Pivotal™

PRODUCT DOCUMENTATION

Greenplum® Database

Version 4.3

Database Administrator Guide

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Greenplum Database DBA Guide 4.3 - Contents

Preface

This guide provides information for database administrators and database superusers responsible for administering a Greenplum Database system.

- About This Guide
- Document Conventions
- Getting Support

About This Guide

This guide explains how clients connect to a Greenplum Database system, how to configure access control and workload management, perform basic administration tasks such as defining database objects, loading and unloading data, writing queries, and managing data, and provides guidance on identifying and troubleshooting common performance issues.

This guide assumes knowledge of database management systems, database administration, and structured query language (SQL).

Because Greenplum Database is based on PostgreSQL 8.2.15, this guide assumes some familiarity with PostgreSQL. References to PostgreSQL documentation are provided for features that are similar to those in Greenplum Database.

About the Greenplum Database Documentation Set

The Greenplum Database 4.3 documentation set consists of the following guides.

Table 1 Greenplum Database documentation set

Guide Name	Description
Greenplum Database Database Administrator Guide	Every day DBA tasks such as configuring access control and workload management, writing queries, managing data, defining database objects, and performance troubleshooting.
Greenplum Database System Administrator Guide	Describes the Greenplum Database architecture and concepts such as parallel processing, and system administration tasks for Greenplum Database such as configuring the server, monitoring system activity, enabling high-availability, backing up and restoring databases, and expanding the system.
Greenplum Database Reference Guide	Reference information for Greenplum Database systems: SQL commands, system catalogs, environment variables, character set support, datatypes, the Greenplum MapReduce specification, postGIS extension, server parameters, the gp_toolkit administrative schema, and SQL 2008 support.
Greenplum Database Utility Guide	Reference information for command-line utilities, client programs, and Oracle compatibility functions.
Greenplum Database Installation Guide	Information and instructions for installing and initializing a Greenplum Database system.

Document Conventions

The following conventions are used throughout the Greenplum Database documentation to help you identify certain types of information.

- Text Conventions
- Command Syntax Conventions

Text Conventions

Table 2 Text Conventions

Text Convention	Usage	Examples
bold	Button, menu, tab, page, and field names in GUI applications	Click **Cancel** to exit the page without saving your changes.
italics	New terms where they are defined Database objects, such as schema, table, or columns names	The *master instance* is the `postgres` process that accepts client connections. Catalog information for Greenplum Database resides in the *pg_catalog* schema.
`monospace`	File names and path names Programs and executables Command names and syntax Parameter names	Edit the `postgresql.conf` file. Use `gpstart` to start Greenplum Database.

`monospace italics`	Variable information within file paths and file names
	Variable information within command syntax
		`/home/gpadmin/`*`config_file`*
		`COPY` *`tablename`* `FROM '`*`filename`*`'`

`monospace bold`	Used to call attention to a particular part of a command, parameter, or code snippet.	Change the host name, port, and database name in the JDBC connection URL: `jdbc:postgresql://`**`host:5432/mydb`**
`UPPERCASE`	Environment variables SQL commands Keyboard keys	Make sure that the Java `/bin` directory is in your `$PATH`. `SELECT * FROM` *`my_table`*`;` Press `CTRL+C` to escape.

Command Syntax Conventions

Table 3 Command Syntax Conventions

Text Convention	Usage	Examples
{ }	Within command syntax, curly braces group related command options. Do not type the curly braces.	FROM **{** '*filename*' | STDIN **}**
[ ]	Within command syntax, square brackets denote optional arguments. Do not type the brackets.	TRUNCATE **[** TABLE **]** *name*
...	Within command syntax, an ellipsis denotes repetition of a command, variable, or option. Do not type the ellipsis.	DROP TABLE *name* [, **...**]
|	Within command syntax, the pipe symbol denotes an "OR" relationship. Do not type the pipe symbol.	VACUUM [FULL **|** FREEZE]

$ *system_command*
# *root_system_command* 	
=> *gpdb_command*
=# *su_gpdb_command*
	Denotes a command prompt - do not type the prompt symbol. $ and # denote terminal command prompts. => and =# denote Greenplum Database interactive program command prompts (psql or gpssh, for example).	**$** createdb mydatabase
		# chown gpadmin -R /datadir
		=> SELECT * FROM mytable;
		=# SELECT * FROM pg_database;

Getting Support

EMC support, product, and licensing information can be obtained as follows.

Product information

For product-specific documentation, release notes, or software updates, go to the EMC Online Support site at support.emc.com.

For information about EMC products, licensing, and service, go to the EMC Powerlink website (registration required) at http://Powerlink.EMC.com.

Technical support

For technical support, go to EMC Online Support. On the Support page, you will see several options, including one for making a service request. Note that to open a service request, you must have a valid support agreement. Please contact your EMC sales representative for details about obtaining a valid support agreement or with questions about your account.

1. Introduction to Greenplum

Greenplum Database is a massively parallel processing (MPP) database server based on PostgreSQL open-source technology. MPP (also known as a *shared nothing* architecture) refers to systems with two or more processors that cooperate to carry out an operation - each processor with its own memory, operating system and disks. Greenplum uses this high-performance system architecture to distribute the load of multi-terabyte data warehouses, and can use all of a system's resources in parallel to process a query.

Greenplum Database is essentially several PostgreSQL database instances acting together as one cohesive database management system (DBMS). It is based on PostgreSQL 8.2.15, and in most cases is very similar to PostgreSQL with regard to SQL support, features, configuration options, and end-user functionality. Database users interact with Greenplum Database as they would a regular PostgreSQL DBMS.

The internals of PostgreSQL have been modified or supplemented to support the parallel structure of Greenplum Database. For example, the system catalog, query planner, optimizer, query executor, and transaction manager components have been modified and enhanced to be able to execute queries simultaneously across all of the parallel PostgreSQL database instances. The Greenplum *interconnect* (the networking layer) enables communication between the distinct PostgreSQL instances and allows the system to behave as one logical database.

Greenplum Database also includes features designed to optimize PostgreSQL for business intelligence (BI) workloads. For example, Greenplum has added parallel data loading (external tables), resource management, query optimizations, and storage enhancements, which are not found in standard PostgreSQL. Many features and optimizations developed by Greenplum make their way into the PostgreSQL community. For example, table partitioning is a feature first developed by Greenplum, and it is now in standard PostgreSQL.

2. Accessing the Database

This chapter explains the various client tools you can use to connect to Greenplum Database, and how to establish a database session. It contains the following topics:

- Establishing a Database Session
- Supported Client Applications
- Troubleshooting Connection Problems

Establishing a Database Session

Users can connect to Greenplum Database using a PostgreSQL-compatible client program, such as `psql`. Users and administrators *always* connect to Greenplum Database through the *master* - the segments cannot accept client connections.

In order to establish a connection to the Greenplum Database master, you will need to know the following connection information and configure your client program accordingly.

Table 2.1 Connection Parameters

Connection Parameter	Description	Environment Variable
Application name	The application name that is connecting to the database. The default value, held in the `application_name` connection parameter is *psql*.	`$PGAPPNAME`
Database name	The name of the database to which you want to connect. For a newly initialized system, use the `template1` database to connect for the first time.	`$PGDATABASE`
Host name	The host name of the Greenplum Database master. The default host is the local host.	`$PGHOST`

Table 2.1 Connection Parameters

Connection Parameter	Description	Environment Variable
Port	The port number that the Greenplum Database master instance is running on. The default is 5432.	`$PGPORT`
User name	The database user (role) name to connect as. This is not necessarily the same as your OS user name. Check with your Greenplum administrator if you are not sure what you database user name is. Note that every Greenplum Database system has one superuser account that is created automatically at initialization time. This account has the same name as the OS name of the user who initialized the Greenplum system (typically `gpadmin`).	`$PGUSER`

Supported Client Applications

Users can connect to Greenplum Database using various client applications:

- A number of Greenplum Database Client Applications are provided with your Greenplum installation. The `psql` client application provides an interactive command-line interface to Greenplum Database.
- pgAdmin III for Greenplum Database is an enhanced version of the popular management tool pgAdmin III. Since version 1.10.0, the pgAdmin III client available from PostgreSQL Tools includes support for Greenplum-specific features. Installation packages are available for download from the pgAdmin download site.
- Using standard Database Application Interfaces, such as ODBC and JDBC, users can create their own client applications that interface to Greenplum Database. Because Greenplum Database is based on PostgreSQL, it uses the standard PostgreSQL database drivers.
- Most Third-Party Client Tools that use standard database interfaces, such as ODBC and JDBC, can be configured to connect to Greenplum Database.

Greenplum Database Client Applications

Greenplum Database comes installed with a number of client applications located in `$GPHOME/bin` of your Greenplum Database master host installation. The following are the most commonly used client applications:

Table 2.2 Commonly used client applications

Name	Usage
`createdb`	create a new database
`createlang`	define a new procedural language
`createuser`	define a new database role
`dropdb`	remove a database
`droplang`	remove a procedural language
`dropuser`	remove a role
`psql`	PostgreSQL interactive terminal
`reindexdb`	reindex a database
`vacuumdb`	garbage-collect and analyze a database

When using these client applications, you must connect to a database through the Greenplum master instance. You will need to know the name of your target database, the host name and port number of the master, and what database user name to connect as. This information can be provided on the command-line using the options `-d`, `-h`, `-p`, and `-U` respectively. If an argument is found that does not belong to any option, it will be interpreted as the database name first.

All of these options have default values which will be used if the option is not specified. The default host is the local host. The default port number is 5432. The default user name is your OS system user name, as is the default database name. Note that OS user names and Greenplum Database user names are not necessarily the same.

If the default values are not correct, you can set the environment variables `PGDATABASE`, `PGHOST`, `PGPORT`, and `PGUSER` to the appropriate values, or use a `psql ~/.pgpass` file to contain frequently-used passwords. For information about Greenplum Database environment variables, see the *Greenplum Database Reference Guide*. For information about psql, see the *Greenplum Database Utility Guide*.

Connecting with psql

Depending on the default values used or the environment variables you have set, the following examples show how to access a database via `psql`:

```
$ psql -d gpdatabase -h master_host -p 5432 -U gpadmin
$ psql gpdatabase
$ psql
```

If a user-defined database has not yet been created, you can access the system by connecting to the `template1` database. For example:

```
$ psql template1
```

After connecting to a database, `psql` provides a prompt with the name of the database to which `psql` is currently connected, followed by the string `=>` (or `=#` if you are the database superuser). For example:

```
gpdatabase=>
```

At the prompt, you may type in SQL commands. A SQL command must end with a `;` (semicolon) in order to be sent to the server and executed. For example:

```
=> SELECT * FROM mytable;
```

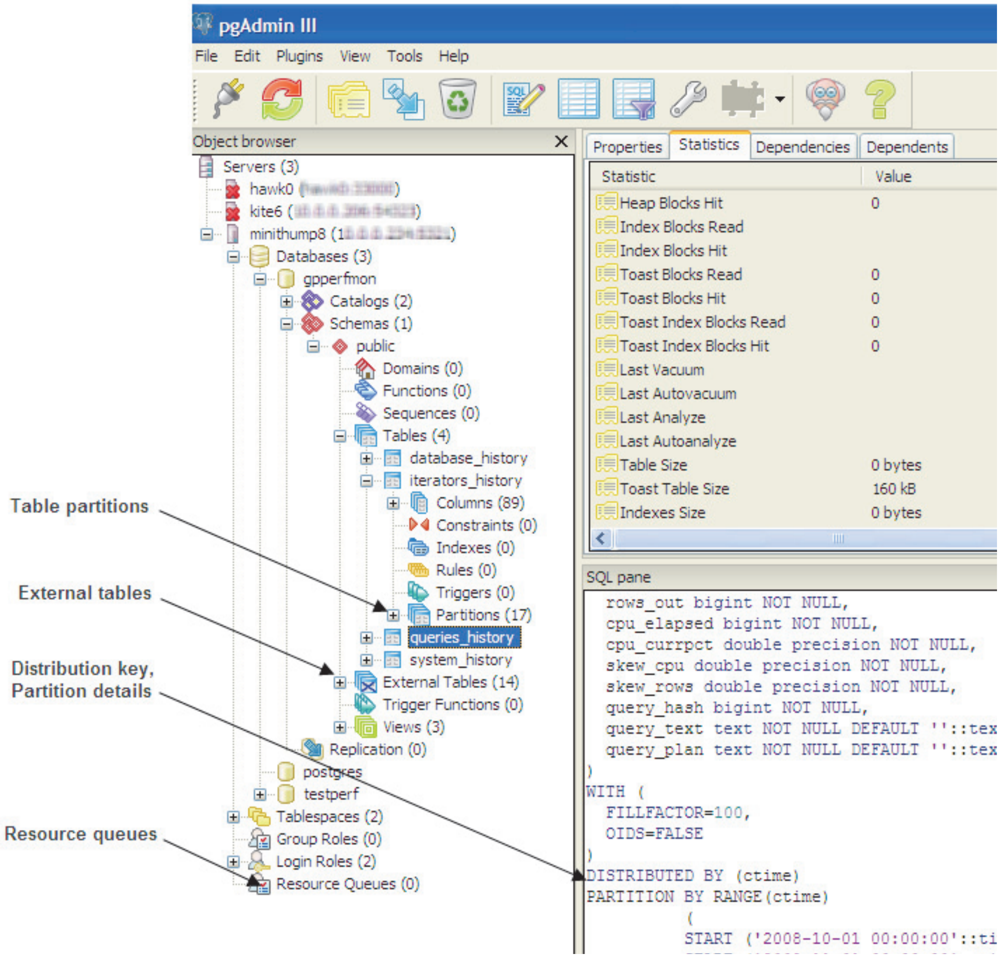
See the *Greenplum Reference Guide* for information about using the `psql` client application and SQL commands and syntax.

pgAdmin III for Greenplum Database

If you prefer a graphic interface, use pgAdmin III for Greenplum Database. This GUI client supports PostgreSQL databases with all standard pgAdmin III features, while adding support for Greenplum-specific features.

pgAdmin III for Greenplum Database supports the following Greenplum-specific features:

- External tables
- Append-optimized tables, including compressed append-optimized tables
- Table partitioning
- Resource queues
- Graphical `EXPLAIN ANALYZE`
- Greenplum server configuration parameters



Statistic	Value
Heap Blocks Hit	0
Index Blocks Read	
Index Blocks Hit	
Toast Blocks Read	0
Toast Blocks Hit	0
Toast Index Blocks Read	0
Toast Index Blocks Hit	0
Last Vacuum	
Last Autovacuum	
Last Analyze	
Last Autoanalyze	
Table Size	0 bytes
Toast Table Size	160 kB
Indexes Size	0 bytes

```
  rows_out bigint NOT NULL,
  cpu_elapsed bigint NOT NULL,
  cpu_currpct double precision NOT NULL,
  skew_cpu double precision NOT NULL,
  skew_rows double precision NOT NULL,
  query_hash bigint NOT NULL,
  query_text text NOT NULL DEFAULT ''::tex
  query_plan text NOT NULL DEFAULT ''::tex
)
WITH (
  FILLFACTOR=100,
  OIDS=FALSE
)
DISTRIBUTED BY (ctime)
PARTITION BY RANGE(ctime)
          (
          START ('2008-10-01 00:00:00'::ti
```

Figure 2.1 Greenplum Options in pgAdmin III

Installing pgAdmin III for Greenplum Database

The installation package for pgAdmin III for Greenplum Database is available for download from the official pgAdmin III download site (http://www.pgadmin.org). Installation instructions are included in the installation package.

Documentation for pgAdmin III for Greenplum Database

For general help on the features of the graphical interface, select **Help contents** from the **Help** menu.

For help with Greenplum-specific SQL support, select **Greenplum Database Help** from the **Help** menu. If you have an active internet connection, you will be directed to online Greenplum SQL reference documentation. Alternately, you can install the Greenplum Client Tools package. This package contains SQL reference documentation that is accessible to the help links in pgAdmin III.

Performing Administrative Tasks with pgAdmin III

This section highlights two of the many Greenplum Database administrative tasks you can perform with pgAdmin III: editing the server configuration, and viewing a graphical representation of a query plan.

Editing Server Configuration

The pgAdmin III interface provides two ways to update the server configuration in `postgresql.conf`: locally, through the **File** menu, and remotely on the server through the **Tools** menu. Editing the server configuration remotely may be more convenient in many cases, because it does not require you to upload or copy `postgresql.conf.`

To edit server configuration remotely

1. Connect to the server whose configuration you want to edit. If you are connected to multiple servers, make sure that the correct server is highlighted in the object browser in the left pane.
2. Select **Tools** > **Server Configuration** > **postgresql.conf**. The Backend Configuration Editor opens, displaying the list of available and enabled server configuration parameters.
3. Locate the parameter you want to edit, and double click on the entry to open the Configuration settings dialog.
4. Enter the new value for the parameter, or select/deselect **Enabled** as desired and click **OK**.
5. If the parameter can be enabled by reloading server configuration, click the green reload icon, or select **File** > **Reload** server. Many parameters require a full restart of the server.

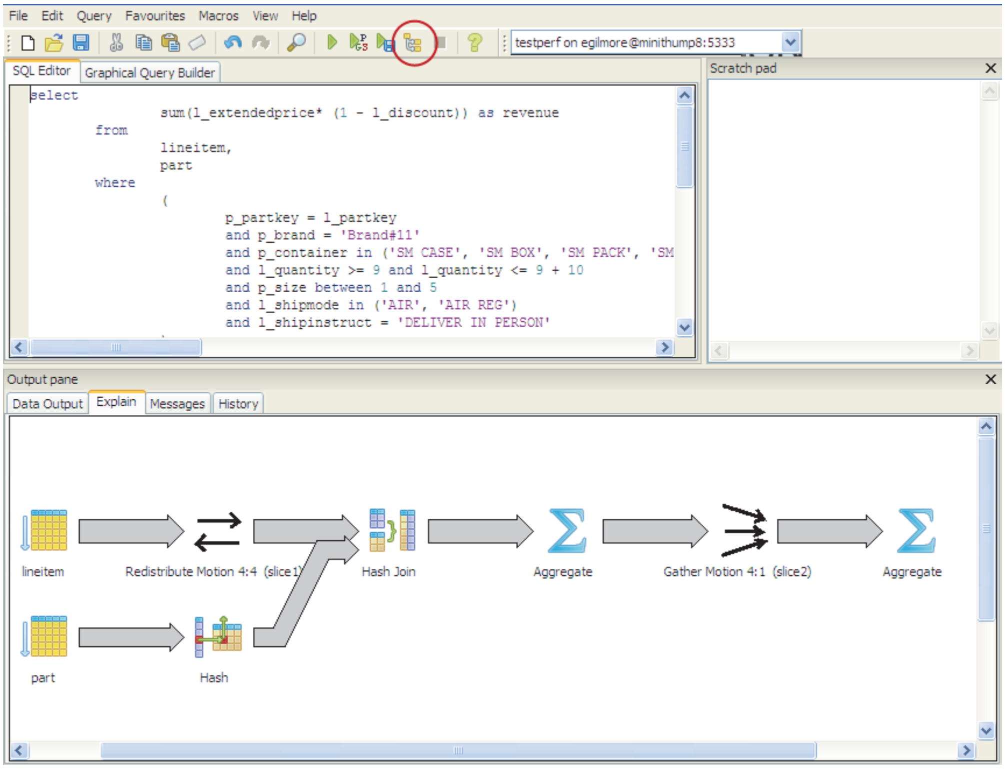
Viewing a Graphical Query Plan

Using the pgAdmin III query tool, you can run a query with EXPLAIN to view the details of the query plan. The output includes details about operations unique to Greenplum distributed query processing such as plan slices and motions between segments. You can view a graphical depiction of the plan as well as the text-based data output.

To view a graphical query plan

1. With the correct database highlighted in the object browser in the left pane, select **Tools** > **Query** tool.
2. Enter the query by typing in the SQL Editor, dragging objects into the Graphical Query Builder, or opening a file.
3. Select **Query** > **Explain** options and verify the following options:
   - Verbose — this must be deselected if you want to view a graphical depiction of the query plan
   - Analyze — select this option if you want to run the query in addition to viewing the plan
4. Trigger the operation by clicking the Explain query option at the top of the pane, or by selecting **Query** > **Explain**.

   The query plan displays in the Output pane at the bottom of the screen. Select the Explain tab to view the graphical output. For example:



```
select
                sum(l_extendedprice* (1 - l_discount)) as revenue
        from
                lineitem,
                part
        where
                (
                        p_partkey = l_partkey
                        and p_brand = 'Brand#11'
                        and p_container in ('SM CASE', 'SM BOX', 'SM PACK', 'SM
                        and l_quantity >= 9 and l_quantity <= 9 + 10
                        and p_size between 1 and 5
                        and l_shipmode in ('AIR', 'AIR REG')
                        and l_shipinstruct = 'DELIVER IN PERSON'
```

Figure 2.2 Graphical Query Plan in pgAdmin III

Database Application Interfaces

You may want to develop your own client applications that interface to Greenplum Database. PostgreSQL provides a number of database drivers for the most commonly used database application programming interfaces (APIs), which can also be used with Greenplum Database. These drivers are not packaged with the Greenplum Database base distribution. Each driver is an independent PostgreSQL development project and must be downloaded, installed and configured to connect to Greenplum Database. The following drivers are available:

Table 2.3 Greenplum Database Interfaces

API	PostgreSQL Driver	Download Link
ODBC	pgodbc	Available in the *Greenplum Database Connectivity* package, which can be downloaded from the EMC Download Center.
JDBC	pgjdbc	Available in the *Greenplum Database Connectivity* package, which can be downloaded from the EMC Download Center.
Perl DBI	pgperl	http://gborg.postgresql.org/project/pgperl
Python DBI	pygresql	http://www.pygresql.org

General instructions for accessing a Greenplum Database with an API are:

1. Download your programming language platform and respective API from the appropriate source. For example, you can get the Java development kit (JDK) and JDBC API from Sun.

2. Write your client application according to the API specifications. When programming your application, be aware of the SQL support in Greenplum Database so you do not include any unsupported SQL syntax. See the *Greenplum Database Reference Guide* for more information.

Download the appropriate PostgreSQL driver and configure connectivity to your Greenplum Database master instance. Greenplum provides a client tools package that contains the supported database drivers for Greenplum Database. Download the client tools package and documentation from the EMC Download Center.

Third-Party Client Tools

Most third-party extract-transform-load (ETL) and business intelligence (BI) tools use standard database interfaces, such as ODBC and JDBC, and can be configured to connect to Greenplum Database. Greenplum has worked with the following tools on previous customer engagements and is in the process of becoming officially certified:

- Business Objects
- Microstrategy
- Informatica Power Center
- Microsoft SQL Server Integration Services (SSIS) and Reporting Services (SSRS)
- Ascential Datastage
- SAS
- Cognos

Greenplum Professional Services can assist users in configuring their chosen third-party tool for use with Greenplum Database.

Troubleshooting Connection Problems

A number of things can prevent a client application from successfully connecting to Greenplum Database. This section explains some of the common causes of connection problems and how to correct them.

Table 2.4 Common connection problems

Problem	Solution
No `pg_hba.conf` entry for host or user	To enable Greenplum Database to accept remote client connections, you must configure your Greenplum Database master instance so that connections are allowed from the client hosts and database users that will be connecting to Greenplum Database. This is done by adding the appropriate entries to the `pg_hba.conf` configuration file (located in the master instance's data directory). For more detailed information, see "Allowing Connections to Greenplum Database" on page 15.
Greenplum Database is not running	If the Greenplum Database master instance is down, users will not be able to connect. You can verify that the Greenplum Database system is up by running the `gpstate` utility on the Greenplum master host.
Network problems Interconnect timeouts	If users connect to the Greenplum master host from a remote client, network problems can prevent a connection (for example, DNS host name resolution problems, the host system is down, and so on.). To ensure that network problems are not the cause, connect to the Greenplum master host from the remote client host. For example: `ping` *`hostname`* If the system cannot resolve the host names and IP addresses of the hosts involved in Greenplum Database, queries and connections will fail. For some operations, connections to the Greenplum Database master use `localhost` and others use the actual host name, so you must be able to resolve both. If you encounter this error, first make sure you can connect to each host in your Greenplum Database array from the master host over the network. In the `/etc/hosts` file of the master and all segments, make sure you have the correct host names and IP addresses for all hosts involved in the Greenplum Database array. The `127.0.0.1` IP must resolve to `localhost`.
Too many clients already	By default, Greenplum Database is configured to allow a maximum of 250 concurrent user connections on the master and 750 on a segment. A connection attempt that causes that limit to be exceeded will be refused. This limit is controlled by the `max_connections` parameter in the `postgresql.conf` configuration file of the Greenplum Database master. If you change this setting for the master, you must also make appropriate changes at the segments.

3. Configuring Client Authentication

When a Greenplum Database system is first initialized, the system contains one predefined *superuser* role. This role will have the same name as the operating system user who initialized the Greenplum Database system. This role is referred to as `gpadmin`. By default, the system is configured to only allow local connections to the database from the `gpadmin` role. If you want to allow any other roles to connect, or if you want to allow connections from remote hosts, you have to configure Greenplum Database to allow such connections. This chapter explains how to configure client connections and authentication to Greenplum Database.

- Allowing Connections to Greenplum Database
- Limiting Concurrent Connections

For information about enabling Kerberos authentication to control access to Greenplum Database, see “Kerberos Authentication” in the *Greenplum Database System Administrator Guide*.

Allowing Connections to Greenplum Database

Client access and authentication is controlled by the standard PostgreSQL host-based authentication file, pg_hba.conf. In Greenplum Database, the `pg_hba.conf` file of the master instance controls client access and authentication to your Greenplum system. Greenplum segments have `pg_hba.conf` files that are configured to allow only client connections from the master host and never accept client connections. Do not alter the `pg_hba.conf` file on your segments.

See The pg_hba.conf File in the PostgreSQL documentation for more information.

The general format of the `pg_hba.conf` file is a set of records, one per line. Greenplum ignores blank lines and any text after the # comment character. A record consists of a number of fields that are separated by spaces and/or tabs. Fields can contain white space if the field value is quoted. Records cannot be continued across lines. Each remote client access record has the following format:

```
host   database   role   CIDR-address   authentication-method
```

Each UNIX-domain socket access record has the following format:

```
local   database   role   authentication-method
```

The following table describes meaning of each field.

Table 3.1 pg_hba.conf Fields

Field	Description
local	Matches connection attempts using UNIX-domain sockets. Without a record of this type, UNIX-domain socket connections are disallowed.
host	Matches connection attempts made using TCP/IP. Remote TCP/IP connections will not be possible unless the server is started with an appropriate value for the listen_addresses server configuration parameter.
hostssl	Matches connection attempts made using TCP/IP, but only when the connection is made with SSL encryption. SSL must be enabled at server start time by setting the ssl configuration parameter
hostnossl	Matches connection attempts made over TCP/IP that do not use SSL.
database	Specifies which database names this record matches. The value `all` specifies that it matches all databases. Multiple database names can be supplied by separating them with commas. A separate file containing database names can be specified by preceding the file name with @.
role	Specifies which database role names this record matches. The value `all` specifies that it matches all roles. If the specified role is a group and you want all members of that group to be included, precede the role name with a +. Multiple role names can be supplied by separating them with commas. A separate file containing role names can be specified by preceding the file name with @.
CIDR-address	Specifies the client machine IP address range that this record matches. It contains an IP address in standard dotted decimal notation and a CIDR mask length. IP addresses can only be specified numerically, not as domain or host names. The mask length indicates the number of high-order bits of the client IP address that must match. Bits to the right of this must be zero in the given IP address. There must not be any white space between the IP address, the /, and the CIDR mask length. Typical examples of a CIDR-address are 172.20.143.89/32 for a single host, or 172.20.143.0/24 for a small network, or 10.6.0.0/16 for a larger one. To specify a single host, use a CIDR mask of 32 for IPv4 or 128 for IPv6. In a network address, do not omit trailing zeroes.
IP-address IP-mask	These fields can be used as an alternative to the CIDR-address notation. Instead of specifying the mask length, the actual mask is specified in a separate column. For example, 255.0.0.0 represents an IPv4 CIDR mask length of 8, and 255.255.255.255 represents a CIDR mask length of 32. These fields only apply to host, hostssl, and hostnossl records.
authentication-method	Specifies the authentication method to use when connecting. Greenplum supports the authentication methods supported by Postgre 9.0.

Editing the pg_hba.conf File

This example shows how to edit the `pg_hba.conf` file of the master to allow remote client access to all databases from all roles using encrypted password authentication.

Note: For a more secure system, consider removing all connections that use trust authentication from your master `pg_hba.conf`. Trust authentication means the role is granted access without any authentication, therefore bypassing all security. Replace trust entries with ident authentication if your system has an ident service available.

Editing pg_hba.conf

1. Open the file `$MASTER_DATA_DIRECTORY/pg_hba.conf` in a text editor.
2. Add a line to the file for each type of connection you want to allow. Records are read sequentially, so the order of the records is significant. Typically, earlier records will have tight connection match parameters and weaker authentication methods, while later records will have looser match parameters and stronger authentication methods. For example:

```
# allow the gpadmin user local access to all databases
# using ident authentication
local   all   gpadmin   ident        sameuser
host    all   gpadmin   127.0.0.1/32  ident
host    all   gpadmin   ::1/128       ident
# allow the 'dba' role access to any database from any
# host with IP address 192.168.x.x and use md5 encrypted
# passwords to authenticate the user
# Note that to use SHA-256 encryption, replace md5 with
# password in the line below
host    all   dba   192.168.0.0/32  md5
# allow all roles access to any database from any
# host and use ldap to authenticate the user. Greenplum role
# names must match the LDAP common name.
host    all   all   192.168.0.0/32  ldap ldapserver=usldap1
ldapport=1389 ldapprefix="cn="
ldapsuffix=",ou=People,dc=company,dc=com"
```

3. Save and close the file.
4. Reload the `pg_hba.conf` configuration file for your changes to take effect:

```
$ gpstop -u
```

Note: Note that you can also control database access by setting object privileges as described in "Managing Object Privileges" on page 24. The `pg_hba.conf` file just controls who can initiate a database session and how those connections are authenticated.

Limiting Concurrent Connections

To limit the number of active concurrent sessions to your Greenplum Database system, you can configure the max_connections server configuration parameter. This is a *local* parameter, meaning that you must set it in the postgresql.conf file of the master, the standby master, and each segment instance (primary and mirror). Pivotal recommends that the value of max_connections on segments be 5-10 times the value on the master.

When you set max_connections, you must also set the dependent parameter max_prepared_transactions. This value must be at least as large as the value of max_connections on the master, and segment instances should be set to the same value as the master.

For example:

In $MASTER_DATA_DIRECTORY/postgresql.conf (including standby master):

```
max_connections=100
max_prepared_transactions=100
```

In *SEGMENT_DATA_DIRECTORY*/postgresql.conf for all segment instances:

```
max_connections=500
max_prepared_transactions=100
```

The following task sets the parameter values with the Greenplum Database utility gpconfig. For information about gpconfig, see the *Greenplum Database Utility Guide*.

To change the number of allowed connections

1. Log into the Greenplum Database master host as the Greenplum Database administrator and source the file $GPHOME/greenplum_path.sh.

2. Set the value of the max_connections parameter. This gpconfig command sets the value on the segments to 100 and the value on the master to 500.

   ```
   $ gpconfig -c max_connections -v 100 -m 500
   ```

   Note: Pivotal recommends that value of max_connections on segments be 5-10 times the value on the master.

3. Set the value of the max_prepared_transactions parameter. This gpconfig command sets the value to 100 on the master and all segments.

   ```
   $ gpconfig -c max_prepared_transactions -v 100
   ```

   Note: The value of max_prepared_transactions must be greater than or equal to max_connections on the master.

4. Stop and restart your Greenplum Database system.

   ```
   $ gpstop -r
   ```

5. You can check the value of parameters on the master and segments with the gpconfig utility -s option. This gpconfig command displays the values of the max_connections parameter.

   ```
   $ gpconfig -s max_connections
   ```

Note: Raising the values of these parameters may cause Greenplum Database to request more shared memory. To mitigate this effect, consider decreasing other memory-related parameters such as `gp_cached_segworkers_threshold`.

Encrypting Client/Server Connections

Greenplum Database has native support for SSL connections between the client and the master server. SSL connections prevent third parties from snooping on the packets, and also prevent man-in-the-middle attacks. SSL should be used whenever the client connection goes through an insecure link, and must be used whenever client certificate authentication is used.

To enable SSL requires that OpenSSL be installed on both the client and the master server systems. Greenplum can be started with SSL enabled by setting the server configuration parameter `ssl=on` in the master `postgresql.conf`. When starting in SSL mode, the server will look for the files `server.key` (server private key) and `server.crt` (server certificate) in the master data directory. These files must be set up correctly before an SSL-enabled Greenplum system can start.

Important: Do not protect the private key with a passphrase. The server does not prompt for a passphrase for the private key, and the database startup fails with an error if one is required.

A self-signed certificate can be used for testing, but a certificate signed by a certificate authority (CA) should be used in production, so the client can verify the identity of the server. Either a global or local CA can be used. If all the clients are local to the organization, a local CA is recommended.

Creating a Self-signed Certificate without a Passphrase for Testing Only

To create a quick self-signed certificate for the server for testing, use the following OpenSSL command:

```
# openssl req -new -text -out server.req
```

Fill out the information that openssl asks for. Be sure to enter the local host name as *Common Name*. The challenge password can be left blank.

The program will generate a key that is passphrase protected, and does not accept a passphrase that is less than four characters long.

To use this certificate with Greenplum Database, remove the passphrase with the following commands:

```
# openssl rsa -in privkey.pem -out server.key
# rm privkey.pem
```

Enter the old passphrase when prompted to unlock the existing key.

Then, enter the following command to turn the certificate into a self-signed certificate and to copy the key and certificate to a location where the server will look for them.

```
# openssl req -x509 -in server.req -text -key server.key -out server.crt
```

Finally, change the permissions on the key with the following command. The server will reject the file if the permissions are less restrictive than these.

```
# chmod og-rwx server.key
```

For more details on how to create your server private key and certificate, refer to the OpenSSL documentation.

4. Managing Roles and Privileges

Greenplum Database manages database access permissions using the concept of *roles*. The concept of roles subsumes the concepts of *users* and *groups*. A role can be a database user, a group, or both. Roles can own database objects (for example, tables) and can assign privileges on those objects to other roles to control access to the objects. Roles can be members of other roles, thus a member role can inherit the object privileges of its parent role.

Every Greenplum Database system contains a set of database roles (users and groups). Those roles are separate from the users and groups managed by the operating system on which the server runs. However, for convenience you may want to maintain a relationship between operating system user names and Greenplum Database role names, since many of the client applications use the current operating system user name as the default.

In Greenplum Database, users log in and connect through the master instance, which then verifies their role and access privileges. The master then issues out commands to the segment instances behind the scenes as the currently logged in role.

Roles are defined at the system level, meaning they are valid for all databases in the system.

In order to bootstrap the Greenplum Database system, a freshly initialized system always contains one predefined *superuser* role (also referred to as the system user). This role will have the same name as the operating system user that initialized the Greenplum Database system. Customarily, this role is named `gpadmin`. In order to create more roles you first have to connect as this initial role.

Security Best Practices for Roles and Privileges

- **Secure the gpadmin system user.** Greenplum requires a UNIX user id to install and initialize the Greenplum Database system. This system user is referred to as `gpadmin` in the Greenplum documentation. This `gpadmin` user is the default database superuser in Greenplum Database, as well as the file system owner of the Greenplum installation and its underlying data files. This default administrator account is fundamental to the design of Greenplum Database. The system cannot run without it, and there is no way to limit the access of this gpadmin user id. Use roles to manage who has access to the database for specific purposes. You should only use the `gpadmin` account for system maintenance tasks such as expansion and upgrade. Anyone who logs on to a Greenplum host as this user id can read, alter or delete any data; including system catalog data and database access rights. Therefore, it is very important to secure the gpadmin user id and only provide access to essential system administrators. Administrators should only log in to Greenplum as `gpadmin` when performing certain system maintenance tasks (such as upgrade or expansion). Database users should never log on as `gpadmin`, and ETL or production workloads should never run as `gpadmin`.

- **Assign a distinct role to each user that logs in.** For logging and auditing purposes, each user that is allowed to log in to Greenplum Database should be given their own database role. For applications or web services, consider creating a distinct role for each application or service. See "Creating New Roles (Users)" on page 22.
- **Use groups to manage access privileges.** See "Role Membership" on page 23.
- **Limit users who have the SUPERUSER role attribute.** Roles that are superusers bypass all access privilege checks in Greenplum Database, as well as resource queuing. Only system administrators should be given superuser rights. See "Altering Role Attributes" on page 22.

Creating New Roles (Users)

A user-level role is considered to be a database role that can log in to the database and initiate a database session. Therefore, when you create a new user-level role using the `CREATE ROLE` command, you must specify the `LOGIN` privilege. For example:

```
=# CREATE ROLE jsmith WITH LOGIN;
```

A database role may have a number of attributes that define what sort of tasks that role can perform in the database. You can set these attributes when you create the role, or later using the `ALTER ROLE` command. See Table 4.1, "Role Attributes" on page 22 for a description of the role attributes you can set.

Altering Role Attributes

A database role may have a number of attributes that define what sort of tasks that role can perform in the database.

Table 4.1 Role Attributes

Attributes	Description
SUPERUSER | NOSUPERUSER	Determines if the role is a superuser. You must yourself be a superuser to create a new superuser. NOSUPERUSER is the default.
CREATEDB | NOCREATEDB	Determines if the role is allowed to create databases. NOCREATEDB is the default.
CREATEROLE | NOCREATEROLE	Determines if the role is allowed to create and manage other roles. NOCREATEROLE is the default.
INHERIT | NOINHERIT	Determines whether a role inherits the privileges of roles it is a member of. A role with the INHERIT attribute can automatically use whatever database privileges have been granted to all roles it is directly or indirectly a member of. INHERIT is the default.
LOGIN | NOLOGIN	Determines whether a role is allowed to log in. A role having the LOGIN attribute can be thought of as a user. Roles without this attribute are useful for managing database privileges (groups). NOLOGIN is the default.
CONNECTION LIMIT *connlimit*	If role can log in, this specifies how many concurrent connections the role can make. -1 (the default) means no limit.

Table 4.1 Role Attributes

Attributes	Description
PASSWORD '*password*'	Sets the role's password. If you do not plan to use password authentication you can omit this option. If no password is specified, the password will be set to null and password authentication will always fail for that user. A null password can optionally be written explicitly as PASSWORD NULL.
ENCRYPTED | UNENCRYPTED	Controls whether the password is stored encrypted in the system catalogs. The default behavior is determined by the configuration parameter `password_encryption` (currently set to **md5**, for SHA-256 encryption, change this setting to **password**). If the presented password string is already in encrypted format, then it is stored encrypted as-is, regardless of whether ENCRYPTED or UNENCRYPTED is specified (since the system cannot decrypt the specified encrypted password string). This allows reloading of encrypted passwords during dump/restore.
VALID UNTIL '*timestamp*'	Sets a date and time after which the role's password is no longer valid. If omitted the password will be valid for all time.
RESOURCE QUEUE *queue_name*	Assigns the role to the named resource queue for workload management. Any statement that role issues is then subject to the resource queue's limits. Note that the RESOURCE QUEUE attribute is not inherited; it must be set on each user-level (LOGIN) role.
DENY {deny_interval | deny_point}	Restricts access during an interval, specified by day or day and time. For more information see "Time-based Authentication" on page 28.

You can set these attributes when you create the role, or later using the `ALTER ROLE` command. For example:

```
=# ALTER ROLE jsmith WITH PASSWORD 'passwd123';
=# ALTER ROLE admin VALID UNTIL 'infinity';
=# ALTER ROLE jsmith LOGIN;
=# ALTER ROLE jsmith RESOURCE QUEUE adhoc;
=# ALTER ROLE jsmith DENY DAY 'Sunday';
```

A role can also have role-specific defaults for many of the server configuration settings. For example, to set the default schema search path for a role:

```
=# ALTER ROLE admin SET search_path TO myschema, public;
```

Role Membership

It is frequently convenient to group users together to ease management of object privileges: that way, privileges can be granted to, or revoked from, a group as a whole. In Greenplum Database this is done by creating a role that represents the group, and then granting membership in the group role to individual user roles.

Use the `CREATE ROLE` SQL command to create a new group role. For example:

```
=# CREATE ROLE admin CREATEROLE CREATEDB;
```

Once the group role exists, you can add and remove members (user roles) using the `GRANT` and `REVOKE` commands. For example:

```
=# GRANT admin TO john, sally;
=# REVOKE admin FROM bob;
```

For managing object privileges, you would then grant the appropriate permissions to the group-level role only (see Table 4.2, "Object Privileges" on page 24). The member user roles then inherit the object privileges of the group role. For example:

```
=# GRANT ALL ON TABLE mytable TO admin;
=# GRANT ALL ON SCHEMA myschema TO admin;
=# GRANT ALL ON DATABASE mydb TO admin;
```

The role attributes LOGIN, SUPERUSER, CREATEDB, and CREATEROLE are never inherited as ordinary privileges on database objects are. User members must actually SET ROLE to a specific role having one of these attributes in order to make use of the attribute. In the above example, we gave CREATEDB and CREATEROLE to the admin role. If sally is a member of admin, she could issue the following command to assume the role attributes of the parent role:

```
=> SET ROLE admin;
```

Managing Object Privileges

When an object (table, view, sequence, database, function, language, schema, or tablespace) is created, it is assigned an owner. The owner is normally the role that executed the creation statement. For most kinds of objects, the initial state is that only the owner (or a superuser) can do anything with the object. To allow other roles to use it, privileges must be granted. Greenplum Database supports the following privileges for each object type:

Table 4.2 Object Privileges

Object Type	Privileges

Tables, Views, Sequences	SELECT
	INSERT
	UPDATE
	DELETE
	RULE
	ALL

External Tables	SELECT RULE ALL
Databases	CONNECT CREATE TEMPORARY | TEMP ALL
Functions	EXECUTE
Procedural Languages	USAGE

Table 4.2 Object Privileges

Object Type	Privileges
Schemas	CREATE USAGE ALL

Custom Protocol	SELECT
	INSERT
	UPDATE
	DELETE
	RULE
	ALL

Note: Privileges must be granted for each object individually. For example, granting ALL on a database does not grant full access to the objects within that database. It only grants all of the database-level privileges (CONNECT, CREATE, TEMPORARY) to the database itself.

Use the `GRANT` SQL command to give a specified role privileges on an object. For example:

```
=# GRANT INSERT ON mytable TO jsmith;
```

To revoke privileges, use the `REVOKE` command. For example:

```
=# REVOKE ALL PRIVILEGES ON mytable FROM jsmith;
```

You can also use the `DROP OWNED` and `REASSIGN OWNED` commands for managing objects owned by deprecated roles (Note: only an object's owner or a superuser can drop an object or reassign ownership). For example:

```
=# REASSIGN OWNED BY sally TO bob;
=# DROP OWNED BY visitor;
```

Simulating Row and Column Level Access Control

Row-level or column-level access is not supported, nor is labeled security. Row-level and column-level access can be simulated using views to restrict the columns and/or rows that are selected. Row-level labels can be simulated by adding an extra column to the table to store sensitivity information, and then using views to control row-level access based on this column. Roles can then be granted access to the views rather than the base table.

Encrypting Data

PostgreSQL provides an optional package of encryption/decryption functions called `pgcrypto`, which can also be installed and used in Greenplum Database. The `pgcrypto` package is not installed by default with Greenplum Database, however you can download a `pgcrypto` package from the EMC Download Center, then use the Greenplum Package Manager (`gppkg`) to install `pgcrypto` across your entire cluster .

The `pgcrypto` functions allow database administrators to store certain columns of data in encrypted form. This adds an extra layer of protection for sensitive data, as data stored in Greenplum Database in encrypted form cannot be read by users who do not have the encryption key, nor be read directly from the disks.

It is important to note that the `pgcrypto` functions run inside database server. That means that all the data and passwords move between `pgcrypto` and the client application in clear-text. For optimal security, consider also using SSL connections between the client and the Greenplum master server.

Encrypting Passwords

In Greenplum Database versions before 4.2.1, passwords were encrypted using MD5 hashing by default. Since some customers require cryptographic algorithms that meet the Federal Information Processing Standard140-2, as of version 4.2.1, Greenplum Database features RSA's BSAFE implementation that lets customers store passwords hashed using SHA-256 encryption.
To use SHA-256 encryption, you must set a parameter either at the system or the session level. This technical note outlines how to use a server parameter to implement SHA-256 encrypted password storage. Note that in order to use SHA-256 encryption for storage, the client authentication method must be set to `password` rather than the default, `MD5`. (See "Encrypting Client/Server Connections" on page 19 for more details.) This means that the password is transmitted in clear text over the network, so we highly recommend that you set up SSL to encrypt the client server communication channel.

Enabling SHA-256 Encryption

You can set your chosen encryption method system-wide or on a per-session basis. There are three encryption methods available: `SHA-256`, `SHA-256-FIPS`, and `MD5` (for backward compatibility). The `SHA-256-FIPS` method requires that FIPS compliant libraries are used.

System-wide

To set the `password_hash_algorithm` server parameter on a complete Greenplum system (master and its segments):

1. Log into your Greenplum Database instance as a superuser.
2. Execute `gpconfig` with the `password_hash_algorithm` set to `SHA-256` (or `SHA-256-FIPS` to use the FIPS-compliant libraries for SHA-256)

   ```
   $ gpconfig -c password_hash_algorithm -v 'SHA-256'
   ```

   or:

```
$ gpconfig -c password_hash_algorithm -v 'SHA-256-FIPS'
```

3. Verify the setting:

```
$ gpconfig -s
```

You will see:

```
Master value: SHA-256
Segment value: SHA-256
```

or:

```
Master  value: SHA-256-FIPS
Segment value: SHA-256-FIPS
```

Individual Session

To set the `password_hash_algorithm` server parameter for an individual session:

1. Log into your Greenplum Database instance as a superuser.
2. Set the `password_hash_algorithm` to `SHA-256` (or `SHA-256-FIPS` to use the FIPS-compliant libraries for SHA-256):

```
# set password_hash_algorithm = 'SHA-256'
SET
```

or:

```
# set password_hash_algorithm = 'SHA-256-FIPS'
SET
```

3. Verify the setting:

```
# show password_hash_algorithm;
password_hash_algorithm
```

You will see:

```
SHA-256
```

or:

```
SHA-256-FIPS
```

Example

Following is an example of how the new setting works:

1. Login in as a super user and verify the password hash algorithm setting:

```
# show password_hash_algorithm
password_hash_algorithm
-------------------------------
SHA-256-FIPS
```

2. Create a new role with password that has login privileges.

```
create role testdb with password 'testdb12345#' LOGIN;
```

3. Change the client authentication method to allow for storage of SHA-256 encrypted passwords:

Open the `pg_hba.conf` file on the master and add the following line:

```
host all testdb 0.0.0.0/0 password
```

4. Restart the cluster.
5. Login to the database as user just created `testdb`.

   ```
   psql -U testdb
   ```

6. Enter the correct password at the prompt.
7. Verify that the password is stored as a SHA-256 hash.

   Note that password hashes are stored in `pg_authid.rolpasswod`

   a. Login as the super user.
   b. Execute the following:

      ```
      # select rolpassword from pg_authid where rolname =
      'testdb';
      Rolpassword
      -----------
      sha256<64 hexidecimal characters>
      ```

Time-based Authentication

Greenplum Database enables the administrator to restrict access to certain times by role. Use the `CREATE ROLE` or `ALTER ROLE` commands to specify time-based constraints.

For details, refer to the *Greenplum Database Security Configuration Guide*.

5. Defining Database Objects

This chapter covers data definition language (DDL) in Greenplum Database and how to create and manage database objects.

Creating and Managing Databases

A Greenplum Database system is a single instance of Greenplum Database. There can be several separate Greenplum Database systems installed, but usually just one is selected by environment variable settings. See your Greenplum administrator for details.

There can be multiple databases in a Greenplum Database system. This is different from some database management systems (such as Oracle) where the database instance *is* the database. Although you can create many databases in a Greenplum system, client programs can connect to and access only one database at a time — you cannot cross-query between databases.

About Template Databases

Each new database you create is based on a *template*. Greenplum provides a default database, `template1`. Use `template1` to connect to Greenplum Database for the first time. Greenplum Database uses `template1` to create databases unless you specify another template. Do not create any objects in `template1` unless you want those objects to be in every database you create.

Greenplum uses two other database templates, `template0` and `postgres`, internally. Do not drop or modify `template0` or `postgres`. You can use `template0` to create a completely clean database containing only the standard objects predefined by Greenplum Database at initialization, especially if you modified `template1`.

Creating a Database

The `CREATE DATABASE` command creates a new database. For example:

```
=> CREATE DATABASE new_dbname;
```

To create a database, you must have privileges to create a database or be a Greenplum superuser. If you do not have the correct privileges, you cannot create a database. Contact your Greenplum administrator to either give you the necessary privilege or to create a database for you.

You can also use the client program `createdb` to create a database. For example, running the following command in a command line terminal connects to Greenplum Database using the provided host name and port and creates a database named *mydatabase*:

```
$ createdb -h masterhost -p 5432 mydatabase
```

The host name and port must match the host name and port of the installed Greenplum Database system.

Some objects, such as roles, are shared by all the databases in a Greenplum Database system. Other objects, such as tables that you create, are known only in the database in which you create them.

Cloning a Database

By default, a new database is created by cloning the standard system database template, `template1`. Any database can be used as a template when creating a new database, thereby providing the capability to 'clone' or copy an existing database and all objects and data within that database. For example:

```
=> CREATE DATABASE new_dbname TEMPLATE old_dbname;
```

Viewing the List of Databases

If you are working in the `psql` client program, you can use the `\l` meta-command to show the list of databases and templates in your Greenplum Database system. If using another client program and you are a superuser, you can query the list of databases from the `pg_database` system catalog table. For example:

```
=> SELECT datname from pg_database;
```

Altering a Database

The `ALTER DATABASE` command changes database attributes such as owner, name, or default configuration attributes. For example, the following command alters a database by setting its default schema search path (the `search_path` configuration parameter):

```
=> ALTER DATABASE mydatabase SET search_path TO myschema,
public, pg_catalog;
```

To alter a database, you must be the owner of the database or a superuser.

Dropping a Database

The `DROP DATABASE` command drops (or deletes) a database. It removes the system catalog entries for the database and deletes the database directory on disk that contains the data. You must be the database owner or a superuser to drop a database, and you cannot drop a database while you or anyone else is connected to it. Connect to `template1` (or another database) before dropping a database. For example:

```
=> \c template1
=> DROP DATABASE mydatabase;
```

You can also use the client program `dropdb` to drop a database. For example, the following command connects to Greenplum Database using the provided host name and port and drops the database *mydatabase*:

```
$ dropdb -h masterhost -p 5432 mydatabase
```

Warning: Dropping a database cannot be undone.

Creating and Managing Tablespaces

Tablespaces allow database administrators to have multiple file systems per machine and decide how to best use physical storage to store database objects. They are named locations within a filespace in which you can create objects. Tablespaces allow you to assign different storage for frequently and infrequently used database objects or to control the I/O performance on certain database objects. For example, place frequently-used tables on file systems that use high performance solid-state drives (SSD), and place other tables on standard hard drives.

A tablespace requires a file system location to store its database files. In Greenplum Database, the master and each segment (primary and mirror) require a distinct storage location. The collection of file system locations for all components in a Greenplum system is a *filespace*. Filespaces can be used by one or more tablespaces.

Creating a Filespace

A filespace sets aside storage for your Greenplum system. A filespace is a symbolic storage identifier that maps onto a set of locations in your Greenplum hosts' file systems. To create a filespace, prepare the logical file systems on all of your Greenplum hosts, then use the `gpfilespace` utility to define the filespace. You must be a database superuser to create a filespace.

Note: Greenplum Database is not directly aware of the file system boundaries on your underlying systems. It stores files in the directories that you tell it to use. You cannot control the location on disk of individual files within a logical file system.

To create a filespace using gpfilespace

1. Log in to the Greenplum Database master as the `gpadmin` user.

   ```
   $ su - gpadmin
   ```

2. Create a filespace configuration file:

```
$ gpfilespace -o gpfilespace_config
```

3. At the prompt, enter a name for the filespace, the primary segment file system locations, the mirror segment file system locations, and a master file system location. For example, if your configuration has 2 primary and 2 mirror segments per host:

```
Enter a name for this filespace> fastdisk
primary location 1> /gpfs1/seg1
primary location 2> /gpfs1/seg2
mirror location 1> /gpfs2/mir1
mirror location 2> /gpfs2/mir2
master location> /gpfs1/master
```

4. `gpfilespace` creates a configuration file. Examine the file to verify that the `gpfilespace` configuration is correct.

5. Run `gpfilespace` again to create the filespace based on the configuration file:

```
$ gpfilespace -c gpfilespace_config
```

Moving the Location of Temporary or Transaction Files

You can move temporary or transaction files to a specific filespace to improve database performance when running queries, creating backups, and to store data more sequentially.

The dedicated filespace for temporary and transaction files is tracked in two separate flat files called `gp_temporary_files_filespace` and `gp_transaction_files_filespace`. These are located in the `pg_system` directory on each primary and mirror segment, and on master and standby. You must be a superuser to move temporary or transaction files. Only the `gpfilespace` utility can write to this file.

About Temporary and Transaction Files

Unless otherwise specified, temporary and transaction files are stored together with all user data. The default location of temporary files, `<filespace_directory>/<tablespace_oid>/<database_oid>/pgsql_tmp` is changed when you use `gpfilespace --movetempfiles` for the first time.

Also note the following information about temporary or transaction files:

- You can dedicate only one filespace for temporary or transaction files, although you can use the same filespace to store other types of files.
- You cannot drop a filespace if it used by temporary files.
- You must create the filespace in advance. See "Creating a Filespace".

To move temporary files using gpfilespace

1. Check that the filespace exists and is different from the filespace used to store all other user data.

2. Issue `smart shutdown` to bring the Greenplum Database offline.

Note: If any connections are still in progess,the `gpfilespace --movetempfiles` utility will fail.

3. Bring Greenplum Database online with no active session and run the following command:

```
gpfilespace --movetempfilespace filespace_name
```

Note: The location of the temporary files is stored in the segment configuration shared memory (`PMModuleState`) and used whenever temporary files are created, opened, or dropped.

To move transaction files using gpfilespace

1. Check that the filespace exists and is different from the filespace used to store all other user data.
2. Issue `smart shutdown` to bring the Greenplum Database offline.

Note: If any connections are still in progess,the `gpfilespace --movetransfiles` utility will fail.

3. Bring Greenplum Database online with no active session and run the following command:

```
gpfilespace --movetransfilespace filespace_name
```

Note: The location of the transaction files is stored in the segment configuration shared memory (`PMModuleState`) and used whenever transaction files are created, opened, or dropped.

Creating a Tablespace

After you create a filespace, use the `CREATE TABLESPACE` command to define a tablespace that uses that filespace. For example:

```
=# CREATE TABLESPACE fastspace FILESPACE fastdisk;
```

Database superusers define tablespaces and grant access to database users with the `GRANT CREATE` command. For example:

```
=# GRANT CREATE ON TABLESPACE fastspace TO admin;
```

Using a Tablespace to Store Database Objects

Users with the `CREATE` privilege on a tablespace can create database objects in that tablespace, such as tables, indexes, and databases. The command is:

```
CREATE TABLE tablename(options) TABLESPACE spacename
```

For example, the following command creates a table in the tablespace space1:

```
CREATE TABLE foo(i int) TABLESPACE space1;
```

You can also use the `default_tablespace` parameter to specify the default tablespace for `CREATE TABLE` and `CREATE INDEX` commands that do not specify a tablespace:

```
SET default_tablespace = space1;
CREATE TABLE foo(i int);
```

The tablespace associated with a database stores that database's system catalogs, temporary files created by server processes using that database, and is the default tablespace selected for tables and indexes created within the database, if no `TABLESPACE` is specified when the objects are created. If you do not specify a tablespace when you create a database, the database uses the same tablespace used by its template database.

You can use a tablespace from any database if you have appropriate privileges.

Viewing Existing Tablespaces and Filespaces

Every Greenplum Database system has the following default tablespaces.

- `pg_global` for shared system catalogs.
- `pg_default`, the default tablespace. Used by the *template1* and *template0* databases.

These tablespaces use the system default filespace, `pg_system`, the data directory location created at system initialization.

To see filespace information, look in the *pg_filespace* and *pg_filespace_entry* catalog tables. You can join these tables with *pg_tablespace* to see the full definition of a tablespace. For example:

```
=# SELECT spcname as tblspc, fsname as filespc,
          fsedbid as seg_dbid, fselocation as datadir
   FROM pg_tablespace pgts, pg_filespace pgfs,
        pg_filespace_entry pgfse
WHERE pgts.spcfsoid=pgfse.fsefsoid
AND pgfse.fsefsoid=pgfs.oid
ORDER BY tblspc, seg_dbid;
```

Dropping Tablespaces and Filespaces

To drop a tablespace, you must be the tablespace owner or a superuser. You cannot drop a tablespace until all objects in all databases using the tablespace are removed.

Only a superuser can drop a filespace. A filespace cannot be dropped until all tablespaces using that filespace are removed.

The `DROP TABLESPACE` command removes an empty tablespace.

The `DROP FILESPACE` command removes an empty filespace.

Note: You cannot drop a filespace if it stores temporary or transaction files.

Creating and Managing Schemas

Schemas logically organize objects and data in a database. Schemas allow you to have more than one object (such as tables) with the same name in the database without conflict if the objects are in different schemas.

The Default "Public" Schema

Every database has a default schema named *public*. If you do not create any schemas, objects are created in the *public* schema. All database roles (users) have `CREATE` and `USAGE` privileges in the *public* schema. When you create a schema, you grant privileges to your users to allow access to the schema.

Creating a Schema

Use the `CREATE SCHEMA` command to create a new schema. For example:

```
=> CREATE SCHEMA myschema;
```

To create or access objects in a schema, write a qualified name consisting of the schema name and table name separated by a period. For example:

```
myschema.table
```

See "Schema Search Paths" on page 35 for information about accessing a schema.

You can create a schema owned by someone else, for example, to restrict the activities of your users to well-defined namespaces. The syntax is:

```
=> CREATE SCHEMA schemaname AUTHORIZATION username;
```

Schema Search Paths

To specify an object's location in a database, use the schema-qualified name. For example:

```
=> SELECT * FROM myschema.mytable;
```

You can set the `search_path` configuration parameter to specify the order in which to search the available schemas for objects. The schema listed first in the search path becomes the *default* schema. If a schema is not specified, objects are created in the default schema.

Setting the Schema Search Path

The `search_path` configuration parameter sets the schema search order. The `ALTER DATABASE` command sets the search path. For example:

```
=> ALTER DATABASE mydatabase SET search_path TO myschema,
public, pg_catalog;
```

You can also set `search_path` for a particular role (user) using the `ALTER ROLE` command. For example:

```
=> ALTER ROLE sally SET search_path TO myschema, public,
pg_catalog;
```

Viewing the Current Schema

Use the `current_schema()` function to view the current schema. For example:

```
=> SELECT current_schema();
```

Use the `SHOW` command to view the current search path. For example:

```
=> SHOW search_path;
```

Dropping a Schema

Use the `DROP SCHEMA`command to drop (delete) a schema. For example:

```
=> DROP SCHEMA myschema;
```

By default, the schema must be empty before you can drop it. To drop a schema and all of its objects (tables, data, functions, and so on) use:

```
=> DROP SCHEMA myschema CASCADE;
```

System Schemas

The following system-level schemas exist in every database:

- **`pg_catalog`** contains the system catalog tables, built-in data types, functions, and operators. It is always part of the schema search path, even if it is not explicitly named in the search path.
- **`information_schema`** consists of a standardized set of views that contain information about the objects in the database. These views get system information from the system catalog tables in a standardized way.
- **`pg_toast`** stores large objects such as records that exceed the page size. This schema is used internally by the Greenplum Database system.
- **`pg_bitmapindex`** stores bitmap index objects such as lists of values. This schema is used internally by the Greenplum Database system.
- **`pg_aoseg`** stores append-optimized table objects. This schema is used internally by the Greenplum Database system.
- **`gp_toolkit`** is an administrative schema that contains external tables, views, and functions that you can access with SQL commands. All database users can access *gp_toolkit* `to` view and query the system log files and other system metrics.

Creating and Managing Tables

Greenplum Database tables are similar to tables in any relational database, except that table rows are distributed across the different segments in the system. When you create a table, you specify the table's distribution policy.

Creating a Table

The `CREATE TABLE` command creates a table and defines its structure. When you create a table, you define:

- The columns of the table and their associated data types. See "Choosing Column Data Types" on page 37.
- Any table or column constraints to limit the data that a column or table can contain. See "Setting Table and Column Constraints" on page 37.

- The distribution policy of the table, which determines how Greenplum divides data is across the segments. See "Choosing the Table Distribution Policy" on page 38.
- The way the table is stored on disk. See "Choosing the Table Storage Model" on page 39.
- The table partitioning strategy for large tables. See "Partitioning Large Tables" on page 51.

Choosing Column Data Types

The data type of a column determines the types of data values the column can contain. Choose the data type that uses the least possible space but can still accommodate your data and that best constrains the data. For example, use character data types for strings, date or timestamp data types for dates, and numeric data types for numbers.

There are no performance differences among the character data types `CHAR`, `VARCHAR`, and `TEXT` apart from the increased storage size when you use the blank-padded type. In most situations, use `TEXT` or `VARCHAR` rather than `CHAR`.

Use the smallest numeric data type that will accomodate your numeric data and allow for future expansion. For example, using `BIGINT` for data that fits in `INT` or `SMALLINT` wastes storage space. If you expect that your data values will expand over time, consider that changing from a smaller datatype to a larger datatype after loading large amounts of data is costly. For example, if your current data values fit in a `SMALLINT` but it is likely that the values will expand, `INT` is the better long-term choice.

Use the same data types for columns that you plan to use in cross-table joins. Cross-table joins usually use the primary key in one table and a foreign key in the other table. When the data types are different, the database must convert one of them so that the data values can be compared correctly, which adds unnecessary overhead.

Greenplum Database has a rich set of native data types available to users. See the *Greenplum Database Reference Guide* for information about the built-in data types.

Setting Table and Column Constraints

You can define constraints on columns and tables to restrict the data in your tables. Greenplum Database support for constraints is the same as PostgreSQL with some limitations, including:

- `CHECK` constraints can refer only to the table on which they are defined.
- `UNIQUE` and `PRIMARY KEY` constraints must be compatible with their table's distribution key and partitioning key, if any.
- `FOREIGN KEY` constraints are allowed, but not enforced.
- Constraints that you define on partitioned tables apply to the partitioned table as a whole. You cannot define constraints on the individual parts of the table.

Check Constraints

Check constraints allow you to specify that the value in a certain column must satisfy a Boolean (truth-value) expression. For example, to require positive product prices:

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

Not-Null Constraints

Not-null constraints specify that a column must not assume the null value. A not-null constraint is always written as a column constraint. For example:

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

Unique Constraints

Unique constraints ensure that the data contained in a column or a group of columns is unique with respect to all the rows in the table. The table must be hash-distributed (not `DISTRIBUTED RANDOMLY`), and the constraint columns must be the same as (or a superset of) the table's distribution key columns. For example:

```
=> CREATE TABLE products
       ( product_no integer UNIQUE,
         name text,
         price numeric)
      DISTRIBUTED BY (product_no);
```

Primary Keys

A primary key constraint is a combination of a `UNIQUE` constraint and a `NOT NULL` constraint. The table must be hash-distributed (not `DISTRIBUTED RANDOMLY`), and the primary key columns must be the same as (or a superset of) the table's distribution key columns. If a table has a primary key, this column (or group of columns) is chosen as the distribution key for the table by default. For example:

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

Foreign Keys

Foreign keys are not supported. You can declare them, but referential integrity is not enforced.

Foreign key constraints specify that the values in a column or a group of columns must match the values appearing in some row of another table to maintain referential integrity between two related tables. Referential integrity checks cannot be enforced between the distributed table segments of a Greenplum database.

Choosing the Table Distribution Policy

All Greenplum Database tables are distributed. When you create or alter a table, you optionally specify `DISTRIBUTED BY` (hash distribution) or `DISTRIBUTED RANDOMLY` (round-robin distribution) to determine the table row distribution.

Consider the following points when deciding on a table distribution policy.

- **Even Data Distribution** — For the best possible performance, all segments should contain equal portions of data. If the data is unbalanced or skewed, the segments with more data must work harder to perform their portion of the query processing. Choose a distribution key that is unique for each record, such as the primary key.
- **Local and Distributed Operations** — Local operations are faster than distributed operations. Query processing is fastest if the work associated with join, sort, or aggregation operations is done locally, at the segment-level. Work done at the system-level requires distributing tuples across the segments, which is less efficient. When tables share a common distribution key, the work of joining or sorting on their shared distribution key columns is done locally. With a random distribution policy, local join operations are not an option.
- **Even Query Processing** — For best performance, all segments should handle an equal share of the query workload. Query workload can be skewed if a table's data distribution policy and the query predicates are not well matched. For example, suppose that a sales transactions table is distributed based on a column that contains corporate names (the distribution key), and the hashing algorithm distributes the data based on those values. If a predicate in a query references a single value from the distribution key, query processing runs on only one segment. This works if your query predicates usually select data on a criteria other than corporation name. For queries that use corporation name in their predicates, it's possible that only one segment instance will handle the query workload.

Declaring Distribution Keys

`CREATE TABLE`'s optional clauses `DISTRIBUTED BY` and `DISTRIBUTED RANDOMLY` specify the distribution policy for a table. The default is a hash distribution policy that uses either the `PRIMARY KEY` (if the table has one) or the first column of the table as the distribution key. Columns with geometric or user-defined data types are not eligible as Greenplum distribution key columns. If a table does not have an eligible column, Greenplum distributes the rows randomly or in round-robin fashion.

To ensure even distribution of data, choose a distribution key that is unique for each record. If that is not possible, choose `DISTRIBUTED RANDOMLY`. For example:

```
=> CREATE TABLE products
                        (name varchar(40),
                         prod_id integer,
                         supplier_id integer)
             DISTRIBUTED BY (prod_id);
=> CREATE TABLE random_stuff
                        (things text,
                         doodads text,
                         etc text)
             DISTRIBUTED RANDOMLY;
```

Choosing the Table Storage Model

Greenplum Database supports several storage models and a mix of storage models. When you create a table, you choose how to store its data. This section explains the options for table storage and how to choose the best storage model for your workload.

- Heap Storage
- Append-Optimized Storage
- Choosing Row or Column-Oriented Storage
- Using Compression (Append-Optimized Tables Only)
- Checking the Compression and Distribution of an Append-Optimized Table

Heap Storage

By default, Greenplum Database uses the same heap storage model as PostgreSQL. Heap table storage works best with OLTP-type workloads where the data is often modified after it is initially loaded. `UPDATE` and `DELETE` operations require storing row-level versioning information to ensure reliable database transaction processing. Heap tables are best suited for smaller tables, such as dimension tables, that are often updated after they are initially loaded.

Append-Optimized Storage

Append-optimized table storage works best with denormalized fact tables in a data warehouse environment. Denormalized fact tables are typically the largest tables in the system. Fact tables are usually loaded in batches and accessed by read-only queries. Moving large fact tables to an append-optimized storage model eliminates the storage overhead of the per-row update visibility information, saving about 20 bytes per row. This allows for a leaner and easier-to-optimize page structure. The storage model of append-optimized tables is optimized for bulk data loading. Single row `INSERT` statements are not recommended.

To create a heap table

Row-oriented heap tables are the default storage type.

```
=> CREATE TABLE foo (a int, b text) DISTRIBUTED BY (a);
```

To create an append-optimized table

Use the `WITH` clause of the `CREATE TABLE` command to declare the table storage options. The default is to create the table as a regular row-oriented heap-storage table. For example, to create an append-optimized table with no compression:

```
=> CREATE TABLE bar (a int, b text)
    WITH (appendonly=true)
    DISTRIBUTED BY (a);
```

`UPDATE` and `DELETE` are not allowed on append-optimized tables in a serializable transaction and will cause the transaction to abort. `CLUSTER`, `DECLARE...FOR UPDATE`, and triggers are not supported with append-optimized tables.

Choosing Row or Column-Oriented Storage

Greenplum provides a choice of storage orientation models: row, column, or a combination of both. This section provides general guidelines for choosing the optimum storage orientation for a table. Evaluate performance using your own data and query workloads.

- Row-oriented storage: good for OLTP types of workloads with many interative transactions and many columns of a single row needed all at once, so retrieving is efficient.
- Column-oriented storage: good for data warehouse workloads with aggregations of data computed over a small number of columns, or for single columns that require regular updates without modifying other column data.

For most general purpose or mixed workloads, row-oriented storage offers the best combination of flexibility and performance. However, there are use cases where a column-oriented storage model provides more efficient I/O and storage. Consider the following requirements when deciding on the storage orientation model for a table:

- **Updates of table data.** If you load and update the table data frequently, choose a row-oriented heap table. Column-oriented table storage is only available on append-optimized tables. See "Heap Storage" on page 40 for more information.
- **Frequent INSERTs.** If rows are frequently inserted into the table, consider a row-oriented model. Column-oriented tables are not optimized for write operations, as column values for a row must be written to different places on disk.
- **Number of columns requested in queries.** If you typically request all or the majority of columns in the `SELECT` list or `WHERE` clause of your queries, consider a row-oriented model. Column-oriented tables are best suited to queries that aggregate many values of a single column where the `WHERE` or `HAVING` predicate is also on the aggregate column. For example:

  ```
  SELECT SUM(salary)...
  SELECT AVG(salary)... WHERE salary > 10000
  ```

  Or where the `WHERE` predicate is on a single column and returns a relatively small number of rows. For example:

  ```
  SELECT salary, dept ... WHERE state='CA'
  ```

- **Number of columns in the table.** Row-oriented storage is more efficient when many columns are required at the same time, or when the row-size of a table is relatively small. Column-oriented tables can offer better query performance on tables with many columns where you access a small subset of columns in your queries.
- **Compression.** Column data has the same data type, so storage size optimizations are available in column-oriented data that are not available in row-oriented data. For example, many compression schemes use the similarity of adjacent data to compress. However, the greater adjacent compression achieved, the more difficult random access can become, as data must be uncompressed to be read.

To create a column-oriented table

The WITH clause of the CREATE TABLE command specifies the table's storage options. The default is a row-oriented heap table. Tables that use column-oriented storage must be append-optimized tables. For example, to create a column-oriented table:

```
=> CREATE TABLE bar (a int, b text)
    WITH (appendonly=true, orientation=column)
    DISTRIBUTED BY (a);
```

Using Compression (Append-Optimized Tables Only)

There are two types of in-database compression available in the Greenplum Database for append-optimized tables:

- Table-level compression is applied to an entire table.
- Column-level compression is applied to a specific column. You can apply different column-level compression algorithms to different columns.

The following table summarizes the available compression algorithms.

Table 5.1 Compression Algorithms for Append-Optimized Tables

Table Orientation	Available Compression Types	Supported Algorithms
Row	Table	ZLIB and QUICKLZ
Column	Column and Table	RLE_TYPE, ZLIB, and QUICKLZ

When choosing a compression type and level for append-optimized tables, consider these factors:

- CPU usage. Your segment systems must have the available CPU power to compress and uncompress the data.
- Compression ratio/disk size. Minimizing disk size is one factor, but also consider the time and CPU capacity required to compress and scan data. Find the optimal settings for efficiently compressing data without causing excessively long compression times or slow scan rates.
- Speed of compression. QuickLZ compression generally uses less CPU capacity and compresses data faster at a lower compression ratio than zlib. zlib provides higher compression ratios at lower speeds.

  For example, at compression level 1 (compresslevel=1), QuickLZ and zlib have comparable compression ratios, though at different speeds. Using zlib with compresslevel=6 can significantly increase the compression ratio compared to QuickLZ, though with lower compression speed.
- Speed of decompression/scan rate. Performance with compressed append-optimized tables depends on hardware, query tuning settings, and other factors. Perform comparison testing to determine the actual performance in your environment.

Note: Do not use compressed append-optimized tables on file systems that use compression. If the file system on which your segment data directory resides is a compressed file system, your append-optimized table must not use compression.

Performance with compressed append-optimized tables depends on hardware, query tuning settings, and other factors. Greenplum recommends performing comparison testing to determine the actual performance in your environment.

Note: QuickLZ compression level can only be set to level 1; no other options are available. Compression level with zlib can be set at any value from 1 - 9.

Note: When an `ENCODING` clause conflicts with a `WITH` clause, the `ENCODING` clause has higher precedence than the `WITH` clause.

To create a compressed table

The `WITH` clause of the `CREATE TABLE` command declares the table storage options. Tables that use compression must be append-optimized tables. For example, to create an append-optimized table with zlib compression at a compression level of 5:

```
=> CREATE TABLE foo (a int, b text)
   WITH (appendonly=true, compresstype=zlib,
         compresslevel=5);
```

Checking the Compression and Distribution of an Append-Optimized Table

Greenplum provides built-in functions to check the compression ratio and the distribution of an append-optimized table. The functions take either the object ID or a table name. You can qualify the table name with a schema name.

Table 5.2 Functions for compressed append-optimized table metadata

Function	Return Type	Description

`get_ao_distribution(name)`
`get_ao_distribution(oid)`
	`Set of (dbid, tuplecount) rows`	Shows the distribution of an append-optimized table's rows across the array. Returns a set of rows, each of which includes a segment *dbid* and the number of tuples stored on the segment.

`get_ao_compression_ratio(name)`
`get_ao_compression_ratio(oid)`
	`float8`	Calculates the compression ratio for a compressed append-optimized table. If information is not available, this function returns a value of -1.

The compression ratio is returned as a common ratio. For example, a returned value of `3.19`, or `3.19:1`, means that the uncompressed table is slightly larger than three times the size of the compressed table.

The distribution of the table is returned as a set of rows that indicate how many tuples are stored on each segment. For example, in a system with four primary segments with *dbid* values ranging from 0 - 3, the function returns four rows similar to the following:

```
=# SELECT get_ao_distribution('lineitem_comp');
 get_ao_distribution
---------------------
(0,7500721)
```

```
(1,7501365)
(2,7499978)
(3,7497731)
(4 rows)
```

Support for Run-length Encoding

Greenplum Database supports Run-length Encoding (RLE) for column-level compression. RLE data compression stores repeated data as a single data value and a count. For example, in a table with two columns, a date and a description, that contains 200,000 entries containing the value `date1` and 400,000 entries containing the value `date2`, RLE compression for the date field is similar to `date1 200000 date2 400000`. RLE is not useful with files that do not have large sets of repeated data as it can greatly increase the file size.

There are four levels of RLE compression available.The levels progressively increase the compression ratio, but decrease the compression speed.

Greenplum Database versions 4.2.1 and later support column-oriented RLE compression. To backup a table with RLE compression and restore it to an earlier version of Greenplum Database, alter the table to have no compression or a compression type supported in the earlier version (`ZLIB` or `QUICKLZ`) before you start the backup operation.

Adding Column-level Compression

You can add the following storage directives to a column for append-optimized tables with row or column orientation:

- Compression type
- Compression level
- Block size for a column

Add storage directives using the `CREATE TABLE`, `ALTER TABLE`, and `CREATE TYPE` commands.

The following table details the types of storage directives and possible values for each.

Table 5.3 Storage Directives for Column-level Compression

Name	Definition	Values	Comment
`COMPRESSTYPE`	Type of compression.	• `zlib:` deflate algorithm • `quicklz`: (ast compression • `RLE_TYPE`: run-length encoding • `none`: no compression	Values are not case-sensitive.

Table 5.3 Storage Directives for Column-level Compression

Name	Definition	Values	Comment
COMPRESSLEVEL	Compression level.	zlib compression: 1-9	1 is the fastest method with the least compression. 1 is the default. 9 is the slowest method with the most compression.
		QuickLZ compression: 1 – use compression	1 is the default.
		RLE_TYPE compression: 1 – 4 • 1 - apply RLE only • 2 - apply RLE then apply zlib compression level 1 • 3 - apply RLE then apply zlib compression level 5 • 4 - apply RLE then apply zlib compression level 9	1 is the fastest method with the least compression. 4 is the slowest method with the most compression. 1 is the default.
BLOCKSIZE	The size in bytes for each block in the table	8192 – 2097152	The value must be a multiple of 8192.

The following is the format for adding storage directives.

```
[ ENCODING ( storage_directive [,…] ) ]
```

where the word ENCODING is required and the storage directive has three parts:

- The name of the directive
- An equals sign
- The specification

Separate multiple storage directives with a comma. Apply a storage directive to a single column or designate it as the default for all columns, as shown in the following CREATE TABLE clauses.

General Usage:

```
column_name data_type ENCODING ( storage_directive [, … ] ), …

COLUMN column_name ENCODING ( storage_directive [, … ] ), …

DEFAULT COLUMN ENCODING ( storage_directive [, … ] )
```

Example:

```
C1 char ENCODING (compresstype=quicklz, blocksize=65536)

COLUMN C1 ENCODING (compresstype=quicklz, blocksize=65536)

DEFAULT COLUMN ENCODING (compresstype=quicklz)
```

Default Compression Values

If the compression type, compression level and block size are not defined, the default is no compression , and the block size is set to the Server Configuration Parameter block_size.

Precedence of Compression Settings

Column compression settings are inherited from the table level to the partition level to the subpartition level. The lowest-level settings have priority.

- Column compression settings specified for subpartitions override any compression settings at the partition, column or table levels.
- Column compression settings specified for partitions override any compression settings at the column or table levels.
- Column compression settings specified at the table level override any compression settings for the entire table.
- When an `ENCODING` clause conflicts with a `WITH` clause, the `ENCODING` clause has higher precedence than the `WITH` clause.

Note: The `INHERITS` clause is not allowed in a table that contains a storage directive or a column reference storage directive.

Tables created using the `LIKE` clause ignore storage directive and column reference storage directives.

Optimal Location for Column Compression Settings

The best practice is to set the column compression settings at the level where the data resides. See "Example 5" on page 47, which shows a table with a partition depth of 2. `RLE_TYPE` compression is added to a column at the subpartition level.

Storage Directives Examples

The following examples show the use of storage directives in `CREATE TABLE` statements.

Example 1

In this example, column `c1` is compressed using `zlib` and uses the block size defined by the system. Column `c2` is compressed with `quicklz`, and uses a block size of `65536`. Column `c3` is not compressed and uses the block size defined by the system.

```
CREATE TABLE T1 (c1 int ENCODING (compresstype=zlib),
                 c2 char ENCODING (compresstype=quicklz, blocksize=65536),
                 c3 char)
   WITH (appendonly=true, orientation=column);
```

Example 2

In this example, column `c1` is compressed using `zlib` and uses the block size defined by the system. Column `c2` is compressed with `quicklz`, and uses a block size of `65536`. Column `c3` is compressed using `RLE_TYPE` and uses the block size defined by the system.

```
CREATE TABLE T2 (c1 int ENCODING (compresstype=zlib),
                 c2 char ENCODING (compresstype=quicklz, blocksize=65536),
                 c3 char,
                 COLUMN c3 ENCODING (RLE_TYPE)
                 )
   WITH (appendonly=true, orientation=column)
```

Example 3

In this example, column c1 is compressed using zlib and uses the block size defined by the system. Column c2 is compressed with quicklz, and uses a block size of 65536. Column c3 is compressed using zlib and uses the block size defined by the system. Note that column c3 uses zlib (not RLE_TYPE) in the partitions, because the column storage in the partition clause has precedence over the storage directive in the column definition for the table.

```
CREATE TABLE T3 (c1 int ENCODING (compresstype=zlib),
                 c2 char ENCODING (compresstype=quicklz, blocksize=65536),
                 c3 char,
COLUMN c3 ENCODING (compresstype=RLE_TYPE)
)
   WITH (appendonly=true, orientation=column)
   PARTITION BY RANGE (c3) (START ('1900-01-01'::DATE)
                            END ('2100-12-31'::DATE),
                            COLUMN c3 ENCODING (zlib));
```

Example 4

In this example, CREATE TABLE assigns a storage directive to c1. Column c2 has no storage directive and inherits the compression type (quicklz) and block size (65536) from the DEFAULT COLUMN ENCODING clause.

Column c3's ENCODING clause defines its compression type, RLE_TYPE. The DEFAULT COLUMN ENCODING clause defines c3's block size, 65536.

The ENCODING clause defined for a specific column overrides the DEFAULT ENCODING clause, so column c4 has a compress type of none and the default block size.

```
CREATE TABLE T4 (c1 int ENCODING (compresstype=zlib),
                 c2 char,
                 c3 char,
                 c4 smallint ENCODING (compresstype=none),
                 DEFAULT COLUMN ENCODING (compresstype=quicklz,
                                          blocksize=65536),
                 COLUMN c3 ENCODING (compresstype=RLE_TYPE)
                 )
   WITH (appendonly=true, orientation=column);
```

Example 5

This example creates an append-optimized, column-oriented table, T5. T5 has two partitions, p1 and p2, each of which has subpartitions. Each subpartition has ENCODING clauses:

- The ENCODING clause for partition p1's subpartition sp1 defines column i's compression type as zlib and block size as 65536.
- The ENCODING clauses for partition p2's subpartition sp1 defines column i's compression type as rle_type and block size is the default value. Column k uses the default compression and its block size is 8192.

```
create table T5(i int, j int, k int, l int)
with (appendonly=true, orientation=column)
partition by range(i) subpartition by range(j)
(
    partition p1 start(1) end(2)
(  subpartition sp1 start(1) end(2)
         column i encoding(compresstype=zlib, blocksize=65536)
    ),
    partition p2 start(2) end(3)
    (  subpartition sp1 start(1) end(2)
         column i encoding(compresstype=rle_type)
         column k encoding(blocksize=8192)
    )
);
```

For an example showing how to add a compressed column to an existing table with the ALTER TABLE command, see "Adding a Compressed Column to Table" on page 50.

Adding Compression in a TYPE Command

You can define a compression type to simplify column compression statements. For example, the following CREATE TYPE command defines a compression type, comptype, that specifies quicklz compression.

where comptype is defined as:

```
CREATE TYPE comptype (
  internallength = 4,
  input = comptype_in,
  output = comptype_out,
  alignment = int4,
  default = 123,
  passedbyvalue,
  compresstype="quicklz",
  blocksize=65536,
  compresslevel=1
  );
```

You can then use comptype in a CREATE TABLE command to specify quicklz compression for a column:

```
CREATE TABLE t2 (c1 comptype)
   WITH (APPENDONLY=true, ORIENTATION=column);
```

For information about creating and adding compression parameters to a type, see CREATE TYPE. For information about changing compression specifications in a type, see ALTER TYPE.

Choosing Block Size

The blocksize is the size, in bytes, for each block in a table. Block sizes must be between 8192 and 2097152 bytes, and be a multiple of 8192. The default is 32768.

Specifying large block sizes can consume large amounts of memory. Block size determines buffering in the storage layer. Greenplum maintains a buffer per partition, and per column in column-oriented tables. Tables with many partitions or columns consume large amounts of memory.

Altering a Table

The ALTER TABLE command changes the definition of a table. Use ALTER TABLE to change table attributes such as column definitions, distribution policy, storage model, and partition structure (see also "Maintaining Partitioned Tables" on page 58). For example, to add a not-null constraint to a table column:

```
=> ALTER TABLE address ALTER COLUMN street SET NOT NULL;
```

Altering Table Distribution

ALTER TABLE provides options to change a table's distribution policy . When the table distribution options change, the table data is redistributed on disk, which can be resource intensive. You can also redistribute table data using the existing distribution policy.

Changing the Distribution Policy

For partitioned tables, changes to the distribution policy apply recursively to the child partitions. This operation preserves the ownership and all other attributes of the table. For example, the following command redistributes the table sales across all segments using the customer_id column as the distribution key:

```
ALTER TABLE sales SET DISTRIBUTED BY (customer_id);
```

When you change the hash distribution of a table, table data is automatically redistributed. Changing the distribution policy to a random distribution does not cause the data to be redistributed. For example:

```
ALTER TABLE sales SET DISTRIBUTED RANDOMLY;
```

Redistributing Table Data

To redistribute table data for tables with a random distribution policy (or when the hash distribution policy has not changed) use REORGANIZE=TRUE. Reorganizing data may be necessary to correct a data skew problem, or when segment resources are added to the system. For example, the following command redistributes table data across all segments using the current distribution policy, including random distribution.

```
ALTER TABLE sales SET WITH (REORGANIZE=TRUE);
```

Altering the Table Storage Model

Table storage, compression, and orientation can be declared only at creation. To change the storage model, you must create a table with the correct storage options, load the original table data into the new table, drop the original table, and rename the new table with the original table's name. You must also re-grant any table permissions. For example:

```
CREATE TABLE sales2 (LIKE sales)
WITH (appendonly=true, compresstype=quicklz,
compresslevel=1, orientation=column);

INSERT INTO sales2 SELECT * FROM sales;
DROP TABLE sales;
```

```
ALTER TABLE sales2 RENAME TO sales;
GRANT ALL PRIVILEGES ON sales TO admin;
GRANT SELECT ON sales TO guest;
```

See "Exchanging a Partition" on page 60 to learn how to change the storage model of a partitioned table.

Adding a Compressed Column to Table

Use ALTER TABLE command to add a compressed column to a table. All of the options and constraints for compressed columns described in "Adding Column-level Compression" on page 44 apply to columns added with the ALTER TABLE command.

The following example shows how to add a column with zlib compression to a table, T1.

```
ALTER TABLE T1
      ADD COLUMN c4 int DEFAULT 0
      ENCODING (COMPRESSTYPE=zlib);
```

Inheritance of Compression Settings

A partition that is added to a table that has subpartitions with compression settings inherits the compression settings from the subpartition.The following example shows how to create a table with subpartition encodings, then alter it to add a partition.

```
CREATE TABLE ccddl (i int, j int, k int, l int)
  WITH
    (APPENDONLY = TRUE, ORIENTATION=COLUMN)
  PARTITION BY range(j)
  SUBPARTITION BY list (k)
  SUBPARTITION template(
    SUBPARTITION sp1 values(1, 2, 3, 4, 5),
    COLUMN i ENCODING(COMPRESSTYPE=ZLIB),
    COLUMN j ENCODING(COMPRESSTYPE=QUICKLZ),
    COLUMN k ENCODING(COMPRESSTYPE=ZLIB),
    COLUMN l ENCODING(COMPRESSTYPE=ZLIB))
  (PARTITION p1 START(1) END(10),
   PARTITION p2 START(10) END(20))
;
ALTER TABLE ccddl
  ADD PARTITION p3 START(20) END(30)
;
```

Running the ALTER TABLE command creates partitions of table ccddl named ccddl_1_prt_p3 and ccddl_1_prt_p3_2_prt_sp1. Partition ccddl_1_prt_p3 inherits the different compression encodings of subpartition sp1.

Dropping a Table

The DROP TABLE command removes tables from the database. For example:

```
DROP TABLE mytable;
```

To empty a table of rows without removing the table definition, use DELETE or TRUNCATE. For example:

```
DELETE FROM mytable;
TRUNCATE mytable;
```

`DROP TABLE` always removes any indexes, rules, triggers, and constraints that exist for the target table. Specify `CASCADE` to drop a table that is referenced by a view. `CASCADE` removes dependent views.

Partitioning Large Tables

Table partitioning enables supporting very large tables, such as fact tables, by logically dividing them into smaller, more manageable pieces. Partitioned tables can improve query performance by allowing the Greenplum Database query planner to scan only the data needed to satisfy a given query instead of scanning all the contents of a large table.

Partitioning does not change the physical distribution of table data across the segments. Table distribution is physical: Greenplum Database physicially divides partitioned tables and non-partitioned tables across segments to enable parallel query processing. Table partitioning is logical: Greenplum Database logically divides big tables to improve query performance and facilitate data warehouse maintenance tasks, such as rolling old data out of the data warehouse.

Greenplum Database supports:

- *range partitioning*: division of data based on a numerical range, such as date or price.
- *list partitioning*: division of data based on a list of values, such as sales territory or product line.
- A combination of both types.

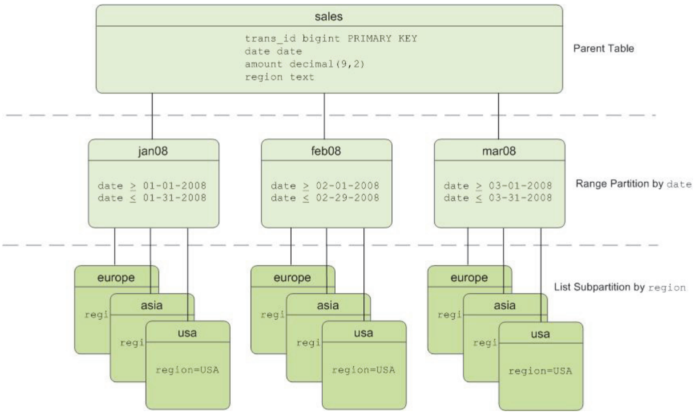


Figure 5.1 Example Multi-level Partition Design

Table Partitioning in Greenplum Database

Greenplum Database divides tables into parts (also known as partitions) to enable massively parallel processing. Tables are partitioned during `CREATE TABLE` using the `PARTITION BY` (and optionally the `SUBPARTITION BY`) clause. When you partition a table in Greenplum Database, you create a top-level (or parent) table with one or more levels of sub-tables (or child tables). Internally, Greenplum Database creates an inheritance relationship between the top-level table and its underlying partitions, similar to the functionality of the `INHERITS` clause of PostgreSQL.

Greenplum uses the partition criteria defined during table creation to create each partition with a distinct `CHECK` constraint, which limits the data that table can contain. The query planner uses `CHECK` constraints to determine which table partitions to scan to satisfy a given query predicate.

The Greenplum system catalog stores partition hierarchy information so that rows inserted into the top-level parent table propagate correctly to the child table partitions. To change the partition design or table structure, alter the parent table using `ALTER TABLE` with the `PARTITION` clause.

Execution of `INSERT`, `UPDATE` and `DELETE` commands directly on a specific partition (child table) of a partitioned table is not supported. Instead, these commands must be executed on the root partitioned table, the table created with the `CREATE TABLE` command.

Deciding on a Table Partitioning Strategy

Not all tables are good candidates for partitioning. If the answer is *yes* to all or most of the following questions, table partitioning is a viable database design strategy for improving query performance. If the answer is *no* to most of the following questions, table partitioning is not the right solution for that table. Test your design strategy to ensure that query performance improves as expected.

- **Is the table large enough?** Large fact tables are good candidates for table partitioning. If you have millions or billions of records in a table, you will see performance benefits from logically breaking that data up into smaller chunks. For smaller tables with only a few thousand rows or less, the administrative overhead of maintaining the partitions will outweigh any performance benefits you might see.

- **Are you experiencing unsatisfactory performance?** As with any performance tuning initiative, a table should be partitioned only if queries against that table are producing slower response times than desired.

- **Do your query predicates have identifiable access patterns?** Examine the `WHERE` clauses of your query workload and look for table columns that are consistently used to access data. For example, if most of your queries tend to look up records by date, then a monthly or weekly date-partitioning design might be beneficial. Or if you tend to access records by region, consider a list-partitioning design to divide the table by region.

- **Does your data warehouse maintain a window of historical data?** Another consideration for partition design is your organization's business requirements for maintaining historical data. For example, your data warehouse may require that you keep data for the past twelve months. If the data is partitioned by month, you can easily drop the oldest monthly partition from the warehouse and load current data into the most recent monthly partition.
- **Can the data be divided into somewhat equal parts based on some defining criteria?** Choose partitioning criteria that will divide your data as evenly as possible. If the partitions contain a relatively equal number of records, query performance improves based on the number of partitions created. For example, by dividing a large table into 10 partitions, a query will execute 10 times faster than it would against the unpartitioned table, provided that the partitions are designed to support the query's criteria.

Creating Partitioned Tables

You partition tables when you create them with `CREATE TABLE`. This section provides examples of SQL syntax for creating a table with various partition designs.

To partition a table:

1. Decide on the partition design: date range, numeric range, or list of values.
2. Choose the column(s) on which to partition the table.
3. Decide how many levels of partitions you want. For example, you can create a date range partition table by month and then subpartition the monthly partitions by sales region.

- Defining Date Range Table Partitions
- Defining Numeric Range Table Partitions
- Defining List Table Partitions
- Defining Multi-level Partitions
- Partitioning an Existing Table

Defining Date Range Table Partitions

A date range partitioned table uses a single `date` or `timestamp` column as the partition key column. You can use the same partition key column to create subpartitions if necessary, for example, to partition by month and then subpartition by day. Consider partitioning by the most granular level. For example, for a table partitioned by date, you can partition by day and have 365 daily partitions, rather than partition by year then subpartition by month then subpartition by day. A multi-level design can reduce query planning time, but a flat partition design runs faster.

You can have Greenplum Database automatically generate partitions by giving a `START` value, an `END` value, and an `EVERY` clause that defines the partition increment value. By default, `START` values are always inclusive and `END` values are always exclusive. For example:

```
CREATE TABLE sales (id int, date date, amt decimal(10,2))
DISTRIBUTED BY (id)
```

```
PARTITION BY RANGE (date)
( START (date '2008-01-01') INCLUSIVE
   END (date '2009-01-01') EXCLUSIVE
   EVERY (INTERVAL '1 day') );
```

You can also declare and name each partition individually. For example:

```
CREATE TABLE sales (id int, date date, amt decimal(10,2))
DISTRIBUTED BY (id)
PARTITION BY RANGE (date)
( PARTITION Jan08 START (date '2008-01-01') INCLUSIVE ,
  PARTITION Feb08 START (date '2008-02-01') INCLUSIVE ,
  PARTITION Mar08 START (date '2008-03-01') INCLUSIVE ,
  PARTITION Apr08 START (date '2008-04-01') INCLUSIVE ,
  PARTITION May08 START (date '2008-05-01') INCLUSIVE ,
  PARTITION Jun08 START (date '2008-06-01') INCLUSIVE ,
  PARTITION Jul08 START (date '2008-07-01') INCLUSIVE ,
  PARTITION Aug08 START (date '2008-08-01') INCLUSIVE ,
  PARTITION Sep08 START (date '2008-09-01') INCLUSIVE ,
  PARTITION Oct08 START (date '2008-10-01') INCLUSIVE ,
  PARTITION Nov08 START (date '2008-11-01') INCLUSIVE ,
  PARTITION Dec08 START (date '2008-12-01') INCLUSIVE
                  END (date '2009-01-01') EXCLUSIVE );
```

You do not have to declare an `END` value for each partition, only the last one. In this example, `Jan08` ends where `Feb08` starts.

Defining Numeric Range Table Partitions

A numeric range partitioned table uses a single numeric data type column as the partition key column. For example:

```
CREATE TABLE rank (id int, rank int, year int, gender
char(1), count int)
DISTRIBUTED BY (id)
PARTITION BY RANGE (year)
( START (2001) END (2008) EVERY (1),
  DEFAULT PARTITION extra );
```

For more information about default partitions, see "Adding a Default Partition" on page 60.

Defining List Table Partitions

A list partitioned table can use any data type column that allows equality comparisons as its partition key column. A list partition can also have a multi-column (composite) partition key, whereas a range partition only allows a single column as the partition key. For list partitions, you must declare a partition specification for every partition (list value) you want to create. For example:

```
CREATE TABLE rank (id int, rank int, year int, gender
char(1), count int )
DISTRIBUTED BY (id)
PARTITION BY LIST (gender)
( PARTITION girls VALUES ('F'),
  PARTITION boys VALUES ('M'),
  DEFAULT PARTITION other );
```

For more information about default partitions, see "Adding a Default Partition" on page 60.

Defining Multi-level Partitions

You can create a multi-level partition design with subpartitions of partitions. Using a *subpartition template* ensures that every partition has the same subpartition design, including partitions that you add later. For example, the following SQL creates the two-level partition design shown in Figure 5.1, "Example Multi-level Partition Design" on page 51:

```
CREATE TABLE sales (trans_id int, date date, amount
decimal(9,2), region text)
DISTRIBUTED BY (trans_id)
PARTITION BY RANGE (date)
SUBPARTITION BY LIST (region)
SUBPARTITION TEMPLATE
( SUBPARTITION usa VALUES ('usa'),
  SUBPARTITION asia VALUES ('asia'),
  SUBPARTITION europe VALUES ('europe'),
  DEFAULT SUBPARTITION other_regions)
  (START (date '2011-01-01') INCLUSIVE
  END (date '2012-01-01') EXCLUSIVE
  EVERY (INTERVAL '1 month'),
  DEFAULT PARTITION outlying_dates );
```

The following example shows a three-level partition design where the `sales` table is partitioned by `year`, then `month`, then `region`. The `SUBPARTITION TEMPLATE` clauses ensure that each yearly partition has the same subpartition structure. The example declares a `DEFAULT` partition at each level of the hierarchy.

```
CREATE TABLE p3_sales (id int, year int, month int, day int,
region text)
DISTRIBUTED BY (id)
PARTITION BY RANGE (year)
    SUBPARTITION BY RANGE (month)
       SUBPARTITION TEMPLATE (
        START (1) END (13) EVERY (1),
        DEFAULT SUBPARTITION other_months )
           SUBPARTITION BY LIST (region)
             SUBPARTITION TEMPLATE (
               SUBPARTITION usa VALUES ('usa'),
               SUBPARTITION europe VALUES ('europe'),
               SUBPARTITION asia VALUES ('asia'),
               DEFAULT SUBPARTITION other_regions )
( START (2002) END (2012) EVERY (1),
  DEFAULT PARTITION outlying_years );
```

Partitioning an Existing Table

Tables can be partitioned only at creation. If you have a table that you want to partition, you must create a partitioned table, load the data from the original table into the new table, drop the original table, and rename the partitioned table with the original table's name. You must also re-grant any table permissions. For example:

```
CREATE TABLE sales2 (LIKE sales)
PARTITION BY RANGE (date)
( START (date '2008-01-01') INCLUSIVE
   END (date '2009-01-01') EXCLUSIVE
   EVERY (INTERVAL '1 month') );

INSERT INTO sales2 SELECT * FROM sales;
DROP TABLE sales;
ALTER TABLE sales2 RENAME TO sales;
GRANT ALL PRIVILEGES ON sales TO admin;
GRANT SELECT ON sales TO guest;
```

Limitations of Partitioned Tables

A primary key or unique constraint on a partitioned table must contain all the partitioning columns. A unique index can omit the partitioning columns; however, it is enforced only on the parts of the partitioned table, not on the partitioned table as a whole.

Loading Partitioned Tables

After you create the partitioned table structure, top-level parent tables are empty. Data is routed to the bottom-level child table partitions. In a multi-level partition design, only the subpartitions at the bottom of the hierarchy can contain data.

Rows that cannot be mapped to a child table partition are rejected and the load fails. To avoid unmapped rows being rejected at load time, define your partition hierarchy with a DEFAULT partition. Any rows that do not match a partition's CHECK constraints load into the DEFAULT partition. See"Adding a Default Partition" on page 60.

At runtime, the query planner scans the entire table inheritance hierarchy and uses the CHECK table constraints to determine which of the child table partitions to scan to satisfy the query's conditions. The DEFAULT partition (if your hierarchy has one) is always scanned. DEFAULT partitions that contain data slow down the overall scan time.

When you use COPY or INSERT to load data into a parent table, the data is automatically rerouted to the correct partition, just like a regular table.

Best practice for loading data into partitioned tables is to create an intermediate staging table, load it, and then exchange it into your partition design. See "Exchanging a Partition" on page 60.

Verifying Your Partition Strategy

When a table is partitioned based on the query predicate, you can use `EXPLAIN` to verify that the query planner scans only the relevant data to examine the query plan.

For example, suppose a *sales* table is date-range partitioned by month and subpartitioned by region as shown in Figure 5.1, "Example Multi-level Partition Design" on page 51. For the following query:

```
EXPLAIN SELECT * FROM sales WHERE date='01-07-12' AND
region='usa';
```

The query plan for this query should show a table scan of only the following tables:

- the default partition returning 0-1 rows (if your partition design has one)
- the January 2012 partition (*sales_1_prt_1*) returning 0-1 rows
- the USA region subpartition (*sales_1_2_prt_usa*) returning *some number* of rows.

The following example shows the relevant portion of the query plan.

```
->  Seq Scan on sales_1_prt_1 sales (cost=0.00..0.00 rows=0
     width=0)
Filter: "date"=01-07-08::date AND region='USA'::text
->  Seq Scan on sales_1_2_prt_usa sales (cost=0.00..9.87
rows=20
      width=40)
```

Ensure that the query planner does not scan unnecessary partitions or subpartitions (for example, scans of months or regions not specified in the query predicate), and that scans of the top-level tables return 0-1 rows.

Troubleshooting Selective Partition Scanning

The following limitations can result in a query plan that shows a non-selective scan of your partition hierarchy.

- The query planner can selectively scan partitioned tables only when the query contains a direct and simple restriction of the table using immutable operators such as:

  ```
  =        <        <=        >        >=        <>
  ```

- Selective scanning recognizes `STABLE` and `IMMUTABLE` functions, but does not recognize `VOLATILE` functions within a query. For example, `WHERE` clauses such as `date > CURRENT_DATE` cause the query planner to selectively scan partitioned tables, but `time > TIMEOFDAY` does not.

Viewing Your Partition Design

You can look up information about your partition design using the *pg_partitions* view. For example, to see the partition design of the *sales* table:

```
SELECT partitionboundary, partitiontablename, partitionname,
```

```
partitionlevel, partitionrank FROM pg_partitions WHERE
tablename='sales';
```

The following table and views show information about partitioned tables.

- *pg_partition* - Tracks partitioned tables and their inheritance level relationships.
- *pg_partition_templates* - Shows the subpartitions created using a subpartition template.
- *pg_partition_columns* - Shows the partition key columns used in a partition design.

For information about Greenplum Database system catalog tables and views, see the *Greenplum Database Reference Guide*.

Maintaining Partitioned Tables

To maintain a partitioned table, use the `ALTER TABLE` command against the top-level parent table. The most common scenario is to drop old partitions and add new ones to maintain a rolling window of data in a range partition design. You can convert (*exchange*) older partitions to the append-optimized compressed storage format to save space. If you have a default partition in your partition design, you add a partition by *splitting* the default partition.

- Adding a Partition
- Renaming a Partition
- Adding a Default Partition
- Dropping a Partition
- Truncating a Partition
- Exchanging a Partition
- Splitting a Partition
- Modifying a Subpartition Template

Important: When defining and altering partition designs, use the given *partition name*, not the table object name. Although you can query and load any table (including partitioned tables) directly using SQL commands, you can only modify the structure of a partitioned table using the `ALTER TABLE...PARTITION` clauses.

Partitions are not required to have names. If a partition does not have a name, use one of the following expressions to specify a part: `PARTITION FOR (value)` or `PARTITION FOR(RANK(number))`.

Adding a Partition

You can add a partition to a partition design with the `ALTER TABLE` command. If the original partition design included subpartitions defined by a *subpartition template*, the newly added partition is subpartitioned according to that template. For example:

```
ALTER TABLE sales ADD PARTITION
            START (date '2009-02-01') INCLUSIVE
            END (date '2009-03-01') EXCLUSIVE;
```

If you did not use a subpartition template when you created the table, you define subpartitions when adding a partition:

```
ALTER TABLE sales ADD PARTITION
            START (date '2009-02-01') INCLUSIVE
            END (date '2009-03-01') EXCLUSIVE
      ( SUBPARTITION usa VALUES ('usa'),
        SUBPARTITION asia VALUES ('asia'),
        SUBPARTITION europe VALUES ('europe') );
```

When you add a subpartition to an existing partition, you can specify the partition to alter. For example:

```
ALTER TABLE sales ALTER PARTITION FOR (RANK(12))
      ADD PARTITION africa VALUES ('africa');
```

Note: You cannot add a partition to a partition design that has a default partition. You must split the default partition to add a partition. See "Splitting a Partition" on page 61.

Renaming a Partition

Partitioned tables use the following naming convention. Partitioned subtable names are subject to uniqueness requirements and length limitations.

```
<parentname>_<level>_prt_<partition_name>
```

For example:

sales_1_prt_jan08

For auto-generated range partitions, where a number is assigned when no name is given):

sales_1_prt_1

To rename a partitioned child table, rename the top-level parent table. The `<parentname>` changes in the table names of all associated child table partitions. For example, the following command:

```
ALTER TABLE sales RENAME TO globalsales;
```

Changes the associated table names:

globalsales_1_prt_1

You can change the name of a partition to make it easier to identify. For example:

```
ALTER TABLE sales RENAME PARTITION FOR ('2008-01-01') TO
jan08;
```

Changes the associated table name as follows:

sales_1_prt_jan08

When altering partitioned tables with the `ALTER TABLE` command, always refer to the tables by their partition name (*jan08*) and not their full table name (*sales_1_prt_jan08*).

Note: The table name cannot be a partition name in an `ALTER TABLE` statement. For example, `ALTER TABLE sales...` is correct, `ALTER TABLE sales_1_part_jan08...` is not allowed.

Adding a Default Partition

You can add a default partition to a partition design with the ALTER TABLE command.

```
ALTER TABLE sales ADD DEFAULT PARTITION other;
```

If your partition design is multi-level, each level in the hierarchy must have a default partition. For example:

```
ALTER TABLE sales ALTER PARTITION FOR (RANK(1)) ADD DEFAULT
PARTITION other;
ALTER TABLE sales ALTER PARTITION FOR (RANK(2)) ADD DEFAULT
PARTITION other;
ALTER TABLE sales ALTER PARTITION FOR (RANK(3)) ADD DEFAULT
PARTITION other;
```

If incoming data does not match a partition's CHECK constraint and there is no default partition, the data is rejected. Default partitions ensure that incoming data that does not match a partition is inserted into the default partition.

Dropping a Partition

You can drop a partition from your partition design using the ALTER TABLE command. When you drop a partition that has subpartitions, the subpartitions (and all data in them) are automatically dropped as well. For range partitions, it is common to drop the older partitions from the range as old data is rolled out of the data warehouse. For example:

```
ALTER TABLE sales DROP PARTITION FOR (RANK(1));
```

Truncating a Partition

You can truncate a partition using the ALTER TABLE command. When you truncate a partition that has subpartitions, the subpartitions are automatically truncated as well.

```
ALTER TABLE sales TRUNCATE PARTITION FOR (RANK(1));
```

Exchanging a Partition

You can exchange a partition using the ALTER TABLE command. Exchanging a partition swaps one table in place of an existing partition. You can exchange partitions only at the lowest level of your partition hierarchy (only partitions that contain data can be exchanged).

Partition exchange can be useful for data loading. For example, load a staging table and swap the loaded table into your partition design. You can use partition exchange to change the storage type of older partitions to append-optimized tables. For example:

```
CREATE TABLE jan12 (LIKE sales) WITH (appendonly=true);
INSERT INTO jan12 SELECT * FROM sales_1_prt_1 ;
ALTER TABLE sales EXCHANGE PARTITION FOR (DATE '2012-01-01')
WITH TABLE jan12;
```

Note: This example refers to the single-level definition of the table sales, before partitions were added and altered in the previous examples.

Splitting a Partition

Splitting a partition divides a partition into two partitions. You can split a partition using the ALTER TABLE command. You can split partitions only at the lowest level of your partition hierarchy: only partitions that contain data can be split. The split value you specify goes into the *latter* partition.

For example, to split a monthly partition into two with the first partition containing dates January 1-15 and the second partition containing dates January 16-31:

```
ALTER TABLE sales SPLIT PARTITION FOR ('2008-01-01')
AT ('2008-01-16')
INTO (PARTITION jan081to15, PARTITION jan0816to31);
```

If your partition design has a default partition, you must split the default partition to add a partition.

When using the INTO clause, specify the current default partition as the second partition name. For example, to split a default range partition to add a new monthly partition for January 2009:

```
ALTER TABLE sales SPLIT DEFAULT PARTITION
START ('2009-01-01') INCLUSIVE
END ('2009-02-01') EXCLUSIVE
INTO (PARTITION jan09, default partition);
```

Modifying a Subpartition Template

Use ALTER TABLE SET SUBPARTITION TEMPLATE to modify the subpartition template for an existing partition. Partitions added after you set a new subpartition template have the new partition design. Existing partitions are not modified.

For example, to modify the subpartition design shown in Figure 5.1, “Example Multi-level Partition Design” on page 51:

```
ALTER TABLE sales SET SUBPARTITION TEMPLATE
( SUBPARTITION usa VALUES ('usa'),
  SUBPARTITION asia VALUES ('asia'),
  SUBPARTITION europe VALUES ('europe'),
  SUBPARTITION africa VALUES ('africa')
  DEFAULT SUBPARTITION other );
```

When you add a date-range partition of the table sales, it includes the new regional list subpartition for Africa. For example, the following command creates the subpartitions usa, asia, europe, africa, and a default partition named other:

```
ALTER TABLE sales ADD PARTITION sales_prt_3
  START ('2009-03-01') INCLUSIVE
  END ('2009-04-01') EXCLUSIVE );
```

To remove a subpartition template, use SET SUBPARTITION TEMPLATE with empty parentheses. For example, to clear the sales table subpartition template:

```
ALTER TABLE sales SET SUBPARTITION TEMPLATE ()
```

Creating and Using Sequences

You can use sequences to auto-increment unique ID columns of a table whenever a record is added. Sequences are often used to assign unique identification numbers to rows added to a table. You can declare an identifier column of type `SERIAL` to implicitly create a sequence for use with a column.

Creating a Sequence

The `CREATE SEQUENCE` command creates and initializes a special single-row sequence generator table with the given sequence name. The sequence name must be distinct from the name of any other sequence, table, index, or view in the same schema. For example:

```
CREATE SEQUENCE myserial START 101;
```

Using a Sequence

After you create a sequence generator table using `CREATE SEQUENCE`, you can use the `nextval` function to operate on the sequence. For example, to insert a row into a table that gets the next value of a sequence:

```
INSERT INTO vendors VALUES (nextval('myserial'), 'acme');
```

You can also use the `setval` function to reset a sequence's counter value. For example:

```
SELECT setval('myserial', 201);
```

A `nextval` operation is never rolled back. Afetched value is considered used, even if the transaction that performed the `nextval` fails. This means that failed transactions can leave unused holes in the sequence of assigned values. `setval` operations are never rolled back.

Note that the `nextval` function is not allowed in `UPDATE` or `DELETE` statements if mirroring is enabled, and the `currval` and `lastval` functions are not supported in Greenplum Database.

To examine the current settings of a sequence, query the sequence table:

```
SELECT * FROM myserial;
```

Altering a Sequence

The `ALTER SEQUENCE` command changes the parameters of an existing sequence generator. For example:

```
ALTER SEQUENCE myserial RESTART WITH 105;
```

Any parameters not set in the `ALTER SEQUENCE` command retain their prior settings.

Dropping a Sequence

The `DROP SEQUENCE` command removes a sequence generator table. For example:

```
DROP SEQUENCE myserial;
```

Using Indexes in Greenplum Database

In most traditional databases, indexes can greatly improve data access times. However, in a distributed database such as Greenplum, indexes should be used more sparingly. Greenplum Database performs very fast sequential scans; indexes use a random seek pattern to locate records on disk. Greenplum data is distributed across the segments, so each segment scans a smaller portion of the overall data to get the result. With table partitioning, the total data to scan may be even smaller. Because business intelligence (BI) query workloads generally return very large data sets, using indexes is not efficient.

Greenplum recommends trying your query workload without adding indexes. Indexes are more likely to improve performance for OLTP workloads, where the query is returning a single record or a small subset of data. Indexes can also improve performance on compressed append-optimized tables for queries that return a targeted set of rows, as the optimizer can use an index access method rather than a full table scan when appropriate. For compressed data, an index access method means only the necessary rows are uncompressed.

Greenplum Database automatically creates `PRIMARY KEY` constraints for tables with primary keys. To create an index on a partitioned table, index each partitioned child table. Indexes on the parent table do not apply to child table partitions.

Note that a `UNIQUE CONSTRAINT` (such as a `PRIMARY KEY CONSTRAINT`) implicitly creates a `UNIQUE INDEX` that must include all the columns of the distribution key and any partitioning key. The `UNIQUE CONSTRAINT` is enforced across the entire table, including all table partitions (if any).

Indexes add some database overhead — they use storage space and must be maintained when the table is updated. Ensure that the query workload uses the indexes that you create, and check that the indexes you add improve query performance (as compared to a sequential scan of the table). To determine whether indexes are being used, examine the query `EXPLAIN` plans. See "Query Profiling" on page 159.

Consider the following points when you create indexes.

- **Your Query Workload.** Indexes improve performance for workloads where queries return a single record or a very small data set, such as OLTP workloads.
- **Compressed Tables.** Indexes can improve performance on compressed append-optimized tables for queries that return a targeted set of rows. For compressed data, an index access method means only the necessary rows are uncompressed.
- **Avoid indexes on frequently updated columns.** Creating an index on a column that is frequently updated increases the number of writes required when the column is updated.

- **Create selective B-tree indexes.** Index selectivity is a ratio of the number of distinct values a column has divided by the number of rows in a table. For example, if a table has 1000 rows and a column has 800 distinct values, the selectivity of the index is 0.8, which is considered good. Unique indexes always have a selectivity ratio of 1.0, which is the best possible. Greenplum Database allows unique indexes only on distribution key columns.
- **Use Bitmap indexes for low selectivity columns.** The Greenplum Database Bitmap index type is not available in regular PostgreSQL. See "About Bitmap Indexes" on page 65.
- **Index columns used in joins.** An index on a column used for frequent joins (such as a foreign key column) can improve join performance by enabling more join methods for the query planner to use.
- **Index columns frequently used in predicates.** Columns that are frequently referenced in `WHERE` clauses are good candidates for indexes.
- **Avoid overlapping indexes.** Indexes that have the same leading column are redundant.
- **Drop indexes for bulk loads.** For mass loads of data into a table, consider dropping the indexes and re-creating them after the load completes. This is often faster than updating the indexes.
- **Consider a clustered index.** Clustering an index means that the records are physically ordered on disk according to the index. If the records you need are distributed randomly on disk, the database has to seek across the disk to fetch the records requested. If the records are stored close together, the fetching operation is more efficient. For example, a clustered index on a date column where the data is ordered sequentially by date. A query against a specific date range results in an ordered fetch from the disk, which leverages fast sequential access.

To cluster an index in Greenplum Database

Using the `CLUSTER` command to physically reorder a table based on an index can take a long time with very large tables. To achieve the same results much faster, you can manually reorder the data on disk by creating an intermediate table and loading the data in the desired order. For example:

```
CREATE TABLE new_table (LIKE old_table)
       AS SELECT * FROM old_table ORDER BY myixcolumn;
DROP old_table;
ALTER TABLE new_table RENAME TO old_table;
CREATE INDEX myixcolumn_ix ON old_table;
VACUUM ANALYZE old_table;
```

Index Types

Greenplum Database supports the Postgres index types B-tree and GiST. Hash and GIN indexes are not supported. Each index type uses a different algorithm that is best suited to different types of queries. B-tree indexes fit the most common situations and are the default index type. See Index Types in the PostgreSQL documentation for a description of these types.

Note: Greenplum Database allows unique indexes only if the columns of the index key are the same as (or a superset of) the Greenplum distribution key. Unique indexes are not supported on append-optimized tables. On partitioned tables, a unique index cannot be enforced across all child table partitions of a partitioned table. A unique index is supported only within a partition.

About Bitmap Indexes

Greenplum Database provides the Bitmap index type. Bitmap indexes are best suited to data warehousing applications and decision support systems with large amounts of data, many ad hoc queries, and few data modification (DML) transactions.

An index provides pointers to the rows in a table that contain a given key value. A regular index stores a list of tuple IDs for each key corresponding to the rows with that key value. Bitmap indexes store a bitmap for each key value. Regular indexes can be several times larger than the data in the table, but bitmap indexes provide the same functionality as a regular index and use a fraction of the size of the indexed data.

Each bit in the bitmap corresponds to a possible tuple ID. If the bit is set, the row with the corresponding tuple ID contains the key value. A mapping function converts the bit position to a tuple ID. Bitmaps are compressed for storage. If the number of distinct key values is small, bitmap indexes are much smaller, compress better, and save considerable space compared with a regular index. The size of a bitmap index is proportional to the number of rows in the table times the number of distinct values in the indexed column.

Bitmap indexes are most effective for queries that contain multiple conditions in the `WHERE` clause. Rows that satisfy some, but not all, conditions are filtered out before the table is accessed. This improves response time, often dramatically.

When to Use Bitmap Indexes

Bitmap indexes are best suited to data warehousing applications where users query the data rather than update it. Bitmap indexes perform best for columns that have between 100 and 100,000 distinct values and when the indexed column is often queried in conjunction with other indexed columns. Columns with fewer than 100 distinct values, such as a gender column with two distinct values (male and female), usually do not benefit much from any type of index. On a column with more than 100,000 distinct values, the performance and space efficiency of a bitmap index decline.

Bitmap indexes can improve query performance for ad hoc queries. `AND` and `OR` conditions in the `WHERE` clause of a query can be resolved quickly by performing the corresponding Boolean operations directly on the bitmaps before converting the resulting bitmap to tuple ids. If the resulting number of rows is small, the query can be answered quickly without resorting to a full table scan.

When Not to Use Bitmap Indexes

Do not use bitmap indexes for unique columns or columns with high cardinality data, such as customer names or phone numbers. The performance gains and disk space advantages of bitmap indexes start to diminish on columns with 100,000 or more unique values, regardless of the number of rows in the table.

Bitmap indexes are not suitable for OLTP applications with large numbers of concurrent transactions modifying the data.

Use bitmap indexes sparingly. Test and compare query performance with and without an index. Add an index only if query performance improves with indexed columns.

Creating an Index

The CREATE INDEX command defines an index on a table. A B-tree index is the default index type. For example, to create a B-tree index on the column *gender* in the table *employee*:

```
CREATE INDEX gender_idx ON employee (gender);
```

To create a bitmap index on the column *title* in the table *films*:

```
CREATE INDEX title_bmp_idx ON films USING bitmap (title);
```

Examining Index Usage

Greenplum Database indexes do not require maintenance and tuning. You can check which indexes are used by the real-life query workload. Use the EXPLAIN command to examine index usage for a query.

The query plan shows the steps or *plan nodes* that the database will take to answer a query and time estimates for each plan node. To examine the use of indexes, look for the following query plan node types in your EXPLAIN output:

- **Index Scan** - A scan of an index.
- **Bitmap Heap Scan** - Retrieves all
- from the bitmap generated by BitmapAnd, BitmapOr, or BitmapIndexScan and accesses the heap to retrieve the relevant rows.
- **Bitmap Index Scan** - Compute a bitmap by OR-ing all bitmaps that satisfy the query predicates from the underlying index.
- **BitmapAnd** or **BitmapOr** - Takes the bitmaps generated from multiple BitmapIndexScan nodes, ANDs or ORs them together, and generates a new bitmap as its output.

You have to experiment to determine the indexes to create. Consider the following points.

- Run ANALYZE after you create or update an index. ANALYZE collects table statistics. The query planner uses table statistics to estimate the number of rows returned by a query and to assign realistic costs to each possible query plan.
- Use real data for experimentation. Using test data for setting up indexes tells you what indexes you need for the test data, but that is all.
- Do not use very small test data sets as the results can be unrealistic or skewed.
- Be careful when developing test data. Values that are similar, completely random, or inserted in sorted order will skew the statistics away from the distribution that real data would have.

- You can force the use of indexes for testing purposes by using run-time parameters to turn off specific plan types. For example, turn off sequential scans (`enable_seqscan`) and nested-loop joins (`enable_nestloop`), the most basic plans, to force the system to use a different plan. Time your query with and without indexes and use the `EXPLAIN ANALYZE` command to compare the results.

Managing Indexes

Use the `REINDEX` command to rebuild a poorly-performing index. `REINDEX` rebuilds an index using the data stored in the index's table, replacing the old copy of the index.

Update and delete operations do not update bitmap indexes. Rebuild bitmap indexes with the `REINDEX` command.

To rebuild all indexes on a table

```
REINDEX my_table;
```

To rebuild a particular index

```
REINDEX my_index;
```

Dropping an Index

The `DROP INDEX` command removes an index. For example:

```
DROP INDEX title_idx;
```

When loading data, it can be faster to drop all indexes, load, then recreate the indexes.

Creating and Managing Views

Views enable you to save frequently used or complex queries, then access them in a `SELECT` statement as if they were a table. A view is not physically materialized on disk: the query runs as a subquery when you access the view.

If a subquery is associated with a single query, consider using the `WITH` clause of the `SELECT` command instead of creating a seldom-used view.

Creating Views

The `CREATE VIEW` command defines a view of a query. For example:

```
CREATE VIEW comedies AS SELECT * FROM films WHERE kind = 
'comedy';
```

Views ignore `ORDER BY` and `SORT` operations stored in the view.

Dropping Views

The `DROP VIEW` command removes a view. For example:

```
DROP VIEW topten;
```

6. Managing Data

This chapter provides information about managing data and concurrent access in Greenplum Database. It contains the following topics:

About Concurrency Control in Greenplum Database

Greenplum Database and PostgreSQL do not use locks for concurrency control. They maintain data consistency using a multiversion model, Multiversion Concurrency Control (MVCC). MVCC achieves transaction isolation for each database session, and each query transaction sees a snapshot of data. This ensures the transaction sees consistent data that is not affected by other concurrent transactions.

Because MVCC does not use explicit locks for concurrency control, lock contention is minimized and Greenplum Database maintains reasonable performance in multiuser environments. Locks acquired for querying (reading) data do not conflict with locks acquired for writing data.

Greenplum Database provides multiple lock modes to control concurrent access to data in tables. Most Greenplum Database SQL commands automatically acquire the appropriate locks to ensure that referenced tables are not dropped or modified in incompatible ways while a command executes. For applications that cannot adapt easily to MVCC behavior, you can use the `LOCK` command to acquire explicit locks. However, proper use of MVCC generally provides better performance.

Table 6.1 Lock Modes in Greenplum Database

Lock Mode	Associated SQL Commands	Conflicts With
ACCESS SHARE	SELECT	ACCESS EXCLUSIVE
ROW SHARE	SELECT FOR UPDATE, SELECT FOR SHARE	EXCLUSIVE, ACCESS EXCLUSIVE
ROW EXCLUSIVE	INSERT, COPY	SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE
SHARE UPDATE EXCLUSIVE	VACUUM (without FULL), ANALYZE	SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE
SHARE	CREATE INDEX	ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE

Table 6.1 Lock Modes in Greenplum Database

Lock Mode	Associated SQL Commands	Conflicts With
SHARE ROW EXCLUSIVE		ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE
EXCLUSIVE	DELETE, UPDATE[1]	ROW SHARE, ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE
ACCESS EXCLUSIVE	ALTER TABLE, DROP TABLE, TRUNCATE, REINDEX, CLUSTER, VACUUM FULL	ACCESS SHARE, ROW SHARE, ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE

[1] In Greenplum Database, UPDATE and DELETE acquire the more restrictive lock EXCLUSIVE rather than ROW EXCLUSIVE.

Inserting Rows

Use the INSERT command to create rows in a table. This command requires the table name and a value for each column in the table; you may optionally specify the column names in any order. If you do not specify column names, list the data values in the order of the columns in the table, separated by commas.

For example, to specify the column names and the values to insert:

```
INSERT INTO products (name, price, product_no) VALUES
('Cheese', 9.99, 1);
```

For example, to specify only the values to insert:

```
    INSERT INTO products VALUES (1, 'Cheese', 9.99);
```

Usually, the data values are literals (constants), but you can also use scalar expressions. For example:

```
    INSERT INTO films SELECT * FROM tmp_films WHERE date_prod <
    '2004-05-07';
```

You can insert multiple rows in a single command. For example:

```
    INSERT INTO products (product_no, name, price) VALUES
        (1, 'Cheese', 9.99),
        (2, 'Bread', 1.99),
        (3, 'Milk', 2.99);
```

To insert large amounts of data, use external tables or the COPY command. These load mechanisms are more efficient than INSERT for inserting large quantities of rows. See "Loading and Unloading Data" on page 74 for more information about bulk data loading.

The storage model of append-optimized tables is optimized for bulk data loading. Greenplum does not recommend single row INSERT statements for append-optimized tables.

Updating Existing Rows

The `UPDATE` command updates rows in a table. You can update all rows, a subset of all rows, or individual rows in a table. You can update each column separately without affecting other columns.

To perform an update, you need:

- The name of the table and columns to update
- The new values of the columns
- A condition(s) specifying the row(s) to be updated.

For example, the following command updates all products that have a price of *5* to have a price of *10*:

```
UPDATE products SET price = 10 WHERE price = 5;
```

Using `UPDATE` in Greenplum Database has the following restrictions:

- The Greenplum distribution key columns may not be updated.
- If mirrors are enabled, you cannot use `STABLE` or `VOLATILE` functions in an `UPDATE` statement.
- Greenplum Database does not support the `RETURNING` clause.
- Greenplum Database partitioning columns cannot be updated.

Deleting Rows

The `DELETE` command deletes rows from a table. Specify a `WHERE` clause to delete rows that match certain criteria. If you do not specify a `WHERE` clause, all rows in the table are deleted. The result is a valid, but empty, table. For example, to remove all rows from the products table that have a price of *10*:

```
DELETE FROM products WHERE price = 10;
```

To delete all rows from a table:

```
DELETE FROM products;
```

Using `DELETE` in Greenplum Database has similar restrictions to using `UPDATE`:

- If mirrors are enabled, you cannot use `STABLE` or `VOLATILE` functions in an `UPDATE` statement.
- The `RETURNING` clause is not supported in Greenplum Database.

Truncating a Table

Use the `TRUNCATE` command to quickly remove all rows in a table. For example:

```
TRUNCATE mytable;
```

This command empties a table of all rows in one operation. Note that `TRUNCATE` does not scan the table, therefore it does not process inherited child tables or `ON DELETE` rewrite rules. The command truncates only rows in the named table.

Working With Transactions

Transactions allow you to bundle multiple SQL statements in one all-or-nothing operation.

The following are the Greenplum Database SQL transaction commands:

- `BEGIN` or `START TRANSACTION` starts a transaction block.
- `END` or `COMMIT` commits the results of a transaction.
- `ROLLBACK` abandons a transaction without making any changes.
- `SAVEPOINT` marks a place in a transaction and enables partial rollback. You can roll back commands executed after a savepoint while maintaining commands executed before the savepoint.
- `ROLLBACK TO SAVEPOINT` rolls back a transaction to a savepoint.
- `RELEASE SAVEPOINT` destroys a savepoint within a transaction.

Transaction Isolation Levels

Greenplum Database accepts the standard SQL transaction levels as follows:

- *read uncommitted* and *read committed* behave like the standard *read committed*
- *serializable* and *repeatable read* behave like the standard *serializable*

The following information describes the behavior of the Greenplum transaction levels:

- **read committed/read uncommitted** — Provides fast, simple, partial transaction isolation. With *read committed* and *read uncommitted* transaction isolation, `SELECT`, `UPDATE`, and `DELETE` transactions operate on a snapshot of the database taken when the query started.

  A `SELECT` query:

  - Sees data committed before the query starts.
  - Sees updates executed within the transaction.
  - Does not see uncommitted data outside the transaction.
  - Can possibly see changes that concurrent transactions made if the concurrent transaction is commited after the initial read in its own transaction.

  Successive `SELECT` queries in the same transaction can see different data if other concurrent transactions commit changes before the queries start. `UPDATE` and `DELETE` commands find only rows committed before the commands started.

  Read committed or *read uncommitted* transaction isolation allows concurrent transactions to modify or lock a row before `UPDATE` or `DELETE` finds the row. *Read committed* or *read uncommitted* transaction isolation may be inadequate for applications that perform complex queries and updates and require a consistent view of the database.

- **serializable/repeatable read** — Provides strict transaction isolation in which transactions execute as if they run one after another rather than concurrently. Applications on the *serializable* or *repeatable read* level must be designed to retry transactions in case of serialization failures.

  A `SELECT` query:

  - Sees a snapshot of the data as of the start of the transaction (not as of the start of the current query within the transaction).
  - Sees only data committed before the query starts.
  - Sees updates executed within the transaction.
  - Does not see uncommitted data outside the transaction.
  - Does not see changes that concurrent transactions made.

  Successive `SELECT` commands within a single transaction always see the same data.

  `UPDATE`, `DELETE, SELECT FOR UPDATE,` and `SELECT FOR SHARE` commands find only rows committed before the command started. If a concurrent transaction has already updated, deleted, or locked a target row when the row is found, the *serializable* or *repeatable read* transaction waits for the concurrent transaction to update the row, delete the row, or roll back.

  If the concurrent transaction updates or deletes the row, the *serializable* or *repeatable read* transaction rolls back. If the concurrent transaction rolls back, then the *serializable* or *repeatable read* transaction updates or deletes the row.

The default transaction isolation level in Greenplum Database is *read committed*. To change the isolation level for a transaction, declare the isolation level when you `BEGIN` the transaction or use the `SET TRANSACTION` command after the transaction starts.

Vacuuming the Database

Deleted or updated data rows occupy physical space on disk even though new transactions cannot see them. Periodically running the `VACUUM` command removes these expired rows. For example:

```
VACUUM mytable;
```

The `VACUUM` command collects table-level statistics such as the number of rows and pages. Vacuum all tables after loading data, including append-optimized tables. For information about recommended routine vacuum operations, see the *Greenplum Database System Administration Guide*.

Configuring the Free Space Map

Expired rows are held in the *free space map*. The free space map must be sized large enough to hold all expired rows in your database. If not, a regular `VACUUM` command cannot reclaim space occupied by expired rows that overflow the free space map.

`VACUUM FULL` reclaims all expired row space, but it is an expensive operation and can take an unacceptably long time to finish on large, distributed Greenplum Database tables. If the free space map overflows, you can recreate the table with a `CREATE TABLE AS` statement and drop the old table. Greenplum recommends not using `VACUUM FULL`.

Size the free space map with the following server configuration parameters:

```
max_fam_pages
max_fam_relations
```

7. Loading and Unloading Data

Greenplum supports parallel data loading and unloading for large amounts of data, as well as single file, non-parallel import and export for small amounts of data. This chapter covers the following topics:

- Greenplum Database Loading Tools Overview
- Loading Data into Greenplum Database
- Unloading Data from Greenplum Database
- Transforming XML Data
- Formatting Data Files

The first sections of this chapter describe methods for loading and writing data into and out of a Greenplum Database. The last section describes how to format data files.

Greenplum Database Loading Tools Overview

Greenplum provides the following tools for loading and unloading data.

- External Tables enable accessing external files as if they are regular database tables.
- `gpload` provides an interface to the Greenplum Database parallel loader.
- `COPY` is the standard PostgreSQL non-parallel data loading tool.

External Tables

External tables enable accessing external files as if they are regular database tables. Used with `gpfdist,` Greenplum's parallel file distribution program, external tables provide full parallelism by using the resources of all Greenplum segments to load or unload data. Greenplum Database leverages the parallel architecture of the Hadoop Distributed File System to access files on that system.

You can query external table data directly and in parallel using SQL commands such as `SELECT`, `JOIN`, or `SORT EXTERNAL TABLE DATA`, and you can create views for external tables.

The steps for using external tables are:

1. Define the external table.
2. Do one of the following:
   - Start the Greenplum files server(s) if you plan to use the `gpfdist` or `gpdists` protocols.
   - Verify that you have already set up the required one-time configuration for `gphdfs`.
3. Place the data files in the correct location.

4. Query the external table with SQL commands.

Greenplum Database provides readable and writable external tables:

- Readable external tables for data loading. Readable external tables support basic extraction, transformation, and loading (ETL) tasks common to data warehousing. Greenplum Database segment instances read external table data in parallel to optimize large load operations. You cannot modify readable external tables.
- Writable external tables for data unloading. Writable external tables support:
  - Selecting data from database tables to insert into the writable external table.
  - Sending data to an application as a stream of data. For example, unload data from Greenplum Database and send it to an application that connects to another database or ETL tool to load the data elsewhere.
  - Receiving output from Greenplum parallel MapReduce calculations.

  Writable external tables allow only `INSERT` operations.

External tables can be file-based or web-based. External tables using the `file://` protocol are read-only tables.

- Regular (file-based) external tables access static flat files. Regular external tables are rescannable: the data is static while the query runs.
- Web (web-based) external tables access dynamic data sources, either on a web server with the `http://` protocol or by executing OS commands or scripts. Web external tables are not rescannable: the data can change while the query runs.

Dump and restore operate only on external and web external table definitions, not on the data sources.

gpload

`The gpload` data loading utility is the interface to Greenplum's external table parallel loading feature. `gpload` uses a load specification defined in a YAML formatted control file to load data into the target database as follows.

1. Invoke the Greenplum parallel file server program (`gpfdist).`

2. Create an external table definition based on the source data defined.

3. Load the source data into the target table in the database according to `gpload MODE` (Insert, Update or Merge).

COPY

Greenplum Database offers the standard PostgreSQL `COPY` command for loading and unloading data. `COPY` is a non-parallel load/unload mechanism: data is loaded/unloaded in a single process using the Greenplum master database instance. For small amounts of data, `COPY` offers a simple way to move data into or out of a database in a single transaction, without the administrative overhead of setting up an external table.

Loading Data into Greenplum Database

This section covers the following topics.

- Accessing File-Based External Tables
- Using the Greenplum Parallel File Server (gpfdist)
- Using Hadoop Distributed File System (HDFS) Tables
- Command-based Web External Tables
- URL-based Web External Tables
- Using a Custom Format
- Unloading Data from Greenplum Database
- Handling Load Errors
- Optimizing Data Load and Query Performance
- Loading Data with gpload
- Loading Data with COPY
- Optimizing Data Load and Query Performance

Accessing File-Based External Tables

To create an external table definition, you specify the format of your input files and the location of your external data sources. For information about input file formats, see “Formatting Data Files” on page 117.

Use one of the following protocols to access external table data sources. You cannot mix protocols in `CREATE EXTERNAL TABLE` statements.

- `gpfdist:` points to a directory on the file host and serves external data files to all Greenplum Database segments in parallel.
- `gpfdists:` the secure version of `gpfdist`.
- `file://` accesses external data files on a segment host that the Greenplum superuser (`gpadmin`) can access.
- `gphdfs:` accesses files on a Hadoop Distributed File System (HDFS).

`gpfdist` and `gpfdists` require a one-time setup during table creation.

gpfdist

`gpfdist` serves external data files from a directory on the file host to all Greenplum Database segments in parallel. `gpfdist` uncompresses `gzip (.gz)` and `bzip2 (.bz2)` files automatically. Run `gpfdist` on the host on which the external data files reside.

All primary segments access the external file(s) in parallel, subject to the number of segments set in `gp_external_max_segments`. Use multiple `gpfdist` data sources in a `CREATE EXTERNAL TABLE` statement to scale the external table’s scan performance. For more information about configuring this, see “Controlling Segment Parallelism” on page 81.

You can use the wildcard character (`*`) or other C-style pattern matching to denote multiple files to get. The files specified are assumed to be relative to the directory that you specified when you started `gpfdist`.

`gpfdist` is located in `$GPHOME/bin` on your Greenplum Database master host and on each segment host. See the `gpfdist` reference documentation for more information about using `gpfdist` with external tables.

gpfdists

`The gpfdists` protocol is a secure version of gpfdist. `gpfdists` enables encrypted communication and secure identification of the file server and the Greenplum Database to protect against attacks such as eavesdropping and man-in-the-middle attacks.

`gpfdists` implements SSL security in a client/server scheme as follows.

- Client certificates are required.
- Multilingual certificates are not supported.
- A Certificate Revocation List (CRL) is not supported.
- The `TLSv1` protocol is used with the `TLS_RSA_WITH_AES_128_CBC_SHA` encryption algorithm.
- SSL parameters cannot be changed.
- SSL renegotiation is supported.
- The SSL ignore host mismatch parameter is set to `false`.
- Private keys containing a passphrase are not supported for the `gpfdist` file server (server.key) and for the Greenplum Database (client.key).
- Issuing certificates that are appropriate for the operating system in use is the user's responsibility. Generally, converting certificates as shown in https://www.sslshopper.com/ssl-converter.html is supported.

Note: A server started with the `gpfdist --ssl` option can only communicate with the *gpfdists* protocol. A server that was started with `gpfdist` without the `--ssl` option can only communicate with the *gpfdist* protocol.

Use one of the following methods to invoke the *gpfdists* protocol.

- Run `gpfdist` with the `--ssl` option and then use the *gpfdists* protocol in the `LOCATION` clause of a `CREATE EXTERNAL TABLE` statement.
- Use a YAML Control File with the `SSL` option set to true and run `gpload`. Running `gpload` starts the `gpfdist` server with the `--ssl` option, then uses the *gpfdists* protocol.

Important: Do not protect the private key with a passphrase. The server does not prompt for a passphrase for the private key, and loading data fails with an error if one is required.

`gpfdists` requires that the following client certificates reside in the `$PGDATA/gpfdists` directory on each segment.

- The client certificate file, `client.crt`
- The client private key file, `client.key`

- The trusted certificate authorities, root.crt

For an example of loading data into an external table securely, see "Example 3—Multiple gpfdists instances" on page 95.

file

The file:// protocol requires that the external data file(s) reside on a segment host in a location accessible by the Greenplum superuser (gpadmin). The number of URIs that you specify corresponds to the number of segment instances that will work in parallel to access the external table. For example, if you have a Greenplum Database system with 8 primary segments and you specify 2 external files, only 2 of the 8 segments will access the external table in parallel at query time. The number of external files per segment host cannot exceed the number of primary segment instances on that host. For example, if your array has 4 primary segment instances per segment host, you can place 4 external files on each segment host. The host name used in the URI must match the segment host name as registered in the *gp_segment_configuration* system catalog table. Tables based on the file:// protocol can only be readable tables.

The system view pg_max_external_files shows how many external table files are permitted per external table. This view lists the available file slots per segment host when using the file:// protocol. The view is only applicable for the file:// protocol. For example:

```
SELECT * FROM pg_max_external_files;
```

gphdfs

This protocol specifies a path that can contain wild card characters on a Hadoop Distributed File System. TEXT and custom formats are allowed for HDFS files.

When Greenplum links with HDFS files, all the data is read in parallel from the HDFS data nodes into the Greenplum segments for rapid processing. Greenplum determines the connections between the segments and nodes.

Each Greenplum segment reads one set of Hadoop data blocks. For writing, each Greenplum segment writes only the data contained on it.

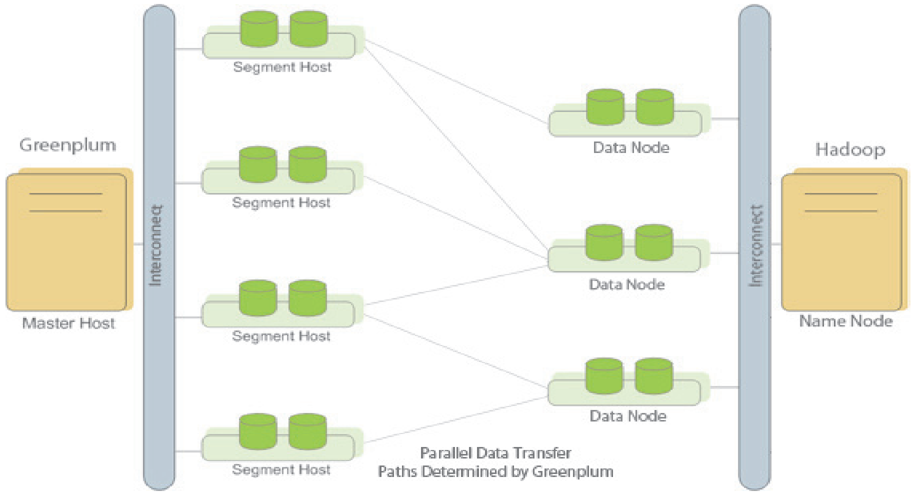


Figure 7.1 External Table Located on a Hadoop Distributed File System

The `FORMAT` clause describes the format of the external table files. Valid file formats are similar to the formatting options available with the PostgreSQL `COPY` command and user-defined formats for the `gphdfs` protocol.

- Delimited text (`TEXT`) for all protocols.
- Comma separated values (`CSV`) format for `gpfdist`, `gpfdists`, and `file` protocols.

If the data in the file does not use the default column delimiter, escape character, null string and so on, you must specify the additional formatting options so that Greenplum Database reads the data in the external file correctly.

The `gphdfs` protocol requires a one-time setup. See “One-time HDFS Protocol Installation”.

Errors in External Table Data

By default, if external table data contains an error, the command fails and no data loads into the target database table. Define the external table with single row error handling to enable loading correctly-formatted rows and to isolate data errors in external table data. See “Handling Load Errors”.

The `gpfdist` file server uses the `HTTP` protocol. External table queries that use `LIMIT` end the connection after retrieving the rows, causing an `HTTP` socket error. If you use `LIMIT` in queries of external tables that use the `gpfdist://` or `http://` protocols, ignore these errors – data is returned to the database as expected.

Using the Greenplum Parallel File Server (gpfdist)

The `gpfdist` protocol provides the best performance and is the easiest to set up. `gpfdist` ensures optimum use of all segments in your Greenplum Database system for external table reads.

This section describes the setup and management tasks for using `gpfdist` with external tables.

- About gpfdist Setup and Performance
- Controlling Segment Parallelism
- Installing gpfdist
- Starting and Stopping gpfdist
- Troubleshooting gpfdist

About gpfdist Setup and Performance

Consider the following scenarios for optimizing your ETL network performance.

- Allow network traffic to use all ETL host Network Interface Cards (NICs) simultaneously. Run one instance of `gpfdist` on the ETL host, then declare the host name of each NIC in the `LOCATION` clause of your external table definition (see "Creating External Tables - Examples" on page 94).

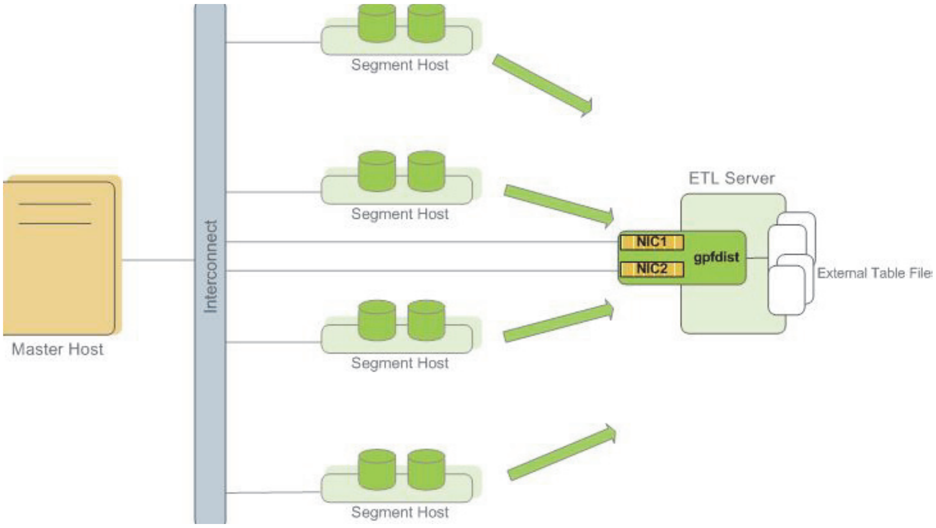


Figure 7.2 External Table Using Single gpfdist Instance with Multiple NICs

- Divide external table data equally among multiple gpfdist instances on the ETL host. For example, on an ETL system with two NICs, run two gpfdist instances (one on each NIC) to optimize data load performance and divide the external table data files evenly between the two gpfdists.

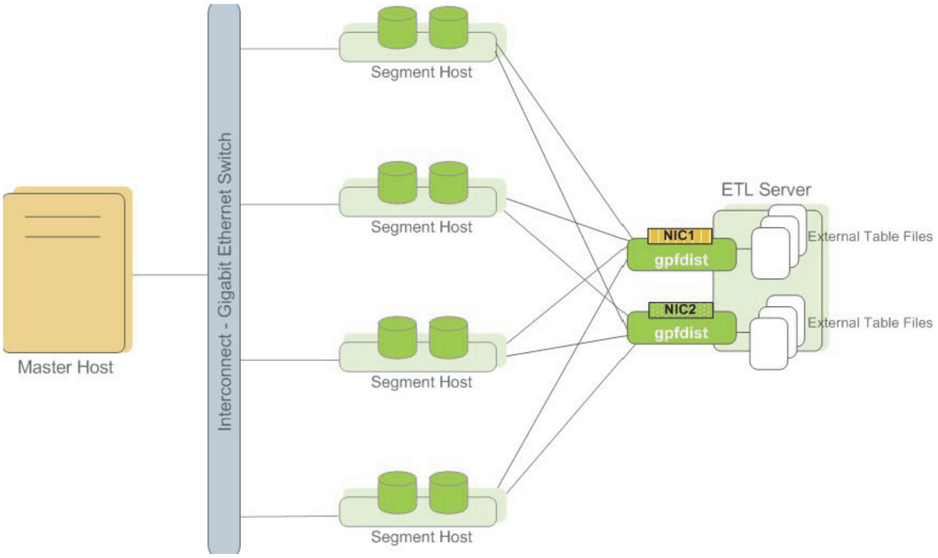


Figure 7.3 External Tables Using Multiple gpfdist Instances with Multiple NICs

Note: Use pipes (|) to separate formatted text when you submit files to gpfdist. Greenplum Database encloses comma-separated text strings in single or double quotes. gpfdist has to remove the quotes to parse the strings. Using pipes to separate formatted text avoids the extra step and improves performance.

Controlling Segment Parallelism

The gp_external_max_segs server configuration parameter controls the number of segment instances that can access a single gpfdist instance simultaneously. 64 is the default. You can set the number of segments such that some segments process external data files and some perform other database processing. Set this parameter in the postgresql.conf file of your master instance.

Installing gpfdist

gpfdist is installed in $GPHOME/bin of your Greenplum Database master host installation. Run gpfdist from a machine other than the Greenplum Database master, such as on a machine devoted to ETL processing. If you want to install gpfdist on your ETL server, get it from the *Greenplum Load Tools* package and follow its installation instructions.

Starting and Stopping gpfdist

You can start gpfdist in your current directory location or in any directory that you specify. The default port is 8080.

From your current directory, type:

```
& gpfdist
```

From a different directory, specify the directory from which to serve files, and optionally, the HTTP port to run on.

To start `gpfdist` in the background and log output messages and errors to a log file:

```
$ gpfdist -d /var/load_files -p 8081 -l /home/gpadmin/log &
```

For multiple `gpfdist` instances on the same ETL host (see Figure 7.3), use a different base directory and port for each instance. For example:

```
$ gpfdist -d /var/load_files1 -p 8081 -l /home/gpadmin/log1 &
$ gpfdist -d /var/load_files2 -p 8082 -l /home/gpadmin/log2 &
```

To stop `gpfdist` when it is running in the background:

First find its process id:

```
$ ps -ef | grep gpfdist
```

Then kill the process, for example (where 3456 is the process ID in this example):

```
$ kill 3456
```

Troubleshooting gpfdist

The segments access `gpfdist` at runtime. Ensure that the Greenplum segment hosts have network access to `gpfdist`. `gpfdist` is a web server: test connectivity by running the following command from each host in the Greenplum array (segments and master):

```
$ wget http://gpfdist_hostname:port/filename
```

The `CREATE EXTERNAL TABLE` definition must have the correct host name, port, and file names for `gpfdist`. Specify file names and paths relative to the directory from which `gpfdist` serves files (the directory path specified when `gpfdist` started). See "Creating External Tables - Examples" on page 94.

If you start `gpfdist` on your system and IPv6 networking is disabled, `gpfdist` displays this warning message when testing for an IPv6 port.

```
[WRN gpfdist.c:2050] Creating the socket failed
```

If the corresponding IPv4 port is available, `gpfdist` uses that port and the warning for IPv6 port can be ignored. To see information about the ports that `gpfdist` tests, use the `-V` option.

For information about IPv6 and IPv4 networking, see your operating system documentation.

Using Hadoop Distributed File System (HDFS) Tables

Greenplum Database leverages the parallel architecture of a Hadoop Distributed File System to read and write data files efficiently with the `gphdfs` protocol. There are three components to using HDFS:

- One-time setup
- Grant privileges for the `HDFS` protocol
- Specify Hadoop Distributed File System data in an external table definition

One-time HDFS Protocol Installation

Install and configure Hadoop for use with `gphdfs` as follows.

1. Install Java 1.6 or later on **all** segments.
2. Greenplum Database includes the following Greenplum HD targets:
   - The Pivotal HD 1.0 target (`gphd-2.0`). A distribution of Hadoop 2.0.
   - The Greenplum HD target (`gphd-1.0`, `gphd-1.1`, and `gphd-1.2`)

     The default target. To use any other target, set the Server Configuration Parameter to one of the values shown in Table 7.1, "Server Configuration Parameters for Hadoop Targets" on page 84.
   - The Greenplum MR target for MR v. 1.0 or 1.2 (`gpmr-1.0` and `gpmr-1.2`)

     If you are using `gpmr-1.0` or `gpmr-1.2`, you can install the MapR client program. For information about setting up the MapR client, see the MapR documentation. http://doc.mapr.com/display/MapR/Home.
   - The Greenplum Cloudera Hadoop Connect (`cdh3u2` and `cdh4.1`).

     For CDH 4.1, only CDH4 with MRv1 is supported.
3. After installation, ensure that the Greenplum system user (`gpadmin`) has read and execute access to the Hadoop libraries or to the Greenplum MR client.
4. Set the following environment variables on all segments.

   `JAVA_HOME` – the Java home directory

   `HADOOP_HOME` – the Hadoop home directory

   For example, add lines such as the following to the `gpadmin` user `.bashrc` profile.

   ```
   export JAVA_HOME=/opt/jdk1.6.0_21
   export HADOOP_HOME=/bin/hadoop
   ```

   Note: The variables must be set in `.bashrc` because Greenplum Database always uses SSH.

5. Set the following Server Configuration Parameters.

Table 7.1 Server Configuration Parameters for Hadoop Targets

Configuration Parameter	Description	Default Value	Set Classifications

`gp_hadoop_target_version`	The Hadoop target. Choose one of the following.
	`gphd-1.0`
	`gphd-1.1`
	`gphd-1.2`
	`gphd-2.0`
	`gpmr-1.0`
	`gpmr-1.2`
	`cdh3u2`
	`cdh4.1`
		`gphd-1.1`	master
			session
			reload

`gp_hadoop_home`	Same value as `HADOOP_HOME`.	`NULL`	master session reload

6. Restart the database.

Grant Privileges for the HDFS Protocol

To enable privileges required to create external tables that access files on HDFS:

1. Grant the following privileges on `gphdfs` to the owner of the external table.
   - Grant `SELECT` privileges to enable creating readable external tables on HDFS.
   - Grant `INSERT` privileges to enable creating writable external tables on HDFS.

   Use the `GRANT` command to grant read privileges (`SELECT`) and, if needed, write privileges (`INSERT`) on HDFS to the Greenplum system user (`gpadmin`).

   ```
   GRANT INSERT ON PROTOCOL gphdfs TO gpadmin;
   ```

2. Greenplum Database uses Greenplum OS credentials to connect to HDFS. Grant read privileges and, if needed, write privileges to HDFS to the Greenplum administrative user (`gpadmin` OS user).

Specify HDFS Data in an External Table Definition

`CREATE EXTERNAL TABLE's LOCATION` option for Hadoop files has the following format:

```
LOCATION ('gphdfs://hdfs_host[:port]/path/filename.txt')
```

- For any connector except `gpmr-1.0-gnet-1.0.0.1`, specify a name node port. Do not specify a port with the `gpmr-1.0-gnet-1.0.0.1` connector.

Restrictions for `HDFS` files are as follows.

- You can specify one path for a readable external table with `gphdfs`. Wildcard characters are allowed. If you specify a directory, the default is all files in the directory.

  You can specify only a directory for writable external tables.

- Format restrictions are as follows.
  - Only TEXT format is allowed for readable and writable external tables.
  - Only the gphdfs_import formatter is allowed for readable external tables with a custom format.
  - Only the gphdfs_export formatter is allowed for writable external tables with a custom format.
- You can set compression only for writable external tables. Compression settings are automatic for readable external tables.

Setting Compression Options for Hadoop Writable External Tables

Compression options for Hadoop Writable External Tables use the form of a URI query and begin with a question mark. Specify multiple compression options with an ampersand (&).

Table 7.2 Compression Options

Compression Option	Values	Default Value
compress	true or false	false
compression_type	BLOCK or RECORD	RECORD
codec	Codec class name	GzipCodec for text format and DefaultCodec for gphdfs_export format.

Place compression options in the query portion of the URI.

HDFS Readable and Writable External Table Examples

The following code defines a readable external table for an HDFS file named *filename.txt* on port 8081.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gphdfs://hdfshost-1:8081/data/filename.txt')
   FORMAT 'TEXT' (DELIMITER ',');
```

Note: Omit the port number when using the gpmr-1.0-gnet-1.0.0.1 connector.

The following code defines a set of readable external tables that have a custom format located in the same HDFS directory on port 8081.

```
=# CREATE EXTERNAL TABLE ext_expenses
   LOCATION ('gphdfs://hdfshost-1:8081/data/custdat*.dat')
   FORMAT 'custom' (formatter='gphdfs_import');
```

Note: Omit the port number when using the gpmr-1.0-gnet-1.0.0.1 connector.

The following code defines an HDFS directory for a writable external table on port 8081 with all compression options specified.

```
=# CREATE WRITABLE EXTERNAL TABLE ext_expenses
   LOCATION ('gphdfs://hdfshost-1:8081/data/
   ?compress=true&compression_type=RECORD
   &codec=org.apache.hadoop.io.compress.DefaultCodec')
   FORMAT 'custom' (formatter='gphdfs_export');
```

Note: Omit the port number when using the `gpmr-1.0-gnet-1.0.0.1` connector.

Because the previous code uses the default compression options for `compression_type` and `codec`, the following command is equivalent.

```
=# CREATE WRITABLE EXTERNAL TABLE ext_expenses
   LOCATION    ('gphdfs://hdfshost-1:8081/data?compress=true')
   FORMAT 'custom' (formatter='gphdfs_export');
```

Note: Omit the port number when using the `gpmr-1.0-gnet-1.0.0.1` connector.

Reading and Writing Custom-Formatted HDFS Data

Use MapReduce and the `CREATE EXTERNAL TABLE` command to read and write data with custom formats on HDFS.

To read custom-formatted data:

1. Author and run a MapReduce job that creates a copy of the data in a format accessible to Greenplum Database.
2. Use `CREATE EXTERNAL TABLE` to read the data into Greenplum Database.

See "Example 1 - Read Custom-Formatted Data from HDFS" on page 87.

To write custom-formatted data:

1. Write the data.
2. Author and run a MapReduce program to convert the data to the custom format and place it on the Hadoop Distributed File System.

See "Example 2 - Write Custom-Formatted Data from Greenplum Database to HDFS" on page 88.

MapReduce is written in Java. Greenplum provides Java APIs for use in the MapReduce code. The Javadoc is available in the `$GPHOME/docs` directory. To view the Javadoc, expand the file gphd-xnet-1.0.0.0-javadoc`.tgz` and open `index.html`. The Javadoc documents the following packages:

```
com.emc.greenplum.gpdb.hadoop.io
com.emc.greenplum.gpdb.hadoop.mapred
com.emc.greenplum.gpdb.hadoop.mapreduce.lib.input
com.emc.greenplum.gpdb.hadoop.mapreduce.lib.output
```

The HDFS cross-connect packages contain the Java library, which contains the packages `GPDBWritable`, `GPDBInputFormat`, and `GPDBOutputFormat`. The Java packages are available in `$GPHOME/lib/hadoop`. For Greenplum HD, compile and run the MapReduce job with `gphd_xnet_1.0.0.0.jar`. For Greenplum MR, compile and run the MapReduce job with `gpmr_xnet_1.0.0.0.jar`.

To make the Java library available to all Hadoop users, the Hadoop cluster administrator should place the corresponding `gphdfs` connector jar in the `$HADOOP_HOME/lib` directory and restart the job tracker. If this is not done, a Hadoop user can still use the `gphdfs` connector jar; but with the *distributed cache* technique.

Example 1 - Read Custom-Formatted Data from HDFS

The sample code makes the following assumptions.

- The data is contained in HDFS directory `/demo/data/temp` and the name node is running on port 8081.
- This code writes the data in Greenplum Database format to `/demo/data/MRTest1` on HDFS.
- The data contains the following columns, in order.
    1. A long integer
    2. A Boolean
    3. A text string

Sample MapReduce Code

```
import com.emc.greenplum.gpdb.hadoop.io.GPDBWritable;
import com.emc.greenplum.gpdb.hadoop.mapreduce.lib.input.GPDBInputFormat;
import
com.emc.greenplum.gpdb.hadoop.mapreduce.lib.output.GPDBOutputFormat;

import java.io.*;
import java.util.*;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.conf.*;
import org.apache.hadoop.io.*;
import org.apache.hadoop.mapreduce.*;
import org.apache.hadoop.mapreduce.lib.output.*;
import org.apache.hadoop.mapreduce.lib.input.*;
import org.apache.hadoop.util.*;

public class demoMR {
    /*
     * Helper routine to create our generic record. This section shows the
     * format of the data. Modify as necessary.
     */
     public static GPDBWritable generateGenericRecord() throws
      IOException{
        int[] colType = new int[3];
        colType[0] = GPDBWritable.BIGINT;
        colType[1] = GPDBWritable.BOOLEAN;
        colType[2] = GPDBWritable.VARCHAR;

    /*
     * This section passes the values of the data. Modify as necessary.
     */
        GPDBWritable gw = new GPDBWritable(colType);
        gw.setLong   (0, (long)12345);
        gw.setBoolean(1, true);
        gw.setString (2, "abcdef");

        return gw;
    }

    /*
     * DEMO Map/Reduce class test1
     * -- Regardless of the input, this section dumps the generic record
```

```
   *    into GPDBFormat/
   */
  public static class Map_test1 extends Mapper<LongWritable, Text,
   LongWritable, GPDBWritable> {
  private LongWritable word = new LongWritable(1);

  public void map(LongWritable key, Text value, Context context) throws
   IOException {
      try {
            GPDBWritable gw = generateGenericRecord();
            context.write(word, gw);
      } catch (Exception e) { throw new IOException (e.getMessage()); }
  }
}

public static void runTest1() throws Exception{
Configuration conf = new Configuration(true);
   Job job = new Job(conf, "test1");

   job.setJarByClass(demoMR.class);

   job.setInputFormatClass(TextInputFormat.class);

   job.setOutputKeyClass   (LongWritable.class);
   job.setOutputValueClass (GPDBWritable.class);
   job.setOutputFormatClass(GPDBOutputFormat.class);

   job.setMapperClass(Map_test1.class);

   FileInputFormat.setInputPaths (job, new Path("/demo/data/tmp"));
   GPDBOutputFormat.setOutputPath(job, new Path("/demo/data/MRTest1"));

   job.waitForCompletion(true);
}
```

Run CREATE EXTERNAL TABLE

The Hadoop location corresponds to the output path in the MapReduce job.

```
=# CREATE EXTERNAL TABLE demodata
   LOCATION ('gphdfs://hdfshost-1:8081/demo/data/MRTest1')
   FORMAT 'custom' (formatter='gphdfs_import');
```

Note: Omit the port number when using the `gpmr-1.0-gnet-1.0.0.1` connector.

Example 2 - Write Custom-Formatted Data from Greenplum Database to HDFS

The sample code makes the following assumptions.

- The data in Greenplum Database format is located on the Hadoop Distributed File System on `/demo/data/writeFromGPDB_42` on port 8081.
- This code writes the data to `/demo/data/MRTest2` on port 8081.

1. Run a SQL command to create the writable table.

```
=# CREATE WRITABLE EXTERNAL TABLE demodata
   LOCATION ('gphdfs://hdfshost-1:8081/demo/data/MRTest2')
```

```
    FORMAT 'custom' (formatter='gphdfs_export');
```

2. Author and run code for a MapReduce job. Use the same import statements shown in “Example 1 - Read Custom-Formatted Data from HDFS” on page 87.

Note: Omit the port number when using the `gpmr-1.0-gnet-1.0.0.1` connector.

MapReduce Sample Code

```
/*
 * DEMO Map/Reduce class test2
 * -- Convert GPDBFormat back to TEXT
 */

public static class Map_test2 extends Mapper<LongWritable, GPDBWritable,
       Text, NullWritable> {
  public void map(LongWritable key, GPDBWritable value, Context context )
         throws IOException {
    try {
      context.write(new Text(value.toString()), NullWritable.get());
    } catch (Exception e) { throw new IOException (e.getMessage()); }
  }
}

public static void runTest2() throws Exception{
Configuration conf = new Configuration(true);
    Job job = new Job(conf, "test2");

    job.setJarByClass(demoMR.class);

    job.setInputFormatClass(GPDBInputFormat.class);

    job.setOutputKeyClass  (Text.class);
    job.setOutputValueClass(NullWritable.class);
    job.setOutputFormatClass(TextOutputFormat.class);

    job.setMapperClass(Map_test2.class);

    GPDBInputFormat.setInputPaths (job,
     new Path("/demo/data/writeFromGPDB_42"));
    GPDBOutputFormat.setOutputPath(job, new Path("/demo/data/MRTest2"));

    job.waitForCompletion(true);
}
```

Creating and Using Web External Tables

`CREATE EXTERNAL WEB TABLE` creates a web table definition. Web external tables allow Greenplum Database to treat dynamic data sources like regular database tables. Because web table data can change as a query runs, the data is not rescannable.

You can define command-based or URL-based web external tables. The definition forms are distinct: you cannot mix command-based and URL-based definitions.

Command-based Web External Tables

The output of a shell command or script defines command-based web table data. Specify the command in the `EXECUTE` clause of `CREATE EXTERNAL WEB TABLE.` The data is current as of the time the command runs. The `EXECUTE` clause runs the shell command or script on the specified master, and/or segment host or hosts. The command or script must reside on the hosts corresponding to the host(s) defined in the `EXECUTE` clause.

By default, the command is run on segment hosts when active segments have output rows to process. For example, if each segment host runs four primary segment instances that have output rows to process, the command runs four times per segment host. You can optionally limit the number of segment instances that execute the web table command. All segments included in the web table definition in the `ON` clause run the command in parallel.

The command that you specify in the external table definition executes from the database and cannot access environment variables from `.bashrc` or `.profile`. Set environment variables in the `EXECUTE` clause. For example:

```
=# CREATE EXTERNAL WEB TABLE output (output text)
    EXECUTE 'PATH=/home/gpadmin/programs; export PATH;
myprogram.sh'
    FORMAT 'TEXT';
```

Scripts must be executable by the `gpadmin` user and reside in the same location on the master or segment hosts.

The following command defines a web table that runs a script. The script runs on each segment host where a segment has output rows to process.

```
=# CREATE EXTERNAL WEB TABLE log_output
    (linenum int, message text)
    EXECUTE '/var/load_scripts/get_log_data.sh' ON HOST
    FORMAT 'TEXT' (DELIMITER '|');
```

URL-based Web External Tables

A URL-based web table accesses data from a web server using the HTTP protocol. Web table data is dynamic: the data is not rescannable.

Specify the `LOCATION` of files on a web server using `http://`. The web data file(s) must reside on a web server that Greenplum segment hosts can access. The number of URLs specified corresponds to the number of segment instances that work in parallel to access the web table. For example, if you specify 2 external files to a Greenplum Database system with 8 primary segments, 2 of the 8 segments access the web table in parallel at query runtime.

The following sample command defines a web table that gets data from several URLs.

```
=# CREATE EXTERNAL WEB TABLE ext_expenses (name text,
  date date, amount float4, category text, description text)
  LOCATION (
  'http://intranet.company.com/expenses/sales/file.csv',
  'http://intranet.company.com/expenses/exec/file.csv',
  'http://intranet.company.com/expenses/finance/file.csv',
  'http://intranet.company.com/expenses/ops/file.csv',
  'http://intranet.company.com/expenses/marketing/file.csv',
  'http://intranet.company.com/expenses/eng/file.csv'
   )
  FORMAT 'CSV' ( HEADER );
```

Loading Data Using an External Table

Use SQL commands such as INSERT and SELECT to query a readable external table, the same way that you query a regular database table. For example, to load travel expense data from an external table, *ext_expenses*, into a database table, *expenses_travel*:

```
=# INSERT INTO expenses_travel
    SELECT * from ext_expenses where category='travel';
```

To load all data into a new database table:

```
=# CREATE TABLE expenses AS SELECT * from ext_expenses;
```

Loading and Writing Non-HDFS Custom Data

Greenplum supports TEXT and CSV formats for importing and exporting data. You can load and write the data in other formats by defining and using a custom format or custom protocol.

- Using a Custom Format
- Using a Custom Protocol

For information about importing custom data from HDFS, see "Reading and Writing Custom-Formatted HDFS Data" on page 86.

Using a Custom Format

You specify a custom data format in the FORMAT clause of CREATE EXTERNAL TABLE.

FORMAT 'CUSTOM' (formatter=*format_function*, *key1*=*val1*,...*keyn*=*valn*)

Where the 'CUSTOM' keyword indicates that the data has a custom format and formatter specifies the function to use to format the data, followed by comma-separated parameters to the formatter function.

Greenplum Database provides functions for formatting fixed-width data, but you must author the formatter functions for variable-width data. The steps are as follows.

1. Author and compile input and output functions as a shared library.
2. Specify the shared library function with CREATE FUNCTION in Greenplum Database.
3. Use the formatter parameter of CREATE EXTERNAL TABLE's FORMAT clause to call the function.

Importing and Exporting Fixed Width Data

Specify custom formats for fixed-width data with the Greenplum Database functions `fixedwith_in` and `fixedwidth_out`. These functions already exist in the file *$GPHOME\share\postgresql\cdb_external_extensions.sql*. The following example declares a custom format, then calls the `fixedwidth_in` function to format the data.

```
CREATE READABLE EXTERNAL TABLE students (
name varchar(20), address varchar(30), age int)
LOCATION ('file://<host>/file/path/')
FORMAT 'CUSTOM' (formatter=fixedwidth_in,
        name='20', address='30', age='4');
```

The following options specify how to import fixed width data.

- Read all the data.

  To load all the fields on a line of fixed with data, you must load them in their physical order. You must specify the field length, but cannot specify a starting and ending position. The fields names in the fixed width arguments must match the order in the field list at the beginning of the `CREATE TABLE` command.

- Set options for blank and null characters.

  Trailing blanks are trimmed by default. To keep trailing blanks, use the `preserve_blanks=on` option.You can reset the trailing blanks option to the default with the `preserve_blanks=off` option.

  Use the null=`'null_string_value'` option to specify a value for null characters.

  - If you specify `preserve_blanks=on`, you must also define a value for null characters.

  - If you specify `preserve_blanks=off`, null is not defined, and the field contains only blanks, Greenplum writes a null to the table. If null is defined, Greenplum writes an empty string to the table.

  Use the `line_delim='line_ending'` parameter to specify the line ending character. The following examples cover most cases. The E specifies an escape string constant.

  ```
  line_delim=E'\n'
  line_delim=E'\r'
  line_delim=E'\r\n'
  line_delim='abc'
  ```

Examples: Read Fixed-Width Data

The following examples show how to read fixed-width data.

Example 1 – Loading a table with all fields defined

```
CREATE READABLE EXTERNAL TABLE students (
name varchar(20), address varchar(30), age int)
LOCATION ('file://<host>/file/path/')
FORMAT 'CUSTOM' (formatter=fixedwidth_in,
        name=20, address=30, age=4);
```

Example 2 – Loading a table with PRESERVED_BLANKS ON

```
CREATE READABLE EXTERNAL TABLE students (
name varchar(20), address varchar(30), age int)
LOCATION ('gpfdist://<host>:<portNum>/file/path/')
FORMAT 'CUSTOM' (formatter=fixedwidth_in,
        name=20, address=30, age=4,
        preserve_blanks='on',null='NULL');
```

Example 3 – Loading data with no line delimiter

```
CREATE READABLE EXTERNAL TABLE students (
name varchar(20), address varchar(30), age int)
LOCATION ('file://<host>/file/path/')
FORMAT 'CUSTOM' (formatter=fixedwidth_in,
        name='20', address='30', age='4', line_delim='?@')
```

Example 4 – Create a writable external table with a \r\n line delimiter

```
CREATE WRITABLE EXTERNAL TABLE students_out (
name varchar(20), address varchar(30), age int)
LOCATION ('gpfdist://<host>:<portNum>/file/path/')
FORMAT 'CUSTOM' (formatter=fixedwidth_out,
        name=20, address=30, age=4, line_delim=E'\r\n');
```

Using a Custom Protocol

Greenplum provides protocols such as `gpfdist`, `http`, and `file` for accessing data over a network, or you can author a custom protocol. You can use the standard data formats, `TEXT` and `CSV`, or a custom data format with custom protocols.

You can create a custom protocol whenever the available built-in protocols do not suffice for a particular need. For example, if you need to connect Greenplum Database in parallel to another system directly, and stream data from one to the other without the need to materialize the system data on disk or use an intermdiate process such as `gpfdist`.

1. Author the send, receive, and (optionally) validator functions in C, with a predefined API. These functions are compiled and registered with the Greenplum Database. For an example custom protocol, see "Example Custom Data Access Protocol" on page 120.
2. After writing and compiling the read and write functions into a shared object (.so), declare a database function that points to the .so file and function names.

   The following examples use the compiled import and export code.

   ```
   CREATE FUNCTION myread() RETURNS integer
   as '$libdir/gpextprotocol.so', 'myprot_import'
   LANGUAGE C STABLE;
   ```

```
CREATE FUNCTION mywrite() RETURNS integer
as '$libdir/gpextprotocol.so', 'myprot_export'
LANGUAGE C STABLE;
```

The format of the optional function is:

```
CREATE OR REPLACE FUNCTION myvalidate() RETURNS void
AS '$libdir/gpextprotocol.so', 'myprot_validate'
LANGUAGE C STABLE;
```

3. Create a protocol that accesses these functions. `Validatorfunc` is optional.

```
CREATE TRUSTED PROTOCOL myprot(
   writefunc='mywrite'
   readfunc='myread',
   validatorfunc='myvalidate');
```

4. Grant access to any other users, as necessary

```
GRANT ALL ON PROTOCOL myprot TO otheruser
```

5. Use the protocol in readable or writable external tables.

```
CREATE WRITABLE EXTERNAL TABLE ext_sales(LIKE sales)
LOCATION ('myprot://<meta>/<meta>/…')
FORMAT 'TEXT';

CREATE READABLE EXTERNAL TABLE ext_sales(LIKE sales)
LOCATION('myprot://<meta>/<meta>/…')
FORMAT 'TEXT';
```

Declare custom protocols with the SQL command `CREATE TRUSTED PROTOCOL`, then use the `GRANT` command to grant access to your users. For example:

- Allow a user to create a readable external table with a trusted protocol
  ```
  GRANT SELECT ON PROTOCOL <protocol name> TO <user name>
  ```
- Allow a user to create a writable external table with a trusted protocol
  ```
  GRANT INSERT ON PROTOCOL <protocol name> TO <user name>
  ```
- Allow a user to create readable and writable external tables with a trusted protocol
  ```
  GRANT ALL ON PROTOCOL <protocol name> TO <user name>
  ```

Creating External Tables - Examples

The following examples show how to define external data with different protocols. Each `CREATE EXTERNAL TABLE` command can contain only one protocol.

Note: When using IPv6, always enclose the numeric IP addresses in square brackets.

Start `gpfdist` before you create external tables with the `gpfdist` protocol. The following code starts the `gpfdist` file server program in the background on port *8081* serving files from directory */var/data/staging*. The logs are saved in */home/gpadmin/log*.

```
gpfdist -p 8081 -d /var/data/staging -l /home/gpadmin/log &
```

The CREATE EXTERNAL TABLE SQL command defines external tables, the location and format of the data to load, and the protocol to use to load the data, but does not load data into the table. For example, the following command creates an external table, ext_expenses, from pipe ('|') delimited text data located on etlhost-1:8081 and etlhost-2:8081. See the *Greenplum Database Reference Guide* for information about CREATE EXTERNAL TABLE.

Example 1—Single gpfdist instance on single-NIC machine

Creates a readable external table, *ext_expenses,* using the gpfdist protocol. The files are formatted with a pipe (|) as the column delimiter.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date, amount float4, category text, desc1 text )
   LOCATION ('gpfdist://etlhost-1:8081/*',
             'gpfdist://etlhost-1:8082/*')
   FORMAT 'TEXT' (DELIMITER '|');
```

Example 2—Multiple gpfdist instances

Creates a readable external table, *ext_expenses,* using the gpfdist protocol from all files with the *txt* extension. The column delimiter is a pipe (|) and NULL (' ') is a space.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gpfdist://etlhost-1:8081/*.txt',
             'gpfdist://etlhost-2:8081/*.txt')
   FORMAT 'TEXT' ( DELIMITER '|' NULL ' ') ;
```

Example 3—Multiple gpfdists instances

Creates a readable external table, *ext_expenses,* from all files with the *txt* extension using the gpfdists protocol. The column delimiter is a pipe (|) and NULL (' ') is a space. For information about the location of security certificates, see "gpfdists" on page 77.

1. Run gpfdist with the --ssl option.
2. Run the following command.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gpfdists://etlhost-1:8081/*.txt',
             'gpfdists://etlhost-2:8082/*.txt')
   FORMAT 'TEXT' ( DELIMITER '|' NULL ' ') ;
```

Example 4—Single gpfdist instance with error logging

Uses the gpfdist protocol to create a readable external table, *ext_expenses,* from all files with the *txt* extension. The column delimiter is a pipe (|) and NULL (' ') is a space.

Access to the external table is single row error isolation mode. Input data formatting errors are written to the error table, `err_customer`, with a description of the error. Query `err_customer` to see the errors, then fix the issues and reload the rejected data. If the error count on a segment is greater than five (the `SEGMENT REJECT LIMIT` value), the entire external table operation failes and no rows are processed.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gpfdist://etlhost-1:8081/*.txt',
             'gpfdist://etlhost-2:8082/*.txt')
   FORMAT 'TEXT' ( DELIMITER '|' NULL ' ')
   LOG ERRORS INTO err_customer SEGMENT REJECT LIMIT 5;
```

To create the readable *ext_expenses* table from CSV-formatted text files:

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gpfdist://etlhost-1:8081/*.txt',
             'gpfdist://etlhost-2:8082/*.txt')
   FORMAT 'CSV' ( DELIMITER ',' )
   LOG ERRORS INTO err_customer SEGMENT REJECT LIMIT 5;
```

Example 5—TEXT Format on a Hadoop Distributed File Server

Creates a readable external table, *ext_expenses,* using the `gphdfs` protocol. The column delimiter is a pipe (|).

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gphdfs://hdfshost-1:8081/data/filename.txt')
   FORMAT 'TEXT' (DELIMITER '|');
```

Note: gphdfs requires only one data path.

For examples of reading and writing custom formatted data on a Hadoop Distributed File System, see “Reading and Writing Custom-Formatted HDFS Data” on page 86.

Example 6—Multiple files in CSV format with header rows

Creates a readable external table, *ext_expenses,* using the `file` protocol. The files are `CSV` format and have a header row.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('file://filehost:5432/data/international/*',
             'file://filehost:5432/data/regional/*'
             'file://filehost:5432/data/supplement/*.csv')
   FORMAT 'CSV' (HEADER);
```

Example 7—Readable Web External Table with Script

Creates a readable web external table that executes a script once per segment host:

```
=# CREATE EXTERNAL WEB TABLE log_output (linenum int,
  message text)
 EXECUTE '/var/load_scripts/get_log_data.sh' ON HOST
 FORMAT 'TEXT' (DELIMITER '|');
```

Example 8—Writable External Table with gpfdist

Creates a writable external table, *sales_out,* that uses `gpfdist` to write output data to the file *sales.out*. The column delimiter is a pipe (|) and NULL (‘ ‘) is a space. The file will be created in the directory specified when you started the gpfdist file server.

```
=# CREATE WRITABLE EXTERNAL TABLE sales_out (LIKE sales)
   LOCATION ('gpfdist://etl1:8081/sales.out')
   FORMAT 'TEXT' ( DELIMITER '|' NULL ' ')
   DISTRIBUTED BY (txn_id);
```

Example 9—Writable External Web Table with Script

Creates a writable external web table, *campaign_out*, that pipes output data received by the segments to an executable script, *to_adreport_etl.sh*:

```
=# CREATE WRITABLE EXTERNAL WEB TABLE campaign_out
   (LIKE campaign)
   EXECUTE '/var/unload_scripts/to_adreport_etl.sh'
   FORMAT 'TEXT' (DELIMITER '|');
```

Example 10—Readable and Writable External Tables with XML Transformations

Greenplum Database can read and write XML data to and from external tables with gpfdist. For information about setting up an XML transform, see "Transforming XML Data" on page 106.

Handling Load Errors

Readable external tables are most commonly used to select data to load into regular database tables. You use the `CREATE TABLE AS SELECT` or `INSERT INTO` commands to query the external table data. By default, if the data contains an error, the entire command fails and the data is not loaded into the target database table.

The `SEGMENT REJECT LIMIT` clause allows you to isolate format errors in external table data and to continue loading correctly formatted rows. Use `SEGMENT REJECT LIMIT` to set an error threshold, specifying the reject limit *`count`* as number of `ROWS` (the default) or as a `PERCENT` of total rows (1-100).

The entire external table operation is aborted, and no rows are processed, if the number of error rows reaches the `SEGMENT REJECT LIMIT`. The limit of error rows is per-segment, not per entire operation. The operation processes all good rows, and it discards or logs any erroneous rows into an error table (if you specified an error table), if the number of error rows does not reach the `SEGMENT REJECT LIMIT`.

The `LOG ERRORS INTO` clause allows you to keep error rows for further examination. Use `LOG ERRORS INTO` to declare an error table in which to write error rows.

When you set `SEGMENT REJECT LIMIT`, Greenplum scans the external data in single row error isolation mode. Single row error isolation mode applies to external data rows with format errors such as extra or missing attributes, attributes of a wrong data type, or invalid client encoding sequences. Greenplum does not check constraint errors, but you can filter constraint errors by limiting the `SELECT` from an external table at runtime. For example, to eliminate duplicate key errors:

```
=# INSERT INTO table_with_pkeys
    SELECT DISTINCT * FROM external_table;
```

Define an External Table with Single Row Error Isolation

The following example creates an external table, *ext_expenses*, sets an error threshold of 10 errors, and writes error rows to the table *err_expenses*.

```
=# CREATE EXTERNAL TABLE ext_expenses ( name text,
   date date,  amount float4, category text, desc1 text )
   LOCATION ('gpfdist://etlhost-1:8081/*',
             'gpfdist://etlhost-2:8082/*')
   FORMAT 'TEXT' (DELIMITER '|')
   LOG ERRORS INTO err_expenses SEGMENT REJECT LIMIT 10
     ROWS;
```

Create an Error Table and Declare a Reject Limit

The following SQL fragment creates an error table, *err_expenses*, and declares a reject limit of 10 rows.

```
LOG ERRORS INTO err_expenses SEGMENT REJECT LIMIT 10 ROWS
```

Viewing Bad Rows in the Error Table

If you use single row error isolation (see "Define an External Table with Single Row Error Isolation" on page 98 or "Running COPY in Single Row Error Isolation Mode" on page 101), any rows with formatting errors are logged into an error table. The error table has the following columns:

Table 7.3 Error Table Format

column	type	description
cmdtime	timestampz	Timestamp when the error occurred.
relname	text	The name of the external table or the target table of a COPY command.
filename	text	The name of the load file that contains the error.
linenum	int	If COPY was used, the line number in the load file where the error occurred. For external tables using file:// protocol or gpfdist:// protocol and CSV format, the file name and line number is logged.

Table 7.3 Error Table Format

column	type	description
bytenum	int	For external tables with the gpfdist:// protocol and data in TEXT format: the byte offset in the load file where the error occurred. gpfdist parses TEXT files in blocks, so logging a line number is not possible. CSV files are parsed a line at a time so line number tracking is possible for CSV files.
errmsg	text	The error message text.
rawdata	text	The raw data of the rejected row.
rawbytes	bytea	In cases where there is a database encoding error (the client encoding used cannot be converted to a server-side encoding), it is not possible to log the encoding error as *rawdata*. Instead the raw bytes are stored and you will see the octal code for any non seven bit ASCII characters.

You can use SQL commands to query the error table and view the rows that did not load. For example:

```
=# SELECT * from err_expenses;
```

Identifying Invalid CSV Files in Error Table Data

If a CSV file contains invalid formatting, the *rawdata* field in the error table can contain several combined rows. For example, if a closing quote for a specific field is missing, all the following newlines are treated as embedded newlines. When this happens, Greenplum stops parsing a row when it reaches 64K, puts that 64K of data into the error table as a single row, resets the quote flag, and continues. If this happens three times during load processing, the load file is considered invalid and the entire load fails with the message "`rejected` *`N`* `or more rows`". See "Escaping in CSV Formatted Files" on page 119 for more information on the correct use of quotes in CSV files.

Moving Data between Tables

You can use `CREATE TABLE AS` or `INSERT...SELECT` to load external and web external table data into another (non-external) database table, and the data will be loaded in parallel according to the external or web external table definition.

If an external table file or web external table data source has an error, one of the following will happen, depending on the isolation mode used:

- **Tables without error isolation mode**: any operation that reads from that table fails. Loading from external and web external tables without error isolation mode is an all or nothing operation.
- **Tables with error isolation mode**: the entire file will be loaded, except for the problematic rows (subject to the configured REJECT_LIMIT)

Loading Data

The following methods load data from readable external tables.

- Use the `gpload` utility
- Use the `gphdfs` protocol
- Load with `copy`

Loading Data with gpload

The Greenplum `gpload` utility loads data using readable external tables and the Greenplum parallel file server (`gpfdist` or `gpfdists`). It handles parallel file-based external table setup and allows users to configure their data format, external table definition, and `gpfdist` or `gpfdists` setup in a single configuration file.

To use gpload

1. Ensure that your environment is set up to run `gpload`. Some dependent files from your Greenplum Database installation are required, such as `gpfdist` and Python, as well as network access to the Greenplum segment hosts. See the *Greenplum Database Reference Guide* for details.

2. Create your load control file. This is a YAML-formatted file that specifies the Greenplum Database connection information, `gpfdist` configuration information, external table options, and data format. See the Greenplum Database Reference Guide for details.

   For example:

```
---
VERSION: 1.0.0.1
DATABASE: ops
USER: gpadmin
HOST: mdw-1
PORT: 5432
GPLOAD:
   INPUT:
    - SOURCE:
         LOCAL_HOSTNAME:
           - etl1-1
           - etl1-2
           - etl1-3
           - etl1-4
         PORT: 8081
         FILE:
           - /var/load/data/*
    - COLUMNS:
           - name: text
             - amount: float4
           - category: text
           - desc: text
           - date: date
```

```
 - FORMAT: text
 - DELIMITER: '|'
 - ERROR_LIMIT: 25
 - ERROR_TABLE: payables.err_expenses
OUTPUT:
 - TABLE: payables.expenses
 - MODE: INSERT
 SQL:
- BEFORE: "INSERT INTO audit VALUES('start', current_timestamp)"
- AFTER: "INSERT INTO audit VALUES('end', current_timestamp)"
```

3. Run gpload, passing in the load control file. For example:

   ```
   gpload -f my_load.yml
   ```

Loading Data with the gphdfs Protocol

If you use INSERT INTO to insert data into a Greenplum table from a table on the Hadoop Distributed File System that was defined as an external table with the gphdfs protocol, the data is copied in parallel. For example:

```
INSERT INTO gpdb_table (select * from hdfs_ext_table);
```

Loading Data with COPY

COPY FROM copies data from a file or standard input into a table and appends the data to the table contents. COPY is non-parallel: data is loaded in a single process using the Greenplum master instance.

To optimize the performance and throughput of COPY, run multiple COPY commands concurrently in separate sessions and divide the data evenly across all concurrent processes. To optimize throughput, run one concurrent COPY operation per CPU.

The COPY source file must be accessible to the master host. Specify the COPY source file name relative to the master host location.

Greenplum copies data from STDIN or STDOUT using the connection between the client and the master server.

Running COPY in Single Row Error Isolation Mode

By default, COPY stops an operation at the first error: if the data contains an error, the operation fails and no data loads. If you run COPY FROM in single row error isolation mode, Greenplum skips rows that contain format errors and loads properly formatted rows. Single row error isolation mode applies only to rows in the input file that contain format errors. If the data contains a contraint error such as violation of a NOT NULL, CHECK, or UNIQUE constraint, the operation fails and no data loads.

Specifying SEGMENT REJECT LIMIT runs the COPY operation in single row error isolation mode. Specify the acceptable number of error rows on each segment, after which the entire COPY FROM operation fails and no rows load. The error row count is for each Greenplum segment, not for the entire load operation.

If the COPY operation does not reach the error limit, Greenplum loads all correctly-formatted rows and discards the error rows. The LOG ERRORS INTO clause allows you to keep error rows for further examination. Use LOG ERRORS INTO to declare an error table in which to write error rows. For example:

```
=> COPY country FROM '/data/gpdb/country_data'
   WITH DELIMITER '|' LOG ERRORS INTO err_country
   SEGMENT REJECT LIMIT 10 ROWS;
```

See "Viewing Bad Rows in the Error Table" on page 98 for information about investigating error rows.

Optimizing Data Load and Query Performance

Use the following tips to help optimize your data load and subsequent query performance.

- Drop indexes before loading data into existing tables.

  Creating an index on pre-existing data is faster than updating it incrementally as each row is loaded. You can temporarily increase the *maintenance_work_mem* server configuration parameter to help speed up CREATE INDEX commands, though load performance is affected. Drop and recreate indexes only when there are no active users on the system.
- Create indexes last when loading data into new tables. Create the table, load the data, and create any required indexes.
- Run ANALYZE after loading data. If you significantly altered the data in a table, run ANALYZE or VACUUM ANALYZE to update table statistics for the query planner. Current statistics ensure that the planner makes the best decisions during query planning and avoids poor performance due to inaccurate or nonexistent statistics.
- Run VACUUM after load errors. If the load operation does not run in single row error isolation mode, the operation stops at the first error. The target table contains the rows loaded before the error occurred. You cannot access these rows, but they occupy disk space. Use the VACUUM command to recover the wasted space.

Unloading Data from Greenplum Database

A writable external table allows you to select rows from other database tables and output the rows to files, named pipes, to applications, or as output targets for Greenplum parallel MapReduce calculations. You can define file-based and web-based writable external tables.

This section describes how to unload data from Greenplum Database using parallel unload (writable external tables) and non-parallel unload (COPY).

- Defining a File-Based Writable External Table
- Defining a Command-Based Writable External Web Table
- Unloading Data Using a Writable External Table
- Unloading Data Using COPY

Defining a File-Based Writable External Table

Writable external tables that output data to files use the Greenplum parallel file server program, `gpfdist`, or the Hadoop Distributed File System interface, `gphdfs`.

Use the `CREATE WRITABLE EXTERNAL TABLE` command to define the external table and specify the location and format of the output files. See "Using the Greenplum Parallel File Server (gpfdist)" on page 80 for instructions on setting up `gpfdist` for use with an external table and "Using Hadoop Distributed File System (HDFS) Tables" on page 82 for instructions on setting up `gphdfs` for use with an external table.

- With a writable external table using the `gpfdist` protocol, the Greenplum segments send their data to `gpfdist`, which writes the data to the named file. `gpfdist` must run on a host that the Greenplum segments can access over the network. `gpfdist` points to a file location on the output host and writes data received from the Greenplum segments to the file. To divide the output data among multiple files, list multiple `gpfdist` URIs in your writable external table definition.
- A writable external web table sends data to an application as a stream of data. For example, unload data from Greenplum Database and send it to an application that connects to another database or ETL tool to load the data elsewhere. Writable external web tables use the `EXECUTE` clause to specify a shell command, script, or application to run on the segment hosts and accept an input stream of data. See "Defining a Command-Based Writable External Web Table" for more information about using `EXECUTE` commands in a writable external table definition.

You can optionally declare a distribution policy for your writable external tables. By default, writable external tables use a random distribution policy. If the source table you are exporting data from has a hash distribution policy, defining the same distribution key column(s) for the writable external table improves unload performance by eliminating the requirement to move rows over the interconnect. If you unload data from a particular table, you can use the `LIKE` clause to copy the column definitions and distribution policy from the source table.

Example 1—Greenplum file server (gpfdist)

```
=# CREATE WRITABLE EXTERNAL TABLE unload_expenses
   ( LIKE expenses )
   LOCATION ('gpfdist://etlhost-1:8081/expenses1.out',
             'gpfdist://etlhost-2:8081/expenses2.out')
 FORMAT 'TEXT' (DELIMITER ',')
 DISTRIBUTED BY (exp_id);
```

Example 2—Hadoop file server (gphdfs)

```
=# CREATE WRITABLE EXTERNAL TABLE unload_expenses
   ( LIKE expenses )
   LOCATION ('gphdfs://hdfslhost-1:8081/path')
 FORMAT 'TEXT' (DELIMITER ',')
```

```
    DISTRIBUTED BY (exp_id);
```

You can only specify a directory for a writable external table with the gphdfs protocol. (You can only specify one file for a readable external table with the gphdfs protocol)

Note: The default port number is 9000.

Defining a Command-Based Writable External Web Table

You can define writable external web tables to send output rows to an application or script. The application must accept an input stream, reside in the same location on all of the Greenplum segment hosts, and be executable by the gpadmin user. All segments in the Greenplum system run the application or script, whether or not a segment has output rows to process.

Use CREATE WRITABLE EXTERNAL WEB TABLE to define the external table and specify the application or script to run on the segment hosts. Commands execute from within the database and cannot access environment variables (such as $PATH). Set environment variables in the EXECUTE clause of your writable external table definition. For example:

```
=# CREATE WRITABLE EXTERNAL WEB TABLE output (output text)
    EXECUTE 'export PATH=$PATH:/home/gpadmin/programs;
    myprogram.sh'
    FORMAT 'TEXT'
    DISTRIBUTED RANDOMLY;
```

The following Greenplum Database variables are available for use in OS commands executed by a web or writable external table. Set these variables as environment variables in the shell that executes the command(s). They can be used to identify a set of requests made by an external table statement across the Greenplum Database array of hosts and segment instances.

Table 7.4 External Table EXECUTE Variables

Variable	Description
$GP_CID	Command count of the transaction executing the external table statement.
$GP_DATABASE	The database in which the external table definition resides.
$GP_DATE	The date on which the external table command ran.
$GP_MASTER_HOST	The host name of the Greenplum master host from which the external table statement was dispatched.
$GP_MASTER_PORT	The port number of the Greenplum master instance from which the external table statement was dispatched.
$GP_SEG_DATADIR	The location of the data directory of the segment instance executing the external table command.
$GP_SEG_PG_CONF	The location of the postgresql.conf file of the segment instance executing the external table command.

Table 7.4 External Table EXECUTE Variables

Variable	Description
$GP_SEG_PORT	The port number of the segment instance executing the external table command.
$GP_SEGMENT_COUNT	The total number of primary segment instances in the Greenplum Database system.
$GP_SEGMENT_ID	The ID number of the segment instance executing the external table command (same as `dbid` in `gp_segment_configuration`).
$GP_SESSION_ID	The database session identifier number associated with the external table statement.
$GP_SN	Serial number of the external table scan node in the query plan of the external table statement.
$GP_TIME	The time the external table command was executed.
$GP_USER	The database user executing the external table statement.
$GP_XID	The transaction ID of the external table statement.

Disabling EXECUTE for Web or Writable External Tables

There is a security risk associated with allowing external tables to execute OS commands or scripts. To disable the use of `EXECUTE` in web and writable external table definitions, set the `gp_external_enable_exec` server configuration parameter to `off` in your master `postgresql.conf` file:

```
gp_external_enable_exec = off
```

Unloading Data Using a Writable External Table

Writable external tables allow only `INSERT` operations. You must grant `INSERT` permission on a table to enable access to users who are not the table owner or a superuser. For example:

```
GRANT INSERT ON writable_ext_table TO admin;
```

To unload data using a writable external table, select the data from the source table(s) and insert it into the writable external table. The resulting rows are output to the writable external table. For example:

```
INSERT INTO writable_ext_table SELECT * FROM regular_table;
```

Unloading Data Using COPY

`COPY TO` copies data from a table to a file (or standard input) on the Greenplum master host using a single process on the Greenplum master instance. Use `COPY` to output a table's entire contents, or filter the output using a `SELECT` statement. For example:

```
COPY (SELECT * FROM country WHERE country_name LIKE 'A%') TO
'/home/gpadmin/a_list_countries.out';
```

Transforming XML Data

The Greenplum Database data loader *gpfdist* provides transformation features to load XML data into a table and to write data from the Greenplum Database to XML files. The following diagram shows *gpfdist* performing an XML transform.

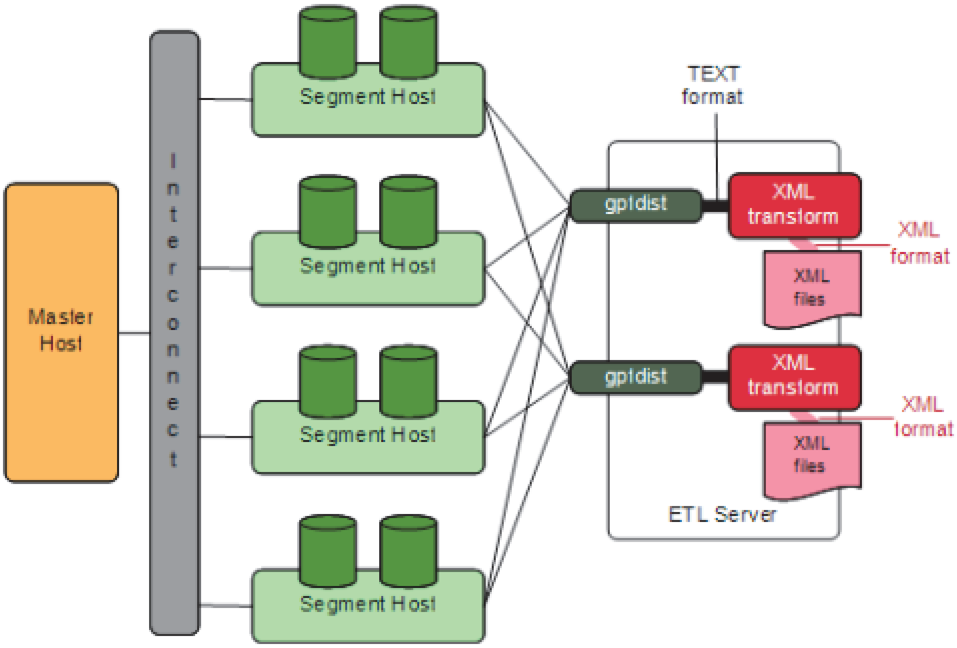


Figure 7.4 External Tables using XML Transformations

To load or extract XML data:

- Determine the Transformation Schema
- Write a Transform
- Write the gpfdist Configuration
- Load the Data
- Transfer and Store the Data

The first three steps comprise most of the development effort. The last two steps are straightforward and repeatable, suitable for production.

Determine the Transformation Schema

To prepare for the transformation project:

1. Determine the goal of the project, such as indexing data, analyzing data, combining data, and so on.
2. Examine the XML file and note the file structure and element names.
3. Choose the elements to import and decide if any other limits are appropriate.

For example, the following XML file, *prices.xml*, is a simple, short file that contains price records. Each price record contains two fields: an item number and a price.

```
<?xml version="1.0" encoding="ISO-8859-1" ?>
<prices>
  <pricerecord>
    <itemnumber>708421</itemnumber>
    <price>19.99</price>
  </pricerecord>
  <pricerecord>
    <itemnumber>708466</itemnumber>
    <price>59.25</price>
  </pricerecord>
  <pricerecord>
    <itemnumber>711121</itemnumber>
    <price>24.99</price>
  </pricerecord>
</prices>
```

The goal is to import all the data into a Greenplum Database table with an integer `itemnumber` column and a decimal `price` column.

Write a Transform

The transform specifies what to extract from the data.You can use any authoring environment and language appropriate for your project. For XML transformations Greenplum suggests choosing a technology such as XSLT, Joost (STX), Java, Python, or Perl, based on the goals and scope of the project.

In the price example, the next step is to transform the XML data into a simple two-column delimited format.

```
708421|19.99
708466|59.25
711121|24.99
```

The following STX transform, called *input_transform.stx*, completes the data transformation.

```
<?xml version="1.0"?>
<stx:transform version="1.0"
   xmlns:stx="http://stx.sourceforge.net/2002/ns"
   pass-through="none">

  <!-- declare variables -->

  <stx:variable name="itemnumber"/>
  <stx:variable name="price"/>

  <!-- match and output prices as columns delimited by | -->

  <stx:template match="/prices/pricerecord">
    <stx:process-children/>
    <stx:value-of select="$itemnumber"/>
<stx:text>|</stx:text>
    <stx:value-of select="$price"/>     <stx:text>
</stx:text>
  </stx:template>
  <stx:template match="itemnumber">
    <stx:assign name="itemnumber" select="."/>
  </stx:template>

  <stx:template match="price">
    <stx:assign name="price" select="."/>
  </stx:template>

</stx:transform>
```

This STX transform declares two temporary variables, `itemnumber` and `price`, and the following rules.

1. When an element that satisfies the XPath expression `/prices/pricerecord` is found, examine the child elements and generate output that contains the value of the `itemnumber` variable, a | character, the value of the price variable, and a newline.
2. When an `<itemnumber>` element is found, store the content of that element in the variable `itemnumber`.
3. When a <price> element is found, store the content of that element in the variable `price`.

Write the gpfdist Configuration

The `gpfdist` configuration is specified as a YAML 1.1 document. It specifies rules that `gpfdist` uses to select a Transform to apply when loading or extracting data.

This example `gpfdist` configuration contains the following items:

- the `config.yaml` file defining `TRANSFORMATIONS`
- the `input_transform.sh` wrapper script, referenced in the `config.yaml` file
- the `input_transform.stx` joost transformation, called from `input_transform.sh`

Aside from the ordinary YAML rules, such as starting the document with three dashes (`---`), a `gpfdist` configuration must conform to the following restrictions:

1. a `VERSION` setting must be present with the value `1.0.0.1`.
2. a `TRANSFORMATIONS` setting must be present and contain one or more mappings.
3. Each mapping in the `TRANSFORMATION` must contain:
   - a `TYPE` with the value 'input' or 'output'
   - a `COMMAND` indicating how the transform is run.
4. Each mapping in the `TRANSFORMATION` can contain optional `CONTENT`, `SAFE`, and `STDERR` settings.

The following `gpfdist` configuration called `config.YAML` applies to the prices example. The initial indentation on each line is significant and reflects the hierarchical nature of the specification. The name `prices_input` in the following example will be referenced later when creating the table in SQL.

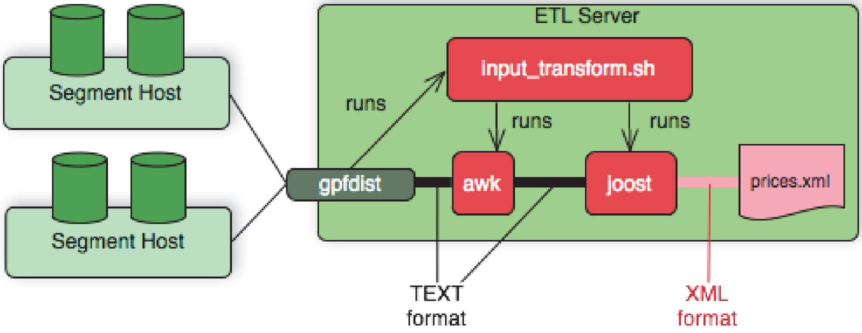
```
---
VERSION: 1.0.0.1

TRANSFORMATIONS:
  prices_input:
    TYPE:     input
    COMMAND:  /bin/bash input_transform.sh %filename%
```

The COMMAND setting uses a wrapper script called input_transform.sh with a %filename% placeholder. When gpfdist runs the prices_input transform, it invokes input_transform.sh with /bin/bash and replaces the %filename% placeholder with the path to the input file to transform. The wrapper script called input_transform.sh contains the logic to invoke the STX transformation and return the output.

If Joost is used, the Joost STX engine must be installed.

```
#!/bin/bash
# input_transform.sh - sample input transformation,
# demonstrating use of Java and Joost STX to convert XML into
# text to load into Greenplum Database.
# java arguments:
#   -jar joost.jar         joost STX engine
#   -nodecl                don't generate a <?xml?> declaration
#   $1                        filename to process
#   input_transform.stx    the STX transformation
#
# the AWK step eliminates a blank line joost emits at the end
java \
    -jar joost.jar \
    -nodecl \
    $1 \
    input_transform.stx \
 | awk 'NF>0
```

The input_transform.sh file uses the Joost STX engine with the AWK interpreter. The following diagram shows the process flow as gpfdist runs the transformation.



Load the Data

Create the tables with SQL statements based on the appropriate schema.

There are no special requirements for the Greenplum Database tables that hold loaded data. In the prices example, the following command creates the appropriate table.

```
CREATE TABLE prices (
  itemnumber integer,
  price       decimal
)
DISTRIBUTED BY (itemnumber);
```

Transfer and Store the Data

Use one of the following approaches to transform the data with `gpfdist`.

- `GPLOAD` supports only input transformations, but is easier to implement in many cases.
- `INSERT INTO SELECT FROM supports both input and output transformations, but exposes more details.`

Transforming with GPLOAD

Transforming data with `GPLOAD` requires that the settings `TRANSFORM` and `TRANSFORM_CONFIG` appear in the `INPUT` section of the `GPLOAD` control file. For more information about the syntax and placement of these settings in the `GPLOAD` control file, see the Greenplum Database Reference Guide.

- `TRANSFORM_CONFIG` specifies the name of the `gpfdist` configuration file.
- The `TRANSFORM` setting indicates the name of the transformation that is described in the file named in `TRANSFORM_CONFIG`.

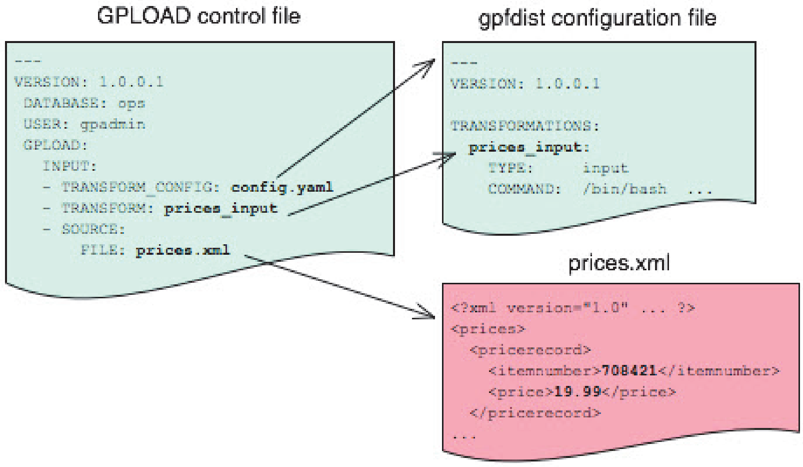
```
---

VERSION: 1.0.0.1
   DATABASE: ops
   USER: gpadmin
   GPLOAD:
      INPUT:
```

```
      - TRANSFORM_CONFIG: config.yaml
      - TRANSFORM: prices_input
      - SOURCE:
          FILE: prices.xml
```

The transformation name must appear in two places: in the TRANSFORM setting of the gpfdist configuration file and in the TRANSFORMATIONS section of the file named in the TRANSFORM_CONFIG section.

In the GPLOAD control file, the optional parameter MAX_LINE_LENGTH specifies the maximum length of a line in the XML transformation data that is passed to gpload.

The following diagram shows the relationships between the GPLOAD control file, the gpfdist configuration file, and the XML data file.



```
---
VERSION: 1.0.0.1
 DATABASE: ops
 USER: gpadmin
 GPLOAD:
   INPUT:
   - TRANSFORM_CONFIG: config.yaml
   - TRANSFORM: prices_input
   - SOURCE:
       FILE: prices.xml
```

```
---
VERSION: 1.0.0.1

TRANSFORMATIONS:
  prices_input:
    TYPE:     input
    COMMAND:  /bin/bash  ...
```

```
<?xml version="1.0" ... ?>
<prices>
  <pricerecord>
    <itemnumber>708421</itemnumber>
    <price>19.99</price>
  </pricerecord>
...
```

Transforming with INSERT INTO SELECT FROM

Specify the transformation in the CREATE EXTERNAL TABLE definition's LOCATION clause. For example, the transform is shown in bold in the following command. (Run gpfdist first, using the command gpfdist -c config.yaml).

```
CREATE READABLE EXTERNAL TABLE prices_readable (LIKE prices)
   LOCATION ('gpfdist://hostname:8080/prices.xml#transform=prices_input')
   FORMAT 'TEXT' (DELIMITER '|')
   LOG ERRORS INTO prices_errortable SEGMENT REJECT LIMIT 10;
```

In the command above, change hostname to your hostname. Prices_input comes from the configuration file.

The following query loads data into the **prices** table.

```
INSERT INTO prices SELECT * FROM prices_readable;
```

Configuration File Format

The `gpfdist` configuration file uses the YAML 1.1 document format and implements a schema for defining the transformation parameters. The configuration file must be a valid YAML document.

The `gpfdist` program processes the document in order and uses indentation (spaces) to determine the document hierarchy and relationships of the sections to one another. The use of white space is significant. Do not use white space for formatting and do not use tabs.

The following is the basic structure of a configuration file.

```
---
VERSION: 1.0.0.1

TRANSFORMATIONS:
  transformation_name1:
      TYPE:       input | output
      COMMAND:    command
      CONTENT:    data | paths
      SAFE:       posix-regex
      STDERR:     server | console

  transformation_name2:
      TYPE:       input | output
      COMMAND:    command
      ...
```

VERSION

Required. The version of the `gpfdist` configuration file schema. The current version is 1.0.0.1.

TRANSFORMATIONS

Required. Begins the transformation specification section. A configuration file must have at least one transformation. When `gpfdist` receives a transformation request, it looks in this section for an entry with the matching transformation name.

TYPE

Required. Specifies the direction of transformation. Values are `input` or `output`.

- `input`: `gpfdist` treats the standard output of the transformation process as a stream of records to load into Greenplum Database.

- `output`: `gpfdist` treats the standard input of the transformation process as a stream of records from Greenplum Database to transform and write to the appropriate output.

COMMAND

Required. Specifies the command `gpfdist` will execute to perform the transformation.

For input transformations, `gpfdist` invokes the command specified in the `CONTENT` setting. The command is expected to open the underlying file(s) as appropriate and produce one line of `TEXT` for each row to load into Greenplum Database. The input transform determines whether the entire content should be converted to one row or to multiple rows.

For output transformations, `gpfdist` invokes this command as specified in the `CONTENT` setting. The output command is expected to open and write to the underlying file(s) as appropriate. The output transformation determines the final placement of the converted output.

CONTENT

Optional. The values are `data` and `paths`. The default value is `data`.

- When `CONTENT` specifies `data`, the text `%filename%` in the `COMMAND` section is replaced by the path to the file to read or write.
- When `CONTENT` specifies `paths`, the text `%filename%` in the `COMMAND` section is replaced by the path to the temporary file that contains the list of files to read or write.

The following is an example of a `COMMAND` section showing the text `%filename%` that is replaced.

```
COMMAND:  /bin/bash input_transform.sh %filename%
```

SAFE

Optional. A `POSIX` regular expression that the paths must match to be passed to the transformation. Specify `SAFE` when there is a concern about injection or improper interpretation of paths passed to the command. The default is no restriction on paths.

STDERR

Optional.The values are `server` and `console`.

This setting specifies how to handle standard error output from the transformation. The default, `server`, specifies that `gpfdist` will capture the standard error output from the transformation in a temporary file and send the first 8k of that file to Greenplum Database as an error message. The error message will appear as a SQL error. `Console` specifies that `gpfdist` does not redirect or transmit the standard error output from the transformation.

XML Transformation Examples

The following examples demonstrate the complete process for different types of XML data and STX transformations. Files and detailed instructions associated with these examples are in `demo/gpfdist_transform.tar.gz.` Read the README file in the *Before You Begin* section before you run the examples. The README file explains how to download the example data file used in the examples.

Example 1 - DBLP Database Publications (In demo Directory)

This example demonstrates loading and extracting database research data. The data is in the form of a complex XML file downloaded from the University of Washington. The DBLP information consists of a top level <dblp> element with multiple child elements such as <article>, <proceedings>, <mastersthesis>, <phdthesis>, and so on, where the child elements contain details about the associated publication. For example, the following is the XML for one publication.

```
<?xml version="1.0" encoding="UTF-8"?>
<mastersthesis key="ms/Brown92">
<author>Kurt P. Brown</author>
<title>PRPL: A Database Workload Language, v1.3.</title>
<year>1992</year>
<school>Univ. of Wisconsin-Madison</school>
</mastersthesis>
```

The goal is to import these `<mastersthesis>` and `<phdthesis>` records into the Greenplum Database. The sample document, *dblp.xml*, is about 130MB in size uncompressed. The input contains no tabs, so the relevent information can be converted into tab-delimited records as follows:

```
ms/Brown92 tab masters tab Kurt P. Brown tab PRPL: A Database
Workload Specification Language, v1.3. tab 1992 tab Univ. of
Wisconsin-Madison newline
```

With the columns:

```
key       text, -- e.g. ms/Brown92
type      text, -- e.g. masters
author    text, -- e.g. Kurt P. Brown
title     text, -- e.g. PRPL: A Database Workload Language, v1.3.
year      text, -- e.g. 1992
school    text, -- e.g. Univ. of Wisconsin-Madison
```

Then, load the data into Greenplum Database.

After the data loads, verify the data by extracting the loaded records as XML with an output transformation.

Example 2 - IRS MeF XML Files (In demo Directory)

This example demonstrates loading a sample IRS Modernized eFile tax return using a joost STX transformation. The data is in the form of a complex XML file.

The U.S. Internal Revenue Service (IRS) made a significant commitment to XML and specifies its use in its Modernized e-File (MeF) system. In MeF, each tax return is an XML document with a deep hierarchical structure that closely reflects the particular form of the underlying tax code.

XML, XML Schema and stylesheets play a role in their data representation and business workflow. The actual XML data is extracted from a ZIP file attached to a MIME "transmission file" message. For more information about MeF, see Modernized e-File (Overview) on the IRS web site.

The sample XML document, *RET990EZ_2006.xml*, is about 350KB in size with two elements:

- ReturnHeader
- ReturnData

The <ReturnHeader> contains general details about the tax return such as the taxpayer's name, the tax year of the return, and the preparer. The <ReturnData> contains multiple sections with specific details about the tax return and associated schedules.

The following is an abridged sample of the XML file.

```
<?xml version="1.0" encoding="UTF-8"?>
<Return returnVersion="2006v2.0"
   xmlns="http://www.irs.gov/efile"
   xmlns:efile="http://www.irs.gov/efile"
   xsi:schemaLocation="http://www.irs.gov/efile"
   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
   <ReturnHeader binaryAttachmentCount="1">
     <ReturnId>AAAAAAAAAAAAAAAAAAAA</ReturnId>
     <Timestamp>1999-05-30T12:01:01+05:01</Timestamp>
     <ReturnType>990EZ</ReturnType>
     <TaxPeriodBeginDate>2005-01-01</TaxPeriodBeginDate>
     <TaxPeriodEndDate>2005-12-31</TaxPeriodEndDate>
     <Filer>
       <EIN>011248772</EIN>
       ... more data ...
     </Filer>
     <Preparer>
       <Name>Percy Polar</Name>
       ... more data ...
     </Preparer>
     <TaxYear>2005</TaxYear>
   </ReturnHeader>
   ... more data ..
```

The goal is to import all the data into a Greenplum database. First, convert the XML document into text with newlines "escaped", with two columns: `ReturnId` and a single column on the end for the entire MeF tax return. For example:

```
   AAAAAAAAAAAAAAAAAAAA|<Return returnVersion="2006v2.0"...
```

Load the data into Greenplum Database.

Example 3 - WITSML™ Files (In demo Directory)

This example demonstrates loading sample data describing an oil rig using a joost STX transformation. The data is in the form a complex XML file downloaded from energistics.org.

The Wellsite Information Transfer Standard Markup Language (WITSML™) is an oil industry initiative to provide open, non-proprietary, standard interfaces for technology and software to share information among oil companies, service companies, drilling contractors, application vendors, and regulatory agencies. For more information about WITSML™, see http://www.witsml.org.

The oil rig information consists of a top level `<rigs>` element with multiple child elements such as `<documentInfo>, <rig>`, and so on. The following excerpt from the file shows the type of information in the `<rig>` tag.

```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-stylesheet href="../stylesheets/rig.xsl" type="text/xsl"
media="screen"?>
<rigs
xmlns="http://www.witsml.org/schemas/131"
   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xsi:schemaLocation="http://www.witsml.org/schemas/131  ../obj_rig.xsd"
   version="1.3.1.1">
   <documentInfo>
          ... misc data ...
   </documentInfo>
   <rig uidWell="W-12" uidWellbore="B-01" uid="xr31">
        <nameWell>6507/7-A-42</nameWell>
        <nameWellbore>A-42</nameWellbore>
        <name>Deep Drill #5</name>
        <owner>Deep Drilling Co.</owner>
        <typeRig>floater</typeRig>
        <manufacturer>Fitsui Engineering</manufacturer>
        <yearEntService>1980</yearEntService>
        <classRig>ABS Class A1 M CSDU AMS ACCU</classRig>
        <approvals>DNV</approvals>
      ... more data ...
```

The goal is to import the information for this rig into Greenplum Database.

The sample document, *rig.xml*, is about 11KB in size. The input does not contain tabs so the relevant information can be converted into records delimited with a pipe (|).

```
W-12|6507/7-A-42|xr31|Deep Drill #5|Deep Drilling Co.|John
Doe|John.Doe@his-ISP.com|<?xml version="1.0" encoding="UTF-8" ...
```

With the columns:

```
    well_uid    text,  -- e.g. W-12
    well_name   text,  -- e.g. 6507/7-A-42
    rig_uid     text,  -- e.g. xr31
    rig_name    text,  -- e.g. Deep Drill #5
    rig_owner   text,  -- e.g. Deep Drilling Co.
    rig_contact text,  -- e.g. John Doe
    rig_email   text,  -- e.g. John.Doe@his-ISP.com
    doc         xml
```

Then, load the data into Greenplum Database.

Formatting Data Files

When you use the Greenplum tools for loading and unloading data, you must specify how your data is formatted. COPY, CREATE EXTERNAL TABLE, and gpload have clauses that allow you to specify how your data is formatted. Data can be delimited text (TEXT) or comma separated values (CSV) format. External data must be formatted correctly to be read by Greenplum Database. This section explains the format of data files expected by Greenplum Database.

- Formatting Rows
- Formatting Columns
- Representing NULL Values
- Escaping
- Character Encoding

Formatting Rows

Greenplum Database expects rows of data to be separated by the LF character (Line feed, 0x0A), CR (Carriage return, 0x0D), or CR followed by LF (CR+LF, 0x0D 0x0A). LF is the standard newline representation on UNIX or UNIX-like operating systems. Operating systems such as Windows or Mac OS 9 use CR or CR+LF. All of these representations of a newline are supported by Greenplum Database as a row delimiter. For more information, see "Importing and Exporting Fixed Width Data" on page 92.

Formatting Columns

The default column or field delimiter is the horizontal TAB character (0x09) for text files and the comma character (0x2C) for CSV files. You can declare a single character delimiter using the DELIMITER clause of COPY, CREATE EXTERNAL TABLE or gpload when you define your data format. The delimiter character must appear between any two data value fields. Do not place a delimiter at the beginning or end of a row. For example, if the pipe character (|) is your delimiter:

```
data value 1|data value 2|data value 3
```

The following command shows the use of the pipe character as a column delimiter:

```
=# CREATE EXTERNAL TABLE ext_table (name text, date date)
   LOCATION ('gpfdist://<hostname>/filename.txt)
   FORMAT 'TEXT' (DELIMITER '|');
```

Representing NULL Values

`NULL` represents an unknown piece of data in a column or field. Within your data files you can designate a string to represent null values. The default string is `\N` (backslash-N) in `TEXT` mode, or an empty value with no quotations in `CSV` mode. You can also declare a different string using the `NULL` clause of `COPY`, `CREATE EXTERNAL TABLE` or `gpload` when defining your data format. For example, you can use an empty string if you do not want to distinguish nulls from empty strings. When using the Greenplum Database loading tools, any data item that matches the designated null string is considered a null value.

Escaping

There are two reserved characters that have special meaning to Greenplum Database:

- The designated delimiter character separates columns or fields in the data file.
- The newline character designates a new row in the data file.

If your data contains either of these characters, you must escape the character so that Greenplum treats it as data and not as a field separator or new row. By default, the escape character is a \ (backslash) for text-formatted files and a double quote (") for csv-formatted files.

Escaping in Text Formatted Files

By default, the escape character is a \ (backslash) for text-formatted files. You can declare a different escape character in the `ESCAPE` clause of `COPY`, `CREATE EXTERNAL TABLE` or `gpload`. If your escape character appears in your data, use it to escape itself.

For example, suppose you have a table with three columns and you want to load the following three fields:

- `backslash = \`
- `vertical bar = |`
- `exclamation point = !`

Your designated delimiter character is `|` (pipe character), and your designated escape character is `\` (backslash). The formatted row in your data file looks like this:

```
backslash = \\ | vertical bar = \| | exclamation point = !
```

Notice how the backslash character that is part of the data is escaped with another backslash character, and the pipe character that is part of the data is escaped with a backslash character.

You can use the escape character to escape octal and hexidecimal sequences. The escaped value is converted to the equivalent character when loaded into Greenplum Database. For example, to load the ampersand character (`&`), use the escape character to escape its equivalent hexidecimal (`\0x26`) or octal (`\046`) representation.

You can disable escaping in `TEXT`-formatted files using the `ESCAPE` clause of `COPY`, `CREATE EXTERNAL TABLE` or `gpload` as follows:

```
ESCAPE 'OFF'
```

This is useful for input data that contains many backslash characters, such as web log data.

Escaping in CSV Formatted Files

By default, the escape character is a `"` (double quote) for CSV-formatted files. If you want to use a different escape character, use the `ESCAPE` clause of `COPY`, `CREATE EXTERNAL TABLE` or `gpload` to declare a different escape character. In cases where your selected escape character is present in your data, you can use it to escape itself.

For example, suppose you have a table with three columns and you want to load the following three fields:

- `Free trip to A,B`
- `5.89`
- `Special rate "1.79"`

Your designated delimiter character is `,` (comma), and your designated escape character is `"` (double quote). The formatted row in your data file looks like this:

```
"Free trip to A,B","5.89","Special rate ""1.79"""
```

The data value with a comma character that is part of the data is enclosed in double quotes. The double quotes that are part of the data are escaped with a double quote even though the field value is enclosed in double quotes.

Embedding the entire field inside a set of double quotes guarantees preservation of leading and trailing whitespace characters:

```
"Free trip to A,B ","5.89 ","Special rate ""1.79"" "
```

Note: In CSV mode, all characters are significant. A quoted value surrounded by white space, or any characters other than `DELIMITER`, includes those characters. This can cause errors if you import data from a system that pads CSV lines with white space to some fixed width. In this case, preprocess the CSV file to remove the trailing white space before importing the data into Greenplum Database.

Character Encoding

Character encoding systems consist of a code that pairs each character from a character set with something else, such as a sequence of numbers or octets, to facilitate data stransmission and storage. Greenplum Database supports a variety of character sets, including single-byte character sets such as the ISO 8859 series and multiple-byte character sets such as EUC (Extended UNIX Code), UTF-8, and Mule internal code. Clients can use all supported character sets transparently, but a few are not supported for use within the server as a server-side encoding.

Data files must be in a character encoding recognized by Greenplum Database. See the Greenplum Database Reference Guide for the supported character sets. Data files that contain invalid or unsupported encoding sequences encounter errors when loading into Greenplum Database.

Note: On data files generated on a Microsoft Windows operating system, run the `dos2unix` system command to remove any Windows-only characters before loading into Greenplum Database.

Example Custom Data Access Protocol

The following is the API for the Greenplum Database custom data access protocol. The example protocol implementation gpextprotocal.c is written in C and shows how the API can be used. For information about accessing a custom data access protocol, see "Using a Custom Protocol" on page 93.

```
/* ---- Read/Write function API ------*/

CALLED_AS_EXTPROTOCOL(fcinfo)

EXTPROTOCOL_GET_URL(fcinfo)(fcinfo)
EXTPROTOCOL_GET_DATABUF(fcinfo)
EXTPROTOCOL_GET_DATALEN(fcinfo)
EXTPROTOCOL_GET_SCANQUALS(fcinfo)
EXTPROTOCOL_GET_USER_CTX(fcinfo)
EXTPROTOCOL_IS_LAST_CALL(fcinfo)
EXTPROTOCOL_SET_LAST_CALL(fcinfo)
EXTPROTOCOL_SET_USER_CTX(fcinfo, p)


/* ------ Validator function API ------*/

CALLED_AS_EXTPROTOCOL_VALIDATOR(fcinfo)

EXTPROTOCOL_VALIDATOR_GET_URL_LIST(fcinfo)
EXTPROTOCOL_VALIDATOR_GET_NUM_URLS(fcinfo)
EXTPROTOCOL_VALIDATOR_GET_NTH_URL(fcinfo, n)
EXTPROTOCOL_VALIDATOR_GET_DIRECTION(fcinfo)
```

Notes

The protocol corresponds to the example described in "Using a Custom Protocol" on page 93. The source code file name and shared object are `gpextprotocol.c` and `gpextprotocol.so`.

The protocol has the following properties:

- The name defined for the protocol is `myprot`.
- The protocol has the following simple form: the protocol name and a path, separated by `://`.

  `myprot://`*`path`*
- Three functions are implemented:
  - `myprot_import()` a read function
  - `myprot_export()` a write function
  - `myprot_validate_urls()` a validation function

  These functions are referenced in the `CREATE PROTOCOL` statement when the protocol is created and declared in the database.

The example implementation gpextprotocal.c uses `fopen()` and `fread()` to simulate a simple protocol that reads local files. In practice, however, the protocol would implement functionality such as a remote connection to some process over the network.

Installing the External Table Protocol

To use the example external table protocol, you use the C compiler cc to compile and link the source code to create a shared object that can be dynamically loaded by Greenplum Database. The commands to compile and link the source code on a Linux system are similar to this:

```
cc -fpic -c gpextprotocal.c
cc -shared -o gpextprotocal.so gpextprotocal.o
```

The option -fpic specifies creating position-independent code (PIC) and the -c option compiles the source code without linking and creates an object file. The object file needs to be created as position-independent code (PIC) so that it can be loaded at any arbitrary location in memory by Greenplum Database.

The flag -shared specifies creating a shared object (shared library) and the -o option specifies the shared object file name gpextprotocal.so. Refer to the GCC manual for more information on the cc options.

The header files that are declared as include files in gpextprotocal.c are located in subdirectories of $GPHOME/include/postgresql/.

For more information on compiling and linking dynamically-loaded functions and examples of compiling C source code to create a shared library on other operating systems, see the Postgres documentation at http://www.postgresql.org/docs/8.4/static/xfunc-c.html#DFUNC.

The manual pages for the C compiler cc and the link editor ld for your operating system also contain information on compiling and linking source code on your system.

The compiled code (shared object file) for the custom protocol must be placed in the same location on every host in your Greenplum Database array (master and all segments). This location must also be in the LD_LIBRARY_PATH so that the server can locate the files. It is recommended to locate shared libraries either relative to $libdir (which is located at $GPHOME/lib) or through the dynamic library path (set by the dynamic_library_path server configuration parameter) on all master segment instances in the Greenplum array. You can use the Greenplum Database utilities gpssh and gpscp to update segments.

gpextprotocal.c

```
#include "postgres.h"
#include "fmgr.h"
#include "funcapi.h"

#include "access/extprotocol.h"
#include "catalog/pg_proc.h"
#include "utils/array.h"
#include "utils/builtins.h"
#include "utils/memutils.h"
```

```
/* Our chosen URI format. We can change it however needed */
typedef struct DemoUri
{
   char     *protocol;
   char     *path;
}  DemoUri;

static DemoUri *ParseDemoUri(const char *uri_str);
static void FreeDemoUri(DemoUri* uri);


/* Do the module magic dance */
PG_MODULE_MAGIC;
PG_FUNCTION_INFO_V1(demoprot_export);
PG_FUNCTION_INFO_V1(demoprot_import);
PG_FUNCTION_INFO_V1(demoprot_validate_urls);

Datum demoprot_export(PG_FUNCTION_ARGS);
Datum demoprot_import(PG_FUNCTION_ARGS);
Datum demoprot_validate_urls(PG_FUNCTION_ARGS);


/* A user context that persists across calls. Can be declared in
any other way */

typedef struct {
  char    *url;
  char    *filename;
  FILE    *file;
} extprotocol_t;

/*
* The read function - Import data into GPDB.
*/
Datum
myprot_import(PG_FUNCTION_ARGS)
{
  extprotocol_t   *myData;
  char            *data;
  int             datlen;
  size_t          nread = 0;


  /* Must be called via the external table format manager */
  if (!CALLED_AS_EXTPROTOCOL(fcinfo))
    elog(ERROR, "myprot_import: not called by external
       protocol manager");


  /* Get our internal description of the protocol */
  myData = (extprotocol_t *) EXTPROTOCOL_GET_USER_CTX(fcinfo);


  if(EXTPROTOCOL_IS_LAST_CALL(fcinfo))
  {
    /* we're done receiving data. close our connection */
    if(myData && myData->file)
      if(fclose(myData->file))
        ereport(ERROR,
            (errcode_for_file_access(),
             errmsg("could not close file \"%s\": %m",
                 myData->filename)));
    PG_RETURN_INT32(0);
  }
  if (myData == NULL)
  {
    /* first call. do any desired init */

    const char    *p_name = "myprot";
    DemoUri       *parsed_url;
    char          *url = EXTPROTOCOL_GET_URL(fcinfo);
    myData        = palloc(sizeof(extprotocol_t));
    myData->url   = pstrdup(url);
    parsed_url    = ParseDemoUri(myData->url);
    myData->filename = pstrdup(parsed_url->path);
    if(strcasecmp(parsed_url->protocol, p_name) != 0)
      elog(ERROR, "internal error: myprot called with a
          different protocol (%s)",
            parsed_url->protocol);
    FreeDemoUri(parsed_url);
    /* open the destination file (or connect to remote server in
         other cases) */
    myData->file = fopen(myData->filename, "r");
    if (myData->file == NULL)
      ereport(ERROR,
          (errcode_for_file_access(),
           errmsg("myprot_import: could not open file \"%s\"
              for reading: %m",
               myData->filename),
           errOmitLocation(true)));

    EXTPROTOCOL_SET_USER_CTX(fcinfo, myData);
  }
  /* ==========================================
   *          DO THE IMPORT
   * ========================================== */
  data     = EXTPROTOCOL_GET_DATABUF(fcinfo);
  datlen   = EXTPROTOCOL_GET_DATALEN(fcinfo);
  /* read some bytes (with fread in this example, but normally
  in some other method over the network) */
  if(datlen > 0)
  {
    nread = fread(data, 1, datlen, myData->file);
    if (ferror(myData->file))
      ereport(ERROR,
          (errcode_for_file_access(),
           errmsg("myprot_import: could not write to file
             \"%s\": %m",
               myData->filename)));
  }
```

```
  PG_RETURN_INT32((int)nread);
}

/*
 * Write function - Export data out of GPDB
 */
Datum
myprot_export(PG_FUNCTION_ARGS)
{
  extprotocol_t  *myData;
  char           *data;
  int            datlen;
  size_t         wrote = 0;

  /* Must be called via the external table format manager */

  if (!CALLED_AS_EXTPROTOCOL(fcinfo))
    elog(ERROR, "myprot_export: not called by external
       protocol manager");

  /* Get our internal description of the protocol */
  myData = (extprotocol_t *) EXTPROTOCOL_GET_USER_CTX(fcinfo);

  if(EXTPROTOCOL_IS_LAST_CALL(fcinfo))
  {
    /* we're done sending data. close our connection */
    if(myData && myData->file)
      if(fclose(myData->file))
        ereport(ERROR,
            (errcode_for_file_access(),
             errmsg("could not close file \"%s\": %m",
                 myData->filename)));

    PG_RETURN_INT32(0);
  }

  if (myData == NULL)
  {
    /* first call. do any desired init */

    const char *p_name = "myprot";
    DemoUri    *parsed_url;
    char       *url = EXTPROTOCOL_GET_URL(fcinfo);

    myData           = palloc(sizeof(extprotocol_t));

    myData->url      = pstrdup(url);
    parsed_url       = ParseDemoUri(myData->url);
    myData->filename = pstrdup(parsed_url->path);

    if(strcasecmp(parsed_url->protocol, p_name) != 0)
      elog(ERROR, "internal error: myprot called with a
         different protocol (%s)",
            parsed_url->protocol);

    FreeDemoUri(parsed_url);

    /* open the destination file (or connect to remote server in
       other cases) */
    myData->file = fopen(myData->filename, "a");

    if (myData->file == NULL)
      ereport(ERROR,
          (errcode_for_file_access(),
           errmsg("myprot_export: could not open file \"%s\"
             for writing: %m",
               myData->filename),
           errOmitLocation(true)));

    EXTPROTOCOL_SET_USER_CTX(fcinfo, myData);
  }

  /* ========================================
   *      DO THE EXPORT
   * ======================================== */

  data   = EXTPROTOCOL_GET_DATABUF(fcinfo);
  datlen   = EXTPROTOCOL_GET_DATALEN(fcinfo);

  if(datlen > 0)
  {
    wrote = fwrite(data, 1, datlen, myData->file);
    if (ferror(myData->file))
      ereport(ERROR,
          (errcode_for_file_access(),
           errmsg("myprot_import: could not read from file
              \"%s\": %m",
               myData->filename)));
  }

  PG_RETURN_INT32((int)wrote);
}

Datum
myprot_validate_urls(PG_FUNCTION_ARGS)
{
  List         *urls;
  int          nurls;
  int          i;
  ValidatorDirection  direction;

  /* Must be called via the external table format manager */
  if (!CALLED_AS_EXTPROTOCOL_VALIDATOR(fcinfo))
    elog(ERROR, "myprot_validate_urls: not called by external
       protocol manager");

  nurls       = EXTPROTOCOL_VALIDATOR_GET_NUM_URLS(fcinfo);
  urls        = EXTPROTOCOL_VALIDATOR_GET_URL_LIST(fcinfo);
  direction   = EXTPROTOCOL_VALIDATOR_GET_DIRECTION(fcinfo);

  /*
   * Dumb example 1: search each url for a substring
   * we don't want to be used in a url. in this example
   * it's 'secured_directory'.
   */
  for (i = 1 ; i <= nurls ; i++)
  {
    char *url = EXTPROTOCOL_VALIDATOR_GET_NTH_URL(fcinfo, i);

    if (strstr(url, "secured_directory") != 0)
    {
            ereport(ERROR,
                    (errcode(ERRCODE_PROTOCOL_VIOLATION),
                     errmsg("using 'secured_directory' in a url
                       isn't allowed ")));
    }
  }

  /*
   * Dumb example 2: set a limit on the number of urls
   * used. In this example we limit readable external
   * tables that use our protocol to 2 urls max.
   */
  if(direction == EXT_VALIDATE_READ && nurls > 2)
  {
        ereport(ERROR,
                (errcode(ERRCODE_PROTOCOL_VIOLATION),
                 errmsg("more than 2 urls aren't allowed in
this protocol ")));
  }

  PG_RETURN_VOID();
}

/* --- utility functions --- */

static
DemoUri *ParseDemoUri(const char *uri_str)
{
  DemoUri *uri = (DemoUri *) palloc0(sizeof(DemoUri));
  int     protocol_len;

   uri->path = NULL;
   uri->protocol = NULL;

  /*
   * parse protocol
   */
  char *post_protocol = strstr(uri_str, "://");

  if(!post_protocol)
  {
    ereport(ERROR,
        (errcode(ERRCODE_SYNTAX_ERROR),
         errmsg("invalid protocol URI \'%s\'", uri_str),
         errOmitLocation(true)));
  }

  protocol_len = post_protocol - uri_str;
  uri->protocol = (char *)palloc0(protocol_len + 1);
  strncpy(uri->protocol, uri_str, protocol_len);

  /* make sure there is more to the uri string */
  if (strlen(uri_str) <= protocol_len)
```

```
    ereport(ERROR,
        (errcode(ERRCODE_SYNTAX_ERROR),
    errmsg("invalid myprot URI \'%s\' : missing path",
      uri_str),
    errOmitLocation(true)));

  /* parse path */
  uri->path = pstrdup(uri_str + protocol_len + strlen("://"));

  return uri;
}

static
void FreeDemoUri(DemoUri *uri)
{
  if (uri->path)
    pfree(uri->path);
  if (uri->protocol)
    pfree(uri->protocol);

  pfree(uri);
}
```

8. About Greenplum Query Processing

Users issue queries to Greenplum Database as they would to any database management system (DBMS). They connect to the database instance on the Greenplum master host using a client application such as `psql` and submit SQL statements.

Understanding Query Planning and Dispatch

The master receives, parses, and optimizes the query. The resulting query plan is either *parallel* or *targeted*. The master dispatches parallel query plans to all segments, as shown in Figure 8.1. The master dispatches targeted query plans to a single segment, as shown in Figure 8.2. Each segment is responsible for executing local database operations on its own set of data.

Most database operations—such as table scans, joins, aggregations, and sorts—execute across all segments in parallel. Each operation is performed on a segment database independent of the data stored in the other segment databases.

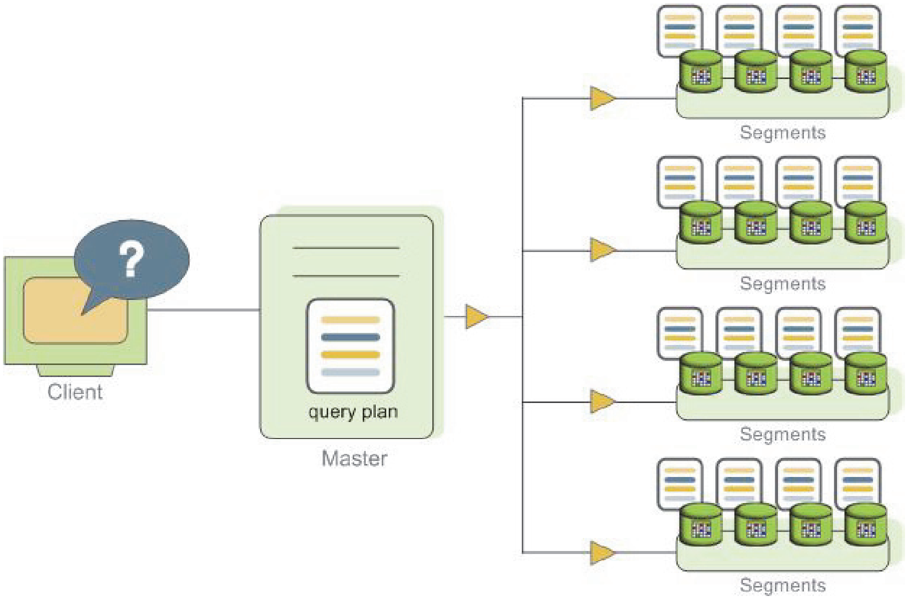


Figure 8.1 Dispatching the Parallel Query Plan

Certain queries may access only data on a single segment, such as single-row `INSERT`, `UPDATE`, `DELETE`, or `SELECT` operations or queries that filter on the table distribution key column(s). In queries such as these, the query plan is not dispatched to all segments, but is targeted at the segment that contains the affected or relevant row(s).

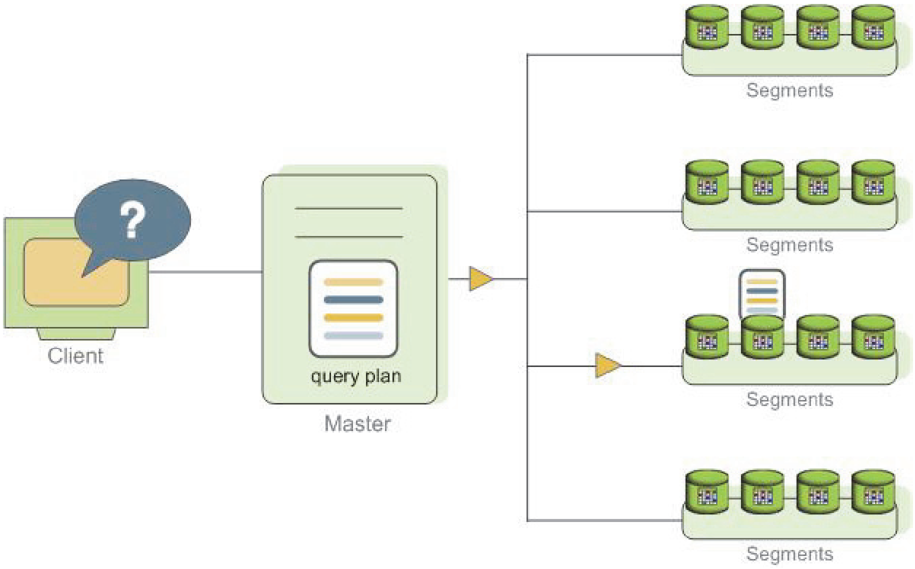


Figure 8.2 Dispatching a Targeted Query Plan

Understanding Greenplum Query Plans

A *query plan* is the set of operations Greenplum Database will perform to produce the answer to a query. Each *node* or step in the plan represents a database operation such as a table scan, join, aggregation, or sort. Plans are read and executed from bottom to top.

In addition to common database operations such as tables scans, joins, and so on, Greenplum Database has an additional operation type called *motion*. A motion operation involves moving tuples between the segments during query processing. Note that not every query requires a motion. For example, a targeted query plan does not require data to move across the interconnect.

To achieve maximum parallelism during query execution, Greenplum divides the work of the query plan into *slices*. A slice is a portion of the plan that segments can work on independently. A query plan is sliced wherever a motion operation occurs in the plan, with one slice on each side of the motion.

For example, consider the following simple query involving a join between two tables:

```
SELECT customer, amount
FROM sales JOIN customer USING (cust_id)
```

```
WHERE dateCol = '04-30-2008';
```

Figure 8.3 shows the query plan. Each segment receives a copy of the query plan and works on it in parallel.

The query plan for this example has a *redistribute motion* that moves tuples between the segments to complete the join. The redistribute motion is necessary because the customer table is distributed across the segments by `cust_id`, but the sales table is distributed across the segments by `sale_id`. To perform the join, the `sales` tuples must be redistributed by `cust_id`. The plan is sliced on either side of the redistribute motion, creating *slice 1* and *slice 2*.

This query plan has another type of motion operation called a *gather motion*. A gather motion is when the segments send results back up to the master for presentation to the client. Because a query plan is always sliced wherever a motion occurs, this plan also has an implicit slice at the very top of the plan (*slice 3*). Not all query plans involve a gather motion. For example, a `CREATE TABLE x AS SELECT...` statement would not have a gather motion because tuples are sent to the newly created table, not to the master.

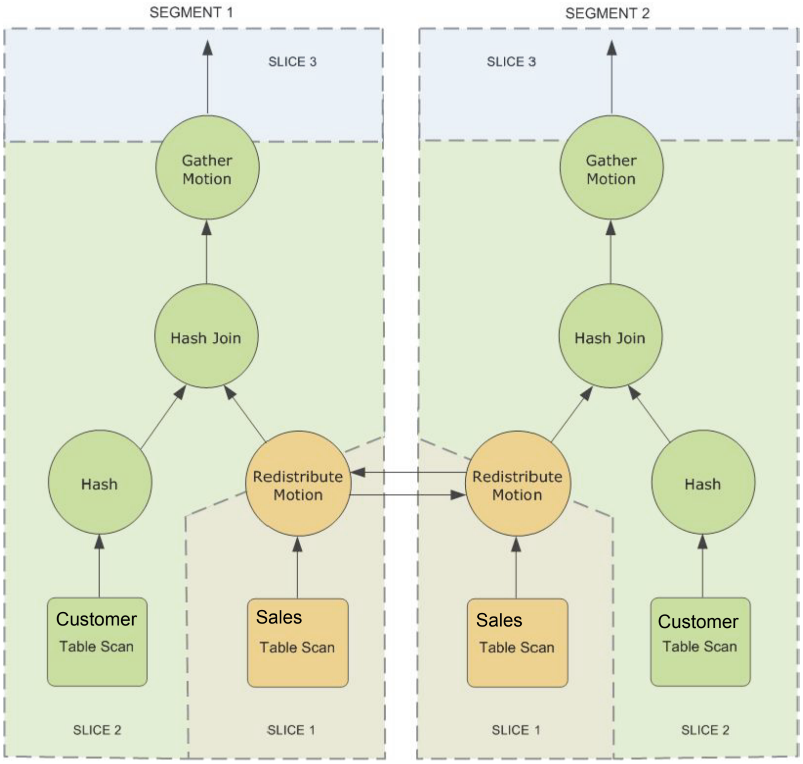


Figure 8.3 Query Slice Plan

Understanding Parallel Query Execution

Greenplum creates a number of database processes to handle the work of a query. On the master, the query worker process is called the *query dispatcher* (QD). The QD is responsible for creating and dispatching the query plan. It also accumulates and presents the final results. On the segments, a query worker process is called a *query executor* (QE). A QE is responsible for completing its portion of work and communicating its intermediate results to the other worker processes.

There is at least one worker process assigned to each *slice* of the query plan. A worker process works on its assigned portion of the query plan independently. During query execution, each segment will have a number of processes working on the query in parallel.

Related processes that are working on the same slice of the query plan but on different segments are called *gangs*. As a portion of work is completed, tuples flow up the query plan from one gang of processes to the next. This inter-process communication between the segments is referred to as the *interconnect* component of Greenplum Database.

Figure 8.4 shows the query worker processes on the master and two segment instances for the query plan illustrated in Figure 8.3.

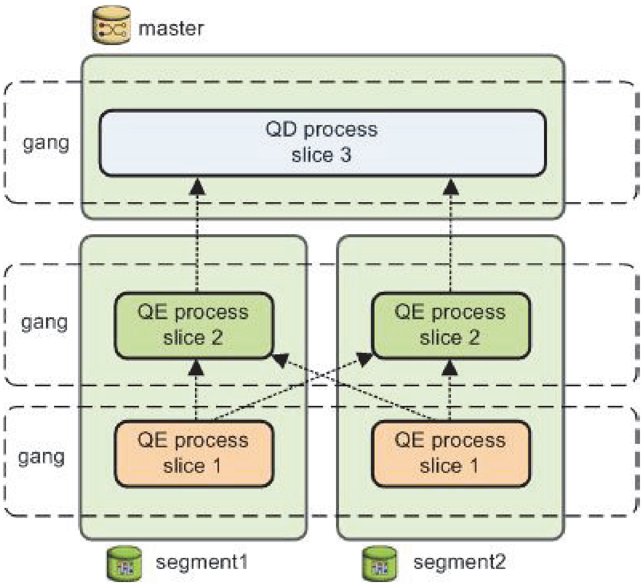


Figure 8.4 Query Worker Processes

9. Querying Data

This chapter describes how to use SQL (Structured Query Language) in Greenplum Database. You enter SQL commands called *queries* to view, change, and analyze data in a database using the PostgreSQL client `psql` or similar client tools.

- Defining Queries
- Using Functions and Operators
- Query Performance
- Query Profiling

Defining Queries

This section describes how to construct SQL queries in Greenplum Database.

- SQL Lexicon
- SQL Value Expressions

SQL Lexicon

SQL is a standard language for accessing databases. The language consists of elements that enable data storage, retrieval, analysis, viewing, manipulation, and so on. You use SQL commands to construct queries and commands that the Greenplum Database engine understands. SQL queries consist of a sequence of commands. Commands consist of a sequence of valid tokens in correct syntax order, terminated by a semicolon (`;`). For more information about SQL commands, see the *Greenplum Database Reference Guide*.

Greenplum Database uses PostgreSQL's structure and syntax with some exceptions. For more information about SQL rules and concepts in PostgreSQL, see SQL Syntax in the PostgreSQL documentation.

SQL Value Expressions

SQL value expressions consist of one or more values, symbols, operators, SQL functions, and data. The expressions compare data or perform calculations and return a value as the result. Calculations include logical, arithmetic, and set operations.

The following are value expressions:

- An aggregate expression
- An array constructor
- A column reference
- A constant or literal value
- A correlated subquery
- A field selection expression

- A function call
- A new column value in an `INSERT` or `UPDATE`
- An operator invocationcolumn reference
- A positional parameter reference, in the body of a function definition or prepared statement
- A row constructor
- A scalar subquery
- A search condition in a `WHERE` clause
- A target list of a `SELECT` command
- A type cast
- A value expression in parentheses, useful to group sub-expressions and override precedence
- A window expression

SQL constructs such as functions and operators are expressions but do not follow any general syntax rules. Fore more information about these constructs, see "Using Functions and Operators" on page 142.

Column References

A column reference has the form:

```
correlation.columnname
```

Here, *`correlation`* is the name of a table (possibly qualified with a schema name) or an alias for a table defined with a `FROM` clause or one of the keywords `NEW` or `OLD`. `NEW` and `OLD` can appear only in rewrite rules, but you can use other correlation names in any SQL statement. If the column name is unique across all tables in the query, you can omit the "*`correlation.`*" part of the column reference.

Positional Parameters

Positional parameters are arguments to SQL statements or functions that you reference by their positions in a series of arguments. For example, `$1` refers to the first argument, `$2` to the second argument, and so on. The values of positional parameters are set from arguments external to the SQL statement or supplied when SQL functions are invoked. Some client libraries support specifying data values separately from the SQL command, in which case parameters refer to the out-of-line data values. A parameter reference has the form:

```
$number
```

For example:

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

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

Subscripts

If an expression yields a value of an array type, you can extract a specific element of the array value as follows:

```
expression[subscript]
```

You can extract multiple adjacent elements, called an *array slice*, as follows (including the brackets):

```
expression[lower_subscript:upper_subscript]
```

Each subscript is an expression and yields an integer value.

Array expressions usually must be in parentheses, but you can omit the parentheses when the expression to be subscripted is a column reference or positional parameter. You can concatenate multiple subscripts when the original array is multidimensional. For example (including the parentheses):

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

Field Selection

If an expression yields a value of a composite type (row type), you can extract a specific field of the row as follows:

```
expression.fieldname
```

The row expression usually must be in parentheses, but you can omit these parentheses when the expression to be selected from is a table reference or positional parameter. For example:

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

A qualified column reference is a special case of field selection syntax.

Operator Invocations

Operator invocations have the following possible syntaxes:

`expression operator expression` (binary infix operator)

`operator expression` (unary prefix operator)

`expression operator` (unary postfix operator)

Where *operator* is an operator token, one of the key words `AND`, `OR`, or `NOT`, or qualified operator name in the form:

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

Available operators and whether they are unary or binary depends on the operators that the system or user defines. For more information about built-in operators, see "Built-in Functions and Operators" on page 144.

Function Calls

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

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

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

```
sqrt(2)
```

“Built-in Functions and Operators” on page 144 lists the built-in functions. You can add custom functions, too.

Aggregate Expressions

An aggregate expression applies an aggregate function across the rows that a query selects. An aggregate function performs a calculation on a set of values and returns a single value, such as the sum or average of the set of values. The syntax of an aggregate expression is one of the following:

- `aggregate_name (expression [ , ... ] ) [FILTER (WHERE condition)]`—operates across all input rows for which the expected result value is non-null. `ALL` is the default.
- `aggregate_name (ALL expression [ , ... ] ) [FILTER (WHERE condition)]`—operates identically to the first form because `ALL` is the default
- `aggregate_name (DISTINCT expression [ , ... ] ) [FILTER (WHERE condition)]`—operates across all distinct non-null values of input rows
- `aggregate_name (*) [FILTER (WHERE condition)]`—operates on all rows with values both null and non-null. Generally, this form is most useful for the `count(*)` aggregate function.

Where *aggregate_name* is a previously defined aggregate (possibly schema-qualified) and *expression* is any value expression that does not contain an aggregate expression.

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

You can specify a condition with the `FILTER` clause to limit the input rows to the aggregate function. For example:

```
SELECT count(*) FILTER (WHERE gender='F') FROM employee;
```

The `WHERE condition` of the `FILTER` clause cannot contain a set-returning function, subquery, window function, or outer reference. If you use a user-defined aggregate function, declare the state transition function as `STRICT` (see `CREATE AGGREGATE`).

For predefined aggregate functions, see “Aggregate Functions” on page 145. You can also add custom aggregate functions.

Greenplum Database provides the `MEDIAN` aggregate function, which returns the fiftieth percentile of the `PERCENTILE_CONT` result and special aggregate expressions for inverse distribution functions as follows:

```
PERCENTILE_CONT(_percentage_) WITHIN GROUP (ORDER BY
_expression_)
PERCENTILE_DISC(_percentage_) WITHIN GROUP (ORDER BY
    _expression_)
```

Currently you can use only these two expressions with the keyword WITHIN GROUP.

Limitations of Aggregate Expressions

The following are current limitations of the aggregate expressions:

- Greenplum Database does not support the following keywords: ALL, DISTINCT, FILTER and OVER. See Table 9.5, "Advanced Aggregate Functions" on page 148 for more details.
- Greenplum Database does not support the following grouping specifications: CUBE, ROLLUP, and GROUPING SETS.
- An aggregate expression can appear only in the result list or HAVING clause of a SELECT command. It is forbidden in other clauses, such as WHERE, because those clauses are logically evaluated before the results of aggregates form. This restriction applies to the query level to which the aggregate belongs.
- When an aggregate expression appears in a subquery, the aggregate is normally evaluated over the rows of the subquery. If the aggregate's arguments contain only outer-level variables, the aggregate belongs to the nearest such outer level and evaluates over the rows of that query. The aggregate expression as a whole is then an outer reference for the subquery in which it appears, and the aggregate expression acts as a constant over any one evaluation of that subquery. See "Scalar Subqueries" on page 138 and "Subquery Expressions" on page 145.
- Greenplum Database does not support DISTINCT with multiple input expressions.

Window Expressions

Window expressions allow application developers to more easily compose complex online analytical processing (OLAP) queries using standard SQL commands. For example, with window expressions, users can calculate moving averages or sums over various intervals, reset aggregations and ranks as selected column values change, and express complex ratios in simple terms.

A window expression represents the application of a *window function* applied to a *window frame*, which is defined in a special OVER() clause. A *window partition* is a set of rows that are grouped together to apply a window function. Unlike aggregate functions, which return a result value for each group of rows, window functions return a result value for every row, but that value is calculated with respect to the rows in a particular window partition. If no partition is specified, the window function is computed over the complete intermediate result set.

The syntax of a window expression is:

```
window_function ( [expression [, ...]] ) OVER (
window_specification )
```

Where *window_function* is one of the functions listed in "Window Functions" on page 146, *expression* is any value expression that does not contain a window expression, and *window_specification* is:

```
[window_name]
[PARTITION BY expression [, ...]]
[[ORDER BY expression [ASC | DESC | USING operator] [, ...]
    [{RANGE | ROWS}
       { UNBOUNDED PRECEDING
       | expression PRECEDING
       | CURRENT ROW
       | BETWEEN window_frame_bound AND window_frame_bound }]]
```

and where *window_frame_bound* can be one of:

```
UNBOUNDED PRECEDING
expression PRECEDING
CURRENT ROW
expression FOLLOWING
UNBOUNDED FOLLOWING
```

A window expression can appear only in the select list of a `SELECT` command. For example:

```
SELECT count(*) OVER(PARTITION BY customer_id), * FROM
sales;
```

The `OVER` clause differentiates window functions from other aggregate or reporting functions. The `OVER` clause defines the *`window_specification`* to which the window function is applied. A window specification has the following characteristics:

- The `PARTITION BY` clause defines the window partitions to which the window function is applied. If omitted, the entire result set is treated as one partition.
- The `ORDER BY` clause defines the expression(s) for sorting rows within a window partition. The `ORDER BY` clause of a window specification is separate and distinct from the `ORDER BY` clause of a regular query expression. The `ORDER BY` clause is required for the window functions that calculate rankings, as it identifies the measure(s) for the ranking values. For OLAP aggregations, the `ORDER BY` clause is required to use window frames (the `ROWS` | `RANGE` clause).

Note: Columns of data types without a coherent ordering, such as `time`, are not good candidates for use in the `ORDER BY` clause of a window specification. `Time`, with or without a specified time zone, lacks a coherent ordering because addition and subtraction do not have the expected effects. For example, the following is not generally true: `x::time < x::time + '2 hour'::interval`

- The `ROWS/RANGE` clause defines a window frame for aggregate (non-ranking) window functions. A window frame defines a set of rows within a window partition. When a window frame is defined, the window function computes on the contents of this moving frame rather than the fixed contents of the entire window partition. Window frames are row-based (`ROWS`) or value-based (`RANGE`).

Type Casts

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

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

The `CAST` syntax conforms to SQL; the syntax with `::` is historical PostgreSQL usage.

A cast applied to a value expression of a known type is a run-time type conversion. The cast succeeds only if a suitable type conversion function is defined. This differs from the use of casts with constants. A cast applied to a string literal represents the initial assignment of a type to a literal constant value, so it succeeds for any type if the contents of the string literal are acceptable input syntax for the data type.

You can usually omit an explicit type cast if there is no ambiguity about the type a value expression must produce; for example, when it is assigned to a table column, the system automatically applies a type cast. The system applies automatic casting only to casts marked "OK to apply implicitly" in system catalogs. Other casts must be invoked with explicit casting syntax to prevent unexpected conversions from being applied without the user's knowledge.

Scalar Subqueries

A scalar subquery is a `SELECT` query in parentheses that returns exactly one row with one column. Do not use a `SELECT` query that returns multiple rows or columns as a scalar subquery. The query runs and uses the returned value in the surrounding value expression. A correlated scalar subquery contains references to the outer query block.

Correlated Subqueries

A correlated subquery (CSQ) is a `SELECT` query with a `WHERE` clause or target list that contains references to the parent outer clause. CSQs efficiently express results in terms of results of another query. Greenplum Database supports correlated subqueries that provide compatibility with many existing applications. A CSQ is a scalar or table subquery, depending on whether it returns one or multiple rows. Greenplum Database does not support correlated subqueries with skip-level correlations.

Correlated Subquery Examples

Example 1 – Scalar correlated subquery

```
SELECT * FROM t1 WHERE t1.x

            > (SELECT MAX(t2.x) FROM t2 WHERE t2.y = t1.y);
```

Example 2 – Correlated EXISTS subquery

```
SELECT * FROM t1 WHERE
            EXISTS (SELECT 1 FROM t2 WHERE t2.x = t1.x);
```

Greenplum Database uses one of the following methods to run CSQs:

- Unnest the CSQ into join operations--This method is most efficient, and it is how Greenplum Database runs most CSQs, including queries from the TPC-H benchmark.
- Run the CSQ on every row of the outer query--This method is relatively inefficient, and it is how Greenplum Database runs queries that contain CSQs in the `SELECT` list or are connected by `OR` conditions.

The following examples illustrate how to rewrite some of these types of queries to improve performance.

Example 3 - CSQ in the Select List

Original Query

```
SELECT T1.a,
    (SELECT COUNT(DISTINCT T2.z) FROM t2 WHERE t1.x = t2.y) dt2
FROM t1;
```

Rewrite this query to perform an inner join with `t1` first and then perform a left join with `t1` again. The rewrite applies for only an equijoin in the correlated condition.

Rewritten Query

```
SELECT t1.a, dt2 FROM t1
       LEFT JOIN
       (SELECT t2.y AS csq_y, COUNT(DISTINCT t2.z) AS dt2
             FROM t1, t2 WHERE t1.x = t2.y GROUP BY t1.x)
       ON (t1.x = csq_y);
```

Example 4 - CSQs connected by OR Clauses

Original Query

```
SELECT * FROM t1
WHERE
x > (SELECT COUNT(*) FROM t2 WHERE t1.x = t2.x)
OR x < (SELECT COUNT(*) FROM t3 WHERE t1.y = t3.y)
```

Rewrite this query to separate it into two parts with a union on the `OR` conditions.

Rewritten Query

```
SELECT * FROM t1
WHERE x > (SELECT count(*) FROM t2 WHERE t1.x = t2.x)
UNION
SELECT * FROM t1
WHERE x < (SELECT count(*) FROM t3 WHERE t1.y = t3.y)
```

To view the query plan, use `EXPLAIN SELECT` or `EXPLAIN ANALYZE SELECT`. Subplan nodes in the query plan indicate that the query will run on every row of the outer query, and the query is a candidate for rewriting. For more information about these statements, see "Query Profiling" on page 159.

Advanced Table Functions

Greenplum Database supports table functions with `TABLE` value expressions. You can sort input rows for advanced table functions with an `ORDER BY` clause. You can redistribute them with a `SCATTER BY` clause to specify one or more columns or an expression for which rows with the specified characteristics are available to the same process. This usage is similar to using a `DISTRIBUTED BY` clause when creating a table, but the redistribution occurs when the query runs.

The following command uses the `TABLE` function with the `SCATTER BY` clause in the the GPText function `gptext.index()` to populate the index `mytest.articles` with data from the messages table:

```
SELECT * FROM gptext.index(TABLE(SELECT * FROM messages
SCATTER BY distrib_id), 'mytest.articles');
```

Note: Based on the distribution of data, Greenplum Database automatically parallelizes table functions with `TABLE` value parameters over the nodes of the cluster.

For information about the function `gptext.index()`, see the Pivotal GPText documentation.

Array Constructors

An array constructor is an expression that builds an array value from values for its member elements. A simple array constructor consists of the key word ARRAY, a left square bracket [, one or more expressions separated by commas for the array element values, and a right square bracket]. For example,

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

The array element type is the common type of its member expressions, determined using the same rules as for UNION or CASE constructs.

You can build multidimensional array values by nesting array constructors. In the inner constructors, you can omit the keyword ARRAY. For example, the following two SELECT statements produce the same result:

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

Since multidimensional arrays must be rectangular, inner constructors at the same level must produce sub-arrays of identical dimensions.

Multidimensional array constructor elements are not limited to a sub-ARRAY construct; they are anything that produces an array of the proper kind. For example:

```
CREATE TABLE arr(f1 int[], f2 int[]);
INSERT INTO arr VALUES (ARRAY[[1,2],[3,4]],
ARRAY[[5,6],[7,8]]);
SELECT ARRAY[f1, f2, '{{9,10},{11,12}}'::int[]] FROM arr;
                     array
------------------------------------------------
 {{{1,2},{3,4}},{{5,6},{7,8}},{{9,10},{11,12}}}
```

You can construct an array from the results of a subquery. Write the array constructor with the keyword ARRAY followed by a subquery in parentheses. For example:

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

The subquery must return a single column. The resulting one-dimensional array has an element for each row in the subquery result, with an element type matching that of the subquery's output column. The subscripts of an array value built with ARRAY always begin with 1.

Row Constructors

A row constructor is an expression that builds a row value (also called a composite value) from values for its member fields. For example,

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

Row constructors have the syntax `rowvalue.*`, which expands to a list of the elements of the row value, as when you use the syntax `.*` at the top level of a `SELECT` list. For example, if table `t` has columns `f1` and `f2`, the following queries are the same:

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

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

```
CREATE TABLE mytable(f1 int, f2 float, f3 text);
CREATE FUNCTION getf1(mytable) RETURNS int AS 'SELECT $1.f1'
LANGUAGE SQL;
```

-- In the following query, you do not need to cast the value because there is only one `getf1()` function and therefore no ambiguity:

```
SELECT getf1(ROW(1,2.5,'this is a test'));
 getf1
-------
     1
CREATE TYPE myrowtype AS (f1 int, f2 text, f3 numeric);
CREATE FUNCTION getf1(myrowtype) RETURNS int AS 'SELECT
$1.f1' LANGUAGE SQL;
```

-- Now we need a cast to indicate which function to call:

```
SELECT getf1(ROW(1,2.5,'this is a test'));
ERROR:  function getf1(record) is not unique
SELECT getf1(ROW(1,2.5,'this is a test')::mytable);
 getf1
-------
     1
SELECT getf1(CAST(ROW(11,'this is a test',2.5) AS
myrowtype));
 getf1
-------
    11
```

You can use row constructors to build composite values to be stored in a composite-type table column or to be passed to a function that accepts a composite parameter.

Expression Evaluation Rules

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

If you can determine the result of an expression by evaluating only some parts of the expression, then other subexpressions might not be evaluated at all. For example, in the following expression:

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

`somefunc()` would probably not be called at all. The same is true in the following expression:

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

This is not the same as the left-to-right evaluation order that Boolean operators enforce in some programming languages.

Do not use functions with side effects as part of complex expressions, especially in `WHERE` and `HAVING` clauses, because those clauses are extensively reprocessed when developing an execution plan. Boolean expressions (`AND`/`OR`/`NOT` combinations) in those clauses can be reorganized in any manner that Boolean algebra laws allow.

Use a `CASE` construct to force evaluation order. The following example is an untrustworthy way to avoid division by zero in a `WHERE` clause:

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

The following example shows a trustworthy evaluation order:

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

This `CASE` construct usage defeats optimization attempts; use it only when necessary.

Using Functions and Operators

- Using Functions in Greenplum Database
- User-Defined Functions
- Built-in Functions and Operators
- Window Functions
- Advanced Analytic Functions

Using Functions in Greenplum Database

Table 9.1 Functions in Greenplum Database

Function Type	Greenplum Support	Description	Comments
IMMUTABLE	Yes	Relies only on information directly in its argument list. Given the same argument values, always returns the same result.	
STABLE	Yes, in most cases	Within a single table scan, returns the same result for same argument values, but results change across SQL statements.	Results depend on database lookups or parameter values. `current_timestamp` family of functions is `STABLE`; values do not change within an execution.
VOLATILE	Restricted	Function values can change within a single table scan. For example: `random()`, `currval()`, `timeofday()`.	Any function with side effects is volatile, even if its result is predictable. For example: `setval()`.

In Greenplum Database, data is divided up across segments — each segment is a distinct PostgreSQL database. To prevent inconsistent or unexpected results, do not execute functions classified as `VOLATILE` at the segment level if they contain SQL commands or modify the database in any way. For example, functions such as `setval()` are not allowed to execute on distributed data in Greenplum Database because they can cause inconsistent data between segment instances.

To ensure data consistency, you can safely use `VOLATILE` and `STABLE` functions in statements that are evaluated on and run from the master. For example, the following statements run on the master (statements without a `FROM` clause):

```
SELECT setval('myseq', 201);
SELECT foo();
```

If a statement has a `FROM` clause containing a distributed table and the function in the `FROM` clause returns a set of rows, the statement can run on the segments:

```
SELECT * from foo();
```

Greenplum Database does not support functions that return a table reference (`rangeFuncs`) or functions that use the `refCursor` datatype.

User-Defined Functions

Greenplum Database supports user-defined functions. See Extending SQL in the PostgreSQL documentation for more information.

Use the `CREATE FUNCTION` command to register user-defined functions that are used as described in "Using Functions in Greenplum Database" on page 143. By default, user-defined functions are declared as `VOLATILE`, so if your user-defined function is `IMMUTABLE` or `STABLE`, you must specify the correct volatility level when you register your function.

When you create user-defined functions, avoid using fatal errors or destructive calls. Greenplum Database may respond to such errors with a sudden shutdown or restart.

In Greenplum Database, the shared library files for user-created functions must reside in the same library path location on every host in the Greenplum Database array (masters, segments, and mirrors).

Built-in Functions and Operators

The following table lists the categories of built-in functions and operators supported by PostgreSQL. All functions and operators are supported in Greenplum Database as in PostgreSQL with the exception of `STABLE` and `VOLATILE` functions, which are subject to the restrictions noted in "Using Functions in Greenplum Database" on page 143. See the Functions and Operators section of the PostgreSQL documentation for more information about these built-in functions and operators.

Table 9.2 Built-in functions and operators

Operator/Function Category	VOLATILE Functions	STABLE Functions	Restrictions
Logical Operators			
Comparison Operators			
Mathematical Functions and Operators	random setseed		
String Functions and Operators	*All built-in conversion functions*	convert pg_client_encoding	
Binary String Functions and Operators			
Bit String Functions and Operators			
Pattern Matching			
Data Type Formatting Functions		to_char to_timestamp	
Date/Time Functions and Operators	timeofday	age current_date current_time current_timestamp localtime localtimestamp now	
Geometric Functions and Operators			

Table 9.2 Built-in functions and operators

Operator/Function Category	VOLATILE Functions	STABLE Functions	Restrictions
Network Address Functions and Operators			
Sequence Manipulation Functions	currval lastval nextval setval		
Conditional Expressions			
Array Functions and Operators		*All array functions*	
Aggregate Functions			
Subquery Expressions			
Row and Array Comparisons			
Set Returning Functions	generate_series		
System Information Functions		*All session information functions* *All access privilege inquiry functions* *All schema visibility inquiry functions* *All system catalog information functions* *All comment information functions*	
System Administration Functions	set_config pg_cancel_backend pg_reload_conf pg_rotate_logfile pg_start_backup pg_stop_backup pg_size_pretty pg_ls_dir pg_read_file pg_stat_file	current_setting *All database object size functions*	

XML Functions		xmlagg(xml)
		xmlexists(text, xml)
		xml_is_well_formed(text)
		xml_is_well_formed_document(text)
		xml_is_well_formed_content(text)
		xpath(text, xml)
		xpath(text, xml, text[])
		xpath_exists(text, xml)
		xpath_exists(text, xml, text[])
		xml(text)
		text(xml)
		xmlcomment(xml)
		xmlconcat2(xml, xml)	

Window Functions

The following built-in window functions are Greenplum extensions to the PostgreSQL database. All window functions are *immutable*. For more information about window functions, see "Window Expressions" on page 136.

Table 9.3 Window functions

Function	Return Type	Full Syntax	Description
`cume_dist()`	`double precision`	`CUME_DIST() OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Calculates the cumulative distribution of a value in a group of values. Rows with equal values always evaluate to the same cumulative distribution value.
`dense_rank()`	`bigint`	`DENSE_RANK () OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`*`)`	Computes the rank of a row in an ordered group of rows without skipping rank values. Rows with equal values are given the same rank value.
`first_value(`*`expr`*`)`	same as input *expr* type	`FIRST_VALUE(`*`expr`*`) OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `[ROWS|RANGE` *`frame_expr`*`] )`	Returns the first value in an ordered set of values.
`lag(`*`expr`* `[,`*`offset`*`] [,`*`default`*`])`	same as input *expr* type	`LAG(`*`expr`* `[,`*`offset`*`] [,`*`default`*`]) OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Provides access to more than one row of the same table without doing a self join. Given a series of rows returned from a query and a position of the cursor, `LAG` provides access to a row at a given physical offset prior to that position. The default `offset` is 1. *`default`* sets the value that is returned if the offset goes beyond the scope of the window. If *`default`* is not specified, the default value is null.
`last_value(`*`expr`*`)`	same as input *expr* type	`LAST_VALUE(`*`expr`*`) OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `[ROWS|RANGE` *`frame_expr`*`] )`	Returns the last value in an ordered set of values.
`lead(`*`expr`* `[,`*`offset`*`] [,`*`default`*`])`	same as input *expr* type	`LEAD(`*`expr`* `[,`*`offset`*`] [,`*`default`*`]) OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Provides access to more than one row of the same table without doing a self join. Given a series of rows returned from a query and a position of the cursor, `lead` provides access to a row at a given physical offset after that position. If *`offset`* is not specified, the default offset is 1. *`default`* sets the value that is returned if the offset goes beyond the scope of the window. If *`default`* is not specified, the default value is null.

Table 9.3 Window functions

Function	Return Type	Full Syntax	Description
`ntile(`*`expr`*`)`	`bigint`	`NTILE(`*`expr`*`) OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Divides an ordered data set into a number of buckets (as defined by *`expr`*) and assigns a bucket number to each row.
`percent_rank( )`	`double precision`	`PERCENT_RANK () OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Calculates the rank of a hypothetical row *R* minus 1, divided by 1 less than the number of rows being evaluated (within a window partition).
`rank()`	`bigint`	`RANK () OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Calculates the rank of a row in an ordered group of values. Rows with equal values for the ranking criteria receive the same rank. The number of tied rows are added to the rank number to calculate the next rank value. Ranks may not be consecutive numbers in this case.
`row_number()`	`bigint`	`ROW_NUMBER () OVER ( [PARTITION BY` *`expr`*`] ORDER BY` *`expr`* `)`	Assigns a unique number to each row to which it is applied (either each row in a window partition or each row of the query).

Advanced Analytic Functions

The following built-in advanced analytic functions are Greenplum extensions of the PostgreSQL database. Analytic functions are *immutable*..

Table 9.4 Advanced Analytic Functions

Function	Return Type	Full Syntax	Description
`matrix_add( array[], array[])`	`smallint[], int[], bigint[], float[]`	`matrix_add( array[[1,1],[2,2]], array[[3,4],[5,6]])`	Adds two two-dimensional matrices. The matrices must be conformable.
`matrix_multiply(array[], array[])`	`smallint[]int[], bigint[], float[]`	`matrix_multiply( array[[2,0,0],[0,2,0],[0,0,2]], array[[3,0,3],[0,3,0],[0,0,3]] )`	Multiplies two, three-dimensional arrays. The matrices must be conformable.
`matrix_multiply(array[], `*`expr`*`)`	`int[], float[]`	`matrix_multiply( array[[1,1,1], [2,2,2], [3,3,3]], 2)`	Multiplies a two-dimensional array and a scalar numeric value.
`matrix_transpose(array[])`	Same as input array type.	`matrix_transpose( array [[1,1,1],[2,2,2]])`	Transposes a two-dimensional array.

Table 9.4 Advanced Analytic Functions

Function	Return Type	Full Syntax	Description

`pinv(array [])`	`smallint[]int[],`
	`bigint[],`
	`float[]`
		`pinv(array[[2.5,0,0],[0,1,0],[0,0,.5]])`	Calculates the Moore-Penrose pseudoinverse of a matrix.

`unnest (array[])`	set of `anyelement`	`unnest( array['one', 'row', 'per', 'item'])`	Transforms a one dimensional array into rows. Returns a set of `anyelement`, a polymorphic pseudotype in PostgreSQL.

Table 9.5 Advanced Aggregate Functions

Function	Return Type	Full Syntax	Description

`MEDIAN (expr)`	`timestamp,`
	`timestampz,`
	`interval,`
	`float`
		`MEDIAN (_expression_)`
		Example:
		`SELECT department_id, MEDIAN(salary)`
		`FROM employees`
		`GROUP BY department_id;`
			Can take a two-dimensional array as input. Treats such arrays as matrices.

`PERCENTILE_CONT (expr) WITHIN GROUP (ORDER BY expr [DESC/ASC])`	`timestamp,`
	`timestampz,`
	`interval,`
	`float`
		`PERCENTILE_CONT(_percentage_) WITHIN GROUP (ORDER BY _expression_)`
		Example:
		`SELECT department_id,`
		`PERCENTILE_CONT (0.5) WITHIN GROUP (ORDER BY salary DESC)`
		`“Median_cont”;`
		`FROM employees GROUP BY department_id;`
			Performs an inverse distribution function that assumes a continuous distribution model. It takes a percentile value and a sort specification and returns the same datatype as the numeric datatype of the argument. This returned value is a computed result after performing linear interpolation. Null are ignored in this calculation.

`PERCENTILE_DESC (expr) WITHIN GROUP (ORDER BY expr [DESC/ASC])`	`timestamp,`
	`timestampz,`
	`interval,`
	`float`
		`PERCENTILE_DESC(_percentage_) WITHIN GROUP (ORDER BY _expression_)`
		Example:
		`SELECT department_id,`
		`PERCENTILE_DESC (0.5) WITHIN GROUP (ORDER BY salary DESC)`
		`“Median_desc”;`
		`FROM employees GROUP BY department_id;`
			Performs an inverse distribution function that assumes a discrete distribution model. It takes a percentile value and a sort specification. This returned value is an element from the set. Null are ignored in this calculation.

Table 9.5 Advanced Aggregate Functions

Function	Return Type	Full Syntax	Description

`sum(array[])`	`smallint[]`, `int[]`, `bigint[]`, `float[]`	`sum(array[[1,2],[3,4]])`
		Example:
		CREATE TABLE mymatrix (myvalue int[]);
		INSERT INTO mymatrix VALUES (array[[1,2],[3,4]]);
		INSERT INTO mymatrix VALUES (array[[0,1],[1,0]]);
		SELECT sum(myvalue) FROM mymatrix;
		sum
		--------------- 	
		{{1,3},{4,4}}
			Performs matrix summation. Can take as input a two-dimensional array that is treated as a matrix.

`pivot_sum(label[], label, `*`expr`*`)`	`int[]`, `bigint[]`, `float[]`	`pivot_sum( array['A1','A2'], attr, value)`	A pivot aggregation using sum to resolve duplicate entries.
`mregr_coef(`*`expr`*`, array[])`	`float[]`	`mregr_coef(y, array[1, x1, x2])`	The four `mregr_*` aggregates perform linear regressions using the ordinary-least-squares method. `mregr_coef` calculates the regression coefficients. The size of the return array for `mregr_coef` is the same as the size of the input array of independent variables, since the return array contains the coefficient for each independent variable.
`mregr_r2(`*`expr`*`, array[])`	`float`	`mregr_r2(y, array[1, x1, x2])`	The four `mregr_*` aggregates perform linear regressions using the ordinary-least-squares method. `mregr_r2` calculates the r-squared error value for the regression.
`mregr_pvalues(`*`expr`*`, array[])`	`float[]`	`mregr_pvalues(y, array[1, x1, x2])`	The four `mregr_*` aggregates perform linear regressions using the ordinary-least-squares method. `mregr_pvalues` calculates the p-values for the regression.
`mregr_tstats(`*`expr`*`, array[])`	`float[]`	`mregr_tstats(y, array[1, x1, x2])`	The four `mregr_*` aggregates perform linear regressions using the ordinary-least-squares method. `mregr_tstats` calculates the t-statistics for the regression.

Table 9.5 Advanced Aggregate Functions

Function	Return Type	Full Syntax	Description
`nb_classify (text[], bigint, bigint[], bigint[])`	`text`	`nb_classify(classes, attr_count, class_count, class_total)`	Classify rows using a Naive Bayes Classifier. This aggregate uses a baseline of training data to predict the classification of new rows and returns the class with the largest likelihood of appearing in the new rows.
`nb_probabilities(text[], bigint, bigint[], bigint[])`	`text`	`nb_probabilities(classes, attr_count, class_count, class_total)`	Determine probability for each class using a Naive Bayes Classifier. This aggregate uses a baseline of training data to predict the classification of new rows and returns the probabilities that each class will appear in new rows.

Advanced Analytic Function Examples

These examples illustrate selected advanced analytic functions in queries on simplified example data. They are for the multiple linear regression aggregate functions and for Naive Bayes Classification with `nb_classify`.

Linear Regression Aggregates Example

The following example uses the four linear regression aggregates `mregr_coef`, `mregr_r2`, `mregr_pvalues`, and `mregr_tstats` in a query on the example table `regr_example`. In this example query, all the aggregates take the dependent variable as the first parameter and an array of independent variables as the second parameter.

```
SELECT mregr_coef(y, array[1, x1, x2]),
       mregr_r2(y, array[1, x1, x2]),
       mregr_pvalues(y, array[1, x1, x2]),
       mregr_tstats(y, array[1, x1, x2])
from regr_example;
```

Table `regr_example`:

```
 id | y  | x1 | x2
----+----+----+----
  1 |  5 |  2 |  1
  2 | 10 |  4 |  2
  3 |  6 |  3 |  1
  4 |  8|   3 |  1
```

Running the example query against this table yields one row of data with the following values:

`mregr_coef`:

```
{-7.105427357601e-15,2.00000000000003,0.999999999999943}
```

`mregr_r2`:

```
0.86440677966103

mregr_pvalues:

{0.999999999999999,0.454371051656992,0.783653104061216}

mregr_tstats:

{-2.24693341988919e-15,1.15470053837932,0.35355339059327}
```

Greenplum Database returns `NaN` (not a number) if the results of any of these agregates are undefined. This can happen if there is a very small amount of data.

Note: The intercept is computed by setting one of the independent variables to `1`, as shown in the preceding example.

Naive Bayes Classification Examples

The aggregates `nb_classify and nb_probabilities` are used within a larger four-step classification process that involves the creation of tables and views for training data. The following two examples show all the steps. The first example shows a small data set with arbitrary values, and the second example is the Greenplum implementation of a popular Naive Bayes example based on weather conditions.

Overview

The following describes the Naive Bayes classification procedure. In the examples, the value names become the values of the field *attr*:

1. Unpivot the data.

   If the data is not denormalized, create a view with the identification and classification that unpivots all the values. If the data is already in denormalized form, you do not need to unpivot the data.

2. Create a training table.

   The training table shifts the view of the data to the values of the field *attr*.

3. Create a summary view of the training data.

4. Aggregate the data with `nb_classify`, `nb_probabilities`,or both.

Naive Bayes Example 1 – Small Table

This example begins with the normalized data in the example table `class_example` and proceeds through four discrete steps:

Table `class_example`:

```
 id | class | a1 | a2 | a3
----+-------+----+----+----
  1 | C1    |  1 |  2 |  3
  2 | C1    |  1 |  4 |  3
  3 | C2    |  0 |  2 |  2
  4 | C1    |  1 |  2 |  1
  5 | C2    |  1 |  2 |  2
  6 | C2    |  0 |  1 |  3
```

1. Unpivot the data

For use as training data, the data in `class_example` must be unpivoted because the data is in denormalized form. The terms in single quotation marks define the values to use for the new field *attr*. By convention, these values are the same as the field names in the normalized table. In this example, these values are capitalized to highlight where they are created in the command.

```
CREATE view class_example_unpivot AS
SELECT id, class, unnest(array['A1', 'A2', 'A3']) as attr,
unnest(array[a1,a2,a3]) as value FROM class_example;
```

The unpivoted view shows the normalized data. It is not necessary to use this view. Use the command `SELECT * from class_example_unpivot` to see the denormalized data:

```
 id | class | attr | value
----+-------+------+-------
  2 | C1    | A1   |     1
  2 | C1    | A2   |     2
  2 | C1    | A3   |     1
  4 | C2    | A1   |     1
  4 | C2    | A2   |     2
  4 | C2    | A3   |     2
  6 | C2    | A1   |     0
  6 | C2    | A2   |     1
  6 | C2    | A3   |     3
  1 | C1    | A1   |     1
  1 | C1    | A2   |     2
  1 | C1    | A3   |     3
  3 | C1    | A1   |     1
  3 | C1    | A2   |     4
  3 | C1    | A3   |     3
  5 | C2    | A1   |     0
  5 | C2    | A2   |     2
  5 | C2    | A3   |     2
(18 rows)
```

2. Create a training table from the unpivoted data.

   The terms in single quotation marks define the values to sum. The terms in the array passed into `pivot_sum` must match the number and names of classifications in the original data. In the example, C1 and C2:

```
CREATE table class_example_nb_training AS
SELECT attr, value, pivot_sum(array['C1', 'C2'], class, 1)
as class_count
FROM   class_example_unpivot
GROUP BY attr, value
DISTRIBUTED by (attr);
```

   The following is the resulting training table:

```
 attr | value | class_count
```

```
------+-------+-------------
 A3   |     1 | {1,0}
 A3   |     3 | {2,1}
 A1   |     1 | {3,1}
 A1   |     0 | {0,2}
 A3   |     2 | {0,2}
 A2   |     2 | {2,2}
 A2   |     4 | {1,0}
 A2   |     1 | {0,1}
(8 rows)
```

3. Create a summary view of the training data.

```
CREATE VIEW class_example_nb_classify_functions AS
SELECT attr, value, class_count, array['C1', 'C2'] as classes,
sum(class_count) over (wa)::integer[] as class_total,
count(distinct value) over (wa) as attr_count
FROM class_example_nb_training
WINDOW wa as (partition by attr);
```

The following is the resulting training table:

```
attr| value | class_count| classes | class_total |attr_count
-----+-------+------------+---------+-------------+---------
 A2  |     2 | {2,2}      | {C1,C2} | {3,3}       |        3
 A2  |     4 | {1,0}      | {C1,C2} | {3,3}       |        3
 A2  |     1 | {0,1}      | {C1,C2} | {3,3}       |        3
 A1  |     0 | {0,2}      | {C1,C2} | {3,3}       |        2
 A1  |     1 | {3,1}      | {C1,C2} | {3,3}       |        2
 A3  |     2 | {0,2}      | {C1,C2} | {3,3}       |        3
 A3  |     3 | {2,1}      | {C1,C2} | {3,3}       |        3
 A3  |     1 | {1,0}      | {C1,C2} | {3,3}       |        3
(8 rows)
```

4. Classify rows with `nb_classify` and display the probability with `nb_probabilities`.

After you prepare the view, the training data is ready for use as a baseline for determining the class of incoming rows. The following query predicts whether rows are of class `C1` or `C2` by using the `nb_classify` aggregate:

```
SELECT nb_classify(classes, attr_count, class_count,
class_total) as class
FROM class_example_nb_classify_functions
where (attr = 'A1' and value = 0) or (attr = 'A2' and value =
2) or (attr = 'A3' and value = 1);
```

Running the example query against this simple table yields one row of data displaying these values:

This query yields the expected single-row result of `C1`.

```
class
```

```
-------
C2
(1 row)
```

Display the probabilities for each class with `nb_probabilities`.

Once the view is prepared, the system can use the training data as a baseline for determining the class of incoming rows. The following query predicts whether rows are of class `C1` or `C2` by using the `nb_probabilities` aggregate:

```
SELECT nb_probabilities(classes, attr_count, class_count,
class_total) as probability
FROM class_example_nb_classify_functions
where (attr = 'A1' and value = 0) or (attr = 'A2' and value =
2) or (attr = 'A3' and value = 1);
```

Running the example query against this simple table yields one row of data displaying the probabilities for each class:

This query yields the expected single-row result showing two probabilities, the first for `C1`,and the second for `C2`.

```
probability
-------------
 {0.4,0.6}
(1 row)
```

You can display the classification and the probabilities with the following query.

```
SELECT nb_classify(classes, attr_count, class_count,
class_total) as class, nb_probabilities(classes, attr_count,
class_count, class_total) as probability FROM
class_example_nb_classify where (attr = 'A1' and value = 0)
or (attr = 'A2' and value = 2) or (attr = 'A3' and value =
1);
```

This query produces the following result:

```
   class | probability
   -------+-------------
    C2    | {0.4,0.6}
(1 row)
```

Actual data in production scenarios is more extensive than this example data and yields better results. Accuracy of classification with `nb_classify and` `nb_probabilities` improves significantly with larger sets of training data.

Naive Bayes Example 2 – Weather and Outdoor Sports

This example calculates the probabilities of whether the user will play an outdoor sport, such as golf or tennis, based on weather conditions. The table `weather_example` contains the example values. The identification field for the table is *day*. There are two classifications held in the field *play*: `Yes` or `No`. There are four weather attributes, *outlook*, *temperature*, *humidity*, and *wind*. The data is normalized.

```
 day | play | outlook  | temperature | humidity |  wind
-----+------+----------+-------------+----------+--------
   2 | No   | Sunny    | Hot         | High     | Strong
   4 | Yes  | Rain     | Mild        | High    | Weak
   6 | No   | Rain     | Cool        | Normal  | Strong
   8 | No   | Sunny    | Mild        | High    | Weak
  10 | Yes  | Rain     | Mild        | Normal  | Weak
  12 | Yes  | Overcast | Mild        | High    | Strong
  14 | No   | Rain     | Mild        | High    | Strong
   1 | No   | Sunny    | Hot         | High    | Weak
   3 | Yes  | Overcast | Hot         | High    | Weak
   5 | Yes  | Rain     | Cool        | Normal  | Weak
   7 | Yes  | Overcast | Cool        | Normal  | Strong
   9 | Yes  | Sunny    | Cool        | Normal  | Weak
  11 | Yes  | Sunny    | Mild        | Normal  | Strong
  13 | Yes  | Overcast | Hot         | Normal  | Weak
(14 rows)
```

Because this data is normalized, all four Naive Bayes steps are required.

1. Unpivot the data.

```
CREATE view weather_example_unpivot AS SELECT day, play,
unnest(array['outlook','temperature', 'humidity','wind']) as
attr, unnest(array[outlook,temperature,humidity,wind]) as
value FROM weather_example;
```

Note the use of quotation marks in the command.

The `SELECT * from weather_example_unpivot` displays the denormalized data and contains the following 56 rows.

```
 day | play |    attr     |  value
-----+------+-------------+----------
   2 | No   | outlook     | Sunny
   2 | No   | temperature | Hot
   2 | No   | humidity    | High
   2 | No   | wind        | Strong
   4 | Yes  | outlook     | Rain
   4 | Yes  | temperature | Mild
   4 | Yes  | humidity    | High
   4 | Yes  | wind        | Weak
   6 | No   | outlook     | Rain
   6 | No   | temperature | Cool
   6 | No   | humidity    | Normal
   6 | No   | wind        | Strong
   8 | No   | outlook     | Sunny
   8 | No   | temperature | Mild
   8 | No   | humidity    | High
   8 | No   | wind        | Weak
  10 | Yes  | outlook     | Rain
  10 | Yes  | temperature | Mild
  10 | Yes  | humidity    | Normal
  10 | Yes  | wind        | Weak
  12 | Yes  | outlook     | Overcast
  12 | Yes  | temperature | Mild
  12 | Yes  | humidity    | High
  12 | Yes  | wind        | Strong
  14 | No   | outlook     | Rain
  14 | No   | temperature | Mild
  14 | No   | humidity    | High
  14 | No   | wind        | Strong
   1 | No   | outlook     | Sunny
   1 | No   | temperature | Hot
   1 | No   | humidity    | High
   1 | No   | wind        | Weak
   3 | Yes  | outlook     | Overcast
   3 | Yes  | temperature | Hot
   3 | Yes  | humidity    | High
   3 | Yes  | wind        | Weak
   5 | Yes  | outlook     | Rain
   5 | Yes  | temperature | Cool
   5 | Yes  | humidity    | Normal
   5 | Yes  | wind        | Weak
   7 | Yes  | outlook     | Overcast
   7 | Yes  | temperature | Cool
   7 | Yes  | humidity    | Normal
   7 | Yes  | wind        | Strong
   9 | Yes  | outlook     | Sunny
   9 | Yes  | temperature | Cool
   9 | Yes  | humidity    | Normal
   9 | Yes  | wind        | Weak
  11 | Yes  | outlook     | Sunny
  11 | Yes  | temperature | Mild
  11 | Yes  | humidity    | Normal
  11 | Yes  | wind        | Strong
  13 | Yes  | outlook     | Overcast
  13 | Yes  | temperature | Hot
  13 | Yes  | humidity    | Normal
  13 | Yes  | wind        | Weak
(56 rows)
```

2. Create a training table.

```
CREATE table weather_example_nb_training AS SELECT attr,
value, pivot_sum(array['Yes','No'], play, 1) as class_count
FROM weather_example_unpivot GROUP BY attr, value
DISTRIBUTED by (attr);
```

The `SELECT * from weather_example_nb_training` displays the training data and contains the following 10 rows.

```
    attr     |  value   | class_count
-------------+----------+-------------
 outlook     | Rain     | {3,2}
 humidity    | High     | {3,4}
 outlook     | Overcast | {4,0}
 humidity    | Normal   | {6,1}
 outlook     | Sunny    | {2,3}
 wind        | Strong   | {3,3}
 temperature | Hot      | {2,2}
 temperature | Cool     | {3,1}
 temperature | Mild     | {4,2}
 wind        | Weak     | {6,2}
(10 rows)
```

3. Create a summary view of the training data.

```
CREATE VIEW weather_example_nb_classify_functions AS SELECT
attr, value, class_count, array['Yes','No'] as
classes,sum(class_count) over (wa)::integer[] as
class_total,count(distinct value) over (wa) as attr_count
FROM weather_example_nb_training WINDOW wa as (partition by
attr);
```

The `SELECT * from weather_example_nb_classify_function` displays the training data and contains the following 10 rows.

```
attr        |  value   | class_count| classes | class_total| attr_count
------------+-------- +------------+---------+------------+-----------
temperature | Mild     | {4,2}      | {Yes,No}| {9,5}      |          3
temperature | Cool     | {3,1}      | {Yes,No}| {9,5}      |          3
temperature | Hot      | {2,2}      | {Yes,No}| {9,5}      |          3
wind        | Weak     | {6,2}      | {Yes,No}| {9,5}      |          2
wind        | Strong   | {3,3}      | {Yes,No}| {9,5}      |          2
humidity    | High     | {3,4}      | {Yes,No}| {9,5}      |          2
humidity    | Normal   | {6,1}      | {Yes,No}| {9,5}      |          2
outlook     | Sunny    | {2,3}      | {Yes,No}| {9,5}      |          3
outlook     | Overcast| {4,0}      | {Yes,No}| {9,5}      |          3
outlook     | Rain     | {3,2}      | {Yes,No}| {9,5}      |          3
(10 rows)
```

4. Aggregate the data with `nb_classify`, `nb_probabilities`,or both.

Decide what to classify. To classify only one record with the following values:

```
temperature | wind | humidity | outlook
------------+------+----------+---------
 Cool       | Weak | High     | Overcast
```

Use the following command to aggregate the data. The result gives the classification `Yes` or `No` and the probability of playing outdoor sports under this particular set of conditions.

```
SELECT nb_classify(classes, attr_count, class_count,
class_total) as class,
       nb_probabilities(classes, attr_count, class_count,
class_total) as probability
FROM weather_example_nb_classify_functions where
  (attr = 'temperature' and value = 'Cool') or
  (attr = 'wind'        and value = 'Weak') or
  (attr = 'humidity'    and value = 'High') or
  (attr = 'outlook'     and value = 'Overcast');
```

The result is a single row.

```
class |              probability
-------+-------------------------------------
 Yes   | {0.858103353920726,0.141896646079274}
(1 row)
```

To classify a group of records, load them into a table. In this example, the table `t1` contains the following records:

```
 day | outlook   | temperature | humidity |  wind
-----+----------+-------------+----------+--------
  15 | Sunny    | Mild        | High     | Strong
  16 | Rain     | Cool        | Normal   | Strong
  17 | Overcast | Hot         | Normal   | Weak
  18 | Rain     | Hot         | High     | Weak
(4 rows)
```

The following command aggregates the data against this table. The result gives the classification `Yes` or `No` and the probability of playing outdoor sports for each set of conditions in the table `t1`. Both the `nb_classify` and `nb_probabilities` aggregates are used.

```
SELECT t1.day,
       t1.temperature, t1.wind, t1.humidity, t1.outlook,
       nb_classify(classes, attr_count, class_count,
class_total) as class,
       nb_probabilities(classes, attr_count, class_count,
class_total) as probability
FROM t1, weather_example_nb_classify_functions
WHERE
  (attr = 'temperature' and value = t1.temperature) or
  (attr = 'wind'        and value = t1.wind) or
  (attr = 'humidity'    and value = t1.humidity) or
  (attr = 'outlook'     and value = t1.outlook)
GROUP BY t1.day, t1.temperature, t1.wind, t1.humidity,
t1.outlook;
```

The result is a four rows, one for each record in `t1`.

```
day| temp| wind   | humidity | outlook  | class |  probability
---+-----+--------+----------+----------+-------+--------------
15 | Mild| Strong | High     | Sunny    | No    | {0.244694132334582,0.755305867665418}
```

```
16 | Cool| Strong | Normal   | Rain     | Yes   | {0.751471997809119,0.248528002190881}
18 | Hot | Weak   | High     | Rain     | No    | {0.446387538890131,0.553612461109869}
17 | Hot | Weak   | Normal   | Overcast | Yes   | {0.9297192642788,0.0702807357212004}
(4 rows)
```

Query Performance

Greenplum Database dynamically eliminates irrelevant partitions in a table and optimally allocates memory for different operators in a query. These enhancements scan less data for a query, accelerate query processing, and support more concurrency.

- Dynamic Partition Elimination

  In the Greenplum Database, values available only when a query runs are used to dynamically prune partitions, which improves query processing speed. Enable or disable dynamic partition elimination by setting the server configuration parameter `gp_dynamic_partition_pruning` to `ON` or `OFF`; it is `ON` by default.

- Memory Optimizations

  Greenplum Database allocates memory optimally for different operators in a query and frees and re-allocates memory during the stages of processing a query.

Query Profiling

Greenplum Database devises a *query plan* for each query. Choosing the right query plan to match the query and data structure is necessary for good performance. A query plan defines how Greenplum Database will run the query in the parallel execution environment. Examine the query plans of poorly performing queries to identify possible performance tuning opportunities.

The query planner uses data statistics maintained by the database to choose a query plan with the lowest possible cost. Cost is measured in disk I/O, shown as units of disk page fetches. The goal is to minimize the total execution cost for the plan.

View the plan for a given query with the `EXPLAIN` command. `EXPLAIN` shows the query planner's estimated cost for the query plan. For example:

```
EXPLAIN SELECT * FROM names WHERE id=22;
```

`EXPLAIN ANALYZE` runs the statement in addition to displaying its plan. This is useful for determining how close the planner's estimates are to reality. For example:

```
EXPLAIN ANALYZE SELECT * FROM names WHERE id=22;
```

Reading EXPLAIN Output

A query plan is a tree of nodes. Each node in the plan represents a single operation, such as a table scan, join, aggregation, or sort.

Read plans from the bottom to the top: each node feeds rows into the node directly above it. The bottom nodes of a plan are usually table scan operations: sequential, index, or bitmap index scans. If the query requires joins, aggregations, sorts, or other operations on the rows, there are additional nodes above the scan nodes to perform these operations. The topmost plan nodes are usually Greenplum Database motion nodes: redistribute, explicit redistribute, broadcast, or gather motions. These operations move rows between segment instances during query processing.

The output of `EXPLAIN` has one line for each node in the plan tree and shows the basic node type and the following execution cost estimates for that plan node:

- **cost** —Measured in units of disk page fetches. 1.0 equals one sequential disk page read. The first estimate is the start-up cost of getting the first row and the second is the total cost of cost of getting all rows. The total cost assumes all rows will be retrieved, which is not always true; for example, if the query uses `LIMIT`, not all rows are retrieved.
- **rows** —The total number of rows output by this plan node. This number is usually less than the number of rows processed or scanned by the plan node, reflecting the estimated selectivity of any `WHERE` clause conditions. Ideally, the estimate for the topmost node approximates the number of rows that the query actually returns, updates, or deletes.
- **width** —The total bytes of all the rows that this plan node outputs.

Note the following:

- The cost of a node includes the cost of its child nodes. The topmost plan node has the estimated total execution cost for the plan. This is the number the planner intends to minimize.
- The cost reflects only the aspects of plan execution that the query planner takes into consideration. For example, the cost does not reflect time spent transmitting result rows to the client.

EXPLAIN Example

The following example describes how to read an `EXPLAIN` query plan for a query:

```
EXPLAIN SELECT * FROM names WHERE name = 'Joelle';
                    QUERY PLAN
------------------------------------------------------------
Gather Motion 2:1 (slice1) (cost=0.00..20.88 rows=1 width=13)
   -> Seq Scan on 'names' (cost=0.00..20.88 rows=1 width=13)
         Filter: name::text ~~ 'Joelle'::text
```

Read the plan from the bottom to the top. To start, the query planner sequentially scans the *names* table. Notice the `WHERE` clause is applied as a *filter* condition. This means the scan operation checks the condition for each row it scans and outputs only the rows that satisfy the condition.

The results of the scan operation are passed to a *gather motion* operation. In Greenplum Database, a gather motion is when segments send rows to the master. In this example, we have two segment instances that send to one master instance. This operation is working on `slice1` of the parallel query execution plan. A query plan is divided into *slices* so the segments can work on portions of the query plan in parallel.

The estimated startup cost for this plan is `00.00` (no cost) and a total cost of `20.88` disk page fetches. The planner estimates this query will return one row.

Reading EXPLAIN ANALYZE Output

`EXPLAIN ANALYZE` plans and runs the statement. The `EXPLAIN ANALYZE` plan shows the actual execution cost along with the planner's estimates. This allows you to see if the planner's estimates are close to reality. `EXPLAIN ANALYZE` also shows the following:

- The total runtime (in milliseconds) in which the query executed.
- The memory used by each slice of the query plan, as well as the memory reserved for the whole query statement.
- The number of *workers* (segments) involved in a plan node operation. Only segments that return rows are counted.
- The maximum number of rows returned by the segment that produced the most rows for the operation. If multiple segments produce an equal number of rows, `EXPLAIN ANALYZE` shows the segment with the longest *<time> to end*.
- The segment id of the segment that produced the most rows for an operation.
- For relevant operations, the amount of memory (`work_mem`) used by the operation. If the `work_mem` was insufficient to perform the operation in memory, the plan shows the amount of data spilled to disk for the lowest-performing segment. For example:

  ```
  Work_mem used: 64K bytes avg, 64K bytes max (seg0).
  Work_mem wanted: 90K bytes avg, 90K byes max (seg0) to lessen
  workfile I/O affecting 2 workers.
  ```

- The time (in milliseconds) in which the segment that produced the most rows retrieved the first row, and the time taken for that segment to retrieve all rows. The result may omit *<time> to first row* if it is the same as the *<time> to end*.

EXPLAIN ANALYZE Example

This example describes how to read an `EXPLAIN ANALYZE` query plan using the same query. The **`bold`** parts of the plan show actual timing and rows returned for each plan node, as well as memory and time statistics for the whole query.

```
   EXPLAIN ANALYZE SELECT * FROM names WHERE name = 'Joelle';
                        QUERY PLAN
   ------------------------------------------------------------
Gather Motion 2:1  (slice1; segments: 2)  (cost=0.00..20.88 rows=1
width=13)
   Rows out:  1 rows at destination with 0.305 ms to first row,
0.537 ms to end, start offset by 0.289 ms.
   ->  Seq Scan on names  (cost=0.00..20.88 rows=1 width=13)
         Rows out:  Avg 1 rows x 2 workers.  Max 1 rows (seg0) with
0.255 ms to first row, 0.486 ms to end, start offset by 0.968 ms.
             Filter: name = 'Joelle'::text
 Slice statistics:
   (slice0)    Executor memory: 135K bytes.
(slice1)    Executor memory: 151K bytes avg x 2 workers, 151K bytes
max (seg0).
```

```
Statement statistics:
  Memory used: 128000K bytes
Total runtime: 22.548 ms
```

Read the plan from the bottom to the top. The total elapsed time to run this query was *22.548* milliseconds.

The *sequential scan* operation had only one segment (*seg0*) that returned rows, and it returned just *1 row*. It took *0.255* milliseconds to find the first row and *0.486* to scan all rows. This result is close to the planner's estimate: the query planner estimated it would return one row for this query. The *gather motion* (segments sending data to the master) received 1 row . The total elapsed time for this operation was *0.537* milliseconds.

Examining Query Plans to Solve Problems

If a query performs poorly, examine its query plan and ask the following questions:

- **Do operations in the plan take an exceptionally long time?** Look for an operation consumes the majority of query processing time. For example, if an index scan takes longer than expected, the index could be out-of-date and need to be reindexed. Or, adjust `enable_<operator>` parameters to see if you can force the planner to choose a different plan by disabling a particular query plan operator for that query.
- **Are the planner's estimates close to reality?** Run `EXPLAIN ANALYZE` and see if the number of rows the planner estimates is close to the number of rows the query operation actually returns. If there is a large discrepancy, collect more statistics on the relevant columns. See the *Greenplum Database Reference Guide* for more information on the `EXPLAIN ANALYZE` and `ANALYZE` commands.
- **Are selective predicates applied early in the plan?** Apply the most selective filters early in the plan so fewer rows move up the plan tree. If the query plan does not correctly estimate query predicate selectivity, collect more statistics on the relevant columns. See the `ANALYZE` command in the *Greenplum Database Reference Guide* for more information collecting statistics. You can also try reordering the `WHERE` clause of your SQL statement.
- **Does the planner choose the best join order?** When you have a query that joins multiple tables, make sure that the planner chooses the most selective join order. Joins that eliminate the largest number of rows should be done earlier in the plan so fewer rows move up the plan tree.

  If the plan is not choosing the optimal join order, set `join_collapse_limit=1` and use explicit `JOIN` syntax in your SQL statement to force the planner to the specified join order. You can also collect more statistics on the relevant join columns. See the `ANALYZE` command in the *Greenplum Database Reference Guide* for more information collecting statistics.
- **Does the planner selectively scan partitioned tables?** If you use table partitioning, is the planner selectively scanning only the child tables required to satisfy the query predicates? Scans of the parent tables should return 0 rows since the parent tables do not contain any data. See "Verifying Your Partition Strategy" on page 57 for an example of a query plan that shows a selective partition scan.

- **Does the planner choose hash aggregate and hash join operations where applicable?** Hash operations are typically much faster than other types of joins or aggregations. Row comparison and sorting is done in memory rather than reading/writing from disk. To enable the query planner to choose hash operations, there must be sufficient memory available to hold the estimated number of rows. Try increasing work memory to improve performance for a query. If possible, run an `EXPLAIN ANALYZE` for the query to show which plan operations spilled to disk, how much work memory they used, and how much memory was required to avoid spilling to disk. For example:

  ```
  Work_mem used:  23430K bytes avg, 23430K bytes max (seg0).
  Work_mem wanted: 33649K bytes avg, 33649K bytes max (seg0) to lessen
  workfile I/O affecting 2 workers.
  ```

  The “bytes wanted” message from `EXPLAIN ANALYZE` is based on the amount of data written to work files and is not exact. The minimum `work_mem` needed can differ from the suggested value.

10. Managing Workload and Resources

This chapter describes the workload management feature of Greenplum Database, and explains the tasks involved in creating and managing resource queues. The following topics are covered in this chapter:

- Overview of Greenplum Workload Management
- Configuring Workload Management
- Creating Resource Queues
- Assigning Roles (Users) to a Resource Queue
- Modifying Resource Queues
- Checking Resource Queue Status

Overview of Greenplum Workload Management

The purpose of workload management is to limit the number of active queries in the system at any given time in order to avoid exhausting system resources such as memory, CPU, and disk I/O. This is accomplished in Greenplum Database with role-based *resource queues*. A resource queue has attributes that limit the size and/or total number of queries that can be executed by the users (or roles) in that queue. Also, you can assign a priority level that controls the relative share of available CPU used by queries associated with the resource queue. By assigning all database roles to the appropriate resource queue, administrators can control concurrent user queries and prevent the system from being overloaded.

How Resource Queues Work in Greenplum Database

Resource scheduling is enabled by default when you install Greenplum Database. All database roles must be assigned to a resource queue. If an administrator creates a role without explicitly assigning it to a resource queue, the role is assigned to the default resource queue, `pg_default`.

Greenplum recommends that administrators create resource queues for the various types of workloads in their organization. For example, you may have resource queues for power users, web users, and management reports. You would then set limits on the resource queue based your estimate of how resource-intensive the queries associated with that workload are likely to be. Currently, the configurable limits on a queue include:

- Active statement count. The maximum number of statements that can run concurrently.
- Active statement memory. The total amount of memory that all queries submitted through this queue can consume.
- Active statement priority. This value defines a queue’s priority relative to other queues in terms of available CPU resources.

- Active statement cost. This value is compared with the cost estimated by the query planner, measured in units of disk page fetches.

After resource queues are created, database roles (users) are then assigned to the appropriate resource queue. A resource queue can have multiple roles, but a role can have only one assigned resource queue.

How Resource Queue Limits Work

At runtime, when the user submits a query for execution, that query is evaluated against the resource queue's limits. If the query does not cause the queue to exceed its resource limits, then that query will run immediately. If the query causes the queue to exceed its limits (for example, if the maximum number of active statement slots are currently in use), then the query must wait until queue resources are free before it can run. Queries are evaluated on a first in, first out basis. If query prioritization is enabled, the active workload on the system is periodically assessed and processing resources are reallocated according to query priority (see "How Priorities Work" on page 166).

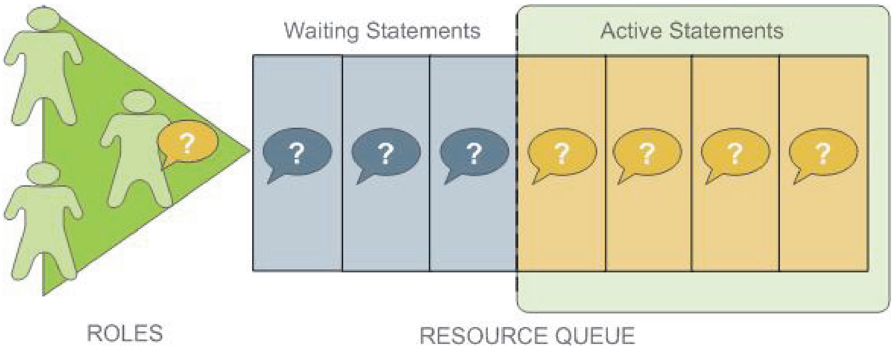


Figure 10.1 Resource Queue Example

Roles with the `SUPERUSER` attribute are always exempt from resource queue limits. Superuser queries are always allowed to run immediately regardless of the limits of their assigned resource queue.

How Memory Limits Work

Setting a memory limit on a resource queue sets the maximum amount of memory that all queries submitted through the queue can consume on a segment host. The amount of memory allotted to a particular query is based on the queue memory limit divided by the active statement limit (Greenplum recommends that memory limits be used in conjunction with statement-based queues rather than cost-based queues). For example, if a queue has a memory limit of 2000MB and an active statement limit of 10, each query submitted through the queue is allotted 200MB of memory by default. The default memory allotment can be overridden on a per-query basis using the `statement_mem` server configuration parameter (up to the queue memory limit). Once a query has started executing, it holds its allotted memory in the queue until it completes (even if during execution it actually consumes less than its allotted amount of memory).

For more information on configuring memory limits on a resource queue, and other memory utilization controls, see "Creating Queues with Memory Limits" on page 171.

How Priorities Work

Resource limits on active statement count, memory and query cost are *admission* limits, which determine whether a query is admitted into the group of actively running statements, or whether it is queued with other waiting statements. After a query becomes active, it must share available CPU resources as determined by the priority settings for its resource queue. When a statement from a high-priority queue enters the group of actively running statements, it may claim a significant share of the available CPU, reducing the share allotted to already-running statements.

The comparative size or complexity of the queries does not affect the allotment of CPU. If a simple, low-cost query is running simultaneously with a large, complex query, and their priority settings are the same, they will be allotted the same share of available CPU resources. When a new query becomes active, the exact percentage shares of CPU will be recalculated, but queries of equal priority will still have equal amounts of CPU allotted.

For example, an administrator creates three resource queues: *adhoc* for ongoing queries submitted by business analysts, *reporting* for scheduled reporting jobs, and *executive* for queries submitted by executive user roles. The administrator wants to ensure that scheduled reporting jobs are not heavily affected by unpredictable resource demands from ad-hoc analyst queries. Also, the administrator wants to make sure that queries submitted by executive roles are allotted a significant share of CPU. Accordingly, the resource queue priorities are set as shown:

- *adhoc* — Low priority
- *reporting* — High priority
- *executive* — Maximum priority

For more information about commands to set priorities, see "Setting Priority Levels" on page 173.

At runtime, the CPU share of active statements is determined by these priority settings. If queries 1 and 2 from the reporting queue are running simultaneously, they have equal shares of CPU. When an ad-hoc query becomes active, it claims a smaller share of CPU. The exact share used by the reporting queries is adjusted, but remains equal due to their equal priority setting:

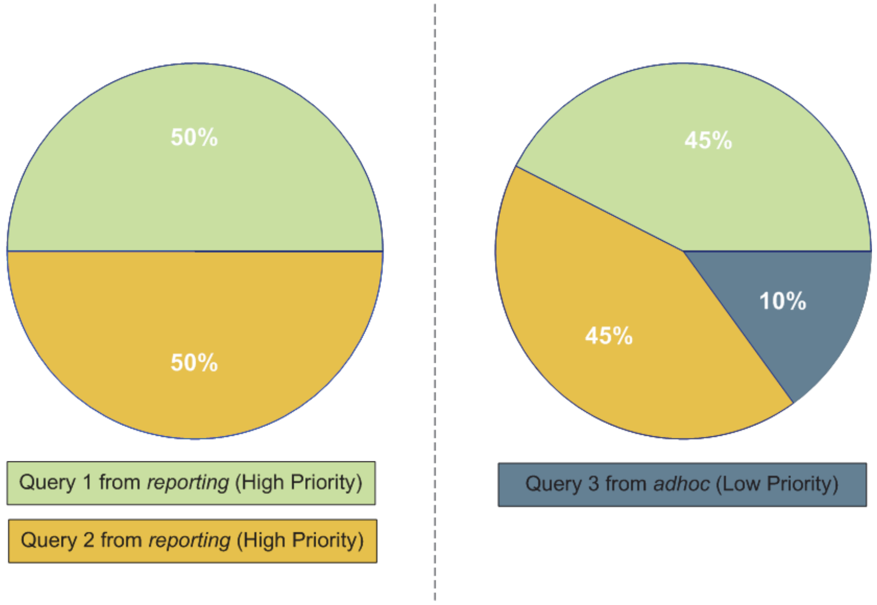


Figure 10.2 CPU share readjusted according to priority

Note: The percentages shown in these graphics are approximate. CPU usage between high, low and maximum priority queues is not always calculated in precisely these proportions.

When an executive query enters the group of running statements, CPU usage is adjusted to account for its maximum priority setting. It may be a simple query compared to the analyst and reporting queries, but until it is completed, it will claim the largest share of CPU.

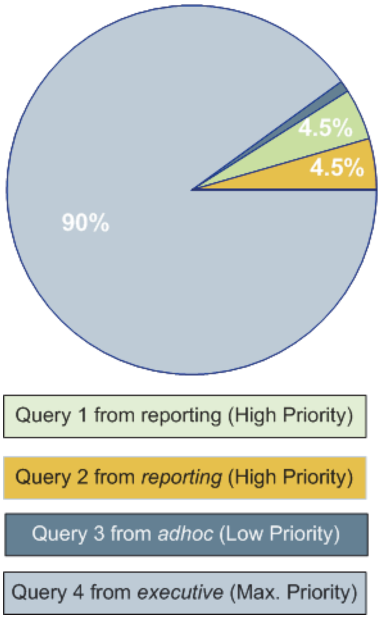


Figure 10.3 CPU share readjusted for maximum priority query

Types of Queries Evaluated for Resource Queues

Not all SQL statements submitted through a resource queue are evaluated against the queue limits. By default only `SELECT`, `SELECT INTO`, `CREATE TABLE AS SELECT`, and `DECLARE CURSOR` statements are evaluated. If the server configuration parameter `resource_select_only` is set to *off*, then `INSERT`, `UPDATE`, and `DELETE` statements will be evaluated as well.

Steps to Enable Workload Management

Enabling and using workload management in Greenplum Database involves the following high-level tasks:

1. Creating the resource queues and setting limits on them. See "Creating Resource Queues" on page 170.
2. Assigning a queue to one or more user roles. See "Assigning Roles (Users) to a Resource Queue" on page 173.
3. Using the workload management system views to monitor and manage the resource queues. See "Checking Resource Queue Status" on page 174.

Configuring Workload Management

Resource scheduling is enabled by default when you install Greenplum Database, and is required for all roles. The default resource queue, `pg_default`, has an active statement limit of 20, no cost limit, no memory limit, and a medium priority setting. Greenplum recommends that you create resource queues for the various types of workloads.

To configure workload management

1. The following parameters are for the general configuration of resource queues:
   - `max_resource_queues` - Sets the maximum number of resource queues.
   - `max_resource_portals_per_transaction` - Sets the maximum number of simultaneously open cursors allowed per transaction. Note that an open cursor will hold an active query slot in a resource queue.
   - `resource_select_only` - If set to *on*, then `SELECT`, `SELECT INTO`, `CREATE TABLE AS SELECT`, and `DECLARE CURSOR` commands are evaluated. If set to *off* `INSERT`, `UPDATE`, and `DELETE` commands will be evaluated as well.
   - `resource_cleanup_gangs_on_wait` - Cleans up idle segment worker processes before taking a slot in the resource queue.
   - `stats_queue_level` - Enables statistics collection on resource queue usage, which can then be viewed by querying the *pg_stat_resqueues* system view.
2. The following parameters are related to memory utilization:
   - `gp_resqueue_memory_policy` - Enables Greenplum memory management features.

     In Greenplum Database 4.2 and later, the distribution algorithm `eager_free` takes advantage of the fact that not all operators execute at the same time. The query plan is divided into stages and Greenplum Database eagerly frees memory allocated to a previous stage at the end of that stage's execution, then allocates the eagerly freed memory to the new stage.

     When set to `none`, memory management is the same as in Greenplum Database releases prior to 4.1. When set to `auto`, query memory usage is controlled by `statement_mem` and resource queue memory limits.
   - `statement_mem` and `max_statement_mem` - Used to allocate memory to a particular query at runtime (override the default allocation assigned by the resource queue). `max_statement_mem` is set by database superusers to prevent regular database users from over-allocation.
   - `gp_vmem_protect_limit` - Sets the upper boundary that all query processes can consume that should not exceed the amount of physical memory of a segment host. When a segment host reaches this limit during query execution, the queries that cause the limit to be exceeded will be cancelled.
   - `gp_vmem_idle_resource_timeout` and `gp_vmem_protect_segworker_cache_limit` - used to free memory on segment hosts held by idle database processes. Administrators may want to adjust these settings on systems with lots of concurrency.

3. The following parameters are related to query prioritization. Note that the following parameters are all *local* parameters, meaning they must be set in the `postgresql.conf` files of the master and all segments:

   - `gp_resqueue_priority` - The query prioritization feature is enabled by default.
   - `gp_resqueue_priority_sweeper_interval` - Sets the interval at which CPU usage is recalculated for all active statements. The default value for this parameter should be sufficient for typical database operations.
   - `gp_resqueue_priority_cpucores_per_segment` - Specifies the number of CPU cores per segment. The default is 4 for segments and 24 for the master, the correct values for the EMC Greenplum Data Computing Appliance. Each host checks its own `postgresql.conf` file for the value of this parameter.

     This parameter also affects the master node, where it should be set to a value reflecting the higher ratio of CPU cores. For example, on a cluster that has 8 CPU cores per host and 4 segments per host, you would use the following settings:

     Master and standby master

     ```
     gp_resqueue_priority_cpucores_per_segment = 8
     ```

     Segment hosts

     ```
     gp_resqueue_priority_cpucores_per_segment = 2
     ```

Important: If you have fewer than one segment per CPU core on your segment hosts, make sure you adjust this value accordingly. An improperly low value for this parameter can result in under-utilization of CPU resources.

4. If you wish to view or change any of the workload management parameter values, you can use the `gpconfig` utility.

5. For example, to see the setting of a particular parameter:

   ```
   $ gpconfig --show gp_vmem_protect_limit
   ```

6. For example, to set one value on all segments and a different value on the master:

   ```
   $ gpconfig -c gp_resqueue_priority_cpucores_per_segment -v 2
   -m 8
   ```

7. Restart Greenplum Database to make the configuration changes effective:

   ```
   $ gpstop -r
   ```

Creating Resource Queues

Creating a resource queue involves giving it a name and setting either a query cost limit or an active query limit (or both), and optionally a query priority on the resource queue. Use the `CREATE RESOURCE QUEUE` command to create new resource queues.

Creating Queues with an Active Query Limit

Resource queues with an ACTIVE_STATEMENTS setting limit the number of queries that can be executed by roles assigned to that queue. For example, to create a resource queue named *adhoc* with an active query limit of three:

```
=# CREATE RESOURCE QUEUE adhoc WITH (ACTIVE_STATEMENTS=3);
```

This means that for all roles assigned to the *adhoc* resource queue, only three active queries can be running on the system at any given time. If this queue has three queries running, and a fourth query is submitted by a role in that queue, that query must wait until a slot is free before it can run.

Creating Queues with Memory Limits

Resource queues with a MEMORY_LIMIT setting control the amount of memory for all the queries submitted through the queue. The total memory should not exceed the physical memory available per-segment. Greenplum recommends that you set MEMORY_LIMIT to 90% of memory available on a per-segment basis. For example, if a host has 48 GB of physical memory and 6 segments, then the memory available per segment is 8 GB. You can calculate the recommended MEMORY_LIMIT for a single queue as 0.90*8=7.2 GB. If there are multiple queues created on the system, their total memory limits must also add up to 7.2 GB.

When used in conjunction with ACTIVE_STATEMENTS, the default amount of memory allotted per query is: MEMORY_LIMIT / ACTIVE_STATEMENTS. When used in conjunction with MAX_COST, the default amount of memory allotted per query is: MEMORY_LIMIT * (query_cost / MAX_COST). Greenplum recommends that MEMORY_LIMIT be used in conjunction with ACTIVE_STATEMENTS rather than with MAX_COST.

For example, to create a resource queue with an active query limit of 10 and a total memory limit of 2000MB (each query will be allocated 200MB of segment host memory at execution time):

```
=# CREATE RESOURCE QUEUE myqueue WITH (ACTIVE_STATEMENTS=20,
MEMORY_LIMIT='2000MB');
```

The default memory allotment can be overridden on a per-query basis using the statement_mem server configuration parameter, provided that MEMORY_LIMIT or max_statement_mem is not exceeded. For example, to allocate more memory to a particular query:

```
=> SET statement_mem='2GB';

=> SELECT * FROM my_big_table WHERE column='value' ORDER BY id;

=> RESET statement_mem;
```

As a general guideline, MEMORY_LIMIT for all of your resource queues should not exceed the amount of physical memory of a segment host. If workloads are staggered over multiple queues, it may be OK to oversubscribe memory allocations, keeping in mind that queries may be cancelled during execution if the segment host memory limit (gp_vmem_protect_limit) is exceeded.

Creating Queues with a Query Planner Cost Limits

Resource queues with a MAX_COST setting limit the total cost of queries that can be executed by roles assigned to that queue. Cost is specified as a floating point number (for example 100.0) or can also be specified as an exponent (for example 1e+2).

Cost is measured in the *estimated total cost* for the query as determined by the Greenplum query planner (as shown in the EXPLAIN output for a query). Therefore, an administrator must be familiar with the queries typically executed on the system in order to set an appropriate cost threshold for a queue. Cost is measured in units of disk page fetches; 1.0 equals one sequential disk page read.

For example, to create a resource queue named *webuser* with a query cost limit of 100000.0 (1e+5):

```
=# CREATE RESOURCE QUEUE webuser WITH (MAX _COST=100000.0);
```

or

```
=# CREATE RESOURCE QUEUE webuser WITH (MAX _COST=1e+5);
```

This means that for all roles assigned to the *webuser* resource queue, it will only allow queries into the system until the cost limit of 100000.0 is reached. So for example, if this queue has 200 queries with a 500.0 cost all running at the same time, and query 201 with a 1000.0 cost is submitted by a role in that queue, that query must wait until space is free before it can run.

Allowing Queries to Run on Idle Systems

If a resource queue is limited based on a cost threshold, then the administrator can allow COST_OVERCOMMIT (the default). Resource queues with a cost threshold and overcommit enabled will allow a query that exceeds the cost threshold to run, provided that there are no other queries in the system at the time the query is submitted. The cost threshold will still be enforced if there are concurrent workloads on the system.

If COST_OVERCOMMIT is false, then queries that exceed the cost limit will always be rejected and never allowed to run.

Allowing Small Queries to Bypass Queue Limits

Workloads may have certain small queries that administrators want to allow to run without taking up an active statement slot in the resource queue. For example, simple queries to look up metadata information in the system catalogs do not typically require significant resources or interfere with query processing on the segments. An administrator can set MIN_COST to denote a query planner cost associated with a small query. Any query that falls below the MIN_COST limit will be allowed to run immediately. MIN_COST can be used on resource queues with either an active statement or a maximum query cost limit. For example:

```
=# CREATE RESOURCE QUEUE adhoc WITH (ACTIVE_STATEMENTS=10,
MIN_COST=100.0);
```

Setting Priority Levels

To control a resource queue's consumption of available CPU resources, an administrator can assign an appropriate priority level. When high concurrency causes contention for CPU resources, queries and statements associated with a high-priority resource queue will claim a larger share of available CPU than lower priority queries and statements.

Priority settings are created or altered using the `WITH` parameter of the commands `CREATE RESOURCE QUEUE` and `ALTER RESOURCE QUEUE`. For example, to specify priority settings for the *adhoc* and *reporting* queues, an administrator would use the following commands:

```
=# ALTER RESOURCE QUEUE adhoc WITH (PRIORITY=LOW);
=# ALTER RESOURCE QUEUE reporting WITH (PRIORITY=HIGH);
```

To create the *executive* queue with maximum priority, an administrator would use the following command:

```
=# CREATE RESOURCE QUEUE executive WITH (ACTIVE_STATEMENTS=3,
PRIORITY=MAX);
```

When the query prioritization feature is enabled, resource queues are given a `MEDIUM` priority by default if not explicitly assigned. For more information on how priority settings are evaluated at runtime, see "How Priorities Work" on page 166.

Important: In order for resource queue priority levels to be enforced on the active query workload, you must enable the query prioritization feature by setting the associated server configuration parameters. See "Configuring Workload Management" on page 169.

Assigning Roles (Users) to a Resource Queue

Once a resource queue is created, you must assign roles (users) to their appropriate resource queue. If roles are not explicitly assigned to a resource queue, they will go to the default resource queue, `pg_default`. The default resource queue has an active statement limit of 20, no cost limit, and a medium priority setting.

Use the `ALTER ROLE` or `CREATE ROLE` commands to assign a role to a resource queue. For example:

```
    =# ALTER ROLE name RESOURCE QUEUE queue_name;
    =# CREATE ROLE name WITH LOGIN RESOURCE QUEUE queue_name;
```

A role can only be assigned to one resource queue at any given time, so you can use the `ALTER ROLE` command to initially assign or change a role's resource queue.

Resource queues must be assigned on a user-by-user basis. If you have a role hierarchy (for example, a group-level role) then assigning a resource queue to the group does not propagate down to the users in that group.

Superusers are always exempt from resource queue limits. Superuser queries will always run regardless of the limits set on their assigned queue.

Removing a Role from a Resource Queue

All users *must* be assigned to a resource queue. If not explicitly assigned to a particular queue, users will go into the default resource queue, `pg_default`. If you wish to remove a role from a resource queue and put them in the default queue, change the role's queue assignment to `none`. For example:

```
=# ALTER ROLE role_name RESOURCE QUEUE none;
```

Modifying Resource Queues

After a resource queue has been created, you can change or reset the queue limits using the `ALTER RESOURCE QUEUE` command. You can remove a resource queue using the `DROP RESOURCE QUEUE` command. To change the roles (users) assigned to a resource queue, see "Assigning Roles (Users) to a Resource Queue" on page 173.

Altering a Resource Queue

The `ALTER RESOURCE QUEUE` command changes the limits of a resource queue. A resource queue must have either an `ACTIVE_STATEMENTS` or a `MAX_COST` value (or it can have both). To change the limits of a resource queue, specify the new values you want for the queue. For example:

```
=# ALTER RESOURCE QUEUE adhoc WITH (ACTIVE_STATEMENTS=5);
=# ALTER RESOURCE QUEUE exec WITH (MAX_COST=100000.0);
```

To reset active statements or memory limit to no limit, enter a value of `-1`. To reset the maximum query cost to no limit, enter a value of `-1.0`. For example:

```
=# ALTER RESOURCE QUEUE adhoc WITH (MAX_COST=-1.0,
MEMORY_LIMIT='2GB');
```

You can use the `ALTER RESOURCE QUEUE` command to change the priority of queries associated with a resource queue. For example, to set a queue to the minimum priority level:

```
ALTER RESOURCE QUEUE webuser WITH (PRIORITY=MIN);
```

Dropping a Resource Queue

The `DROP RESOURCE QUEUE` command drops a resource queue. To drop a resource queue, the queue cannot have any roles assigned to it, nor can it have any statements waiting in the queue. See "Removing a Role from a Resource Queue" on page 174 and "Clearing a Waiting Statement From a Resource Queue" on page 176 for instructions on emptying a resource queue. To drop a resource queue:

```
=# DROP RESOURCE QUEUE name;
```

Checking Resource Queue Status

Checking resource queue status involves the following tasks:

- Viewing Queued Statements and Resource Queue Status
- Viewing Resource Queue Statistics
- Viewing the Roles Assigned to a Resource Queue
- Viewing the Waiting Queries for a Resource Queue
- Clearing a Waiting Statement From a Resource Queue
- Viewing the Priority of Active Statements
- Resetting the Priority of an Active Statement

Viewing Queued Statements and Resource Queue Status

The *gp_toolkit.gp_resqueue_status* view allows administrators to see status and activity for a workload management resource queue. It shows how many queries are waiting to run and how many queries are currently active in the system from a particular resource queue. To see the resource queues created in the system, their limit attributes, and their current status:

```
=# SELECT * FROM gp_toolkit.gp_resqueue_status;
```

Viewing Resource Queue Statistics

If you want to track statistics and performance of resource queues over time, you can enable statistics collecting for resource queues. This is done by setting the following server configuration parameter in your master `postgresql.conf` file:

```
stats_queue_level = on
```

Once this is enabled, you can use the *pg_stat_resqueues* system view to see the statistics collected on resource queue usage. Note that enabling this feature does incur slight performance overhead, as each query submitted through a resource queue must be tracked. It may be useful to enable statistics collecting on resource queues for initial diagnostics and administrative planning, and then disable the feature for continued use.

See the Statistics Collector section in the PostgreSQL documentation for more information about collecting statistics in Greenplum Database.

Viewing the Roles Assigned to a Resource Queue

To see the roles assigned to a resource queue, perform the following query of the `pg_roles` and `gp_toolkit`.*gp_resqueue_status* system catalog tables:

```
=# SELECT rolname, rsqname FROM pg_roles,
           gp_toolkit.gp_resqueue_status
   WHERE
pg_roles.rolresqueue=gp_toolkit.gp_resqueue_status.queueid;
```

You may want to create a view of this query to simplify future inquiries. For example:

```
=# CREATE VIEW role2queue AS
   SELECT rolname, rsqname FROM pg_roles, pg_resqueue
   WHERE
```

```
pg_roles.rolresqueue=gp_toolkit.gp_resqueue_status.queueid;
```

Then you can just query the view:

```
=# SELECT * FROM role2queue;
```

Viewing the Waiting Queries for a Resource Queue

When a slot is in use for a resource queue, it is recorded in the `pg_locks` system catalog table. This is where you can see all of the currently active and waiting queries for all resource queues. To check that statements are being queued (even statements that are not waiting), you can also use the *gp_toolkit.gp_locks_on_resqueue* view. For example:

```
=# SELECT * FROM gp_toolkit.gp_locks_on_resqueue WHERE
lorwaiting='true';
```

If this query returns no results, then that means there are currently no statements waiting in a resource queue.

Clearing a Waiting Statement From a Resource Queue

In some cases, you may want to clear a waiting statement from a resource queue. For example, you may want to remove a query that is waiting in the queue but has not been executed yet. You may also want to stop a query that has been started if it is taking too long to execute, or if it is sitting idle in a transaction and taking up resource queue slots that are needed by other users. To do this, you must first identify the statement you want to clear, determine its process id (pid), and then, use `pg_cancel_backend` with the process id to end that process, as shown below.

For example, to see process information about all statements currently active or waiting in all resource queues, run the following query:

```
=# SELECT rolname, rsqname, pid, granted,
          current_query, datname
   FROM pg_roles, gp_toolkit.gp_resqueue_status, pg_locks,
        pg_stat_activity
   WHERE pg_roles.rolresqueue=pg_locks.objid
   AND pg_locks.objid=gp_toolkit.gp_resqueue_status.queueid
   AND pg_stat_activity.procpid=pg_locks.pid;
```

If this query returns no results, then that means there are currently no statements in a resource queue. A sample of a resource queue with two statements in it looks something like this:

```
rolname | rsqname |  pid  | granted |     current_query      | datname
-----------------------------------------------------------------------
  sammy | webuser | 31861 | t       | <IDLE> in transaction  | namesdb
  daria | webuser | 31905 | f      | SELECT * FROM topten;  | namesdb
```

Use this output to identify the process id (pid) of the statement you want to clear from the resource queue. To clear the statement, you would then open a terminal window (as the `gpadmin` database superuser or as root) on the master host and cancel the corresponding process. For example:

```
=# pg_cancel_backend(31905)
```

Note: Do not use any operating system `KILL` command.

Viewing the Priority of Active Statements

The *gp_toolkit* administrative schema has a view called *gp_resq_priority_statement*, which lists all statements currently being executed and provides the priority, session ID, and other information.

This view is only available through the *gp_toolkit* administrative schema. See the *Greenplum Database Reference Guide* for more information.

Resetting the Priority of an Active Statement

Superusers can adjust the priority of a statement currently being executed using the built-in function `gp_adjust_priority(session_id, statement_count, priority)`. Using this function, superusers can raise or lower the priority of any query. For example:

```
=# SELECT gp_adjust_priority(752, 24905, 'HIGH')
```

To obtain the session ID and statement count parameters required by this function, Superusers can use the *gp_toolkit* administrative schema view, *gp_resq_priority_statement*. This function affects only the specified statement . Subsequent statements in the same resource queue are executed using the queue's normally assigned priority.

11. Defining Database Performance

Greenplum measures database performance based on the rate at which the database management system (DBMS) supplies information to those requesting it.

- Understanding the Performance Factors
- Determining Acceptable Performance

Understanding the Performance Factors

Several key performance factors influence database performance. Understanding these factors helps identify performance opportunities and avoid problems:

- System Resources
- Workload
- Throughput
- Contention
- Optimization

System Resources

Database performance relies heavily on disk I/O and memory usage. To accurately set performance expectations, you need to know the baseline performance of the hardware on which your DBMS is deployed. Performance of hardware components such as CPUs, hard disks, disk controllers, RAM, and network interfaces will significantly affect how fast your database performs.

Workload

The workload equals the total demand from the DBMS, and it varies over time. The total workload is a combination of user queries, applications, batch jobs, transactions, and system commands directed through the DBMS at any given time. For example, it can increase when month-end reports are run or decrease on weekends when most users are out of the office. Workload strongly influences database performance. Knowing your workload and peak demand times helps you plan for the most efficient use of your system resources and enables processing the largest possible workload.

Throughput

A system's throughput defines its overall capability to process data. DBMS throughput is measured in queries per second, transactions per second, or average response times. DBMS throughput is closely related to the processing capacity of the underlying systems (disk I/O, CPU speed, memory bandwidth, and so on), so it is important to know the throughput capacity of your hardware when setting DBMS throughput goals.

Contention

Contention is the condition in which two or more components of the workload attempt to use the system in a conflicting way — for example, multiple queries that try to update the same piece of data at the same time or multiple large workloads that compete for system resources. As contention increases, throughput decreases.

Optimization

DBMS optimizations can affect the overall system performance. SQL formulation, database configuration parameters, table design, data distribution, and so on enable the database query planner and optimizer to create the most efficient access plans.

Determining Acceptable Performance

When approaching a performance tuning initiative, you should know your system's expected level of performance and define measurable performance requirements so you can accurately evaluate your system's performance. Consider the following when setting performance goals:

- Baseline Hardware Performance
- Performance Benchmarks

Baseline Hardware Performance

Most database performance problems are caused not by the database, but by the underlying systems on which the database runs. I/O bottlenecks, memory problems, and network issues can notably degrade database performance. Knowing the baseline capabilities of your hardware and operating system (OS) will help you identify and troubleshoot hardware-related problems before you explore database-level or query-level tuning initiatives. See the *Greenplum Database Reference Guide* for information about running the `gpcheckperf` utility to validate hardware and network performance.

Performance Benchmarks

To maintain good performance or fix performance issues, you should know the capabilities of your DBMS on a defined workload. A benchmark is a predefined workload that produces a known result set. Periodically run the same benchmark tests to help identify system-related performance degradation over time. Use benchmarks to compare workloads and identify queries or applications that need optimization.

Many third-party organizations, such as the Transaction Processing Performance Council (TPC), provide benchmark tools for the database industry. TPC provides TPC-H, a decision support system that examines large volumes of data, executes queries with a high degree of complexity, and gives answers to critical business questions. For more information about TPC-H, go to:

`http://www.tpc.org/tpch`

12. Common Causes of Performance Issues

This chapter explains the troubleshooting processes for common performance issues and potential solutions to these issues. The following list describes solutions for the most common causes of performance problems in Greenplum Database:

- Identifying Hardware and Segment Failures
- Managing Workload
- Avoiding Contention
- Maintaining Database Statistics
- Optimizing Data Distribution
- Optimizing Your Database Design

Identifying Hardware and Segment Failures

The performance of Greenplum Database depends on the hardware and IT infrastructure on which it runs. Greenplum Database is comprised of several servers (hosts) acting together as one cohesive system (array). Greenplum Database's performance will be as fast as the slowest host in the array. Problems with CPU utilization, memory management, I/O processing, or network load affect performance. Common hardware-related issues are:

- **Disk Failure** – Although a single disk failure should not dramatically affect database performance if you are using RAID, disk resynchronization does consume resources on the host with failed disks. The `gpcheckperf` utility can help identify segment hosts that have disk I/O issues.
- **Host Failure** – When a host is offline, the segments on that host are nonoperational. This means other hosts in the array must perform twice their usual workload because they are running the primary segments and multiple mirrors. If mirrors are not enabled, service is interrupted. Service is temporarily interrupted to recover failed segments. The `gpstate` utility helps identify failed segments.
- **Network Failure** – Failure of a network interface card, a switch, or DNS server can bring down segments. If host names or IP addresses cannot be resolved within your Greenplum array, these manifest themselves as interconnect errors in Greenplum Database. The `gpcheckperf` utility helps identify segment hosts that have network issues.
- **Disk Capacity** – Disk capacity on your segment hosts should never exceed 70 percent full. Greenplum Database needs some free space for runtime processing. To reclaim disk space that deleted rows occupy, run `VACUUM` after loads or updates. The *gp_toolkit* administrative schema has many views for checking the size of distributed database objects. See the *Greenplum Database Reference Guide* for information about checking database object sizes and disk space.

Managing Workload

A database system has a limited CPU capacity, memory, and disk I/O resources. When multiple workloads compete for access to these resources, database performance suffers. Workload management maximizes system throughput while meeting varied business requirements. With role-based resource queues, Greenplum Database workload management limits active queries and conserves system resources.

A resource queue limits the size and/or total number of queries that users or roles can execute in the particular queue. By assigning all your database roles to the appropriate resource queue, administrators can control concurrent user queries and prevent system overload. See Chapter 10, "Managing Workload and Resources" for more information about setting up resource queues.

Greenplum Database administrators should run maintenance workloads such as data loads and `VACUUM ANALYZE` operations after business hours. Do not compete with database users for system resources; perform administrative tasks at low-usage times.

Avoiding Contention

Contention arises when multiple users or workloads try to use the system in a conflicting way; for example, contention occurs when two transactions try to update a table simultaneously. A transaction that seeks a table-level or row-level lock will wait indefinitely for conflicting locks to be released. Applications should not hold transactions open for long periods of time, for example, while waiting for user input.

Maintaining Database Statistics

Greenplum Database uses a cost-based query planner that relies on database statistics. Accurate statistics allow the query planner to better estimate the number of rows retrieved by a query to choose the most efficient query plan. Without database statistics, the query planner cannot estimate how many records will be returned. The planner does not assume it has sufficient memory to perform certain operations such as aggregations, so it takes the most conservative action and does these operations by reading and writing from disk. This is significantly slower than doing them in memory. `ANALYZE` collects statistics about the database that the query planner needs.

Identifying Statistics Problems in Query Plans

Before you interpret a query plan for a query using `EXPLAIN` or `EXPLAIN ANALYZE`, familiarize yourself with the data to help identify possible statistics problems. Check the plan for the following indicators of inaccurate statistics:

- **Are the planner's estimates close to reality?** Run `EXPLAIN ANALYZE` and see if the number of rows the planner estimated is close to the number of rows the query operation returned .
- **Are selective predicates applied early in the plan?** The most selective filters should be applied early in the plan so fewer rows move up the plan tree.

- **Is the planner choosing the best join order?** When you have a query that joins multiple tables, make sure the planner chooses the most selective join order. Joins that eliminate the largest number of rows should be done earlier in the plan so fewr less rows move up the plan tree.

See "Query Profiling" on page 159 for more information about reading query plans.

Tuning Statistics Collection

The following configuration parameters control the amount of data sampled for statistics collection:

- `default_statistics_target`
- `gp_analyze_relative_error`

These parameters control statistics sampling at the system level. It is better to sample only increased statistics for columns used most frequently in query predicates. You can adjust statistics for a particular column using the command:

```
ALTER TABLE...SET STATISTICS
```

For example:

```
ALTER TABLE sales ALTER COLUMN region SET STATISTICS 50;
```

This is equivalent to increasing `default_statistics_target` for a particular column. Subsequent `ANALYZE` operations will then gather more statistics data for that column and produce better query plans as a result.

Optimizing Data Distribution

When you create a table in Greenplum Database, you must declare a distribution key that allows for even data distribution across all segments in the system. Because the segments work on a query in parallel, Greenplum Database will always be as fast as the slowest segment. If the data is unbalanced, the segments that have more data will return their results slower and therefore slow down the entire system.

Optimizing Your Database Design

Many performance issues can be improved by database design. Examine your database design and consider the following:

- Does the schema reflect the way the data is accessed?
- Can larger tables be broken down into partitions?
- Are you using the smallest data type possible to store column values?
- Are columns used to join tables of the same datatype?
- Are your indexes being used?

Greenplum Database Maximum Limits

To help optimize database design, review the maximum limits that Greenplum Database supports:

Table 12.1 Maximum Limits of Greenplum Database

Dimension	Limit
Database Size	Unlimited
Table Size	Unlimited, 128 TB per partition per segment
Row Size	1.6 TB (1600 columns * 1 GB)
Field Size	1 GB
Rows per Table	281474976710656 (2^48)
Columns per Table/View	1600
Indexes per Table	Unlimited
Columns per Index	32
Table-level Constraints per Table	Unlimited
Table Name Length	63 Bytes (Limited by *name* data type)

Dimensions listed as unlimited are not intrinsically limited by Greenplum Database. However, they are limited in practice to available disk space and memory/swap space. Performance may suffer when these values are unusually large.

Note: There is a maximum limit on the number of objects (tables, views, and indexes, but not rows) that may exist at one time. This limit is 4294967296 (2^32).

13. Investigating a Performance Problem

This section lists steps you can take to help identify the cause of a performance problem. If the problem affects a particular workload or query, you can focus on tuning that particular workload. If the performance problem is system-wide, then hardware problems, system failures, or resource contention may be the cause.

Checking System State

Use the `gpstate` utility to identify failed segments. A Greenplum Database system will incur performance degradation when segment instances are down because other hosts must pick up the processing responsibilities of the down segments.

Failed segments can indicate a hardware failure, such as a failed disk drive or network card. Greenplum Database provides the hardware verification tool `gpcheckperf` to help identify the segment hosts with hardware issues.

Checking Database Activity

- Checking for Active Sessions (Workload)
- Checking for Locks (Contention)
- Checking Query Status and System Utilization

Checking for Active Sessions (Workload)

The *pg_stat_activity* system catalog view shows one row per server process; it shows the database OID, database name, process ID, user OID, user name, current query, time at which the current query began execution, time at which the process was started, client address, and port number. To obtain the most information about the current system workload, query this view as the database superuser. For example:

```
SELECT * FROM pg_stat_activity;
```

Note the information does not update instantaneously.

Checking for Locks (Contention)

The *pg_locks* system catalog view allows you to see information about outstanding locks. If a transaction is holding a lock on an object, any other queries must wait for that lock to be released before they can continue. This may appear to the user as if a query is hanging.

Examine *pg_locks* for ungranted locks to help identify contention between database client sessions. *pg_locks* provides a global view of all locks in the database system, not only those relevant to the current database. You can join its relation column against `pg_class.oid` to identify locked relations (such as tables), but this works correctly only for relations in the current database. You can join the `pid` column to the `pg_stat_activity.procpid` to see more information about the session holding or waiting to hold a lock. For example:

```
SELECT locktype, database, c.relname, l.relation,
l.transactionid, l.transaction, l.pid, l.mode, l.granted,
a.current_query
        FROM pg_locks l, pg_class c, pg_stat_activity a
        WHERE l.relation=c.oid AND l.pid=a.procpid
        ORDER BY c.relname;
```

If you use resource queues for workload management, queries that are waiting in a queue will also show in *pg_locks*. To see how many queries are waiting to run from a resource queue, use the *gp_resqueue_status* system catalog view. For example:

```
SELECT * FROM gp_toolkit.gp_resqueue_status;
```

Checking Query Status and System Utilization

You can use system monitoring utilities such as `ps`, `top`, `iostat`, `vmstat`, `netstat` and so on to monitor database activity on the hosts in your Greenplum Database array. These tools can help identify Greenplum Database processes (`postgres` processes) currently running on the system and the most resource intensive tasks with regards to CPU, memory, disk I/O, or network activity. Look at these system statistics to identify queries that degrade database performance by overloading the system and consuming excessive resources. Greenplum Database's management tool `gpssh` allows you to run these system monitoring commands on several hosts simultaneously.

The Greenplum Command Center collects query and system utilization metrics. See the *Greenplum Command Center Administrator Guide* for procedures to enable Greenplum Command Center.

Troubleshooting Problem Queries

If a query performs poorly, look at its query plan to help identify problems. The `EXPLAIN` command shows the query plan for a given query. See "Query Profiling" on page 159 for more information about reading query plans and identifying problems.

Investigating Error Messages

Greenplum Database log messages are written to files in the `pg_log` directory within the master's or segment's data directory. Because the master log file contains the most information, you should always check it first. Log files roll over daily and use the naming convention: `gpdb-`*`YYYY-MM-DD_hhmmss`*`.csv`. To locate the log files on the master host:

```
$ cd $MASTER_DATA_DIRECTORY/pg_log
```

Log lines have the format of:

```
timestamp | user | database | statement_id | con# cmd#
|:-LOG_LEVEL: log_message
```

You may want to focus your search for `WARNING`, `ERROR`, `FATAL` or `PANIC` log level messages. You can use the Greenplum utility `gplogfilter` to search through Greenplum Database log files. For example, when you run the following command on the master host, it checks for problem log messages in the standard logging locations:

```
$ gplogfilter -t
```

To search for related log entries in the segment log files, you can run `gplogfilter` on the segment hosts using `gpssh`. You can identify corresponding log entries by the *`statement_id`* or `con#` (session identifier). For example, to search for log messages in the segment log files containing the string `con6` and save output to a file:

```
gpssh -f seg_hosts_file -e 'source
/usr/local/greenplum-db/greenplum_path.sh ; gplogfilter -f
con6 /gpdata/*/pg_log/gpdb*.csv' > seglog.out
```

Gathering Information for Greenplum Support

The `gpdetective` utility collects information from a running Greenplum Database system and creates a bzip2-compressed tar output file. You can then send the output file to Greenplum Customer Support to aid the diagnosis of Greenplum Database errors or system failures. Run `gpdetective` on your master host, for example:

```
$ gpdetective -f /var/data/my043008gp.tar
```