PostgreSQL 7.3.2 Developer's Guide

The PostgreSQL Global Development Group

PostgreSQL 7.3.2 Developer's Guide

by The PostgreSQL Global Development Group

This document contains assorted information that can be of use to PostgreSQL developers.

Legal Notice

Table of Contents

List of Tables

List of Figures

List of Examples

Chapter 1. PostgreSQL Source Code

1.1. Formatting

Source code formatting uses a 4 column tab spacing, currently with tabs preserved (i.e. tabs are not expanded to spaces).

For Emacs, add the following (or something similar) to your `~/.emacs` initialization file:

```
    ;; check for files with a path containing "postgres" or "pgsql"
    (setq auto-mode-alist
      (cons '("\\(postgres\\|pgsql\\).*\\.[ch]\\'" . pgsql-c-mode)
            auto-mode-alist))
    (setq auto-mode-alist
      (cons '("\\(postgres\\|pgsql\\).*\\.cc\\'" . pgsql-c-mode)
            auto-mode-alist))

    (defun pgsql-c-mode ()
      ;; sets up formatting for PostgreSQL C code
      (interactive)
      (c-mode)
      (setq-default tab-width 4)
      (c-set-style "bsd")             ; set c-basic-offset to 4, plus other stuff
      (c-set-offset 'case-label '+)   ; tweak case indent to match PG custom
      (setq indent-tabs-mode t))      ; make sure we keep tabs when indent-
ing
```

For vi, your `~/.vimrc` or equivalent file should contain the following:

```
    set tabstop=4
```

or equivalently from within vi, try

```
    :set ts=4
```

The text browsing tools more and less can be invoked as

```
    more -x4
    less -x4
```

Chapter 2. Overview of PostgreSQL Internals

Author: This chapter originally appeared as a part of *Enhancement of the ANSI SQL Implementation of PostgreSQL*, Stefan Simkovics' Master's Thesis prepared at Vienna University of Technology under the direction of O.Univ.Prof.Dr. Georg Gottlob and Univ.Ass. Mag. Katrin Seyr.

This chapter gives an overview of the internal structure of the backend of PostgreSQL. After having read the following sections you should have an idea of how a query is processed. Don't expect a detailed description here (I think such a description dealing with all data structures and functions used within PostgreSQL would exceed 1000 pages!). This chapter is intended to help understanding the general control and data flow within the backend from receiving a query to sending the results.

2.1. The Path of a Query

Here we give a short overview of the stages a query has to pass in order to obtain a result.

1. A connection from an application program to the PostgreSQL server has to be established. The application program transmits a query to the server and receives the results sent back by the server.
2. The *parser stage* checks the query transmitted by the application program (client) for correct syntax and creates a *query tree*.
3. The *rewrite system* takes the query tree created by the parser stage and looks for any *rules* (stored in the *system catalogs*) to apply to the *querytree* and performs the transformations given in the *rule bodies*. One application of the rewrite system is given in the realization of *views*.

   Whenever a query against a view (i.e. a *virtual table*) is made, the rewrite system rewrites the user's query to a query that accesses the *base tables* given in the *view definition* instead.
4. The *planner/optimizer* takes the (rewritten) querytree and creates a *queryplan* that will be the input to the *executor*.

   It does so by first creating all possible *paths* leading to the same result. For example if there is an index on a relation to be scanned, there are two paths for the scan. One possibility is a simple sequential scan and the other possibility is to use the index. Next the cost for the execution of each plan is estimated and the cheapest plan is chosen and handed back.
5. The executor recursively steps through the *plan tree* and retrieves tuples in the way represented by the plan. The executor makes use of the *storage system* while scanning relations, performs *sorts* and *joins*, evaluates *qualifications* and finally hands back the tuples derived.

In the following sections we will cover every of the above listed items in more detail to give a better understanding on PostgreSQL's internal control and data structures.

2.2. How Connections are Established

PostgreSQL is implemented using a simple "process per-user" client/server model. In this model there is one *client process* connected to exactly one *server process*. As we don't know *per se* how many connections will be made, we have to use a *master process* that spawns a new server process every time a connection is requested. This master process is called `postmaster` and listens at a specified

TCP/IP port for incoming connections. Whenever a request for a connection is detected the `postmaster` process spawns a new server process called `postgres`. The server tasks (`postgres` processes) communicate with each other using *semaphores* and *shared memory* to ensure data integrity throughout concurrent data access. Figure \ref{connection} illustrates the interaction of the master process `postmaster` the server process `postgres` and a client application.

The client process can either be the psql frontend (for interactive SQL queries) or any user application implemented using the `libpg` library. Note that applications implemented using ecpg (the PostgreSQL embedded SQL preprocessor for C) also use this library.

Once a connection is established the client process can send a query to the *backend* (server). The query is transmitted using plain text, i.e. there is no parsing done in the *frontend* (client). The server parses the query, creates an *execution plan*, executes the plan and returns the retrieved tuples to the client by transmitting them over the established connection.

2.3. The Parser Stage

The *parser stage* consists of two parts:

- The *parser* defined in `gram.y` and `scan.l` is built using the Unix tools yacc and lex.
- The *transformation process* does modifications and augmentations to the data structures returned by the parser.

2.3.1. Parser

The parser has to check the query string (which arrives as plain ASCII text) for valid syntax. If the syntax is correct a *parse tree* is built up and handed back otherwise an error is returned. For the implementation the well known Unix tools lex and yacc are used.

The *lexer* is defined in the file `scan.l` and is responsible for recognizing *identifiers*, the *SQL keywords* etc. For every keyword or identifier that is found, a *token* is generated and handed to the parser.

The parser is defined in the file `gram.y` and consists of a set of *grammar rules* and *actions* that are executed whenever a rule is fired. The code of the actions (which is actually C-code) is used to build up the parse tree.

The file `scan.l` is transformed to the C-source file `scan.c` using the program lex and `gram.y` is transformed to `gram.c` using yacc. After these transformations have taken place a normal C-compiler can be used to create the parser. Never make any changes to the generated C-files as they will be overwritten the next time lex or yacc is called.

> **Note:** The mentioned transformations and compilations are normally done automatically using the *makefiles* shipped with the PostgreSQL source distribution.

A detailed description of yacc or the grammar rules given in `gram.y` would be beyond the scope of this paper. There are many books and documents dealing with lex and yacc. You should be familiar with yacc before you start to study the grammar given in `gram.y` otherwise you won't understand what happens there.

For a better understanding of the data structures used in PostgreSQL for the processing of a query we use an example to illustrate the changes made to these data structures in every stage. This example contains the following simple query that will be used in various descriptions and figures throughout the following sections. The query assumes that the tables given in *The Supplier Database* have already been defined.

Example 2-1. A Simple Select

```
select s.sname, se.pno
    from supplier s, sells se
    where s.sno > 2 and s.sno = se.sno;
```

Figure \ref{parsetree} shows the *parse tree* built by the grammar rules and actions given in `gram.y` for the query given in Example 2-1 (without the *operator tree* for the *where clause* which is shown in figure \ref{where_clause} because there was not enough space to show both data structures in one figure).

The top node of the tree is a `SelectStmt` node. For every entry appearing in the *from clause* of the SQL query a `RangeVar` node is created holding the name of the *alias* and a pointer to a `RelExpr` node holding the name of the *relation*. All `RangeVar` nodes are collected in a list which is attached to the field `fromClause` of the `SelectStmt` node.

For every entry appearing in the *select list* of the SQL query a `ResTarget` node is created holding a pointer to an `Attr` node. The `Attr` node holds the *relation name* of the entry and a pointer to a `Value` node holding the name of the *attribute*. All `ResTarget` nodes are collected to a list which is connected to the field `targetList` of the `SelectStmt` node.

Figure \ref{where_clause} shows the operator tree built for the where clause of the SQL query given in Example 2-1 which is attached to the field `qual` of the `SelectStmt` node. The top node of the operator tree is an `A_Expr` node representing an `AND` operation. This node has two successors called `lexpr` and `rexpr` pointing to two *subtrees*. The subtree attached to `lexpr` represents the qualification `s.sno` $>$ `2` and the one attached to `rexpr` represents `s.sno = se.sno`. For every attribute an `Attr` node is created holding the name of the relation and a pointer to a `Value` node holding the name of the attribute. For the constant term appearing in the query a `Const` node is created holding the value.

2.3.2. Transformation Process

The *transformation process* takes the tree handed back by the parser as input and steps recursively through it. If a `SelectStmt` node is found, it is transformed to a `Query` node that will be the top most node of the new data structure. Figure \ref{transformed} shows the transformed data structure (the part for the transformed *where clause* is given in figure \ref{transformed_where} because there was not enough space to show all parts in one figure).

Now a check is made, if the *relation names* in the *FROM clause* are known to the system. For every relation name that is present in the *system catalogs* a RTE node is created containing the relation name, the *alias name* and the *relation id*. From now on the relation ids are used to refer to the *relations* given in the query. All RTE nodes are collected in the *range table entry list* that is connected to the field `rtable` of the `Query` node. If a name of a relation that is not known to the system is detected in the query an error will be returned and the query processing will be aborted.

Next it is checked if the *attribute names* used are contained in the relations given in the query. For every attribute} that is found a TLE node is created holding a pointer to a `Resdom` node (which

holds the name of the column) and a pointer to a VAR node. There are two important numbers in the VAR node. The field varno gives the position of the relation containing the current attribute} in the range table entry list created above. The field varattno gives the position of the attribute within the relation. If the name of an attribute cannot be found an error will be returned and the query processing will be aborted.

2.4. The PostgreSQL Rule System

PostgreSQL supports a powerful *rule system* for the specification of *views* and ambiguous *view updates*. Originally the PostgreSQL rule system consisted of two implementations:

- The first one worked using *tuple level* processing and was implemented deep in the *executor*. The rule system was called whenever an individual tuple had been accessed. This implementation was removed in 1995 when the last official release of the PostgreSQL project was transformed into Postgres95.
- The second implementation of the rule system is a technique called *query rewriting*. The *rewrite system*} is a module that exists between the *parser stage* and the *planner/optimizer*. This technique is still implemented.

For information on the syntax and creation of rules in the PostgreSQL system refer to *The PostgreSQL User's Guide*.

2.4.1. The Rewrite System

The *query rewrite system* is a module between the parser stage and the planner/optimizer. It processes the tree handed back by the parser stage (which represents a user query) and if there is a rule present that has to be applied to the query it rewrites the tree to an alternate form.

2.4.1.1. Techniques To Implement Views

Now we will sketch the algorithm of the query rewrite system. For better illustration we show how to implement views using rules as an example.

Let the following rule be given:

```
create rule view_rule
as on select
to test_view
do instead
   select s.sname, p.pname
   from supplier s, sells se, part p
   where s.sno = se.sno and
         p.pno = se.pno;
```

The given rule will be *fired* whenever a select against the relation test_view is detected. Instead of selecting the tuples from test_view the select statement given in the *action part* of the rule is executed.

Let the following user-query against `test_view` be given:

```
select sname
from test_view
where sname <> 'Smith';
```

Here is a list of the steps performed by the query rewrite system whenever a user-query against `test_view` appears. (The following listing is a very informal description of the algorithm just intended for basic understanding. For a detailed description refer to *A commentary on the POSTGRES rules system*).

`test_view` Rewrite

1. Take the query given in the action part of the rule.
2. Adapt the targetlist to meet the number and order of attributes given in the user-query.
3. Add the qualification given in the where clause of the user-query to the qualification of the query given in the action part of the rule.

Given the rule definition above, the user-query will be rewritten to the following form (Note that the rewriting is done on the internal representation of the user-query handed back by the parser stage but the derived new data structure will represent the following query):

```
select s.sname
from supplier s, sells se, part p
where s.sno = se.sno and
      p.pno = se.pno and
      s.sname <> 'Smith';
```

2.5. Planner/Optimizer

The task of the *planner/optimizer* is to create an optimal execution plan. It first combines all possible ways of *scanning* and *joining* the relations that appear in a query. All the created paths lead to the same result and it's the task of the optimizer to estimate the cost of executing each path and find out which one is the cheapest.

2.5.1. Generating Possible Plans

The planner/optimizer decides which plans should be generated based upon the types of indexes defined on the relations appearing in a query. There is always the possibility of performing a sequential scan on a relation, so a plan using only sequential scans is always created. Assume an index is defined on a relation (for example a B-tree index) and a query contains the restriction `relation.attribute OPR constant`. If `relation.attribute` happens to match the key of the B-tree index and `OPR` is anything but '<>' another plan is created using the B-tree index to scan the relation. If there are further indexes present and the restrictions in the query happen to match a key of an index further plans will be considered.

After all feasible plans have been found for scanning single relations, plans for joining relations are created. The planner/optimizer considers only joins between every two relations for which there exists a corresponding join clause (i.e. for which a restriction like `where rel1.attr1=rel2.attr2` exists) in the where qualification. All possible plans are generated for every join pair considered by the planner/optimizer. The three possible join strategies are:

- *nested iteration join*: The right relation is scanned once for every tuple found in the left relation. This strategy is easy to implement but can be very time consuming.
- *merge sort join*: Each relation is sorted on the join attributes before the join starts. Then the two relations are merged together taking into account that both relations are ordered on the join attributes. This kind of join is more attractive because every relation has to be scanned only once.
- *hash join*: the right relation is first hashed on its join attributes. Next the left relation is scanned and the appropriate values of every tuple found are used as hash keys to locate the tuples in the right relation.

2.5.2. Data Structure of the Plan

Here we will give a little description of the nodes appearing in the plan. Figure \ref{plan} shows the plan produced for the query in example \ref{simple_select}.

The top node of the plan is a `MergeJoin` node that has two successors, one attached to the field `lefttree` and the second attached to the field `righttree`. Each of the subnodes represents one relation of the join. As mentioned above a merge sort join requires each relation to be sorted. That's why we find a `Sort` node in each subplan. The additional qualification given in the query (`s.sno` $>$ `2`) is pushed down as far as possible and is attached to the `qpqual` field of the leaf `SeqScan` node of the corresponding subplan.

The list attached to the field `mergeclauses` of the `MergeJoin` node contains information about the join attributes. The values `65000` and `65001` for the `varno` fields in the `VAR` nodes appearing in the `mergeclauses` list (and also in the `targetlist`) mean that not the tuples of the current node should be considered but the tuples of the next "deeper" nodes (i.e. the top nodes of the subplans) should be used instead.

Note that every `Sort` and `SeqScan` node appearing in figure \ref{plan} has got a `targetlist` but because there was not enough space only the one for the `MergeJoin` node could be drawn.

Another task performed by the planner/optimizer is fixing the *operator ids* in the `Expr` and `Oper` nodes. As mentioned earlier, PostgreSQL supports a variety of different data types and even user defined types can be used. To be able to maintain the huge amount of functions and operators it is necessary to store them in a system table. Each function and operator gets a unique operator id. According to the types of the attributes used within the qualifications etc., the appropriate operator ids have to be used.

2.6. Executor

The *executor* takes the plan handed back by the planner/optimizer and starts processing the top node. In the case of our example (the query given in example \ref{simple_select}) the top node is a `MergeJoin` node.

Before any merge can be done two tuples have to be fetched (one from each subplan). So the executor recursively calls itself to process the subplans (it starts with the subplan attached to `lefttree`). The new top node (the top node of the left subplan) is a `SeqScan` node and again a tuple has to be fetched before the node itself can be processed. The executor calls itself recursively another time for the subplan attached to `lefttree` of the `SeqScan` node.

Now the new top node is a `Sort` node. As a sort has to be done on the whole relation, the executor starts fetching tuples from the `Sort` node's subplan and sorts them into a temporary relation (in memory or a file) when the `Sort` node is visited for the first time. (Further examinations of the `Sort` node will always return just one tuple from the sorted temporary relation.)

Every time the processing of the `Sort` node needs a new tuple the executor is recursively called for the `SeqScan` node attached as subplan. The relation (internally referenced by the value given in the `scanrelid` field) is scanned for the next tuple. If the tuple satisfies the qualification given by the tree attached to `qpqual` it is handed back, otherwise the next tuple is fetched until the qualification is satisfied. If the last tuple of the relation has been processed a `NULL` pointer is returned.

After a tuple has been handed back by the `lefttree` of the `MergeJoin` the `righttree` is processed in the same way. If both tuples are present the executor processes the `MergeJoin` node. Whenever a new tuple from one of the subplans is needed a recursive call to the executor is performed to obtain it. If a joined tuple could be created it is handed back and one complete processing of the plan tree has finished.

Now the described steps are performed once for every tuple, until a `NULL` pointer is returned for the processing of the `MergeJoin` node, indicating that we are finished.

Chapter 3. System Catalogs

3.1. Overview

The system catalogs are the place where a relational database management system stores schema metadata, such as information about tables and columns, and internal bookkeeping information. PostgreSQL's system catalogs are regular tables. You can drop and recreate the tables, add columns, insert and update values, and severely mess up your system that way. Normally one should not change the system catalogs by hand, there are always SQL commands to do that. (For example, `CREATE DATABASE` inserts a row into the `pg_database` catalog -- and actually creates the database on disk.) There are some exceptions for especially esoteric operations, such as adding index access methods.

Most system catalogs are copied from the template database during database creation, and are thereafter database-specific. A few catalogs are physically shared across all databases in an installation; these are marked in the descriptions of the individual catalogs.

Table 3-1. System Catalogs

Catalog Name	Purpose
pg_aggregate	aggregate functions
pg_am	index access methods
pg_amop	access method operators
pg_amproc	access method support procedures
pg_attrdef	column default values
pg_attribute	table columns (“attributes”, “fields”)
pg_cast	casts (data type conversions)
pg_class	tables, indexes, sequences (“relations”)
pg_constraint	check constraints, unique / primary key constraints, foreign key constraints
pg_conversion	encoding conversion information
pg_database	databases within this database cluster
pg_depend	dependencies between database objects
pg_description	descriptions or comments on database objects
pg_group	groups of database users
pg_index	additional index information
pg_inherits	table inheritance hierarchy
pg_language	languages for writing functions
pg_largeobject	large objects
pg_listener	asynchronous notification
pg_namespace	namespaces (schemas)
pg_opclass	index access method operator classes
pg_operator	operators
pg_proc	functions and procedures
pg_rewrite	query rewriter rules
pg_shadow	database users

Catalog Name	Purpose
pg_statistic	optimizer statistics
pg_trigger	triggers
pg_type	data types

More detailed documentation of each catalog follows below.

3.2. pg_aggregate

`pg_aggregate` stores information about aggregate functions. An aggregate function is a function that operates on a set of values (typically one column from each row that matches a query condition) and returns a single value computed from all these values. Typical aggregate functions are `sum`, `count`, and `max`. Each entry in `pg_aggregate` is an extension of an entry in `pg_proc`. The `pg_proc` entry carries the aggregate's name, input and output datatypes, and other information that is similar to ordinary functions.

Table 3-2. pg_aggregate Columns

Name	Type	References	Description
aggfnoid	`regproc`	pg_proc.oid	pg_proc OID of the aggregate function
aggtransfn	`regproc`	pg_proc.oid	Transition function
aggfinalfn	`regproc`	pg_proc.oid	Final function (zero if none)
aggtranstype	`oid`	pg_type.oid	The type of the aggregate function's internal transition (state) data
agginitval	`text`		The initial value of the transition state. This is a text field containing the initial value in its external string representation. If the field is NULL, the transition state value starts out NULL.

New aggregate functions are registered with the `CREATE AGGREGATE` command. See the *Programmer's Guide* for more information about writing aggregate functions and the meaning of the transition functions, etc.

3.3. pg_am

`pg_am` stores information about index access methods. There is one row for each index access method supported by the system.

Table 3-3. pg_am Columns

Name	Type	References	Description
amname	`name`		name of the access method
amowner	`int4`	pg_shadow.usesysid	user ID of the owner (currently not used)
amstrategies	`int2`		number of operator strategies for this access method
amsupport	`int2`		number of support routines for this access method
amorderstrategy	`int2`		zero if the index offers no sort order, otherwise the strategy number of the strategy operator that describes the sort order
amcanunique	`bool`		does AM support unique indexes?
amcanmulticol	`bool`		does AM support multicolumn indexes?
amindexnulls	`bool`		does AM support NULL index entries?
amconcurrent	`bool`		does AM support concurrent updates?
amgettuple	`regproc`	pg_proc.oid	“next valid tuple” function
aminsert	`regproc`	pg_proc.oid	“insert this tuple” function
ambeginscan	`regproc`	pg_proc.oid	“start new scan” function
amrescan	`regproc`	pg_proc.oid	“restart this scan” function
amendscan	`regproc`	pg_proc.oid	“end this scan” function
ammarkpos	`regproc`	pg_proc.oid	“mark current scan position” function
amrestrpos	`regproc`	pg_proc.oid	“restore marked scan position” function
ambuild	`regproc`	pg_proc.oid	“build new index” function
ambulkdelete	`regproc`	pg_proc.oid	bulk-delete function
amcostestimate	`regproc`	pg_proc.oid	estimate cost of an indexscan

An index AM that supports multiple columns (has `amcanmulticol` true) *must* support indexing nulls

in columns after the first, because the planner will assume the index can be used for queries on just the first column(s). For example, consider an index on (a,b) and a query WHERE a = 4. The system will assume the index can be used to scan for rows with a = 4, which is wrong if the index omits rows where b is null. However it is okay to omit rows where the first indexed column is null. (GiST currently does so.) `amindexnulls` should be set true only if the index AM indexes all rows, including arbitrary combinations of nulls.

3.4. pg_amop

`pg_amop` stores information about operators associated with index access method operator classes. There is one row for each operator that is a member of an operator class.

Table 3-4. pg_amop Columns

Name	Type	References	Description
amopclaid	`oid`	pg_opclass.oid	the index opclass this entry is for
amopstrategy	`int2`		operator strategy number
amopreqcheck	`bool`		index hit must be rechecked
amopopr	`oid`	pg_operator.oid	the operator's pg_operator OID

3.5. pg_amproc

`pg_amproc` stores information about support procedures associated with index access method operator classes. There is one row for each support procedure belonging to an operator class.

Table 3-5. pg_amproc Columns

Name	Type	References	Description
amopclaid	`oid`	pg_opclass.oid	the index opclass this entry is for
amprocnum	`int2`		support procedure index
amproc	`regproc`	pg_proc.oid	OID of the proc

3.6. pg_attrdef

This catalog stores column default values. The main information about columns is stored in `pg_attribute` (see below). Only columns that explicitly specify a default value (when the table is created or the column is added) will have an entry here.

Table 3-6. pg_attrdef Columns

Name	Type	References	Description
adrelid	oid	pg_class.oid	The table this column belongs to
adnum	int2	pg_attribute.attnum	The number of the column
adbin	text		An internal representation of the column default value
adsrc	text		A human-readable representation of the default value

3.7. pg_attribute

pg_attribute stores information about table columns. There will be exactly one pg_attribute row for every column in every table in the database. (There will also be attribute entries for indexes and other objects. See pg_class.)

The term attribute is equivalent to column and is used for historical reasons.

Table 3-7. pg_attribute Columns

Name	Type	References	Description
attrelid	oid	pg_class.oid	The table this column belongs to
attname	name		Column name
atttypid	oid	pg_type.oid	The data type of this column

Name	Type	References	Description
attstattarget	`int4`		`attstattarget` controls the level of detail of statistics accumulated for this column by `ANALYZE`. A zero value indicates that no statistics should be collected. A negative value says to use the system default statistics target. The exact meaning of positive values is datatype-dependent. For scalar datatypes, `attstattarget` is both the target number of “most common values” to collect, and the target number of histogram bins to create.
attlen	`int2`		This is a copy of `pg_type.typlen` of this column’s type.
attnum	`int2`		The number of the column. Ordinary columns are numbered from 1 up. System columns, such as `oid`, have (arbitrary) negative numbers.
attndims	`int4`		Number of dimensions, if the column is an array type; otherwise 0. (Presently, the number of dimensions of an array is not enforced, so any nonzero value effectively means “it’s an array”.)
attcacheoff	`int4`		Always -1 in storage, but when loaded into a tuple descriptor in memory this may be updated to cache the offset of the attribute within the tuple.

Name	Type	References	Description
atttypmod	`int4`		`atttypmod` records type-specific data supplied at table creation time (for example, the maximum length of a `varchar` column). It is passed to type-specific input functions and length coercion functions. The value will generally be -1 for types that do not need typmod.
attbyval	`bool`		A copy of `pg_type.typbyval` of this column's type
attstorage	`char`		Normally a copy of `pg_type.typstorage` of this column's type. For TOASTable datatypes, this can be altered after column creation to control storage policy.
attisset	`bool`		If true, this attribute is a set. In that case, what is really stored in the attribute is the OID of a tuple in the `pg_proc` catalog. The `pg_proc` tuple contains the query string that defines this set - i.e., the query to run to get the set. So the `atttypid` (see above) refers to the type returned by this query, but the actual length of this attribute is the length (size) of an `oid`. --- At least this is the theory. All this is probably quite broken these days.
attalign	`char`		A copy of `pg_type.typalign` of this column's type

Name	Type	References	Description
attnotnull	bool		This represents a NOT NULL constraint. It is possible to change this field to enable or disable the constraint.
atthasdef	bool		This column has a default value, in which case there will be a corresponding entry in the pg_attrdef catalog that actually defines the value.
attisdropped	bool		This column has been dropped and is no longer valid. A dropped column is still physically present in the table, but is ignored by the parser and so cannot be accessed via SQL.
attislocal	bool		This column is defined locally in the relation. Note that a column may be locally defined and inherited simultaneously.
attinhcount	int4		The number of direct ancestors this column has. A column with a nonzero number of ancestors cannot be dropped nor renamed.

3.8. pg_cast

pg_cast stores data type conversion paths, both built-in paths and those defined with CREATE CAST.

Table 3-8. pg_cast Columns

Name	Type	References	Description
castsource	oid	pg_type.oid	OID of the source data type
casttarget	oid	pg_type.oid	OID of the target data type

Name	Type	References	Description
castfunc	oid	pg_proc.oid	The OID of the function to use to perform this cast. Zero is stored if the data types are binary coercible (that is, no run-time operation is needed to perform the cast).
castcontext	char		Indicates what contexts the cast may be invoked in. e means only as an explicit cast (using CAST, ::, or function-call syntax). a means implicitly in assignment to a target column, as well as explicitly. i means implicitly in expressions, as well as the other cases.

3.9. pg_class

pg_class catalogs tables and most everything else that has columns or is otherwise similar to a table. This includes indexes (but see also pg_index), sequences, views, and some kinds of special relation; see relkind. Below, when we mean all of these kinds of objects we speak of “relations”. Not all fields are meaningful for all relation types.

Table 3-9. pg_class Columns

Name	Type	References	Description
relname	name		Name of the table, index, view, etc.
relnamespace	oid	pg_namespace.oid	The OID of the namespace that contains this relation
reltype	oid	pg_type.oid	The OID of the data type that corresponds to this table, if any (zero for indexes, which have no pg_type entry)
relowner	int4	pg_shadow.usesysid	Owner of the relation
relam	oid	pg_am.oid	If this is an index, the access method used (B-tree, hash, etc.)

Name	Type	References	Description
relfilenode	`oid`		Name of the on-disk file of this relation; 0 if none
relpages	`int4`		Size of the on-disk representation of this table in pages (size `BLCKSZ`). This is only an estimate used by the planner. It is updated by `VACUUM`, `ANALYZE`, and `CREATE INDEX`.
reltuples	`float4`		Number of tuples in the table. This is only an estimate used by the planner. It is updated by `VACUUM`, `ANALYZE`, and `CREATE INDEX`.
reltoastrelid	`oid`	pg_class.oid	OID of the TOAST table associated with this table, 0 if none. The TOAST table stores large attributes “out of line” in a secondary table.
reltoastidxid	`oid`	pg_class.oid	For a TOAST table, the OID of its index. 0 if not a TOAST table.
relhasindex	`bool`		True if this is a table and it has (or recently had) any indexes. This is set by CREATE INDEX, but not cleared immediately by DROP INDEX. VACUUM clears relhasindex if it finds the table has no indexes.
relisshared	`bool`		True if this table is shared across all databases in the cluster. Only certain system catalogs (such as `pg_database`) are shared.

Name	Type	References	Description
relkind	char		'r' = ordinary table, 'i' = index, 'S' = sequence, 'v' = view, 'c' = composite type, 's' = special, 't' = TOAST table
relnatts	int2		Number of user columns in the relation (system columns not counted). There must be this many corresponding entries in pg_attribute. See also pg_attribute.attnum.
relchecks	int2		Number of check constraints on the table; see pg_constraint catalog
reltriggers	int2		Number of triggers on the table; see pg_trigger catalog
relukeys	int2		unused (*Not* the number of unique keys)
relfkeys	int2		unused (*Not* the number of foreign keys on the table)
relrefs	int2		unused
relhasoids	bool		True if we generate an OID for each row of the relation.
relhaspkey	bool		True if the table has (or once had) a primary key.
relhasrules	bool		Table has rules; see pg_rewrite catalog
relhassubclass	bool		At least one table inherits from this one
relacl	aclitem[]		Access permissions. See the descriptions of GRANT and REVOKE for details.

3.10. pg_constraint

This system catalog stores CHECK, PRIMARY KEY, UNIQUE, and FOREIGN KEY constraints on

tables. (Column constraints are not treated specially. Every column constraint is equivalent to some table constraint.) See under `CREATE TABLE` for more information.

> **Note:** NOT NULL constraints are represented in the `pg_attribute` catalog.

CHECK constraints on domains are stored here, too. Global ASSERTIONS (a currently-unsupported SQL feature) may someday appear here as well.

Table 3-10. pg_constraint Columns

Name	Type	References	Description
conname	`name`		Constraint name (not necessarily unique!)
connamespace	`oid`	pg_namespace.oid	The OID of the namespace that contains this constraint
contype	`char`		’c’ = check constraint, ’f’ = foreign key constraint, ’p’ = primary key constraint, ’u’ = unique constraint
condeferrable	`boolean`		Is the constraint deferrable?
condeferred	`boolean`		Is the constraint deferred by default?
conrelid	`oid`	pg_class.oid	The table this constraint is on; 0 if not a table constraint
contypid	`oid`	pg_type.oid	The domain this constraint is on; 0 if not a domain constraint
confrelid	`oid`	pg_class.oid	If a foreign key, the referenced table; else 0
confupdtype	`char`		Foreign key update action code
confdeltype	`char`		Foreign key deletion action code
confmatchtype	`char`		Foreign key match type
conkey	`int2[]`	pg_attribute.attnum	If a table constraint, list of columns which the constraint constrains
confkey	`int2[]`	pg_attribute.attnum	If a foreign key, list of the referenced columns
conbin	`text`		If a check constraint, an internal representation of the expression

Name	Type	References	Description
consrc	text		If a check constraint, a human-readable representation of the expression

Note: pg_class.relchecks needs to agree with the number of check-constraint entries found in this table for the given relation.

3.11. pg_conversion

This system catalog stores encoding conversion information. See CREATE CONVERSION for more information.

Table 3-11. pg_conversion Columns

Name	Type	References	Description
conname	name		Conversion name (unique within a namespace)
connamespace	oid	pg_namespace.oid	The OID of the namespace that contains this conversion
conowner	int4	pg_shadow.usesysid	Owner (creator) of the namespace
conforencoding	int4		Source(for) encoding ID
contoencoding	int4		Destination(to) encoding ID
conproc	regproc	pg_proc.oid	Conversion procedure
condefault	boolean		true if this is the default conversion

3.12. pg_database

The pg_database catalog stores information about the available databases. Databases are created with the CREATE DATABASE command. Consult the *Administrator's Guide* for details about the meaning of some of the parameters.

Unlike most system catalogs, pg_database is shared across all databases of a cluster: there is only one copy of pg_database per cluster, not one per database.

Table 3-12. pg_database Columns

Name	Type	References	Description

Name	Type	References	Description
datname	`name`		Database name
datdba	`int4`	pg_shadow.usesysid	Owner of the database, usually the user who created it
encoding	`int4`		Character/multibyte encoding for this database
datistemplate	`bool`		If true then this database can be used in the "TEMPLATE" clause of `CREATE DATABASE` to create a new database as a clone of this one.
datallowconn	`bool`		If false then no one can connect to this database. This is used to protect the template0 database from being altered.
datlastsysoid	`oid`		Last system OID in the database; useful particularly to pg_dump
datvacuumxid	`xid`		All tuples inserted or deleted by transaction IDs before this one have been marked as known committed or known aborted in this database. This is used to determine when commit-log space can be recycled.
datfrozenxid	`xid`		All tuples inserted by transaction IDs before this one have been relabeled with a permanent ("frozen") transaction ID in this database. This is useful to check whether a database must be vacuumed soon to avoid transaction ID wraparound problems.

Name	Type	References	Description
datpath	text		If the database is stored at an alternative location then this records the location. It's either an environment variable name or an absolute path, depending how it was entered.
datconfig	text[]		Session defaults for run-time configuration variables
datacl	aclitem[]		Access permissions

3.13. pg_depend

The pg_depend table records the dependency relationships between database objects. This information allows DROP commands to find which other objects must be dropped by DROP CASCADE, or prevent dropping in the DROP RESTRICT case.

Table 3-13. pg_depend Columns

Name	Type	References	Description
classid	oid	pg_class.oid	The oid of the system catalog the dependent object is in
objid	oid	any oid attribute	The oid of the specific dependent object
objsubid	int4		For a table attribute, this is the attribute's column number (the objid and classid refer to the table itself). For all other object types, this field is presently zero.
refclassid	oid	pg_class.oid	The oid of the system catalog the referenced object is in
refobjid	oid	any oid attribute	The oid of the specific referenced object
refobjsubid	int4		For a table attribute, this is the attribute's column number (the refobjid and refclassid refer to the table itself). For all other object types, this field is presently zero.

Name	Type	References	Description
deptype	char		A code defining the specific semantics of this dependency relationship.

In all cases, a pg_depend entry indicates that the referenced object may not be dropped without also dropping the dependent object. However, there are several subflavors identified by deptype:

- DEPENDENCY_NORMAL ('n'): normal relationship between separately-created objects. The dependent object may be dropped without affecting the referenced object. The referenced object may only be dropped by specifying CASCADE, in which case the dependent object is dropped too. Example: a table column has a normal dependency on its datatype.
- DEPENDENCY_AUTO ('a'): the dependent object can be dropped separately from the referenced object, and should be automatically dropped (regardless of RESTRICT or CASCADE mode) if the referenced object is dropped. Example: a named constraint on a table is made auto-dependent on the table, so that it will go away if the table is dropped.
- DEPENDENCY_INTERNAL ('i'): the dependent object was created as part of creation of the referenced object, and is really just a part of its internal implementation. A DROP of the dependent object will be disallowed outright (we'll tell the user to issue a DROP against the referenced object, instead). A DROP of the referenced object will be propagated through to drop the dependent object whether CASCADE is specified or not. Example: a trigger that's created to enforce a foreign-key constraint is made internally dependent on the constraint's pg_constraint entry.
- DEPENDENCY_PIN ('p'): there is no dependent object; this type of entry is a signal that the system itself depends on the referenced object, and so that object must never be deleted. Entries of this type are created only during initdb. The fields for the dependent object contain zeroes.

Other dependency flavors may be needed in future.

3.14. pg_description

The pg_description table can store an optional description or comment for each database object. Descriptions can be manipulated with the COMMENT command and viewed with psql's \d commands. Descriptions of many built-in system objects are provided in the initial contents of pg_description.

Table 3-14. pg_description Columns

Name	Type	References	Description
objoid	oid	any oid attribute	The oid of the object this description pertains to
classoid	oid	pg_class.oid	The oid of the system catalog this object appears in

Name	Type	References	Description
objsubid	int4		For a comment on a table attribute, this is the attribute's column number (the objoid and classoid refer to the table itself). For all other object types, this field is presently zero.
description	text		Arbitrary text that serves as the description of this object.

3.15. pg_group

This catalog defines groups and stores what users belong to what groups. Groups are created with the CREATE GROUP command. Consult the *Administrator's Guide* for information about user permission management.

Because user and group identities are cluster-wide, pg_group is shared across all databases of a cluster: there is only one copy of pg_group per cluster, not one per database.

Table 3-15. pg_group Columns

Name	Type	References	Description
groname	name		Name of the group
grosysid	int4		An arbitrary number to identify this group
grolist	int4[]	pg_shadow.usesysid	An array containing the ids of the users in this group

3.16. pg_index

pg_index contains part of the information about indexes. The rest is mostly in pg_class.

Table 3-16. pg_index Columns

Name	Type	References	Description
indexrelid	oid	pg_class.oid	The OID of the pg_class entry for this index
indrelid	oid	pg_class.oid	The OID of the pg_class entry for the table this index is for
indproc	regproc	pg_proc.oid	The function's OID if this is a functional index, else zero

Name	Type	References	Description
indkey	int2vector	pg_attribute.attnum	This is a vector (array) of up to INDEX_MAX_KEYS values that indicate which table columns this index pertains to. For example a value of 1 3 would mean that the first and the third column make up the index key. For a functional index, these columns are the inputs to the function, and the function's return value is the index key.
indclass	oidvector	pg_opclass.oid	For each column in the index key this contains a reference to the "operator class" to use. See pg_opclass for details.
indisclustered	bool		If true, the table was last clustered on this index.
indisunique	bool		If true, this is a unique index.
indisprimary	bool		If true, this index represents the primary key of the table. (indisunique should always be true when this is true.)
indreference	oid		unused
indpred	text		Expression tree (in the form of a nodeToString representation) for partial index predicate. Empty string if not a partial index.

3.17. pg_inherits

This catalog records information about table inheritance hierarchies.

Table 3-17. pg_inherits Columns

Name	Type	References	Description

Name	Type	References	Description
inhrelid	oid	pg_class.oid	The OID of the child table.
inhparent	oid	pg_class.oid	The OID of the parent table.
inhseqno	int4		If there is more than one parent for a child table (multiple inheritance), this number tells the order in which the inherited columns are to be arranged. The count starts at 1.

3.18. pg_language

pg_language registers call interfaces or languages in which you can write functions or stored procedures. See under CREATE LANGUAGE and in the *Programmer's Guide* for more information about language handlers.

Table 3-18. pg_language Columns

Name	Type	References	Description
lanname	name		Name of the language (to be specified when creating a function)
lanispl	bool		This is false for internal languages (such as SQL) and true for user-defined languages. Currently, pg_dump still uses this to determine which languages need to be dumped, but this may be replaced by a different mechanism sometime.
lanpltrusted	bool		This is a trusted language. See under CREATE LANGUAGE what this means. If this is an internal language (lanispl is false) then this field is meaningless.

Name	Type	References	Description
lanplcallfoid	oid	pg_proc.oid	For non-internal languages this references the language handler, which is a special function that is responsible for executing all functions that are written in the particular language.
lanvalidator	oid	pg_proc.oid	This references a language validator function that is responsible for checking the syntax and validity of new functions when they are created. See under CREATE LANGUAGE for further information about validators.
lanacl	aclitem[]		Access permissions

3.19. pg_largeobject

pg_largeobject holds the data making up “large objects”. A large object is identified by an OID assigned when it is created. Each large object is broken into segments or “pages” small enough to be conveniently stored as rows in pg_largeobject. The amount of data per page is defined to be LOBLKSIZE (which is currently BLCKSZ/4, or typically 2Kbytes).

Table 3-19. pg_largeobject Columns

Name	Type	References	Description
loid	oid		Identifier of the large object that includes this page
pageno	int4		Page number of this page within its large object (counting from zero)
data	bytea		Actual data stored in the large object. This will never be more than LOBLKSIZE bytes, and may be less.

Each row of pg_largeobject holds data for one page of a large object, beginning at byte offset (pageno * LOBLKSIZE) within the object. The implementation allows sparse storage: pages may be missing, and may be shorter than LOBLKSIZE bytes even if they are not the last page of the object.

Missing regions within a large object read as zeroes.

3.20. pg_listener

`pg_listener` supports the `LISTEN` and `NOTIFY` commands. A listener creates an entry in `pg_listener` for each notification name it is listening for. A notifier scans `pg_listener` and updates each matching entry to show that a notification has occurred. The notifier also sends a signal (using the PID recorded in the table) to awaken the listener from sleep.

Table 3-20. pg_listener Columns

Name	Type	References	Description
relname	`name`		Notify condition name. (The name need not match any actual relation in the database; the term “relname” is historical.)
listenerpid	`int4`		PID of the backend process that created this entry.
notification	`int4`		Zero if no event is pending for this listener. If an event is pending, the PID of the backend that sent the notification.

3.21. pg_namespace

A namespace is the structure underlying SQL92 schemas: each namespace can have a separate collection of relations, types, etc without name conflicts.

Table 3-21. pg_namespace Columns

Name	Type	References	Description
nspname	`name`		Name of the namespace
nspowner	`int4`	pg_shadow.usesysid	Owner (creator) of the namespace
nspacl	`aclitem[]`		Access permissions

3.22. pg_opclass

`pg_opclass` defines index access method operator classes. Each operator class defines semantics for index columns of a particular datatype and a particular index access method. Note that there can be multiple operator classes for a given datatype/access method combination, thus supporting multiple

behaviors.

Operator classes are described at length in the *Programmer's Guide*.

Table 3-22. pg_opclass Columns

Name	Type	References	Description
opcamid	oid	pg_am.oid	index access method opclass is for
opcname	name		name of this opclass
opcnamespace	oid	pg_namespace.oid	namespace of this opclass
opcowner	int4	pg_shadow.usesysid	opclass owner
opcintype	oid	pg_type.oid	type of input data for opclass
opcdefault	bool		true if opclass is default for opcintype
opckeytype	oid	pg_type.oid	type of index data, or zero if same as opcintype

The majority of the information defining an operator class is actually not in its pg_opclass row, but in the associated rows in pg_amop and pg_amproc. Those rows are considered to be part of the operator class definition --- this is not unlike the way that a relation is defined by a single pg_class row, plus associated rows in pg_attribute and other tables.

3.23. pg_operator

See CREATE OPERATOR and the *Programmer's Guide* for details on these operator parameters.

Table 3-23. pg_operator Columns

Name	Type	References	Description
oprname	name		Name of the operator
oprnamespace	oid	pg_namespace.oid	The OID of the namespace that contains this operator
oprowner	int4	pg_shadow.usesysid	Owner (creator) of the operator
oprkind	char		'b' = infix ("both"), 'l' = prefix ("left"), 'r' = postfix ("right")
oprcanhash	bool		This operator supports hash joins.
oprleft	oid	pg_type.oid	Type of the left operand
oprright	oid	pg_type.oid	Type of the right operand
oprresult	oid	pg_type.oid	Type of the result

Name	Type	References	Description
oprcom	oid	pg_operator.oid	Commutator of this operator, if any
oprnegate	oid	pg_operator.oid	Negator of this operator, if any
oprlsortop	oid	pg_operator.oid	If this operator supports merge joins, the operator that sorts the type of the left-hand operand (L<L)
oprrsortop	oid	pg_operator.oid	If this operator supports merge joins, the operator that sorts the type of the right-hand operand (R<R)
oprltcmpop	oid	pg_operator.oid	If this operator supports merge joins, the less-than operator that compares the left and right operand types (L<R)
oprgtcmpop	oid	pg_operator.oid	If this operator supports merge joins, the greater-than operator that compares the left and right operand types (L>R)
oprcode	regproc	pg_proc.oid	Function that implements this operator
oprrest	regproc	pg_proc.oid	Restriction selectivity estimation function for this operator
oprjoin	regproc	pg_proc.oid	Join selectivity estimation function for this operator

Unused fields contain zeroes, for example oprleft is zero for a prefix operator.

3.24. pg_proc

This catalog stores information about functions (or procedures). The description of CREATE FUNCTION and the *Programmer's Guide* contain more information about the meaning of some fields.

The table contains data for aggregate functions as well as plain functions. If proisagg is true, there should be a matching row in pg_aggregate.

Table 3-24. pg_proc Columns

Name	Type	References	Description
proname	`name`		Name of the function
pronamespace	`oid`	pg_namespace.oid	The OID of the namespace that contains this function
proowner	`int4`	pg_shadow.usesysid	Owner (creator) of the function
prolang	`oid`	pg_language.oid	Implementation language or call interface of this function
proisagg	`bool`		Function is an aggregate function
prosecdef	`bool`		Function is a security definer (i.e., a “setuid” function)
proisstrict	`bool`		Function returns null if any call argument is null. In that case the function won’t actually be called at all. Functions that are not “strict” must be prepared to handle null inputs.
proretset	`bool`		Function returns a set (ie, multiple values of the specified data type)

Name	Type	References	Description
provolatile	`char`		`provolatile` tells whether the function's result depends only on its input arguments, or is affected by outside factors. It is `i` for "immutable" functions, which always deliver the same result for the same inputs. It is `s` for "stable" functions, whose results (for fixed inputs) do not change within a scan. It is `v` for "volatile" functions, whose results may change at any time. (Use `v` also for functions with side-effects, so that calls to them cannot get optimized away.)
pronargs	`int2`		Number of arguments
prorettype	`oid`	pg_type.oid	Data type of the return value
proargtypes	`oidvector`	pg_type.oid	A vector with the data types of the function arguments
prosrc	`text`		This tells the function handler how to invoke the function. It might be the actual source code of the function for interpreted languages, a link symbol, a file name, or just about anything else, depending on the implementation language/call convention.
probin	`bytea`		Additional information about how to invoke the function. Again, the interpretation is language-specific.
proacl	`aclitem[]`		Access permissions

Currently, prosrc contains the function's C-language name (link symbol) for compiled functions, both

built-in and dynamically loaded. For all other language types, prosrc contains the function's source text.

Currently, probin is unused except for dynamically-loaded C functions, for which it gives the name of the shared library file containing the function.

3.25. pg_rewrite

This system catalog stores rewrite rules for tables and views.

Table 3-25. pg_rewrite Columns

Name	Type	References	Description
rulename	`name`		Rule name
ev_class	`oid`	pg_class.oid	The table this rule is for
ev_attr	`int2`		The column this rule is for (currently, always zero to indicate the whole table)
ev_type	`char`		Event type that the rule is for: '1' = SELECT, '2' = UPDATE, '3' = INSERT, '4' = DELETE
is_instead	`bool`		True if the rule is an INSTEAD rule
ev_qual	`text`		Expression tree (in the form of a nodeToString representation) for the rule's qualifying condition
ev_action	`text`		Query tree (in the form of a nodeToString representation) for the rule's action

Note: `pg_class.relhasrules` must be true if a table has any rules in this catalog.

3.26. pg_shadow

`pg_shadow` contains information about database users. The name stems from the fact that this table should not be readable by the public since it contains passwords. `pg_user` is a publicly readable view on `pg_shadow` that blanks out the password field.

The *Administrator's Guide* contains detailed information about user and permission management.

Because user identities are cluster-wide, `pg_shadow` is shared across all databases of a cluster: there is only one copy of `pg_shadow` per cluster, not one per database.

Table 3-26. pg_shadow Columns

Name	Type	References	Description
usename	name		User name
usesysid	int4		User id (arbitrary number used to reference this user)
usecreatedb	bool		User may create databases
usesuper	bool		User is a superuser
usecatupd	bool		User may update system catalogs. (Even a superuser may not do this unless this attribute is true.)
passwd	text		Password
valuntil	abstime		Account expiry time (only used for password authentication)
useconfig	text[]		Session defaults for run-time configuration variables

3.27. pg_statistic

pg_statistic stores statistical data about the contents of the database. Entries are created by ANALYZE and subsequently used by the query planner. There is one entry for each table column that has been analyzed. Note that all the statistical data is inherently approximate, even assuming that it is up-to-date.

Since different kinds of statistics may be appropriate for different kinds of data, pg_statistic is designed not to assume very much about what sort of statistics it stores. Only extremely general statistics (such as NULL-ness) are given dedicated columns in pg_statistic. Everything else is stored in "slots", which are groups of associated columns whose content is identified by a code number in one of the slot's columns. For more information see src/include/catalog/pg_statistic.h.

pg_statistic should not be readable by the public, since even statistical information about a table's contents may be considered sensitive. (Example: minimum and maximum values of a salary column might be quite interesting.) pg_stats is a publicly readable view on pg_statistic that only exposes information about those tables that are readable by the current user. pg_stats is also designed to present the information in a more readable format than the underlying pg_statistic table --- at the cost that its schema must be extended whenever new slot types are added.

Table 3-27. pg_statistic Columns

Name	Type	References	Description
starelid	oid	pg_class.oid	The table that the described column belongs to

Name	Type	References	Description
staattnum	`int2`	pg_attribute.attnum	The number of the described column
stanullfrac	`float4`		The fraction of the column's entries that are NULL
stawidth	`int4`		The average stored width, in bytes, of non-NULL entries
stadistinct	`float4`		The number of distinct non-NULL data values in the column. A value greater than zero is the actual number of distinct values. A value less than zero is the negative of a fraction of the number of rows in the table (for example, a column in which values appear about twice on the average could be represented by stadistinct = -0.5). A zero value means the number of distinct values is unknown.
stakindN	`int2`		A code number indicating the kind of statistics stored in the Nth "slot" of the `pg_statistic` row.
staopN	`oid`	pg_operator.oid	An operator used to derive the statistics stored in the Nth "slot". For example, a histogram slot would show the < operator that defines the sort order of the data.
stanumbersN	`float4[]`		Numerical statistics of the appropriate kind for the Nth "slot", or NULL if the slot kind does not involve numerical values.

Name	Type	References	Description
stavaluesN	text[]		Column data values of the appropriate kind for the Nth “slot”, or NULL if the slot kind does not store any data values. For data-type independence, all column data values are converted to external textual form and stored as TEXT datums.

3.28. pg_trigger

This system catalog stores triggers on tables. See under CREATE TRIGGER for more information.

Table 3-28. pg_trigger Columns

Name	Type	References	Description
tgrelid	oid	pg_class.oid	The table this trigger is on
tgname	name		Trigger name (must be unique among triggers of same table)
tgfoid	oid	pg_proc.oid	The function to be called
tgtype	int2		Bitmask identifying trigger conditions
tgenabled	bool		True if trigger is enabled (not presently checked everywhere it should be, so disabling a trigger by setting this false does not work reliably)
tgisconstraint	bool		True if trigger implements an RI constraint
tgconstrname	name		RI constraint name
tgconstrrelid	oid	pg_class.oid	The table referenced by an RI constraint
tgdeferrable	bool		True if deferrable
tginitdeferred	bool		True if initially deferred

Name	Type	References	Description
tgnargs	int2		Number of argument strings passed to trigger function
tgattr	int2vector		Currently unused
tgargs	bytea		Argument strings to pass to trigger, each null-terminated

Note: pg_class.reltriggers needs to match up with the entries in this table.

3.29. pg_type

This catalog stores information about data types. Scalar types ("base types") are created with CREATE TYPE. A complex type is automatically created for each table in the database, to represent the row structure of the table. It is also possible to create complex types with CREATE TYPE AS, and derived types with CREATE DOMAIN.

Table 3-29. pg_type Columns

Name	Type	References	Description
typname	name		Data type name
typnamespace	oid	pg_namespace.oid	The OID of the namespace that contains this type
typowner	int4	pg_shadow.usesysid	Owner (creator) of the type
typlen	int2		For a fixed-size type, typlen is the number of bytes in the internal representation of the type. But for a variable-length type, typlen is negative. -1 indicates a "varlena" type (one that has a length word), -2 indicates a null-terminated C string.

Name	Type	References	Description
typbyval	`bool`		`typbyval` determines whether internal routines pass a value of this type by value or by reference. Only `char`, `short`, and `int` equivalent items can be passed by value, so if the type is not 1, 2, or 4 bytes long, PostgreSQL does not have the option of passing by value and so `typbyval` had better be false. Variable-length types are always passed by reference. Note that `typbyval` can be false even if the length would allow pass-by-value; this is currently true for type `float4`, for example.
typtype	`char`		`typtype` is `b` for a base type, `c` for a complex type (i.e., a table's row type), `d` for a derived type (i.e., a domain), or `p` for a pseudo-type. See also `typrelid` and `typbasetype`.
typisdefined	`bool`		True if the type is defined, false if this is a placeholder entry for a not-yet-defined type. When typisdefined is false, nothing except the type name, namespace, and OID can be relied on.
typdelim	`char`		Character that separates two values of this type when parsing array input. Note that the delimiter is associated with the array element data type, not the array data type.

Name	Type	References	Description
typrelid	`oid`	pg_class.oid	If this is a complex type (see `typtype`), then this field points to the `pg_class` entry that defines the corresponding table. (For a free-standing composite type, the `pg_class` entry doesn't really represent a table, but it is needed anyway for the type's `pg_attribute` entries to link to.) Zero for non-complex types.
typelem	`oid`	pg_type.oid	If `typelem` is not 0 then it identifies another row in `pg_type`. The current type can then be subscripted like an array yielding values of type `typelem`. A "true" array type is variable length (`typlen` = -1), but some fixed-length (`typlen` $>$ 0) types also have nonzero `typelem`, for example `name` and `oidvector`. If a fixed-length type has a `typelem` then its internal representation must be N values of the `typelem` data type with no other data. Variable-length array types have a header defined by the array subroutines.
typinput	`regproc`	pg_proc.oid	Input conversion function
typoutput	`regproc`	pg_proc.oid	Output conversion function

Name	Type	References	Description
typalign	`char`		`typalign` is the alignment required when storing a value of this type. It applies to storage on disk as well as most representations of the value inside PostgreSQL. When multiple values are stored consecutively, such as in the representation of a complete row on disk, padding is inserted before a datum of this type so that it begins on the specified boundary. The alignment reference is the beginning of the first datum in the sequence. Possible values are: • 'c' = CHAR alignment, i.e., no alignment needed. • 's' = SHORT alignment (2 bytes on most machines). • 'i' = INT alignment (4 bytes on most machines). • 'd' = DOUBLE alignment (8 bytes on many machines, but by no means all). **Note:** For types used in system tables, it is critical that the size and alignment defined in `pg_type` agree with the way that the compiler will lay out the field in a struct representing a table row.

Name	Type	References	Description
typstorage	`char`		`typstorage` tells for varlena types (those with `typlen` = -1) if the type is prepared for toasting and what the default strategy for attributes of this type should be. Possible values are • 'p': Value must always be stored plain. • 'e': Value can be stored in a "secondary" relation (if relation has one, see `pg_class.reltoastrelid`). • 'm': Value can be stored compressed inline. • 'x': Value can be stored compressed inline or in "secondary". Note that 'm' fields can also be moved out to secondary storage, but only as a last resort ('e' and 'x' fields are moved first).
typnotnull	`bool`		`typnotnull` represents a NOT NULL constraint on a type. Presently used for domains only.
typbasetype	`oid`	pg_type.oid	If this is a derived type (see `typtype`), then `typbasetype` identifies the type that this one is based on. Zero if not a derived type.

Name	Type	References	Description
typtypmod	`int4`		Domains use `typtypmod` to record the typmod to be applied to their base type (-1 if base type does not use a typmod). -1 if this type is not a domain.
typndims	`int4`		`typndims` is the number of array dimensions for a domain that is an array (that is, typbasetype is an array type; the domain's typelem will match the base type's typelem). Zero for non-domains and non-array domains.
typdefaultbin	`text`		If `typdefaultbin` is not NULL, it is the nodeToString representation of a default expression for the type. Currently this is only used for domains.
typdefault	`text`		`typdefault` is NULL if the type has no associated default value. If `typdefaultbin` is not NULL, `typdefault` must contain a human-readable version of the default expression represented by `typdefaultbin`. If `typdefaultbin` is NULL and `typdefault` is not, then `typdefault` is the external representation of the type's default value, which may be fed to the type's input converter to produce a constant.

Chapter 4. Frontend/Backend Protocol

> **Note:** Written by Phil Thompson (<phil@river-bank.demon.co.uk>). Updates for protocol 2.0 by Tom Lane (<tgl@sss.pgh.pa.us>).

PostgreSQL uses a message-based protocol for communication between frontends and backends. The protocol is implemented over TCP/IP and also on Unix domain sockets. PostgreSQL 6.3 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 PostgreSQL 6.4 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.

4.1. Overview

A frontend opens a connection to the server and sends a start-up packet. This includes the names of the user and of the database the user wants to connect to. The server then uses this, and the information in the `pg_hba.conf` 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 server validates this it responds to the frontend that it is authenticated and sends a message indicating successful start-up (normal case) or failure (for example, an invalid database name).

In order to serve multiple clients efficiently, the server launches a new "backend" process for each client. This is transparent to the protocol, however. In the current implementation, a new child process is created immediately after an incoming connection is detected.

When the frontend wishes to disconnect it sends an appropriate packet and closes the connection without waiting for a response from the backend.

Packets are sent as a data stream. The first byte determines what should be expected in the rest of the packet. The exceptions are packets sent as part of the start-up and authentication exchange, which comprise a packet length followed by the packet itself. The difference is historical.

4.2. Protocol

This section describes the message flow. There are four different types of flows depending on the state of the connection: start-up, query, function call, and termination. There are also special provisions for notification responses and command cancellation, which can occur at any time after the start-up phase.

4.2.1. Start-up

Initially, the frontend sends a StartupPacket. The server uses this info and the contents of the `pg_hba.conf` file to determine what authentication method the frontend must use. The server then

responds with one of the following messages:

ErrorResponse

The server then immediately closes the connection.

AuthenticationOk

The authentication exchange is completed.

AuthenticationKerberosV4

The frontend must then take part in a Kerberos V4 authentication dialog (not described here, part of the Kerberos specification) with the server. If this is successful, the server 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, part of the Kerberos specification) with the server. If this is successful, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationCleartextPassword

The frontend must then send a PasswordPacket containing the password in clear-text form. If this is the correct password, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationCryptPassword

The frontend must then send a PasswordPacket containing the password encrypted via crypt(3), using the 2-character salt specified in the AuthenticationCryptPassword packet. If this is the correct password, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationMD5Password

The frontend must then send a PasswordPacket containing the password encrypted via MD5, using the 4-character salt specified in the AuthenticationMD5Password packet. If this is the correct password, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationSCMCredential

This method is only possible for local Unix-domain connections on platforms that support SCM credential messages. The frontend must issue an SCM credential message and then send a single data byte. (The contents of the data byte are uninteresting; it's only used to ensure that the server waits long enough to receive the credential message.) If the credential is acceptable, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

If the frontend does not support the authentication method requested by the server, then it should immediately close the connection.

After having received AuthenticationOk, the frontend should wait for further messages from the server. The possible messages from the backend in this phase are:

BackendKeyData

This message 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

Start-up is completed. The frontend may now issue query or function call messages.

ErrorResponse

Start-up 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 start-up phase), or to consider ReadyForQuery as ending the start-up phase and each subsequent query cycle.

4.2.2. 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 table. 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 table to the frontend. It then sends a CopyDataRows message, and then a CompletedResponse message with a tag of `COPY`.

CursorResponse

Beginning of the response to a `SELECT`, `FETCH`, `INSERT`, `UPDATE`, or `DELETE` query. In the `FETCH` case the name of the cursor being fetched from is included in the message. Otherwise the message always mentions the “blank” cursor.

RowDescription

Indicates that rows are about to be returned in response to a `SELECT` or `FETCH` query. The message contents describe the layout of the rows. This will be followed by an AsciiRow or BinaryRow message (depending on whether a binary cursor was specified) for each row being returned to the frontend.

EmptyQueryResponse

An empty query string was recognized.

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, i.e., the backend will continue processing the command.

The response to a `SELECT` or `FETCH` query normally consists of CursorResponse, RowDescription, zero or more AsciiRow or BinaryRow messages, and finally CompletedResponse. `INSERT`, `UPDATE`, and `DELETE` queries produce CursorResponse followed by CompletedResponse. `COPY` to or from the frontend invokes special protocol as mentioned above. All other query types normally produce only a CompletedResponse message.

Since a query string could contain several queries (separated by semicolons), there might be several such response sequences before the backend finishes processing the query string. ReadyForQuery is issued when the entire string has been processed and the backend is ready to accept a new query string.

If a completely empty (no contents other than whitespace) query string is received, the response is EmptyQueryResponse followed by ReadyForQuery. (The need to specially distinguish this case is historical.)

In the event of an error, ErrorResponse is issued followed by ReadyForQuery. All further processing of the query string is aborted by ErrorResponse (even if more queries remained in it). Note that this may occur partway through the sequence of messages generated by an individual query.

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 parent process. 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` commands then it must be prepared to accept NotificationResponse messages at any time; see below.

Recommended practice is to code frontends in a state-machine style that will accept any message type at any time that it could make sense, rather than wiring in assumptions about the exact sequence of messages.

4.2.3. 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, i.e., 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` commands then it must be prepared to accept NotificationResponse messages at any time; see below.

4.2.4. Notification Responses

If a frontend issues a `LISTEN` command, then the backend will send a NotificationResponse message (not to be confused with NoticeResponse!) whenever a `NOTIFY` command is executed for the same notification name.

Notification responses are permitted at any point in the protocol (after start-up), 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` command has been executed for a name for which a previous `LISTEN` 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.

4.2.5. Cancelling Requests in Progress

During the processing of a query, the frontend may request cancellation of the query. The cancel request is not sent directly on the open connection 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 server and sends a CancelRequest message, rather than the StartupPacket message that would ordinarily be sent across a new connection. The server 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 start-up. If the request matches the PID and secret key for a currently executing backend, the processing of the current query is aborted. (In the existing implementation, this is done by sending a special signal to the backend process that is processing the 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 across a new connection to the server 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.

4.2.6. 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 server if it doesn't want to terminate itself.

For either normal or abnormal termination, any open transaction is rolled back, not committed. One should note however that if a frontend disconnects while a query is being processed, the backend will probably finish the query before noticing the disconnection. If the query is outside any transaction block (`BEGIN` ... `COMMIT` sequence) then its results may be committed before the disconnection is recognized.

4.2.7. SSL Session Encryption

Recent releases of PostgreSQL allow frontend/backend communication to be encrypted using SSL.

This provides communication security in environments where attackers might be able to capture the session traffic.

To initiate an SSL-encrypted connection, the frontend initially sends an SSLRequest message rather than a StartupPacket. The server then responds with a single byte containing `Y` or `N`, indicating that it is willing or unwilling to perform SSL, respectively. The frontend may close the connection at this point if it is dissatisfied with the response. To continue after `Y`, perform an SSL startup handshake (not described here, part of the SSL specification) with the server. If this is successful, continue with sending the usual StartupPacket. In this case the StartupPacket and all subsequent data will be SSL-encrypted. To continue after `N`, send the usual StartupPacket and proceed without encryption.

The frontend should also be prepared to handle an ErrorMessage response to SSLRequest from the server. This would only occur if the server predates the addition of SSL support to PostgreSQL. In this case the connection must be closed, but the frontend may choose to open a fresh connection and proceed without requesting SSL.

An initial SSLRequest may also be used in a connection that is being opened to send a CancelRequest message.

While the protocol itself does not provide a way for the server to force SSL encryption, the administrator may configure the server to reject unencrypted sessions as a byproduct of authentication checking.

4.3. Message Data Types

This section describes the base data types used in messages.

Int*n*(*i*)

An *n* bit integer in network byte order. If *i* is specified it is the literal value. Eg. Int16, Int32(42).

LimString*n*(*s*)

A character array of exactly *n* bytes interpreted as a null-terminated string. The zero-byte 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 null-terminated string with no length limitation. If *s* is specified it is the literal value. Eg. String, String("user").

> **Note:** *There is no predefined limit* on the length of a string that can be returned by the backend. Good coding strategy for a frontend is to use an expandable buffer so that anything that fits in memory can be accepted. If that's not feasible, read the full string and discard trailing characters that don't fit into your fixed-size buffer.

Byte*n*(*c*)

Exactly *n* bytes. If *c* is specified it is the literal value. Eg. Byte, Byte1('\n').

4.4. Message Formats

This section describes the detailed format of each message. Each can be sent by either a frontend (F), a 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.)

Byte*n*

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.

Byte*n*

Specifies the value of the field itself in ASCII characters. *n* is the above size minus 4. There is no trailing zero-byte 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.

AuthenticationCleartextPassword (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(3)

Specifies that a cleartext password is required.

AuthenticationCryptPassword (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(4)

Specifies that a crypt()-encrypted password is required.

Byte2

The salt to use when encrypting the password.

AuthenticationMD5Password (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(5)

Specifies that an MD5-encrypted password is required.

Byte4

The salt to use when encrypting the password.

AuthenticationSCMCredential (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(6)

Specifies that an SCM credentials message is required.

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.)

Byte*n*

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.

Byte*n*

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 a single word that identifies which SQL command was completed.

For an `INSERT` command, the tag is `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` command, the tag is `DELETE` *`rows`* where *`rows`* is the number of rows deleted.

For an `UPDATE` command, the tag is `UPDATE` *`rows`* where *`rows`* is the number of rows updated.

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.

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.

Byte*n*

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.

Byte*n*

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.

PasswordPacket (F)

Int32

The size of the packet in bytes.

String

The password (encrypted, if requested).

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.

SSLRequest (F)

Int32(8)

The size of the packet in bytes.

Int32(80877103)

The SSL request code. The value is chosen to contain `1234` in the most significant 16 bits, and `5679` in the least 16 significant bits. (To avoid confusion, this code must not be the same as any protocol version number.)

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 child process by the server.

LimString64

Unused.

LimString64

The optional tty the backend should use for debugging messages. (Currently, this field is unsupported and ignored.)

Terminate (F)

Byte1('X')

Identifies the message as a termination.

Chapter 5. gcc Default Optimizations

Note: Contributed by Brian Gallew (<geek+@cmu.edu>)

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 6. BKI Backend Interface

Backend Interface (BKI) files are scripts in a special language that are input to the PostgreSQL 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. (And they are probably not useful for anything else.)

initdb uses a BKI file to do part of its job when creating a new database cluster. The input file used by initdb is created as part of building and installing PostgreSQL by a program named `genbki.sh` from some specially formatted C header files in the source tree. The created BKI file is called `postgres.bki` and is normally installed in the `share` subdirectory of the installation tree.

Related information may be found in the documentation for initdb.

6.1. BKI File Format

This section describes how the PostgreSQL backend interprets BKI files. This description will be easier to understand if the `postgres.bki` file is at hand as an example. You should also study the source code of initdb to get an idea of how the backend is invoked.

BKI input consists of a sequence of commands. Commands are made up of a number of tokens, depending on the syntax of the command. Tokens are usually separated by whitespace, but need not be if there is no ambiguity. There is no special command separator; the next token that syntactically cannot belong to the preceding command starts a new one. (Usually you would put a new command on a new line, for clarity.) Tokens can be certain key words, special characters (parentheses, commas, etc.), numbers, or double-quoted strings. Everything is case sensitive.

Lines starting with a # are ignored.

6.2. BKI Commands

open *`tablename`*

Open the table called *`tablename`* for further manipulation.

close [*`tablename`*]

Close the open table called *`tablename`*. It is an error if *`tablename`* is not already opened. If no *`tablename`* is given, then the currently open table is closed.

create *`tablename`* (*`name1`* = *`type1`* [, *`name2`* = *`type2`*, ...])

Create a table named *`tablename`* with the columns given in parentheses.

The *`type`* is not necessarily the data type that the column will have in the SQL environment; that is determined by the `pg_attribute` system catalog. The type here is essentially only used to allocate storage. The following types are allowed: `bool`, `bytea`, `char` (1 byte), `name`, `int2`, `int2vector`, `int4`, `regproc`, `regclass`, `regtype`, `text`, `oid`, `tid`, `xid`, `cid`, `oidvector`, `smgr`, `_int4` (array), `_aclitem` (array). Array types can also be indicated by writing `[]` after the name of the element type.

> **Note:** The table will only be created on disk, it will not automatically be registered in the system catalogs and will therefore not be accessible unless appropriate rows are inserted in `pg_class`, `pg_attribute`, etc.

insert [OID = *oid_value*] (*value1 value2* ...)

Insert a new row into the open table using *value1*, *value2*, etc., for its column values and *oid_value* for its OID. If *oid_value* is zero (0) or the clause is omitted, then the next available OID is used.

NULL values can be specified using the special key word _null_. Values containing spaces must be double quoted.

declare [unique] index *indexname* on *tablename* using *amname* (*opclass1 name1* [, ...])

Create an index named *indexname* on the table named *tablename* using the *amname* access method. The fields to index are called *name1*, *name2* etc., and the operator classes to use are *opclass1*, *opclass2* etc., respectively.

build indices

Build the indices that have previously been declared.

6.3. Example

The following sequence of commands will create the test_table table with the two columns cola and colb of type int4 and text, respectively, and insert two rows into the table.

```
create test_table (cola = int4, colb = text)
open test_table
insert OID=421 ( 1 "value1" )
insert OID=422 ( 2 _null_ )
close test_table
```

Chapter 7. Page Files

A description of the database file page format.

This section provides an overview of the page format used by PostgreSQL tables and indexes. (Index access methods need not use this page format. At present, all index methods do use this basic format, but the data kept on index metapages usually doesn't follow the item layout rules exactly.) TOAST tables and sequences are formatted just like a regular table.

In the following explanation, a *byte* is assumed to contain 8 bits. In addition, the term *item* refers to an individual data value that is stored on a page. In a table, an item is a tuple (row); in an index, an item is an index entry.

Table 7-1 shows the basic layout of a page. There are five parts to each page.

Table 7-1. Sample Page Layout

Item	Description
PageHeaderData	20 bytes long. Contains general information about the page, including free space pointers.
ItemPointerData	Array of (offset,length) pairs pointing to the actual items.
Free space	The unallocated space. All new tuples are allocated from here, generally from the end.
Items	The actual items themselves.
Special Space	Index access method specific data. Different methods store different data. Empty in ordinary tables.

The first 20 bytes of each page consists of a page header (PageHeaderData). Its format is detailed in Table 7-2. The first two fields deal with WAL related stuff. This is followed by three 2-byte integer fields (`pd_lower`, `pd_upper`, and `pd_special`). These represent byte offsets to the start of unallocated space, to the end of unallocated space, and to the start of the special space.

Table 7-2. PageHeaderData Layout

Field	Type	Length	Description
pd_lsn	XLogRecPtr	8 bytes	LSN: next byte after last byte of xlog
pd_sui	StartUpID	4 bytes	SUI of last changes (currently it's used by heap AM only)
pd_lower	LocationIndex	2 bytes	Offset to start of free space.
pd_upper	LocationIndex	2 bytes	Offset to end of free space.
pd_special	LocationIndex	2 bytes	Offset to start of special space.

Field	Type	Length	Description
pd_pagesize_version	uint16	2 bytes	Page size and layout version number information.

All the details may be found in src/include/storage/bufpage.h.

Special space is a region at the end of the page that is allocated at page initialization time and contains information specific to an access method. The last 2 bytes of the page header, `pd_pagesize_version`, store both the page size and a version indicator. Beginning with PostgreSQL 7.3 the version number is 1; prior releases used version number 0. (The basic page layout and header format has not changed, but the layout of heap tuple headers has.) The page size is basically only present as a cross-check; there is no support for having more than one page size in an installation.

Following the page header are item identifiers (`ItemIdData`), each requiring four bytes. 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. New item identifiers are allocated as needed from the beginning of the unallocated space. The number of item identifiers present can be determined by looking at `pd_lower`, which is increased to allocate a new identifier. Because an item identifier is never moved until it is freed, its index may be used on a long-term basis to reference an item, even when the item itself is moved around on the page to compact free space. In fact, every pointer to an item (`ItemPointer`, also known as `CTID`) created by PostgreSQL consists of a page number and the index of an item identifier.

The items themselves are stored in space allocated backwards from the end of unallocated space. The exact structure varies depending on what the table is to contain. Tables and sequences both use a structure named `HeapTupleHeaderData`, described below.

The final section is the "special section" which may contain anything the access method wishes to store. Ordinary tables do not use this at all (indicated by setting `pd_special` to equal the pagesize).

All table tuples are structured the same way. There is a fixed-size header (occupying 23 bytes on most machines), followed by an optional null bitmap, an optional object ID field, and the user data. The header is detailed in Table 7-3. The actual user data (fields of the tuple) begins at the offset indicated by `t_hoff`, which must always be a multiple of the MAXALIGN distance for the platform. The null bitmap is only present if the *HEAP_HASNULL* bit is set in `t_infomask`. If it is present it begins just after the fixed header and occupies enough bytes to have one bit per data column (that is, `t_natts` bits altogether). In this list of bits, a 1 bit indicates not-null, a 0 bit is a null. When the bitmap is not present, all columns are assumed not-null. The object ID is only present if the *HEAP_HASOID* bit is set in `t_infomask`. If present, it appears just before the `t_hoff` boundary. Any padding needed to make `t_hoff` a MAXALIGN multiple will appear between the null bitmap and the object ID. (This in turn ensures that the object ID is suitably aligned.)

Table 7-3. HeapTupleHeaderData Layout

Field	Type	Length	Description
t_xmin	TransactionId	4 bytes	insert XID stamp
t_cmin	CommandId	4 bytes	insert CID stamp (overlays with t_xmax)
t_xmax	TransactionId	4 bytes	delete XID stamp
t_cmax	CommandId	4 bytes	delete CID stamp (overlays with t_xvac)

Field	Type	Length	Description
t_xvac	TransactionId	4 bytes	XID for VACUUM operation moving tuple
t_ctid	ItemPointerData	6 bytes	current TID of this or newer tuple
t_natts	int16	2 bytes	number of attributes
t_infomask	uint16	2 bytes	various flags
t_hoff	uint8	1 byte	offset to user data

All the details may be found in src/include/access/htup.h.

Interpreting the actual data can only be done with information obtained from other tables, mostly *pg_attribute*. The particular fields are `attlen` and `attalign`. There is no way to directly get a particular attribute, except when there are only fixed width fields and no NULLs. All this trickery is wrapped up in the functions *heap_getattr*, *fastgetattr* and *heap_getsysattr*.

To read the data you need to examine each attribute in turn. First check whether the field is NULL according to the null bitmap. If it is, go to the next. Then make sure you have the right alignment. If the field is a fixed width field, then all the bytes are simply placed. If it's a variable length field (attlen == -1) then it's a bit more complicated, using the variable length structure `varattrib`. Depending on the flags, the data may be either inline, compressed or in another table (TOAST).

Chapter 8. Genetic Query Optimization

Author: Written by Martin Utesch (<utesch@aut.tu-freiberg.de>) for the Institute of Automatic Control at the University of Mining and Technology in Freiberg, Germany.

8.1. 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, hash join, merge join in PostgreSQL) to process individual joins and a diversity of *indexes* (e.g., R-tree, B-tree, hash in PostgreSQL) as access paths for relations.

The current PostgreSQL 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 PostgreSQL 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 in exploring the space of possible query plans created 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.

8.2. Genetic Algorithms

The genetic algorithm (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 adaptation of an individual to its environment is specified by its *fitness*.

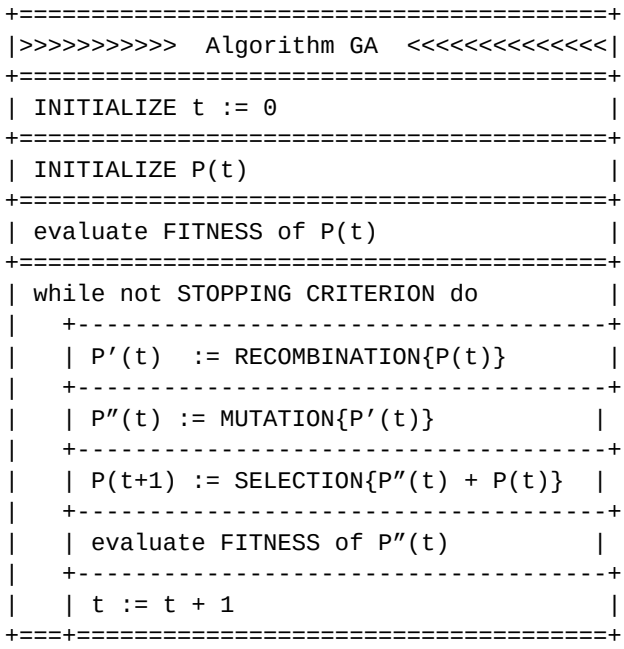
The coordinates of an individual in the search space are represented by *chromosomes*, in essence a set of character strings. A *gene* is a subsection of a chromosome which encodes the value of a single parameter being optimized. Typical encodings for a gene could be *binary* or *integer*.

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).

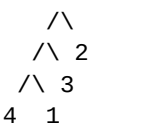
Figure 8-1. Structured Diagram of a Genetic Algorithm

P(t)	generation of ancestors at a time t
P”(t)	generation of descendants at a time t



8.3. Genetic Query Optimization (GEQO) in PostgreSQL

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



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 relation IDs within the PostgreSQL optimizer.

Parts of the GEQO module are adapted from D. Whitley’s Genitor algorithm.

Specific characteristics of the GEQO implementation in PostgreSQL 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 allows the PostgreSQL query optimizer to support large join queries effectively through non-exhaustive search.

8.3.1. Future Implementation Tasks for PostgreSQL GEQO

Work is still needed to improve the 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

8.4. Further Readings

The following resources contain additional information about genetic algorithms:

- The Hitch-Hiker's Guide to Evolutionary Computation[1] (FAQ for comp.ai.genetic[2])
- Evolutionary Computation and its application to art and design[3] by Craig Reynolds
- *Fundamentals of Database Systems*
- *The design and implementation of the POSTGRES query optimizer*

1. http://surf.de.uu.net/encore/www/
2. news://comp.ai.genetic
3. http://www.red3d.com/cwr/evolve.html

Chapter 9. GiST Indexes

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 http://epoch.cs.berkeley.edu:8000/ and http://www.sai.msu.su/~megera/postgres/gist/.

> **Author:** This extraction from an email sent by Eugene Selkov, Jr. (<selkovjr@mcs.anl.gov>) 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[5] 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[6]). 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 (HP-UX) 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!!
```

5. ftp://s2k-ftp.cs.berkeley.edu/pub/gist/pggist/pggist.tgz
6. http://gist.cs.berkeley.edu:8000/gist/

```
-- -- CREATE INDEX pix2 ON polytmp USING RTREE (p poly_ops);
```

Roger that!! I thought it could be related to a number of PostgreSQL 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 10. Native Language Support

10.1. For the Translator

PostgreSQL programs (server and client) can issue their messages in your favorite language -- if the messages have been translated. Creating and maintaining translated message sets needs the help of people who speak their own language well and want to contribute to the PostgreSQL effort. You do not have to be a programmer at all to do this. This section explains how to help.

10.1.1. Requirements

We won't judge your language skills -- this section is about software tools. Theoretically, you only need a text editor. But this is only in the unlikely event that you do not want to try out your translated messages. When you configure your source tree, be sure to use the `--enable-nls` option. This will also check for the libintl library and the `msgfmt` program, which all end users will need anyway. To try out your work, follow the applicable portions of the installation instructions.

If you want to start a new translation effort or want to do a message catalog merge (described later), you will need the programs `xgettext` and `msgmerge`, respectively, in a GNU-compatible implementation. Later, we will try to arrange it so that if you use a packaged source distribution, you won't need `xgettext`. (From CVS, you will still need it.) GNU gettext 0.10.36 or later is currently recommended.

Your local gettext implementation should come with its own documentation. Some of that is probably duplicated in what follows, but for additional details you should look there.

10.1.2. Concepts

The pairs of original (English) messages and their (possibly) translated equivalents are kept in *message catalogs*, one for each program (although related programs can share a message catalog) and for each target language. There are two file formats for message catalogs: The first is the "PO" file (for Portable Object), which is a plain text file with special syntax that translators edit. The second is the "MO" file (for Machine Object), which is a binary file generated from the respective PO file and is used while the internationalized program is run. Translators do not deal with MO files; in fact hardly anyone does.

The extension of the message catalog file is to no surprise either `.po` or `.mo`. The base name is either the name of the program it accompanies, or the language the file is for, depending on the situation. This is a bit confusing. Examples are `psql.po` (PO file for psql) or `fr.mo` (MO file in French).

The file format of the PO files is illustrated here:

```
# comment

msgid "original string"
msgstr "translated string"

msgid "more original"
msgstr "another translated"
"string can be broken up like this"

...
```

The msgid's are extracted from the program source. (They need not be, but this is the most common way.) The msgstr lines are initially empty and are filled in with useful strings by the translator. The strings can contain C-style escape characters and can be continued across lines as illustrated. (The next line must start at the beginning of the line.)

The # character introduces a comment. If whitespace immediately follows the # character, then this is a comment maintained by the translator. There may also be automatic comments, which have a non-whitespace character immediately following the #. These are maintained by the various tools that operate on the PO files and are intended to aid the translator.

```
#. automatic comment
#: filename.c:1023
#, flags, flags
```

The #. style comments are extracted from the source file where the message is used. Possibly the programmer has inserted information for the translator, such as about expected alignment. The #: comment indicates the exact location(s) where the message is used in the source. The translator need not look at the program source, but he can if there is doubt about the correct translation. The #, comments contain flags that describe the message in some way. There are currently two flags: `fuzzy` is set if the message has possibly been outdated because of changes in the program source. The translator can then verify this and possibly remove the fuzzy flag. Note that fuzzy messages are not made available to the end user. The other flag is `c-format`, which indicates that the message is a `printf`-style format template. This means that the translation should also be a format string with the same number and type of placeholders. There are tools that can verify this, which key off the c-format flag.

10.1.3. Creating and maintaining message catalogs

OK, so how does one create a "blank" message catalog? First, go into the directory that contains the program whose messages you want to translate. If there is a file `nls.mk`, then this program has been prepared for translation.

If there are already some `.po` files, then someone has already done some translation work. The files are named *`language`*`.po`, where *`language`* is the ISO 639-1[1] two-letter language code (in lower case), e.g., `fr.po` for French. If there is really a need for more than one translation effort per language then the files may also be named *`language_region`*`.po` where *`region`* is the ISO 3166-1[2] two-letter country code (in upper case), e.g., `pt_BR.po` for Portuguese in Brazil. If you find the language you wanted you can just start working on that file.

If you need to start a new translation effort, then first run the command

```
gmake init-po
```

This will create a file *`progname`*`.pot`. (`.pot` to distinguish it from PO files that are "in production". The `T` stands for "template".) Copy this file to *`language`*`.po` and edit it. To make it known that the new language is available, also edit the file `nls.mk` and add the language (or language and country) code to the line that looks like:

```
AVAIL_LANGUAGES := de fr
```

(Other languages may appear, of course.)

1. http://lcweb.loc.gov/standards/iso639-2/englangn.html
2. http://www.din.de/gremien/nas/nabd/iso3166ma/codlstp1/en_listp1.html

As the underlying program or library changes, messages may be changed or added by the programmers. In this case you do not need to start from scratch. Instead, run the command

```
gmake update-po
```

which will create a new blank message catalog file (the pot file you started with) and will merge it with the existing PO files. If the merge algorithm is not sure about a particular message it marks it "fuzzy" as explained above. For the case where something went really wrong, the old PO file is saved with a `.po.old` extension.

10.1.4. Editing the PO files

The PO files can be edited with a regular text editor. The translator should only change the area between the quotes after the msgstr directive, may add comments and alter the fuzzy flag. There is (unsurprisingly) a PO mode for Emacs, which I find quite useful.

The PO files need not be completely filled in. The software will automatically fall back to the original string if no translation (or an empty translation) is available. It is no problem to submit incomplete translations for inclusions in the source tree; that gives room for other people to pick up your work. However, you are encouraged to give priority to removing fuzzy entries after doing a merge. Remember that fuzzy entries will not be installed; they only serve as reference what might be the right translation.

Here are some things to keep in mind while editing the translations:

- Make sure that if the original ends with a newline, the translation does, too. Similarly for tabs, etc.
- If the original is a printf format string, the translation also needs to be. The translation also needs to have the same format specifiers in the same order. Sometimes the natural rules of the language make this impossible or at least awkward. In this case you can use this format:

  ```
  msgstr "Die Datei %2$s hat %1$u Zeichen."
  ```

  Then the first placeholder will actually use the second argument from the list. The *`digits`*`$` needs to follow the % and come before any other format manipulators. (This feature really exists in the `printf` family of functions. You may not have heard of it because there is little use for it outside of message internationalization.)
- If the original string contains a linguistic mistake, report that (or fix it yourself in the program source) and translate normally. The corrected string can be merged in when the program sources have been updated. If the original string contains a factual mistake, report that (or fix it yourself) and do not translate it. Instead, you may mark the string with a comment in the PO file.
- Maintain the style and tone of the original string. Specifically, messages that are not sentences (`cannot open file %s`) should probably not start with a capital letter (if your language distinguishes letter case) or end with a period (if your language uses punctuation marks).
- If you don't know what a message means, or if it is ambiguous, ask on the developers' mailing list. Chances are that English speaking end users might also not understand it or find it ambiguous, so it's best to improve the message.

10.2. For the Programmer

This section describes how to support native language support in a program or library that is part of the PostgreSQL distribution. Currently, it only applies to C programs.

Adding NLS support to a program

1. Insert this code into the start-up sequence of the program:

```
#ifdef ENABLE_NLS
#include <locale.h>
#endif

...

#ifdef ENABLE_NLS
setlocale(LC_ALL, "");
bindtextdomain("progname", LOCALEDIR);
textdomain("progname");
#endif
```

   (The *progname* can actually be chosen freely.)

2. Wherever a message that is a candidate for translation is found, a call to `gettext()` needs to be inserted. E.g.,

```
fprintf(stderr, "panic level %d\n", lvl);
```

   would be changed to

```
fprintf(stderr, gettext("panic level %d\n"), lvl);
```

   (`gettext` is defined as a no-op if no NLS is configured.)

   This may tend to add a lot of clutter. One common shortcut is to

```
#define _(x) gettext((x))
```

   Another solution is feasible if the program does much of its communication through one or a few functions, such as `elog()` in the backend. Then you make this function call `gettext` internally on all input values.

3. Add a file `nls.mk` in the directory with the program sources. This file will be read as a makefile. The following variable assignments need to be made here:

CATALOG_NAME

The program name, as provided in the `textdomain()` call.

AVAIL_LANGUAGES

List of provided translations -- empty in the beginning.

GETTEXT_FILES

List of files that contain translatable strings, i.e., those marked with `gettext` or an alternative solution. Eventually, this will include nearly all source files of the program. If this list gets too long you can make the first “file” be a + and the second word be a file that contains one file name per line.

GETTEXT_TRIGGERS

> The tools that generate message catalogs for the translators to work on need to know what function calls contain translatable strings. By default, only `gettext()` calls are known. If you used _ or other identifiers you need to list them here. If the translatable string is not the first argument, the item needs to be of the form `func:2` (for the second argument).

The build system will automatically take care of building and installing the message catalogs.

To ease the translation of messages, here are some guidelines:

- Do not construct sentences at run-time out of laziness, like

  ```
  printf("Files where %s.\n", flag ? "copied" : "removed");
  ```

  The word order within the sentence may be different in other languages.

- For similar reasons, this won't work:

  ```
  printf("copied %d file%s", n, n!=1 ? "s" : "");
  ```

  because it assumes how the plural is formed. If you figured you could solve it like this

  ```
  if (n==1)
      printf("copied 1 file");
  else
      printf("copied %d files", n):
  ```

  then be disappointed. Some languages have more than two forms, with some peculiar rules. We may have a solution for this in the future, but for now this is best avoided altogether. You could write:

  ```
  printf("number of copied files: %d", n);
  ```

- If you want to communicate something to the translator, such as about how a message is intended to line up with other output, precede the occurrence of the string with a comment that starts with `translator`, e.g.,

  ```
  /* translator: This message is not what it seems to be. */
  ```

  These comments are copied to the message catalog files so that the translators can see them.

Appendix A. The CVS Repository

The PostgreSQL source code is stored and managed using the CVS code management system.

At least two methods, anonymous CVS and CVSup, are available to pull the CVS code tree from the PostgreSQL server to your local machine.

A.1. Getting The Source Via Anonymous CVS

If you would like to keep up with the current sources on a regular basis, you can fetch them from our CVS server and then use CVS to retrieve updates from time to time.

Anonymous CVS

1. You will need a local copy of CVS (Concurrent Version Control System), which you can get from http://www.cyclic.com/ or any GNU software archive site. We currently recommend version 1.10 (the most recent at the time of writing). Many systems have a recent version of cvs installed by default.

2. Do an initial login to the CVS server:

   ```
   $ cvs -d :pserver:anoncvs@anoncvs.postgresql.org:/projects/cvsroot login
   ```

   You will be prompted for a password; just press `ENTER`. You should only need to do this once, since the password will be saved in `.cvspass` in your home directory.

3. Fetch the PostgreSQL sources:

   ```
   cvs -z3 -d :pserver:anoncvs@anoncvs.postgresql.org:/projects/cvsroot co -P pgsql
   ```

   which installs the PostgreSQL sources into a subdirectory `pgsql` of the directory you are currently in.

   Note: If you have a fast link to the Internet, you may not need `-z3`, which instructs CVS to use gzip compression for transferred data. But on a modem-speed link, it's a very substantial win.

   This initial checkout is a little slower than simply downloading a `tar.gz` file; expect it to take 40 minutes or so if you have a 28.8K modem. The advantage of CVS doesn't show up until you want to update the file set later on.

4. Whenever you want to update to the latest CVS sources, `cd` into the `pgsql` subdirectory, and issue

   ```
   $ cvs -z3 update -d -P
   ```

   This will fetch only the changes since the last time you updated. You can update in just a couple of minutes, typically, even over a modem-speed line.

5. You can save yourself some typing by making a file `.cvsrc` in your home directory that contains

   ```
   cvs -z3
   ```

```
update -d -P
```

This supplies the `-z3` option to all cvs commands, and the `-d` and `-P` options to cvs update. Then you just have to say

```
$ cvs update
```

to update your files.

> **Caution**
>
> Some older versions of CVS have a bug that causes all checked-out files to be stored world-writable in your directory. If you see that this has happened, you can do something like
>
> ```
> $ chmod -R go-w pgsql
> ```
>
> to set the permissions properly. This bug is fixed as of CVS version 1.9.28.

CVS can do a lot of other things, such as fetching prior revisions of the PostgreSQL sources rather than the latest development version. For more info consult the manual that comes with CVS, or see the online documentation at http://www.cyclic.com/.

A.2. CVS Tree Organization

Author: Written by Marc G. Fournier (<scrappy@hub.org>) on 1998-11-05

The command `cvs checkout` has a flag, `-r`, that lets you check out a certain revision of a module. This flag makes it easy to, for example, retrieve the sources that make up release 6_4 of the module 'tc' at any time in the future:

```
$ cvs checkout -r REL6_4 tc
```

This is useful, for instance, if someone claims that there is a bug in that release, but you cannot find the bug in the current working copy.

Tip: You can also check out a module as it was at any given date using the `-D` option.

When you tag more than one file with the same tag you can think about the tag as "a curve drawn through a matrix of filename vs. revision number". Say we have 5 files with the following revisions:

```
file1   file2   file3   file4   file5

1.1     1.1     1.1     1.1  /--1.1*      <-*-  TAG
```

```
1.2*-   1.2     1.2    -1.2*-
1.3  \- 1.3*-   1.3   / 1.3
1.4          \  1.4  /  1.4
              \-1.5*-   1.5
                1.6
```

then the tag `TAG` will reference file1-1.2, file2-1.3, etc.

> **Note:** For creating a release branch, other then a -b option added to the command, it's the same thing.

So, to create the 6.4 release I did the following:

```
$ cd pgsql
$ cvs tag -b REL6_4
```

which will create the tag and the branch for the RELEASE tree.

For those with CVS access, it's simple to create directories for different versions. First, create two subdirectories, RELEASE and CURRENT, so that you don't mix up the two. Then do:

```
cd RELEASE
cvs checkout -P -r REL6_4 pgsql
cd ../CURRENT
cvs checkout -P pgsql
```

which results in two directory trees, `RELEASE/pgsql` and `CURRENT/pgsql`. From that point on, CVS will keep track of which repository branch is in which directory tree, and will allow independent updates of either tree.

If you are *only* working on the `CURRENT` source tree, you just do everything as before we started tagging release branches.

After you've done the initial checkout on a branch

```
$ cvs checkout -r REL6_4
```

anything you do within that directory structure is restricted to that branch. If you apply a patch to that directory structure and do a

```
cvs commit
```

while inside of it, the patch is applied to the branch and *only* the branch.

A.3. Getting The Source Via CVSup

An alternative to using anonymous CVS for retrieving the PostgreSQL source tree is CVSup. CVSup was developed by John Polstra (<jdp@polstra.com>) to distribute CVS repositories and other file trees for the FreeBSD project[3].

A major advantage to using CVSup is that it can reliably replicate the *entire* CVS repository on your local system, allowing fast local access to cvs operations such as `log` and `diff`. Other advantages include fast synchronization to the PostgreSQL server due to an efficient streaming transfer protocol which only sends the changes since the last update.

A.3.1. Preparing A CVSup Client System

Two directory areas are required for CVSup to do it's job: a local CVS repository (or simply a directory area if you are fetching a snapshot rather than a repository; see below) and a local CVSup bookkeeping area. These can coexist in the same directory tree.

Decide where you want to keep your local copy of the CVS repository. On one of our systems we recently set up a repository in `/home/cvs/`, but had formerly kept it under a PostgreSQL development tree in `/opt/postgres/cvs/`. If you intend to keep your repository in `/home/cvs/`, then put

```
setenv CVSROOT /home/cvs
```

in your `.cshrc` file, or a similar line in your `.bashrc` or `.profile` file, depending on your shell.

The cvs repository area must be initialized. Once `CVSROOT` is set, then this can be done with a single command:

```
$ cvs init
```

after which you should see at least a directory named `CVSROOT` when listing the `CVSROOT` directory:

```
$ ls $CVSROOT
CVSROOT/
```

A.3.2. Running a CVSup Client

Verify that cvsup is in your path; on most systems you can do this by typing

```
which cvsup
```

Then, simply run cvsup using:

```
$ cvsup -L 2 postgres.cvsup
```

where `-L 2` enables some status messages so you can monitor the progress of the update, and *`postgres.cvsup`* is the path and name you have given to your CVSup configuration file.

3. http://www.freebsd.org

Here is a CVSup configuration file modified for a specific installation, and which maintains a full local CVS repository:

```
# This file represents the standard CVSup distribution file
# for the PostgreSQL ORDBMS project
# Modified by lockhart@fourpalms.org 1997-08-28
# - Point to my local snapshot source tree
# - Pull the full CVS repository, not just the latest snapshot
#
# Defaults that apply to all the collections
*default host=cvsup.postgresql.org
*default compress
*default release=cvs
*default delete use-rel-suffix
# enable the following line to get the latest snapshot
#*default tag=.
# enable the following line to get whatever was specified above or by default
# at the date specified below
#*default date=97.08.29.00.00.00

# base directory where CVSup will store its 'bookmarks' file(s)
# will create subdirectory sup/
#*default base=/opt/postgres # /usr/local/pgsql
*default base=/home/cvs

# prefix directory where CVSup will store the actual distribution(s)
*default prefix=/home/cvs

# complete distribution, including all below
pgsql

# individual distributions vs 'the whole thing'
# pgsql-doc
# pgsql-perl5
# pgsql-src
```

The following is a suggested CVSup config file from the PostgreSQL ftp site[4] which will fetch the current snapshot only:

```
# This file represents the standard CVSup distribution file
# for the PostgreSQL ORDBMS project
#
# Defaults that apply to all the collections
*default host=cvsup.postgresql.org
*default compress
*default release=cvs
*default delete use-rel-suffix
*default tag=.

# base directory where CVSup will store its 'bookmarks' file(s)
*default base=/usr/local/pgsql
```

4. ftp://ftp.postgresql.org/pub/CVSup/README.cvsup

```
# prefix directory where CVSup will store the actual distribution(s)
*default prefix=/usr/local/pgsql

# complete distribution, including all below
pgsql

# individual distributions vs 'the whole thing'
# pgsql-doc
# pgsql-perl5
# pgsql-src
```

A.3.3. Installing CVSup

CVSup is available as source, pre-built binaries, or Linux RPMs. It is far easier to use a binary than to build from source, primarily because the very capable, but voluminous, Modula-3 compiler is required for the build.

CVSup Installation from Binaries

You can use pre-built binaries if you have a platform for which binaries are posted on the PostgreSQL ftp site[5], or if you are running FreeBSD, for which CVSup is available as a port.

> **Note:** CVSup was originally developed as a tool for distributing the FreeBSD source tree. It is available as a "port", and for those running FreeBSD, if this is not sufficient to tell how to obtain and install it then please contribute a procedure here.

At the time of writing, binaries are available for Alpha/Tru64, ix86/xBSD, HPPA/HP-UX 10.20, MIPS/IRIX, ix86/linux-libc5, ix86/linux-glibc, Sparc/Solaris, and Sparc/SunOS.

1. Retrieve the binary tar file for cvsup (cvsupd is not required to be a client) appropriate for your platform.

    a. If you are running FreeBSD, install the CVSup port.

    b. If you have another platform, check for and download the appropriate binary from the PostgreSQL ftp site[6].

2. Check the tar file to verify the contents and directory structure, if any. For the linux tar file at least, the static binary and man page is included without any directory packaging.

    a. If the binary is in the top level of the tar file, then simply unpack the tar file into your target directory:

    ```
    $ cd /usr/local/bin
    $ tar zxvf /usr/local/src/cvsup-16.0-linux-i386.tar.gz
    $ mv cvsup.1 ../doc/man/man1/
    ```

5. ftp://ftp.postgresql.org/pub
6. ftp://ftp.postgresql.org/pub

b. If there is a directory structure in the tar file, then unpack the tar file within /usr/local/src and move the binaries into the appropriate location as above.

3. Ensure that the new binaries are in your path.

```
$ rehash
$ which cvsup
$ set path=(path to cvsup $path)
$ which cvsup
/usr/local/bin/cvsup
```

A.3.4. Installation from Sources

Installing CVSup from sources is not entirely trivial, primarily because most systems will need to install a Modula-3 compiler first. This compiler is available as Linux RPM, FreeBSD package, or source code.

> **Note:** A clean-source installation of Modula-3 takes roughly 200MB of disk space, which shrinks to roughly 50MB of space when the sources are removed.

Linux installation

1. Install Modula-3.

   a. Pick up the Modula-3 distribution from Polytechnique Montréal[7], who are actively maintaining the code base originally developed by the DEC Systems Research Center[8]. The PM3 RPM distribution is roughly 30MB compressed. At the time of writing, the 1.1.10-1 release installed cleanly on RH-5.2, whereas the 1.1.11-1 release is apparently built for another release (RH-6.0?) and does not run on RH-5.2.

   > **Tip:** This particular rpm packaging has *many* RPM files, so you will likely want to place them into a separate directory.

   b. Install the Modula-3 rpms:

```
# rpm -Uvh pm3*.rpm
```

2. Unpack the cvsup distribution:

```
# cd /usr/local/src
# tar zxf cvsup-16.0.tar.gz
```

7. http://m3.polymtl.ca/m3
8. http://www.research.digital.com/SRC/modula-3/html/home.html

3. Build the cvsup distribution, suppressing the GUI interface feature to avoid requiring X11 libraries:

```
# make M3FLAGS="-DNOGUI"
```

and if you want to build a static binary to move to systems that may not have Modula-3 installed, try:

```
# make M3FLAGS="-DNOGUI -DSTATIC"
```

4. Install the built binary:

```
# make M3FLAGS="-DNOGUI -DSTATIC" install
```

Appendix B. Documentation

PostgreSQL has four primary documentation formats:

- Plain text, for pre-installation information
- HTML, for on-line browsing and reference
- Postscript, for printing
- man pages, for quick reference.

Additionally, a number of plain-text README-type files can be found throughout the PostgreSQL source tree, documenting various implementation issues.

The documentation is organized into several "books":

- *Tutorial*: introduction for new users
- *User's Guide*: documents the SQL implementation
- *Reference Manual*: reference pages for programs and SQL commands
- *Administrator's Guide*: installation and server maintenance
- *Programmer's Guide*: programming client applications and server extensions
- *Developer's Guide*: assorted information for developers of PostgreSQL proper

All books are available as HTML and Postscript. The *Reference Manual* contains reference entries which are also shipped as man pages.

HTML documentation and man pages are part of a standard distribution and are installed by default. Postscript format documentation is available separately for download.

B.1. DocBook

The documentation sources are written in *DocBook*, which is a markup language superficially similar to HTML. Both of these languages are applications of the *Standard Generalized Markup Language*, SGML, which is essentially a language for describing other languages. In what follows, the terms DocBook and SGML are both used, but technically they are not interchangeable.

DocBook allows an author to specify the structure and content of a technical document without worrying about presentation details. A document style defines how that content is rendered into one of several final forms. DocBook is maintained by the OASIS[1] group. The official DocBook site[2] has good introductory and reference documentation and a complete O'Reilly book for your online reading pleasure. The FreeBSD Documentation Project[3] also uses DocBook and has some good information, including a number of style guidelines that might be worth considering.

1. http://www.oasis-open.org
2. http://www.oasis-open.org/docbook
3. http://www.freebsd.org/docproj/docproj.html

B.2. Tool Sets

The following tools are used to process the documentation. Some may be optional, as noted.

DocBook DTD[4]

This is the definition of DocBook itself. We currently use version 3.1; you cannot use later or earlier versions. Note that there is also an XML version of DocBook -- do not use that.

ISO 8879 character entities[5]

These are required by DocBook but are distributed separately because they are maintained by ISO.

OpenJade[6]

This is the base package of SGML processing. It contains an SGML parser, a DSSSL processor (that is, a program to convert SGML to other formats using DSSSL stylesheets), as well as a number of related tools. Jade is now being maintained by the OpenJade group, no longer by James Clark.

DocBook DSSSL Stylesheets[7]

These contain the processing instructions for converting the DocBook sources to other formats, such as HTML.

DocBook2X tools[8]

This optional package is used to create man pages. It has a number of prerequisite packages of its own. Check the web site.

JadeTeX[9]

If you want to, you can also install JadeTeX to use TeX as a formatting backend for Jade. JadeTeX can create Postscript or PDF files (the latter with bookmarks).

However, the output from JadeTeX is inferior to what you get from the RTF backend. Particular problem areas are tables and various artifacts of vertical and horizontal spacing. Also, there is no opportunity to manually polish the results.

We have documented experience with several installation methods for the various tools that are needed to process the documentation. These will be described below. There may be some other packaged distributions for these tools. Please report package status to the docs mailing list and we will include that information here.

B.2.1. Linux RPM Installation

Many vendors provide a complete RPM set for DocBook processing in their distribution, which is usually based on the docbook-tools[10] effort at Red Hat Software. Look for an “SGML” option while installing, or the following packages: `sgml-common`, `docbook`, `stylesheets`, `openjade` (or `jade`).

4. http://www.oasis-open.org/docbook/sgml/
5. http://www.oasis-open.org/cover/ISOEnts.zip
6. http://openjade.sourceforge.net
7. http://docbook.sourceforge.net/projects/dsssl/index.html
8. http://docbook2x.sourceforge.net
9. http://jadetex.sourceforge.net
10. http://sources.redhat.com/docbook-tools/

Possibly `sgml-tools` will be needed as well. If your distributor does not provide these then you should be able to make use of the packages from some other, reasonably compatible vendor.

B.2.2. FreeBSD Installation

The FreeBSD Documentation Project is itself a heavy user of DocBook, so it comes as no surprise that there is a full set of "ports" of the documentation tools available on FreeBSD. The following ports need to be installed to build the documentation on FreeBSD.

- `textproc/sp`
- `textproc/openjade`
- `textproc/docbook-310`
- `textproc/iso8879`
- `textproc/dsssl-docbook-modular`

A number of things from `/usr/ports/print` (`tex`, `jadetex`) might also be of interest.

It's possible that the ports do not update the main catalog file in `/usr/local/share/sgml/catalog`. Be sure to have the following line in there:

```
CATALOG "/usr/local/share/sgml/docbook/3.1/catalog"
```

If you do not want to edit the file you can also set the environment variable `SGML_CATALOG_FILES` to a colon-separated list of catalog files (such as the one above).

More information about the FreeBSD documentation tools can be found in the FreeBSD Documentation Project's instructions[11].

B.2.3. Debian Packages

There is a full set of packages of the documentation tools available for Debian GNU/Linux. To install, simply use:

```
apt-get install jade
apt-get install docbook
apt-get install docbook-stylesheets
```

B.2.4. Manual Installation from Source

The manual installation process of the DocBook tools is somewhat complex, so if you have prebuilt packages available, use them. We describe here only a standard setup, with reasonably standard installation paths, and no "fancy" features. For details, you should study the documentation of the respective package, and read SGML introductory material.

11. http://www.freebsd.org/doc/en_US.ISO8859-1/books/fdp-primer/tools.html

B.2.4.1. Installing OpenJade

1. The installation of OpenJade offers a GNU-style `./configure; make; make install` build process. Details can be found in the OpenJade source distribution. In a nutshell:

   ```
   ./configure --enable-default-catalog=/usr/local/share/sgml/catalog
   make
   make install
   ```

   Be sure to remember where you put the "default catalog"; you will need it below. You can also leave it off, but then you will have to set the environment variable `SGML_CATALOG_FILES` to point to the file whenever you use jade later on. (This method is also an option if OpenJade is already installed and you want to install the rest of the toolchain locally.)

2. Additionally, you should install the files `dsssl.dtd`, `fot.dtd`, `style-sheet.dtd`, and `catalog` from the `dsssl` directory somewhere, perhaps into `/usr/local/share/sgml/dsssl`. It's probably easiest to copy the entire directory:

   ```
   cp -R dsssl /usr/local/share/sgml
   ```

3. Finally, create the file `/usr/local/share/sgml/catalog` and add this line to it:

   ```
   CATALOG "dsssl/catalog"
   ```

   (This is a relative path reference to the file installed in step 2. Be sure to adjust it if you chose your installation layout differently.)

B.2.4.2. Installing the DocBook DTD Kit

1. Obtain the DocBook V3.1[12] distribution.
2. Create the directory `/usr/local/share/sgml/docbook31` and change to it. (The exact location is irrelevant, but this one is reasonable within the layout we are following here.)

   ```
   $ mkdir /usr/local/share/sgml/docbook31
   $ cd /usr/local/share/sgml/docbook31
   ```

3. Unpack the archive.

   ```
   $ unzip -a ...../docbk31.zip
   ```

   (The archive will unpack its files into the current directory.)

4. Edit the file `/usr/local/share/sgml/catalog` (or whatever you told jade during installation) and put a line like this into it:

   ```
   CATALOG "docbook31/docbook.cat"
   ```

5. Optionally, you can edit the file `docbook.cat` and comment out or remove the line containing `DTDDECL`. If you do not then you will get warnings from jade, but there is no further harm.
6. Download the ISO 8879 character entities[13] archive, unpack it, and put the files in the same directory you put the DocBook files in.

   ```
   $ cd /usr/local/share/sgml/docbook31
   ```

12. http://www.oasis-open.org/docbook/sgml/3.1/docbk31.zip
13. http://www.oasis-open.org/cover/ISOEnts.zip

```
$ unzip ...../ISOEnts.zip
```

7. Run the following command in the directory with the DocBook and ISO files:

   ```
   perl -pi -e 's/iso-(.*).gml/ISO\1/g' docbook.cat
   ```

   (This fixes a mixup between the names used in the DocBook catalog file and the actual names of the ISO character entity files.)

B.2.4.3. Installing the DocBook DSSSL Style Sheets

To install the style sheets, unzip and untar the distribution and move it to a suitable place, for example `/usr/local/share/sgml`. (The archive will automatically create a subdirectory.)

```
$ gunzip docbook-dsssl-1.xx.tar.gz
$ tar -C /usr/local/share/sgml -xf docbook-dsssl-1.xx.tar
```

The usual catalog entry in `/usr/local/share/sgml/catalog` can also be made:

```
CATALOG "docbook-dsssl--1.xx/catalog
```

Because stylesheets change rather often, and it's sometimes beneficial to try out alternative versions, PostgreSQL doesn't use this catalog entry. See Section B.3 for information about how to select the stylesheets instead.

B.2.4.4. Installing JadeTeX

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. All of these can be found on your friendly neighborhood CTAN[14] site. The installation of the TeX base system is far beyond the scope of this introduction. Binary packages should be available for any system that can run TeX.

Before you can use JadeTeX with the PostgreSQL documentation sources, you will need to increase the size of TeX's internal data structures. Details on this can be found in the JadeTeX installation instructions.

Once that is finished you can install JadeTeX:

```
$ gunzip jadetex-xxx.tar.gz
$ tar xf jadetex-xxx.tar
$ cd jadetex
$ make install
$ mktexlsr
```

The last two need to be done as root.

14. http://www.ctan.org

B.3. Building The Documentation

Before you can build the documentation you need to run the `configure` script as you would when building the programs themselves. Check the output near the end of the run, it should look something like this:

```
    checking for onsgmls... onsgmls
checking for openjade... openjade
checking for DocBook V3.1... yes
checking for DocBook stylesheets... /usr/lib/sgml/stylesheets/nwalsh-modular
checking for sgmlspl... sgmlspl
```

If neither `onsgmls` nor `nsgmls` were found then you will not see the remaining 4 lines. `nsgmls` is part of the Jade package. If "DocBook V3.1" was not found then you did not install the DocBook DTD kit in a place where jade can find it, or you have not set up the catalog files correctly. See the installation hints above. The DocBook stylesheets are looked for in a number of relatively standard places, but if you have them some other place then you should set the environment variable `DOCBOOKSTYLE` to the location and rerun `configure` afterwards.

Once you have everything set up, change to the directory `doc/src/sgml` and run one of the following commands: (Remember to use GNU make.)

- To build the HTML version of the *Administrator's Guide*:

  ```
  doc/src/sgml$ gmake admin.html
  ```

- For the RTF version of the same:

  ```
  doc/src/sgml$ gmake admin.rtf
  ```

- To get a DVI version via JadeTeX:

  ```
  doc/src/sgml$ gmake admin.dvi
  ```

- And Postscript from the DVI:

  ```
  doc/src/sgml$ gmake admin.ps
  ```

  Note: The official Postscript format documentation is generated differently. See Section B.3.3 below.

The other books can be built with analogous commands by replacing `admin` with one of `developer`, `programmer`, `tutorial`, or `user`. Using `postgres` builds an integrated version of all 5 books, which is practical since the browser interface makes it easy to move around all of the documentation by just clicking.

B.3.1. HTML

When building HTML documentation in `doc/src/sgml`, some of the resulting files will possibly (or quite certainly) have conflicting names between books. Therefore the files are not in that directory in the regular distribution. Instead, the files belonging to each book are stored in a tar archive that is unpacked at installation time. To create a set of HTML documentation packages use the commands

```
cd doc/src
```

```
gmake tutorial.tar.gz
gmake user.tar.gz
gmake admin.tar.gz
gmake programmer.tar.gz
gmake postgres.tar.gz
gmake install
```

In the distribution, these archives live in the `doc` directory and are installed by default with `gmake install`.

B.3.2. Manpages

We use the docbook2man utility to convert DocBook `REFENTRY` pages to *roff output suitable for man pages. The man pages are also distributed as a tar archive, similar to the HTML version. To create the man page package, use the commands

```
cd doc/src
gmake man
```

which will result in a tar file being generated in the `doc/src` directory.

The man build leaves a lot of confusing output, and special care must be taken to produce quality results. There is still room for improvement in this area.

B.3.3. Hardcopy Generation

The hardcopy Postscript documentation is generated by converting the SGML source code to RTF, then importing into Applixware. After a little cleanup (see the following section) the output is “printed” to a postscript file.

Several areas are addressed while generating Postscript hardcopy, including RTF repair, ToC generation, and page break adjustments.

Applixware RTF Cleanup

jade, an integral part of the hardcopy procedure, omits specifying a default style for body text. In the past, this undiagnosed problem led to a long process of Table of Contents (ToC) generation. However, with great help from the Applixware folks the symptom was diagnosed and a workaround is available.

1. Generate the RTF input by typing (for example):

   ```
   % cd doc/src/sgml
   % make tutorial.rtf
   ```

2. Repair the RTF file to correctly specify all styles, in particular the default style. If the document contains `REFENTRY` sections, one must also replace formatting hints which tie a *preceding* paragraph to the current paragraph, and instead tie the current paragraph to the following one. A utility, fixrtf is available in `doc/src/sgml` to accomplish these repairs:

   ```
   % cd doc/src/sgml
   % fixrtf tutorial.rtf
   ```

   or

```
% cd doc/src/sgml
% fixrtf --refentry reference.rtf
```

The script adds `{\s0 Normal;}` as the zero-th style in the document. According to Applixware, the RTF standard would prohibit adding an implicit zero-th style, though M$Word happens to handle this case. For repairing `REFENTRY` sections, the script replaces `\keepn` tags with `\keep`.

3. Open a new document in Applixware Words and then import the RTF file.
4. Generate a new ToC using Applixware.

    a. Select the existing ToC lines, from the beginning of the first character on the first line to the last character of the last line.

    b. Build a new ToC using `Tools.BookBuilding.CreateToC`. Select the first three levels of headers for inclusion in the ToC. This will replace the existing lines imported in the RTF with a native Applixware ToC.

    c. Adjust the ToC formatting by using `Format.Style`, selecting each of the three ToC styles, and adjusting the indents for `First` and `Left`. Use the following values:

Table B-1. Indent Formatting for Table of Contents

Style	First Indent (inches)	Left Indent (inches)
`TOC-Heading 1`	`0.4`	`0.4`
`TOC-Heading 2`	`0.8`	`0.8`
`TOC-Heading 3`	`1.2`	`1.2`

5. Work through the document to:

    - Adjust page breaks.
    - Adjust table column widths.
    - Insert figures into the document. Center each figure on the page using the centering margins button on the Applixware toolbar.

    Note: Not all documents have figures. You can grep the SGML source files for the string `graphic` to identify those parts of the documentation that may have figures. A few figures are replicated in various parts of the documentation.

6. Replace the right-justified page numbers in the Examples and Figures portions of the ToC with correct values. This only takes a few minutes per document.
7. Delete the index section from the document if it is empty.
8. Regenerate and adjust the table of contents.

    a. Select the ToC field.

    b. Select `Tools->Book Building->Create Table of Contents`.

c. Unbind the ToC by selecting `Tools->Field Editing->Unprotect`.

d. Delete the first line in the ToC, which is an entry for the ToC itself.

9. Save the document as native Applixware Words format to allow easier last minute editing later.

10. "Print" the document to a file in Postscript format.

11. Compress the Postscript file using gzip. Place the compressed file into the `doc` directory.

B.3.4. Plain Text Files

Several files are distributed as plain text, for reading during the installation process. The `INSTALL` file corresponds to the chapter in the *Administrator's Guide*, with some minor changes to account for the different context. To recreate the file, change to the directory `doc/src/sgml` and enter **`gmake INSTALL`**. This will create a file `INSTALL.html` that can be saved as text with Netscape Navigator and put into the place of the existing file. Netscape seems to offer the best quality for HTML to text conversions (over lynx and w3m).

The file `HISTORY` can be created similarly, using the command **`gmake HISTORY`**. For the file `src/test/regress/README` the command is **`gmake regress_README`**.

B.4. Documentation Authoring

SGML and DocBook do not suffer from an oversupply of open-source authoring tools. The most common tool set is the Emacs/XEmacs editor with appropriate editing mode. On some systems these tools are provided in a typical full installation.

B.4.1. Emacs/PSGML

PSGML is the most common and most powerful mode for editing SGML documents. When properly configured, it will allow you to use Emacs to insert tags and check markup consistency. You could use it for HTML as well. Check the PSGML web site[15] for downloads, installation instructions, and detailed documentation.

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, either by setting `SGML_CATALOG_FILES` environment variable, or you can customize your PSGML installation (its manual tells you how).

Put the following in your `~/.emacs` environment file (adjusting the path names to be appropriate for your system):

```
; ********** for SGML mode (psgml)

(setq sgml-omittag t)
(setq sgml-shorttag t)
(setq sgml-minimize-attributes nil)
(setq sgml-always-quote-attributes t)
(setq sgml-indent-step 1)
(setq sgml-indent-data t)
(setq sgml-parent-document nil)
```

15. http://www.lysator.liu.se/projects/about_psgml.html

```
(setq sgml-default-dtd-file "./reference.ced")
(setq sgml-exposed-tags nil)
(setq sgml-catalog-files '("/usr/local/share/sgml/catalog"))
(setq sgml-ecat-files nil)

(autoload 'sgml-mode "psgml" "Major mode to edit SGML files." t )
```

and in the same file add an entry for SGML into the (existing) definition for `auto-mode-alist`:

```
(setq
  auto-mode-alist
  '(("\\.sgml$" . sgml-mode)
   ))
```

Currently, each SGML source file has the following block at the end of the file:

```
<!-- Keep this comment at the end of the file
Local variables:
mode: sgml
sgml-omittag:t
sgml-shorttag:t
sgml-minimize-attributes:nil
sgml-always-quote-attributes:t
sgml-indent-step:1
sgml-indent-data:t
sgml-parent-document:nil
sgml-default-dtd-file:"./reference.ced"
sgml-exposed-tags:nil
sgml-local-catalogs:("/usr/lib/sgml/catalog")
sgml-local-ecat-files:nil
End:
-->
```

This will set up a number of editing mode parameters even if you do not set up your `~/.emacs` file, but it is a bit unfortunate, since if you followed the installation instructions above, then the catalog path will not match your location. Hence you might need to turn off local variables:

```
(setq inhibit-local-variables t)
```

The PostgreSQL distribution includes a parsed DTD definitions file `reference.ced`. You may find that when using 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 is 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 "-//OASIS//DTD DocBook V3.1//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`. (But you need to take out that line before building the entire documentation set.)

B.4.2. Other Emacs modes

GNU Emacs ships with a different SGML mode, which is not quite as powerful as PSGML, but it's less confusing and lighter weight. Also, it offers syntax highlighting (font lock), which can be very helpful.

Norm Walsh offers a major mode specifically for DocBook[16] which also has font-lock and a number of features to reduce typing.

B.5. Style Guide

B.5.1. Reference Pages

Reference pages should follow a standard layout. This allows users to find the desired information more quickly, and it also encourages writers to document all relevant aspects of a command. Consistency is not only desired among PostgreSQL reference pages, but also with reference pages provided by the operating system and other packages. Hence the following guidelines have been developed. They are for the most part consistent with similar guidelines established by various operating systems.

Reference pages that describe executable commands should contain the following sections, in this order. Sections that do not apply may be omitted. Additional top-level sections should only be used in special circumstances; often that information belongs in the "Usage" section.

Name

This section is generated automatically. It contains the command name and a half-sentence summary of its functionality.

Synopsis

This section contains the syntax diagram of the command. The synopsis should normally not list each command-line option; that is done below. Instead, list the major components of the command line, such as where input and output files go.

Description

Several paragraphs explaining what the command does.

Options

A list describing each command-line option. If there are a lot of options, subsections may be used.

Exit Status

If the program uses 0 for success and non-zero for failure, then you don't need to document it. If there is a meaning behind the different non-zero exit codes, list them here.

Usage

Describe any sublanguage or run-time interface of the program. If the program is not interactive, this section can usually be omitted. Otherwise, this section is a catch-all for describing run-time features. Use subsections if appropriate.

16. http://nwalsh.com/emacs/docbookide/index.html

Environment

List all environment variables that the program might use. Try to be complete; even seemingly trivial variables like `SHELL` might be of interest to the user.

Files

List any files that the program might access implicitly. That is, do not list input and output files that were specified on the command line, but list configuration files, etc.

Diagnostics

Explain any unusual output that the program might create. Refrain from listing every possible error message. This is a lot of work and has little use in practice. But if, say, the error messages have a standard format that the user can parse, this would be the place to explain it.

Notes

Anything that doesn't fit elsewhere, but in particular bugs, implementation flaws, security considerations, compatibility issues.

Examples

Examples

History

If there were some major milestones in the history of the program, they might be listed here. Usually, this section can be omitted.

See Also

Cross-references, listed in the following order: other PostgreSQL command reference pages, PostgreSQL SQL command reference pages, citation of PostgreSQL manuals, other reference pages (e.g., operating system, other packages), other documentation. Items in the same group are listed alphabetically.

Reference pages describing SQL commands should contain the following sections: Name, Synopsis, Description, Parameters, Usage, Diagnostics, Notes, Examples, Compatibility, History, See Also. The Parameters section is like the Options section, but there is more freedom about which clauses of the command can be listed. The Compatibility section should explain to what extent this command conforms to the SQL standard(s), or to which other database system it is compatible. The See Also section of SQL commands should list SQL commands before cross-references to programs.

Bibliography

Selected references and readings for SQL and PostgreSQL.

Some white papers and technical reports from the original POSTGRES development team are available at the University of California, Berkeley, Computer Science Department web site[1]

SQL Reference Books

Judith Bowman, Sandra Emerson, and Marcy Darnovsky, *The Practical SQL Handbook: Using Structured Query Language*, Third Edition, Addison-Wesley, ISBN 0-201-44787-8, 1996.

C. J. Date and Hugh Darwen, *A Guide to the SQL Standard: A user's guide to the standard database language SQL*, Fourth Edition, Addison-Wesley, ISBN 0-201-96426-0, 1997.

C. J. Date, *An Introduction to Database Systems*, Volume 1, Sixth Edition, Addison-Wesley, 1994.

Ramez Elmasri and Shamkant Navathe, *Fundamentals of Database Systems*, 3rd Edition, Addison-Wesley, ISBN 0-805-31755-4, August 1999.

Jim Melton and Alan R. Simon, *Understanding the New SQL: A complete guide*, Morgan Kaufmann, ISBN 1-55860-245-3, 1993.

Jeffrey D. Ullman, *Principles of Database and Knowledge: Base Systems*, Volume 1, Computer Science Press, 1988.

PostgreSQL-Specific Documentation

Stefan Simkovics, *Enhancement of the ANSI SQL Implementation of PostgreSQL*, Department of Information Systems, Vienna University of Technology, November 29, 1998.

Discusses SQL history and syntax, and describes the addition of `INTERSECT` and `EXCEPT` constructs into PostgreSQL. Prepared as a Master's Thesis with the support of O. Univ. Prof. Dr. Georg Gottlob and Univ. Ass. Mag. Katrin Seyr at Vienna University of Technology.

A. Yu and J. Chen, The POSTGRES Group, *The Postgres95 User Manual*, University of California, Sept. 5, 1995.

Zelaine Fong, *The design and implementation of the POSTGRES query optimizer*[2], University of California, Berkeley, Computer Science Department.

1. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/
2. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/UCB-MS-zfong.pdf

Proceedings and Articles

Nels Olson, *Partial indexing in POSTGRES: research project*, University of California, UCB Engin T7.49.1993 O676, 1993.

L. Ong and J. Goh, "A Unified Framework for Version Modeling Using Production Rules in a Database System", *ERL Technical Memorandum M90/33*, University of California, April, 1990.

L. Rowe and M. Stonebraker, "The POSTGRES data model[3]", Proc. VLDB Conference, Sept. 1987.

P. Seshadri and A. Swami, "Generalized Partial Indexes[4] ", Proc. Eleventh International Conference on Data Engineering, 6-10 March 1995, IEEE Computer Society Press, Cat. No.95CH35724, 1995, p. 420-7.

M. Stonebraker and L. Rowe, "The design of POSTGRES[5]", Proc. ACM-SIGMOD Conference on Management of Data, May 1986.

M. Stonebraker, E. Hanson, and C. H. Hong, "The design of the POSTGRES rules system", Proc. IEEE Conference on Data Engineering, Feb. 1987.

M. Stonebraker, "The design of the POSTGRES storage system[6]", Proc. VLDB Conference, Sept. 1987.

M. Stonebraker, M. Hearst, and S. Potamianos, "A commentary on the POSTGRES rules system[7]", *SIGMOD Record 18(3)*, Sept. 1989.

M. Stonebraker, "The case for partial indexes[8]", *SIGMOD Record 18(4)*, Dec. 1989, p. 4-11.

M. Stonebraker, L. A. Rowe, and M. Hirohama, "The implementation of POSTGRES[9]", *Transactions on Knowledge and Data Engineering 2(1)*, IEEE, March 1990.

M. Stonebraker, A. Jhingran, J. Goh, and S. Potamianos, "On Rules, Procedures, Caching and Views in Database Systems[10]", Proc. ACM-SIGMOD Conference on Management of Data, June 1990.

3. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M87-13.pdf
4. http://simon.cs.cornell.edu/home/praveen/papers/partindex.de95.ps.Z
5. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M85-95.pdf
6. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M87-06.pdf
7. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M89-82.pdf
8. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M89-17.pdf
9. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M90-34.pdf
10. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/papers/ERL-M90-36.pdf