

Module 4: Defining and Securing the User Database

This module examines the Data Definition Language used to manage database objects, roles, privileges, and resource queues. It also examines how to implement security measures to protect data and balance workloads.

Upon completion of this module, you should be able to:

- Identify and manage database objects available in the Greenplum Database
- Use data manipulation language and data query language to access, manage, and query data
- Manage workload management processes by defining and managing roles, privileges, and resource queues
- Implement system-level and database-level security

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Data definition language (DDL) defines the data structures you will manage within the Greenplum Database. You use SQL syntax to create, alter, and remove database objects, including tables, schemas, and views.

As an administrator or developer, you must also learn the SQL syntax to manage the workload resources, which includes managing roles, privileges, and the resource queues. Once you know how to manage these items using SQL syntax, you can implement security measures to protect data and resources from unauthorized users.

In this module, you will:

- Identify and manage database objects for the Greenplum Database.
- Use data manipulation language and data query language to access, manage, and query data
- Manage workload management processes by defining and managing roles, privileges, and resource queues.
- Implement system-level and database-level security.

Module 4: Defining and Securing the User Database

Lesson 1: Data Definition Language

In this lesson, you examine the data structures and the syntax to manage data objects in the Greenplum Database.

Upon completion of this lesson, you should be able to:

- Describe databases
- Describe schemas and tables
- Identify constraints
- Describe data types and constants
- Describe views, indexes, sequences, triggers, and tablespaces

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Data Definition Language is the SQL syntax that you use to manage database objects. In this lesson, you examine the data structures and the syntax for managing database objects in Greenplum.

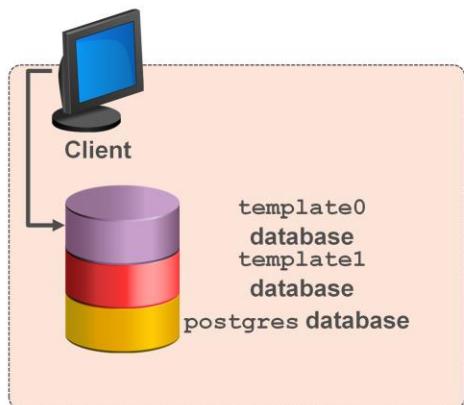
Once you have completed this lesson, you should be able to:

- Describe what a database is and how to manage it with SQL commands.
- Describe schemas and tables and manage these with SQL commands.
- Identify constraints.
- Describe data types and constants in the Greenplum Database.
- Describe other database objects, including views, indexes, sequences, triggers, and tablespaces.

Databases – Overview

Greenplum Database instance:

- Supports multiple databases
- Creates three databases by default:
 - template0
 - template1
 - postgres



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As in PostgreSQL, an Greenplum Database instance can have one or more user created databases. This differs from systems such as Oracle where the DBMS and database instance are one in the same. These databases reside on a single system but do not share data.

Clients can connect to and have access to one database at a time.

Three databases are created by default in a newly initialized array:

- **template1** – This default database is the template used to create other databases. Do not create any objects in this database unless you want those objects to also be in every other database you create moving forward.
Any database can be used as a template. A template provides you with a method of cloning databases and carrying specific base objects forward. Use the SQL syntax, `CREATE DATABASE newname USING TEMPLATE clonename` to create a database based on a template.
- **template0** – This template is a blank template used to create template1. This should not be dropped or modified.
- **postgres** – This is a default PostgreSQL database introduced in PostgreSQL 8.1 and is used internally by the system. It must not be dropped or modified.

Database SQL Commands

To manage databases, use the following SQL syntax or Greenplum application:

Action	SQL Syntax	Greenplum Application
Create a database	CREATE DATABASE	createdb
Drop a database	DROP DATABASE	dropdb
Alter a database: • Rename the database • Assign a new owner • Set configuration parameters	ALTER DATABASE	

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PostgreSQL and Greenplum Database share the same SQL commands for creating the database. You can use either SQL syntax in a PostgreSQL client to create, drop, or alter the database or use the Greenplum application clients available to create and drop the database.

PSQL Database Tips

Here are some tips for working in PSQL:

- PSQL prompt shows which database you are in
EXAMPLE: template1=# (superuser)
 names=> (non-superuser)
- \? To obtain a list of PSQL meta-commands
- \h to obtain a list of SQL commands or additional help on the included command
- To show a list of all databases:
\l
- To connect to another database:
\c db_name



Note: Use PGDATABASE environment variable to set the default database

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Here are some helpful tips for working with databases in the PSQL client program:

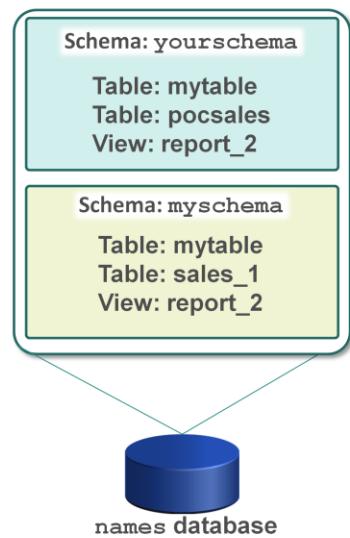
- The psql prompt will show the name of the database you are connected to and if you are in as a superuser role or not. For this class, we are logged in as a superuser.
- You can obtain additional assistance with the list of available meta-commands with \?.
- \h provides a list of SQL commands and lets you obtain additional assistance on a specific command if the command is provided as part of the command line.
- \l shows a list of all databases, including the templates and defaults databases created.
- Use \c to connect to another database or to reconnect to the same database. For example, after setting a parameter on a database you will need to reconnect to the database to see the changes.

Note: If you have set the PGDATABASE variable in your shell, you do not have to type the database name when connecting with psql.

Schemas – Overview

Schemas:

- Logically organize objects
- Do not represent users
- Contain data objects
- Use *qualified* names to access objects
EXAMPLE:
myschema.mytable
- Can be added to the search path (search_path)



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Schemas:

- Are a way to logically organize a database for users or for functional areas. For example, data from third-party applications can be stored in separate schemas to prevent collision with the names of other objects.
- Do not represent users, as is seen in Oracle.
- Contain named objects such as tables, views, indexes, data types, functions, and operators.

Allow you to have more than one object, such as tables, with the same name in the database without conflict, as long as they are in different schemas.

For the database to know in which schema it should look for an object, you use the *qualified* name. If you do not want to type the qualified name all the time, you can set the `search_path` parameter. This tells the database in which order it should search the available schemas for objects. The schema listed first in the search path becomes the default schema, which is where new, unqualified objects will be created by default.

As a best practice, you should always specify a schema when allowed. Changes in data with the addition of more objects with the same name in different schemas may cause issues when the optimizer and the query attempts to resolve table names.

Unlike databases, schemas are not rigidly separated - a user can access objects in any of the schemas in the database he is connected to, if he has privileges to do so.

Schemas and the Search Path

To access the `search_path` parameter:

- Run the following PSQL command to set the parameter:

```
SET search_path TO myschema,public;
```

- Run the following command to view the value of the parameter:

```
SHOW search_path;  
search_path  
-----  
myschema,public
```

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PostgreSQL will search for tables that are named without qualification by using the `search_path` parameter. Tables without qualifications are tables that do not have the schema name specified when calling the table name.

The following is used to access the `search_path` parameter from PSQL:

- To set the `search_path` parameter, issue the following command:
`SET search_path TO myschema,public;`
- To view the contents of the `search_path` parameter, issue the following command:
`SHOW search_path;`

Pre-existing Schemas

The following schemas exist in every database:

- PUBLIC schema
- System level schemas:

Schema	Description
pg_catalog	Stores system catalog names, functions, and operators
information_schema	Contains views that describe objects in the database
pg_toast	Stores large objects that exceed page size
pg_bitmapindex	Stores bitmap index objects
pg_aoseg	Stores append-only objects
gp_toolkit	Administrative schema

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Every newly created database has a default schema named PUBLIC. By default, all roles have CREATE and USAGE privileges on the public schema. Any other schemas you create you will have to grant the appropriate privileges to roles other than the owner.

The following system-level schemas also exist in every database:

- **pg_catalog** is the schema that has the system catalog tables, built-in data types, functions, and operators. It is always part of the search path, even if it is not named.
- **information_schema** consists of a set of views that contain information about the objects in the database. This is used by psql meta-commands to get information from the system catalog tables.
- **pg_toast** are where large objects are stored, such as records that exceed the page size.
- **pg_bitmapindex** where bitmap index objects are stored (list of values, etc).
- **pg_aoseg** is the schema that stores append-only objects.
- **gp_toolkit** is the administrative schema that you use to view and query system log files and other system metrics. It contains a number of external tables, views, and functions that you can access with SQL commands and is accessible by all database users.

Schema SQL Commands

To manage schemas, use the following SQL syntax:

Action	SQL Syntax
Create a schema	CREATE SCHEMA
Drop a schema	DROP SCHEMA
Alter a schema: • Change name • Assign new owner	ALTER SCHEMA

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PostgreSQL and Greenplum Database share the same SQL commands for creating and managing schemas.

PSQL Schema Tips

Here are some tips for working in PSQL:

- To see the current schema, run the following command:
`SELECT current_schema();`
- To see a list of all schemas in the database, run the following:
`\dn`
- To see the schema search path:
`SHOW search_path;`
- To set the search path for a database:
`ALTER DATABASE SET search_path TO myschema, public, pg_catalog;`

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Here are some helpful tips for working with databases in the PSQL client program.

Tables – Overview

Tables in relational databases:

- Consist of columns and rows
- Have a fixed number and order of named columns
- Has a variable number of rows reflecting individual records
- No guaranteed row order

Tables share the following characteristics:

- All tables in Greenplum Database are distributed based on a distribution key
- Some table features are not yet supported in Greenplum Database
 - Foreign key constraints
 - Limit on unique constraints

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A table in a relational database:

- Is much like a table on paper where it consists of columns and rows.
- Has a fixed number and order of columns and each column is named.
- Has a variable number of rows reflecting how much data is stored at a given moment.

PostgreSQL makes no guarantees about the order of the rows in a table.

One important difference about tables in Greenplum Database is that all tables are distributed, meaning they are divided into parts amongst the primary segment instances. The distribution is done using a sophisticated proprietary hashing algorithm on the distribution key of the table.

The distribution key can be declared when the table is created or altered. It should be chosen with care.

Because tables are distributed, some features are not yet supported Greenplum Database:

- Foreign key integrity cannot yet be enforced in a distributed table, so this is not supported.
- A table cannot have multiple columns with unique constraints, and any single column that has a unique constraint must also be declared as the distribution key.

Table Distribution Keys – Overview

When defining distribution keys:

- One or more columns are used to divide the data among the segments
- They should be unique to ensure even data distribution
- Specified with `CREATE TABLE` or `ALTER TABLE` using the `DISTRIBUTED BY` clause

```
CREATE TABLE sales
(dt date, prc float, qty int, cust_id int,
 prod_id int, vend_id int)
DISTRIBUTED BY (dt, cust_id, prod_id);
```

- If table does not have a unique column or set of columns, declare `DISTRIBUTED RANDOMLY` as the distribution key
- If not explicitly declared, defaults to the table's `PRIMARY KEY` or the first column of the table

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Let us examine distribution keys in greater detail, as this is a very important concept in Greenplum Database. Table distribution is critical to getting the best performance possible.

- In a table, one or more columns are used as the distribution key, meaning those columns are used to divide the data amongst all of the segments.
- To ensure an even distribution of data, you want to choose a distribution key that is unique for each record. If that is not possible, declare `DISTRIBUTED RANDOMLY` as the distribution key.
- The distribution key is chosen when the table is created or altered using the `DISTRIBUTED BY` clause. This is a Greenplum extension to the SQL standard. Note that you cannot alter the columns of a table that are used as the distribution key after the table is created.
- If a `DISTRIBUTED BY` clause is not supplied, then either the `PRIMARY KEY`, if the table has one, or the first eligible column of the table will be used as the distribution key. This may or may not be the desirable distribution key. Columns of geometric data types are not eligible as distribution key columns. If a table does not have a column of an eligible data type, the rows are distributed based on a random distribution.

Table SQL Commands

To manage tables, use the following SQL syntax:

Action	SQL Syntax
Create a table	CREATE TABLE
Drop a table	DROP TABLE
Alter a table	ALTER TABLE

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PostgreSQL and Greenplum Database share the same SQL commands for creating and managing tables.

Defining the Default Distribution Method

gp_create_table_random_default_distribution	
Value	Description
OFF	(Default) The table distribution key is based on the CREATE TABLE/CREATE TABLE AS command
ON	When the DISTRIBUTED BY clause is not specified: <ul style="list-style-type: none">Primary key: Not specified Random distributionUnique column: Not specified Primary or Unique key: Specified DISTRIBUTED BY clause must be included

Usage: Update default storage options at role level

```
$ gpconfig -c gp_create_table_random_default_distribution -v 'ON'  
$ gpstop -u
```

gpadmin@mdw:~

```
names=> create table db_lvl32 (nid int, strm text);  
NOTICE: Using default RANDOM distribution since no distribution was specified.  
HINT: Consider including the 'DISTRIBUTED BY' clause to determine the distribution of r  
ows.  
CREATE TABLE  
names=>
```

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The `gp_create_table_random_default_distribution` parameter defines how the `CREATE TABLE` and `CREATE TABLE AS` statements behave with regards to table distribution.

When the parameter is set to `OFF`, which is the default value, the table distribution key follows the methods outlined earlier. If the `DISTRIBUTED BY` clause is not specified:

- The primary key is used, if the table has one, or the first eligible column is used.
- The table inherits the parent table or source table if the `LIKE/INHERITS` clause is used

If the parameter is set to `ON`:

- And neither the primary key or a unique column is defined, random distribution is chosen.
- Either the primary key or the unique column is defined, the `DISTRIBUTED BY` clause must be included in the `CREATE TABLE` command or the command will fail.

The parameter is settable with the `gpconfig` command and requires a reload if set.

Table SQL Commands – Creating a Table

The following is an example of creating a table:

Example: Creating a Table

```
CREATE TABLE dimensions.store
(
    storeId      SMALLINT      NOT NULL,
    storeName    VARCHAR(40)   NOT NULL,
    address      VARCHAR(50)   NOT NULL,
    city         VARCHAR(40)   NOT NULL,
    state        CHAR(2)       NOT NULL,
    zipcode      CHAR(8)       NOT NULL
);
```

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In this example, the table, `store`, is created in the schema, `dimensions`. The table consists of 6 columns of varying data types.

Table SQL Commands – Modifying a Table

You can modify certain attributes of a table, including:

- Renaming columns
- Renaming tables
- Adding and removing columns

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

- Adding and removing constraints

```
ALTER TABLE product ALTER COLUMN prod_no SET NOT NULL;
```

- Changing default values

```
ALTER TABLE product ALTER COLUMN prod_no SET DEFAULT -  
999;
```

- Changing column data types

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

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You can alter several properties of a table, including:

- Column names
- Table name
- The number of columns by adding or removing columns
- Constraints on the table by adding or removing constraints
- Default values for columns in the table
- Column data types

Table SQL Commands – Removing a Table

To remove a table:

- Issue the DROP TABLE command:
`DROP TABLE dimensions.customer_old;`
- And prevent an error should the table not exist, use IF EXISTS in the DROP TABLE statement
`DROP TABLE IF EXISTS dimensions.customer_old;`

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When removing the table, you should qualify the table name and specify the name of the table to be dropped. If the table does not exist, you can avoid error messages by using IF EXISTS in the DROP TABLE statement.

Table Column Basics

In PostgreSQL and Greenplum Database:

- Each column has a data type
- There is a large set of data types available
- You can define named data types
- There is a limit on the number of columns in a table

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With PostgreSQL and the Greenplum Database, there are some criteria to column definition you should be aware of:

- Each column has a data type.
- PostgreSQL includes a sizable set of built-in data types that fit many applications.
- Users can define their own data types.
- There is a limit on the number of columns a table can contain. Depending on the column types, it is between 250 and 1600. However, defining a table with anywhere near this many columns is highly unusual and often a questionable design.

The limit is due to the optimizer. An amount greater than 1600 columns will impact performance.

Table and Column Constraints – Overview

Table and column constraints are supported with some limitations:

- CHECK table or column constraints
- NOT NULL column constraints
- UNIQUE column constraints
 - Only one constraint allowed per table
 - Unique columns must also be in distribution key
 - Not allowed if table also has a primary key
- PRIMARY KEY is used as the distribution key by default
- FOREIGN KEY constraints not supported – *referential integrity* is not enforced

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Constraints are a way to limit and control the data that a table contains, limiting the data to a set of valid values. PostgreSQL supports these table and column constraints as does Greenplum Database, with some exceptions:

- CHECK constraints limit data based on some condition you define.
- NOT NULL constraints verify that a column does not have a null value when a row is created. A way of forcing users to define a value for a column when a new record is created.
- A primary key indicates that a column or group of columns can be used as a unique identifier for rows in a table. Technically, a PRIMARY KEY constraint is simply a combination of a UNIQUE constraint and a NOT NULL constraint. If a table has a primary key, it will be chosen as the Greenplum distribution key by default. The only way Greenplum Database can enforce uniqueness is if a column is also in the distribution key. Therefore, a table cannot have more than one UNIQUE constraint and any UNIQUE column or set of columns must be in the distribution key.
- Also PostgreSQL and Greenplum Database always implicitly creates a pkey index for a table's primary key.
- FOREIGN KEYS, while they can be defined, are not currently supported in Greenplum Database, as there is currently no way to enforce referential integrity between the segment instances.

Table and Column Constraints

Example: Table and Column Constraints

```
CREATE TABLE TR_CONSTRAINTS (
    transactionid int NOT NULL UNIQUE,
    price numeric CHECK (price > 0),
    on_sale char DEFAULT 'n'
);
```

Column cannot be NULL

Data in the column for that table is unique

If no value is entered, a default value of 'n' is entered for that field

Column cannot have a value equal to or less than zero

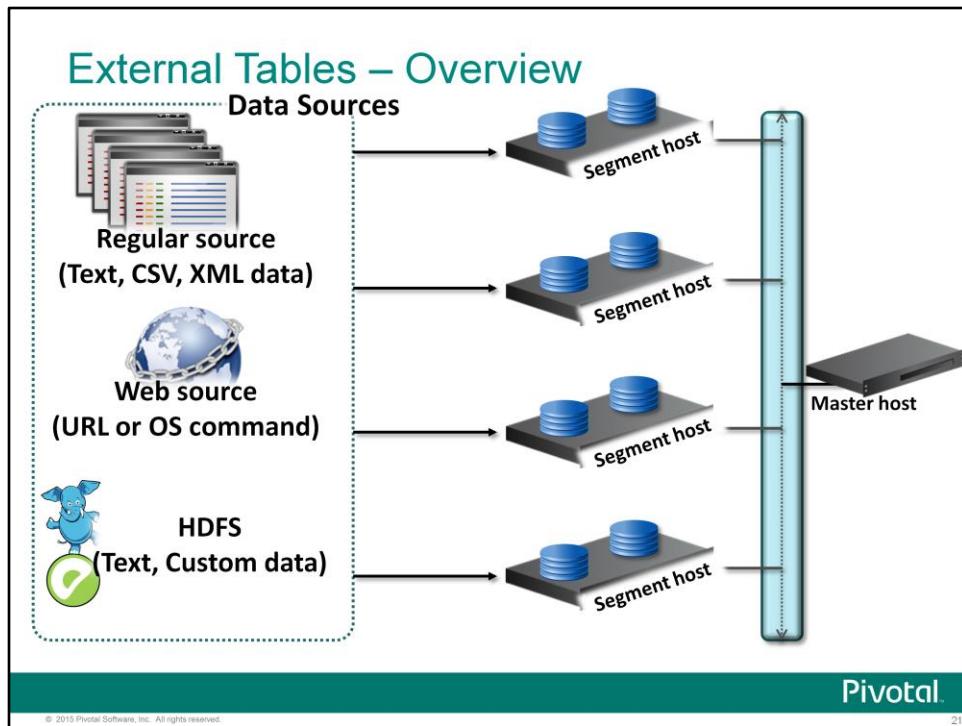
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You can define the following types of constraints:

- A column can be assigned a **DEFAULT** value.
- **CHECK** constraint is the most generic constraint type. It allows you to specify that the value in a certain column must satisfy a Boolean expression.
- **NOT NULL** constraint specifies that a column must not assume the null value.
- **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.



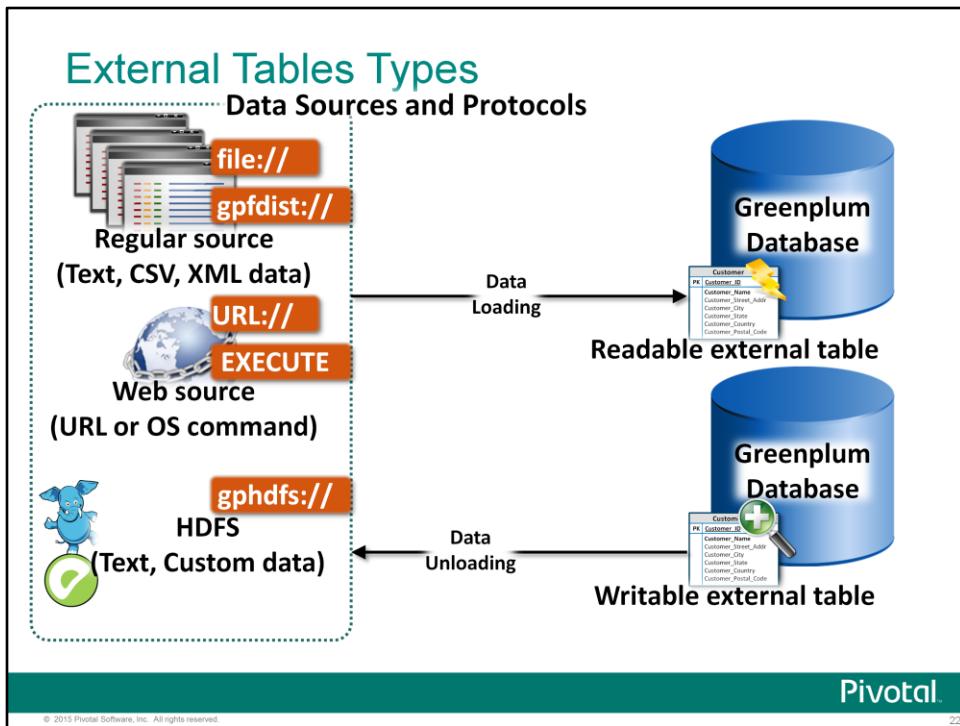
An external table is a definition of a table that specifies how to access a data source outside of the database as well as how that data is formatted. The format varies depending on the type of external table defined.

Large amounts of data can be loaded or unloaded using external tables. Greenplum supports fast, parallel data loading and unloading as well as non-parallel import and export of smaller amounts of data through one of several named protocols.

External tables lets you access data from a data source as though the data source was a regular table.

There are three main types of data sources that Greenplum works with:

- Regular or file-based external sources with support for text data, comma-separated values (CSV) formatted data, or XML data.
- Web-based external sources with support for text and CSV formatted data, as well as operating system commands and scripts.
- Hadoop file-system data sources or tables, with support for text-based data and custom or user-defined formatted data.



Greenplum supports two types of external tables:

- Readable or read-only tables which are used for data loading and cannot be modified.
- Writable or write-only tables which are used for data unloading.

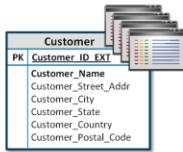
The protocol you use depends on the data source you are interfacing with:

- Regular or flat-file data sources are accessed using the file protocol, `file://`. The Greenplum parallel file distribution program, `gpfdist`, is referenced with the protocol, `gpfdist://`.
- External web tables access data sources with the HTTP protocol, `http://` or by accessing a command or script with `EXECUTE`. The command or script must exist on all segment servers if that is the method you are using.

Once an external table is defined, its data can be queried directly, and in parallel, using SQL commands. For example, you can issue `SELECT`, `JOIN`, or a `SORT` on external table data. You cannot modify the data on a readable external table.

A writable external table allows you to select rows from other database tables and output the rows to files, named pipes, or other executable programs. For example, you could unload data from Greenplum Database and send it to an executable that connects to another database or ETL tool to load the data elsewhere. Writable external tables can also be used as output targets for Greenplum parallel MapReduce calculations. Unlike a readable external table, `INSERT` operations are the only allowed operations. You cannot read from, update, delete, or truncate a writable external table.

Regular, Web, and HDFS External Tables Summary



Regular external tables:

- Access static flat files
- Allows for rescanning



Web external tables:

- Access dynamic data sources
- Is not rescannable when a query is planned



HDFS external tables:

- Require one-time setup
- Require read and/or write privileges to gphdfs protocol

All external tables:

- Support query execution on external data
- Supports single-row error isolation to filter badly formatted rows
- Supports ETL loading and data unloads
- Is accessed by segments at runtime
- Should not be used for frequently executed queries

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The main difference between regular external tables and web tables are their data sources:

- Regular tables access static flat files. The table is rescannable when a query is planned against the external table.
- Web tables access dynamic data sources, either on a web server or by executing OS commands or scripts. The data is not rescannable when a query is planned on the external table. This is because there is a possibility that the data will change during the course of the query's execution.
- Hadoop file system external tables lets you read and write data using the gphdfs protocol to and from Hadoop. As with other external tables, you can either read from or write to a data source. All data is read in parallel from the HDFS data nodes into the Greenplum segment servers for rapid processing of unstructured data. Each Greenplum segment instance reads one set of Hadoop data blocks and writes only the data contained within that segment to the Hadoop file system. The HDFS protocol requires an initial setup process, where Java is installed on all segment servers, Greenplum HD connectors and libraries are configured, gpadmin has read and write access to Hadoop libraries, and environmental variables and server configuration parameters are set. In addition to the initial configuration, any database users who will be using the HDFS protocol must be granted `SELECT` and/or `INSERT` privileges on the protocol if reading from or writing to data sources respectively.

Regular, Web, and HDFS External Tables Summary (continued)

An external table:

- Can be thought of as a view that allows you to run SQL query against external data without first loading the data into the Greenplum database. External tables provide an easy way to perform basic extraction, transformation, and loading (ETL) tasks that are common in data warehousing. External table files are read in parallel by the Greenplum Database segment instances, so they also provide a means for fast data loading.
- Can be defined in *single-row error isolation mode* allowing you to filter out badly formatted rows while still loading good rows.
- Is accessed by segments at runtime in parallel. The same mechanisms used for parallel query execution forms the data into tuples and processes them as a regular parallel query would.
- Should not be used for frequently queried tables. As of now, there is no way to gather detailed statistics for external tables, so the query planner is not able to plan complex queries on external tables effectively.

External Table SQL Commands

To manage external tables, use the following SQL syntax:

Action	SQL Syntax
Create a read-only external table	<code>CREATE EXTERNAL [WEB] TABLE LOCATION (...) EXECUTE '...' FORMAT '...' (DELIMITER, '...');</code>
Create a writable external table	<code>CREATE WRITABLE EXTERNAL [WEB] TABLE LOCATION (...) EXECUTE '...' FORMAT '...' (DELIMITER, '...') DISTRIBUTED BY(...) RANDOMLY;</code>
Drop an external table	<code>DROP EXTERNAL [WEB] TABLE</code>

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To create or remove an external table, use the Greenplum SQL syntax provided. When defining an external table:

- Table is given a name and columns are specified like a normal table definition. Unlike regular tables, external tables do not have column constraints or default values, so do not specify those.
- Use WEB to define the table as a web table. This is valid in both a read-only and write-only definition.
- The LOCATION clause specifies the location and type of the external data and the protocol used to access the external data (file, gpfdist, http, EXECUTE *os_command*, gphdfs). If using the gpfdist:// protocol, you must have the Greenplum file distribution program, gpfdist, running on the host where the external data files reside. This program points to a given directory on the file host.
- The SEGMENT REJECT LIMIT clause is used to specify criteria for single row error handling. Normally a select from an external table is *all or nothing*, meaning it fails on the first format error encountered. This feature allows you to load good rows and ignore, or optionally log to an error table, badly formatted rows. Note this only applies to formatting errors, not constraint errors.
- FORMAT tells how the data is formatted, such as TEXT or CSV.

`DROP EXTERNAL TABLE` removes the table definition only – the data source remains intact and external files are not deleted.

Table Tips

Here are some tips for obtaining table information in PSQL:

- To list tables in the database:
 \dt
- To see structure of a table and distribution key columns:
 \dt+ table_name
- To list system catalog tables:
 \dtS
- To list external tables only:
 \dx
- To see data distribution or the number of rows on each segment:
 SELECT gp_segment_id, count(*)
 FROM table_name GROUP BY gp_segment_id;

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Here are some helpful tips for working with tables in the PSQL client program.

Data Types – Overview

Data types:

- Describe the type of data a column can contain
- In Greenplum are the same as data types in PostgreSQL
- Supported are defined in the SQL standard
- Can be created with the CREATE TYPE SQL command

For Greenplum distribution key columns:

- No geometric data types are supported
- No user-defined data types are supported

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Data types describe the type of data a table column can contain.

Greenplum supports all data types defined in the SQL standard, and all the built in data types supported in PostgreSQL. If desired, you can also define your own custom data types.

For columns that are part of the Greenplum table distribution key, they cannot be of geometric or user-defined data types.

Greenplum Database Data Types

Name	Size	Description
bigint	8 bytes	Large range integer
bigserial	8 bytes	Large autoincrementing integer
bit [(n)]	n bits	Fixed-length bit string
bit varying [(n)]	Actual # of bits	Variable-length bit string
boolean	1 byte	Logical boolean (true/false)
box	32 bytes	Rectangular box in the plane (not allowed in distribution key columns)
bytea	1 byte + binary	Variable-length binary string
character [(n)]	1 byte + n	Fixed-length, blank padded
character varying [(n)]	1 byte + string size	Variable-length with limit
cidr	12 or 24 bytes	IPV4 and IPV6 networks
circle	24 bytes	Circle in the plane (not allowed in distribution key columns)

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The table on this and the next two slides are for reference only. They describe the built-in data types available in Greenplum.

Each data type has an external representation determined by its input and output functions. Many of the built-in types have obvious external formats. However, several types are either unique to PostgreSQL and Greenplum Database, such as geometric paths, or have several possibilities for formats, such as the date and time types. Some of the input and output functions are not invertible. That is, the result of an output function may lose accuracy when compared to the original input.

For more details on the data types, including valid aliases and their defined range, refer to the *Greenplum Database Administrator Guide*.

Greenplum Database Data Types (Cont)

Name	Size	Description
date	4 bytes	Calendar date (year, month, day)
decimal [(p,s)]	variable	User-specified precision, exact
double precision	8 bytes	Variable-precision, inexact
inet	12 or 24 bytes	IPv4 and IPv6 hosts and networks
integer	4 bytes	Usual choice for integer
interval [(p)]	12 bytes	Time span
lseg	32 bytes	Line segment in the plane <i>(not allowed in distribution key columns)</i>
macaddr	6 bytes	MAC addresses
money	4 bytes	Currency amount
path	16+16n bytes	Geometric path in the plane <i>(not allowed in distribution key columns)</i>
point	16 bytes	Geometric point in the plane <i>(not allowed in distribution key columns)</i>

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Greenplum Database Data Types (Continued)

Greenplum Database Data Types (Cont)

Name	Size	Description
polygon	40+16n bytes	Geometric path in the plane <i>(not allowed in distribution key columns)</i>
real	4 bytes	Variable-precision, inexact
serial	4 bytes	Autoincrementing integer
smallint	2 bytes	Small range integer
text	1 byte + <i>string size</i>	Variable unlimited length
time [(p)] [without time zone]	8 bytes	Time of day only
time [(p)] [with time zone]	12 bytes	Time of day only, with time zone
timestamp [(p)] [without timezone]	8 bytes	Both date and time
timestamp [(p)] [with timezone]	8 bytes	Both date and time, with time zone

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Greenplum Database Data Types (Continued)

Array Constructors – Overview

There are two types of arrays:

- An array constructor is an array of values from member elements

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

- A multidimensional or nested array constructor contains nested arrays

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

OR

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

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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 comma separated expressions for the array element values
- A right square bracket (])

For the example shown, there are three items in the array – the last item is a sum of two numbers.

Multidimensional arrays can be built by nesting array constructors. In the inner constructors, the key word ARRAY can be omitted.

In the examples shown at the bottom of the slide, the syntax shown with two ARRAY definitions is the same as the syntax shown with one ARRAY definition and nested brackets.

Constants

There are three types of constants:

- Strings
- Bit strings
- Numbers

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There are three kinds of implicitly-typed constants or literals in PostgreSQL:

- Strings
- Bit strings
- Numbers

Constants can be specified with explicit types which enable more accurate representation and more efficient handling of the constant by the system.

Constants – Strings

A string:

- Is an arbitrary sequence of characters bounded by single quotes

EXAMPLE: 'This is a string.'

- Uses two single quotes to print a single quote

```
SELECT 'Dianne''s Horse';  
Dianne's Horse
```

- Can contain escape string constants. For example:

```
SELECT E'foo\'\tbar';  
foo' bar
```

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A string constant in SQL is an arbitrary sequence of characters bounded by single quotes ('), for example 'This is a string'.

To include a single-quote character within a string constant, write two adjacent single quotes, for example, 'Dianne"’s horse'.

PostgreSQL also accepts *escape* string constants, which are an extension to the SQL standard.

Dollar-quoted Strings

Dollar-quoted strings:

- Can make a query easier to read
- Uses dollar quoting to wrap a string
- Uses the following syntax:
 \$ TAG\$String of words\$ TAG\$

A string can be represented in either of the following ways:

\$\$Dianne's horse\$\$

\$SomeTag\$Dianne's horse\$SomeTag\$

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The standard syntax for specifying string constants is usually convenient, but it can be difficult to read, because of doubled quotes or backslashes.

To allow for more readable queries in such situations, PostgreSQL provides another way to write string constants, called *dollar quoting*.

A dollar-quoted string constant consists of:

- A dollar sign (\$)
- An optional “tag” of zero or more characters
- Another dollar sign
- An arbitrary sequence of characters that makes up the string content
- A dollar sign
- The same tag that began this dollar quote
- A dollar sign

Constants – Escape Strings

Backslash characters are used to represent the following:

Escape Sequence	Description
\b	Backspace
\f	Form feed
\n	New line
\r	Carriage return
\t	Tab
\digits	<i>digits</i> represent an octal byte value
\hexdigits	<i>hexdigits</i> represent a hexadecimal byte value

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Within an escape string, a backslash character (\) begins a C-like backslash escape sequence, in which the combination of backslash and following characters represent a special byte value:

- \b is a backspace
- \f is a form feed
- \n is a newline
- \r is a carriage return
- \t is a tab

Also supported are:

- \digits, where digits represents an octal byte value
- \hexdigits, where hexdigits represents a hexadecimal byte value.

Constants – Bit Strings

Bit strings:

- Use the format, `B'bit_value'` to represent a bit. For example:
`B'1001'`
- Allows only 0's and 1's
- Can be defined in hexadecimal notation using the format, `X'hexadecimal_value'`. For example:
`X'1FF'`
- Can be continued across lines
- Do not support dollar quoting

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Bit-string constants look like regular string constants with a B (upper or lower case) immediately before the opening quote (no intervening whitespace), e.g., `B'1001'`.

The only characters allowed within bit-string constants are 0 and 1.

Alternatively, bit-string constants can be defined in hexadecimal notation, using a leading X (upper or lower case), e.g., `X'1FF'`.

This notation is equivalent to a bit-string constant with four binary digits for each hexadecimal digit.

Both forms of bit-string constant can be continued across lines in the same way as regular string constants.

Dollar quoting cannot be used in a bit-string constant.

Constants – Numbers

Numeric constants are accepted as:

- *Digits*
- *digits.[digits][e[+‐]digits]*
- *[digits].digits[e[+‐]digits]*
- *digitse[+‐]digits*
- Examples of valid number constants:

42	3.5
4.	.001
5e2	1.925e-3

A numeric constant without a decimal point or exponent of size *n*:

- Is an integer if $n \leq 32$ bits
- Is a bigint if $32 > n \leq 64$ bits
- Is numeric if $n > 64$

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Numeric constants are accepted in these general forms:

- digits
- digits.[digits][e[+‐]digits]
- [digits].digits[e[+‐]digits]
- digitse[+‐]digits

where digits is one or more decimal digits, 0 through 9.

The following requirements must be met:

- At least one digit must be before or after the decimal point, if one is used.
- At least one digit must follow the exponent marker (e), if one is present.
- There cannot be any spaces or other characters embedded in the constant.

A numeric constant that contains neither a decimal point nor an exponent:

- Is presumed to be type `integer` if its value fits in the integer size, 32 bits.
- Is presumed to be type `bigint` if its value fits in bigint size, 64 bits.
- Is assumed to be numeric type if none of the above holds true

Constants that contain decimal points and/or exponents are always initially presumed to be type numeric.

Casting Data Types

A type cast:

- Is used to convert one data type to another
- Can be issued with the following syntax:

Syntax	Example
type 'string'	REAL '2.117902'
'string'::type	'2.117902'::REAL
CAST ('string' AS type)	CAST ('2.117902' AS REAL)

- Can be omitted if there is no ambiguity
- Accepts regular SQL notation or dollar quoting for string constants

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A type cast specifies a conversion from one data type to another.

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

- type 'string' REAL '2.117902'
- 'string' ::type '2.117902'::REAL
- CAST ('string' AS type) CAST('2.117902' AS REAL)

The result is a constant of the indicated type.

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

If there is no ambiguity the explicit type cast can be omitted (for example, when constant it is assigned directly to a table column), in which case it is automatically converted to the column type.

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

Additional Database Objects

Let us examine:

- Views
- Indexes
- Sequences
- Triggers
- Tablespaces

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Now we will briefly cover the other database objects we haven't covered yet.

Views – Overview

Views:

- Let you save frequently used or complex queries
- Can be accessed with `SELECT` statement
- Are not materialized on disk
- Are managed and accessed with the following commands:

Action	Command
Create a view	<code>CREATE VIEW</code>
Drop or remove a view	<code>DROP VIEW</code>
List all views	<code>\dv</code>
See view definition	<code>\dv+ view_name</code>

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Views are a way to save frequently used or complex queries and then access them in a `SELECT` statement as if they were a table. A view is not physically materialized on disk as is a table. The query is instead ran whenever the view is accessed.

Note that currently Views ignore `ORDER BY` or `SORT` operations stored in the view, so run those in the query that calls the view.

Working with views in Greenplum Database is the same as in PostgreSQL or as you would expect in any other DBMS.

You can access and manage views with the following commands:

- `CREATE VIEW` – Creates a view
- `DROP VIEW` – Drops a view
- `\dv` – Meta-command to list all of the views in a database
- `\dv+ view_name` – Describes the view

At the bottom of the slide, you will find an example of a view being created.

Views Example

The following example creates the view, `topten`:

```
Example: Creating the view, topten
CREATE VIEW topten
AS SELECT name, ranking, gender, year
FROM names, prod_rank
WHERE ranking < '11' AND names.id=prod_rank.id;
SELECT * FROM topten ORDER BY year, ranking;
```

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In this example, the view, `topten`, is created based on two tables: `names` and `prod_rank`. The data is restricted where the ID exists in both tables and ranking field is less than 11. After creating the view, you can issue a `SELECT` statement to view the rows extracted from the original table.

Index – Overview

Indexes:

- Use random seek to find a record in a relational database
- Should be used sparingly in Greenplum Database
- Are not always favored at query runtime
- Should be checked to see if they improve performance
- Should be dropped if not used
- Are created automatically from a PRIMARY KEY
- Are allowed on Greenplum distribution key columns when columns are UNIQUE

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Greenplum Database is very fast at sequential scanning. Unlike a traditional database, the data is distributed so that each segment scans a smaller portion of the overall data in order to get the result. Add in partitioning and the total data to scan gets even smaller. An index, which uses a random seek to find a record may not always improve query performance in Greenplum Database.

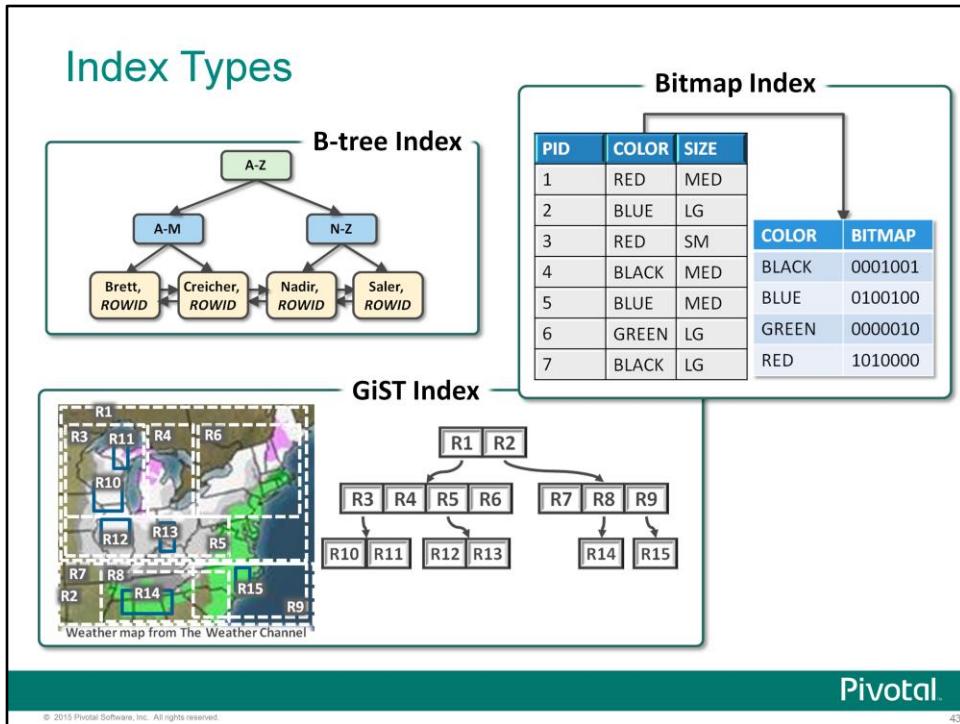
When deciding what indexes to create, examine the WHERE clauses of your query workload. On very large tables, these columns might still be good candidates for indexes.

Note that the query planner tends to favor a sequential scan over an index scan because a sequential scan is often determined by the planner to be faster. If the planner determines an index to be faster, it will use it.

An index does add some database overhead (the index must be maintained whenever a table is updated) so you want to ensure that the indexes you create are being used by your query workload and that they are improving query performance as compared to a sequential scan of the table.

Greenplum Database does have one limitation regarding UNIQUE indexes. To enforce the uniqueness of an index across the segments, unique indexes are only allowed on distribution key columns.

If you create a table with a PRIMARY KEY, a pkey index will be automatically created for that table.



Each index type uses a different algorithm that is best suited to different types of queries. Greenplum Database supports the following index types:

- B-tree (the default index type) fits the most common situations. B-trees can handle equality and range queries on data that can be sorted into some ordering.
- Bitmap is a new type of index only found in Greenplum and not in PostgreSQL.
- GiST indexes are not a single kind of index, but rather an infrastructure within which many different indexing strategies can be implemented.

Commands to Manage Indexes

Commands to manage indexes include:

Action	Command	Greenplum Application
Create an index	CREATE INDEX	
Modify an index	ALTER INDEX	
Drop or remove an index	DROP INDEX	
Cluster an index	CLUSTER	
Re-index your indexes	REINDEX	reindexdb
List all indexes	\di	
View index definition	\d+ <i>index_name</i>	

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You create, modify, or delete an index using the CREATE INDEX, ALTER INDEX, and DROP INDEX commands respectively.

CLUSTER physically reorders a table on disk based on the index information. This can be helpful for queries that access a range of data (by date for example – get June1 –June 30 2007). When an index is in order, the system does not have to hop around the disk seeking for records, but can access a range of records in sequence. Although the CLUSTER command is supported in Greenplum Database, it takes a long time to physically reorder large indexes across several segments. It is much faster to use CREATE TABLE ...AS SELECT ... ORDER BY <the index criteria> to physically reorder the table on disk in this situation.

The SQL command, REINDEX, and the Greenplum application, reindexdb are used to rebuild an index using the data stored in a table and replaces the old copy of an index. This should be used when:

- An index has become corrupted, and no longer contains valid data.
- An index has become bloated, that it is contains many empty or nearly empty pages. This can occur with B-tree indexes in Greenplum Database under certain uncommon access patterns.
- You have altered the fill factor storage parameter for an index and wish to ensure that the change has taken full effect.

Use the \di and \d+ *index_name* meta-commands to list all of the indexes in a database and view details on the indexes respectively.

Bitmap Indexes – Overview

- Bitmap indexes:
- Are ideal for data warehouse applications and decision support systems, where
 - There are large amounts of data and ad-hoc queries
 - There are low numbers of DML transactions
- Are a fraction of the storage size of B-tree indexes
- Are stored as a bitmap, not as tuple (row) IDs
- Uses a mapping function to convert bit positions to a tuple ID
- Are stored in a compressed way

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Bitmap indexes are one of the most promising strategies for indexing high dimensional data in data warehousing applications and decision support systems. These types of applications typically have large amounts of data and ad hoc queries, but a low number of DML transactions.

Fully indexing a large table with a traditional B-tree index can be expensive in terms of space because the indexes can be several times larger than the data in the table. Bitmap indexes are typically only a fraction of the size of the indexed data in the table.

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. In a bitmap index, a bitmap for each key value replaces a list of tuple ids. Each bit in the bitmap corresponds to a possible tuple id, and if the bit is set, it means that the row with the corresponding tuple id contains the key value. A mapping function converts the bit position to an actual tuple id, so that the bitmap index provides the same functionality as a regular index. Bitmap indexes store the bitmaps in a compressed way. If the number of distinct key values is small, bitmap indexes compress better and the space saving benefit compared to a B-tree index becomes even better.

When to Use Bitmap Indexes – Part 1

Bitmap indexes are best used for:

- Low-cardinality columns, where the number of distinct values to the number of rows is small

ROWID	LNAME	FNAME	MARITAL_STATUS
1	Worth	Sam	married
2	Priest	Lara	single
3	Jericho	Val	widowed
		...	
52000221	Mansk	Brett	divorced

Low cardinality

- Columns with less than 10,000 distinct values and less than 1% unique values
- Columns with less than 1% unique values

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Bitmap indexes perform best for columns in which the ratio of the number of distinct values to the number of rows in the table is small. This ratio is known as the degree of cardinality. A marital status column, which has only a few distinct values (single, married, divorced, or widowed), is a good choice for a bitmap index, and is considered low cardinality.

However, columns with higher cardinalities can also have bitmap indexes. For example, on a table with one million rows, a column with 10,000 distinct values is also a good candidate for a bitmap index. A bitmap index on this column can outperform a B-tree index, particularly when this column is often queried in conjunction with other indexed columns. However, the performance gains start to diminish on columns with 10,000 or more unique values, regardless of the number of rows in the table.

A best practice rule to follow is that when less than 1% of the row count is distinct, use bitmap indexes.

When to Use Bitmap Indexes – Part 2

Bitmap indexes are best used for:

- Tables that are not updated frequently
- Queries with multiple WHERE conditions

Query: Which of our customers
who are female are also married?



Example: AND in the WHERE clause for two columns with bitmap index

```
SELECT * FROM customers WHERE gender = 'F' AND  
marital_status = 'married';
```

Column with
bitmap index

Column with
bitmap index

- Boolean operations are performed directly on the bitmaps
- Multiple WHERE clause conditions can be filtered first on the bitmap reducing table scans

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Bitmap indexes can dramatically 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.

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 itself is accessed. This improves response time, often dramatically. FOR EXAMPLE - An analyst for the company might want to know, "Which of our customers who are female are also married?" This corresponds to the following SQL query:

```
SELECT * FROM customers WHERE gender = 'F' AND  
marital_status = 'married';
```

The bitmaps for gender='F' and marital_status='married' are used to identify the rows that have the correct bit values, and the results are merged before accessing the actual tuple id in the customer table. This is more efficient than scanning the entire table multiple times, as only the exact rows that are needed are retrieved.

When Not to Use Bitmap Indexes

Bitmap indexes are not good for:

- OLTP applications
- Frequently updated columns
- Unique or high-cardinality columns

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Bitmap indexes should not be used for unique columns or columns with high cardinality data, such as customer names or phone numbers. B-tree indexes are a better choice for these types of columns.

Bitmap indexes are primarily intended for data warehousing applications where users query the data rather than update it. They are not suitable for OLTP applications with large numbers of concurrent transactions modifying the data.

Bitmap Index – Example

user_id	gender=M	gender=F
1	1	0
2	0	1
3	1	0
4	1	0
5	1	0
6	0	1
7	1	0
8	0	1

Bitmap for **gender=M**: 10111010

Bitmap for **gender=F**: 01000101

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Here is a simple table that illustrates a bitmap index for the gender column.

Each entry (or bit) in the bitmap corresponds to a single row of the table. The value of each bit depends upon the values of the corresponding row in the table. For example, the bitmap for gender='M' would look like this. It contains a '1' as its first bit because the gender is 'M' in the first row of the customer table. The bitmap index also keeps a list of values, which maps the bit to the actual column value. At runtime the value is mapped to a bit number, the bitmap is scanned, rows are identified by their position in the bitmap, and only the tuple ids that match the scan are retrieved.

Sequences – Overview

A sequence:

- Is used to autoincrement unique ID columns
- Is generated by the Greenplum Master sequence generator process (seqserver)
- Has some function limitations:
 - `lastval` and `currval` not supported
 - `setval` cannot be used in queries that update data
 - `nextval` sometimes grabs a block of values for some queries. So values may sometimes be skipped in the sequence if all of the block turns out not to be needed at the segment level.
 - Sequences are based on bigint arithmetic



Note: bigserial and serial data types are auto incrementing integers.

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Creating a sequence generator involves creating and initializing a new special single-row table with the given sequence name. Sequences are often used to increment unique ID columns of a table whenever a new record is added.

In a regular, non-distributed, database, functions that operate on the sequence go to the local sequence table to get values as they are needed. In Greenplum, each segment is its own distinct PostgreSQL database. Therefore they need a single point of truth to go for sequence values so that all segments get incremented correctly and the sequence moves forward in the right order. A sequence server process runs on the master and is the point-of-truth for a sequence in Greenplum distributed database. Segments get sequence values at runtime from the master.

Because of this distributed sequence design, there are some limitations on the functions that operate on a sequence in Greenplum Database:

- `lastval` and `currval` are not supported.
- `setval` can only be used to set the value of the sequence generator on the master, it cannot be used in subqueries to update records on distributed table data.
- `nextval` will sometimes grab a block of values from the master for a segment to use, depending on the query. Values may sometimes be skipped in the sequence if all of the block turns out not to be needed at the segment level. Note that regular PostgreSQL does this as well, so this is not unique to Greenplum.

The bigserial and serial data types are auto incrementing integers. These can be used like sequences.

Sequence SQL Commands

Manage and access sequences with the following commands:

Action	Command
Create a sequence	<code>CREATE SEQUENCE</code>
Modify a sequence	<code>ALTER SEQUENCE</code>
Drop or remove a sequence	<code>DROP SEQUENCE</code>
List all sequences	<code>\ds</code>
View sequence definition	<code>\d+ sequence_name</code>

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Working with sequences in Greenplum is the same as in PostgreSQL or as you would expect in any other DBMS. Creating, altering, and dropping an index are managed with SQL commands.

Use the `\ds` and `\d+ sequence_name` meta-commands to list all of the sequences in a database and view the details on a sequence respectively.

Sequence Example

Here are several examples of implementing sequences:

- Create a sequence named myseq

```
CREATE SEQUENCE myseq START 101;
```

- Insert a row into a table that gets the next value:

```
INSERT INTO distributors  
VALUES (nextval('myseq'), 'acme');
```

- Reset the sequence counter value on the master:

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

- Not allowed in Greenplum Database (set sequence value on segments):

```
INSERT INTO product  
VALUES (setval('myseq', 201), 'gizmo');
```

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The examples on the slide show how to:

- Create a sequence using the CREATE SEQUENCE syntax.
- Insert a row into the distributors table and call the next value of the sequence created. That value is inserted in the first column of the table.
- Reset the sequence counter to the value shown in the slide, 201.
- Reset the value of the sequence to 201 and insert that value into the product table.

Triggers – Overview

Triggers:

- Triggers are considered to be a type of function
- The automatically execute a particular function when a specific type of operation is performed (like updates, deletes, and inserts)
- Have limited support in Greenplum, in that:
 - The function must be `IMMUTABLE` to execute on segment instances
 - The immutable function cannot execute any SQL or modify the database.
 - Triggers are not supported on Append-Optimized tables.
- Are fired in alphabetical order

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Triggers are functions or procedural code that automatically executes whenever a specific type of operation is performed in the database. Triggers are often used for maintaining the integrity of data within the database.

Due to the distributed nature of a Greenplum Database system, the use of triggers is somewhat limited. The function used in the trigger must be `IMMUTABLE`, meaning it cannot use information not directly present in its argument list. The function specified in the trigger also cannot execute any SQL or modify the database in any way. Given that triggers are most often used to alter the database (for example, update these other rows when this row is updated), these limitations offer very little practical use of triggers in Greenplum Database.

If multiple triggers of the same kind are defined for the same event, they will be fired in alphabetical order by name.

Triggers are not supported on append-optimized tables.

Trigger SQL Commands

To manage triggers, use the following SQL commands:

Action	SQL Syntax
Create a trigger	<code>CREATE TRIGGER name {BEFORE AFTER} {event [OR ...]} ON table [FOR [EACH] {ROW STATEMENT}] EXECUTE PROCEDURE funcname (arguments)</code>
Drop a trigger	<code>DROP TRIGGER [IF EXISTS] name ON table [CASCADE RESTRICT]</code>
Alter a trigger	<code>ALTER TRIGGER name ON table RENAME TO newname</code>

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To create, drop, or modify a trigger, use the CREATE TRIGGER, DROP TRIGGER, and ALTER TRIGGER commands respectively.

Tablespaces

Tablespaces:

- Provide an alternate location for tables and indexes
- Can be placed on faster drives
- Require superuser privileges to create or move data objects to it
- Require that a filespace is created for the directory location for each primary and mirror segment instance
`gpfilespace -c gpfilespace_config_file`
- Are created using the following syntax:
`CREATE TABLESPACE tablespace_name
FILESPACE filespace_name`
- Are supported on systems that support symbolic links

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A tablespace allows superusers to define an alternative location on the file system where the data files containing database objects, such as tables and indexes, may reside. This usage allows administrators to store specific tablespaces on faster drives, if the service level agreement requires it.

A user with appropriate privileges can pass the tablespace name to `CREATE DATABASE`, `CREATE TABLE`, or `CREATE INDEX` to have the data files for these objects stored within the specified tablespace.

In Greenplum Database, you must first create a filespace before creating a tablespace that is associated with the directories defined in the filespace. The filespace is the directory location for each segment instance (primary and mirror) in your Greenplum Database array. You use the `gpfilespace` command to first create the filespace. You can use the same location for all your primaries if you want and a separate location for your mirrors (if they are using the same set of hosts as your primaries). The directory must be created before creating the tablespace. Use the `gpfilespace` command to create that filespace.

Tablespaces are only supported on systems that support symbolic links.

Note that the Greenplum implementation of tablespaces is an extension of the SQL standard.

Once the tablespace has been created, data objects can be created in the table space.

Lab: Data Definition Language

In this lab, you create and manage database objects using the Data Definition Language. This includes creating databases, schemas, tables, views, indexes, and schemas.

You will:

- Create a database called `faa` and a schema called `faadata`. You will set the schema search path and learn how to verify which schema you are in.
- Create some tables in Greenplum Database and learn how the Greenplum distribution key for a table is chosen.

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In this lab, you create and manage database objects using the Data Definition Language. This includes creating databases, schemas, tables, views, indexes, and schemas.

Module 4: Defining and Securing the User Database

Lesson 1: Summary

During this lesson the following topics were covered:

- Databases overview
- Schemas and tables
- Constraints
- Data types and constants
- Views, indexes, sequences, triggers, and tablespaces

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This lesson covered an overview of databases, schemas, tables, and how to create and manage these objects. A description of constraints and the various types supported by Greenplum Database, as well as a list and description of various data types supported within the environment. Additionally, the lesson covered descriptions and syntax for creating and managing views, indexes, sequences, triggers, and tablespaces

Module 4: Defining and Securing the User Database

Lesson 2: Data Manipulation Language and Data Query Language

In this lesson, you examine data manipulation language and data query language syntax to access and manage data.

Upon completion of this lesson, you should be able to:

- Describe the SQL support in the Greenplum Database
- Describe concurrency control
- Use functions and operators to build queries
- Examine how transaction concurrency is handled in Greenplum Database

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Data manipulation language consists of SQL syntax that is used to manage and change data. This includes inserting, deleting, and updating data in tables. Data query language is the art of extracting and retrieving data.

Upon completion of this lesson, you should be able to:

- Describe the SQL support available in the Greenplum Database
- Describe concurrency control
- Insert, update, and delete data using SQL syntax
- Use functions and operators to build queries
- Examine how transaction concurrency is handled in Greenplum Database using MVCC

SQL Support in Greenplum Database

Greenplum Database:

- Supports:
 - The majority of features in the SQL 1992 and SQL 1999 standards
 - Several features in the SQL 2003 and SQL 2008 standards
- Intends to fully support all SQL commands as defined in PostgreSQL
- Has some limitations to DDL commands, including:
 - Triggers — External Tables
 - Foreign keys — Workload Management
- Includes support for features not in PostgreSQL, including:
 - Parallelism
 - OLAP

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Both data manipulation language (DML) and data query language (DQL) are supported as in PostgreSQL with some minor limitations. Greenplum supports:

- The majority of features of the SQL 1992 and SQL 1999 standards
- Several of the features of the SQL 2003 and SQL 2008 standards

All other SQL commands are considered Data Definition Language (DDL) or utility commands. Most DDL is supported as in PostgreSQL, but there are a few limitations regarding things like foreign keys and triggers.

Greenplum has also added SQL to support features not in regular PostgreSQL, including:

- Parallelism
- OLAP SQL extensions to SELECT
- Managing external tables
- Managing workload management with resource queues

For details on the supported features in the SQL standards, refer to the *Greenplum Database Administrator Guide*.

Concurrency Control and Multi-version Concurrency Control Features

Data consistency:

- Is maintained by using the MVCC model (Multi-version Concurrency Control).
- Lets each transaction see a snapshot of data
- Protects the user from viewing inconsistent data that could be caused by other transactions executing concurrent updates on the same data rows

MVCC:

- Provides transaction isolation for each database session.
- Uses locking methodologies to minimize lock contention
- Ensures reading never blocks writing and writing never blocks reading

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When you start a transaction, you snapshot the data at the time in point you are looking at it. The advantage of this is that all of the data is captured at that time. If a query takes 3 hours to complete, instead of working on the data that exists after the query completes, it works on the data at the time of the snapshot. This eliminates inconsistencies that can occur when data is changed during that time period, such as when:

- Inserting new rows
- Updating existing rows
- Deleting rows

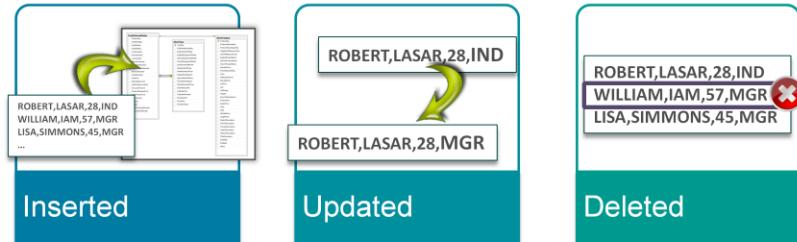
This provides transaction isolation for each database session. By eschewing explicit locking methodologies of traditional database systems, multi-version concurrency control, or MVCC:

- Minimizes lock contention in order to allow for reasonable performance in multiuser environments.
- Ensures locks acquired for querying, or reading, data do not conflict with locks acquired for writing data. Reading never blocks writing and writing never blocks reading.

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

Managing Data

When working with data, data can be:



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Data is managed using the following concepts:

- **Insert** – Data is inserted into tables
- **Update** – Existing data is updated or modified
- **Delete** – Existing data is removed from a table

Inserting Data

INSERT command:

- Is fully supported
- Does not match the performance of COPY or external tables
- Can be substituted with:

```
INSERT INTO <table>
    SELECT FROM <external table>
or
COPY
```

The following is an example of its use:

```
INSERT INTO names VALUES
    (nextval('names_seq'), 'test', 'U');
```

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While the INSERT command contains the same level of support as in PostgreSQL, the performance is not as good in the distributed environment. If you have a lot of rows to insert, consider using COPY or external tables for faster load performance.

Updating Data

The UPDATE command:

- Is used to update individual, multiple, or all rows in a table
- Requires the same distribution key be used when joining using the distribution column and an equijoin
- Does not allow distribution key columns to be updated

The following is an example of its use:

```
UPDATE names SET name='Emily' WHERE name='Emmmily';
```

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The UPDATE command can be used to update rows in Greenplum DB.

Updating data refers to the modification of data that already exists in the database. You can update individual, multiple, or all rows in a table.

Greenplum has the following restrictions or limitations:

- When joining two tables using the UPDATE command, the tables must have the same Greenplum distribution key and be joined on the distribution key column(s). This is referred to as an equijoin.
- Greenplum distribution key columns may not be updated.

With the MVCC transaction model, every update is essentially an upsert, where the updated row's visibility information is marked stale and a newly visible row is inserted.

Deleting Data

The following commands are used to remove data:

- **DELETE** command has the limitation where any table joins must be equijoins

```
DELETE FROM ranking; (deletes all rows)  
DELETE FROM ranking WHERE year='2001';
```

- **TRUNCATE** command deletes rows in a specified table

```
TRUNCATE b2001;
```

- **DROP** command deletes all rows and the table definition

```
DROP TABLE ranking;
```

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The following commands can be used to delete data in Greenplum DB:

- **DELETE** – Greenplum has a limitation when joining two tables in a **DELETE** statement. The tables to be joined must have the same distribution key columns if the join is being performed on the distribution column and be joined using those columns (equijoins).
- **TRUNCATE** – This is like an unqualified delete, but it is faster since it does not scan the tables as the **DELETE** command does. As **TRUNCATE** does not scan tables, it does not truncate child tables, working only on the table specified.
- **DROP** – This command drops the rows and the table definition specified.

For parallel deletes, the **WHERE** clause must be on the distribution columns. The same for is true for the **UPDATE** command.

Selecting Data

The `SELECT` statement:

- Selects data from a table
- Supports the same set of standards as is supported with PostgreSQL

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The support for `SELECT` statements in the Greenplum Database is the same as PostgreSQL. This now includes correlated subquery, which enjoyed less support in Greenplum Database in earlier revisions of the database.

Correlated Subqueries

Greenplum can flatten correlated subqueries that:

- Is a nested `SELECT` statement
- Refers to a column from an outer `SELECT` statement
- Does not need input from parent query
- Produces a scalar value or table values

The screenshot shows a software interface with a teal header bar containing the word "Pivotal". Below the header is a light blue section titled "Example: Correlated subquery finding all flight numbers not associated with a specific tail number". Inside this section is a code snippet:

```
SELECT * FROM transaction t WHERE t.salesamt > 50 AND
t.storeid=
  (SELECT s.storeid FROM store s WHERE
    s.countrycd='CAN' AND s.storeid=t.storeid);
```

A green bracket on the left side of the slide points to the subquery part of the code, specifically the inner `SELECT` statement. A callout box labeled "Subquery" is positioned below the bracket. In the bottom right corner of the slide, there is a small "66" reference.

A correlated subquery is a nested `SELECT` statement that refers to a column from an outer `SELECT` statement. A subquery can be scalar, in that it returns a single row with a single value, or a table subquery, where multiple rows can be returned.

Greenplum Database supports correlated subqueries by unnesting the subquery where possible, or transforming the subquery into a join with the tables of the outer query.

If a correlated subquery has characteristics that do not prevent flattening, then it will be transformed to a join and be executed as expected.

It is important to understand the potential performance impacts on a query. A correlated query may require a rewrite in order to improve the overall performance of the query.

In this specific case, the cost of the correlated subquery is greater than a rewrite. A rewrite on the query displayed on the screen is:

```
SELECT t.* FROM transaction t, store s
WHERE t.salesamt > 50
AND s.countrycd='CAN'
AND s.storeid=t.storeid;
```

Common Table Expressions

A common table expression:

- Is a temporary table used in SELECT statements
- Does not require permissions changes to the schema
- Is considered a transient view
- Is also known as the `WITH` clause

The screenshot shows a slide from Pivotal Software. At the top, there's a title bar with a magnifying glass icon and the text "Example: Obtain a random sampling of 10 unique airline IDs and get a report on the flight numbers associated with those airline IDs using a common table expression". Below this is a code block with a callout pointing to the first line: "WITH random_sampler_cte AS". The callout is labeled "CTE definition". The code itself is as follows:

```
WITH random_sampler_cte AS
  (SELECT DISTINCT(airlineid) FROM factontimeperformance
   LIMIT 10)
  SELECT flightnum, origincityname, originstatename
    FROM factontimeperformance, random_sampler_cte
   WHERE random_sampler_cte.airlineid=
         factontimeperformance.airlineid;
```

At the bottom right of the slide is the Pivotal logo.

The common table expression, introduced in SQL standard 2003, is a temporary table set used in subsequent SELECT statements. It is often preferred over views, in that views require permissions to the schema, necessitating privilege changes. Common table expressions however are transient views, derived from a query. It is often called the *WITH clause*.

CTEs address queries that are generated by business intelligence tools. These are not used as often in adhoc queries because of their potential complexities.

Built-in Functions and Operators

Greenplum:

- Supports all categories of built-in functions and operators provided by PostgreSQL
- Provides full support of `IMMUTABLE` functions
- Provides limited use of `STABLE` and `VOLATILE` functions

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PostgreSQL provides a large number of functions and operators for the built-in data types. Greenplum fully supports all built-in functions that are defined as immutable. An immutable function always returns the same result when given the same argument values; that is, it does not do database lookups or otherwise use information not directly present in its argument list.

For functions that are stable or volatile, they can be used in a limited capacity in Greenplum Database.

The function types are defined as follows:

- **STABLE** indicates that within a single table scan the function will consistently return the same result for the same argument values, but that its result could change across SQL statements. Functions whose results depend on database lookups or parameter variables are classified as `STABLE`. Also note that the `current_timestamp` family of functions qualify as stable, since their values do not change within a transaction.
- **VOLATILE** indicates that the function value can change even within a single table scan. Relatively few database functions are volatile in this sense; some examples are `random()`, `currval()`, `timeofday()`. But note that any function that has side-effects must be classified volatile, even if its result is quite predictable (for example, `setval()`).

Stable and Volatile Functions

Stable and volatile functions:

- Can be used in statements that are evaluated on the master (no FROM clause):

```
SELECT setval('myseq', 201);  
SELECT foo();
```
- Cannot be used in statements that execute at the segment level if the function contains SQL or modifies the database in any way:

```
SELECT * FROM foo();
```

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In Greenplum Database, the data is divided up amongst the segments. Each segment is, in a sense, its own distinct PostgreSQL database. To prevent data from becoming out-of-sync across the segments, any function classified as STABLE or VOLATILE cannot be executed at the segment level if it contains SQL or modifies the database in any way. For example, functions such as `random()` or `timeofday()` are not allowed to execute on distributed data in Greenplum Database because they could potentially cause inconsistent data between the segment instances. Anything in a `FROM` or `WHERE` clause is evaluated at the segment level. The following statement executes on the segments (has a `FROM` clause), however it may be allowed provided that the function used in the `FROM` clause simply returns a set of rows.

To ensure data consistency, VOLATILE and STABLE functions can safely be used in statements that are evaluated on and execute from the master. For example, statements without a `FROM` clause are always evaluated at and dispatched from the master.

Built-in Functions (SELECT)

Function	Description	Example
CURRENT_DATE	Returns the current system date	2006-11-06
CURRENT_TIME	Returns the current system time	16:50:54
CURRENT_TIMESTAMP	Returns the current system date and time	2008-01-06 16:51:44.430000+00:00
LOCALTIME	Returns the current system time with time zone adjustment	19:50:54
LOCALTIMESTAMP	Returns the current system date and time with time zone adjustment	2008-01-06 19:51:44.430000+00:00
CURRENT_ROLE ROLE	Returns the current database user	jdoe

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The functions shown are built-in functions that can be used as part of a SELECT statement.

Mathematical Functions

Function	Returns	Description	Example	Results
+ - * /	same	Add, Subtract, Multiply & Divide	1 + 1	2
%	Integer	Modulo	10%2	0
^	Same	Exponentiation	2^2	4
/	Numeric	Square Root	/9	3
/	Numeric	Cube Root	/8	2
!	Numeric	Factorial	!3	6
& # ~	Numeric	Bitwise And, Or, XOR, Not	9 & 15	11
<< >>	Numeric	Bitwise Shift left, right	1 << 4 8 >> 2	16 2

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Commonly used mathematical functions shown on this and the next slide are supported in Greenplum Database and PostgreSQL. These tables are provided as reference only. For a detailed listing of the functions supported, refer to the *Greenplum Database Administrator Guide*.

Mathematical Functions (Cont)

Function	Returns	Description	Example	Results
abs	same	Absolute Value	abs(-998.2)	998.2
ceiling (numeric)	Numeric	Returns smallest integer not less than argument	ceiling(48.2)	49
floor (numeric)	Numeric	Returns largest integer not greater than argument	floor(48.2)	48
pi()	Numeric	The π constant	pi()	3.1419...
random()	Numeric	Random value between 0.0 and 1.0	random()	.87663
round()	Numeric	Round to nearest integer	round(22.7)	23

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Mathematical Functions (Continued)

String Functions

Function	Returns	Description	Example	Results
string string	Text	String concatenation	'my' 'my'	'mymy'
char_length(string)	Integer	number of chars in string	char_length('mymy')	4
position(string in string)	Integer	Location of specified sub-string	position('my' in 'ohmy')	3
lower(string)	Text	Converts to lower case	lower('MYMY')	'mymy'
upper(string)	Text	Converts to upper case	upper('mymy')	'MYMY'
substring(string from n for n)	Text	Displays portion of string	substring('myohmy' from 3 for 2)	'oh'
trim(both,leading,trailing from string)	Text	Remove leading and/or trailing characters	trim(' mymy ')	'mymy'

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These commonly used string functions are supported in Greenplum Database and PostgreSQL. For a complete listing of the string functions available, refer to the *Greenplum Database Administrator Guide*.

String Functions (Cont)

Function	Returns	Description	Example	Results
initcap (string)	Text	Changes case	initcap ('my my')	'My My'
length (string)	Integer	Returns string length	length ('mymy')	4
split_part (string, delimiter, occurrence)	Text	Separates delimited list	split_part('one two three',' ',2)	'two'

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String Functions (Continued)

Date Functions				
Function	Returns	Description	Example	Results
age(timestamp,timestamp)	Timestamp	Difference in years, months and days	age('2008-08-12' timestamp, current_timestamp)	0 years 1 month 11 days
extract (field from timestamp)	Integer	Returns year, month, day, hour, minute or second	extract(day from current_date)	11
now()	Timestamp	Returns current date & time	now()	2008-09-22 11:00:01
overlaps	Boolean	Simplifies comparing date ranges	WHERE ('2008-01-01','2008-02-11') overlaps ('2008-02-01','2008-09-11')	TRUE

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Commonly used date functions are displayed on the slide. For detailed information and a full listing of all date functions, refer to the *Greenplum Database Administrator Guide*.

Date Manipulation Examples

Here is an example to get the first day of the month:



Example: Retrieve the first day of the current month

```
SELECT CURRENT_DATE -  
       EXTRACT( DAY FROM CURRENT_DATE )::int + 1;
```

You can use this for ANY DATE column in the data warehouse! It can save you time on coding joins to the CALENDAR tables.



Example: Retrieve the first day of any month from facts.transaction

```
SELECT  
       ( t.transdate -  
         EXTRACT(DAY FROM t.transdate)::int + 1) AS  
         MonthStartDate, t.*  
FROM  
       facts.transaction t;
```

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In the examples shown, you can retrieve the first day of the month using the examples shown on the slide. The CURRENT_DATE and EXTRACT functions are used to derive that data in the first example.

The second example allows you to retrieve the first day of any month provided in the data.

Statistical or Aggregate Functions

Function	Returns	Description
sum	bigint for smallint or int arguments, numeric for bigint arguments, double precision for floating-point arguments, otherwise the same as the argument data type	Sum of <i>expression</i> across all input values
count	bigint	Number of input rows for which the value of <i>expression</i> is not null
avg	numeric for any integer type argument, double precision for a floating-point argument, otherwise the same as the argument data type	the average (arithmetic mean) of all input values
min	same as argument type	Minimum value of <i>expression</i> across all input values
max	same as argument type	Maximum value of <i>expression</i> across all input values

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An aggregate function is a function that acts on values within a column. The aggregate function computes multiple input values to a single output value. For example, calculating the total of values in a column can be performed with the SUM aggregate function.

The table shows some of the more commonly used aggregates: SUM, COUNT, AVG, MIN, and MAX. Aggregates are not allowed in the WHERE clause, but are allowed in the HAVING clause.

Statistical Functions – SUM

SUM:

- Returns the arithmetic sum of all values from a specified column:



Example: Sum of all values in itemcnt

```
SELECT    SUM(itemcnt) as ItemQtySold  
FROM      facts.transaction;
```

- When used with a GROUP BY can determine the sum of column values grouped by another column:



Example: GROUP BY column_name

```
SELECT    SUM(itemcnt), storeid  
FROM      facts.transaction  
GROUP BY storeid;
```



Example: GROUP BY position

```
SELECT    SUM(itemcnt), storeid  
FROM      facts.transaction  
GROUP BY 2;
```

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The SUM function returns the arithmetic function of all values from a specified column. It can also be used with the GROUP BY expression to determine the sum of column values grouped by another column.

Statistical Functions - COUNT

COUNT:

- Returns the number of qualified rows in a result tab.

```
SELECT COUNT(*)  
FROM facts.transaction;
```

- Can be used to count distinct values with the DISTINCT operator

```
SELECT COUNT(DISTINCT storeid)  
FROM facts.transaction;
```

- Can be used with GROUP BY to determine the number of rows grouped by a selected column

```
SELECT storeid, COUNT(*)  
FROM facts.transaction  
GROUP BY 1;
```

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The COUNT function returns the number of qualified rows in a result tab. You can obtain the number of unique values in a column by adding the DISTINCT operator to the COUNT function. The example shown returns a count of the number of unique storeids in the transaction table.

The COUNT function used with a GROUP BY can be useful for determining the number of rows grouped by a selected column, as shown by the third example on the slide.

Statistical Functions – AVG

AVG:

- Returns the arithmetic average of a specified column

```
SELECT      AVG(totalamt)
FROM        facts.transaction;
```

- Can be used with GROUP BY to determining the average of values, grouped by another column

```
SELECT      transdt,  AVG(totalamt)
FROM        facts.transaction
GROUP BY    1;
```

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AVG returns the arithmetic average of a specified column in a result table. The query in the first example on the slide shows the average of the total sales amounts from the transaction table.

The AVG function, used with GROUP BY can be useful for determining the average amounts of values, grouped by another column. The second example on the slide obtains the daily average of the totalamt column from the transaction table.

Statistical Functions – MIN and MAX

MIN returns the minimum value of a given column

```
SELECT  MIN(transdt)  
FROM    facts.transaction;
```

MAX returns the maximum value of a given column

```
SELECT  MAX(transdt)  
FROM    facts.transaction;
```



Note: Adding additional dimensions to the select statement requires a GROUP BY for each dimension. This returns the MIN or MAX (or both), aggregated over all dimensions.

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MIN returns the minimum value of a given column. The query in the first example shows the earliest transaction date value from the transaction table.

MAX returns the maximum value of a given column. The query in the second example on the slide returns the maximum transaction date value from the transaction table.

Note that adding additional dimensions to the select statement requires a GROUP BY for each dimension. This returns the MIN or MAX (or both), aggregated over all dimensions.

Logical Operators

x	y	x AND y	x OR y
TRUE	TRUE	TRUE	TRUE
TRUE	FALSE	FALSE	TRUE
FALSE	FALSE	FALSE	FALSE
TRUE	NULL	NULL	TRUE
FALSE	NULL	NULL	FALSE
NULL	NULL	NULL	NULL

x	NOT x
TRUE	FALSE
FALSE	TRUE
NULL	NULL

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Logical operators AND and OR are displayed on the slide. These return a boolean (TRUE or FALSE) based on the operation performed.

POSIX Pattern Matching

Operator	Description	Example
<code>~</code>	Matches regular expression Case sensitive	<code>'thomas' ~ '.*thomas.*'</code>
<code>~*</code>	Matches regular expression Case insensitive	<code>'thomas' ~* '.*Thomas.*'</code>
<code>!~</code>	Does not match regular expression Case sensitive	<code>'thomas' !~ '.*Thomas.*'</code>
<code>!~*</code>	Does not match regular expression Case insensitive	<code>'thomas' !~* '.*vadim.*'</code>

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Pattern matching and the use of regular expression can greatly simplify your string manipulation and comparison needs.

Comparison Operators

Operator	Description
=	Equal to
!= OR <>	NOT Equal to
>	Greater than
>=	Greater than or equal to
<	Less than
<=	Less than or equal to
x BETWEEN y AND z	Short hand for x >= y <u>and</u> x <= z
x IS NULL	True if x has NO VALUE
'abc' LIKE '%abcde%'	Pattern Matching
POSIX Comparisons	POSIX Pattern Matching

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Comparison operators are used to compare two objects to each other.

What Is NULL?

Nulls:

- Represent the absence of value
- Are a place holder indicating that no value is present
- Can be replaced based on business rules

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`NULL` is the value used to represent an unknown piece of data in a column or field. It represents the absence of a value.

Within your data files you can designate a string to represent null values.

The default string is:

- `\N` (backslash-N) in TEXT mode
- 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. It acts as a placeholder indicating that no value is present. For example, you might prefer an empty string for cases where 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 will be considered a null value.

User-defined Functions

Greenplum Database:

- Supports server extensibility as does PostgreSQL
- Limited use of `STABLE` and `VOLATILE` functions
- Lets you register new functions with the following requirements:
 - Declare appropriate volatility level (`VOLATILE`, `STABLE`, `IMMUTABLE`); if not declared, `VOLATILE` is assumed.
 - Place shared library files in the same library path location on every host (master, segments, mirrors)
 - Any functions used for user-defined data types, operators or aggregates must be `IMMUTABLE`

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Both Greenplum Database and PostgreSQL support user-defined functions. The process for extending the server functionality with new functions, and thereby data types, aggregates and operators, is the same as in PostgreSQL.

After you write a function, you must register it with the server using `CREATE FUNCTION`. When doing this make sure to choose the correct volatility level and keep in mind the limitations of `STABLE` and `VOLATILE` functions we discussed on the previous slide. The default level is `VOLATILE`. Any function used in a user-created data type, aggregate, or operator must be `IMMUTABLE` in Greenplum Database or else you will get errors when trying to use the function.

Note that in Greenplum Database, the shared library files for C user-created functions must reside in the same library path location on every host in the Greenplum Database array (masters, segments, and mirrors). Best to place these files relative to the `$GPHOME/lib` directory.

Transactions

Transactions:

- Bundle multiple statements into one *all-or-nothing* operation

Action	SQL Syntax
Start a transaction block	BEGIN or START TRANSACTION
Commit the results of a transaction	END or COMMIT
Abandon the transaction	ROLLBACK
Create a savepoint	SAVEPOINT

Autocommit mode:

- Is enabled by default in psql
- Can be turned off with \set autocommit on|off



Note: Two-phase commit transactions are not supported

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Transactions allow you to bundle together multiple SQL statements in one all-or-nothing operation. They also ensure that the changes are indeed made to permanent storage won't be lost if a crash occurs.

The SQL commands used to perform transactions are:

- **BEGIN or START TRANSACTION** – Start a transaction block
- **END or COMMIT** – Commit the results of the transaction
- **ROLLBACK** – Abandon the transaction without changes.
- **SAVEPOINT** – Savepoints allow you to selectively discard parts of the transaction while committing the rest. After defining a savepoint with the **SAVEPOINT** command, you can roll back to a savepoint with the **ROLLBACK TO** command.

By default, psql runs in **autocommit** mode. This means each command is implicitly wrapped in a **BEGIN** and **COMMIT** (or a **ROLLBACK** if there is an error). Each statement issued in psql is its own transaction. You may want to run several commands in a single transaction, so it may be desired to sometimes turn autocommit off. With autocommit off, you will have to explicitly use **BEGIN** to start a transaction and **COMMIT** or **ROLLBACK** to end it.

Postgres 8.1 introduced the concept of 2 phase commit transactions. After a transaction is prepared, the transaction is no longer associated with the current session; instead, its state is fully stored on disk, and there is a very high probability that it can be committed successfully, even if a database crash occurs before the commit is requested. This feature is currently not supported in Greenplum DB.

Transaction Concurrency Control

Greenplum supports all transaction isolation levels, including:

- READ COMMITTED/READ UNCOMMITTED
- SERIALIZABLE/REPEATABLE READ

In Greenplum:

- INSERT/COPY acquire locks at the row-level
- UPDATE/DELETE acquire locks at the table-level
- You can use the LOCK command to acquire specific locks
- The LOCK command must be used within a transaction block

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The SQL standard defines four transaction isolation levels:

- **READ COMMITTED** – This is the default behavior for transaction isolation. A statement can only see rows committed before it began executing.
- **READ UNCOMMITTED** – In Greenplum Database, READ UNCOMMITTED is the same as READ COMMITTED.
- **SERIALIZABLE** – All statements of the current transaction can only see rows committed before the first statement was executed in the transaction. SERIALIZABLE is the strictest transaction isolation. This level emulates serial transaction execution, as if transactions had been executed one after another, serially, rather than concurrently. Applications using this level must be prepared to retry transactions due to serialization failures.
- **REPEATABLE READ** – In Greenplum Database, REPEATABLE READ is the same as SERIALIZABLE.

Row-level locks are acquired with the INSERT and COPY commands, while table-level locks are acquired using the UPDATE and DELETE commands.

If the MVCC model does not provide the level of concurrency protection you need, you can acquire explicit locks on a table using the LOCK command. Once a lock is acquired, it is held until the end of the transaction. The LOCK command must be used within a BEGIN/END transaction block to hold the lock on the object you specify.

Lock Modes

Lock Mode	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

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The table shows the available lock modes and the contexts in which they are used automatically by Greenplum Database, and the lock modes they conflict with.

You can acquire any of these locks explicitly with the `LOCK` command.

Remember that all of these lock modes are table-level locks, even if the name contains the word *row*; the names of the lock modes are historical. To some extent the names reflect the typical usage of each lock mode — but the semantics are all the same. The main difference between one lock mode and another is the set of lock modes with which each conflicts.

Two transactions cannot hold locks of conflicting modes on the same table at the same time. However, a transaction never conflicts with itself. For example, it may acquire `ACCESS EXCLUSIVE` lock and later acquire `ACCESS SHARE` lock on the same table.

Non-conflicting lock modes may be held concurrently by many transactions.

Lock Modes (Cont)

Lock Mode	SQL Commands	Conflicts With
SHARE ROW EXCLUSIVE		ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, ACCESS EXCLUSIVE
EXCLUSIVE	DELETE, UPDATE	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

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Lock Modes (Continued)

Checking for Lock Conflicts

Lock conflicts can be:

- Verified by querying `pg_locks`
- Resolved by an administrator
- Caused by:
 - Concurrent transactions accessing the same object
 - Resource queue locks
 - Transaction deadlocks between segments (rare)

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When an object is locked, subsequent concurrent queries that try to access the object need to wait for the lock to be freed. This can appear to the end user or application like the query is *hanging* or not being processed.

You should be aware of the following types of conflicts:

- **Lock Conflicts** – As long as a deadlock situation is not detected, a transaction seeking either a table-level or row-level lock will wait indefinitely for conflicting locks to be released. It is therefore a bad idea for applications to hold transactions open for long periods of time, such as while waiting for user input.
- **Queue Locks** – If a query is submitted through a resource queue that has exceeded its limits, the queue is locked until resources are freed. The `pg_locks` table will show a lock on the queue object for a particular query and session.
- **Deadlocks** – PostgreSQL has a built-in deadlock detector that catches most deadlock situations when the query is submitted. However, Greenplum does not have a global deadlock detector across all segments in the system. Deadlock detection is local at the segment level. There are rare cases where a transaction deadlock can occur because of a deadlock at the segment level.

Checking for Lock Conflicts Example



Example: Determine which query has a lock

```
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;
```

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Checking the pg_locks view and joining it with pg_class, which lists the objects involved, and pg_stat_activity, which lists the users and sessions involved, can let an administrator know what is going on and identify lock conflicts. If a conflict is detected, killing the process id of a conflicting query on the master resolves the problem.

Lab: Data Manipulation Language and Data Query Language

In this lab, you use DML and DQL to access and manage data in the tables.

You will:

- Insert, update, and delete records
- Access data to generate a report

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In this lab, you use DML and DQL to access and manage data in the tables.

Module 4: Defining and Securing the User Database

Lesson 2: Summary

During this lesson the following topics were covered:

- Support for SQL statements in the Greenplum Database
- Concurrency control
- Functions and operators to build queries
- Transaction concurrency in the Greenplum Database

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This lesson covered the DML and DDL syntax used to access and manipulate database objects, including how to insert, delete, and update data in tables, using functions, and various other statements for accessing database objects. Concurrency control allows both the system and users to lock database object to ensure that data retrieved is valid, despite changes made to the objects. Users create functions and use operators to repetitively access commonly used syntax.

Module 4: Defining and Securing the User Database

Lesson 3: Roles, Privileges, and Resources

In this lesson, you examine the concepts of roles, privileges, and workload management in Greenplum and identify how to manage resource queues.

Upon completion of this lesson, you should be able to:

- Define roles and privileges
- Describe which roles get object privileges
- Identify security issues that can affect your database and corresponding data
- Create roles with specific privileges to control access
- Isolate users at the physical and functional layers
- Describe the workload management process

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To provide your users access to the database and to ensure each user's data is protected from unauthorized view, you must define roles for the database. You must also manage resources to ensure that users and their queries do not hog system resources.

In this lesson, you will:

- Define roles and privileges for the Greenplum Database system.
- Identify the privileges that can be assigned to specific roles.
- Identify security issues that can affect your database and corresponding data.
- Examine privileges that can be used to enforce access.
- Identify practices designed to isolate users.
- Examine the workload management processes and how to manage resources.

Roles and Privileges Overview

Roles:

- Can be a user, group, or both
- Are not related to OS users and groups
- Use attributes to determine permission levels
- Are given access privileges to database objects
- Can be members of other roles
- Are defined at the system-level

Every system has a default superuser role

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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.

Greenplum Database roles:

- Are separate from the users and groups managed by the operating system on which the server runs. For your convenience, you may want to maintain a relationship between operating system user names and Greenplum Database role names, as many of the client applications use the current operating system user names.
- Have attributes that determine what their permission levels are.
- Can own database objects, such as tables, and can assign privileges on those objects to other roles to control access to the objects. The role that creates an object becomes its owner by default.
- Can be members of other roles, thus a member role can inherit the attributes and privileges of its parent role.
- Are defined at the system level, meaning they are valid for all databases in the system. Managing roles and privileges in Greenplum Database is the same as in PostgreSQL.

Every freshly initialized Greenplum Database system contains one predefined role. This role is a superuser role. By default it has the same name as the operating system user that initialized the Greenplum Database system. In our example, the role is `gpadmin`. Before creating more roles, you first have to connect to Greenplum the superuser role.

Role Privileges

A user account:

- Has login privileges
- Is automatically assigned the following default attributes:
 - **NOSUPERUSER**
 - **NOCREATEDB**
 - **NOCREATEROLE**
 - **INHERIT**
 - **NOLOGIN** (must explicitly give `LOGIN` to user-level roles)

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A user-level role is a role that can log in to the database and issue commands. By default, when you create a new role without declaring any attributes, it is assigned the following permissions:

- **NOSUPERUSER** – No superuser (a superuser is someone who have complete permissions and privileges to everything – should be given with caution)
- **NOCREATEDB** – Cannot create databases
- **NOCREATEROLE** – Cannot create other roles
- **INHERIT** – Does inherit the permissions and privileges of the roles it's a member of
- **NOLOGIN** – No login capabilities (must explicitly give this to user accounts)

While you can create roles with `LOGIN` privileges using the `CREATE USER` command, this command is deprecated in PostgreSQL 8.1. The recommended method is to use the `CREATE ROLE` command. You can also use the Greenplum client, `createuser`, to create a role.

You may create nested roles, where a role is a parent to another role. However, you should not have nested users, or users who are parents to other roles.

Roles – Superusers

A superuser:

- Bypasses all permission checks
- Should not be used for daily administration

Create the following administrative roles to work with:

- SUPERUSER • CREATEROLE
- CREATEDB • PASSWORD



Note: It is good practice to create a role that has the CREATEDB and CREATEROLE privileges, but is not a superuser. Use this role for all routine management of databases and roles. This approach avoids the dangers of operating as a superuser for tasks that do not require it.

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A database superuser bypasses all permission checks.

This is a dangerous privilege and should not be used carelessly. It is best to do most of your work as a role that is not a superuser.

To accomplish this, complete the following tasks:

- Create a database superuser called SUPERUSER – Use the command `CREATE ROLE name SUPERUSER` to create a SUPERUSER role. You must do this as a role that is already a superuser.
- Create a role that can create databases – The new role must be explicitly given permission to create databases. To create such a role, use the command, `CREATE ROLE name CREATEDB`.
- Create a role that can create roles – A role must be explicitly given permission to create more roles. To create such a role, use `CREATE ROLE name CREATEROLE`.
- A role with CREATEROLE privilege can alter and drop other roles, too, as well as grant or revoke membership in them. However, to create, alter, drop, or change membership of a superuser role, superuser status is required; CREATEROLE is not sufficient for that.
- Assign a password – A password is only significant if the client authentication method requires the user to supply a password when connecting to the database. The password, md5, and crypt authentication methods make use of passwords. Database passwords are separate from operating system passwords. Specify a password upon role creation with `CREATE ROLE name PASSWORD 'string'`.

Common Role Attributes

Role Attribute	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. INHERIT is the default.
LOGIN NOLOGIN	Determines whether a role is allowed to log in. NOLOGIN is the default.
CONNECTION LIMIT <i>connlimit</i>	If role can log in, this specifies how many concurrent connections the role can make. -1 (the default) means no limit.

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The table lists common user attributes you use to enforce security.

Common Role Attributes (Cont)

Role Attribute	Description
PASSWORD <i>'password'</i>	Sets the role's password. 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).
VALID UNTIL <i>'timestamp'</i>	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 <i>queue_name</i>	Assigns the role to the named resource queue for workload management.

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Common Role Attributes (Continued)

SQL Commands for Roles

Use the following SQL commands and Greenplum applications to manage roles:

Action	SQL Syntax	Greenplum Application
Create a role	CREATE ROLE	createuser
Drop a role	DROP ROLE	dropuser
Alter a role	ALTER ROLE	

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You can use the SQL commands, CREATE ROLE, DROP ROLE, and ALTER ROLE to manage users. The Greenplum applications, createuser and drop user can also be used to manage roles. Only superusers with CREATEROLE privileges can create roles, and so these SQL commands or Greenplum applications must be invoked by a user role with appropriate privileges, such as the superuser role.

Roles and Privileges – Example

Example: Create roles with the LOGIN privilege

```
CREATE ROLE john WITH LOGIN;  
CREATE USER john;
```

Example: Change a role and assign it CREATEDB privileges

```
ALTER ROLE john WITH CREATEDB;
```

Example: Grant read access to the gphdfs protocol

```
GRANT SELECT ON PROTOCOL gphdfs TO john
```

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The first example on the slide shows two roles being created, both with login privileges.

The second example shows the ALTER ROLE command being used to change permission attributes for a user.

The last example has the SELECT access being granted to the role, john, so that the role can access it, such as when creating a read-only external table using the gphdfs protocol.

Role Membership or Groups

A role:

- Can be a member of other roles
- Inherits object privileges of the parent role
- Allows you to set object privileges in one place
- Will not inherit:
 - LOGIN
 - SUPERUSER
 - CREATEDB
 - CREATEROLE
- Can use `SET ROLE` to obtain privileges

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It is frequently convenient to group users together to ease management of permissions and privileges. This allows you to grant or revoke privileges for a group of users. In PostgreSQL this is done by creating a role that represents the group and granting membership in the group role to individual user roles.

The role attributes `LOGIN`, `SUPERUSER`, `CREATEDB`, and `CREATEROLE` are never inherited as ordinary privileges on database objects. Using the `SET ROLE` command, you must assign a role that already has these attributes defined.

In the example on the slide, the `admin` role is granted `CREATEDB` and `CREATEROLE` attributes. If the user `sally` is a member of the `admin` role, she can issue the following command to assume the role attributes of the parent role: `SET ROLE admin;`

Role Membership or Groups – Examples

To manage access to roles:

- Use GRANT command to grant membership
- Use REVOKE command to remove a member from a role



Example: Grant and revoke privileges

```
CREATE ROLE admin CREATEROLE CREATEDB;  
GRANT admin TO john, sally;  
REVOKE admin FROM bob;  
SET ROLE admin;
```

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Once the group role exists, you can add and remove members (user roles) using the GRANT and REVOKE commands. Those user roles then inherit the attributes and privileges of the parent role.

In the example shown, the `admin` role is assigned to two roles, `john` and `sally`. Both roles now inherit the `CREATEROLE` and `CREATEDB` privileges. In the last line of the example, the current session user has been changed to `admin`.

Object Privileges

Objects:

- Are owned by object creator
- Can be made accessible to other roles
- Can be made accessible to all through the `PUBLIC` role
- Are managed with `GRANT` and `REVOKE` commands
- Assigned to deprecated roles are managed with `DROP OWNED` and `REASSIGN OWNED`

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When an object, such as a table, is created, it is assigned to an owner. The owner is normally the role that created the object. This allows the role completely manage this object.

The owner role is given all privileges on that object and can assign privileges to other roles. The owner, or a superuser, are the only roles that can drop the object.

`PUBLIC` is a special predefined role that includes all roles, even ones that are created later.

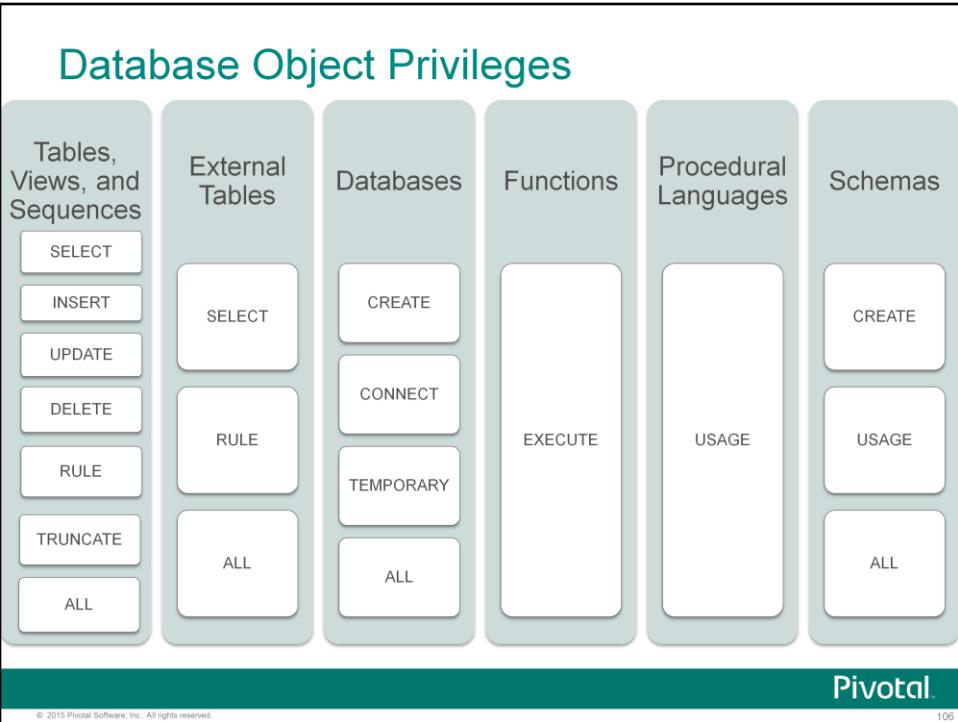
Use the following commands to manage objects owned by deprecated roles:

- `REASSIGN OWNED` reassigns all the objects in the current database that are owned by *old_role* to *new_role*. Note that it does not change the ownership of the database itself.
- `DROP OWNED` drops all the objects in the current database that are owned by one of the specified roles. Any privileges granted to the given roles on objects in the current database will also be revoked.

Note: Privileges are not passed down in inherited table structures from parent to child tables. Must be explicitly set on all tables.

You must grant access to an object if other users wish to use it. For managing object privileges, you grant the appropriate permissions to the group-level role only.

The member user roles then inherit the object privileges of the group role.



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These are the database objects and associated privileges that are relevant in Greenplum Database. Privileges may vary based on the object type. Privileges provide access rights to the named objects, allowing roles to read, access, or modify the object. Privileges are not hierarchical. For example granting **ALL** on a database does not include **ALL** on the tables in that database. Those privileges must be assigned individually.

Object Privileges – Examples

Example: Grant permissions to admin

```
GRANT ALL ON DATABASE  
mydatabase TO admin  
WITH GRANT OPTION;
```

Example: Assign all of one user's objects to another user

```
REASSIGN OWNED BY sally TO bob;
```

Example: Grant SELECT to PUBLIC

```
GRANT SELECT ON TABLE  
mytable TO PUBLIC;
```

Example: Drop all objects owned by visitor

```
DROP OWNED BY visitor;
```

Example: Remove INSERT and UPDATE

```
REVOKE INSERT UPDATE ON TABLE  
mytable FROM sally;
```

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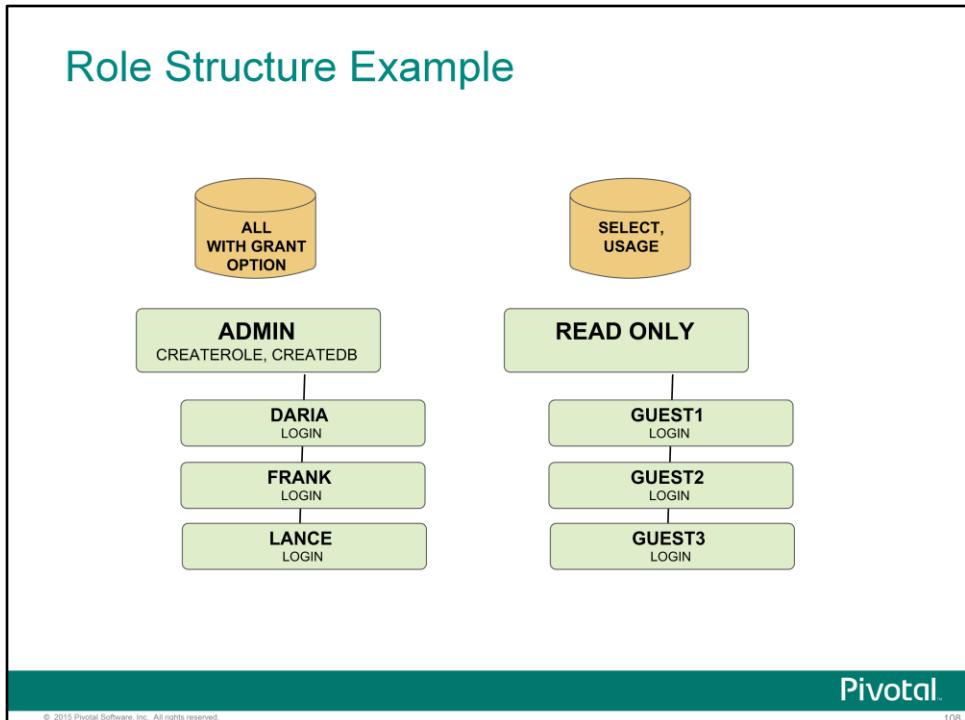
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Here are some examples of how to alter privileges for users and objects:

- In the first example, all privileges are granted to the user role, `admin`, for the database `mydatabase`. The `admin` role is also allowed to grant permissions to other roles for the specified database.
- The second example on the left side shows only `SELECT` privileges on the table, `mytable`, are granted to the role, `public`.
- The third example on the left side of the slide shows both `INSERT` and `UPDATE` permissions on the table, `mytable`, being revoked for the role, `sally`.
- The first example on the right side of the slide shows that all objects owned by one role, `sally`, are being reassigned to another role, `bob`.
- In the last example on the slide, all objects owned by the role, `visitor`, are removed from the database.

Role Structure Example



On this slide is an example of two role hierarchies you can define using the following specifications:

- The first is a top level role named `ADMIN` with permissions to create roles and databases.
- The second is a role called `read-only` with no create permissions.
- Each Group level role has login accounts associated with it. Note that the permission attributes are assigned at the parent level.
- Privileges are assigned at the parent-level role. For the admin role, you can assign all privileges to all database objects and also give the grant option so members of that role could grant privileges to other roles.
- For the read-only role, assign the `SELECT` privileges on tables. You can also assign `USAGE` on schemas.

System-level Security

Problems encountered with system security:

- Pessimistic model is used, so users do not have access to anything unless specifically assigned.
- Sharing accounts makes auditing difficult
- Users are tempted to run additional workloads on master node, such as ETL
- Once logged into the master, all other hosts are available since SSH keys are exchanged
- Network infrastructure is not under our control
- System administration is not under our control

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In system level security, the concern is about defining privileges for users who access the environment. Unauthorized users with access to the system increase their chances of gaining access to data.

Problems that are oftentimes encountered with securing a system include:

- Pessimistic model prevents users from having access to specific items unless specifically assigned. While there is a benefit in that, as roles are implemented at the system level, it can that a user is prevented from performing tasks to which they have been assigned.
- Account sharing can make auditing a difficult task. It is not easy to determine who did what, when, and who approved the action if one or two major accounts are used by multiple individuals.
- Users may be tempted to hog resources and run additional workloads on the master, including data loads through ETL. This can freeze other users out of resources until that action is completed.
- Once logged into the master, all other hosts are available to the user on the master node since SSH keys have been exchanged.
- Network security issues outside of the control of the database can have an adverse impact.
- Other system administration outside of the database can also have an adverse impact.

Database Security

Problems relating to database security include:

- `gpadmin` user has access to everything
- Pessimistic model is used; users do not have access to anything unless specifically assigned privileges
- Unless resource queues are configured, there are no limits on what users can run
- Default `pg_hba.conf` uses trust instead of enforcing passwords
- Customers are tempted to share user accounts

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Problems that are specifically associated with the database include the following:

- The superuser role created on database initialization has access to every aspect of the system. This can be dangerous particularly if the role is used for daily administration and is shared by multiple users.
- Pessimistic model usage in the database has benefits and detractors. By employing a pessimistic model, users do not have access until specifically assigned. However, if the correct privileges are not assigned, this can cause frustration and delay for that user.
- There are no limits on resources unless specifically configured. Once again, a user can hog resources and effectively, shut other users out of the database.
- The default configurations in the `pg_hba.conf` are loosely configured to use trust. This bypasses security measures that should be in place to require authentication from the connecting user.
- As with regular system-level security, users may be tempted to share user accounts. Users, or roles, can be defined for each user to protect their data. If multiple users share the same role, this reduces the chances of finding who had access to the system and to data.

Database Security – Roles

Roles can be used to enhance security with the following:

- Each person should have their own role
- Roles should be further divided into groups, which are usually roles that do not have the `LOGIN` attribute
- Privileges should be granted at the group level whenever possible
- Privileges should be as restrictive as possible
- Column level access can be accomplished with views
- Roles are not related to OS users or groups

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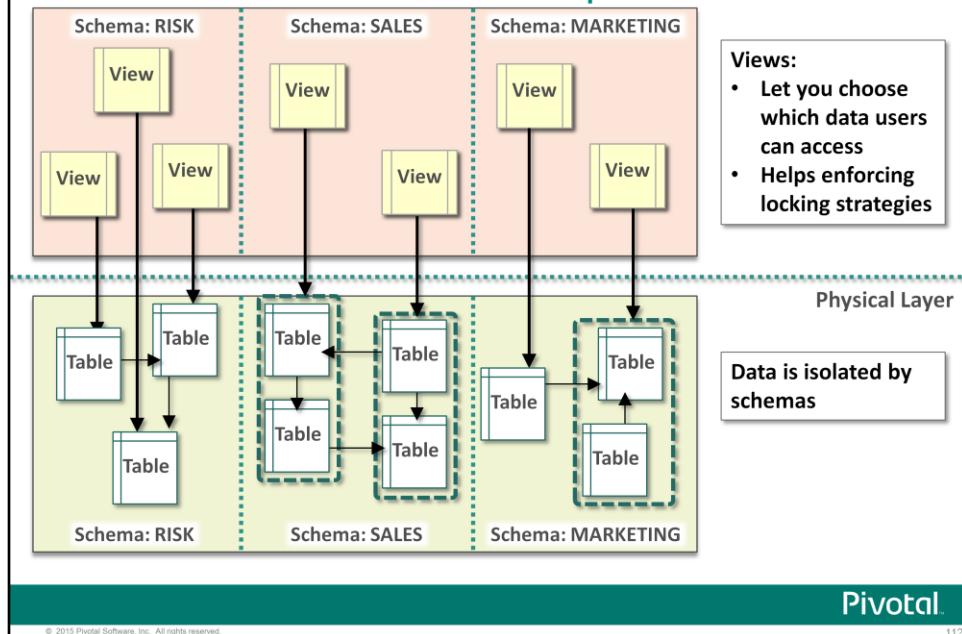
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You can implement the following rules to tighten security using roles:

- Roles are implemented at the system-level and are separate from operating system users. Each person that connects to the database should have their own role assigned to them. Users are roles with login attributes associated with the role. By assigning a role to each individual user, you increase the chances of properly auditing the system to ensure that the appropriate users have access to appropriate data. Application services should also be given a distinct role in the environment.
- Roles should be divided into groups to ease administration tasks. Groups represent role membership, where role is created and membership to that role is granted. The role can be assigned privileges which are inherited by members of the role. This makes it easier to assign privileges to users.
- By assigning privileges at the group level, you reduce the chances that an individual user may have a privilege that should have been revoked. You can also more quickly assign a group of privileges to users by adding them to the appropriate group.
- While the pessimistic model is in use, assigned privileges should be as restrictive as possible. Do not assign superuser privileges to a user who only needs to create roles.
- You can restrict access to data by implementing views instead of providing full access to tables.
- You can make it harder for someone to *guess* what a valid account is by removing the relationship between operating system users and groups to Greenplum roles. If you use the same names, you increase the chances that someone can guess role names.

Database Architecture – Separation and



Users are isolated at the physical layer through the use of views. By isolating users, you:

- Insulate users from changes made to tables
- Control access to columns and rows
- Enforce locking strategies

Data is isolated by separating functional areas into schemas. By doing this, you:

- Simplify security
- Simplify backups and restores to data

Security Example

The following is an example of user and role creation and assignment and how to use the roles to limit or grant privileges to user roles:

Example: Inherit privileges through nested roles

```
CREATE ROLE batch;
GRANT select, insert, update, delete
    ON dimensions.customer TO batch;
CREATE ROLE batchuser LOGIN;
GRANT batch TO batchuser;
```

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In this example:

- The newly created role, `batch` is granted `SELECT`, `INSERT`, `UPDATE`, and `DELETE` privileges on the table `dimensions.customer`.
- The role is not a user as it was not assigned the `LOGIN` attribute.
- The `batchuser` role is then created with the `LOGIN` attribute and granted access to the `batch` role.
- The user, `batchuser`, can now has the privileges assigned to the role, `batch`.
- The object that the role is given access to is fully qualified, indicating the role has access only to the `customer` table in the `dimensions` schema.

Greenplum Workload Management

Let us examine the following:

- What is workload management?
- How do you create resource queues?
- How do you assign roles to resource queues?
- What is the runtime evaluation of resource queues?
- What are resource queue configuration parameters?
- How do you view the status of resource queues?

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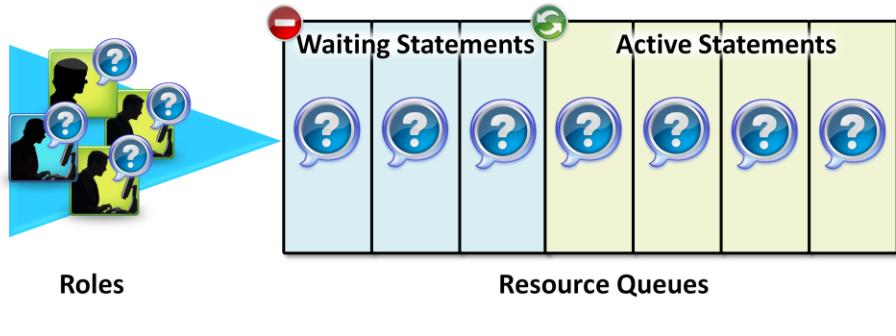
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In this next section, you examine workload and resource management, a feature that gives you the ability to more closely limit the number of active queries in the system at any given time.

Workload Management Overview

Workload management:

- Is used to limit the number of active queries
- Is meant to prevent overloading of system resources
- Looks at resource allocation from statement-level point-of-view



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The purpose of Greenplum Database 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 by creating 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.

By assigning all of your database roles to the appropriate resource queue, administrators can control concurrent user queries and prevent the system from being overloaded.

Administrators create resource queues for the various types of workloads in their organization. For example, you may have a resource queue for power users, web users, and management reports. The administrator would then set limits on the resource queue based on his estimate of how resource-intensive the queries associated with that workload are likely to be. Database roles, which include users and groups, are then assigned to the appropriate resource queue. A resource queue can have multiple roles, but a role can only be assigned to a single resource queue.

Starting with Greenplum 4.1, the Greenplum memory management system looks at allocating memory and CPU resources not from an operator or user point of view, but instead from the statement level point of view.

Configurable Limits on a Queue

Active Statement Count

This parameter determines query entry into the system to actively run.

The maximum number of queries executing in the active queue is limited by the `active_statements` limit.

Active Statement Memory

This parameter determines resources allocated to the query.

Each query submitted to the queue will be given a portion of the memory. This amount is based on the amount of queries that can run in the queue or the cost of the query.

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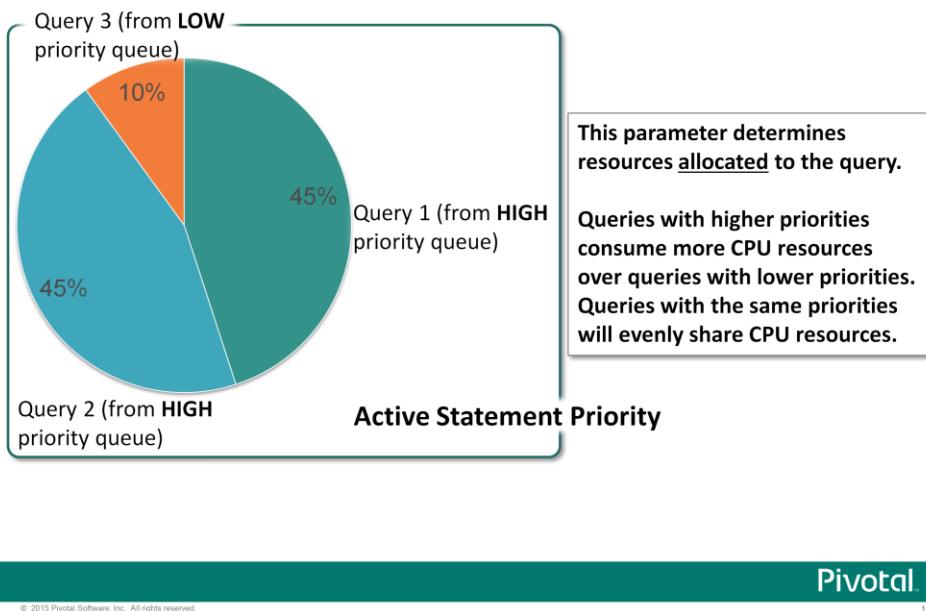
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Resource queues can be created to address different types of workloads, such as workloads for power users, web users, and management reports. A queue for a web user may be fast and require very little resources, whereas the workload for management reports may be more intensive, requiring more resources, such as memory.

You can set limits on a queue using the following configurable limits:

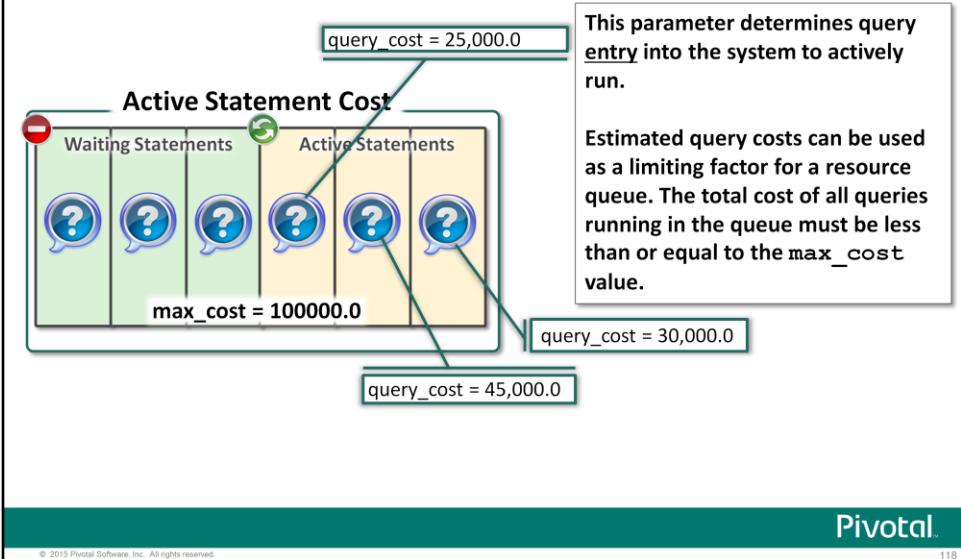
- **Active statement count** – This limit allows you to set the maximum number of statements that can run concurrently. The total number of queries running in a resource queue with an active statement limitation must be less than or equal to the defined ceiling. If the maximum number of queries are running, an additional query that enters the queue must wait for one of the active queries to complete before being allowed to execute on the system.
- **Active statement memory** – The active statement memory limit lets you set the total amount of memory that all queries assigned to the resource queue can consume. No additional memory will be allocated to the queue once the maximum has been reached and each query is allocated the same amount of memory, which is the total available memory divided by the number of active queries. It is recommended you use this limit in conjunction with the active statement count limit.

Configurable Limits on a Queue (Cont)



- **Active statement priority** – The active statement priority queue lets you define the relative priority of the queue to other queues in terms of available CPU resources. All queries entering the queue are given the same priority. If the priority of one resource queue is higher than the priority on another resource queue, the higher priority queue will consume more CPU resources.

Configurable Limits on a Queue (Cont)



- **Active statement cost** – The query planner estimates a cost for each query submitted. You can set the maximum query planner cost for a resource queue, limiting the number of queries that can enter the queue by the total cost of all queries in the queue. The cost is measured in units of disk page fetches, where 1.0 is equal to one sequential disk page read.

Creating Resource Queues

To create resource queues and manage thresholds, use the following commands:

Action	SQL Syntax
Create or alter a resource queue	<code>CREATE ALTER RESOURCE QUEUE <i>name</i> WITH (MAX_COST=<i>n</i> ACTIVE_STATEMENTS=<i>n</i> [, COST_OVERCOMMIT] [,MIN_COST=<i>n</i>] [,MEMORY_LIMIT='<i>nM GB</i>'] [,PRIORITY=<i>level</i>])</code>
Drop a resource queue	<code>DROP RESOURCE QUEUE <i>name</i></code>

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Greenplum has added the SQL commands `CREATE RESOURCE QUEUE`, `ALTER RESOURCE QUEUE`, `DROP RESOURCE QUEUE` which you will use to create and manage the limits of your resource queues. Queries gain entry into the system so that they can actively run with the following resource queue limits:

- **ACTIVE_STATEMENTS** – Limits the number of queries that can be executed by roles assigned to that queue.
- **MAX_COST** – Limit the total size of queries that can be executed by roles assigned to that queue based on query cost. Cost is measured in the estimated total cost for the query as determined by the Greenplum query planner. 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.

The following additional settings can be used in conjunction with `ACTIVE_STATEMENTS` and `MAX_COST` to determine how much resources queries receive once they are actively running:

- **MEMORY_LIMIT** – Setting this limit sets the total memory quota for all queries within the resource queue. Each query is allocated a pre-determined amount of memory.

Creating Resource Queues (Continued)

- **COST_OVERCOMMIT** – Queries that exceed the cost threshold can continue executing, provided there are no other queries in the system at the time the query is submitted.
- **MIN_COST** – The query cost limit of what is considered a small query. Queries with a cost under this limit will not be queued but will instead run immediately.
- **PRIORITY** – The priority does not determine which queries enter the active queue, but instead decides how much CPU resources the query receives. Queries with higher priority receive a larger share of available CPU resources, decreasing the CPU resources available to any in-flight queries with lower priorities.

Managing CPU Utilization with Priorities

Priorities:

- Control a resource queue's consumption of resources
- Are managed with the following SQL commands:

Action	SQL Syntax
Create a resource with a specific priority	<code>CREATE RESOURCE QUEUE name WITH (PRIORITY=level)</code>
Alter a resource queue to have a specific priority	<code>ALTER RESOURCE QUEUE name WITH (PRIORITY=level)</code>
<ul style="list-style-type: none">• Can be one of the following:<ul style="list-style-type: none">— MIN— HIGH— LOW— MAX— MEDIUM (default setting if not specified)	

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To control a resource queue's consumption of available CPU resources, you 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`.

You can assign priorities with the following levels:

- **MIN** – This is the lowest possible priority setting for a resource queue.
- **LOW** – At one time, the lowest possible available setting, resource queues with this level consume greater CPU resources than those with a level of **MIN**.
- **MEDIUM** – This is the default level and is automatically assigned when a `PRIORITY` is not defined for the resource queue.
- **HIGH** – Queries with this setting take precedence over those assigned to **MEDIUM** or **LOW** resource queues.
- **MAX** – This is the highest level that can be assigned to a resource queue. Queries with this setting take precedence over all others.

Managing Memory Allocation with Memory Limits

Query memory allocation is controlled with:

- `MEMORY_LIMIT` parameter for the resource queue:

Action	SQL Syntax	Memory Allocation per Query
Create or alter a resource with a specific memory limit and maximum number of statements	<code>CREATE ALTER RESOURCE QUEUE <i>name</i> WITH (ACTIVE_STATEMENTS = <i>x</i>, MEMORY_LIMIT='<i>xxxM GB</i>')</code>	<code>MEMORY_LIMIT / ACTIVE_STATEMENTS</code>
Create or alter a resource queue to have a specific memory limit with <code>MAX_COST</code> defined	<code>CREATE ALTER RESOURCE QUEUE <i>name</i> WITH (MAX_COST = <i>x.x</i>, MEMORY_LIMIT='<i>xxxM GB</i>')</code>	<code>MEMORY_LIMIT * (query_cost / MAX_COST)</code>

- At the database level with `statement_mem` and `max_statement_mem`

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Memory can be controlled both within a resource queue as well as at the database level.

For a resource queue, a maximum amount of memory is allocated to the queue with the `MEMORY_LIMIT` parameter and value as part of the `CREATE RESOURCE QUEUE` command. The value specified can be in Megabytes or Gigabytes.

Each query is allocated a certain amount of memory depending on how the queue is configured:

- If the resource queue is created with memory limits and `ACTIVE_STATEMENTS` set to a specified value, each query will be allocated an equal amount of memory. The memory allocated is determined by the `MEMORY_LIMIT` value divided by the `ACTIVE_STATEMENTS` value.
- If the resource queue is created with memory limits and `MAX_COST` set to a specified floating value, the query is allocated memory based on the formula, `MEMORY_LIMIT * (query_cost / MAX_COST)`.

The resource queue allocation can be overridden by the use of the `statement_mem` server configuration parameter. A query submitted to the environment after `statement_mem` is set will be allocated the amount of memory defined in `statement_mem`, as long as the amount allocated is less than the value defined in `max_statement_mem`.

One thing to note, the memory limit defined across all resource queues must be less than the total physical memory available to a segment host.

Creating Resource Queues – Examples

Example: Create a resource queue with up to 3 active queries

```
CREATE RESOURCE QUEUE adhoc WITH  
(ACTIVE_STATEMENTS=3);
```

Example: Create a resource queue with a planner cost limit

```
CREATE RESOURCE QUEUE webuser WITH  
(MAX_COST=100000.0);
```

Example: Create a resource queue with a minimum cost limit

```
CREATE RESOURCE QUEUE adhoc WITH  
(ACTIVE_STATEMENTS=10, MIN_COST=100.0);
```

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In the first example, 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.

In the second example, a resource queue named `webuser` is created with a query cost limit of `100000.0` (`1e+5`). For all roles assigned to the `webuser` resource queue, it will only allow queries into the system until the planner cost limit of `100000.0` is reached. 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.

In the third example, any queries that fall below the defined `MIN_COST` limit will run immediately. The restriction of ten active queries still applies however.

Assigning Roles to Resource Queries

Resource queues:

- Must be assigned at the user-level (group-level ignored)
- Do not affect superuser roles
- Are managed with the following SQL commands:

Action	SQL Syntax
Add a resource queue to a role	<code>ALTER ROLE role_name RESOURCE QUEUE queue_name;</code>
Create a role and assign it to a resource queue	<code>CREATE ROLE role_name WITH LOGIN RESOURCE QUEUE queue_name;</code>



Note: All users are assigned to a resource queue, even if one is not specified. The default resource queue is `pg_default`.

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Currently resource queues must be assigned on a user-by-user basis. If you have a role hierarchy such as a group-level role, then assigning a resource queue to the group does not propagate down to the users.

All superuser roles are exempt from resource queue limits. Even if you assign a superuser role to a resource queue, their queries will always run regardless of restrictions defined for the resource queue.

To assign a user to a resource queue use the `CREATE ROLE` and `ALTER ROLE` commands. A user role can only be assigned to one resource queue.

Runtime Evaluation of Resource Queues

For runtime evaluation:

- Resource queues are evaluated independently of each other
- Superusers (and unassigned roles) are exempt
- Queries are evaluated on first-in, first-out basis

If a query causes the queue to exceed its limits:

- Query must wait until queue resources are free
- Query must wait until queue is idle (`COST_OVERCOMMIT=TRUE`)
- Query will never run (`COST_OVERCOMMIT=FALSE`)

Evaluated SQL statements include:

- `SELECT`, `SELECT INTO`, `CREATE TABLE AS SELECT`, `DECLARE CURSOR`
- (optional) `INSERT`, `UPDATE`, `DELETE`

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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, such as 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 execute. If the queue is idle however, and `COST_OVERCOMMIT` is set to true, a query that exceeds the `MAX_COST` will be allowed to run. If `COST_OVERCOMMIT` is set to false, the query will never execute.

Queries submitted through a queue are evaluated and executed on a first in, first out basis.

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.

Resource Queue Configuration Parameters

The following parameters are used to configure resource queues:

Configuration Parameter	Default Value	Description
max_resource_queues	9	The maximum number of resource queues in the system
max_resource_portals_per_transaction	64	The maximum number of open cursors per transaction
resource_select_only	on	Determines which queries are managed by resource queues
stats_queue_level	off	Enables the collection of statistics on resource queue usage
resource_cleanup_gangs_on_wait	on	Clean up idle segment worker processes

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Here are the parameters for resource queues shown with their defaults. All of these must be set in the master postgresql.conf and require server restart to take effect:

- **max_resource_queues** — This parameter sets the maximum number of resource queues that can be created in a Greenplum Database system. Note that resource queues are system-wide (as are roles) so they apply to all databases in the system.
- **max_resource_portals_per_transaction** — This parameter 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** — This parameter sets the types of queries managed by resource queues. 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.
- **stats_queue_level** — Setting this parameter to on enables the collection of statistics on resource queue usage, which can then be viewed by querying the pg_stats_resqueue system view. This is set to off by default.
- **resource_cleanup_gangs_on_wait** — Setting this parameter cleans up idle segment worker processes before taking a slot in the resource queue.

Memory Utilization System Parameters

Configuration Parameter	Default Value	Description
gp_resqueue_memory_policy	eager_free	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
statement_mem max_statement_mem	125 (MB) 2000 (MB)	statement_mem: Allocates segment host memory per query max_statement_mem: Sets the maximum memory limit for a query. (seghost_physical_memory) / (average_number_concurrent_queries)
gp_vmem_protect_limit	8192 (MB)	Upper memory boundary that all query processes can consume on a segment host
gp_vmem_idle_resource_timeout	18000 (Milliseconds)	If database session is idle for longer than the time specified, the session will free system resources (such as shared memory), but remain connected to the database
gp_vmem_protect_segworker_cache_limit	500 (MB)	If a query executor process consumes more than this configured amount, then the process will not be cached for use in subsequent queries after the process completes

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The following parameters determine how memory is utilized at the database level:

- **gp_resqueue_memory_policy** – The parameter enables Greenplum memory management features, where memory management is done at the statement level instead of at the operator level. The parameter can be set to `auto`, `off`, or `eager_free`. If set to `auto` or `eager_free`, the new memory management system will be used. Otherwise, if set to `none`, the system prior to Greenplum Database 4.1 will be used.
- **statement_mem and max_statement_mem** – These parameters are used to both allocate memory to a query and set the maximum amount of memory that can be allocated. Once the `statement_mem` parameter has been set, any queries executed after will ignore the resource queue settings for memory allocation and use this set value.
- **gp_vmem_protect_limit** – The parameter sets the upper boundary that all query processes can consume on a segment host. Queries that cause this limit to be exceeded will be cancelled. This parameter must be set at the local level for each segment instance.
- **gp_vmem_idle_resource_timeout and gp_vmem_protect_segworker_cache_limit** – These two parameters are used to free memory on segments held by idle database processes. The first parameter sets the resource timeout value in milliseconds while the second sets the cache size in megabytes. If the second parameter is exceeded, the process that exceeded the cache will not be cached for subsequent queries.

Viewing Status of Resource Queues

The following query system tables provide insight into resource queues:

System Table	Description
pg_resqueue	Resource queues and attributes
gp_toolkit.gp_resq_role	Role to resource queue assignments
pg_roles	
pg_locks	Queues that have waiting statements
pg_stat_activity	Process information about active and waiting queries

To view queue status and statistics, access the following tables:

System Table	Description
gp_resqueue_status	Queue limits, number of active and waiting queries
pg_resqueue_status	
pg_stat_resqueues	Queue statistics and performance over time

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Currently there is no management interface for workload management and resource queues. To see status information about resource queues, you'll have to query and join these system tables. Your training guides have sample queries for finding out certain information about resource queues. You may want to save these queries as VIEWS in your production Greenplum Database system. Several system tables from the gp_toolkit or pg_catalog schemas are available to track resource queue behavior and activity.

The pg_resqueue_status system 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.

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_stats_resqueue 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.

Lab: Roles, Privileges, and Resources

In this lab, you create and manage roles for the Greenplum Database. You create resource queues to manage the workload in the Greenplum Database system.

You will:

- Create roles that are users and roles that are groups
- Grant privileges on database objects to a group-level role
- Create a resource queue and assign a user role to this resource queue

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In this lab, you create and manage roles for the Greenplum Database. You also create resource queues to manage the workload in the Greenplum Database system. You also implement security measures to tighten access privileges in the Greenplum Database.

Lab: Controlling Access

In this lab, you create users and groups to control the level of access that users receive.

You will:

- Implement basic security at the group level

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In this lab, you create and manage roles for the Greenplum Database. You also create resource queues to manage the workload in the Greenplum Database system. You also implement security measures to tighten access privileges in the Greenplum Database.

Module 4: Defining and Securing the User Database

Lesson 3: Summary

During this lesson the following topics were covered:

- Roles and privileges
- Role assignment to object privileges
- Security issues that can affect your database and corresponding data
- Creating roles with specific privileges to control access
- Isolating users at the physical and functional layers
- Workload management process

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This lesson covered the roles and privileges assigned to roles to protect sensitive data from unauthorized roles and groups. Administrators can assign specific privileges to individual roles or group roles, where the privileges are inherited by users within those group roles. Additionally, workload management lets you assign resource profiles to roles. This allows users to share resources, reducing the chances that queries will be starved out of resources.

Module 4: Summary

Key points covered in this module:

- Identified and managed database objects available in the Greenplum Database
- Used data manipulation language and data query language to access, manage, and query data
- Managed workload management processes by defining and managing roles, privileges, and resource queues
- Implemented system-level and database-level security

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Listed are the key points covered in this module. You should have learned to:

- Identify and manage database objects available in the Greenplum Database.
- Use data manipulation language and data query language to access, manage, and query data.
- Manage workload management processes by defining and managing roles, privileges, and resource queues.
- Implement system-level and database-level security in the Greenplum Database.