----postgresql.util.UnixCrypt

   public class UnixCrypt extends Object

   This class provides us with the ability to encrypt passwords when
sent over the network stream

   Contains static methods to encrypt and compare passwords with Unix
encrypted passwords.

   See John Dumas's Java Crypt page for the original source.

   http://www.zeh.com/local/jfd/crypt.html

Methods

 public static final String crypt(String salt,
                                  String original)

          Encrypt a password given the cleartext password and a
"salt".

        Parameters:
                salt - A two-character string representing the salt
used
                to iterate the encryption engine in lots of different
                ways. If you are generating a new encryption then this
                value should be randomised.
```

```
                original - The password to be encrypted.

        Returns:
                A string consisting of the 2-character salt followed
by
                the encrypted password.

 public static final String crypt(String original)

          Encrypt a password given the cleartext password. This method
generates a random salt using the 'java.util.Random' class.

        Parameters:
                original - The password to be encrypted.

        Returns:
                A string consisting of the 2-character salt followed
by
                the encrypted password.

 public static final boolean matches(String encryptedPassword,
                                     String enteredPassword)

          Check that enteredPassword encrypts to encryptedPassword.

        Parameters:
                encryptedPassword - The encryptedPassword. The first
two characters are assumed to be the salt. This string would be the
same as one found in a Unix /etc/passwd file.
                enteredPassword - The password as entered by the user
(or otherwise aquired).

        Returns:
                true if the password should be considered correct.

Using the driver in a multi Threaded or 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.

PostgreSQL 6.4, brings thread safety to the entire driver. Standard
JDBC was thread safe in 6.3.x, but the Fastpath API wasn't.

So, if your application uses multiple threads (which most decent ones
would), then you don't have to worry about complex schemes to ensure
only one uses the database at any time.

If a thread attempts to use the connection while another is using it,
it will wait until the other thread has finished it's current
operation.

If it's a standard SQL statement, then the operation is sending the
statement, and retrieving any ResultSet (in full).

If it's a Fastpath call (ie: reading a block from a LargeObject), then
it's the time to send, and retrieve that block.

This is fine for applications & 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 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. It 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’s dead.

So, with servlets, it’s 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 is created
for each Connection.

It’s up to you, and your applications requirements.
```

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 on JavaSoft’s web site.

My own web site contains updated information not included in this document, and also includes precompiled drivers for v6.4, and earlier.

Chapter 22. Genetic Query Optimization in Database Systems

Author: Written by Martin Utesch for the Institute of Automatic Control at the University of Mining and Technology in Freiberg, Germany.

Query Handling as a Complex Optimization Problem

Among all relational operators the most difficult one to process and optimize is the join. The number of alternative plans to answer a query grows exponentially with the number of joins included in it. Further optimization effort is caused by the support of a variety of join methods (e.g., nested loop, index scan, merge join in Postgres) to process individual joins and a diversity of indices (e.g., r-tree, b-tree, hash in Postgres) as access paths for relations.

The current Postgres optimizer implementation performs a near- exhaustive search over the space of alternative strategies. This query optimization technique is inadequate to support database application domains that involve the need for extensive queries, such as artificial intelligence.

The Institute of Automatic Control at the University of Mining and Technology, in Freiberg, Germany, encountered the described problems as its folks wanted to take the Postgres DBMS as the backend for a decision support knowledge based system for the maintenance of an electrical power grid. The DBMS needed to handle large join queries for the inference machine of the knowledge based system.

Performance difficulties within exploring the space of possible query plans arose the demand for a new optimization technique being developed.

In the following we propose the implementation of a Genetic Algorithm as an option for the database query optimization problem.

Genetic Algorithms (GA)

The GA is a heuristic optimization method which operates through determined, randomized search. The set of possible solutions for the optimization problem is considered as a population of individuals. The degree of adaption of an individual to its environment is specified by its fitness.

The coordinates of an individual in the search space are represented by chromosomes, in essence a set of character strings. A gene is a subsection of a chromosome which encodes the value of a single parameter being optimized. Typical encodings for a gene could be binary or integer.

Through simulation of the evolutionary operations recombination, mutation, and selection new generations of search points are found that show a higher average fitness than their ancestors.

According to the "comp.ai.genetic" FAQ it cannot be stressed too strongly that a GA is not a pure random search for a solution to a problem. A GA uses stochastic processes, but the result is distinctly non-random (better than random).

```
Structured Diagram of a GA:
---------------------------

P(t)    generation of ancestors at a time t
P''(t)  generation of descendants at a time t

+=========================================+
|>>>>>>>>>>>  Algorithm GA  <<<<<<<<<<<<<<|
+=========================================+
| INITIALIZE t := 0                       |
+=========================================+
| INITIALIZE P(t)                         |
+=========================================+
| evalute FITNESS of P(t)                 |
+=========================================+
| while not STOPPING CRITERION do         |
|   +-------------------------------------+
|   | P'(t)  := RECOMBINATION{P(t)}       |
|   +-------------------------------------+
|   | P''(t) := MUTATION{P'(t)}           |
|   +-------------------------------------+
|   | P(t+1) := SELECTION{P''(t) + P(t)}  |
|   +-------------------------------------+
|   | evalute FITNESS of P''(t)           |
|   +-------------------------------------+
|   | t := t + 1                          |
+===+=====================================+
```

Genetic Query Optimization (GEQO) in Postgres

The GEQO module is intended for the solution of the query optimization problem similar to a traveling salesman problem (TSP). Possible query plans are encoded as integer strings. Each string represents the join order from one relation of the query to the next. E. g., the query tree

```
     /\
    /\ 2
   /\ 3
  4  1
```

is encoded by the integer string '4-1-3-2', which means, first join relation '4' and '1', then '3', and then '2', where 1, 2, 3, 4 are relids in Postgres.

Parts of the GEQO module are adapted from D. Whitley's Genitor algorithm.

Specific characteristics of the GEQO implementation in Postgres are:

- Usage of a steady state GA (replacement of the least fit individuals in a population, not whole-generational replacement) allows fast convergence towards improved query plans. This is essential for query handling with reasonable time;
- Usage of edge recombination crossover which is especially suited to keep edge losses low for the solution of the TSP by means of a GA;
- Mutation as genetic operator is deprecated so that no repair mechanisms are needed to generate legal TSP tours.

The GEQO module gives the following benefits to the Postgres DBMS compared to the Postgres query optimizer implementation:

- Handling of large join queries through non-exhaustive search;
- Improved cost size approximation of query plans since no longer plan merging is needed (the GEQO module evaluates the cost for a query plan as an individual).

Future Implementation Tasks for Postgres GEQO

Basic Improvements

Improve freeing of memory when query is already processed

With large join queries the computing time spent for the genetic query optimization seems to be a mere fraction of the time Postgres needs for freeing memory via routine MemoryContextFree, file backend/utils/mmgr/mcxt.c. Debugging showed that it get stucked in a loop of routine OrderedElemPop, file backend/utils/mmgr/oset.c. The same problems arise with long queries when using the normal Postgres query optimization algorithm.

Improve genetic algorithm parameter settings

In file backend/optimizer/geqo/geqo_params.c, routines gimme_pool_size and gimme_number_generations, we have to find a compromise for the parameter settings to satisfy two competing demands:

- Optimality of the query plan
- Computing time

Find better solution for integer overflow

In file backend/optimizer/geqo/geqo_eval.c, routine geqo_joinrel_size, the present hack for MAXINT overflow is to set the Postgres integer value of rel->size to its logarithm. Modifications of Rel in backend/nodes/relation.h will surely have severe impacts on the whole Postgres implementation.

Find solution for exhausted memory

Memory exhaustion may occur with more than 10 relations involved in a query. In file backend/optimizer/geqo/geqo_eval.c, routine gimme_tree is recursively called. Maybe I forgot something to be freed correctly, but I dunno what. Of course the rel data structure of the join keeps growing and growing the more relations are packed into it. Suggestions are welcome :-(

Further Improvements

Enable bushy query tree processing within Postgres; that may improve the quality of query plans.

References

Reference information for GEQ algorithms.

Chapter 23. Frontend/Backend Protocol

Note: Written by Phil Thompson. Updates for protocol 2.0 by Tom Lane.

Postgres uses a message-based protocol for communication between frontends and backends. The protocol is implemented over TCP/IP and also on Unix sockets. Postgres v6.3 introduced version numbers into the protocol. This was done in such a way as to still allow connections from earlier versions of frontends, but this document does not cover the protocol used by those earlier versions.

This document describes version 2.0 of the protocol, implemented in Postgres v6.4 and later.

Higher level features built on this protocol (for example, how libpq passes certain environment variables after the connection is established) are covered elsewhere.

Overview

The three major components are the frontend (running on the client) and the postmaster and backend (running on the server). The postmaster and backend have different roles but may be implemented by the same executable.

A frontend sends a startup packet to the postmaster. This includes the names of the user and the database the user wants to connect to. The postmaster then uses this, and the information in the pg_hba.conf(5) file to determine what further authentication information it requires the frontend to send (if any) and responds to the frontend accordingly.

The frontend then sends any required authentication information. Once the postmaster validates this it responds to the frontend that it is authenticated and hands over the connection to a backend. The backend then sends a message indicating successful startup (normal case) or failure (for example, an invalid database name).

Subsequent communications are query and result packets exchanged between the frontend and the backend. The postmaster takes no further part in ordinary query/result communication. (However, the postmaster is involved when the frontend wishes to cancel a query currently being executed by its backend. Further details about that appear below.)

When the frontend wishes to disconnect it sends an appropriate packet and closes the connection without waiting for a response for the backend.

Packets are sent as a data stream. The first byte determines what should be expected in the rest of the packet. The exception is packets sent from a frontend to the postmaster, which comprise a packet length then the packet itself. The difference is historical.

Protocol

This section describes the message flow. There are four different types of flows depending on the state of the connection: startup, query, function call, and termination. There are also special provisions for notification responses and command cancellation, which can occur at any time after the startup phase.

Startup

Startup is divided into an authentication phase and a backend startup phase.

Initially, the frontend sends a StartupPacket. The postmaster uses this info and the contents of the pg_hba.conf(5) file to determine what authentication method the frontend must use. The postmaster then responds with one of the following messages:

ErrorResponse

The postmaster then immediately closes the connection.

AuthenticationOk

The postmaster then hands over to the backend. The postmaster takes no further part in the communication.

AuthenticationKerberosV4

The frontend must then take part in a Kerberos V4 authentication dialog (not described here) with the postmaster. If this is successful, the postmaster responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationKerberosV5

The frontend must then take part in a Kerberos V5 authentication dialog (not described here) with the postmaster. If this is successful, the postmaster responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationUnencryptedPassword

The frontend must then send an UnencryptedPasswordPacket. If this is the correct password, the postmaster responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationEncryptedPassword

The frontend must then send an EncryptedPasswordPacket. If this is the correct password, the postmaster responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

If the frontend does not support the authentication method requested by the postmaster, then it should immediately close the connection.

After sending AuthenticationOk, the postmaster attempts to launch a backend process. Since this might fail, or the backend might encounter a failure during startup, the frontend must wait for the backend to acknowledge successful startup. The frontend should send no messages at this point. The possible messages from the backend during this phase are:

BackendKeyData

This message is issued after successful backend startup. It provides secret-key data that the frontend must save if it wants to be able to issue cancel requests later. The frontend should not respond to this message, but should continue listening for a ReadyForQuery message.

ReadyForQuery

Backend startup is successful. The frontend may now issue query or function call messages.

ErrorResponse

Backend startup failed. The connection is closed after sending this message.

NoticeResponse

A warning message has been issued. The frontend should display the message but continue listening for ReadyForQuery or ErrorResponse.

The ReadyForQuery message is the same one that the backend will issue after each query cycle. Depending on the coding needs of the frontend, it is reasonable to consider

ReadyForQuery as starting a query cycle (and then BackendKeyData indicates successful conclusion of the startup phase), or to consider ReadyForQuery as ending the startup phase and each subsequent query cycle.

Query

A Query cycle is initiated by the frontend sending a Query message to the backend. The backend then sends one or more response messages depending on the contents of the query command string, and finally a ReadyForQuery response message. ReadyForQuery informs the frontend that it may safely send a new query or function call.

The possible response messages from the backend are:

CompletedResponse

An SQL command completed normally.

CopyInResponse

The backend is ready to copy data from the frontend to a relation. The frontend should then send a CopyDataRows message. The backend will then respond with a CompletedResponse message with a tag of "COPY".

CopyOutResponse

The backend is ready to copy data from a relation to the frontend. It then sends a CopyDataRows message, and then a CompletedResponse message with a tag of "COPY".

CursorResponse

The query was either an insert(l), delete(l), update(l), fetch(l) or a select(l) command. If the transaction has been aborted then the backend sends a CompletedResponse message with a tag of "*ABORT STATE*". Otherwise the following responses are sent.

For an insert(l) command, the backend then sends a CompletedResponse message with a tag of "INSERT oid rows" where rows is the number of rows inserted, and oid is the object ID of the inserted row if rows is 1, otherwise oid is 0.

For a delete(l) command, the backend then sends a CompletedResponse message with a tag of "DELETE rows" where rows is the number of rows deleted.

For an update(l) command, the backend then sends a CompletedResponse message with a tag of "UPDATE rows" where rows is the number of rows deleted.

For a fetch(l) or select(l) command, the backend sends a RowDescription message. This is then followed by an AsciiRow or BinaryRow message (depending on whether a binary cursor was specified) for each row being returned to the frontend. Finally, the backend sends a CompletedResponse message with a tag of "SELECT".

EmptyQueryResponse

An empty query string was recognized. (The need to specially distinguish this case is historical.)

ErrorResponse

An error has occurred.

ReadyForQuery

Processing of the query string is complete. A separate message is sent to indicate this because the query string may contain multiple SQL commands. (CompletedResponse marks the end of processing one SQL command, not the whole string.) ReadyForQuery will always be sent, whether processing terminates successfully or with an error.

NoticeResponse

A warning message has been issued in relation to the query. Notices are in addition to other responses, ie. the backend will continue processing the command.

A frontend must be prepared to accept ErrorResponse and NoticeResponse messages whenever it is expecting any other type of message.

Actually, it is possible for NoticeResponse to arrive even when the frontend is not expecting any kind of message, that is, the backend is nominally idle. (In particular, the backend can be commanded to terminate by its postmaster. In that case it will send a NoticeResponse before closing the connection.) It is recommended that the frontend check for such asynchronous notices just before issuing any new command.

Also, if the frontend issues any listen(l) commands then it must be prepared to accept NotificationResponse messages at any time; see below.

Function Call

A Function Call cycle is initiated by the frontend sending a FunctionCall message to the backend. The backend then sends one or more response messages depending on the results of the function call, and finally a ReadyForQuery response message. ReadyForQuery informs the frontend that it may safely send a new query or function call.

The possible response messages from the backend are:

ErrorResponse

An error has occurred.

FunctionResultResponse

The function call was executed and returned a result.

FunctionVoidResponse

The function call was executed and returned no result.

ReadyForQuery

Processing of the function call is complete. ReadyForQuery will always be sent, whether processing terminates successfully or with an error.

NoticeResponse

A warning message has been issued in relation to the function call. Notices are in addition to other responses, ie. the backend will continue processing the command.

A frontend must be prepared to accept ErrorResponse and NoticeResponse messages whenever it is expecting any other type of message. Also, if it issues any listen(l) commands then it must be prepared to accept NotificationResponse messages at any time; see below.

Notification Responses

If a frontend issues a listen(l) command, then the backend will send a NotificationResponse message (not to be confused with NoticeResponse!) whenever a notify(l) command is executed for the same notification name.

Notification responses are permitted at any point in the protocol (after startup), except within another backend message. Thus, the frontend must be prepared to recognize a NotificationResponse message whenever it is expecting any message. Indeed, it should be able to handle NotificationResponse messages even when it is not engaged in a query.

NotificationResponse

A notify(l) command has been executed for a name for which a previous listen(l) command was executed. Notifications may be sent at any time.

It may be worth pointing out that the names used in listen and notify commands need not have anything to do with names of relations (tables) in the SQL database. Notification names are simply arbitrarily chosen condition names.

Cancelling Requests in Progress

During the processing of a query, the frontend may request cancellation of the query by sending an appropriate request to the postmaster. The cancel request is not sent directly to the backend for reasons of implementation efficiency: we don't want to have the backend constantly checking for new input from the frontend during query processing. Cancel requests should be relatively infrequent, so we make them slightly cumbersome in order to avoid a penalty in the normal case.

To issue a cancel request, the frontend opens a new connection to the postmaster and sends a CancelRequest message, rather than the StartupPacket message that would ordinarily be sent across a new connection. The postmaster will process this request and then close the connection. For security reasons, no direct reply is made to the cancel request message.

A CancelRequest message will be ignored unless it contains the same key data (PID and secret key) passed to the frontend during connection startup. If the request matches the PID and secret key for a currently executing backend, the postmaster signals the backend to abort processing of the current query.

The cancellation signal may or may not have any effect --- for example, if it arrives after the backend has finished processing the query, then it will have no effect. If the cancellation is effective, it results in the current command being terminated early with an error message.

The upshot of all this is that for reasons of both security and efficiency, the frontend has no direct way to tell whether a cancel request has succeeded. It must continue to wait for the backend to respond to the query. Issuing a cancel simply improves the odds that the current query will finish soon, and improves the odds that it will fail with an error message instead of succeeding.

Since the cancel request is sent to the postmaster and not across the regular frontend/backend communication link, it is possible for the cancel request to be issued by any process, not just the frontend whose query is to be canceled. This may have some benefits of flexibility in building multiple-process applications. It also introduces a security risk, in that unauthorized persons might try to cancel queries. The security risk is addressed by requiring a dynamically generated secret key to be supplied in cancel requests.

Termination

The normal, graceful termination procedure is that the frontend sends a Terminate message and immediately closes the connection. On receipt of the message, the backend immediately closes the connection and terminates.

An ungraceful termination may occur due to software failure (i.e., core dump) at either end. If either frontend or backend sees an unexpected closure of the connection, it should clean up and terminate. The frontend has the option of launching a new backend by recontacting the postmaster, if it doesn't want to terminate itself.

Message Data Types

This section describes the base data types used in messages.

Intn(i)

An n bit integer in network byte order. If i is specified it is the literal value. Eg. Int16, Int32(42).

LimStringn(s)

A character array of exactly n bytes interpreted as a '\0' terminated string. The '\0' is omitted if there is insufficient room. If s is specified it is the literal value. Eg. LimString32, LimString64("user").

String(s)

A conventional C '\0' terminated string with no length limitation. A frontend should always read the full string even though it may have to discard characters if its buffers aren't big enough.

Note: Is 8193 bytes the largest allowed size?

If s is specified it is the literal value. Eg. String, String("user").

Byten(c)

Exactly n bytes. If c is specified it is the literal value. Eg. Byte, Byte1('\n').

Message Formats

This section describes the detailed format of each message. Each can be sent by either a frontend (F), a postmaster/backend (B), or both (F & B).

AsciiRow (B)

Byte1('D')

Identifies the message as an ASCII data row. (A prior RowDescription message defines the number of fields in the row and their data types.)

Byten

A bit map with one bit for each field in the row. The 1st field corresponds to bit 7 (MSB) of the 1st byte, the 2nd field corresponds to bit 6 of the 1st byte, the 8th field corresponds to bit 0 (LSB) of the 1st byte, the 9th field corresponds to bit 7 of the 2nd byte, and so on. Each bit is set if the value of the corresponding field is not NULL. If the number of fields is not a multiple of 8, the remainder of the last byte in the bit map is wasted.

Then, for each field with a non-NULL value, there is the following:

Int32

Specifies the size of the value of the field, including this size.

Byten

Specifies the value of the field itself in ASCII characters. n is the above size minus 4. There is no trailing '\0' in the field data; the front end must add one if it wants one.

AuthenticationOk (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(0)

Specifies that the authentication was successful.

AuthenticationKerberosV4 (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(1)

Specifies that Kerberos V4 authentication is required.

AuthenticationKerberosV5 (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(2)

Specifies that Kerberos V5 authentication is required.

AuthenticationUnencryptedPassword (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(3)

Specifies that an unencrypted password is required.

AuthenticationEncryptedPassword (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(4)

Specifies that an encrypted password is required.

Byte2

The salt to use when encrypting the password.

BackendKeyData (B)

Byte1('K')

Identifies the message as cancellation key data. The frontend must save these values if it wishes to be able to issue CancelRequest messages later.

Int32

The process ID of this backend.

Int32

The secret key of this backend.

BinaryRow (B)

Byte1('B')

Identifies the message as a binary data row. (A prior RowDescription message defines the number of fields in the row and their data types.)

Byten

A bit map with one bit for each field in the row. The 1st field corresponds to bit 7 (MSB) of the 1st byte, the 2nd field corresponds to bit 6 of the 1st byte, the 8th field corresponds to bit 0 (LSB) of the 1st byte, the 9th field corresponds to bit 7 of the 2nd byte, and so on. Each bit is set if the value of the corresponding field is not NULL. If the number of fields is not a multiple of 8, the remainder of the last byte in the bit map is wasted.

Then, for each field with a non-NULL value, there is the following:

Int32

Specifies the size of the value of the field, excluding this size.

Byten

Specifies the value of the field itself in binary format. n is the above size.

CancelRequest (F)

Int32(16)

The size of the packet in bytes.

Int32(80877102)

The cancel request code. The value is chosen to contain "1234" in the most significant 16 bits, and "5678" in the least 16 significant bits. (To avoid confusion, this code must not be the same as any protocol version number.)

Int32

The process ID of the target backend.

Int32

The secret key for the target backend.

CompletedResponse (B)

Byte1('C')

Identifies the message as a completed response.

String

The command tag. This is usually (but not always) a single word that identifies which SQL command was completed.

CopyDataRows (B & F)

This is a stream of rows where each row is terminated by a Byte1('\n'). This is then followed by the sequence Byte1('\\'), Byte1('.'), Byte1('\n').

CopyInResponse (B)

Byte1('G')

Identifies the message as a Start Copy In response. The frontend must now send a CopyDataRows message.

CopyOutResponse (B)

Byte1('H')

Identifies the message as a Start Copy Out response. This message will be followed by a CopyDataRows message.

CursorResponse (B)

Byte1('P')

Identifies the message as a cursor response.

String

The name of the cursor. This will be "blank" if the cursor is implicit.

EmptyQueryResponse (B)

Byte1('I')

Identifies the message as a response to an empty query string.

String("")

Unused.

EncryptedPasswordPacket (F)

Int32

The size of the packet in bytes.

String

The encrypted (using crypt()) password.

ErrorResponse (B)

Byte1('E')

Identifies the message as an error.

String

The error message itself.

FunctionCall (F)

Byte1('F')

Identifies the message as a function call.

String("")

Unused.

Int32

Specifies the object ID of the function to call.

Int32

Specifies the number of arguments being supplied to the function.

Then, for each argument, there is the following:

Int32

Specifies the size of the value of the argument, excluding this size.

Byten

Specifies the value of the field itself in binary format. n is the above size.

FunctionResultResponse (B)

Byte1('V')

Identifies the message as a function call result.

Byte1('G')

Specifies that a nonempty result was returned.

Int32

Specifies the size of the value of the result, excluding this size.

Byten

Specifies the value of the result itself in binary format. n is the above size.

Byte1('0')

Unused. (Strictly speaking, FunctionResultResponse and FunctionVoidResponse are the same thing but with some optional parts to the message.)

FunctionVoidResponse (B)

Byte1('V')

Identifies the message as a function call result.

Byte1('0')

Specifies that an empty result was returned.

NoticeResponse (B)

Byte1('N')

Identifies the message as a notice.

String

The notice message itself.

NotificationResponse (B)

Byte1('A')

Identifies the message as a notification response.

Int32

The process ID of the notifying backend process.

String

The name of the condition that the notify has been raised on.

Query (F)

Byte1('Q')

Identifies the message as a query.

String

The query string itself.

ReadyForQuery (B)

Byte1('Z')

Identifies the message type. ReadyForQuery is sent whenever the backend is ready for a new query cycle.

RowDescription (B)

Byte1('T')

Identifies the message as a row description.

Int16

Specifies the number of fields in a row (may be zero).

Then, for each field, there is the following:

String

Specifies the field name.

Int32

Specifies the object ID of the field type.

Int16

Specifies the type size.

Int32

Specifies the type modifier.

StartupPacket (F)

Int32(296)

The size of the packet in bytes.

Int32

The protocol version number. The most significant 16 bits are the major version number. The least 16 significant bits are the minor version number.

LimString64

The database name, defaults to the user name if empty.

LimString32

The user name.

LimString64

Any additional command line arguments to be passed to the backend by the postmaster.

LimString64

Unused.

LimString64

The optional tty the backend should use for debugging messages.

Terminate (F)

Byte1('X')

Identifies the message as a termination.

UnencryptedPasswordPacket (F)

Int32

The size of the packet in bytes.

String

The unencrypted password.

Chapter 24. Postgres Signals

Note: Contributed by Massimo Dal Zotto

Postgres uses the following signals for communication between the postmaster and backends:

Table 24-1. Postgres Signals

Signal	postmaster Action	Server Action
SIGHUP	kill(*,sighup)	read_pg_options
SIGINT	die	cancel query
SIGQUIT	kill(*,sigterm)	handle_warn
SIGTERM	kill(*,sigterm), kill(*,9), die	die
SIGPIPE	ignored	die
SIGUSR1	kill(*,sigusr1), die	quickdie
SIGUSR2	kill(*,sigusr2)	async notify (SI flush)
SIGCHLD	reaper	ignored (alive test)
SIGTTIN	ignored	
SIGTTOU	ignored	
SIGCONT	dumpstatus	
SIGFPE		FloatExceptionHandler

Note: kill(*,signal) means sending a signal to all backends.

The main changes to the old signal handling are the use of SIGQUIT instead of SIGHUP to handle warns, SIGHUP to re-read the pg_options file and the redirection to all active backends of SIGHUP, SIGTERM, SIGUSR1 and SIGUSR2 sent to the postmaster. In this way these signals sent to the postmaster can be sent automatically to all the backends without need to know their pids. To shut down postgres one needs only to send a SIGTERM to postmaster and it will stop automatically all the backends.

The SIGUSR2 signal is also used to prevent SI cache table overflow which happens when some backend doesn't process SI cache for a long period. When a backend detects the SI table full at 70% it simply sends a signal to the postmaster which will wake up all idle backends and make them flush the cache.

The typical use of signals by programmers could be the following:

```
# stop postgres
kill -TERM $postmaster_pid

# kill all the backends
kill -QUIT $postmaster_pid

# kill only the postmaster
kill -INT $postmaster_pid

# change pg_options
cat new_pg_options > $DATA_DIR/pg_options
kill -HUP $postmaster_pid

# change pg_options only for a backend
cat new_pg_options > $DATA_DIR/pg_options
kill -HUP $backend_pid
cat old_pg_options > $DATA_DIR/pg_options
```

Chapter 25. gcc Default Optimizations

Note: Contributed by Brian Gallew

Configuring gcc to use certain flags by default is a simple matter of editing the /usr/local/lib/gcc-lib/platform/version/specs file. The format of this file pretty simple. The file is broken into sections, each of which is three lines long. The first line is "*section_name:" (e.g. "*asm:"). The second line is a list of flags, and the third line is blank.

The easiest change to make is to append the desired default flags to the list in the appropriate section. As an example, let's suppose that I have linux running on a '486 with gcc 2.7.2 installed in the default location. In the file /usr/local/lib/gcc-lib/i486-linux/2.7.2/specs, 13 lines down I find the following section:

```
- ----------SECTION----------
*cc1:


- ----------SECTION----------
```

As you can see, there aren't any default flags. If I always wanted compiles of C code to use "-m486 -fomit-frame-pointer", I would change it to look like:

```
- ----------SECTION----------
*cc1:
- -m486 -fomit-frame-pointer

- ----------SECTION----------
```

If I wanted to be able to generate 386 code for another, older linux box lying around, I'd have to make it look like this:

```
- ----------SECTION----------
*cc1:
%{!m386:-m486} -fomit-frame-pointer

- ----------SECTION----------
```

This will always omit frame pointers, any will build 486-optimized code unless -m386 is specified on the command line.

You can actually do quite a lot of customization with the specs file. Always remember, however, that these changes are global, and affect all users of the system.

Chapter 26. Backend Interface

Backend Interface (BKI) files are scripts that are input to the Postgres backend running in the special "bootstrap" mode that allows it to perform database functions without a database system already existing. BKI files can therefore be used to create the database system in the first place. initdb uses BKI files to do just that: to create a database system. However, initdb's BKI files are generated internally. It generates them using the files global1.bki.source and local1.template1.bki.source, which it finds in the Postgres "library" directory. They get installed there as part of installing Postgres. These .source files get build as part of the Postgres build process, by a build program called genbki. genbki takes as input Postgres source files that double as genbki input that builds tables and C header files that describe those tables.

Related information may be found in documentation for initdb, createdb, and the SQL command CREATE DATABASE.

BKI File Format

The Postgres backend interprets BKI files as described below. This description will be easier to understand if the global1.bki.source file is at hand as an example. (As explained above, this .source file isn't quite a BKI file, but you'll be able to guess what the resulting BKI file would be anyway).

Commands are composed of a command name followed by space separated arguments. Arguments to a command which begin with a `$` are treated specially. If `$$` are the first two characters, then the first `$` is ignored and the argument is then processed normally. If the `$` is followed by space, then it is treated as a NULL value. Otherwise, the characters following the `$` are interpreted as the name of a macro causing the argument to be replaced with the macro's value. It is an error for this macro to be undefined.

Macros are defined using

```
define macro macro_name = macro_value
```

and are undefined using

```
undefine macro macro_name
```

and redefined using the same syntax as define.

Lists of general commands and macro commands follow.

General Commands

`OPEN classname`

Open the class called classname for further manipulation.

CLOSE [classname]

Close the open class called classname. It is an error if classname is not already opened. If no classname is given, then the currently open class is closed.

PRINT

Print the currently open class.

INSERT [OID=oid_value] (value1 value2 ...)

Insert a new instance to the open class using value1, value2, etc., for its attribute values and oid_value for its OID. If oid_value is not 0 , then this value will be used as the instance's object identifier. Otherwise, it is an error.

INSERT (value1 value2 ...)

As above, but the system generates a unique object identifier.

CREATE classname (name1 = type1 [,name2 = type2[,...]])

Create a class named classname with the attributes given in parentheses.

`OPEN (name1 = type1 [,name2 = type2[,...]]) AS classname`

Open a class named classname for writing but do not record its existence in the system catalogs. (This is primarily to aid in bootstrapping.)

`DESTROY classname`

Destroy the class named classname.

DEFINE INDEX indexname ON class_name USING amname (opclass attr | (function(attr))

Create an index named indexname on the class named classname using the amname access method. The fields to index are called name1, name2 etc., and the operator collections to use are collection_1, collection_2 etc., respectively.

Note: This last sentence doesn't reference anything in the example. Should be changed to make sense. - Thomas 1998-08-04

Macro Commands

DEFINE FUNCTION macro_name AS rettype function_name(args)

Define a function prototype for a function named macro_name which has its value of type rettype computed from the execution function_name with the arguments args declared in a C-like manner.

`DEFINE MACRO macro_name FROM FILE filename`

Define a macro named macro_name which has its value read from the file called filename.

Debugging Commands

Note: This section on debugging commands was commented-out in the original documentation. Thomas 1998-08-05

r

Randomly print the open class.

m -1

Toggle display of time information.

m 0

Set retrievals to now.

m 1 Jan 1 01:00:00 1988

Set retrievals to snapshots of the specfied time.

m 2 Jan 1 01:00:00 1988, Feb 1 01:00:00 1988

Set retrievals to ranges of the specified times. Either time may be replaced with space if an unbounded time range is desired.

&A classname natts name1 type1 name2 type2 ...

Add natts attributes named name1, name2, etc. of types type1, type2, etc. to the class classname.

&RR oldclassname newclassname

Rename the oldclassname class to newclassname.

&RA classname oldattname newattname classname oldattname newattname

Rename the oldattname attribute in the class named classname to newattname.

Example

The following set of commands will create the pg_opclass class containing the int_ops collection as an object with an OID of 421, print out the class, and then close it.

```
create pg_opclass (opcname=name)
open pg_opclass
insert oid=421 (int_ops)
print
close pg_opclass
```

Chapter 27. Page Files

A description of the database file default page format.

This section provides an overview of the page format used by Postgres classes. User-defined access methods need not use this page format.

In the following explanation, a byte is assumed to contain 8 bits. In addition, the term item refers to data which is stored in Postgres classes.

Page Structure

The following table shows how pages in both normal Postgres classes and Postgres index classes (e.g., a B-tree index) are structured.

Table 27-1. Sample Page Layout

Field
itemPointerData
filler
itemData...
Unallocated Space
ItemContinuationData
Special Space
‘‘ItemData 2’’
‘‘ItemData 1’’
ItemIdData
PageHeaderData

The first 8 bytes of each page consists of a page header (PageHeaderData). Within the header, the first three 2-byte integer fields (lower, upper, and special) represent byte offsets to the start of unallocated space, to the end of unallocated space, and to the start of special space. Special space is a region at the end of the page which is allocated at page initialization time and which contains information specific to an access method. The last 2 bytes of the page header, opaque, encode the page size and information on the internal fragmentation of the page. Page size is stored in each page because frames in the buffer pool may be subdivided into equal sized pages on a frame by frame basis within a class. The internal fragmentation information is used to aid in determining when page reorganization should occur.

Following the page header are item identifiers (ItemIdData). New item identifiers are allocated from the first four bytes of unallocated space. Because an item identifier is never moved until it is freed, its index may be used to indicate the location of an item on a page. In fact, every pointer to an item (ItemPointer) created by Postgres consists of a frame number and an index of an item identifier. An item identifier contains a byte-offset to the start of an item, its length in bytes, and a set of attribute bits which affect its interpretation.

The items themselves are stored in space allocated backwards from the end of unallocated space. Usually, the items are not interpreted. However when the item is too long to be placed on a single page or when fragmentation of the item is desired, the item is divided and each piece is handled as distinct items in the following manner. The first through the next to last piece are placed in an item continuation structure (ItemContinuationData). This structure contains itemPointerData which points to the next piece and the piece itself. The last piece is handled normally.

Files

`data/`

Location of shared (global) database files.

`data/base/`

Location of local database files.

Bugs

The page format may change in the future to provide more efficient access to large objects.

This section contains insufficient detail to be of any assistance in writing a new access method.

Appendix A. Documentation

The purpose of documentation is to make Postgres easier to learn, use, and develop. The documentation set should describe the Postgres system, language, and interfaces. It should be able to answer common questions and to allow a user to find those answers on his own without resorting to mailing list support.

Documentation Roadmap

Postgres has four primary documentation formats:

Plain text for pre-installation information.

HTML, for on-line browsing and reference.

Hardcopy, for in-depth reading and reference.

man pages, for quick reference.

Table A-1. Postgres Documentation Products

File	Description	
./COPYRIGHT	Copyright notice	
./INSTALL	Installation instructions (text from sgml->rtf->text)	
./README	Introductory info	
./register.txt	Registration message during make	
./doc/bug.template	Bug report template	
./doc/postgres.tar.gz	Integrated docs (HTML)	
./doc/programmer.ps.gz	Programmer's Guide (Postscript)	
./doc/programmer.tar.gz	Programmer's Guide (HTML)	
./doc/reference.ps.gz	Reference Manual (Postscript)	
./doc/reference.tar.gz	Reference Manual (HTML)	
./doc/tutorial.ps.gz	Introduction (Postscript)	
./doc/tutorial.tar.gz	Introduction (HTML)	

./doc/user.ps.gz	User's Guide (Postscript)	
./doc/user.tar.gz	User's Guide (HTML)	

There are man pages available for installation, as well as a large number of plain-text README-type files throughout the Postgres source tree.

Documentation Sources

Documentation sources include plain text files, man pages, and html. However, most new Postgres documentation will be written using the Standard Generalized Markup Language (SGML) DocBook Document Type Definition (DTD). Much of the existing documentation has been or will be converted to SGML.

The purpose of SGML is to allow an author to specify the structure and content of a document (e.g. using the DocBook DTD), and to have the document style define how that content is rendered into a final form (e.g. using Norm Walsh's stylesheets).

Documentation has accumulated from several sources. As we integrate and assimilate existing documentation into a coherent documentation set, the older versions will become obsolete and will be removed from the distribution. However, this will not happen immediately, and will not happen to all documents at the same time. To ease the transition, and to help guide developers and writers, we have defined a transition roadmap.

Here is the documentation plan for v6.5:

Start compiling index information for the User's and Administrator's Guides.

Write more sections for the User's Guide covering areas outside the reference pages. This would include introductory information and suggestions for approaches to typical design problems.

Merge information in the existing man pages into the reference pages and User's Guide. Condense the man pages down to reminder information, with references into the primary doc set.

Convert the new sgml reference pages to new man pages, replacing the existing man pages.

Convert all source graphics to CGM format files for portability. Currently we mostly have Applix Graphics sources from which we can generate .gif output. One graphic is only available in .gif and .ps, and should be redrawn or removed.

Document Structure

There are currently five separate documents written in DocBook. Each document has a container source document which defines the DocBook environment and other document source files. These primary source files are located in doc/src/sgml/, along with many of the other source files used for the documentation. The primary source files are:

postgres.sgml

This is the integrated document, including all other documents as parts. Output is generated in HTML since the browser interface makes it easy to move around all of the documentation by just clicking. The other documents are available in both HTML and hardcopy.

tutorial.sgml

The introductory tutorial, with examples. Does not include programming topics, and is intended to help a reader unfamiliar with SQL. This is the "getting started" document.

user.sgml

The User's Guide. Includes information on data types and user-level interfaces. This is the place to put information on "why".

reference.sgml

The Reference Manual. Includes Postgres SQL syntax. This is the place to put information on "how".

programming.sgml

The Programmer's Guide. Includes information on Postgres extensibility and on the programming interfaces.

admin.sgml

The Administrator's Guide. Include installation and release notes.

The Documentation Project

Packaged documentation is available in both HTML and Postscript formats. These are available as part of the standard Postgres installation. We discuss here working with the documentation sources and generating documentation packages.

> Note: This is the first release of new Postgres documentation in three years. The content and environment are in flux and still evolving.

The purpose of SGML is to allow an author to specify the structure and content of a document (e.g. using the DocBook DTD), and to have the document style define how that content is rendered into a final form (e.g. using Norm Walsh's stylesheets).

See Introduction to DocBook for a nice "quickstart" summary of DocBook features. DocBook Elements provides a powerful cross-reference for features of DocBook.

This documentation set is constructed using several tools, including James Clark's jade and Norm Walsh's Modular DocBook Stylesheets.

Currently, hardcopy is produced by importing Rich Text Format (RTF) output from jade into ApplixWare for minor formatting fixups then exporting as a Postscript file.

TeX is a supported format for jade output, but was not used at this time for several reasons, including the inability to make minor format fixes before committing to hardcopy and generally inadequate table support in the TeX stylesheets.

Styles and Conventions

DocBook has a rich set of tags and constructs, and a suprisingly large percentage are directly and obviously useful for well-formed documentation. The Postgres documentation set has only recently been adapted to SGML, and in the near future several sections of the set will be selected and maintained as prototypical examples of DocBook usage. Also, a short summary of DocBook tags will be included below.

Authoring Tools

The current Postgres documentation set is written using a plain text editor (or emacs/psgml; see below) with the content marked up using SGML.

SGML and DocBook do not suffer from an oversupply of open-source authoring tools. The most common toolset is the emacs/xemacs editing package with the psgml feature extension. On some systems (e.g. RedHat Linux) these tools are provided in a typical full installation.

emacs/psgml

When using emacs/psgml, a comfortable way of working with these separate files of book parts is to insert a proper DOCTYPE declaration while you're editing them. If you are working on this source, for instance, it's an appendix chapter, so you would specify the document as an "appendix" instance of a DocBook document by making the first line look like this:

```
!doctype appendix PUBLIC "-//Davenport//DTD DocBook V3.0//EN"
```

This means that anything and everything that reads SGML will get it right, and I can verify the document with "nsgmls -s docguide.sgml".

Building Documentation

GNU make is used to build documentation from the DocBook sources. There are a few environment definitions which may need to be set or modified for your installation. The Makefile looks for doc/../src/Makefile and (implicitly) for doc/../src/Makefile.custom to obtain environment information. On my system, the src/Makefile.custom looks like

```
# Makefile.custom
# Thomas Lockhart 1998-03-01

POSTGRESDIR= /opt/postgres/current
CFLAGS+= -m486
YFLAGS+= -v

# documentation

HSTYLE= /home/tgl/SGML/db107.d/docbook/html
PSTYLE= /home/tgl/SGML/db107.d/docbook/print
```

where HSTYLE and PSTYLE determine the path to docbook.dsl for HTML and hardcopy (print) stylesheets, respectively. These stylesheet file names are for Norm Walsh's Modular Style Sheets; if other stylesheets are used then one can define HDSL and PDSL as the full path and file name for the stylesheet, as is done above for HSTYLE and PSTYLE. On many systems, these stylesheets will be found in packages installed in /usr/lib/sgml/, /usr/share/lib/sgml/, or /usr/local/lib/sgml/.

HTML documentation packages can be generated from the SGML source by typing

```
% cd doc/src
% make tutorial.tar.gz
% make user.tar.gz
% make admin.tar.gz
% make programmer.tar.gz
% make postgres.tar.gz
% make install
```

These packages can be installed from the main documentation directory by typing

```
% cd doc
% make install
```

Hardcopy Generation for v6.4

The hardcopy Postscript documentation is generated by converting the SGML source code to RTF, then importing into ApplixWare-4.4.1. After a little cleanup (see the following section) the output is "printed" to a postscript file.

Some figures were redrawn to avoid having bitmap GIF files in the hardcopy documentation. One figure, of the system catalogs, was sufficiently complex that there was not time to redraw it. It was converted to fit using the following commands:

```
% convert -v -geometry 400x400'>' figure03.gif con.gif
% convert -v -crop 400x380 con.gif connections.gif
```

RTF Cleanup Procedure

Several items must be addressed in generating Postscript hardcopy:

Procedure A.1. Applixware RTF Cleanup

Applixware does not seem to do a complete job of importing RTF generated by jade/MSS. In particular, all text is given the Header1 style attribute label, although the text formatting itself is acceptable. Also, the Table of Contents page numbers do not refer to the section listed in the table, but rather refer to the page of the ToC itself.

1. **Generate the RTF input by typing**

   ```
   % cd doc/src/sgml
   % make tutorial.rtf
   ```

2. **Open a new document in Applix Words and then import the RTF file.**
3. **Print out the existing Table of Contents, to mark up in the following few steps.**
4. **Insert figures into the document. Center each figure on the page using the centering margins button.**

   Not all documents have figures. You can grep the SGML source files for the string Graphic to identify those parts of the documentation which may have figures. A few figures are replicated in various parts of the documentation.

5. **Work through the document, adjusting page breaks and table column widths.**
6. **If a bibliography is present, Applix Words seems to mark all remaining text after the first title as having an underlined attribute. Select all remaining text, turn off underlining using the underlining button, then explicitly underline each document and book title.**
7. **Work through the document, marking up the ToC hardcopy with the actual page number of each ToC entry.**
8. **Replace the right-justified incorrect page numbers in the ToC with correct values. This only takes a few minutes per document.**
9. **Save the document as native Applix Words format to allow easier last minute editing later.**
10. **Export the document to a file in Postscript format.**
11. **Compress the Postscript file using gzip. Place the compressed file into the doc directory.**

Toolsets

We have documented experience with two installation methods for the various tools that are needed to process the documentation. One is installation from RPMs on Linux, the other is a general installation from original distributions of the individual tools. Both will be described below.

We understand that there are some other packaged distributions for these tools. FreeBSD seems to have them available. Please report package status to the docs mailing list and we will include that information here.

RPM installation on Linux

Install RPMs for Jade and related packages.

Manual installation of tools

This is a brief run-through of the process of obtaining and installing the software you'll need to edit DocBook source with Emacs and process it with Norman Walsh's DSSSL style sheets to create HTML and RTF.

These instructions do not cover new jade/DocBook support in the sgml-tools package. The authors have not tried this package since it adopted DocBook, but it is almost certainly a good candidate for use.

Prerequisites

What you need:

- A working installation of GCC 2.7.2
- A working installation of Emacs 19.19 or later
- An unzip program for UNIX to unpack things

What you must fetch:

- James Clark's Jade version 1.1
- DocBook version 3.0
- Norman Walsh's Modular Stylesheets version 1.19
- Lennart Staflin's PSGML version 1.0.1

Important URLs:

- The Jade web page
- The DocBook web page
- The Modular Stylesheets web page
- The PSGML web page
- Steve Pepper's Whirlwind Guide
- Robin Cover's database of SGML software

Installing Jade

Procedure A.2. Installing Jade

1. **Read the installation instructions at the above listed URL.**
2. **Unzip the distribution kit in a suitable place. The command to do this will be something like**

   ```
   unzip -aU jade1_1.zip
   ```
3. **Jade is not built using GNU Autoconf, so you'll need to edit a Makefile yourself. Since James Clark has been good enough to prepare his kit for it, it is a good idea to make a build directory (named for your machine architecture, perhaps) under the main directory of the Jade distribution, copy the file Makefile from the main directory into it, edit it there, and then run make there.**

   However, the Makefile does need to be edited. There is a file called Makefile.jade in the main directory, which is intended to be used with make -f Makefile.jade when building Jade (as opposed to just SP, the SGML parser kit that Jade is built upon). We suggest that you don't do that, though, since there is more that you need to change than what is in Makefile.jade, so you'd have to edit one of them anyway.

   Go through the Makefile, reading James' instructions and editing as needed. There are various variables that need to be set. Here is a collected summary of the most important ones, with typical values:

   ```
   prefix = /usr/local
   XDEFINES =
   -DSGML_CATALOG_FILES_DEFAULT=\"/usr/local/share/sgml/catalog\"
   XLIBS = -lm
   RANLIB = ranlib
   srcdir = ..
   XLIBDIRS = grove spgrove style
   XPROGDIRS = jade
   ```

   Note the specification of where to find the default catalog of SGML support files -- you may want to change that to something more suitable for your own installation. If your system doesn't need the above settings for the math library and the ranlib command, leave them as they are in the Makefile.
4. **Type make to build Jade and the various SP tools.**
5. **Once the software is built, make install will do the obvious.**

Installing the DocBook DTD Kit

Procedure A.3. Installing the DocBook DTD Kit

1. **You'll want to place the files that make up the DocBook DTD kit in the directory you built Jade to expect them in, which, if you followed our suggestion above, is /usr/local/share/sgml/. In addition to the actual DocBook files, you'll need to have a catalog file in place, for the mapping of document type specifications and external entity references to actual files in that directory. You'll also want the ISO character set mappings, and probably one or more versions of HTML.**

   One way to install the various DTD and support files and set up the catalog file, is to collect them all into the above mentioned directory, use a single file named CATALOG to describe them all, and then create the file catalog as a catalog pointer to the former, by giving it the single line of content:

   ```
   CATALOG /usr/local/share/sgml/CATALOG
   ```

2. **The CATALOG file should then contain three types of lines. The first is the (optional) SGML declaration, thus:**

   ```
   SGMLDECL docbook.dcl
   ```

   Next, the various references to DTD and entity files must be resolved. For the DocBook files, these lines look like this:

   ```
   PUBLIC "-//Davenport//DTD DocBook V3.0//EN" docbook.dtd
   PUBLIC "-//USA-DOD//DTD Table Model 951010//EN" cals-tbl.dtd
   PUBLIC "-//Davenport//ELEMENTS DocBook Information Pool V3.0//EN"
   dbpool.mod
   PUBLIC "-//Davenport//ELEMENTS DocBook Document Hierarchy V3.0//EN"
   dbhier.mod
   PUBLIC "-//Davenport//ENTITIES DocBook Additional General Entities
   V3.0//EN" dbgenent.mod
   ```

3. **Of course, a file containing these comes with the DocBook kit. Note that the last item on each of these lines is a file name, given here without a path. You can put the files in subdirectories of your main SGML directory if you like, of course, and modify the reference in the CATALOG file. DocBook also references the ISO character set entities, so you need to fetch and install these (they are available from several sources, and are easily found by way of the URLs listed above), along with catalog entries for all of them, such as:**

   ```
   PUBLIC "ISO 8879-1986//ENTITIES Added Latin 1//EN" ISO/ISOlat1
   ```

   Note how the file name here contains a directory name, showing that we've placed the ISO entity files in a subdirectory named ISO. Again, proper catalog entries should accompany the entity kit you fetch.

Installing Norman Walsh's DSSSL Style Sheets

Procedure A.4. Installing Norman Walsh's DSSSL Style Sheets

1. **Read the installation instructions at the above listed URL.**
2. **To install Norman's style sheets, simply unzip the distribution kit in a suitable place. A good place to dot this would be /usr/local/share, which places the kit in a directory tree under /usr/local/share/docbook. The command will be something like**

   ```
   unzip -aU db107.zip
   ```

3. **One way to test the installation is to build the HTML and RTF forms of the PostgreSQL manual.**

   a. **To build the HTML files, go to the SGML source directory, doc/src/sgml, and say**

      ```
      jade -t sgml -d /usr/local/share/docbook/html/docbook.dsl -D
      ../graphics postgres.sgml
      ```

      book1.htm is the top level node of the output..

   b. **To generate the RTF output, ready for importing into your favorite word processing system and printing, type:**

      ```
      jade -t rtf -d /usr/local/share/docbook/print/docbook.dsl -D
      ../graphics postgres.sgml
      ```

Installing PSGML

Procedure A.5. Installing PSGML

1. **Read the installation instructions at the above listed URL.**

2. **Unpack the distribution file, run configure, make and make install to put the byte-compiled files and info library in place.**
3. **Then add the following lines to your /usr/local/share/emacs/site-lisp/site-start.el file to make Emacs properly load PSGML when needed:**

```
(setq load-path
      (cons "/usr/local/share/emacs/site-lisp/psgml" load-path))
(autoload 'sgml-mode "psgml" "Major mode to edit SGML files." t)
```

4. **If you want to use PSGML when editing HTML too, also add this:**

```
(setq auto-mode-alist
      (cons '("\\.s?html?\\'" . sgml-mode) auto-mode-alist))
```

5. **There is one important thing to note with PSGML: its author assumed that your main SGML DTD directory would be /usr/local/lib/sgml. If, as in the examples in this chapter, you use /usr/local/share/sgml, you have to compensate for this.**
    a. **You can set the SGML_CATALOG_FILES environment variable.**
    b. **You can customize your PSGML installation (its manual tells you how).**
    c. **You can even edit the source file psgml.el before compiling and installing PSGML, changing the hard-coded paths to match your own default.**

Installing JadeTeX

If you want to, you can also install JadeTeX to use TeX as a formatting backend for Jade. Note that this is still quite unpolished software, and will generate printed output that is inferior to what you get from the RTF backend. Still, it works all right, especially for simpler documents that don't use tables, and as both JadeTeX and the style sheets are under continuous improvement, it will certainly get better over time.

To install and use JadeTeX, you will need a working installation of TeX and LaTeX2e, including the supported tools and graphics packages, Babel, AMS fonts and AMS-LaTeX, the PSNFSS extension and companion kit of "the 35 fonts", the dvips program for generating PostScript, the macro packages fancyhdr, hyperref, minitoc, url and ot2enc, and of course JadeTeX itself. All of these can be found on your friendly neighborhood CTAN site.

JadeTeX does not at the time of writing come with much of an installation guide, but there is a makefile which shows what is needed. It also includes a directory cooked, wherein you'll find some of the macro packages it needs, but not all, and not complete -- at least last we looked.

Before building the jadetex.fmt format file, you'll probably want to edit the jadetex.ltx file, to change the configuration of Babel to suit your locality. The line to change looks something like

```
\RequirePackage[german,french,english]{babel}[1997/01/23]
```

and you should obviously list only the languages you actually need, and have configured Babel for.

With JadeTeX working, you should be able to generate and format TeX output for the PostgreSQL manuals by giving the commands (as above, in the doc/src/sgml directory)

```
jade -t tex -d /usr/local/share/docbook/print/docbook.dsl -D
../graphics postgres.sgml
jadetex postgres.tex
jadetex postgres.tex
dvips postgres.dvi
```

Of course, when you do this, TeX will stop during the second run, and tell you that its capacity has been exceeded. This is, as far as we can tell, because of the way JadeTeX generates cross referencing information. TeX can, of course, be compiled with larger data structure sizes. The details of this will vary according to your installation.

Alternate Toolsets

sgml-tools v2.x now supports jade and DocBook. It may be the preferred toolset for working with SGML but we have not had a chance to evaluate the new package.

SQL References

Selected references and readings for SQL and Postgres.

SQL Reference Books

The Practical SQL Handbook, Judity Bowman, Sandra Emerson, and Marcy Damovsky, ISBN: 0-201-44787-8, 1996, Addison-Wesley.

A Guide to the SQL Standard, C. J. Date and Hugh Darwen, ISBN: 0-201-96426-0, 1997, Addison-Wesley.

Understanding the New SQL, Jim Melton and Alan R. Simon, ISBN: 1-55860-245-3, 1993, Morgan Kaufmann.

PostgreSQL-Specific Documentation

The PostgreSQL Administrator's Guide, 1998-10-01, The PostgreSQL Global Development Group.

The PostgreSQL Developer's Guide, 1998-10-01, The PostgreSQL Global Development Group.

The PostgreSQL Programmer's Guide, 1998-10-01, The PostgreSQL Global Development Group.

The PostgreSQL Tutorial Introduction, 1998-10-01, The PostgreSQL Global Development Group.

The PostgreSQL User's Guide, 1998-10-01, The PostgreSQL Global Development Group.

The Postgres95 User Manual, A. Yu and J. Chen, The POSTGRES Group, Sept. 5, 1995, University of California, Berkeley CA.

Proceedings and Articles

Partial indexing in POSTGRES : research project, Nels Olson, 1993, ISSN: UCB Engin T7.49.1993 O676, University of California, Berkeley CA.

A Unified Framework for Version Modeling Using Production Rules in a Database System, L. Ong and J. Goh, April, 1990, ISSN: ERL Technical Memorandum M90/33, University of California, Berkeley CA.

The Postgres Data Model, L. Rowe and M. Stonebraker.

Generalized partial indexes, P. Seshadri and A. Swami, 1995, ISSN: Cat. No.95CH35724, IEEE Computer Society Press.

The Design of Postgres, M. Stonebraker and L. Rowe.

The Design of the Postgres Rules System, M. Stonebraker, E. Hanson, and C. H. Hong.

The Postgres Storage System, M. Stonebraker.

A Commentary on the Postgres Rules System, M. Stonebraker, M. Hearst, and S. Potamianos.

The case for partial indexes (DBMS), M. Stonebraker.

The Implementation of Postgres, M. Stonebraker, L. A. Rowe, and M. Hirohama.

On Rules, Procedures, Caching and Views in Database Systems, M. Stonebraker and et al.