GaussDB

Distributed Edition Feature Guide

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Contents

1 Materialized View

A materialized view is a special physical table, which is relative to a common view. A common view is a virtual table and has many application limitations. Any query on a view is actually converted into a query on an SQL statement, and performance is not actually improved. The materialized view actually stores the results of the statements executed by the SQL statement, and is used to cache the results.

1.1 Full Materialized View

1.1.1 Overview

Full materialized views can be fully refreshed only. The syntax for creating a full materialized view is the same as the CREATE TABLE AS syntax. You cannot specify a NodeGroup to create a full materialized view.

1.1.2 Usage

Syntax

- Create a full materialized view.
  ```
  CREATE MATERIALIZED VIEW [ view_name ] AS { query_block };
  ```
- Refresh a complete-refresh materialized view.
  ```
  REFRESH MATERIALIZED VIEW [ view_name ];
  ```
- Delete a materialized view.
  ```
  DROP MATERIALIZED VIEW [ view_name ];
  ```
- Query a materialized view.
  ```
  SELECT * FROM [ view_name ];
  ```

Examples

```
-- Prepare data.
CREATE TABLE t1(c1 int, c2 int);
INSERT INTO t1 VALUES(1, 1);
INSERT INTO t1 VALUES(2, 2);

-- Create a full materialized view.
gaussdb=# CREATE MATERIALIZED VIEW mv AS select count(*) from t1;
CREATE MATERIALIZED VIEW
```

```
-- Query the materialized view result.
gaussdb=# SELECT * FROM mv;
 count
-------
     2
(1 row)

-- Insert data into the base table in the materialized view again.
gaussdb=# INSERT INTO t1 VALUES(3, 3);

-- Fully refresh a full materialized view.
gaussdb=# REFRESH MATERIALIZED VIEW mv;
REFRESH MATERIALIZED VIEW

-- Query the materialized view result.
gaussdb=# SELECT * FROM mv;
 count
-------
     3
(1 row)

-- Delete a materialized view.
gaussdb=# DROP MATERIALIZED VIEW mv;
DROP MATERIALIZED VIEW
```

1.1.3 Support and Constraints

Supported Scenarios

- Generally, the query scope supported by full materialized views is the same as that supported by the CREATE TABLE AS statement.
- The distribution column can be specified when a full materialized view is created.
- Indexes can be created in a full materialized view.
- ANALYZE and EXPLAIN are supported.

Unsupported Scenarios

- Full materialized views do not support node groups.
- Materialized views cannot be added, deleted, or modified. Only query statements are supported.

Constraints

- The base table used to create a full materialized view must be defined on all DNs, and the node group to which the base table belongs must be an installation group.
- When a full materialized view is refreshed or deleted, a high-level lock is added to the base table. If the definition of a materialized view involves multiple tables, pay attention to the service logic to avoid deadlock.

1.2 Incremental Materialized View

1.2.1 Overview

Fast-refresh materialized views can be incrementally refreshed. You need to manually execute statements to incrementally refresh materialized views in a period of time. The difference between the incremental and the full materialized views is that the incremental materialized view supports only a small number of scenarios. Currently, only base table scanning statements or UNION ALL can be used to create materialized views.

1.2.2 Usage

Syntax

- Create a fast-refresh materialized view.
  ```
  CREATE INCREMENTAL MATERIALIZED VIEW [ view_name ] AS { query_block };
  ```
- Fully refresh a materialized view.
  ```
  REFRESH MATERIALIZED VIEW [ view_name ];
  ```
- Incrementally refresh a materialized view.
  ```
  REFRESH INCREMENTAL MATERIALIZED VIEW [ view_name ];
  ```
- Delete a materialized view.
  ```
  DROP MATERIALIZED VIEW [ view_name ];
  ```
- Query a materialized view.
  ```
  SELECT * FROM [ view_name ];
  ```

Examples

```
-- Prepare data.
CREATE TABLE t1(c1 int, c2 int);
INSERT INTO t1 VALUES(1, 1);
INSERT INTO t1 VALUES(2, 2);

-- Create a fast-refresh materialized view.
gaussdb=# CREATE INCREMENTAL MATERIALIZED VIEW mv AS SELECT * FROM t1;
CREATE MATERIALIZED VIEW

-- Insert data.
gaussdb=# INSERT INTO t1 VALUES(3, 3);
INSERT 0 1

-- Incrementally refresh a materialized view.
gaussdb=# REFRESH INCREMENTAL MATERIALIZED VIEW mv;
REFRESH MATERIALIZED VIEW

-- Query the materialized view result.
gaussdb=# SELECT * FROM mv;
 c1 | c2
----+----
  1 |  1
  2 |  2
  3 |  3
(3 rows)

-- Insert data.
gaussdb=# INSERT INTO t1 VALUES(4, 4);
INSERT 0 1

-- Fully refresh a materialized view.
gaussdb=# REFRESH MATERIALIZED VIEW mv;
REFRESH MATERIALIZED VIEW

-- Query the materialized view result.
gaussdb=# select * from mv;
 c1 | c2
----+----
  1 |  1
  2 |  2
  3 |  3
```

```
  4 |  4
(4 rows)

-- Delete a materialized view.
gaussdb=# DROP MATERIALIZED VIEW mv;
DROP MATERIALIZED VIEW
```

1.2.3 Support and Constraints

Supported Scenarios

- Supports statements for querying a single table.
- Supports UNION ALL for querying multiple single tables.
- Creates an index in the materialized view.
- Performs the Analyze operation in the materialized view.
- Creates an incremental materialized view based on the node group of base tables. (Check whether the base tables are in the same node group and create the incremental materialized view based on the node group).

Unsupported Scenarios

- Materialized views do not support the Stream plan, multi-table join plan, or subquery plan.
- Except for a few ALTER operations, most DDL operations cannot be performed on base tables in materialized views.
- A distribution column of a materialized view cannot be specified when the materialized view is created.
- Materialized views cannot be added, deleted, or modified. Only query statements are supported.
- Materialized views cannot be created using the temporary table, hash bucket, unlog, or partitioned table. Only the hash distribution table is supported.
- Materialized views cannot be created in nested mode (that is, a materialized view cannot be created in another materialized view).
- The column-store tables are not supported. Only row-store tables are supported.
- Materialized views of the UNLOGGED type are not supported, and the WITH syntax is not supported.

Constraints

- If the materialized view is defined as UNION ALL, each subquery must use a different base table and the distribution column of each base table must be the same. The distribution column of the materialized view is automatically deduced and is the same as that of each base table.
- The columns defined in the materialized view must contain all distribution columns in the base table.
- When an incremental materialized view is created, fully refreshed, or deleted, a high-level lock is added to the base table. If the materialized view is defined as UNION ALL, pay attention to the service logic to avoid deadlock.

2 Setting Encrypted Equality Queries

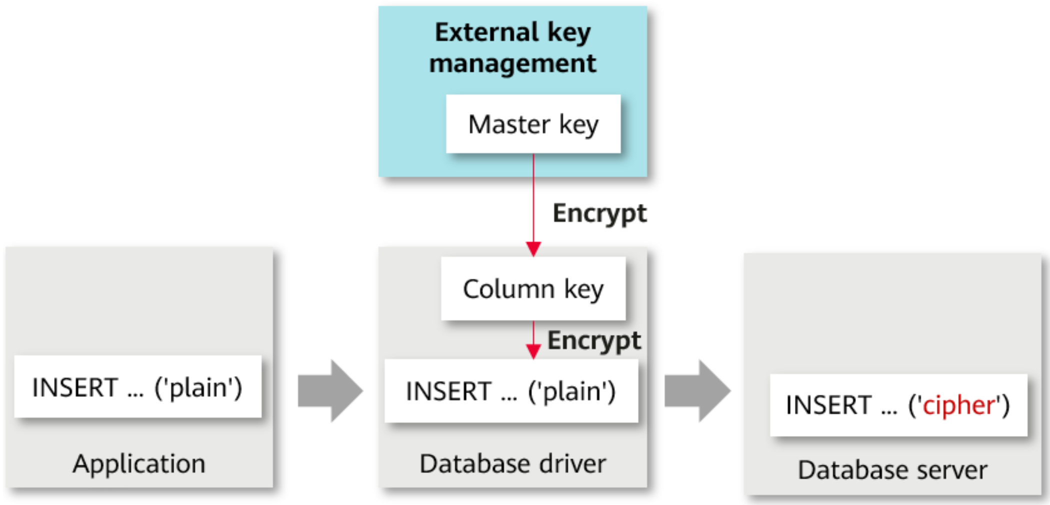
2.1 Overview

As enterprise data is migrated to the cloud, data security and privacy protection are facing increasingly severe challenges. The encrypted database will solve the privacy protection issues in the entire data lifecycle, covering network transmission, data storage, and data running status. Furthermore, the encrypted database can implement data privacy permission separation in a cloud scenario, that is, separate data owners from data administrators in terms of the read permission. The encrypted equality query is used to solve equality query issues of ciphertext data.

Encrypted Model

A fully-encrypted database uses a multi-level encrypted model. The functions of keys in different encryption scenarios are as follows:

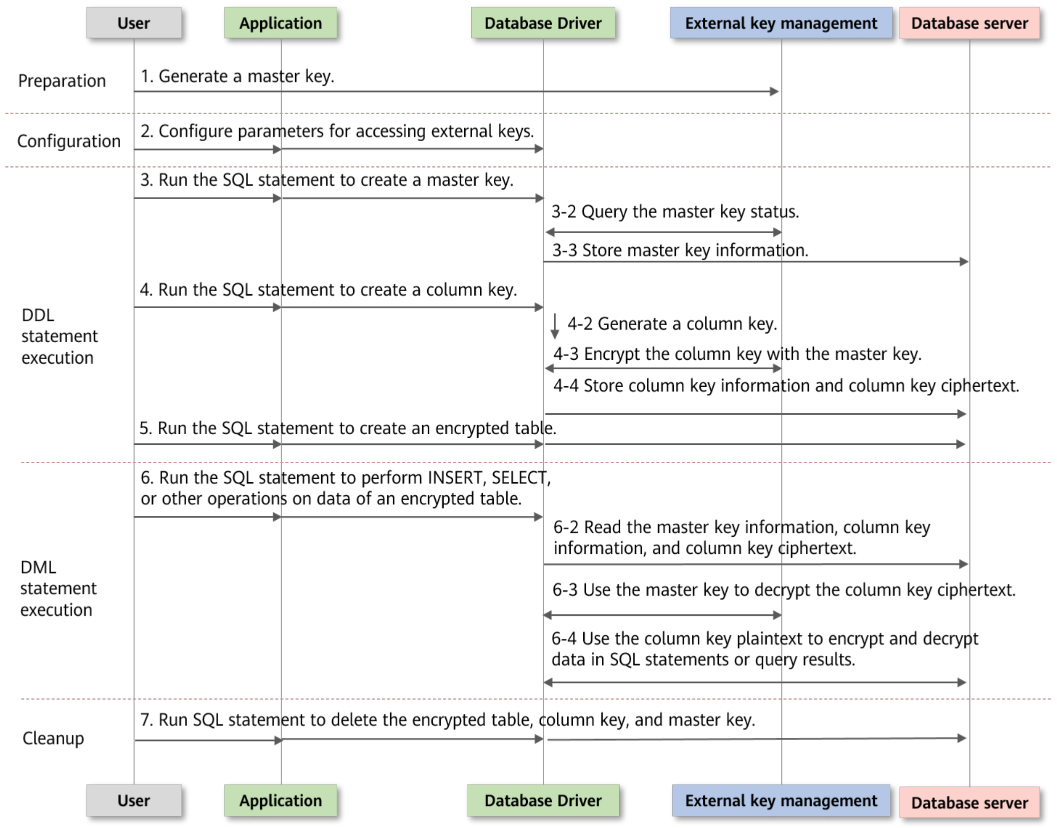
- Data: The encrypted database encrypts data of an encrypted column in SQL statements and decrypts the query result of the encrypted column returned by the database server.
- Column key: Data is encrypted by a column key, and the column key is encrypted by a master key. The column key ciphertext is stored on the database server.
- Master key: It is generated and stored in the external key management service. The database driver automatically accesses the external key management service to encrypt and decrypt column keys.



Overall Process

The process of using a fully-encrypted database consists of the following five phases. This section describes the overall process. **Using gsql to Operate an Encrypted Database** and **Using JDBC to Operate an Encrypted Database** describe the detailed process.

1. Preparation phase: First, you need to generate a master key in the external key management service. External key management services include Huawei Cloud key management service, and gs_ktool key management tool. Select one of them as required.
2. Configuration phase: In an application, environment variables or database driver parameters are used to set information for accessing external key management service. In subsequent operations, the database driver needs to use the configuration information in this phase to access external key management service.
3. DDL statement execution phase: In this phase, you need to use the key syntax of the encrypted database to define a master key and a column key, define a table, and specify a column in the table as an encrypted column.
4. DML statement execution phase: After an encrypted table is created, you can directly execute syntax including but not limited to INSERT, SELECT, UPDATE, and DELETE. The database driver automatically encrypts and decrypts data of the encrypted column based on the encryption definition in the previous phase.
5. Cleanup phase: You can delete the encrypted table, column key, and master key in sequence.

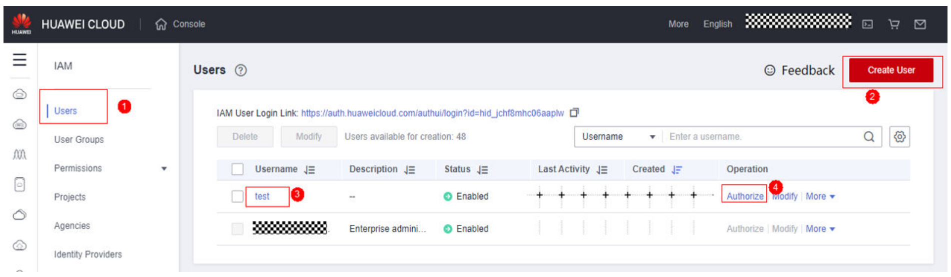

User
Application
Database Driver
External key management
Database server
Preparation
1. Generate a master key.
Configuration
2. Configure parameters for accessing external keys.
3. Run the SQL statement to create a master key.
3-2 Query the master key status.
3-3 Store master key information.
DDL statement execution
4. Run the SQL statement to create a column key.
4-2 Generate a column key.
4-3 Encrypt the column key with the master key.
4-4 Store column key information and column key ciphertext.
5. Run the SQL statement to create an encrypted table.
6. Run the SQL statement to perform INSERT, SELECT, or other operations on data of an encrypted table.
DML statement execution
6-2 Read the master key information, column key information, and column key ciphertext.
6-3 Use the master key to decrypt the column key ciphertext.
6-4 Use the column key plaintext to encrypt and decrypt data in SQL statements or query results.
Cleanup
7. Run SQL statement to delete the encrypted table, column key, and master key.
User
Application
Database Driver
External key management
Database server

Preparation Phase

If you use the encrypted database for the first time, you need to perform the preparation. The next time you use the database, you can skip this phase.

The encrypted database can use different external keys to manage the master key. Select one of them as required.

- Huawei Cloud scenario
  a. Open the Huawei Cloud official website (**https://www.huaweicloud.com/intl/en-us/**), register an account, and log in to the system.
  b. Search for **Identity and Access Management (IAM)** on Huawei Cloud. On the page that is displayed, click **Users**, create an IAM user, set the IAM password for the IAM user, and grant the data encryption workshop (DEW) permission to the new IAM user.



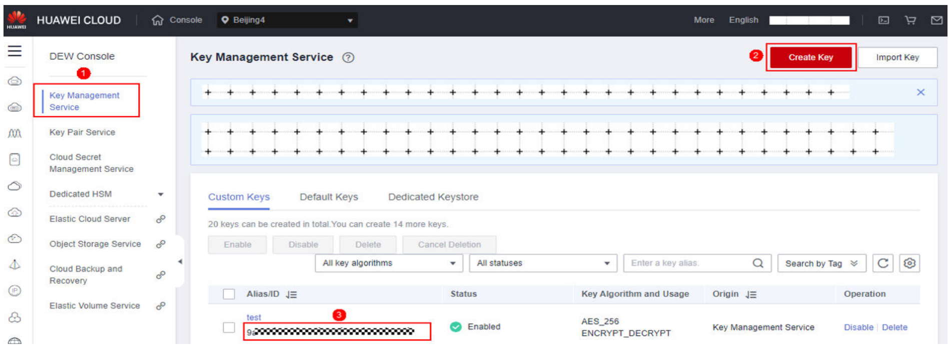
IAM User Login Link: https://auth.huaweicloud.com/authui/login?id=hid_jchf8mhc06aaplw

Users available for creation: 48

Username	Description	Status	Last Activity	Created	Operation
test	--	Enabled	[redacted]	[redacted]	Authorize | Modify | More
[redacted]	Enterprise admini...	Enabled			Authorize | Modify | More

  c. Go back to the login page, click **IAM User**, and log in to the system as the newly created IAM user. The subsequent operations are performed by the IAM user.

d. Search for **Data Encryption Workshop** on Huawei Cloud. On the page that is displayed, click **Key Management Service** and click **Create Key** to create a key. After the key is created, you can see that each key has a key ID. Remember the key ID, which will be used when you create a master key in the DDL statement execution phase.



20 keys can be created in total.You can create 14 more keys.

e. The key generated in this step is the master key used in the encrypted database. The key is stored in Huawei Cloud key management service. When SQL statements related to encryption and decryption are executed, the database driver automatically accesses the key through the RESTful API of Huawei Cloud. For details about RESTful APIs, visit **https://www.huaweicloud.com/intl/en-us/product/dew.html**

- gs_ktool scenario

  a. Search for the **GaussDB-Kernel_***Database version number*_*OS version number*_**64bit_Gsql.tar.gz** installation package from the database installation package.

  b. Decompress the installation package and find the **gsql_env.sh** file that contains the commands for configuring environment variables. Run the following command to create a key. After the key is created, you can see that each key has a key ID.

```
# 1. Configure environment variables using a script.
[terminal] # source gsql_env.sh

# 2. Use the key management service tool gs_ktool to generate a key. After the key is
generated, the key ID is returned. The key ID starts from 1 and increases by 1 each time a key is
created.
[terminal] # gs_ktool -g
GENERATE
1
```

  c. The key generated in this step is the master key used in the encrypted database. The key is stored in gs_ktool. When SQL statements related to encryption and decryption are executed, the database driver accesses the key through the dynamic or static library. For details about how to use gs_ktool, see "Client Tools > gs_ktool" in *Tool Reference*.

Configuration Phase

Configuring Parameters for Accessing External Keys

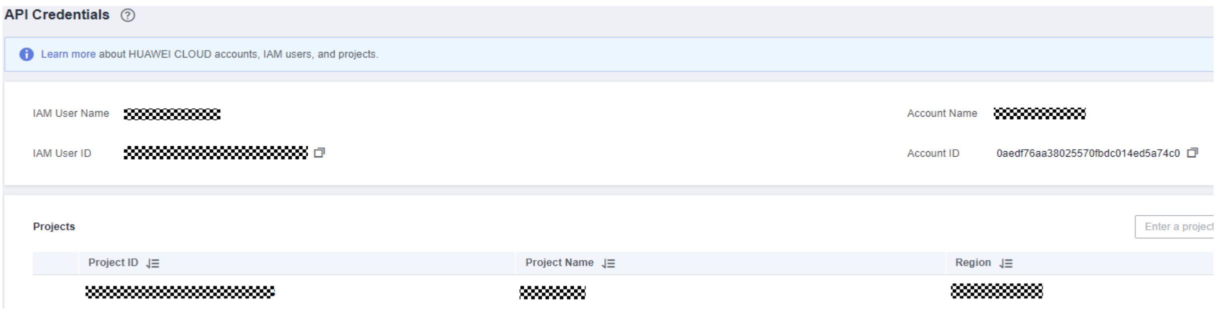
- Huawei Cloud scenario

  Configure the following information through environment variables.

```
[terminal] # export HUAWEI_KMS_INFO='iamUrl=https://iam.{Project}.myhuaweicloud.com/v3/auth/
tokens, iamUser={IAM user name}, iamPassword={IAM user key}, iamDomain={Account name},
kmsProject={Project}'
```

On the Huawei Cloud management console, click the user name in the upper right corner and go to the **API Credentials** page. On this page, you can obtain the required parameters, including project, IAM user name, and account name. Remember the project ID on this page, which will be used when you create a master key in the DDL statement execution phase.

Figure 2-1 Obtaining parameters on the Huawei Cloud page



API Credentials

Learn more about HUAWEI CLOUD accounts, IAM users, and projects.

IAM User Name [redacted]

Account Name [redacted]

IAM User ID [redacted]

Account ID 0aedf76aa38025570fbdc014ed5a74c0

Projects

Enter a project

Project ID	Project Name	Region
[redacted]	[redacted]	[redacted]

```
# Example
[terminal] # export HUAWEI_KMS_INFO='iamUrl=https://iam.cn-north-4.myhuaweicloud.com/v3/auth/
tokens, iamUser=test_user, iamPassword=*********, iamDomain=test_account, kmsProject=cn-north-4'
```

- gs_ktool

  Configure the following information through environment variables.

```
# Method 1: Manually configure the gs_ktool_conf.ini configuration file in the GaussDB-
Kernel_Database version number_OS version number_64bit_Gsql.tar.gz installation package.
Configure the file path in the environment variables.
[terminal] # export GS_KTOOL_FILE_PATH=Folder where the configuration file is located

# Method 2: Configure the gsql_env.sh script in the GaussDB-Kernel_Database version number_OS
version number_64bit_Gsql.tar.gz installation package. The GS_KTOOL_FILE_PATH environment
variable is automatically configured in the script.
[terminal] # source gsql_env.sh
```

2.2 Using gsql to Operate an Encrypted Database

Executing SQL Statements

Before running the SQL statements in this section, ensure that the preparation and configuration phases are complete.

This section uses a complete execution process as an example to describe how to use the encrypted database syntax, including three phases: DDL statement execution, DML statement execution, and cleanup.

```
# 1. Connect to the database and use the -C parameter to enable the full encryption function.
[terminal] # gsql -p PORT gaussdb -h HOST -U USER -W PASSWORD -r -C

-- 2. Create a master key.
-- The following describes how to create a master key in multiple scenarios. Select one of the following
methods as required: key management tool gs_ktool, Huawei Cloud key management service (huawei_kms).
-- For details about the KEY_PATH format, see "SQL Reference > SQL Syntax > CREATE CLIENT MASTER
KEY" in Developer Guide.
gaussdb=# CREATE CLIENT MASTER KEY cmk1 WITH ( KEY_STORE = gs_ktool , KEY_PATH =
'gs_ktool/1', ALGORITHM = AES_256_CBC);
CREATE CLIENT MASTER KEY
-- In the Huawei Cloud scenario, the project ID and key ID are required in KEY_PATH. For details about how
to obtain the key ID, see the preparation phase. For details about how to obtain the project ID, see the
configuration phase.
```

```
gaussdb=#  -- CREATE CLIENT MASTER KEY cmk1 WITH ( KEY_STORE = huawei_kms , KEY_PATH = 
'https://kms.cn-north-4.myhuaweicloud.com/v1.0/00000000000000000000000000000000/kms/
00000000-0000-0000-0000-00000000000', ALGORITHM = AES_256);
-- 3. Create a column key. The column key is encrypted by the master key created in the previous step. For 
details about the syntax, see "SQL Reference > SQL Syntax > CREATE COLUMN ENCRYPTION KEY " in 
Developer Guide.
gaussdb=# CREATE COLUMN ENCRYPTION KEY cek1 WITH VALUES (CLIENT_MASTER_KEY = cmk1, 
ALGORITHM  = AES_256_GCM);

-- 4. Create an encrypted table and use syntax to specify name and credit_card in the table as encrypted 
columns.
gaussdb=# CREATE TABLE creditcard_info (
  id_number int,
  name text encrypted with (column_encryption_key = cek1, encryption_type = DETERMINISTIC),
  credit_card varchar(19) encrypted with (column_encryption_key = cek1, encryption_type = 
DETERMINISTIC));
NOTICE: The 'DISTRIBUTE BY' clause is not specified. Using 'id_number' as the distribution column by 
default.
HINT: Please use 'DISTRIBUTE BY' clause to specify suitable data distribution column.
CREATE TABLE

-- 5. Write data to the encrypted table.
gaussdb=# INSERT INTO creditcard_info VALUES (1,'joe','6217986500001288393');
INSERT 0 1
gaussdb=# INSERT INTO creditcard_info VALUES (2, 'joy','6219985678349800033');
INSERT 0 1

-- 6. Query data from the encrypted table.
gaussdb=# select * from creditcard_info where name = 'joe';
 id_number | name |     credit_card
-----------+------+---------------------
         1 | joe  | 6217986500001288393

-- 7. Update data in the encrypted table.
gaussdb=# update creditcard_info set credit_card = '80000000011111111' where name = 'joy';
UPDATE 1

-- 8. Other operations: Add an encrypted column to a table.
gaussdb=# ALTER TABLE creditcard_info ADD COLUMN age int ENCRYPTED WITH 
(COLUMN_ENCRYPTION_KEY = cek1, ENCRYPTION_TYPE = DETERMINISTIC);
ALTER TABLE

-- 9. Other operations: Delete an encrypted column from a table.
gaussdb=# ALTER TABLE creditcard_info DROP COLUMN age;
ALTER TABLE

-- 10. Other operations: Query master key information from the system catalog.
gaussdb=# SELECT * FROM gs_client_global_keys;
 global_key_name | key_namespace | key_owner | key_acl |        create_date
-----------------+---------------+-----------+---------+----------------------------
 cmk1            |          2200 |        10 |         | 2021-04-21 11:04:00.656617
(1 rows)

-- 11. Other operations: Query column key information from the system catalog.
gaussdb=# SELECT column_key_name,column_key_distributed_id ,global_key_id,key_owner  FROM 
gs_column_keys;
 column_key_name | column_key_distributed_id | global_key_id | key_owner
-----------------+---------------------------+---------------+-----------
 cek1            |                 760411027 |         16392 |        10
(1 rows)

-- 12. Other operations: View the metadata of a column in a table.
gaussdb=# \d creditcard_info
        Table "public.creditcard_info"
   Column    |       Type        | Modifiers
-------------+-------------------+------------
 id_number   | integer           |
 name        | text              |  encrypted
 credit_card | character varying |  encrypted
```

```
-- 13. Delete an encrypted table.
gaussdb=# DROP TABLE creditcard_info;
DROP TABLE

-- 14. Delete a column key.
gaussdb=# DROP COLUMN ENCRYPTION KEY cek1;
DROP COLUMN ENCRYPTION KEY

-- 15. Delete a master key.
gaussdb=# DROP CLIENT MASTER KEY cmk1;
DROP CLIENT MASTER KEY
```

2.3 Using JDBC to Operate an Encrypted Database

Obtain the JDBC driver package.

1. Obtain the JDBC driver package.

   The encrypted database supports the **gsjdbc4.jar**, **opengaussjdbc.jar**, and **gscejdbc.jar** driver packages.

   – **gsjdbc4.jar**: The main class name is **org.postgresql.Driver**, and the URL prefix of the database connection is **jdbc:postgresql**.

   – **opengaussjdbc.jar**: The main class name is **com.huawei.opengauss.jdbc.Driver**, and the URL prefix of the database connection is **jdbc:opengauss**.

   – **gscejdbc.jar** (supported only in some OSs): The main class name is **com.huawei.gaussdb.jdbc.Driver**. The URL prefix of the database connection is **jdbc:gaussdb**. The driver package is recommended in encrypted scenarios. If the driver package does not contain **gscejdbc.jar**, you can also use the **opengaussjdbc.jar** or **gsjdbc4.jar** package.

2. Configure *LD_LIBRARY_PATH*.

   Before using the JDBC driver package in encrypted scenarios, you need to set the environment variable *LD_LIBRARY_PATH*.

   – When the **gscejdbc.jar** driver package is used, the dependent library required by the encrypted database in the **gscejdbc.jar** driver package is automatically copied to the path and loaded when the encrypted function is enabled to connect to the database.

   – When using **opengaussjdbc.jar** or **gsjdbc4.jar**, you need to decompress **GaussDB-Kernel_***Database version number_OS version number***_64bit_libpq.tar.gz** to a specified directory, and add the path of the **lib** folder to the *LD_LIBRARY_PATH* environment variable.

   CAUTION

   To use the JDBC driver package in the full-encryption scenario, you must have the System.loadLibrary permission as well as the read and write permissions on files in the first-priority path of the environment variable *LD_LIBRARY_PATH*. You are advised to use an independent directory to store the full-encryption dependent library. If **java.library.path** is specified during execution, the value must be the same as the first-priority path of *LD_LIBRARY_PATH*.

When **gscejdbc.jar** is used, JVM loading class files depends on the libstdc++ library of the system. If the encryption mode is enabled, **gscejdbc.jar** automatically copies the dynamic libraries (including the libstdc++ library) on which the encryption database depends to the *LD_LIBRARY_PATH* path set by the user. If the version of a dependent library does not match that of the existing system library, only the dependent library is deployed during the first running. After the dependent library is invoked again, it can be used normally.

Executing SQL Statements

Before running the SQL statements in this section, ensure that the preparation and configuration phases are complete.

This section uses a complete execution process as an example to describe how to use the encrypted database syntax, including three phases: DDL statement execution, DML statement execution, and cleanup.

For details about JDBC development operations that are the same as those in non-encrypted scenarios, see "Application Development Guide > Development Based on JDBC" in *Developer Guide*.

- Connection parameters of an encrypted database

  enable_ce: string type. If **enable_ce** is set to **0**, the full encryption function is disabled. If **enable_ce** is set to **1**, the basic capability of encrypted equality query is supported. If **enable_ce** is set to **2**, client sorting is supported based on the encrypted equality query capability (lab feature). If **enable_ce** is set to **3**, software and hardware integration is supported based on the encrypted equality query capability. (The current feature is a lab feature. Contact Huawei technical support before using it.)

```
// The following uses gs_ktool as an example. Before executing the test case, run the gs_ktool -g
command on the client to generate a key file.

// The following uses the gscejdbc.jar driver as an example. If other driver packages are used, you
only need to change the driver class name and the URL prefix of the database connection.
// gsjdbc4.jar: The main class name is org.postgresql.Driver, and the URL prefix of the database
connection is jdbc:postgresql.
// opengaussjdbc.jar: The main class name is com.huawei.opengauss.jdbc.Driver, and the URL
prefix of the database connection is jdbc:opengauss.
// gscejdbc.jar: The main class name is com.huawei.gaussdb.jdbc.Driver, and the URL prefix of the
database connection is jdbc:gaussdb.

public static void main(String[] args) {
    // Driver class.
    String driver = "com.huawei.gaussdb.jdbc.Driver";
    // Database connection descriptor. If enable_ce is set to 1, the basic capability of encrypted
equality query is supported.
    String sourceURL = "jdbc:gaussdb://10.10.0.13:8000/postgres?enable_ce=1";
    String username = "admin";
    String passwd = "Gauss_234";
    Connection conn = null;
    try {
        // Load the driver.
        Class.forName(driver);
        // Create a connection.
        conn = DriverManager.getConnection(sourceURL, username, passwd);
        System.out.println("Connection succeed!");
        // Create a statement object.
        Statement stmt = conn.createStatement();

        // Create a CMK.
        // The following describes how to create a master key in multiple scenarios. Select one of the
following methods as required: key management tool gs_ktool, Huawei Cloud key management
service (huawei_kms).
        // For details about the KEY_PATH format, see "SQL Reference > SQL Syntax > CREATE CLIENT
MASTER KEY" in Developer Guide.
        int rc = stmt.executeUpdate("CREATE CLIENT MASTER KEY ImgCMK1 WITH ( KEY_STORE =
gs_ktool , KEY_PATH = \"gs_ktool/1\" , ALGORITHM = AES_256_CBC);");
        // In the Huawei Cloud scenario, the project ID and key ID are required in KEY_PATH. For details
about how to obtain the key ID, see the preparation phase. For details about how to obtain the
project ID, see the configuration phase.
        // int rc = stmt.executeUpdate("CREATE CLIENT MASTER KEY ImgCMK1 WITH ( KEY_STORE =
huawei_kms , KEY_PATH = 'https://kms.cn-north-4.myhuaweicloud.com/
v1.0/00000000000000000000000000000000/kms/00000000-0000-0000-0000-00000000000',
ALGORITHM = AES_256);");

        // Create a CEK.
        int rc2 = stmt.executeUpdate("CREATE COLUMN ENCRYPTION KEY ImgCEK1 WITH VALUES
(CLIENT_MASTER_KEY = ImgCMK1, ALGORITHM  = AES_256_GCM);");
        // Create an encrypted table.
        int rc3 = stmt.executeUpdate("CREATE TABLE creditcard_info (id_number int, name varchar(50)
encrypted with (column_encryption_key = ImgCEK1, encryption_type = DETERMINISTIC),credit_card
varchar(19) encrypted with (column_encryption_key = ImgCEK1, encryption_type =
DETERMINISTIC));");
        // Insert data.
        int rc4 = stmt.executeUpdate("INSERT INTO creditcard_info VALUES
(1,'joe','6217986500001288393');");
        // Query the encrypted table.
        ResultSet rs = null;
        rs = stmt.executeQuery("select * from creditcard_info where name = 'joe';");
        // Delete the encrypted table.
        int rc5 = stmt.executeUpdate("DROP TABLE IF EXISTS creditcard_info;");
        // Delete a CEK.
        int rc6 = stmt.executeUpdate("DROP COLUMN ENCRYPTION KEY IF EXISTS ImgCEK1;");
        // Delete the CMK.
        int rc7 = stmt.executeUpdate("DROP CLIENT MASTER KEY IF EXISTS ImgCMK1;");
        // Close the statement object.
        stmt.close();
        // Close the connection.
        conn.close();
    } catch (Exception e) {
        e.printStackTrace();
        return;
    }
}
```

NOTE

[Proposal] When JDBC is used to perform operations on an encrypted database, one database connection object corresponds to one thread. Otherwise, conflicts may occur due to thread changes.

[Proposal] When JDBC is used to perform operations on an encrypted database, different connections change the encrypted configuration data. The client invokes the **isvalid** method to ensure that the connections can hold the changed encrypted configuration data. In this case, the **refreshClientEncryption** parameter must be set to **1** (default value). In a scenario where a single client performs operations on encrypted data, the **refreshClientEncryption** parameter can be set to **0**.

Example of Calling the IsValid Method to Refresh the Cache

```
// Create a connection conn1.
Connection conn1 = DriverManager.getConnection("url","user","password");
// Create a CMK in another connection conn2.
...
// conn1 calls the IsValid method to refresh the cache.
try {
    if (!conn1.isValid(60)) {
        System.out.println("isValid Failed for connection 1");
    }
} catch (SQLException e) {
    e.printStackTrace();
        return null;
}
```

Decrypting the Encrypted Equality Ciphertext

The decryption interface is added to the database connection interfaces of the PgConnection class. The decryption interface can be used to decrypt the encrypted equality ciphertext of the fully-encrypted database. After decryption, the plaintext value is returned. The ciphertext column corresponding to the decryption is found based on **schema.table.column** and the original data type is returned.

Table 2-1 org.postgresql.jdbc.PgConnection function interface

Method	Return Type	Support JDBC 4
decryptData(String ciphertext, Integer len, String schema, String table, String column)	ClientLogicDecryptRe-sult	Yes

Parameter description:

- **ciphertext**

  Ciphertext to be decrypted.

- **len**

  Ciphertext length. If the value is less than the actual ciphertext length, decryption fails.

- **schema**

  Name of the schema to which the encrypted column belongs.

- **table**

  Name of the table to which the encrypted column belongs.

- **column**

  Name of the column to which the encrypted column belongs.

  NOTE

  Decryption is successful in the following scenarios, but is not recommended:

  - The input ciphertext length is longer than the actual ciphertext.
  - The **schema.table.column** points to other encrypted columns. In this case, the original data type of the encrypted column is returned.

Table 2-2 org.postgresql.jdbc.clientlogic.ClientLogicDecryptResult function interface

Method	Return Type	Description	Support JDBC 4
isFailed()	Boolean	Indicates whether the decryption fails. If the decryption fails, **True** is returned. Otherwise, **False** is returned.	Yes
getErrMsg()	String	Obtains error information.	Yes
getPlaintext()	String	Obtains the decrypted plaintext.	Yes
getPlaintextSize()	Integer	Obtains the length of the decrypted plaintext.	Yes
getOriginalType()	String	Obtains the original data type of the encrypted column.	Yes

```
// After the ciphertext is obtained through non-encrypted connection or logical decoding, this interface can
be used to decrypt the ciphertext.
import org.postgresql.jdbc.PgConnection;
import org.postgresql.jdbc.clientlogic.ClientLogicDecryptResult;

// conn is an encrypted connection.
// Call the decryptData method of PgConnection to decrypt the ciphertext, locate the encrypted column to
which the ciphertext belongs based on the column name, and return the original data type.
ClientLogicDecryptResult decrypt_res = null;
decrypt_res = ((PgConnection)conn).decryptData(ciphertext, ciphertext.length(), schemaname_str,
        tablename_str, colname_str);
// Check whether the decryption of the returned result class is successful. If the decryption fails, obtain the
error information. If the decryption is successful, obtain the plaintext, length, and original data type.
if (decrypt_res.isFailed()) {
    System.out.println(String.format("%s\n", decrypt_res.getErrMsg()));
} else {
    System.out.println(String.format("decrypted plaintext: %s size: %d type: %s\n", decrypt_res.getPlaintext(),
        decrypt_res.getPlaintextSize(), decrypt_res.getOriginalType()));
}
```

Precompiling an Encrypted Table

```
// Create a prepared statement object by calling the prepareStatement method in Connection.
PreparedStatement pstmt = conn.prepareStatement("INSERT INTO creditcard_info VALUES (?, ?, ?);");
// Set parameters by triggering the setShort method in PreparedStatement.
pstmt.setInt(1, 2);
pstmt.setString(2, "joy");
pstmt.setString(3, "6219985678349800033");
// Execute the precompiled SQL statement by triggering the executeUpdate method in
PreparedStatement.
int rowcount = pstmt.executeUpdate();
// Close the precompiled statement object by calling the close method in PreparedStatement.
pstmt.close();
```

Batch Processing on an Encrypted Table

```
// Create a prepared statement object by calling the prepareStatement method in Connection.
Connection conn = DriverManager.getConnection("url","user","password");
PreparedStatement pstmt = conn.prepareStatement("INSERT INTO batch_table (id, name, address) VALUES
(?,?,?)");
// Call the setShort method for each piece of data, and call addBatch to confirm that the setting is
complete.
int loopCount = 20;
 for (int i = 1; i < loopCount + 1; ++i) {
      statemnet.setInt(1, i);
      statemnet.setString(2, "Name " + i);
      statemnet.setString(3, "Address " + i);
      // Add row to the batch.
      statemnet.addBatch();
}
// Execute batch processing by calling the executeBatch method in PreparedStatement.
int[] rowcount = pstmt.executeBatch();
// Close the precompiled statement object by calling the close method in PreparedStatement.
pstmt.close();
```

2.4 Enhancing Security in the Configuration Phase

Setting Environment Variables Securely

Sensitive information exists in *HUAWEI_KMS_INFO*. You are advised to set the environment variables as follows:

1. Set temporary environment variables: When an encrypted database is used, run the **export** command to set environment variables. After the database is used, run the **unset** command to clear environment variables. In this method, OS logs may record sensitive information. You are advised to use process-level environment variables or JDBC APIs to set connection parameters.
2. Set process-level environment variables: In the application code, set environment variables through programming interfaces. The following are examples of setting environment variables in different programming languages:
    a. C/C++: setenv(name, value)
    b. Go: os.Setenv(name, value)
    c. Java does not support the setting of process-level environment variables. Connection parameters can be set only through the JDBC APIs.

Verifying External Key Management Service Identity

When the database driver accesses Huawei Cloud key management service, to prevent attackers from masquerading as the key management service, the CA certificate can be used to verify the validity of the key server during the establishment of HTTPS connections between the database driver and the key management service. Therefore, you need to configure the CA certificate in advance. If the CA certificate is not configured, the key management service identity will not be verified. The configuration method is as follows:

In the Huawei Cloud scenario, add the following parameters to the environment variables:

```
export HUAWEI_KMS_INFO='Other parameters, iamCaCert=Path/IAM CA certificate file,
kmsCaCert=Path/KMS CA certificate file'
```

Most browsers automatically download a CA certificate of a website and provide the certificate export function. Some websites (such as **https://www.ssleye.com/ssltool/certs_down.html**) provide the function of automatically downloading CA certificates. However, the CA certificates may be unavailable due to proxy or gateway in the local environment. Therefore, you are advised to use a browser to download the CA certificate. You can perform the following steps:

CAUTION

The RESTful API is used to access the key management service. When you enter the URL of the API in the address box of the browser, ignore the failure page in **Step 2**. The browser has automatically downloaded the CA certificate in advance even if the failure page is displayed.

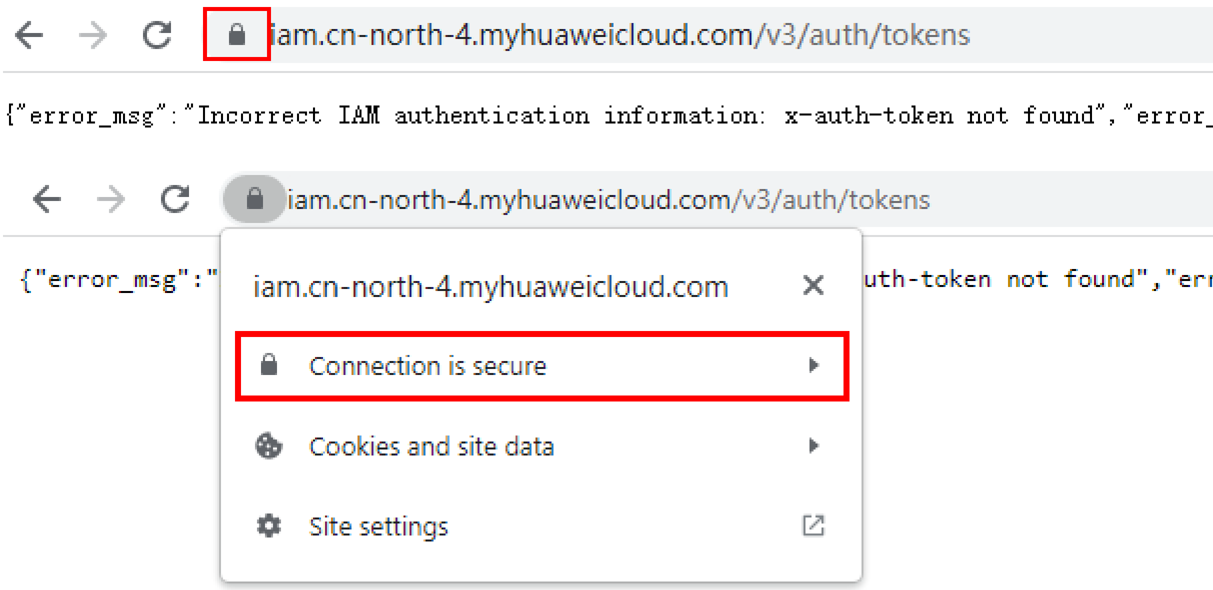
Step 1 Enter domain names: Open a browser and enter the domain names of IAM and KMS in the Huawei Cloud scenario.

Example:

https://iam.cn-north-4.myhuaweicloud.com/v3/auth/tokens

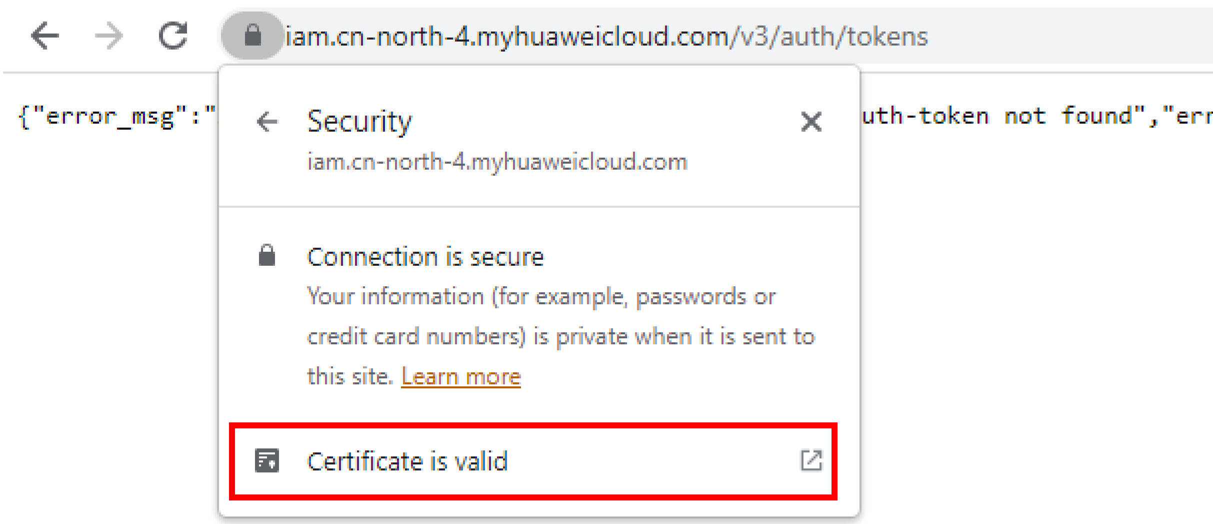
https://kms.cn-north-4.myhuaweicloud.com/v1.0

Step 2 Search for a certificate: Each time you enter a domain name, find the SSL connection information and click the information to view the certificate content.


iam.cn-north-4.myhuaweicloud.com/v3/auth/tokens

```
{"error_msg":"Incorrect IAM authentication information: x-auth-token not found","error_
```

iam.cn-north-4.myhuaweicloud.com/v3/auth/tokens
iam.cn-north-4.myhuaweicloud.com
Connection is secure
Cookies and site data
Site settings


iam.cn-north-4.myhuaweicloud.com/v3/auth/tokens

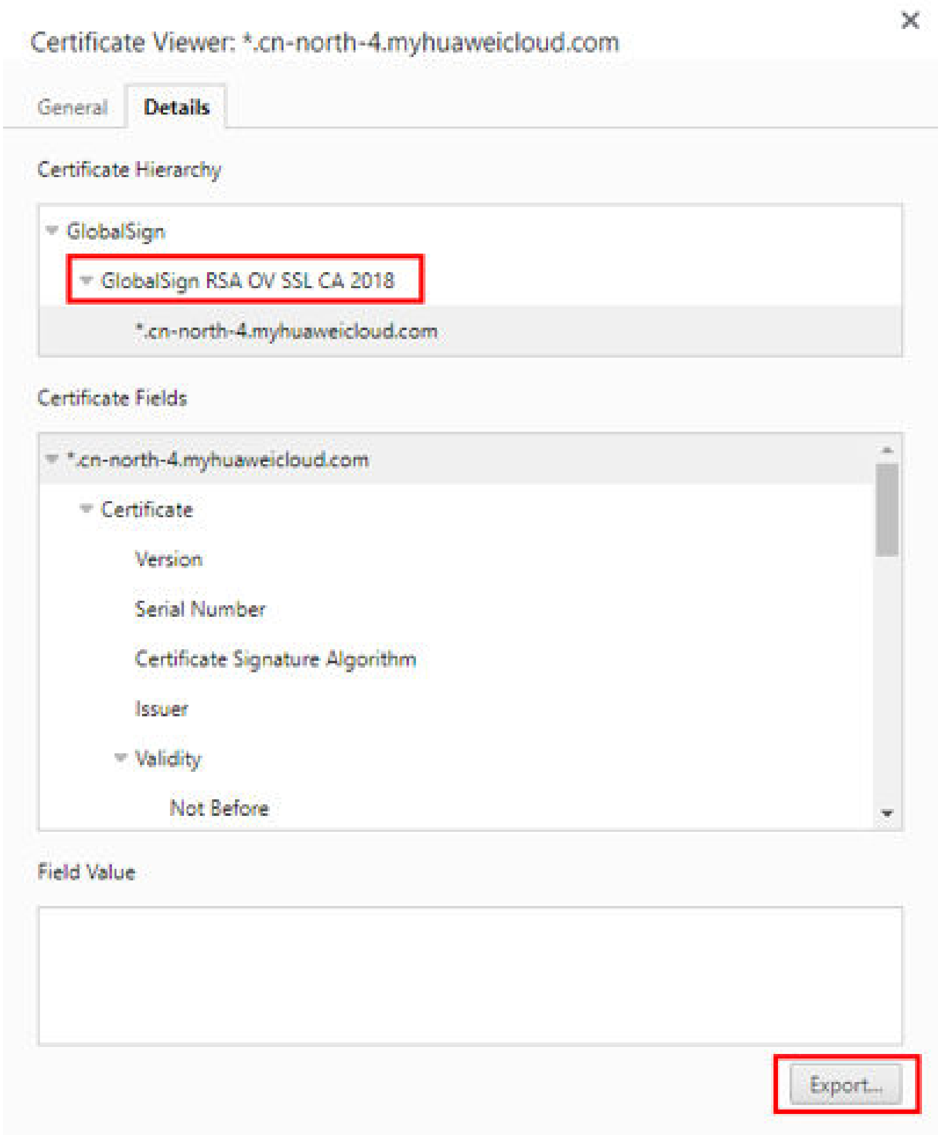
```
{"error_msg":"
uth-token not found","err
```

Security
iam.cn-north-4.myhuaweicloud.com

Connection is secure
Your information (for example, passwords or credit card numbers) is private when it is sent to this site. Learn more

Certificate is valid

Step 3 Export the certificate: On the **Certificate Viewer** page, certificates may be classified into multiple levels. You only need to select the upper-level certificate of the domain name and click **Export** to generate a certificate file, that is, the required certificate file.


Certificate Viewer: *.cn-north-4.myhuaweicloud.com
General
Details
Certificate Hierarchy
GlobalSign
GlobalSign RSA OV SSL CA 2018
*.cn-north-4.myhuaweicloud.com
Certificate Fields
*.cn-north-4.myhuaweicloud.com
Certificate
Version
Serial Number
Certificate Signature Algorithm
Issuer
Validity
Not Before
Field Value
Export...

Step 4 Upload the certificate: Upload the exported certificate to the application and set the preceding parameters.

----End

2.5 Encrypted Functions and Stored Procedures

In the current version, only encrypted functions and stored procedures in SQL or PL/pgSQL are supported. Because users are unaware of the creation and execution of functions or stored procedures in an encrypted stored procedure, the syntax has no difference from that of non-encrypted functions and stored procedures.

The **gs_encrypted_proc** system catalog is added to the function or stored procedure for encrypted equality query to store the returned original data type.

Creating and Executing a Function or Stored Procedure that Involves Encrypted Columns

Step 1 Create a key. For details, see **Using gsql to Operate an Encrypted Database** and **Using JDBC to Operate an Encrypted Database**.

Step 2 Create an encrypted table.

```
gaussdb=# CREATE TABLE creditcard_info (
gaussdb(#   id_number int,
gaussdb(#   name  text,
gaussdb(#   credit_card varchar(19) encrypted with (column_encryption_key = ImgCEK1,
encryption_type = DETERMINISTIC)
gaussdb(# ) with (orientation=row) distribute by hash(id_number);
CREATE TABLE
```

Step 3 Insert data.

```
gaussdb=# insert into creditcard_info values(1, 'Avi', '1234567890123456');
INSERT 0 1
gaussdb=# insert into creditcard_info values(2, 'Eli', '2345678901234567');
INSERT 0 1
```

Step 4 Create a function supporting encrypted equality query.

```
gaussdb=# CREATE FUNCTION f_encrypt_in_sql(val1 text, val2 varchar(19)) RETURNS text AS 'SELECT
name from creditcard_info where name=$1 or credit_card=$2 LIMIT 1' LANGUAGE SQL;
CREATE FUNCTION
gaussdb=# CREATE FUNCTION f_encrypt_in_plpgsql (val1 text, val2 varchar(19), OUT c text) AS $$
gaussdb$# BEGIN
gaussdb$# SELECT into c name from creditcard_info where name=$1 or credit_card =$2 LIMIT 1;
gaussdb$# END; $$
gaussdb-# LANGUAGE plpgsql;
CREATE FUNCTION
```

Step 5 Execute the function.

```
gaussdb=# SELECT f_encrypt_in_sql('Avi','1234567890123456');
 f_encrypt_in_sql
------------------
 Avi
(1 row)

gaussdb=# SELECT f_encrypt_in_plpgsql('Avi', val2=>'1234567890123456');
 f_encrypt_in_plpgsql
----------------------
 Avi
(1 row)
```

----End

NOTE

1. Because the query, that is, the dynamic query statement executed in a function or stored procedure, is compiled during execution, the table name and column name in the function or stored procedure must be known in the creation phase. The input parameter cannot be used as a table name or column name, or any connection mode.
2. In a function or stored procedure that executes dynamic clauses, data values to be encrypted cannot be contained in the clauses.
3. Among the **RETURNS**, **IN**, and **OUT** parameters, encrypted and non-encrypted parameters cannot be used together. Although the parameter types are all original, the actual types are different.
4. In advanced package interfaces, for example, **dbe_output.print_line()**, decryption is not performed on the interfaces whose output is printed on the server. This is because when the encrypted data type is forcibly converted into the plaintext original data type, the default value of the data type is printed.
5. In the current version, **LANGUAGE** of functions and stored procedures can only be **SQL** and **PL/pgSQL**, and does not support other procedural languages such as **C** and **Java**.
6. Other functions or stored procedures for querying encrypted columns cannot be executed in a function or stored procedure.
7. In the current version, default values cannot be assigned to variables in **DEFAULT** or **DECLARE** statements, and return values in **DECLARE** statements cannot be decrypted. You can use input parameters and output parameters instead when executing functions.
8. **gs_dump** cannot be used to back up functions involving encrypted columns.
9. Keys cannot be created in functions or stored procedures.
10. In this version, encrypted functions and stored procedures do not support triggers.
11. Encrypted equality query functions and stored procedures do not support the escape of the PL/pgSQL syntax. The **CREATE FUNCTION AS'***Syntax body*' syntax whose syntax body is marked with single quotation marks ('') can be replaced with the **CREATE FUNCTION AS $$***Syntax body* **$$** syntax.
12. The definition of an encrypted column cannot be modified in an encrypted equality query function or stored procedure, including creating an encrypted table and adding an encrypted column. Because the function is executed on the server, the client cannot determine whether to refresh the cache. The column can be encrypted only after the client is disconnected or the cache of the encrypted column on the client is refreshed.
13. Functions and stored procedures cannot be created using encrypted data types (byteawithoutorderwithequalcol, byteawithoutordercol, _byteawithoutorderwithequalcol or _byteawithoutordercol).
14. If an encrypted function returns a value of an encrypted type, the result cannot be an uncertain row type, for example, **RETURN [SETOF] RECORD**. You can replace it with a definite row type, for example, **RETURN TABLE(columnname typename[, ...])**.
15. When an encrypted function is created, the OID of the encrypted column corresponding to a parameter is added to the system catalog **gs_encrypted_proc**. Therefore, if a table with the same name is deleted and created again, the encrypted function may become invalid and you need to create the encrypted function again.

2.6 Sorting Encrypted Data on Clients (Lab Feature)

The current feature is a lab feature. Contact Huawei technical support before using it.

The client decrypts and sorts the ciphertext returned by the query on the client. To enable encrypted data sorting on clients, use gsql to enable **-C2** or set **--enable-client-encryption** to **2**, and set enable_ ce to 2 by using JDBC connections.

Currently, the client supports the following sorting syntax:

```
SELECT [ DISTINCT ] { * | {colname [ [ AS ] output_name ] | [ SUM | MIN | MAX | COUNT | AVG ]
( colname ) [ [ AS ] output_name ] } [, ...] }
[ FROM tablename ]
[ [ INNER ] JOIN | LEFT [ OUTER ] JOIN | RIGHT [ OUTER ] JOIN | FULL [ OUTER ] JOIN | CROSS JOIN ]
{ tablename } ON condition { [ AND | OR ] condition }
[ WHERE condition ]
[ GROUP BY {colname | output_name} [, ...] ]
[ ORDER BY { {colname | output_name} [ ASC | DESC | USING operator ] [ NULLS { FIRST | LAST } ]} [, ...] ]
[ LIMIT count ]
[ OFFSET start ];
```

Parameter Description

- **colname**

  When **colname** is used as the input parameter of aggregate functions MAX, MIN, SUM, AVG, and COUNT, only column names can be directly referenced and column types cannot be converted.

- **output_name**

  output_name is the alias of **colname**. GROUP BY and ORDER BY cannot be followed by the alias of an aggregate function.

- **WHERE clause**

  condition is an equivalent condition connected by AND or OR, for example, **colname=1**, **colname!=1**, and **colname IS NULL**. It cannot contain expressions.

For details about other parameters, see section "SQL Reference > SQL Syntax > SELECT" in *Developer Guide*.

NOTE

This version supports the ORDER BY, GROUP BY, DISTINCT, LIMIT, and OFFSET operations on encrypted columns, but does not support the following sorting scenarios:

- DISTINCT ON, HAVING, and EXECUTE DIRECT clauses, functions, stored procedures, nested SQL statements, and views are not supported.
- Only aggregate functions MAX, MIN, SUM, AVG, and COUNT can be used for sorting encrypted columns. The corresponding window functions are not supported. The five aggregate functions override the aggregate operations on the ciphertext on the client. You cannot use this method to call a server-defined aggregate function with the same name or use a schema name combined with a function name, for example, PG_CATALOG.MAX, to call a client aggregate function. The result of executing the SUM or AVG aggregate function on strings is **0**.
- If GROUP BY is followed by an encrypted column, the column name must be explicitly specified in the SELECT target column. The asterisk (*) cannot be used.
- If ORDER BY or GROUP BY contains encrypted columns, LIMIT and OFFSET cannot be followed by any expression, for example, 2+2. In this example, replace it with 4.
- The ORDER BY 1,2 syntax is not supported. The encrypted column name must be explicitly specified.
- Encrypted strings can only be sorted in ASCII order, regardless of the character set on the server. Encrypted data of the floating-point or numeric type is calculated using the default precision on the client, regardless of the precision setting on the server.
- Table names, column names, and aliases after GROUP BY and ORDER BY cannot contain special characters such as single quotation marks ('), for example, **SELECT i2 as c FROM t1 as "'a" ORDER BY "'a".i2;**.
- Multiple queries sent in a PQexec call are not supported. Example: PQexec("PREPARE p1 select distinct i1 from t1 order by i1;EXECUTE p1;");
- Columns with the same name are not verified in join scenarios. Otherwise, it may cause unexpected results. If two tables have identical column names, you are not advised to use JOIN for sorting on clients.

The ciphertext data returned by the server is decrypted on the client before being sorted, which consumes some resources on the client. It is recommended that a maximum of 100,000 data records be returned for each query.

The current version supports only a limited number of sorting scenarios. In other scenarios where no proper syntax is provided, unexpected results may occur. Therefore, you are not advised to sort encrypted columns in this case.

Querying and Sorting Data in an Encrypted Table

Step 1 Create a key. For details, see **Using gsql to Operate an Encrypted Database** and **Using JDBC to Operate an Encrypted Database**.

Step 2 Create an encrypted table.

```
gaussdb=# CREATE TABLE IF NOT EXISTS t1(
gaussdb=# id int, i1 int,
gaussdb=# i2 INT ENCRYPTED WITH (COLUMN_ENCRYPTION_KEY = cek1, ENCRYPTION_TYPE =
DETERMINISTIC),
gaussdb=# i3 varchar(20) ENCRYPTED WITH (COLUMN_ENCRYPTION_KEY = cek1, ENCRYPTION_TYPE
= DETERMINISTIC),
gaussdb=# i4 INT);
CREATE TABLE
```

Step 3 Insert data.

```
gaussdb=# INSERT INTO t1 VALUES(2,2,200, 'two hundreds - 1', 10);
INSERT 0 1
gaussdb=# INSERT INTO t1 VALUES(3,7,300, 'three hundreds - 1', 11);
INSERT 0 1
gaussdb=# INSERT INTO t1 VALUES(4,6,400, 'four hundreds', 12);
```

```
INSERT 0 1
gaussdb=# INSERT INTO t1 VALUES(5,5,300, 'three hundreds - 2');
INSERT 0 1
gaussdb=# INSERT INTO t1 VALUES(6,4,200, 'two hundreds - 2');
INSERT 0 1
gaussdb=# INSERT INTO t1 VALUES(7,3,200, 'two hundreds - 3');
INSERT 0 1
```

Step 4 Perform sorting.

```
gaussdb=# select sum(id), i2 from t1 group by i2 order by i2;
 sum | i2
-----+-----
   1 | 100
  15 | 200
   8 | 300
   4 | 400
(4 rows)
gaussdb=# select min(id), i2 from t1 group by i2 order by i2;
 min | i2
-----+-----
   1 | 100
   2 | 200
   3 | 300
   4 | 400
(4 rows)
```

----End

3 Partitioned Table

This chapter describes how to perform query optimization and O&M management on stored data in partitioned tables in scenarios with a large amount of data, including semantics, principles, and constraints.

3.1 Large-Capacity Database

3.1.1 Background

With the increasing amount of data to be processed and diversified application scenarios, databases are facing more and more scenarios with large capacity and diversified data. In the past 20 years, the data volume has gradually increased from MB- and GB-level to TB-level. Facing such a large amount of data, the database management system (DBMS) has higher requirements on data query and management. Objectively, the database must support multiple optimization search policies and O&M methods.

In classic algorithms of computer science, people usually use the Divide and Conquer method to solve problems in large-scale scenarios. The basic idea is to divide a complex problem into two or more same or similar problems. These problems are divided into smaller problems until they can be solved directly. The solution of the original problem can be regarded as the combination of the solutions to all small problems. In a large-capacity data scenario, the database provides a Divide and Conquer method, that is, partitioning. The logical database or its components are divided into different independent partitions. Each partition maintains data with similar attributes logically. In this way, the large amount of data is divided, facilitating data management, search, and maintenance.

3.1.2 Table Partitioning

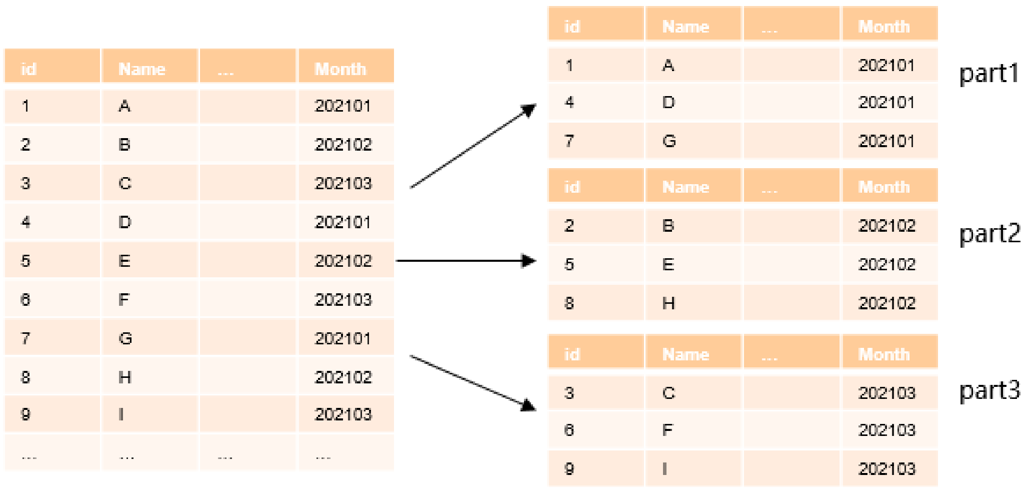
Table partitioning logically divides a large table or index into smaller and easier-to-manage logical units (partitions), minimizing the impact on table query and modification statements. Users can quickly locate a partition where data is located by using a partition key. In this way, users do not need to scan all large tables in the database and can concurrently perform DDL and DML operations on different partitions. Table partitioning provides users with the following capabilities:

1. Improve query efficiency in large-capacity data scenarios: Because data in a table is logically partitioned by partition key, the query result can be implemented by accessing a partition subset instead of the entire table. This partition pruning technique can provide an order of magnitude performance gain.
2. Reduce the impact of concurrent O&M and query operations: The mutual impact of concurrent DML and DDL statements is reduced, especially in scenarios where a large amount of data is partitioned by time, for example, data import to new partitions, real-time point query, data cleaning in old partitions, and partition merging.
3. Provide flexible data O&M management in large-capacity scenarios: Partitioned tables physically isolate data in different partitions at the table file level. Each partition can have independent physical attributes, such as data compression, physical storage settings, and tablespaces. In addition, it supports data management operations, such as data loading, index creation and rebuilding, and partition-level backup and restoration, instead of performing operations on the entire table, reducing operation time.

3.1.3 Data Partition Query Optimization

Partitioned tables help you query data by using predicates based on partition keys. For example, if a table uses month as the partition key, as shown in **Figure 3-1**, you need to access all data in the table (full table scan). If the table is redesigned based on the date when the data is imported to the database, the original full table scan is optimized to partition scan. When the table contains a large amount of data and has a long historical period, the performance is greatly improved due to data reduction, as shown in **Figure 3-2**.

Figure 3-1 Example of a partitioned table



id	Name	...	Month
1	A		202101
2	B		202102
3	C		202103
4	D		202101
5	E		202102
6	F		202103
7	G		202101
8	H		202102
9	I		202103
...	...	...	...

part1

id	Name	...	Month
1	A		202101
4	D		202101
7	G		202101

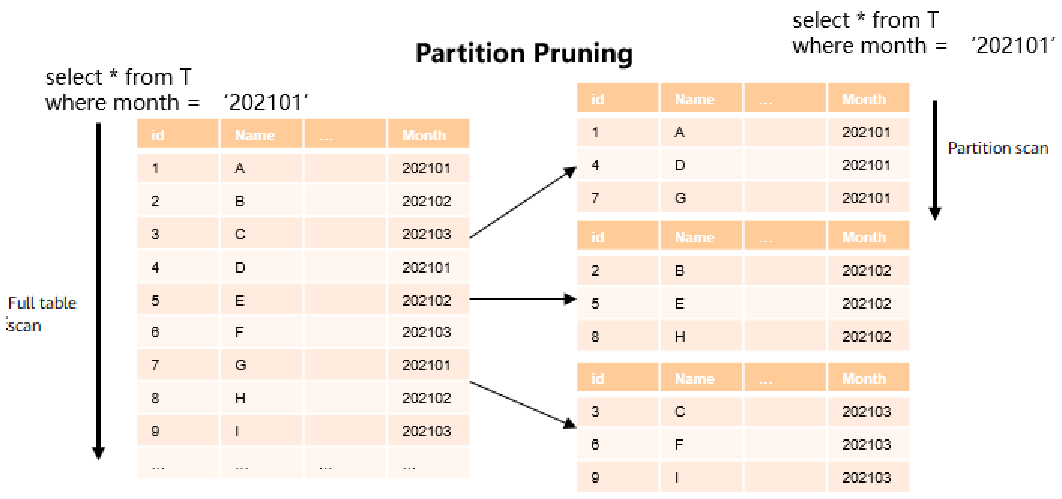
part2

id	Name	...	Month
2	B		202102
5	E		202102
8	H		202102

part3

id	Name	...	Month
3	C		202103
6	F		202103
9	I		202103

Figure 3-2 Example of partition pruning



3.1.4 Data Partition O&M Management

A partitioned table provides flexible support for data lifecycle management (DLM). DLM is a set of processes and policies used to manage data throughout the service life of data. An important component is to determine the most appropriate and cost-effective medium for storing data at any point in the data lifecycle. New data used in daily operations is stored on the fastest and most available storage tier, while old data that is infrequently accessed may be stored on a less costly and inefficient storage tier. Old data may also be updated less frequently, so it makes sense to compress the data and store it as read-only.

Partitioned tables provide an ideal environment for implementing the DLM solution. Different partitions use different tablespaces, maximizing usability and reducing costs in the data lifecycle. The settings are performed by database O&M personnel on the server. Actually, users are unaware of the optimization settings. Logically, users still query the same table. In addition, O&M operations, such as backup, restoration, and index rebuilding, can be performed on different partitions. The Divide and Conquer method is implemented on different subsets of a single dataset to meet differentiated requirements of service scenarios.

3.2 Introduction to Partitioned Tables

A partitioned table logically divides table data on a single node based on a partition key and its partitioning policy. From the perspective of data partitioning, it is a horizontal partitioning policy. Partitioned tables enhance the performance, manageability, and usability of database applications, and help reduce the total cost of ownership (TCO) for storing large amounts of data. Partitioning allows tables, indexes, and index-organized tables to be further divided into smaller parts, enabling these database objects to be managed and accessed at a finer granularity level. GaussDB Kernel provides various partitioning policies and extensions to meet the requirements of different service scenarios. The partitioning policy is implemented inside the database and is transparent to users. Therefore, it enables smooth data migration after the partitioning optimization policy is implemented, without the need to change applications that consume manpower and material resources. This section describes GaussDB Kernel partitioned tables from the following aspects:

1. Basic concepts of partitioned tables: catalog storage and its principle.
2. Partitioning policies: basic partitioning types, and features, optimization, and effects of each partitioning type.

3.2.1 Basic Concepts

3.2.1.1 Partitioned Table

A partitioned table is user-facing table on which users can add, delete, query, and modify data in the table using common DML statements. Generally, the PARTITION BY clause of the CREATE TABLE statement is used to define a table. After the table is created, an entry is added to the **pg_class** table. If **'p'** is displayed in the **parttype** column, the entry is a partitioned table. The partitioned table is usually a logical form, and does not store any data.

Example 1: **t1_hash** is a partitioned table whose partitioning type is hash.

```
gaussdb=# \d+ t1_hash
                    Table "public.t1_hash"
Column |  Type    | Modifiers | Storage | Stats target | Description
--------+---------+-----------+---------+--------------+-------------
c1     | integer |           | plain   |              |
c2     | integer |           | plain   |              |
c3     | integer |           | plain   |              |
Partition By HASH(c1)
Number of partitions: 10 (View pg_partition to check each partition range.)
Has OIDs: no
Options: orientation=row, compression=no

-- Query the partitioning type of table t1_hash.
gaussdb=#  SELECT relname, parttype FROM pg_class WHERE relname = 't1_hash';
relname | parttype
---------+----------
t1_hash | p
(1 row)
```

3.2.1.2 Partition

A partition stores data actually. The corresponding entry is usually stored in **pg_partition**. The **parentid** of each partition is used as a foreign key to associate with the **oid** column of its partitioned table in the **pg_class** table.

Example 1: **t1_hash** is a partitioned table.

```
CREATE TABLE t1_hash (c1 INT, c2 INT, c3 INT)
PARTITION BY HASH(c1)
(
    PARTITION p0,
    PARTITION p1,
    PARTITION p2,
    PARTITION p3,
    PARTITION p4,
    PARTITION p5,
    PARTITION p6,
    PARTITION p7,
    PARTITION p8,
    PARTITION p9
);

-- Query the partitioning type of table t1_hash.
```

```
gaussdb=# SELECT oid, relname, parttype FROM pg_class WHERE relname = 't1_hash';
oid  | relname | parttype
-------+---------+----------
16685 | t1_hash | p
(1 row)

-- Query the partition information about table t1_hash.
gaussdb=# SELECT oid, relname, parttype, parentid FROM pg_partition WHERE parentid = 16685;
oid  | relname | parttype | parentid
-------+---------+----------+----------
16688 | t1_hash | r        |    16685
16689 | p0      | p        |    16685
16690 | p1      | p        |    16685
16691 | p2      | p        |    16685
16692 | p3      | p        |    16685
16693 | p4      | p        |    16685
16694 | p5      | p        |    16685
16695 | p6      | p        |    16685
16696 | p7      | p        |    16685
16697 | p8      | p        |    16685
16698 | p9      | p        |    16685
(11 rows)
```

3.2.1.3 Partition Key

A partition key consists of one or more columns. The partition key value and the corresponding partitioning method can uniquely identify the partition where a tuple is located. Generally, the partition key value is specified by the PARTITION BY clause during table creation.

```
CREATE TABLE table_name (...) PARTITION BY part_strategy (partition_key) (...)
```

NOTICE

Range partitioned tables and list partitioned tables support a partition key with up to 16 columns. Other partitioned tables support a one-column partition key only.

3.2.2 Partitioning Policy

A partitioning policy is specified by the PARTITION BY clause of the CREATE TABLE statement. A partitioning policy describes the mapping between data in a partitioned table and partition routing. Common partitioning types include range partitioning (based on conditions), hash partitioning (based on hash functions), and list partitioning (based on data enumeration).

```
CREATE TABLE table_name (...) PARTITION BY partition_strategy (partition_key) (...)
```

3.2.2.1 Range Partitioning

Range partitioning maps data to partitions based on the value range of the partition key created for each partition. Range partitioning is the most common partitioning type in production systems and is usually used in scenarios where data is described by date or timestamp. There are two syntax formats for range partitioning. The following is an example:

1. VALUES LESS THAN

   If the VALUE LESS THAN clause is used, a range partitioning policy supports a partition key with up to 16 columns.

– The following is an example of a single-column partition key:

```
CREATE TABLE range_sales
(
    product_id      INT4 NOT NULL,
    customer_id     INT4 NOT NULL,
    time            DATE,
    channel_id      CHAR(1),
    type_id         INT4,
    quantity_sold   NUMERIC(3),
    amount_sold     NUMERIC(10,2)
)
PARTITION BY RANGE (time_id)
(
    PARTITION date_202001 VALUES LESS THAN ('2020-02-01'),
    PARTITION date_202002 VALUES LESS THAN ('2020-03-01'),
    PARTITION date_202003 VALUES LESS THAN ('2020-04-01'),
    PARTITION date_202004 VALUES LESS THAN ('2020-05-01')
    ...
);
```

date_202002 indicates the partition of February 2020, which contains the data of the partition key from February 1, 2020 to February 29, 2020.

Each partition has a VALUES LESS clause that specifies the upper limit (excluded) of the partition. Any value greater than or equal to that partition key will be added to the next partition. Except the first partition, all partitions have an implicit lower limit specified by the VALUES LESS clause of the previous partition. You can define the MAXVALUE keyword for the last partition. MAXVALUE represents a virtual infinite value that is prior to any other possible value (including null) of the partition key.

– The following is an example of a multi-column partition key:

```
CREATE TABLE range_sales
(
    c1      INT4 NOT NULL,
    c2      INT4 NOT NULL,
    c3      CHAR(1)
)
PARTITION BY RANGE (c1,c2)
(
    PARTITION p1 VALUES LESS THAN (10,10),
    PARTITION p2 VALUES LESS THAN (10,20),
    PARTITION p3 VALUES LESS THAN (20,10)
);
INSERT INTO range_sales VALUES(9,5,'a');
INSERT INTO range_sales VALUES(9,20,'a');
INSERT INTO range_sales VALUES(9,21,'a');
INSERT INTO range_sales VALUES(10,5,'a');
INSERT INTO range_sales VALUES(10,15,'a');
INSERT INTO range_sales VALUES(10,20,'a');
INSERT INTO range_sales VALUES(10,21,'a');
INSERT INTO range_sales VALUES(11,5,'a');
INSERT INTO range_sales VALUES(11,20,'a');
INSERT INTO range_sales VALUES(11,21,'a');

gaussdb=# SELECT * FROM range_sales PARTITION (p1);
 c1 | c2 | c3
----+----+----
  9 |  5 | a
  9 | 20 | a
  9 | 21 | a
 10 |  5 | a
(4 rows)

gaussdb=# SELECT * FROM range_sales PARTITION (p2);
 c1 | c2 | c3
----+----+----
 10 | 15 | a
```

```
(1 row)

gaussdb=# SELECT * FROM range_sales PARTITION (p3);
 c1 | c2 | c3
----+----+----
 10 | 20 | a
 10 | 21 | a
 11 |  5 | a
 11 | 20 | a
 11 | 21 | a
(5 rows)
```

NOTE

The partitioning rules for multi-column partition keys are as follows:

1. The comparison starts from the first column.
2. If the value of the inserted first column is smaller than the boundary value of the current column in the target partition, the values are directly inserted.
3. If the value of the inserted first column is equal to the boundary of the current column in the target partition, compare the value of the inserted second column with the boundary of the next column in the target partition. If the value of the inserted second column is smaller than the boundary of the next column in the target partition, the values are directly inserted. Otherwise, the comparison of the next columns between the source and target continues.
4. If the value of the inserted first column is greater than the boundary of the current column in the target partition, compare the value with that in the next partition.

2. START END

   If the START END clause is used, a range partitioning policy supports only a one-column partition key.

   Example:

```
-- Create tablespaces.
CREATE TABLESPACE startend_tbs1 LOCATION '/home/omm/startend_tbs1';
CREATE TABLESPACE startend_tbs2 LOCATION '/home/omm/startend_tbs2';
CREATE TABLESPACE startend_tbs3 LOCATION '/home/omm/startend_tbs3';
CREATE TABLESPACE startend_tbs4 LOCATION '/home/omm/startend_tbs4';
-- Create a temporary schema.
CREATE SCHEMA tpcds;
SET CURRENT_SCHEMA TO tpcds;
-- Create a partitioned table with the partition key of the integer type.
CREATE TABLE tpcds.startend_pt (c1 INT, c2 INT)
TABLESPACE startend_tbs1
PARTITION BY RANGE (c2) (
    PARTITION p1 START(1) END(1000) EVERY(200) TABLESPACE startend_tbs2,
    PARTITION p2 END(2000),
    PARTITION p3 START(2000) END(2500) TABLESPACE startend_tbs3,
    PARTITION p4 START(2500),
    PARTITION p5 START(3000) END(5000) EVERY(1000) TABLESPACE startend_tbs4
)
ENABLE ROW MOVEMENT;

-- View the information of the partitioned table.
gaussdb=# SELECT relname, boundaries, spcname FROM pg_partition p JOIN pg_tablespace t ON
    p.reltablespace=t.oid and p.parentid='tpcds.startend_pt'::regclass ORDER BY 1;
relname | boundaries | spcname
-------------+------------+---------------
p1_0 | {1} | startend_tbs2
p1_1 | {201} | startend_tbs2
p1_2 | {401} | startend_tbs2
p1_3 | {601} | startend_tbs2
p1_4 | {801} | startend_tbs2
p1_5 | {1000} | startend_tbs2
p2 | {2000} | startend_tbs1
```

```
p3 | {2500} | startend_tbs3
p4 | {3000} | startend_tbs1
p5_1 | {4000} | startend_tbs4
p5_2 | {5000} | startend_tbs4
startend_pt | | startend_tbs1
(12 rows)
```

3.2.2.2 Hash Partitioning

Hash partitioning uses a hash algorithm to map data to partitions based on partition keys. The GaussDB Kernel built-in hash algorithm is used. When the value range of partition keys has no data skew, the hash algorithm evenly distributes rows among partitions to ensure that the partition sizes are roughly the same. Therefore, hash partitioning is an ideal method for evenly distributing data among partitions. Hash partitioning is also an easy-to-use alternative to range partitioning, especially when the data to be partitioned is not historical data or has no obvious partition key. The following is an example:

```
CREATE TABLE bmsql_order_line (
    ol_w_id          INTEGER   NOT NULL,
    ol_d_id          INTEGER   NOT NULL,
    ol_o_id          INTEGER   NOT NULL,
    ol_number        INTEGER   NOT NULL,
    ol_i_id          INTEGER   NOT NULL,
    ol_delivery_d    TIMESTAMP,
    ol_amount        DECIMAL(6,2),
    ol_supply_w_id   INTEGER,
    ol_quantity      INTEGER,
    ol_dist_info     CHAR(24)
)
-- Define 100 partitions.
PARTITION BY HASH(ol_d_id)
(
    PARTITION p0,
    PARTITION p1,
    PARTITION p2,
    …
    PARTITION p99
);
```

In the preceding example, the **bmsql_order_line** table is partitioned by the **ol_d_id** column. The **ol_d_id** column is an identifier column and does not distinguish time or a specific dimension. Using the hash partitioning policy to divide tables is an ideal choice. Compared with other partitioning types, it ensures that the partition key does not have too much data skew (one or more values are highly repeated), and you only need to specify the partition key and the number of partitions to be created. In addition, data in each partition is evenly distributed, improving usability of partitioned tables.

3.2.2.3 List Partitioning

List partitioning can explicitly control how rows are mapped to partitions by specifying a list of discrete values for the partition key in the description for each partition. The advantages of list partitioning are that data can be partitioned by enumerating partition values, and unordered and irrelevant datasets can be grouped and organized. For partition key values that are not defined in the list, you can use the default partition (DEFAULT) to save data. In this way, all rows that are not mapped to any other partition do not generate errors. Example:

```
CREATE TABLE bmsql_order_line (
    ol_w_id          INTEGER   NOT NULL,
    ol_d_id          INTEGER    NOT NULL,
    ol_o_id          INTEGER    NOT NULL,
    ol_number        INTEGER    NOT NULL,
    ol_i_id          INTEGER    NOT NULL,
    ol_delivery_d    TIMESTAMP,
    ol_amount        DECIMAL(6,2),
    ol_supply_w_id   INTEGER,
    ol_quantity      INTEGER,
    ol_dist_info     CHAR(24)
)
PARTITION BY LIST(ol_d_id)
(
    PARTITION p0 VALUES (1,4,7),
    PARTITION p1 VALUES (2,5,8),
    PARTITION p2 VALUES (3,6,9),
    PARTITION p3 VALUES (DEFAULT)
);
```

The preceding example is similar to that of hash partitioning. The **ol_d_id** column is used for partitioning. However, list partitioning limits a possible range of **ol_d_id** values, and data that is not in the list enters the **p3** partition (DEFAULT). Compared with hash partitioning, list partitioning has better control over partition keys and can accurately store target data in the expected partitions. However, if there are a large number of list values, it is difficult to define partitions. In this case, hash partitioning is recommended. List partitioning and hash partitioning are used to group and organize unordered and irrelevant datasets.

CAUTION

List partitioning supports a partition key with up to 16 columns. For one-column partition keys, the enumerated values in the list cannot be NULL during partition defining. For multi-column partition keys, the enumerated values in the list can be NULL during partition defining.

3.2.2.4 Impact of Partitioned Tables on Import Performance

In the GaussDB Kernel kernel implementation, compared with the non-partitioned table, the partitioned table has partition routing overheads during data insertion. The overall data insertion overheads include: (1) heap base table insertion and (2) partition routing. The heap base table insertion solves the problem of importing tuples to the corresponding heap table and is shared by ordinary tables and partitioned tables. The partition routing solves the problem that the tuple is inserted into the corresponding partRel.

Therefore, data insertion optimization focuses on the following aspects:

1. Heap base table insertion in a partitioned table:
   a. The operator noise floor is optimized.
   b. Heap data insertion is optimized.
   c. Index insertion build (with indexes) is optimized.
2. Partition routing in a partitioned table:
   a. The logic of the routing search algorithm is optimized.
   b. The routing noise floor is optimized, including enabling the partRel handle of the partitioned table and adding the logic overhead of function calling.

NOTE

The performance of partition routing is reflected by a single INSERT statement with a large amount of data. In the UPDATE scenario, the system searches for the tuple to be updated, deletes the tuple, and then inserts new tuple. Therefore, the performance is not as good as that of a single INSERT statement.

Table 3-1 shows the routing algorithm logic of different partitioning types.

Table 3-1 Routing algorithm logic

Partitioning Type	Routing Algorithm Complexity	Implementation Description
Range partitioning	O(logN)	Implemented based on binary search
Interval partitioning	O(logN)	Implemented based on binary search
Hash partitioning	O(1)	Implemented based on the key-partOid hash table
List partitioning	O(1)	Implemented based on the key-partOid hash table

CAUTION

The main processing logic of routing is to calculate the partition where the imported data tuple is located based on the partition key. Compared with a non-partitioned table, this part is an extra overhead. The performance loss caused by this overhead in the final data import is related to the CPU processing capability of the server, table width, and actual disk/memory capacity. Generally, it can be roughly considered that:

- In the x86 server scenario, the import performance of a partitioned table is 10% lower than that of an ordinary table.
- In the Arm server scenario, the performance decreases by 20%. The main reason is that routing is performed in the in-memory computing enhancement scenario. The single-core instruction processing capability of mainstream x86 CPUs is slightly better than that of Arm CPUs.

3.2.3 Basic Usage of Partitions

3.2.3.1 Creating Partitioned Tables

Creating Partitioned Tables

The SQL syntax tree is complex due to the powerful and flexible functions of the SQL language. So do partitioned tables. The creation of a partitioned table can be regarded as adding partition attributes to the original non-partitioned table.

Therefore, the syntax interface of a partitioned table can be regarded to extend the CREATE TABLE statement of a non-partitioned table with a PARTITION BY clause and specify the following three core elements related to the partition:

1. **partType**: describes the partitioning policy of a partitioned table. The options are **RANGE**, **INTERVAL**, **LIST**, and **HASH**.
2. **partKey**: describes the partition key of a partitioned table. Currently, range and list partitioning supports a partition key with up to 16 columns, while hash partitioning supports a one-column partition key only.
3. **partExpr**: describes the specific partitioning type of a partitioned table, that is, the mapping between key values and partitions.

The three elements are reflected in the PARTITION BY clause of the CREATE TABLE statement, for example, **PARTITION BY** *partType* (*partKey*) (*partExpr[,partExpr]***...)**. Example:

```
CREATE TABLE [ IF NOT EXISTS ] partition_table_name
(
    [ /* Inherited from the CREATE TABLE statement of an ordinary table */
    { column_name data_type [ COLLATE collation ] [ column_constraint [ ... ] ]
    | table_constraint
    | LIKE source_table [ like_option [...] ] }[, ... ]
    ]
)
[ WITH ( {storage_parameter = value} [, ... ] ) ]
[ COMPRESS | NOCOMPRESS ]
[ TABLESPACE tablespace_name ]
/* Range partitioning */
PARTITION BY RANGE (partKey) [ INTERVAL ('interval_expr') [ STORE IN (tablespace_name [, ... ] ) ] ] (
    partition_start_end_item [, ... ]
    partition_less_then_item [, ... ]
)
/* List partitioning */
PARTITION BY LIST (partKey)
(
    PARTITION partition_name VALUES (list_values_clause) [ TABLESPACE tablespace_name [, ... ] ]
...
)
/* Hash partitioning */
PARTITION BY HASH (partKey) (
    PARTITION partition_name [ TABLESPACE tablespace_name [, ... ] ]
...
)
/* Enable or disable row migration for a partitioned table. */
[ { ENABLE | DISABLE } ROW MOVEMENT ];
```

Restrictions

1. Range and list partitioning supports a partition key with up to 16 columns. Hash partitioning supports a one-column partition key only.
2. The partition key value cannot be null except for hash partitioning. Otherwise, the DML statement reports an error. The only exception is the MAXVALUE partition defined for a range partitioned table and the DEFAULT partition defined for a list partitioned table.
3. The maximum number of partitions is 1048575, which can meet the requirements of most service scenarios. If the number of partitions increases, the number of files in the system increases, which affects the system performance. It is recommended that the number of partitions for a single table be less than or equal to 200.

Modifying Partition Attributes

You can run the **ALTER TABLE** command similar to that of a non-partitioned table to modify attributes related to partitioned tables and partitions. Common statements for modifying partition attributes are as follows:

1. ADD PARTITION
2. DROP PARTITION
3. TRUNCATE PARTITION
4. SPLIT PARTITION
5. MERGE PARTITION
6. MOVE PARTITION
7. EXCHANGE PARTITION
8. RENAME PARTITION

The preceding statements for modifying partition attributes are extended based on the ALTER TABLE statement of an ordinary table. Most of the statements are used in a similar way. The following is an example of the basic syntax framework for modifying partitioned table attributes:

```
/* Basic ALTER TABLE syntax */
ALTER TABLE [ IF EXISTS ] { table_name [*] | ONLY table_name | ONLY ( table_name )}
action [, ... ];
```

For details about how to use the ALTER TABLE statement, see **Partitioned Table O&M Management** and section "SQL Reference > SQL Syntax > ALTER TABLE PARTITION" in *Developer Guide*.

3.2.3.2 DML Statements for Querying Partitioned Tables

Partitioning is implemented in the database kernel. Therefore, users can query partitioned tables and non-partitioned tables using the same syntax except for querying specified partitions.

For ease of use of partitioned tables, GaussDB Kernel allows you to query specified partitions using **PARTITION (partname)** or **PARTITION FOR (partvalue)**. The DML statements for specifying partitions are as follows:

1. SELECT
2. INSERT
3. UPDATE
4. DELETE
5. UPSERT
6. MERGE INTO

The following is an example of DML statements for specifying partitions:

```
/* Create a partitioned table list_02. */
CREATE TABLE IF NOT EXISTS list_02
(
    id   INT,
    role VARCHAR(100),
    data VARCHAR(100)
)
PARTITION BY LIST (id)
(
    PARTITION p_list_2 VALUES(0,1,2,3,4,5,6,7,8,9),
    PARTITION p_list_3 VALUES(10,11,12,13,14,15,16,17,18,19),
    PARTITION p_list_4 VALUES( DEFAULT ),
    PARTITION p_list_5 VALUES(20,21,22,23,24,25,26,27,28,29),
    PARTITION p_list_6 VALUES(30,31,32,33,34,35,36,37,38,39),
    PARTITION p_list_7 VALUES(40,41,42,43,44,45,46,47,48,49)
) ENABLE ROW MOVEMENT;
/* Import data. */
INSERT INTO list_02 VALUES(null, 'alice', 'alice data');
INSERT INTO list_02 VALUES(2, null, 'bob data');
INSERT INTO list_02 VALUES(null, null, 'peter data');

/* Query a specified partition. */
-- Query all data in a partitioned table.
gaussdb=# SELECT * FROM list_02 ORDER BY data;
 id | role  |    data
----+-------+------------
    | alice | alice data
  2 |       | bob data
    |       | peter data
(3 rows)
-- Query data in the p_list_2 partition.
gaussdb=# SELECT * FROM list_02 PARTITION (p_list_2) ORDER BY data;
 id | role |   data
----+------+----------
  2 |      | bob data
(1 row)
-- Query the data of the partition corresponding to (100), that is, partition p_list_4.
gaussdb=# SELECT * FROM list_02 PARTITION FOR (100) ORDER BY data;
 id | role  |    data
----+-------+------------
    | alice | alice data
    |       | peter data
(2 rows)

/* Perform INSERT, UPDATE, and DELETE (IUD) operations on the specified partition. */
-- Delete all data from the p_list_5 partition.
gaussdb=# DELETE FROM list_02 PARTITION (p_list_5);
-- Insert data into the specified partition p_list_7. An error is reported because the data does not comply
with the partitioning restrictions.
gaussdb=# INSERT INTO list_02 PARTITION (p_list_7) VALUES(null, 'cherry', 'cherry data');
ERROR:  inserted partition key does not map to the table partition
-- Update the data of the partition to which the partition value 100 belongs, that is, partition p_list_4.
gaussdb=# UPDATE list_02 PARTITION FOR (100) SET data = '';
```

3.3 Partitioned Table Query Optimization

3.3.1 Partition Pruning

3.3.1.1 Static Partition Pruning

For partitioned table query statements with constants in the search criteria, the search criteria contained in operators such as index scan, bitmap index scan, and index-only scan are used as pruning conditions in the optimizer phase to filter partitions. The search criteria must contain at least one partition key. For a partitioned table with a multi-column partition key, the search criteria can contain any column of the partition key.

Static pruning is supported in the following scenarios:

1. Supported partitioning types: range partitioning, hash partitioning, and list partitioning.

2. Supported expression types: comparison expression (<, <=, =, >=, >), logical expression, and array expression.

CAUTION

Currently, static pruning does not support subquery expressions.

- Typical scenarios where static pruning is supported are as follows:
  a. Comparison expressions

```
-- Create a partitioned table.
CREATE TABLE t1 (c1 int, c2 int)
PARTITION BY RANGE (c1)
(
    PARTITION p1 VALUES LESS THAN(10),
    PARTITION p2 VALUES LESS THAN(20),
    PARTITION p3 VALUES LESS THAN(MAXVALUE)
);
SET max_datanode_for_plan = 1;

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 = 1;
                        QUERY PLAN
-----------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: datanode1
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = 1

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = 1
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = 1)
           Selected Partitions:  1

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 < 1;
                        QUERY PLAN
-----------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 < 1

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 < 1
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 < 1)
           Selected Partitions:  1

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 > 11;
                        QUERY PLAN
------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 > 11

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 > 11
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 2
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 > 11)
           Selected Partitions:  2..3

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 is NULL;
                          QUERY PLAN
------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: datanode1
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 IS NULL

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 IS NULL
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 IS NULL)
           Selected Partitions:  3

(15 rows)
```

b. Logical expressions

```
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 = 1 AND c2 = 2;
                              QUERY PLAN
-------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: datanode1
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = 1 AND c2 = 2

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = 1 AND c2 = 2
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: ((t1.c1 = 1) AND (t1.c2 = 2))
           Selected Partitions:  1

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 = 1 OR c1 = 2;
                             QUERY PLAN
------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = 1 OR c1 = 2

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = 1 OR c1 = 2
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: ((t1.c1 = 1) OR (t1.c1 = 2))
           Selected Partitions:  1

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE NOT c1 = 1;
                          QUERY PLAN
----------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE NOT c1 = 1

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE NOT c1 = 1
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 3
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 <> 1)
           Selected Partitions:  1..3

(15 rows)
```

c. Array expressions

```
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 IN (1, 2, 3);
                                 QUERY PLAN
-------------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = ANY (ARRAY[1, 2, 3])

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = ANY (ARRAY[1, 2, 3])
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = ANY ('{1,2,3}'::integer[]))
           Selected Partitions:  1

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 = ALL(ARRAY[1,
2, 3]);
                                 QUERY PLAN
-------------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = ALL (ARRAY[1, 2, 3])

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = ALL (ARRAY[1, 2, 3])
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 0
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = ALL ('{1,2,3}'::integer[]))
           Selected Partitions:  NONE

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 = ANY(ARRAY[1,
2, 3]);
                                 QUERY PLAN
```

```
-------------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = ANY (ARRAY[1, 2, 3])

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = ANY (ARRAY[1, 2, 3])
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = ANY ('{1,2,3}'::integer[]))
           Selected Partitions:  1

(15 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 =
SOME(ARRAY[1, 2, 3]);
                                  QUERY PLAN
-------------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = ANY (ARRAY[1, 2, 3])

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = ANY (ARRAY[1, 2, 3])
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 1
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = ANY ('{1,2,3}'::integer[]))
           Selected Partitions:  1

(15 rows)
```

- Typical scenarios where static pruning is not supported are as follows:

  a. Subquery expressions

```
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 WHERE c1 = ALL(SELECT c2
FROM t1 WHERE c1 > 10);
                               QUERY PLAN
-------------------------------------------------------------------------
 Streaming (type: GATHER)
   Output: public.t1.c1, public.t1.c2
   Node/s: All datanodes
   ->  Partition Iterator
         Output: public.t1.c1, public.t1.c2
         Iterations: 3
         ->  Partitioned Seq Scan on public.t1
               Output: public.t1.c1, public.t1.c2
               Distribute Key: public.t1.c1
               Filter: (SubPlan 1)
               Selected Partitions:  1..3
               SubPlan 1
                 ->  Materialize
                       Output: public.t1.c2
                       ->  Streaming(type: BROADCAST)
                             Output: public.t1.c2
                             Spawn on: All datanodes
                             Consumer Nodes: All datanodes
                             ->  Partition Iterator
                                   Output: public.t1.c2
                                   Iterations: 2
                                   ->  Partitioned Seq Scan on public.t1
                                         Output: public.t1.c2
                                         Distribute Key: public.t1.c1
```

```
                    Filter: (public.t1.c1 > 10)
                    Selected Partitions:  2..3
(26 rows)
```

3.3.1.2 Dynamic Partition Pruning

If a partitioned table query statement with variables exists in the search criteria, the optimizer cannot obtain the bound parameters of the user. Therefore, only the search criteria of operators such as index scan, bitmap index scan, and index-only scan can be parsed in the optimizer phase. After the bound parameters are obtained in the executor phase, the partition filtering is complete. The search criteria must contain at least one partition key. For a partitioned table with a multi-column partition key, the search criteria can contain any column of the partition key. Currently, dynamic partition pruning supports only the parse-bind-execute (PBE) and parameterized path scenarios.

3.3.1.2.1 Dynamic PBE Pruning

Dynamic PBE pruning is supported in the following scenarios:

1. Supported partitioning types: range partitioning, hash partitioning, and list partitioning.
2. Supported expression types: comparison expression (<, <=, =, >=, >), logical expression, and array expression.
3. Supported conversions and functions: some implicit type conversions and the IMMUTABLE function.

CAUTION

- Dynamic PBE pruning supports expressions, implicit conversions, the IMMUTABLE function, and the STABLE function, but does not support subquery expressions or VOLATILE function. For the STABLE function, type conversion functions such as **to_timestamp** may be affected by GUC parameters and lead to different pruning results. To ensure performance optimization, you can analyze table to regenerate a generic plan.
- Dynamic PBE pruning is based on the generic plan. Therefore, when determining whether a statement can be dynamically pruned, you need to set **plan_cache_mode** to **'force_generic_plan'** to eliminate the interference of the custom plan.

- Typical scenarios where dynamic PBE pruning is supported are as follows:
  a. Comparison expressions

```
-- Create a partitioned table.
CREATE TABLE t1 (c1 int, c2 int)
PARTITION BY RANGE (c1)
(
    PARTITION p1 VALUES LESS THAN(10),
    PARTITION p2 VALUES LESS THAN(20),
    PARTITION p3 VALUES LESS THAN(MAXVALUE)
);

gaussdb=# PREPARE p1(int) AS SELECT * FROM t1 WHERE c1 = $1;
PREPARE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) EXECUTE p1(1);
                         QUERY PLAN
```

```
------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: datanode1
   Node expr: $1
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = $1

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = $1
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: PART
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = $1)
           Selected Partitions:  1 (pbe-pruning)

(16 rows)
```

b. Logical expressions

```
gaussdb=# PREPARE p2(INT, INT) AS SELECT * FROM t1 WHERE c1 = $1 AND c2 = $2;
PREPARE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) EXECUTE p2(1, 2);
                              QUERY PLAN
------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: datanode1
   Node expr: $1
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = $1 AND c2 = $2

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = $1 AND c2 = $2
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: PART
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: ((t1.c1 = $1) AND (t1.c2 = $2))
           Selected Partitions:  1 (pbe-pruning)

(16 rows)
```

c. Implicit type conversion

```
gaussdb=# set plan_cache_mode = 'force_generic_plan';
gaussdb=# PREPARE p3(TEXT) AS SELECT * FROM t1 WHERE c1 = $1;
PREPARE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) EXECUTE p3('12');
                            QUERY PLAN
--------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: datanode1
   Node expr: $1
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1 = $1::bigint

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1 = $1::bigint
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: PART
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: (t1.c1 = ($1)::bigint)
           Selected Partitions:  2 (pbe-pruning)

(16 rows)
```

- Typical scenarios where dynamic PBE pruning is not supported are as follows:

a. Subquery expressions

```
gaussdb=# PREPARE p4(INT) AS SELECT * FROM t1 WHERE c1 = ALL(SELECT c2 FROM t1
WHERE c1 > $1);
PREPARE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) EXECUTE p4(1);
                              QUERY PLAN
-------------------------------------------------------------------------
 Streaming (type: GATHER)
   Output: public.t1.c1, public.t1.c2
   Node/s: All datanodes
   ->  Partition Iterator
         Output: public.t1.c1, public.t1.c2
         Iterations: 3
         ->  Partitioned Seq Scan on public.t1
               Output: public.t1.c1, public.t1.c2
               Distribute Key: public.t1.c1
               Filter: (SubPlan 1)
               Selected Partitions:  1..3
               SubPlan 1
                 ->  Materialize
                       Output: public.t1.c2
                       ->  Streaming(type: BROADCAST)
                             Output: public.t1.c2
                             Spawn on: All datanodes
                             Consumer Nodes: All datanodes
                             ->  Partition Iterator
                                   Output: public.t1.c2
                                   Iterations: 3
                                   ->  Partitioned Seq Scan on public.t1
                                         Output: public.t1.c2
                                         Distribute Key: public.t1.c1
                                         Filter: (public.t1.c1 > 1)
                                         Selected Partitions:  1..3
(26 rows)
```

b. Implicit type conversion failure

```
gaussdb=# PREPARE p5(name) AS SELECT * FROM t1 WHERE c1 = $1;
PREPARE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) EXECUTE p5('12');
                               QUERY PLAN
-------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM public.t1 WHERE c1::text = '12'::text

 Remote SQL: SELECT c1, c2 FROM public.t1 WHERE c1::text = '12'::text
 Datanode Name: datanode1
   Partition Iterator
     Output: c1, c2
     Iterations: 3
     ->  Partitioned Seq Scan on public.t1
           Output: c1, c2
           Filter: ((t1.c1)::text = '12'::text)
           Selected Partitions:  1..3

(15 rows)
```

c. STABLE and VOLATILE functions

```
gaussdb=# create sequence seq;
gaussdb=# PREPARE p6(TEXT) AS SELECT * FROM t1 WHERE c1 = currval($1);-- The VOLATILE
function does not support pruning.
PREPARE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) EXECUTE p6('seq');
                                QUERY PLAN
---------------------------------------------------------------------------
 Data Node Scan
   Output: t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT c1, c2 FROM ONLY public.t1 WHERE true
```

```
  Coordinator quals: ((t1.c1)::numeric = curval(('seq'::text)::regclass))

Remote SQL: SELECT c1, c2 FROM ONLY public.t1 WHERE true
Datanode Name: datanode1
  Partition Iterator
    Output: c1, c2
    Iterations: 3
    ->  Partitioned Seq Scan on public.t1
          Output: c1, c2
          Selected Partitions:  1..3

(15 rows)
```

3.3.1.2.2 Dynamic Parameterized Path Pruning

Dynamic parameterized path pruning is supported in the following scenarios:

1. Supported partitioning types: range partitioning, hash partitioning, and list partitioning.
2. Supported operator types: index scan, index-only scan, and bitmap scan.
3. Supported expression types: comparison expression (<, <=, =, >=, >) and logical expression.

CAUTION

Dynamic parameterized path pruning does not support subquery expressions, STABLE and VOLATILE functions, cross-QueryBlock parameterized paths, bitmapOr operator, or bitmapAnd operator.

- Typical scenarios where dynamic parameterized path pruning is supported are as follows:
  a. Comparison expressions

```
-- Create partitioned tables and indexes.
CREATE TABLE t1 (c1 INT, c2 INT)
PARTITION BY RANGE (c1)
(
    PARTITION p1 VALUES LESS THAN(10),
    PARTITION p2 VALUES LESS THAN(20),
    PARTITION p3 VALUES LESS THAN(MAXVALUE)
);
CREATE TABLE t2 (c1 INT, c2 INT)
PARTITION BY RANGE (c1)
(
    PARTITION p1 VALUES LESS THAN(10),
    PARTITION p2 VALUES LESS THAN(20),
    PARTITION p3 VALUES LESS THAN(MAXVALUE)
);
CREATE INDEX t1_c1 ON t1(c1) LOCAL;
CREATE INDEX t2_c1 ON t2(c1) LOCAL;
CREATE INDEX t1_c2 ON t1(c2) LOCAL;
CREATE INDEX t2_c2 ON t2(c2) LOCAL;

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT /*+ nestloop(t1 t2) indexscan(t1)
indexscan(t2) */ * FROM t2 JOIN t1 ON t1.c1 = t2.c1;
                                                    QUERY
PLAN
------------------------------------------------------------------------------------------------------------------
----------------------------------
 Data Node Scan
   Output: t2.c1, t2.c2, t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT/*+ NestLoop(t1 t2) IndexScan(t1) IndexScan(t2)*/ t2.c1, t2.c2, t1.c1,
t1.c2 FROM public.t2 JOIN public.t1 ON t1.c1 = t2.c1

 Remote SQL: SELECT/*+ NestLoop(t1 t2) IndexScan(t1) IndexScan(t2)*/ t2.c1, t2.c2, t1.c1, t1.c2
FROM public.t2 JOIN public.t1 ON t1.c1 = t2.c1
 Datanode Name: datanode1
   Nested Loop
     Output: t2.c1, t2.c2, t1.c1, t1.c2
     ->  Partition Iterator
           Output: t2.c1, t2.c2
           Iterations: 3
           ->  Partitioned Index Scan using t2_c1 on public.t2
                 Output: t2.c1, t2.c2
                 Selected Partitions:  1..3
     ->  Partition Iterator
           Output: t1.c1, t1.c2
           Iterations: PART
           ->  Partitioned Index Scan using t1_c1 on public.t1
                 Output: t1.c1, t1.c2
                 Index Cond: (t1.c1 = t2.c1)
                 Selected Partitions:  1 (ppi-pruning)

(23 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT /*+ nestloop(t1 t2) indexscan(t1)
indexscan(t2) */ * FROM t2 JOIN t1 ON t1.c1 < t2.c1;
                            QUERY PLAN
--------------------------------------------------------------------
 Streaming (type: GATHER)
   Output: t2.c1, t2.c2, t1.c1, t1.c2
   Node/s: All datanodes
   ->  Nested Loop
         Output: t2.c1, t2.c2, t1.c1, t1.c2
         ->  Streaming(type: BROADCAST)
               Output: t2.c1, t2.c2
               Spawn on: All datanodes
               Consumer Nodes: All datanodes
               ->  Partition Iterator
                     Output: t2.c1, t2.c2
                     Iterations: 3
                     ->  Partitioned Seq Scan on public.t2
                           Output: t2.c1, t2.c2
                           Distribute Key: t2.c1
                           Selected Partitions:  1..3
         ->  Partition Iterator
               Output: t1.c1, t1.c2
               Iterations: PART
               ->  Partitioned Index Scan using t1_c1 on public.t1
                     Output: t1.c1, t1.c2
                     Distribute Key: t1.c1
                     Index Cond: (t1.c1 < t2.c1)
                     Selected Partitions:  1 (ppi-pruning)
(24 rows)

gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT /*+ nestloop(t1 t2) indexscan(t1)
indexscan(t2) */ * FROM t2 JOIN t1 ON t1.c1 < t2.c1;
                            QUERY PLAN
--------------------------------------------------------------------
 Streaming (type: GATHER)
   Output: t2.c1, t2.c2, t1.c1, t1.c2
   Node/s: All datanodes
   ->  Nested Loop
         Output: t2.c1, t2.c2, t1.c1, t1.c2
         ->  Streaming(type: BROADCAST)
               Output: t2.c1, t2.c2
               Spawn on: All datanodes
               Consumer Nodes: All datanodes
               ->  Partition Iterator
                     Output: t2.c1, t2.c2
```

```
                    Iterations: 3
                    ->  Partitioned Seq Scan on public.t2
                          Output: t2.c1, t2.c2
                          Distribute Key: t2.c1
                          Selected Partitions:  1..3
        ->  Partition Iterator
              Output: t1.c1, t1.c2
              Iterations: PART
              ->  Partitioned Index Scan using t1_c1 on public.t1
                    Output: t1.c1, t1.c2
                    Distribute Key: t1.c1
                    Index Cond: (t1.c1 > t2.c1)
                    Selected Partitions:  1..3 (ppi-pruning)
(24 rows)
```

b. Logical expressions

```
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT /*+ nestloop(t1 t2) indexscan(t1)
indexscan(t2) */ * FROM t2 JOIN t1 ON t1.c1 = t2.c1 AND t1.c2 = 2;
                                                                          QUERY
PLAN
--------------------------------------------------------------------------------------------------------------------
------------------------------------------------
 Data Node Scan
   Output: t2.c1, t2.c2, t1.c1, t1.c2
   Node/s: All datanodes
   Remote query: SELECT/*+ NestLoop(t1 t2) IndexScan(t1) IndexScan(t2)*/ t2.c1, t2.c2, t1.c1,
t1.c2 FROM public.t2 JOIN public.t1 ON t1.c1 = t2.c1 AND t1.c2 = 2

 Remote SQL: SELECT/*+ NestLoop(t1 t2) IndexScan(t1) IndexScan(t2)*/ t2.c1, t2.c2, t1.c1, t1.c2
FROM public.t2 JOIN public.t1 ON t1.c1 = t2.c1 AND t1.c2 = 2
 Datanode Name: datanode1
   Nested Loop
     Output: t2.c1, t2.c2, t1.c1, t1.c2
     ->  Partition Iterator
           Output: t1.c1, t1.c2
           Iterations: 3
           ->  Partitioned Index Scan using t1_c2 on public.t1
                 Output: t1.c1, t1.c2
                 Index Cond: (t1.c2 = 2)
                 Selected Partitions:  1..3
     ->  Partition Iterator
           Output: t2.c1, t2.c2
           Iterations: PART
           ->  Partitioned Index Scan using t2_c1 on public.t2
                 Output: t2.c1, t2.c2
                 Index Cond: (t2.c1 = t1.c1)
                 Selected Partitions:  1..3 (ppi-pruning)

(24 rows)
```

- Typical scenarios where dynamic parameterized path pruning is not supported are as follows:

a. BitmapOr and BitmapAnd operators

```
gaussdb=# set enable_seqscan=off;
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT /*+ nestloop(t1 t2) */ * FROM t2 JOIN
t1 ON t1.c1 = t2.c1 OR t1.c2 = 2;
                              QUERY PLAN
---------------------------------------------------------------------
 Streaming (type: GATHER)
   Output: t2.c1, t2.c2, t1.c1, t1.c2
   Node/s: All datanodes
   ->  Nested Loop
         Output: t2.c1, t2.c2, t1.c1, t1.c2
         ->  Streaming(type: BROADCAST)
               Output: t2.c1, t2.c2
               Spawn on: All datanodes
               Consumer Nodes: All datanodes
               ->  Partition Iterator
                     Output: t2.c1, t2.c2
                     Iterations: 3
                     ->  Partitioned Seq Scan on public.t2
                           Output: t2.c1, t2.c2
                           Distribute Key: t2.c1
                           Selected Partitions:  1..3
         ->  Partition Iterator
               Output: t1.c1, t1.c2
               Iterations: 3
               ->  Partitioned Bitmap Heap Scan on public.t1
                     Output: t1.c1, t1.c2
                     Distribute Key: t1.c1
                     Recheck Cond: ((t1.c1 = t2.c1) OR (t1.c2 = 2))
                     Selected Partitions:  1..3
                     ->  BitmapOr
                           ->  Partitioned Bitmap Index Scan on t1_c1
                                 Index Cond: (t1.c1 = t2.c1)
                                 Selected Partitions:  1..3
                           ->  Partitioned Bitmap Index Scan on t1_c2
                                 Index Cond: (t1.c2 = 2)
                                 Selected Partitions:  1..3
(31 rows)
```

b. Implicit conversion

```
gaussdb=# CREATE TABLE t3(c1 TEXT, c2 INT);
CREATE TABLE
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 JOIN t3 ON t1.c1 = t3.c1;
                         QUERY PLAN
-------------------------------------------------------------
 Nested Loop
   Output: t1.c1, t1.c2, t3.c1, t3.c2
   ->  Seq Scan on public.t3
         Output: t3.c1, t3.c2
   ->  Partition Iterator
         Output: t1.c1, t1.c2
         Iterations: 3
         ->  Partitioned Index Scan using t1_c1 on public.t1
               Output: t1.c1, t1.c2
               Index Cond: (t1.c1 = (t3.c1)::bigint)
               Selected Partitions:  1..3
(11 rows)
```

c. Functions

```
gaussdb=# EXPLAIN (VERBOSE ON, COSTS OFF) SELECT * FROM t1 JOIN t3 ON t1.c1 =
LENGTHB(t3.c1);
                         QUERY PLAN
-------------------------------------------------------------
 Nested Loop
   Output: t1.c1, t1.c2, t3.c1, t3.c2
   ->  Seq Scan on public.t3
         Output: t3.c1, t3.c2
   ->  Partition Iterator
         Output: t1.c1, t1.c2
         Iterations: 3
         ->  Partitioned Index Scan using t1_c1 on public.t1
               Output: t1.c1, t1.c2
               Index Cond: (t1.c1 = lengthb(t3.c1))
               Selected Partitions:  1..3
(11 rows)
```

3.3.2 Partitioned Indexes

There are three types of indexes on a partitioned table:

1. Global non-partitioned index
2. Global partitioned index
3. Local partitioned index

Currently, GaussDB Kernel supports the global non-partitioned index and local partitioned index.

Figure 3-3 Global non-partitioned index

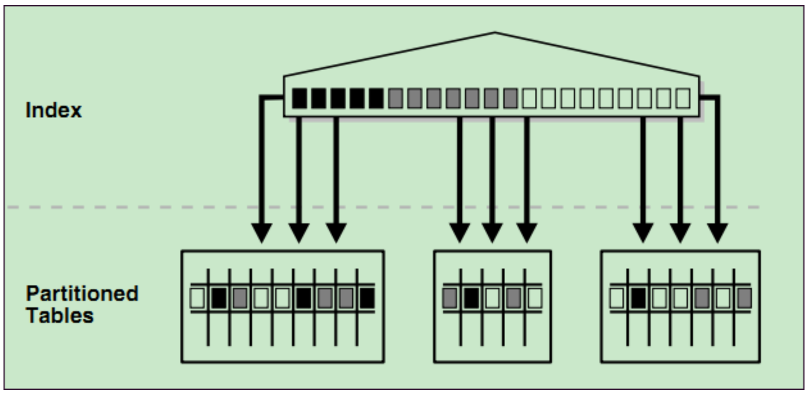


Figure 3-4 Global partitioned index

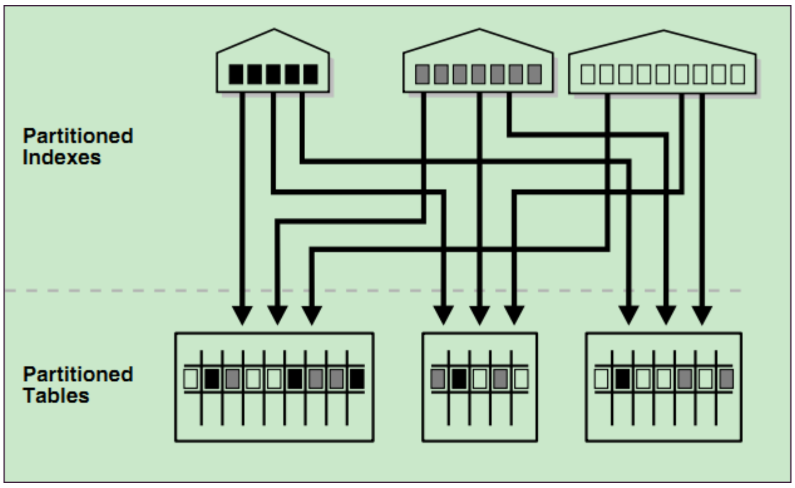
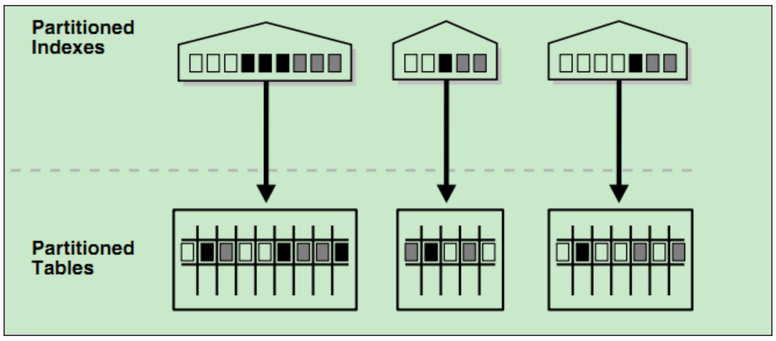


Figure 3-5 Local partitioned index



Constraints

- Partitioned indexes are classified into local indexes and global indexes. A local index binds to a specific partition, and a global index corresponds to the entire partitioned table.

- If the constraint key of the unique constraint and primary key constraint contains all partition keys, a local index is created for the constraints. Otherwise, a global index is created.

NOTE

If the query statement involves multiple partitions, you are advised to use the global index. Otherwise, you are advised to use the local index. However, note that the global index has extra overhead in the partition maintenance syntax.

Examples

- Create a table.
```
CREATE TABLE web_returns_p2
(
    ca_address_sk INTEGER NOT NULL ,
    ca_address_id CHARACTER(16) NOT NULL ,
    ca_street_number CHARACTER(10) ,
    ca_street_name CHARACTER VARYING(60) ,
    ca_street_type CHARACTER(15) ,
    ca_suite_number CHARACTER(10) ,
    ca_city CHARACTER VARYING(60) ,
    ca_county CHARACTER VARYING(30) ,
    ca_state CHARACTER(2) ,
    ca_zip CHARACTER(10) ,
    ca_country CHARACTER VARYING(20) ,
    ca_gmt_offset NUMERIC(5,2) ,
    ca_location_type CHARACTER(20)
)
PARTITION BY RANGE (ca_address_sk)
(
    PARTITION P1 VALUES LESS THAN(5000),
    PARTITION P2 VALUES LESS THAN(10000),
    PARTITION P3 VALUES LESS THAN(15000),
    PARTITION P4 VALUES LESS THAN(20000),
    PARTITION P5 VALUES LESS THAN(25000),
    PARTITION P6 VALUES LESS THAN(30000),
    PARTITION P7 VALUES LESS THAN(40000),
    PARTITION P8 VALUES LESS THAN(MAXVALUE)
)
ENABLE ROW MOVEMENT;
```
- Create an index.
  - Create the local index **tpcds_web_returns_p2_index1** without specifying the partition name.
```
gaussdb=# CREATE INDEX tpcds_web_returns_p2_index1 ON web_returns_p2 (ca_address_id)
LOCAL;
```
    If the following information is displayed, the test table has been created:
```
CREATE INDEX
```
  - Create the local index **tpcds_web_returns_p2_index2** with the specified partition name.
```
gaussdb=# CREATE INDEX tpcds_web_returns_p2_index2 ON web_returns_p2 (ca_address_sk)
LOCAL
(
    PARTITION web_returns_p2_P1_index,
    PARTITION web_returns_p2_P2_index TABLESPACE example3,
    PARTITION web_returns_p2_P3_index TABLESPACE example4,
    PARTITION web_returns_p2_P4_index,
    PARTITION web_returns_p2_P5_index,
    PARTITION web_returns_p2_P6_index,
    PARTITION web_returns_p2_P7_index,
    PARTITION web_returns_p2_P8_index
) TABLESPACE example2;
```
    If the following information is displayed, the test table has been created:

```
CREATE INDEX
```

- Create the global index **tpcds_web_returns_p2_global_index** for a partitioned table.

  ```
  gaussdb=# CREATE INDEX tpcds_web_returns_p2_global_index ON web_returns_p2
  (ca_street_number) GLOBAL;
  ```

  If the following information is displayed, the test table has been created:

  ```
  CREATE INDEX
  ```

- Modify the tablespace of an index partition.
  - Change the tablespace of index partition **web_returns_p2_P2_index** to **example1**.

    ```
    gaussdb=# ALTER INDEX tpcds_web_returns_p2_index2 MOVE PARTITION
    web_returns_p2_P2_index TABLESPACE example1;
    ```

    If the following information is displayed, the tablespace of the index partition has been modified:

    ```
    ALTER INDEX
    ```

  - Change the tablespace of index partition **web_returns_p2_P3_index** to **example2**.

    ```
    gaussdb=# ALTER INDEX tpcds_web_returns_p2_index2 MOVE PARTITION
    web_returns_p2_P3_index TABLESPACE example2;
    ```

    If the following information is displayed, the tablespace of the index partition has been modified:

    ```
    ALTER INDEX
    ```

- Rename an index partition.
  - Rename the name of index partition **web_returns_p2_P8_index** to **web_returns_p2_P8_index_new**.

    ```
    gaussdb=# ALTER INDEX tpcds_web_returns_p2_index2 RENAME PARTITION
    web_returns_p2_P8_index TO web_returns_p2_P8_index_new;
    ```

    If the following information is displayed, the index partition has been renamed:

    ```
    ALTER INDEX
    ```

- Query indexes.
  - Run the following command to query all indexes defined by the system and users:

    ```
    gaussdb=# SELECT RELNAME FROM PG_CLASS WHERE RELKIND='i' or RELKIND='I';
    ```

  - Run the following command to query information about a specified index:

    ```
    gaussdb=# \di+ tpcds_web_returns_p2_index2
    ```

- Delete an index.

  ```
  gaussdb=# DROP INDEX tpcds_web_returns_p2_index1;
  ```

  If the following information is displayed, the index has been deleted:

  ```
  DROP INDEX
  ```

3.4 Partitioned Table O&M Management

Partitioned table O&M management includes partition management, partitioned table management, partitioned index management, and partitioned table statement concurrency support.

- Partition management: also known as partition-level DDL operations, including ADD, DROP, EXCHANGE, TRUNCATE, SPLIT, MERGE, MOVE, and RENAME.

CAUTION

- For hash partitions, operations involving partition quantity change will cause data re-shuffling, including ADD, DROP, SPLIT, and MERGE. Therefore, GaussDB Kernel does not support these operations.
- Operations involving partition data change will invalidate global indexes, including DROP, EXCHANGE, TRUNCATE, SPLIT, and MERGE. You can use the UPDATE GLOBAL INDEX clause to update global indexes synchronously.

NOTE

- Most partition DDL operations use PARTITION and PARTITION FOR to specify partitions. For PARTITION, you need to specify the partition name. For PARTITION FOR, you need to specify any partition value within the partition range. For example, if the range of partition **part1** is defined as [100, 200), **partition part1** and **partition for(150)** function the same.
- The DDL execution cost varies depending on the partition. The target partition will be locked during DDL execution. Therefore, you need to evaluate the cost and impact on services. Generally, the execution cost of splitting and merging is much greater than that of other partition DDL operations and is positively correlated with the size of the source partition. The cost of exchanging is mainly caused by global index rebuilding and validation. The cost of moving is limited by disk I/O. The execution cost of other partition DDL operations is low.

- Partitioned table management: In addition to the functions inherited from ordinary tables, you can enable or disable row migration for partitioned tables.
- Partitioned index management: You can invalidate indexes or index partitions or rebuild invalid indexes or index partitions. For example, global indexes become invalid due to partition management operations.
- Partitioned table statement concurrency support: DDL operations on distributed partitioned tables lock the entire table. Cross-partition DDL-DQL/DML concurrency is not supported.

3.4.1 ADD PARTITION

You can add partitions to an existing partitioned table to maintain new services. Currently, a partitioned table can contain a maximum of 1048575 partitions. If the number of partitions reaches the upper limit, no more partitions can be added. In addition, the memory usage of partitions must be considered. Typically, the memory usage of a partitioned table is about (Number of partitions x 3/1024) MB. The memory usage of a partition cannot be greater than the value of **local_syscache_threshold**. In addition, some space must be reserved for other functions.

CAUTION

- This command cannot be applied to hash partitions.

3.4.1.1 Adding a Partition to a Range Partitioned Table

You can use ALTER TABLE ADD PARTITION to add a partition to the end of an existing partitioned table. The upper boundary of the new partition must be greater than that of the last partition.

For example, add a partition to the range partitioned table **range_sales**.

```
ALTER TABLE range_sales ADD PARTITION date_202005 VALUES LESS THAN ('2020-06-01') TABLESPACE tb1;
```

NOTICE

If a range partitioned table has the MAXVALUE partition, partitions cannot be added. You can use the ALTER TABLE SPLIT PARTITION statement to split partitions. Partition splitting is also applicable to the scenario where partitions need to be added before or in the middle of an existing partitioned table.

3.4.1.2 Adding a Partition to a List Partitioned Table

You can use ALTER TABLE ADD PARTITION to add a partition to a list partitioned table. The enumerated values of the new partition cannot be the same as those of any existing partition.

For example, add a partition to the list partitioned table **list_sales**.

```
ALTER TABLE list_sales ADD PARTITION channel5 VALUES ('X') TABLESPACE tb1;
```

NOTICE

If a list partitioned table has the DEFAULT partition, partitions cannot be added. You can use the ALTER TABLE SPLIT PARTITION statement to split partitions.

3.4.2 DROP PARTITION

You can run this command to remove unnecessary partitions. You can delete a partition by specifying the partition name or partition value.

⚠ CAUTION

- This command cannot be applied to hash partitions.
- Running this command will invalidate the global index. You can use the UPDATE GLOBAL INDEX clause to update the global index synchronously or rebuild the global index.

You can use ALTER TABLE DROP PARTITION to delete any partition from a range partitioned table or list partitioned table.

For example, delete the partition **date_202005** from the range partitioned table **range_sales** by specifying the partition name and update the global index.

```
ALTER TABLE range_sales DROP PARTITION date_202005 UPDATE GLOBAL INDEX;
```

Alternatively, delete the partition corresponding to the partition value **'2020-05-08'** in the range partitioned table **range_sales**. Global indexes become invalid after this command is executed because the UPDATE GLOBAL INDEX clause is not used.

```
ALTER TABLE range_sales DROP PARTITION FOR ('2020-05-08');
```

NOTICE

- If a partitioned table has only one partition, the partition cannot be deleted by using the ALTER TABLE DROP PARTITION statement.
- If the partitioned table is a hash partitioned table, partitions in the table cannot be deleted by using the ALTER TABLE DROP PARTITION statement.

3.4.3 EXCHANGE PARTITION

You can run this command to exchange the data in a partition with that in an ordinary table. This command can quickly import data to or export data from a partitioned table, achieving efficient data loading. In service migration scenarios, using EXCHANGE PARTITION is much faster than using common import operation. You can exchange a partition by specifying the partition name or partition value.

CAUTION

- Running this command will invalidate the global index. You can use the UPDATE GLOBAL INDEX clause to update the global index synchronously or rebuild the global index.

NOTICE

- When exchanging partitions, you can declare WITH/WITHOUT VALIDATION, indicating whether to validate that ordinary table data meets the partition key constraint rules of the target partition (validated by default). The overhead of data validation is high. If you ensure that the exchanged data belongs to the target partition, you can declare WITHOUT VALIDATION to improve the exchange performance.
- You can declare WITH VALIDATION VERBOSE. In this case, the database validates each row of the ordinary table, inserts the data that does not meet the partition key constraint of the target partition to other partitions of the partitioned table, and exchanges the ordinary table with the target partition.

For example, if the following partition definition and data distribution of the **exchange_sales** table are provided, and the **DATE_202001** partition is exchanged with the **exchange_sales** table, the following behaviors exist based on the declaration clause:

- If WITHOUT VALIDATION is declared, all data is exchanged to the **DATE_202001** partition. Because **'2020-02-03**' and **'2020-04-08'** do not meet the range constraint of the **DATE_202001** partition, subsequent services may be abnormal.

- If WITH VALIDATION is declared, and **'2020-02-03'** and **'2020-04-08'** do not meet the range constraint of the **DATE_202001** partition, the database reports an error.
- If WITH VALIDATION VERBOSE is declared, the database inserts **'2020-02-03'** into the **DATE_202002** partition, inserts **'2020-04-08'** into the **DATE_202004** partition, and exchanges the remaining data with the **DATE_202001** partition.

```
-- Partition definition
PARTITION DATE_202001 VALUES LESS THAN ('2020-02-01'),
PARTITION DATE_202002 VALUES LESS THAN ('2020-03-01'),
PARTITION DATE_202003 VALUES LESS THAN ('2020-04-01'),
PARTITION DATE_202004 VALUES LESS THAN ('2020-05-01')
-- Data distribution of exchange_sales
('2020-01-15', '2020-01-17', '2020-01-23', '2020-02-03', '2020-04-08')
```

WARNING

If the data to be exchanged does not completely belong to the target partition, do not declare WITHOUT VALIDATION. Otherwise, the partition constraint rules will be damaged, and subsequent DML statement results of the partitioned table will be abnormal.

The ordinary table and partition whose data is to be exchanged must meet the following requirements:

- The number of columns in an ordinary table is the same as that in a partition, and the information in the corresponding columns is strictly consistent.
- The compression information of the ordinary table and partitioned table is consistent.
- The number of ordinary table indexes is the same as that of local indexes of the partition, and the index information is the same.
- The number and information of constraints of the ordinary table and partition are consistent.
- The ordinary table is not a temporary table.
- The ordinary table and partitioned table do not support dynamic data masking and row-level access control constraints.

You can use ALTER TABLE EXCHANGE PARTITION to exchange partitions for a partitioned table.

For example, exchange the partition **date_202001** of the partitioned table **range_sales** with the ordinary table **exchange_sales** by specifying the partition name without validating the partition key, and update the global index.

```
ALTER TABLE range_sales EXCHANGE PARTITION (date_202001) WITH TABLE exchange_sales WITHOUT
VALIDATION UPDATE GLOBAL INDEX;
```

Alternatively, exchange the partition corresponding to **'2020-01-08'** in the range partitioned table **range_sales** with the ordinary table **exchange_sales** by specifying a partition value, validate the partition, and insert data that does not meet the target partition constraints into another partition of the partitioned table. Global indexes become invalid after this command is executed because the UPDATE GLOBAL INDEX clause is not used.

```
ALTER TABLE range_sales EXCHANGE PARTITION FOR ('2020-01-08') WITH TABLE exchange_sales WITH
VALIDATION VERBOSE;
```

3.4.4 TRUNCATE PARTITION

You can run this command to quickly clear data in a partition. The function is similar to that of DROP PARTITION. The difference is that TRUNCATE PARTITION deletes only data in a partition, and the definition and physical files of the partition are retained. You can clear a partition by specifying the partition name or partition value.

CAUTION

- Running this command will invalidate the global index. You can use the UPDATE GLOBAL INDEX clause to update the global index synchronously or rebuild the global index.

You can use ALTER TABLE TRUNCATE PARTITION to clear any partition in a specified partitioned table.

For example, truncate the partition **date_202005** in the range partitioned table **range_sales** by specifying the partition name and update the global index.

```
ALTER TABLE range_sales TRUNCATE PARTITION date_202005 UPDATE GLOBAL INDEX;
```

Alternatively, truncate the partition corresponding to the partition value **'2020-05-08'** in the range partitioned table **range_sales**. Global indexes become invalid after this command is executed because the UPDATE GLOBAL INDEX clause is not used.

```
ALTER TABLE range_sales TRUNCATE PARTITION FOR ('2020-05-08');
```

3.4.5 SPLIT PARTITION

You can run this command to split a partition into two or more partitions. This operation is considered when the partition data is too large or you need to add a partition to a range partition with MAXVALUE or a list partition with DEFAULT. You can specify a split point to split a partition into two partitions, or split a partition into multiple partitions without specifying a split point. You can split a partition by specifying the partition name or partition value.

CAUTION

- This command cannot be applied to hash partitions.
- Running this command will invalidate the global index. You can use the UPDATE GLOBAL INDEX clause to update the global index synchronously or rebuild the global index.

NOTICE

The names of the new partitions can be the same as that of the source partition. For example, partition **p1** is split into **p1** and **p2**. However, the database does not consider the partitions with the same name before and after the splitting as the same partition.

3.4.5.1 Splitting a Partition for a Range Partitioned Table

You can use ALTER TABLE SPLIT PARTITION to split a partition for a range partitioned table.

For example, the range of the **date_202001** partition in the range partitioned table **range_sales** is ['2020-01-01', '2020-02-01'). You can specify the split point **'2020-01-16'** to split the **date_202001** partition into two partitions and update the global index.

```
ALTER TABLE range_sales SPLIT PARTITION date_202001 AT ('2020-01-16') INTO
(
    PARTITION date_202001_p1, -- The upper boundary of the first partition is '2020-01-16'.
    PARTITION date_202001_p2  -- The upper boundary of the second partition is '2020-02-01'.
) UPDATE GLOBAL INDEX;
```

Alternatively, split the partition **date_202001** into multiple partitions without specifying a split point, and update the global index.

```
ALTER TABLE range_sales SPLIT PARTITION date_202001 INTO
(
    PARTITION date_202001_p1 VALUES LESS THAN ('2020-01-11'),
    PARTITION date_202001_p2 VALUES LESS THAN ('2020-01-21'),
    PARTITION date_202001_p3 -- The upper boundary of the third partition is '2020-02-01'.
)UPDATE GLOBAL INDEX;
```

Alternatively, split the partition by specifying the partition value instead of the partition name.

```
ALTER TABLE range_sales SPLIT PARTITION FOR ('2020-01-15') AT ('2020-01-16') INTO
(
    PARTITION date_202001_p1, -- The upper boundary of the first partition is '2020-01-16'.
    PARTITION date_202001_p2  -- The upper boundary of the second partition is '2020-02-01'.
) UPDATE GLOBAL INDEX;
```

NOTICE

If the MAXVALUE partition is split, the MAXVALUE range cannot be declared for the first several partitions, and the last partition inherits the MAXVALUE range.

3.4.5.2 Splitting a Partition for a List Partitioned Table

You can use ALTER TABLE SPLIT PARTITION to split a partition for a list partitioned table.

For example, assume that the range defined for the partition **channel2** of the list partitioned table **list_sales** is ('6', '7', '8', '9'). You can specify the split point **('6', '7')** to split the **channel2** partition into two partitions and update the global index.

```
ALTER TABLE list_sales SPLIT PARTITION channel2 VALUES ('6', '7') INTO
(
    PARTITION channel2_1, -- The first partition range is ('6', '7').
    PARTITION channel2_2  -- The second partition range is ('8', '9').
) UPDATE GLOBAL INDEX;
```

Alternatively, split the partition **channel2** into multiple partitions without specifying a split point, and update the global index.

```
ALTER TABLE list_sales SPLIT PARTITION channel2 INTO
(
    PARTITION channel2_1 VALUES ('6'),
    PARTITION channel2_2 VALUES ('8'),
    PARTITION channel2_3 -- The third partition range is ('7', '9').
)UPDATE GLOBAL INDEX;
```

Alternatively, split the partition by specifying the partition value instead of the partition name.

```
ALTER TABLE list_sales SPLIT PARTITION FOR ('6') VALUES ('6', '7') INTO
(
    PARTITION channel2_1, -- The first partition range is ('6', '7').
    PARTITION channel2_2  -- The second partition range is ('8', '9').
) UPDATE GLOBAL INDEX;
```

CAUTION

If the DEFAULT partition is split, the DEFAULT range cannot be declared for the first several partitions, and the last partition inherits the DEFAULT range.

3.4.6 MERGE PARTITION

You can run this command to merge multiple partitions into one partition. Partitions can be merged only by specifying partition names, instead of partition values.

CAUTION

- This command cannot be applied to hash partitions.
- Running this command will invalidate the global index. You can use the UPDATE GLOBAL INDEX clause to update the global index synchronously or rebuild the global index.

NOTICE

For a range partition, the name of the new partition can be the same as that of the last source partition. For example, partitions **p1** and **p2** can be merged into **p2**. For a list partition, the name of the new partition can be the same as that of any source partition. For example, **p1** and **p2** can be merged into **p1**.

If the name of the new partition is the same as that of the source partition, the database considers the new partition as inheritance of the source partition.

You can use ALTER TABLE MERGE PARTITIONS to merge multiple partitions into one partition.

For example, merge the partitions **date_202001** and **date_202002** of the range partitioned table **range_sales** into a new partition and update the global index.

```
ALTER TABLE range_sales MERGE PARTITIONS date_202001, date_202002 INTO
    PARTITION date_2020_old UPDATE GLOBAL INDEX;
```

3.4.7 MOVE PARTITION

You can run this command to move a partition to a new tablespace. You can move a partition by specifying the partition name or partition value.

You can use ALTER TABLE MOVE PARTITION to move partitions in a partitioned table.

For example, move the partition **date_202001** from the range partitioned table **range_sales** to the tablespace **tb1** by specifying the partition name.

```
ALTER TABLE range_sales MOVE PARTITION date_202001 TABLESPACE tb1;
```

Alternatively, move the partition corresponding to **'0'** in the list partitioned table **list_sales** to the tablespace **tb1** by specifying a partition value.

```
ALTER TABLE list_sales MOVE PARTITION FOR ('0') TABLESPACE tb1;
```

3.4.8 RENAME PARTITION

You can run this command to rename a partition. You can rename a partition by specifying the partition name or partition value.

3.4.8.1 Renaming a Partition in a Partitioned Table

You can use ALTER TABLE RENAME PARTITION to rename a partition in a partitioned table.

For example, rename the partition **date_202001** in the range partitioned table **range_sales** by specifying the partition name.

```
ALTER TABLE range_sales RENAME PARTITION date_202001 TO date_202001_new;
```

Alternatively, rename the partition corresponding to **'0'** in the list partitioned table **list_sales** by specifying a partition value.

```
ALTER TABLE list_sales RENAME PARTITION FOR ('0') TO channel_new;
```

3.4.8.2 Renaming an Index Partition for a Local Index

You can use ALTER INDEX RENAME PARTITION to rename an index partition for a local index. The method is the same as that for renaming a partition in a partitioned table.

3.4.9 ALTER TABLE ENABLE/DISABLE ROW MOVEMENT

You can run this command to enable or disable row movement for a partitioned table.

When row migration is enabled, data in a partition can be migrated to another partition through an UPDATE operation. When row migration is disabled, if such an UPDATE operation occurs, a service error is reported.

NOTICE

If you are not allowed to update the column where the partition key is located, you are advised to disable row migration.

For example, if you create a list partitioned table and enable row migration, you can update the column where the partition key is located across partitions. If you disable row migration, an error is reported when you update the column where the partition key is located across partitions.

```
CREATE TABLE list_sales
(
    product_id     INT4 NOT NULL,
    customer_id    INT4 PRIMARY KEY,
    time_id        DATE,
    channel_id     CHAR(1),
    type_id         INT4,
    quantity_sold   NUMERIC(3),
    amount_sold     NUMERIC(10,2)
)
PARTITION BY LIST (channel_id)
(
    PARTITION channel1 VALUES ('0', '1', '2'),
    PARTITION channel2 VALUES ('3', '4', '5'),
    PARTITION channel3 VALUES ('6', '7'),
    PARTITION channel4 VALUES ('8', '9')
) ENABLE ROW MOVEMENT;
INSERT INTO list_sales VALUES (153241,65143129,'2021-05-07','0',864134,89,34);
-- The cross-partition update is successful, and data is migrated from partition channel1 to partition
channel2.
UPDATE list_sales SET channel_id = '3' WHERE channel_id = '0';
-- Disable row migration for the partitioned table.
ALTER TABLE list_sales DISABLE ROW MOVEMENT;
-- The cross-partition update fails, and an error is reported: fail to update partitioned table "list_sales".
UPDATE list_sales SET channel_id = '0' WHERE channel_id = '3';
-- The update in the partition is still successful.
UPDATE list_sales SET channel_id = '4' WHERE channel_id = '3';
```

3.4.10 Invalidating/Rebuilding Indexes of a Partition

You can run commands to invalidate or rebuild a partitioned index or an index partition. In this case, the index or index partition is no longer maintained. You can rebuild a partitioned index to restore the index function.

In addition, some partition-level DDL operations also invalidate global indexes, including DROP, EXCHANGE, TRUNCATE, SPLIT, and MERGE. You can use the UPDATE GLOBAL INDEX clause to update the global index synchronously. Otherwise, you need to rebuild the index.

3.4.10.1 Invalidating/Rebuilding Indexes

You can use ALTER INDEX to invalidate or rebuild indexes.

For example, if the **range_sales_idx** index exists in the **range_sales** partitioned table, run the following command to invalidate the index:

```
ALTER INDEX range_sales_idx UNUSABLE;
```

Run the following command to rebuild the **range_sales_idx** index:

```
ALTER INDEX range_sales_idx REBUILD;
```

3.4.10.2 Invalidating/Rebuilding Local Indexes of a Partition

- You can use ALTER INDEX PARTITION to invalidate or rebuild local indexes of a partition.
- You can use ALTER TABLE MODIFY PARTITION to invalidate or rebuild all indexes of a specified partition in a partitioned table.

For example, assume that the partitioned table **range_sales** has two local indexes **range_sales_idx1** and **range_sales_idx2**, and the corresponding indexes on the partition **date_202001** are **range_sales_idx1_part1** and **range_sales_idx2_part1**.

The syntax for maintaining partitioned indexes of a partitioned table is as follows:

- Run the following command to disable all indexes on the **date_202001** partition:
  ```
  ALTER TABLE range_sales MODIFY PARTITION date_202001 UNUSABLE LOCAL INDEXES;
  ```

- Alternatively, run the following command to disable the index **range_sales_idx1_part1** on the **date_202001** partition:
  ```
  ALTER INDEX range_sales_idx1 MODIFY PARTITION range_sales_idx1_part1 UNUSABLE;
  ```
- Run the following command to rebuild all indexes on the **date_202001** partition:
  ```
  ALTER TABLE range_sales MODIFY PARTITION date_202001 REBUILD UNUSABLE LOCAL INDEXES;
  ```
- Alternatively, run the following command to rebuild the index **range_sales_idx1_part1** on the **date_202001** partition:
  ```
  ALTER INDEX range_sales_idx1 REBUILD PARTITION range_sales_idx1_part1;
  ```

3.5 System Views & DFX Related to Partitioned Tables

3.5.1 System Views Related to Partitioned Tables

The system views related to partitioned tables are classified into three types based on permissions. For details about the columns, see section "System Catalogs and System Views > System Views" in *Developer Guide*.

1. Views related to all partitions:
   - ADM_PART_TABLES: stores information about all partitioned tables.
   - ADM_TAB_PARTITIONS: stores information about all partitions.
   - ADM_PART_INDEXES: stores information about all local indexes.
   - ADM_IND_PARTITIONS: stores information about all index partitions.
2. Views accessible to the current user:
   - DB_PART_TABLES: stores information about partitioned tables accessible to the current user.
   - DB_TAB_PARTITIONS: stores information about partitions accessible to the current user.
   - DB_PART_INDEXES: stores local index information accessible to the current user.
   - DB_IND_PARTITIONS: stores information about index partitions accessible to the current user.
3. Views owned by the current user:
   - MY_PART_TABLES: stores information about partitioned tables owned by the current user.
   - MY_TAB_PARTITIONS: stores information about partitions owned by the current user.
   - MY_PART_INDEXES: stores local indexes owned by the current user.
   - MY_IND_PARTITIONS: stores information about index partitions owned by the current user.

3.5.2 Built-in Tool Functions Related to Partitioned Tables

Information About Table Creation

- Create a table.
  ```
  CREATE TABLE test_range_pt (a INT, b INT, c INT)
  PARTITION BY RANGE (a)
  ```

```
(
    PARTITION p1 VALUES LESS THAN (2000),
    PARTITION p2 VALUES LESS THAN (3000),
    partition p3 VALUES LESS THAN (4000),
    partition p4 VALUES LESS THAN (5000),
    partition p5 VALUES LESS THAN (MAXVALUE)
)ENABLE ROW MOVEMENT;
```

- View the OID of the partitioned table.

```
SELECT oid FROM pg_class WHERE relname = 'test_range_pt';
oid
-------
49290
(1 row)
```

- View the partition information.

```
SELECT oid,relname,parttype,parentid,boundaries FROM pg_partition WHERE parentid = 49290;
oid  |    relname    | parttype | parentid | boundaries
-------+---------------+----------+----------+------------
49293 | test_range_pt   | r        |    49290 |
49294 | p1            | p        |    49290 | {2000}
49295 | p2            | p        |    49290 | {3000}
49296 | p3            | p        |    49290 | {4000}
49297 | p4            | p        |    49290 | {5000}
49298 | p5            | p        |    49290 | {NULL}
(6 rows)
```

- Create an index.

```
CREATE INDEX idx_range_a ON test_range_pt(a) LOCAL;
CREATE INDEX
-- Check the OID of the partitioned index.
SELECT oid FROM pg_class WHERE relname = 'idx_range_a';
oid
-------
90250
(1 row)
```

- View the index partition information.

```
SELECT oid,relname,parttype,parentid,boundaries,indextblid FROM pg_partition WHERE parentid =
90250;
oid  | relname  | parttype | parentid | boundaries | indextblid
-------+----------+----------+----------+------------+------------
90255 | p5_a_idx | x        |    90250 |            |      49298
90254 | p4_a_idx | x        |    90250 |            |      49297
90253 | p3_a_idx | x        |    90250 |            |      49296
90252 | p2_a_idx | x        |    90250 |            |      49295
90251 | p1_a_idx | x        |    90250 |            |      49294
(5 rows)
```

Example of Tool Functions

- **pg_get_tabledef** is used to obtain the definition of a partitioned table. The input parameter can be the table OID or table name.

```
SELECT pg_get_tabledef('test_range_pt');
                        pg_get_tabledef
-------------------------------------------------------------------
 SET search_path = public;                                  +
 CREATE TABLE test_range_pt (                               +
     a integer,                                             +
     b integer,                                             +
     c integer                                              +
 )                                                          +
 WITH (orientation=row, compression=no)                     +
 PARTITION BY RANGE (a)                                     +
 (                                                          +
     PARTITION p1 VALUES LESS THAN (2000) TABLESPACE pg_default,   +
     PARTITION p2 VALUES LESS THAN (3000) TABLESPACE pg_default,   +
     PARTITION p3 VALUES LESS THAN (4000) TABLESPACE pg_default,   +
     PARTITION p4 VALUES LESS THAN (5000) TABLESPACE pg_default,   +
     PARTITION p5 VALUES LESS THAN (MAXVALUE) TABLESPACE pg_default+
 )                                                          +
 ENABLE ROW MOVEMENT;
(1 row)
```

- **pg_stat_get_partition_tuples_hot_updated** is used to return the number of hot updated tuples in a partition with a specified partition ID.

  Insert 10 data records into partition **p1** and update the data. Count the number of hot updated tuples in partition **p1**.

```
INSERT INTO test_range_pt VALUES(generate_series(1,10),1,1);
INSERT 0 10
SELECT pg_stat_get_partition_tuples_hot_updated(49294);
pg_stat_get_partition_tuples_hot_updated
------------------------------------------
0
(1 row)
UPDATE test_range_pt SET b = 2;
UPDATE 10
SELECT pg_stat_get_partition_tuples_hot_updated(49294);
pg_stat_get_partition_tuples_hot_updated
------------------------------------------
10
(1 row)
```

- **pg_partition_size(oid,oid)** is used to specify the disk space used by the partition with a specified OID. The first **oid** is the OID of the table and the second **oid** is the OID of the partition.

  Check the disk space of partition **p1**.

```
SELECT pg_partition_size(49290, 49294);
pg_partition_size
-------------------
90112
(1 row)
```

- **pg_partition_size(text, text)** is used to specify the disk space used by the partition with a specified name. The first **text** is the table name and the second **text** is the partition name.

  Check the disk space of partition **p1**.

```
SELECT pg_partition_size('test_range_pt', 'p1');
pg_partition_size
-------------------
90112
(1 row)
```

- **pg_partition_indexes_size(oid,oid)** is used to specify the disk space used by the index of the partition with a specified OID. The first **oid** is the OID of the table and the second **oid** is the OID of the partition.

  Check the disk space of the index partition of partition **p1**.

```
SELECT pg_partition_indexes_size(49290, 49294);
pg_partition_indexes_size
---------------------------
204800
(1 row)
```

- **pg_partition_indexes_size(text,text)** is used to specify the disk space used by the index of the partition with a specified name. The first **text** is the table name and the second **text** is the partition name.

  Check the disk space of the index partition of partition **p1**.

```
SELECT pg_partition_indexes_size('test_range_pt', 'p1');
pg_partition_indexes_size
---------------------------
204800
(1 row)
```

- **pg_partition_filenode(partition_oid)** is used to obtain the file node corresponding to the OID of the specified partitioned table.

  Check the file node of partition **p1**.

  ```
  SELECT pg_partition_filenode(49294);
  pg_partition_filenode
  -----------------------
  49294
  (1 row)
  ```

- **pg_partition_filepath(partition_oid)** is used to specify the file path name of the partition.

  Check the file path of partition **p1**.

  ```
  SELECT pg_partition_filepath(49294);
  pg_partition_filepath
  -----------------------
  base/16521/49294
  (1 row)
  ```

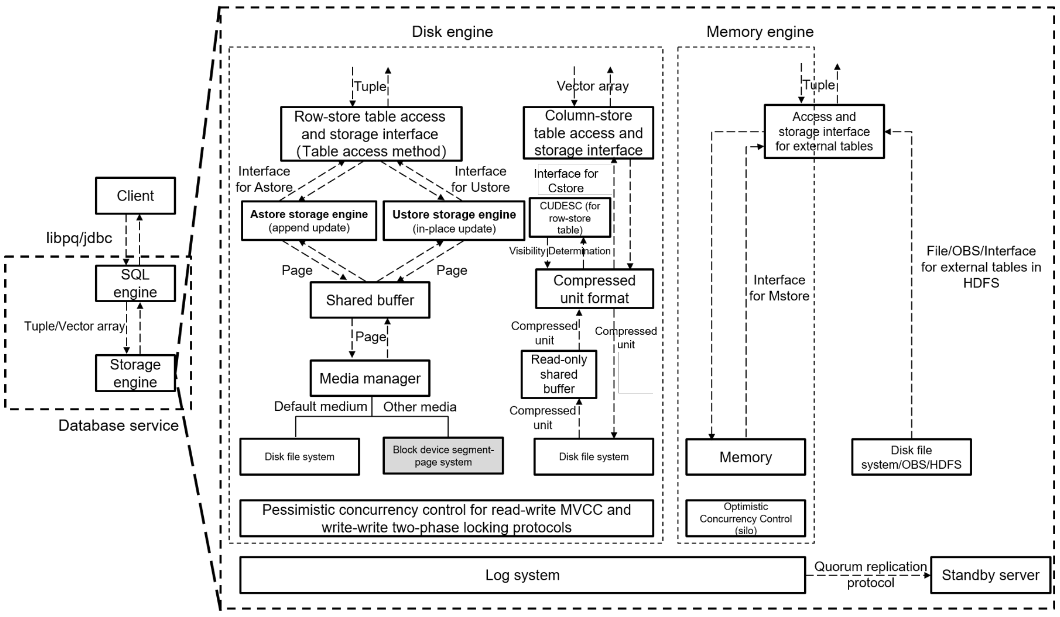
4 Storage Engine

4.1 Storage Engine Architecture

4.1.1 Overview

4.1.1.1 Static Compilation Architecture

As for the whole architecture of database services, the storage engine connects to the SQL engine upwards to send standard data (tuples or vector arrays) to or receive such data from the SQL engine. Besides, the storage engine also connects to storage media downwards to read and write data in a specific data form such as pages and compression units through specific interfaces provided by storage media. By providing static compilation, GaussDB Kernel allows database professionals to select a dedicated storage engine based on the special requirements of applications. To reduce interference to the execution, an interface layer TableAM for accessing row-store tables is provided to shield differences brought by underlying row-store engines, enabling independent evolution of different row-store engines. See the following figure.


Client
libpq/jdbc
SQL engine
Tuple/Vector array
Storage engine
Database service
Disk engine
Memory engine
Tuple
Row-store table access and storage interface (Table access method)
Interface for Astore
Interface for Ustore
Astore storage engine (append update)
Ustore storage engine (in-place update)
Page
Shared buffer
Media manager
Default medium
Other media
Disk file system
Block device segment-page system
Vector array
Column-store table access and storage interface
Interface for Cstore
CUDESC (for row-store table)
Visibility Determination
Compressed unit format
Compressed unit
Read-only shared buffer
Disk file system
Pessimistic concurrency control for read-write MVCC and write-write two-phase locking protocols
Access and storage interface for external tables
Interface for Mstore
File/OBS/Interface for external tables in HDFS
Memory
Disk file system/OBS/HDFS
Optimistic Concurrency Control (silo)
Log system
Quorum replication protocol
Standby server

On this basis, the storage engine provides the log system to ensure data persistence and reliability, provides the concurrency control (transaction) system to ensure atomicity, consistency, and isolation among multiple read and write operations that are executed at the same time, provides the index system to accelerate addressing and query for specific data, and provides the primary-standby replication system to ensure high availability of the entire database services.

Row-store engines are oriented to online transaction processing (OLTP) scenarios, which are suitable for single read/write transactions on a small amount of data or highly concurrent read/write transactions on data within a small range. Row-store engines provide interfaces for the SQL engine to read and write tuples, perform read and write operations on storage media in pages through an extensible media manager, and improve read and write operation efficiency in the shared buffer by page. For concurrent read and write operations, multi-version concurrency control (MVCC) is used. For concurrent write and write operations, pessimistic concurrency control (PCC) based on the two-phase locking (2PL) protocol is used. Currently, the default media manager of row-store engines uses the disk file system interface. Other types of storage media such as block devices will be supported in the future. GaussDB Kernel row-store engine can use append update Astore or in-place update Ustore.

4.1.1.2 Database Service Layer

From the technical perspective, a storage engine requires some infrastructure components.

Concurrency: The overhead of a storage engine can be reduced by properly employing locks, so as to improve overall performance. In addition, it provides functions such as multi-version concurrency control and snapshot reading.

Transaction: All transactions must meet the ACID requirements and their statuses can be queried.

Memory cache: Typically, storage engines cache indexes and data when accessing them. You can directly process common data in the cache pool, which facilitates the handling speed. The basic logic of this part is the same.

Checkpoint: Storage engines support the incremental checkpoint/double write mode or full checkpoint/full page write mode. You can select the incremental or full mode based on different conditions, which is transparent to storage engines.

Log: GaussDB Kernel uses physical logs. The write, transmission, and replay operations of physical logs are transparent to the storage engine.

Choosing a proper storage engine for a set of specific application requirements can have a significant impact on the overall system efficiency and performance.

4.1.2 Setting Up a Storage Engine

You can run **WITH ([ORIENTATION | STORAGE_TYPE] [= value] [, ...])** to specify an optional storage parameter for a table or index. The parameters are described as follows.

ORIENTATION	STORAGE_TYPE
ROW (default value): The data will be stored in rows.	[USTORE (default value)|ASTORE|Null]
COLUMN: The data will be stored in columns.	[Null]

If **ORIENTATION** is set to **ROW** and **STORAGE_TYPE** is set to **Null**, the type of the created table depends on the value of **enable_default_ustore_table**. If this parameter is set to **TRUE**, a Ustore table is created. If this parameter is set to **FALSE**, an Astore table is created.

4.2 Astore Storage Engine

4.2.1 Overview

The biggest difference between Astore and Ustore lies in whether the latest data and historical data are stored separately. Astore does not perform separated storage. Ustore only separates data, but does not separate indexes.

Astore Advantages

1. Astore does not have rollback segments, but Ustore does. For Ustore, rollback segments are very important. If rollback segments are damaged, data will be lost or even the database cannot be started. In addition, redo and undo operations are required for Ustore restoration. For Astore, it does not have a rollback segment, therefore, old data is stored in the original files, whose restoration is not as complex as that of Ustore.
2. Besides, the error "Snapshot Too Old" is not frequently reported, because old data is directly recorded in data files instead of rollback segments.

3. The rollback operation can be completed quickly since no data needs to be deleted. However, the rollback operation is complex, because the modifications and the inserted records must be deleted, and the updated records must be undone. In addition, a large number of redo logs are generated during rollback.
4. WAL in Astore is simpler than that in Ustore. Only data file changes need to be recorded in WALs. Rollback segment changes do not need to be recorded.

4.3 Ustore Storage Engine

4.3.1 Overview

Unified storage (Ustore) is an in-place update storage engine launched by GaussDB Kernel. The biggest difference between Ustore and Astore lies in that, the latest data and historical data (excluding indexes) are stored separately.

Ustore Advantages

1. The latest data and historical data are stored separately. Compared with Astore, Ustore has a smaller scanning scope. The HOT chain of Astore is removed. Non-index columns, index columns, and heaps can be updated in-place without change to row IDs. Historical data can be recycled in batches, which is friendly to the expansion of the latest data.
2. If the same row is updated in a large concurrency, the in-place update mechanism of Ustore ensures the stability of tuple row IDs and update latency.
3. VACUUM is not the only way to clear historical data. Indexes are decoupled from heaps and can be cleared separately with good I/O stability.
4. The flashback function is supported.

However, in addition to modifying data pages, Ustore DML operations also modify undo logs. Therefore, the update overhead is higher. In addition, the scanning overhead of a single tuple is high because of replication (Astore returns pointers).

4.3.1.1 Ustore Features and Specifications

4.3.1.1.1 Feature Constraints

Category	Feature	Supported or Not
Transaction	Repeatable read/Serializable	×
	DDL operations on a partitioned table in a transaction block	×
Index	Gist index/Gin index	×
Scalability	Hash bucket	×

Category	Feature	Supported or Not
SQL	Table sampling/Materialized view/Key-value lock	×
File managem ent	Segment-page storage	×

4.3.1.1.2 Storage Specifications

1. The maximum number of columns in a data table is 1600.
2. The maximum tuple length of a Ustore table (excluding toast) cannot exceed 8192 – MAXALIGN(56 + init_td x 26 + 4), where **MAXALIGN** indicates 8-byte alignment. When the length of the inserted data exceeds the threshold, you will receive an error reporting that the tuple is too long to be inserted. The impact of **init_td** on the tuple length is as follows:
   - If the value of **init_td** is the minimum value **2**, the tuple length cannot exceed 8192 – MAXALIGN(56 + 2 x 26 + 4) = 8080 bytes.
   - If the value of **init_td** is the default value **4**, the tuple length cannot exceed 8192 – MAXALIGN(56 + 4 x 26 + 4) = 8024 bytes.
   - If the value of **init_td** is the maximum value **128**, the tuple length cannot exceed 8192 – MAXALIGN(56 + 128 x 26 + 4) = 4800 bytes.
3. The value range of **init_td** is [2,128], and the default value is **4**. A single page supports a maximum of 128 concurrent transactions.
4. The maximum number of index columns is 32. The maximum number of columns in a global partitioned index is 31.
5. The length of an index tuple cannot exceed (8192 – MAXALIGN(28 + 3 x 4 + 3 x 10) – MAXALIGN(42))/3, where **MAXALIGN** indicates 8-byte alignment. When the length of the inserted data exceeds the threshold, you will receive an error reporting that the tuple is too long to be inserted. As for the threshold, the index page header is 28 bytes, row pointer is 4 bytes, tuple CTID+INFO flag is 10 bytes, and page tail is 42 bytes.
6. The maximum rollback segment size is 16 TB.

4.3.1.2 Example

Create a Ustore table.

Run the **CREATE TABLE** statement to create a Ustore table.

```
gaussdb=# CREATE TABLE ustore_table(a INT PRIMARY KEY, b CHAR (20)) WITH (STORAGE_TYPE=USTORE);
NOTICE:  CREATE TABLE / PRIMARY KEY will create implicit index "ustore_table_pkey" for table
"ustore_table"
CREATE TABLE
gaussdb=# \d+ ustore_table
Table "public.ustore_table"
Column |     Type      | Modifiers | Storage  | Stats target | Description
--------+---------------+-----------+----------+--------------+-------------
a      | integer       | not null  | plain    |              |
b      | character(20) |           | extended |              |
Indexes:
"ustore_table_pkey" PRIMARY KEY, ubtree (a) WITH (storage_type=USTORE) TABLESPACE pg_default
```

```
Has OIDs: no
Options: orientation=row, storage_type=ustore, compression=no
```

Create an index for a Ustore table.

Currently, Ustore supports only multi-version B-tree indexes. In some scenarios, to distinguish them from Astore B-tree indexes, a multi-version B-tree index of the Ustore table is also called a Ustore B-tree or UB-tree. For details about UB-tree, see **Index**. You can run the **CREATE INDEX** statement to create a UB-tree index for the "a" attribute of a Ustore table.

If no index type is specified for a Ustore table, a UB-tree index is created by default.

```
gaussdb=# CREATE INDEX UB-tree_index ON ustore_table(a);
CREATE INDEX
gaussdb=# \d+ ustore_table
Table "public.ustore_table"
Column |     Type      | Modifiers | Storage  | Stats target | Description
--------+---------------+-----------+----------+--------------+-------------
a      | integer       | not null  | plain    |              |
b      | character(20) |           | extended |              |
Indexes:
"ustore_table_pkey" PRIMARY KEY, ubtree (a) WITH (storage_type=USTORE) TABLESPACE pg_default
"ubtree_index" ubtree (a) WITH (storage_type=USTORE) TABLESPACE pg_default
Has OIDs: no
Options: orientation=row, storage_type=ustore, compression=no
```

4.3.1.3 Best Practices of Ustore

4.3.1.3.1 How Can I Configure init_td

Transaction directory (TD) is a unique structure used by Ustore tables to store page transaction information. The number of TDs determines the maximum number of concurrent transactions supported on a page. When creating a table or index, you can specify the initial TD size **init_td**, whose default value is **4**. That is, four concurrent transactions are supported to modify the page. The maximum value of **init_td** is **128**.

You can configure **init_td** based on the service concurrency requirements. Besides, you can also configure it based on the occurrence frequency of **wait available td** events during service running. Generally, the value of **wait available td** is **0**. If the value of **wait available td** is not **0**, there are events waiting for available TDs. In this case, you are advised to increase the value of **init_td**. If the value **0** is an occasional situation, you are not advised to adjust **init_td** because extra TD slots occupy more space. You are advised to gradually increase the value in ascending order, such as 8, 16, 32, 48, ..., and 128, and check whether the number of wait events decreases significantly in this process. Use the minimum value of **init_td** with few wait events as the default value to save space. For details about how to configure and modify **init_td**, see "SQL Reference > SQL Syntax > CREATE TABLE" in *Developer Guide*.

4.3.1.3.2 How Can I Configure fillfactor

fillfactor is a parameter used to describe the page filling rate and is directly related to the number and size of tuples that can be stored on a page and the physical space of a table. The default page filling rate of Ustore tables is 92%. The reserved 8% space is used for page update and TD list expansion. For details about how to configure and modify **fillfactor**, see "SQL Reference > SQL Syntax > CREATE TABLE" in *Developer Guide*.

You can configure **fillfactor** after analyzing services. If only query or fixed-length update operations are performed after table data is imported, you can increase the page filling rate to 100%. If a large number of fixed-length updates are performed after data is imported, you are advised to retain or decrease the page filling rate to reduce performance loss caused by cross-page update.

4.3.1.3.3 Collecting Statistics

Clearing invalid tuples in Ustore tables depends on the accuracy of statistics. Disabling **track_counts** and **track_activities** will cause tablespace bloat. By default, they are enabled. You are advised to enable them, except in performance-sensitive scenarios.

To enable them, run the following commands:

```
gs_guc reload -Z datanode -N all -I all -c "track_counts=on;"
gs_guc reload -Z datanode -N all -I all -c "track_activities=on;"
```

To disable them, run the following commands:

```
gs_guc reload -Z datanode -N all -I all -c "track_counts=off;"
gs_guc reload -Z datanode -N all -I all -c "track_activities=off;"
```

4.3.1.3.4 Online Verification

Online verification is unique to Ustore. It can effectively prevent logic damage on a page caused by encoding logic errors during running. By default, it is enabled. Keep it enabled on the live network, except in performance scenarios.

To disable it, run the following command:

```
gs_guc reload -Z datanode -N all -I all -c "ustore_attr='';"
```

To enable it, run the following command:

```
gs_guc reload -Z datanode -N all -I all -c
"ustore_attr='ustore_verify_level=fast;ustore_verify_module=upage:ubtree:undo"
```

4.3.1.3.5 How Can I Configure the Size of Rollback Segments

Generally, use the default size of rollback segments. To achieve optimal performance, you can adjust the parameters related to the rollback segment size in some scenarios. The scenarios and corresponding configurations are as follows:

1. Historical data within a specified period needs to be retained.

   To use flashback or locate faults, you can change the value of **undo_retention_time** to retain more historical data. The default value of **undo_retention_time** is **0**. The value ranges from 0 to 3 days.

   You are advised to set it to **900s**. Note that a larger value of **undo_retention_time** indicates more undo space usage and data space bloat, which further affects the data scanning and update performance. When flashback is not used, you are advised to set **undo_retention_time** to a smaller value to reduce the disk space occupied by historical data and achieve optimal performance. You can use the following method to select a value that is more suitable for your service model:

Recommended value of **undo_retention_time**: new_val = 0.5 x (undo_space_limit_size x 0.8 – curr_used_undo_size)/avg_space_increse_speed, where **undo_space_limit_size** is the GUC parameter you query, **avg_space_increse_speed** is the recent average growth speed of the undo space, and **curr_used_undo_size** is the current undo space. The last two can be queried in the gs_stat_undo view.

2. Historical data within a specified size needs to be retained.

   If long transactions or large transactions exist in your service, undo space may bloat. In this case, you need to increase the value of **undo_space_limit_size**. The default value of **undo_space_limit_size** is **256GB**, and the value ranges from 800 MB to 16 TB.

   If the disk space is sufficient, you are advised to double the value of **undo_space_limit_size**. In addition, a larger value of **undo_space_limit_size** indicates more disk space occupation and deteriorated performance. If no undo space bloat is found by querying **curr_used_undo_size** of **gs_stat_undo()**, you can restore the value to the original value.

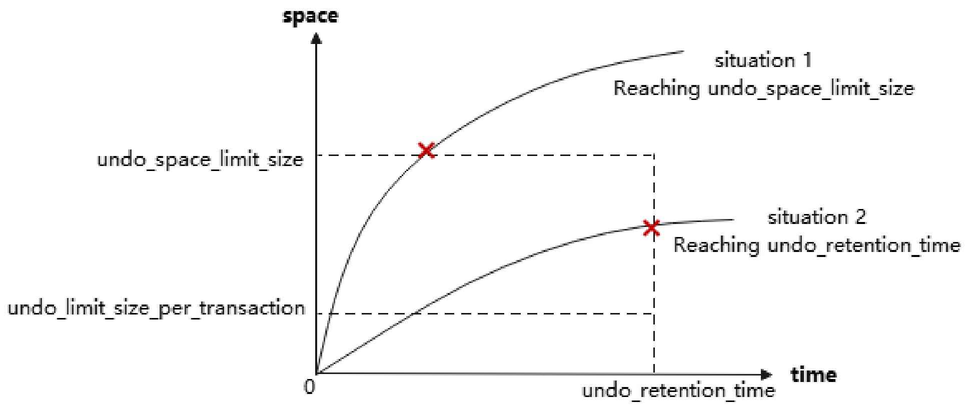
   After adjusting the value of **undo_space_limit_size**, you can increase the value of **undo_limit_size_per_transaction**, which ranges from 2 MB to 16 TB. The default value is **32GB**. It is recommended that the value of **undo_limit_size_per_transaction** be less than or equal to that of **undo_space_limit_size**, that is, the threshold of the undo space allocated to a single transaction be less than or equal to the threshold of the total undo space.

   To accurately set this parameter to achieve optimal performance, you are advised to determine the new value by using the following methods:

   – **undo_space_limit_size**: new_val = 86400 x 30 x avg_space_increse_speed + curr_used_undo_size, where **avg_space_increse_speed** and **curr_used_undo_size** can be queried in the gs_stat_undo view.
   – **undo_limit_size_per_transaction**: new_val = 10 x max_xact_space, where **max_xact_space** indicates the maximum undo space occupied by a single transaction and can be queried in the gs_stat_undo() view in the 503.2 version.

3. Historical data needs to be retained according to constraints of different space threshold parameters.

   If any space threshold of **undo_retention_time**, **undo_space_limit_size** and **undo_limit_size_per_transaction** is exceeded, the corresponding constraint is triggered.

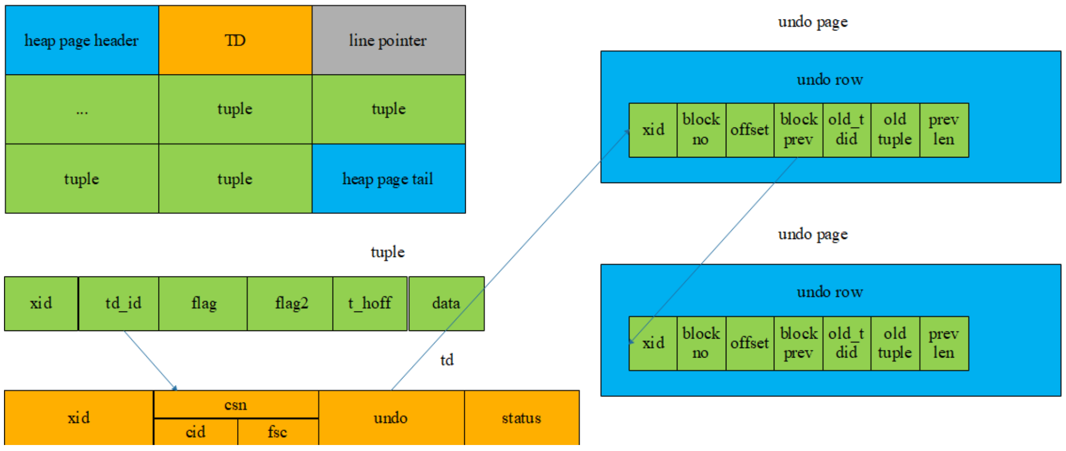


For example, assume that **undo_space_limit_size** is set to **1GB**, and **undo_retention_time** is set to **900s**. If the size of historical data generated within 900s is less than 1 GB x 0.8, the system recycles the data generated within 900s. If the data exceeds 1 GB x 0.8 generated within 900s, only 1 GB x 0.8 data will be recycled. In this case, if the disk space is sufficient, you can increase the value of **undo_space_limit_size**. If not, decrease the value of **undo_retention_time**.

4.3.2 Storage Format

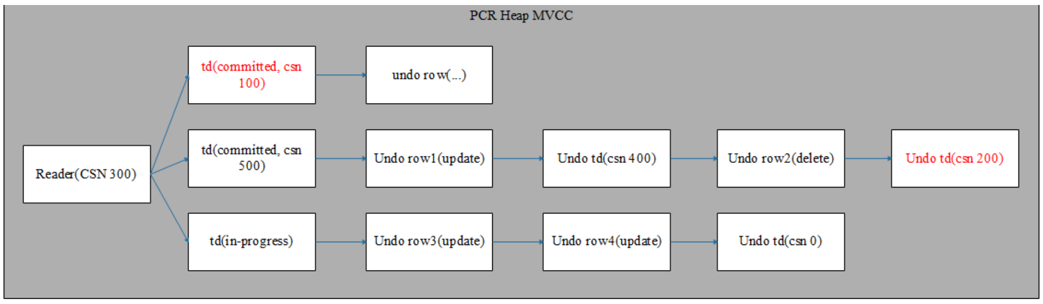
4.3.2.1 Relation

4.3.2.1.1 Page-based Row Consistency Read (PbRCR) Heap Multi-Version Management



1. The heap multi-version management is row-level multi-version management based on tuples.
2. When a transaction modifies a record, historical data is recorded in an undo row.
3. The address of the generated undo row (zone_id, block no, page offset) is recorded in **td_id** in a tuple.
4. New data is overwritten to the heap page.
5. Each data modification generates an undo row. Undo rows with the same record is connected by **block_prev**.

4.3.2.1.2 PbPCR Heap Visibility Mechanism



1. Currently, only row consistency read is supported. In the future, CR page construction and page consistency read will be supported, greatly improving the sequence scanning efficiency.
2. Space can be reused after data deletion transactions are committed without waiting for oldestxmin, increasing the space utilization. Historical versions of old snapshots can be obtained through undo records.

4.3.2.1.3 Heap Space Management

Ustore uses the free space map (FSM) file to record the free space of each data page and organizes it in the tree structure. When you want to perform insert operations or non-in-place update operations on a table, search an FSM file corresponding to the table to check whether the maximum free space recorded in current FSM file meets the requirement of the insert operation. If yes, perform the insert operation after the corresponding block number is returned. If no, expand the page logic.

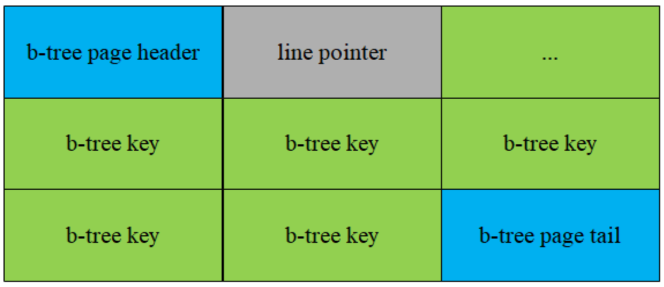
The FSM structure corresponding to each table or partition is stored in an independent FSM file. The FSM file and the table data are stored in the same directory. For example, if the data file corresponding to table **t1** is **32181**, the corresponding FSM file is **32181_fsm**. FSM is stored in the format of data blocks, which are called FSM block. The logical structure among FSM blocks is a tree with three layers of nodes. The nodes of the tree in logic are max heaps. Each searching on FSM starts from the root node to leaf nodes to search for and return an available page for the following operations. This structure may not keep real-time consistency with the actual available space of data pages and is maintained during DML execution. Ustore occasionally repairs and rebuilds FSM during the automatic vacuum process.

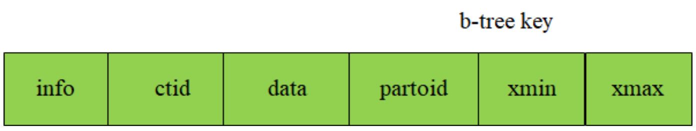
4.3.2.2 Index

The UB-tree is enhanced as follows:

1. Added the MVCC capability.
2. Added the capability of recycling independent empty pages.

4.3.2.2.1 Row Consistency Read (RCR) UB-tree Multi-Version Management

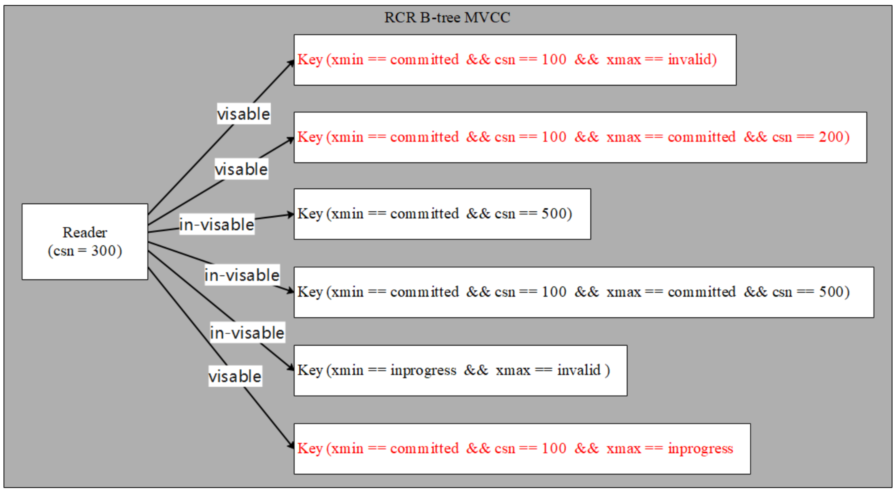




1. The UB-tree multi-version management adopts the key-based multi-version management. The latest version and historical versions are both on UB-tree.

2. To save the space, xmin/xmax is expressed in xid-base + delta. The 64-bit xid-base is stored on pages and the 32-bit delta is stored on tuples. The xid-base on pages also needs to be maintained through additional logic.
3. Keys are inserted into or deleted from the UB-tree in the sequence of key + TID. Tuples with the same index column are sorted based on their TIDs as the second keywords. The **xmin** and **xmax** are added to the end of the key.
4. During index splitting, multi-version information is migrated with key migration.

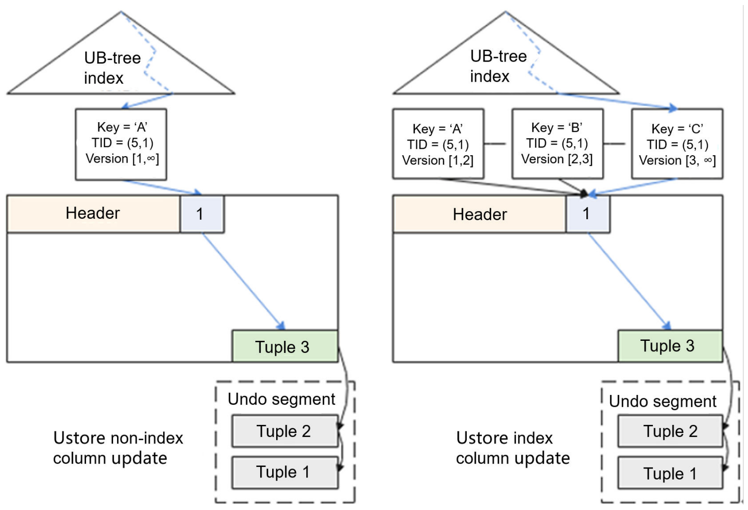
4.3.2.2.2 RCR UB-tree Visibility Mechanism


RCR B-tree MVCC
Reader (csn = 300)
visable
visable
in-visable
in-visable
in-visable
visable
Key (xmin == committed && csn == 100 && xmax == invalid)
Key (xmin == committed && csn == 100 && xmax == committed && csn == 200)
Key (xmin == committed && csn == 500)
Key (xmin == committed && csn == 100 && xmax == committed && csn == 500)
Key (xmin == inprogress && xmax == invalid)
Key (xmin == committed && csn == 100 && xmax == inprogress

1. Multi-version management and visibility check of index data are supported to identify tuples of historical versions and recycle them. In addition, the visibility check at the index layer greatly improves the probability of index scanning and index-only scanning.
2. In addition to the index insertion operation, an index deletion operation is added to mark an index tuple corresponding to a deleted or modified tuple.

4.3.2.2.3 Inserting, Deleting, Updating, and Scanning UB-tree

- **Insert**: The insertion logic of UB-tree is basically not changed, except that you need to directly obtain the transaction information and fill in the **xmin** column during index insertion.
- **Delete**: The index deletion process is added for UB-tree. The main procedure of index deletion is similar to that of index insertion. That is, obtain the transaction information, fill in the xmax column (The B-tree index does not maintain the version information so that the deletion operation is required.), and update **active_tuple_count** on pages. If **active_tuple_count** is reduced to **0**, the system attempts to recycle the page.
- **Update**: For Ustore, data update operations on UB-tree index columns are different from those on Astore. Data update includes index column update and non-index column update. The following figure shows the processing of UB-tree data update.


UB-tree index
Key = 'A' TID = (5,1) Version [1,∞]
Header
1
Tuple 3
Undo segment
Tuple 2
Tuple 1
Ustore non-index column update
UB-tree index
Key = 'A' TID = (5,1) Version [1,2]
Key = 'B' TID = (5,1) Version [2,3]
Key = 'C' TID = (5,1) Version [3, ∞]
Header
1
Tuple 3
Undo segment
Tuple 2
Tuple 1
Ustore index column update

The preceding figure shows the differences between UB-tree updates in index columns and non-index columns.

a. When a non-index column is updated, the index does not change. The index tuple points to the data tuple inserted at the first time. The Uheap does not insert a new data tuple. Instead, the Uheap modifies the current data tuple and saves historical data to the undo segment.

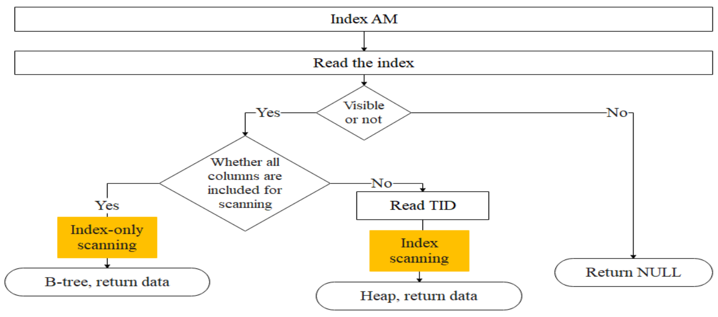
b. When the index column is updated, a new index tuple is inserted into UB-tree and points to the same data linepointer and data tuple. To scan the data of historical versions, you need to read it from the undo segment.

- **Scan**: When reading data, you can use index to speed up scanning. UB-tree supports multi-version management and visibility check of index data. The visibility check at the index layer improves the performance of index scanning and index-only scanning.

  For index scanning:

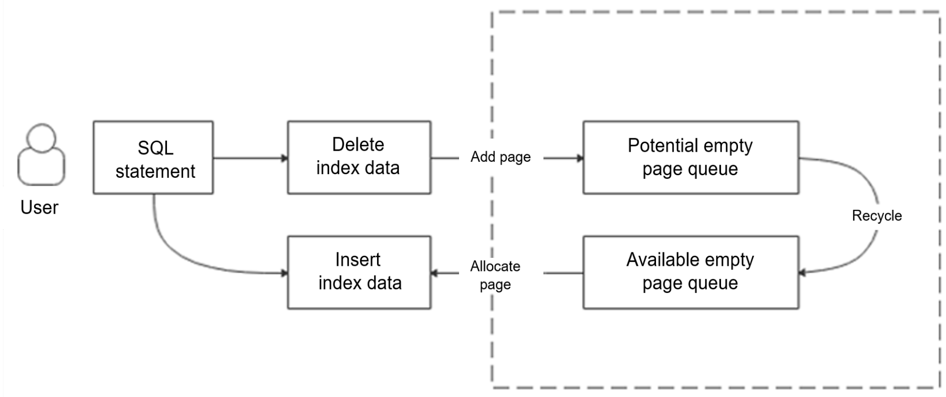
  a. If the index column contains all columns to be scanned (index-only scanning), binary search is performed on indexes based on the scanning conditions. If a tuple that meets the conditions is found, data is returned.

  b. If the index column does not contain all columns to be scanned (index scanning), binary search is performed on indexes based on the scanning conditions to find TIDs of the tuples that meet the conditions, and then the corresponding data tuples are found in data tables based on the TIDs. See the following figure.



4.3.2.2.4 UB-tree Space Management

Currently, Astore indexes depend on AutoVacuum and FSM for space management. The space may not be recycled in a timely manner. However, Ustore indexes use the UB-tree recycle queue (URQ) to manage idle index space. The URQ contains two circular queues: potential empty page queue and available empty page queue. Completing space management of indexes in a DML process can effectively alleviate the sharp space expansion caused during the DML process. Index recycle queues are separately stored in FSM files corresponding to the B-tree indexes.



As shown in the preceding figure, the index page flow in the URQ is as follows:

1. **Index empty page > Potential queue**

   The index page tail column records the number of active tuples (activeTupleCount) on the page. During the DML process, all tuples on a page are deleted, that is, when **activeTupleCount** is set to **0**, the index page is placed in the potential queue.

2. **Potential queue > Available queue**

   The flow from a potential queue to an available queue mainly achieves an income and expense balance for the potential queue and ensure that pages are available for the available queue. That is, after an index empty page is used up in an available queue, at least one index page is transferred from a potential queue to the available queue. Besides, if a new index page is added to a potential queue, at least one index page can be removed from the potential queue and inserted into the available queue.

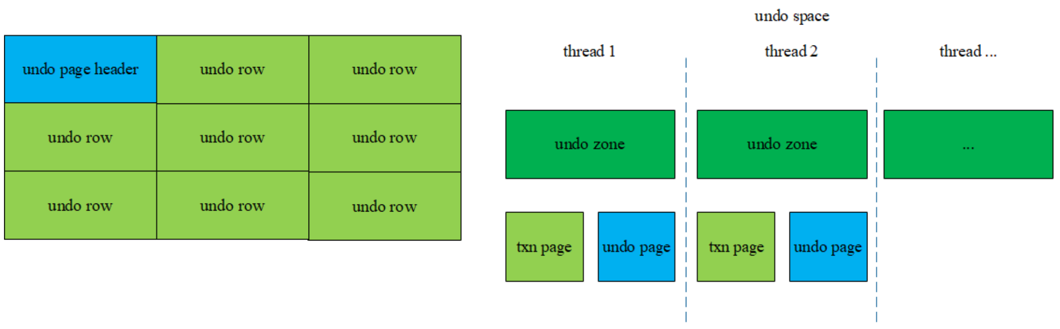
3. **Available queue > Index empty page**

   When an empty index page is obtained during index splitting, the system first searches an available queue for an index page that can be reused. If such index page is found, it is directly reused. If no index page can be reused, physical page expansion is performed.

4.3.2.3 Undo

Data of historical versions is stored in the **$GAUSS_HOME/undo** directory. The rollback segment log is a collection of all undo logs associated with a single write transaction. Permanent, unlogged, and temp tables are supported.

4.3.2.3.1 Rollback Segment Management



1. Each undo zone manages some txn pages and undo pages.
2. Undo rows are stored on undo pages. Therefore, the modified data of historical versions is recorded on the undo pages.
3. Records on the undo pages are also data. Therefore, modifications on the undo pages are also recorded on the redo pages.

4.3.2.3.2 File Structure

Structure of the file where the txn page is stored

```
$GAUSS_HOME/undo/{permanent|unlogged|temp}/$undo_zone_id.meta.$segno
```

Structure of the file where the undo row is stored

```
$GAUSS_HOME/undo/{permanent|unlogged|temp}/$undo_zone_id.$segno
```

4.3.2.3.3 Undo Space Management

The undo subsystem relies on the backend recycle thread to recycle free space. It recycles the space of the undo module on the primary server. As for the standby server, it recycles the space by replaying the Xlog. The recycle thread traverses the undo zones in use. The txn pages in the undo zone are scanned in the ascending order of XIDs. The transactions that have been committed or rolled back are also recycled. The commit time of transactions must be earlier than *$* (current_time – undo_retention_time). For a transaction that needs to be rolled back during a traversal, the recycle thread adds an asynchronous rollback task for the transaction.

When the database has transactions that run for a long time and contain a large amount of modified data, or it takes a long time to enable flashback, the undo space may continuously expand. When the undo space is close to the value specified by **undo_space_limit_size**, forcible recycling is triggered. As long as a transaction has been committed or rolled back, the transaction may be recycled even if it is committed later than *$* (current_time – undo_retention_time).

4.3.3 Ustore Transaction Model

GaussDB Kernel transaction basis:

1. An XID is not automatically allocated when a transaction is started, unless the first DML/DDL statement in the transaction is executed.
2. When a transaction ends, a commit log (CLOG) indicating the transaction commit state is generated. The states can be IN_PROGRESS, COMMITTED,

ABORTED, or SUB_COMMITTED. Each transaction has two CLOG status bits. Each byte on the CLOG page indicates four transaction commit states.

3. When a transaction ends, a commit sequence number (CSN) is generated, which is an instance-level variable. Each XID has its unique CSN. The CSN can mark the following transaction states: IN_PROGRESS, COMMITTED, ABORTED, or SUB_COMMITTED.

4.3.3.1 Transaction Commit

1. Implicit transaction. A single DML/DDL statement can automatically trigger an implicit transaction, which does not have explicit transaction block control statements (such as START TRANSACTION/BEGIN/COMMIT/END). After a DML/DDL statement ends, the transaction is automatically committed.
2. Explicit transaction. An explicit transaction uses an explicit statement, such as START TRANSACTION or BEGIN, to control the start of the transaction. The COMMIT and END statements control the commit of a transaction.

   Sub-transactions must be in explicit transactions or stored procedures. The SAVEPOINT statement controls the start of sub-transactions, and the RELEASE SAVEPOINT statement controls the end of sub-transactions. If sub-transactions that are not released during transaction committing, the sub-transactions are committed before the transaction is committed.

   Ustore supports READ COMMITTED. At the beginning of statement execution, the current system CSN is obtained for querying the current statement. The visible result of the entire statement is determined at the beginning of statement execution and is not affected by subsequent transaction modifications. By default, READ COMMITTED in the Ustore is consistent. Ustore also supports standard 2PC transactions.

4.3.3.2 Transaction Rollback

Rollback is a process in which a transaction cannot be executed if a fault occurs during transaction running. In this case, the system needs to cancel the modification operations that have been completed in the transaction. Astore and UB-tree do not have rollback segments. Therefore, there is no dedicated rollback operation. To ensure performance, the Ustore rollback process supports synchronous, asynchronous, and in-page instant rollback.

1. **Synchronous rollback.**

   Transaction rollback is triggered in any of the following scenarios:

   a. The ROLLBACK keyword in a transaction block triggers a synchronous rollback.
   b. If an error is reported during transaction running, the COMMIT keyword has the same function as ROLLBACK and triggers synchronous rollback.
   c. If a fatal/panic error is reported during transaction running, the system attempts to roll back the transaction bound to the thread before exiting the thread.
2. **Asynchronous rollback.** When the synchronous rollback fails or the system is restarted after breakdown, the undo recycling thread initiates an asynchronous rollback task for the transaction that is not rolled back completely and provides services for external systems immediately. The task initiation thread Undo Launch of asynchronous rollback starts the working

thread Undo Worker to execute the rollback task. The Undo Launch thread can start a maximum of five Undo Worker threads at the same time.

3. **In-page rollback.** If the rollback operation of a transaction page is not completed, but other transactions need to reuse the TD occupied by this transaction, the in-page rollback operation is performed for all modifications on the current page. In-page rollback only rolls back modifications on the current page. Other pages are not involved.

   The rollback of a Ustore sub-transaction is controlled by the ROLLBACK TO SAVEPOINT statement. After a sub-transaction is rolled back, the parent transaction can continue to run. The rollback of a sub-transaction does not affect the transaction status of the parent transaction. If sub-transactions that are not released during the parent transaction rollback, the sub-transactions are rolled back before the parent transaction is rolled back.

4.3.4 Common View Tools

View Type	Type	Function	Application Scenario	Function
Parsing	All types	Parses a specified table page and returns the path for storing the parsed content.	● Page information viewing ● Tuple (non-user data) information ● Damaged pages and tuples ● Tuple visibility problems ● Verification errors	gs_parse_page_by path
	Index recycle queue (URQ)	Parses key information in the URQ.	● UB-tree index space expansion ● UB-tree index space recycle exceptions ● Verification errors	gs_urq_dump_stat

View Type	Type	Function	Application Scenario	Function
	Rollback segment (undo)	Parses the specified undo record, excluding the tuple data of old versions.	• Expanded undo space • Undo recycling exceptions • Rollback exceptions • Routine maintenance • Verification errors • Visibility judgment exceptions • Parameter modifications	gs_undo_dump_record
		Parses all undo records generated by a specified transaction, excluding tuple data of old versions.		gs_undo_dump_xid
		Parses all information about transaction slots in a specified undo zone.		gs_undo_translot_dump_slot
		Parses the transaction slot information of a specified transaction, including the XID and the range of undo records generated by the transaction.		gs_undo_translot_dump_xid
		Parses the metadata of a specified undo zone and displays the pointer usage of undo records and transaction slots.		gs_undo_meta_dump_zone
		Parses the undo space metadata corresponding to a specified undo zone and displays the file usage of undo records.		gs_undo_meta_dump_spaces
		Parses the slot space metadata corresponding to a specified undo zone and displays the file usage of transaction slots.		gs_undo_meta_dump_slot
		Parses the data page and all data of historical versions and returns the path for storing the parsed content.		gs_undo_dump_parsepage_mv
	Write ahead log (WAL)	Parses Xlog within the specified LSN range and returns the path for storing parsed content. You can use **pg_current_xlog_location()** to obtain the current Xlog position.	• WAL errors • Log replay errors • Damaged pages	gs_xlogdump_lsn
		Parses Xlog of a specified XID and returns the path for storing parsed content. You can use **txid_current()** to obtain the current XID.		gs_xlogdump_xid
		Parses logs corresponding to a specified table page and returns the path for storing the parsed content.		gs_xlogdump_tablepath

View Type	Type	Function	Application Scenario	Function
		Parses the specified table page and logs corresponding to the table page and returns the path for storing the parsed content. It can be regarded as one execution of **gs_parse_page_bypath** and **gs_xlogdump_tablepath**. The prerequisite for executing this function is that the table file exists. To view logs of deleted tables, call **gs_xlogdump_tablepath**.		gs_xlogdump_parsepage_tablepath
Collecting	Rollback segment (undo)	Displays the statistics of the Undo module, including the usage of undo zones and undo links, creation and deletion of undo module files, and recommended values of undo module parameters.	● Undo space expansion ● Undo resource monitoring	gs_stat_undo
	Write ahead log (WAL)	Collects statistics of the memory status table when WALs are written to disks.	● WAL write/disk flushing monitoring ● Suspended WAL write/disk flushing	gs_stat_wal_entrytable
		Collects WAL statistics about the disk flushing status and location.		gs_walwriter_flush_position
		Collects WAL statistic about the frequency of disk flushing, data volume, and flushing files.		gs_walwriter_flush_stat
Validation	Heap table/ Index	Checks whether the disk page data of tables or index files is normal offline.	● Damaged pages and tuples ● Visibility issues ● Log replay errors	ANALYZE VERIFY
		Checks whether physical files of the current database in the current instance are lost.	Lost files	gs_verify_data_file
	Index recycle queue (URQ)	Checks whether the data of the URQ (potential queue/available queue/single page) is normal.	● UB-tree index space expansion ● UB-tree index space recycle exceptions	gs_verify_urq

View Type	Type	Function	Application Scenario	Function
	Rollback segment (undo)	Checks whether undo records are normal offline.	• Abnormal or damaged undo records • Visibility issues • Abnormal or damaged rollback	gs_verify_undo_record
		Checks whether the transaction slot data is normal offline.	• Abnormal or damaged undo records • Visibility issues • Abnormal or damaged rollback	gs_verify_undo_slot
		Checks whether the undo metadata is normal offline.	• Node startup failure caused by undo metadata • Undo space recycling exceptions • Outdated snapshots	gs_verify_undo_meta
Restoration	Heap table/Index/Undo file	Restores lost physical files on the primary server based on the standby server.	Lost heap tables/Indexes/undo files	gs_repair_file
	Heap table/Index/Undo page	Checks and restores damaged pages on the primary server based on the standby server.	Damaged heap tables/indexes/undo pages	gs_verify_and_tryrepair_page

View Type	Type	Function	Application Scenario	Function
		Restores the pages of the primary server based on the pages of the standby server.		gs_repair_page
		Modifies the bytes of the page backup based on the offset.		gs_edit_page_bypath
		Overwrites the modified page to the target page.		gs_repair_page_bypath
	Rollback segment (undo)	Rebuilds undo metadata. If the undo metadata is proper, rebuilding is not required.	Abnormal or damaged undo metadata	gs_repair_undo_byzone
	Index recycle queue (URQ)	Rebuilds the URQ.	Abnormal or damaged URQ	gs_repair_urq

4.3.5 Common Problems and Troubleshooting Methods

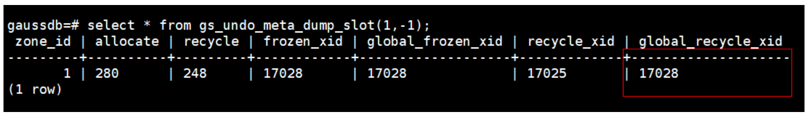
4.3.5.1 Snapshot Too Old

Undo space cannot save historical data if the execution time of the query SQL statement is too long or other reasons. Therefore, an error may be reported if the historical data is forcibly recycled. Generally, the rollback segment space needs to be expanded. However, the specific problem needs to be analyzed.

4.3.5.1.1 Undo Space Recycling Blocked by Long Transactions

Symptom

1. The following error information is printed in **pg_log**:
```
snapshot too old! the undo record has been forcibly discarded
xid xxx, the undo size xxx of the transaction exceeds the threshold xxx. trans_undo_threshold_size
xxx,undo_space_limit_size xxx.
```
   In the actual error information, *xxx* indicates the actual data.
2. The value of **global_recycle_xid** (global recycling XID of the Undo subsystem) does not change for a long time.

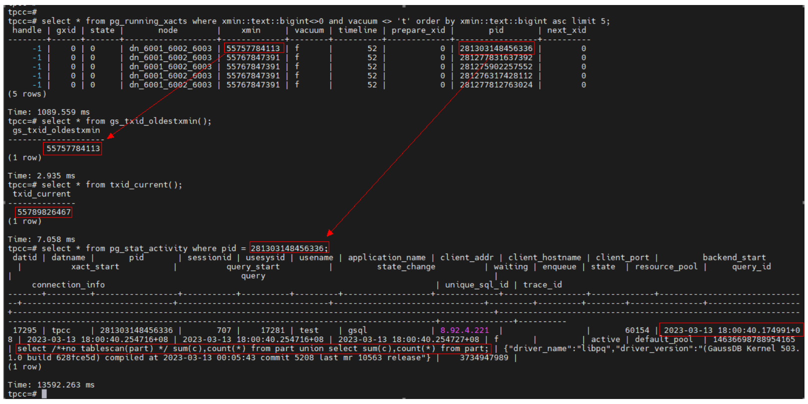


```
gaussdb=# select * from gs_undo_meta_dump_slot(1,-1);
 zone_id | allocate | recycle | frozen_xid | global_frozen_xid | recycle_xid | global_recycle_xid
---------+----------+---------+------------+-------------------+-------------+-------------------
       1 | 280      | 248     | 17028      | 17028             | 17025       | 17028
(1 row)
```

3. Long transactions exist in the **pg_running_xacts** and **pg_stat_activity** views, blocking the progress of **oldestxmin** and **global_recycle_xid**. If the value of **xmin** for querying active transactions in **pg_running_xacts** is the same as

that of **gs_txid_oldestxmin** and the execution time of the **pg_stat_activity** query thread based on a PID is too long, the recycling is suspended by a long transaction.

```
select * from pg_running_xacts where xmin::text::bigint<>0 and vacuum <> 't' order by
xmin::text:bigint asc      limit 5;
select * from gs_txid_oldextxmin();
select * from pg_stat_activity where pid = Thread PID where the long transaction exists
```



```
tpcc=#
tpcc=# select * from pg_running_xacts where xmin::text::bigint<>0 and vacuum <> 't' order by xmin::text::bigint asc limit 5;
 handle | gxid | state |        node        |    xmin     | vacuum | timeline | prepare_xid |       pid        | next_xid
--------+------+-------+--------------------+-------------+--------+----------+-------------+------------------+----------
     -1 |    0 | 0     | dn_6001_6002_6003 | 55757784113 | f      |       52 |           0 | 281303148456336 |        0
     -1 |    0 | 0     | dn_6001_6002_6003 | 55767847391 | f      |       52 |           0 | 281277831637392 |        0
     -1 |    0 | 0     | dn_6001_6002_6003 | 55767847391 | f      |       52 |           0 | 281275902257552 |        0
     -1 |    0 | 0     | dn_6001_6002_6003 | 55767847391 | f      |       52 |           0 | 281276317428112 |        0
     -1 |    0 | 0     | dn_6001_6002_6003 | 55767847391 | f      |       52 |           0 | 281277812763024 |        0
(5 rows)

Time: 1089.559 ms
tpcc=# select * from gs_txid_oldestxmin();
 gs_txid_oldestxmin
--------------------
        55757784113
(1 row)

Time: 2.935 ms
tpcc=# select * from txid_current();
 txid_current
--------------
  55789826467
(1 row)

Time: 7.058 ms
tpcc=# select * from pg_stat_activity where pid = 281303148456336;
 datid | datname |       pid        | sessionid | usesysid | usename | application_name | client_addr | client_hostname | client_port |         backend_start
  |          xact_start           |          query_start          |         state_change          | waiting | enqueue | state  | resource_pool |     query_id
|                                     query                                      |
     connection_info                                                                                                       | unique_sql_id | trace_id
-------+---------+------------------+-----------+----------+---------+------------------+-------------+-----------------+-------------+------------------------------
--+-------------------------------+-------------------------------+-------------------------------+---------+---------+--------+---------------+-------------------
+--------------------------------------------------------------------------------+----------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------+---------------+----------
 17295 | tpcc    | 281303148456336 |       707 |    17281 | test    | gsql             | 8.92.4.221  |                 |       60154 | 2023-03-13 18:00:40.174991+0
8 | 2023-03-13 18:00:40.254716+08 | 2023-03-13 18:00:40.254716+08 | 2023-03-13 18:00:40.254727+08 | f       |         | active | default_pool  | 14636698788954165
| select /*+no tablescan(part) */ sum(c),count(*) from part union select sum(c),count(*) from part; | {"driver_name":"libpq","driver_version":"(GaussDB Kernel 503.
1.0 build 628fce5d) compiled at 2023-03-13 00:05:43 commit 5208 last mr 10563 release"} |    3734947989 |
(1 row)

Time: 13592.263 ms
tpcc=#
```

Solution

Use **pg_terminate_session(pid, sessionid)** to terminate the sessions of the long transactions. (Note: There is no fixed quick restoration method for long transactions. Forcibly ending the execution of SQL statements is a common but high-risk operation. Exercise caution when performing this operation. Before performing this operation, please confirm with the administrator and Huawei technical personnel to prevent service failures or errors.)

4.3.5.1.2 Slow Undo Space Recycling Caused by Many Rollback Transactions

Symptom

The **gs_async_rollback_xact_status** view shows that there are a large number of transactions to be rolled back, and the number of transactions to be rolled back remains unchanged or keeps increasing.

```
select * from gs_async_rollback_xact_status();
```

Solution

Increase the number of asynchronous rollback threads in either of the following ways:

Method 1: Configure **max_undo_workers** in **postgresql.conf** and restart the node.

Method 2: Restart the instance using **gs_guc reload -Z NODE-TYPE [-N NODE-NAME] [-I INSTANCE-NAME | -D DATADIR] -c max_undo_workers=100**.

4.3.5.2 Storage Test Error

During service execution, if a data page, index, or undo page changes, logic damage detection is performed before the page is locked. If a page damage is detected, log information containing the keyword "storage test error" is exported to the database running log file **pg_log**. The page is restored to the status before the modification after rollback.

Symptom

The keyword "storage test error" is printed in **pg_log**.

Solution

Contact Huawei technical support.

4.3.5.3 An Error "UBTreeSearch::read_page has conflict with recovery, please try again later" Is Reported when a Service Uses a Standby Node to Read Data

Symptom

When the service uses the standby node to read data, an error (error code 43244) is reported. The error information contains "UBTreeSearch::read_page has conflict with recovery, please try again later."

Analysis

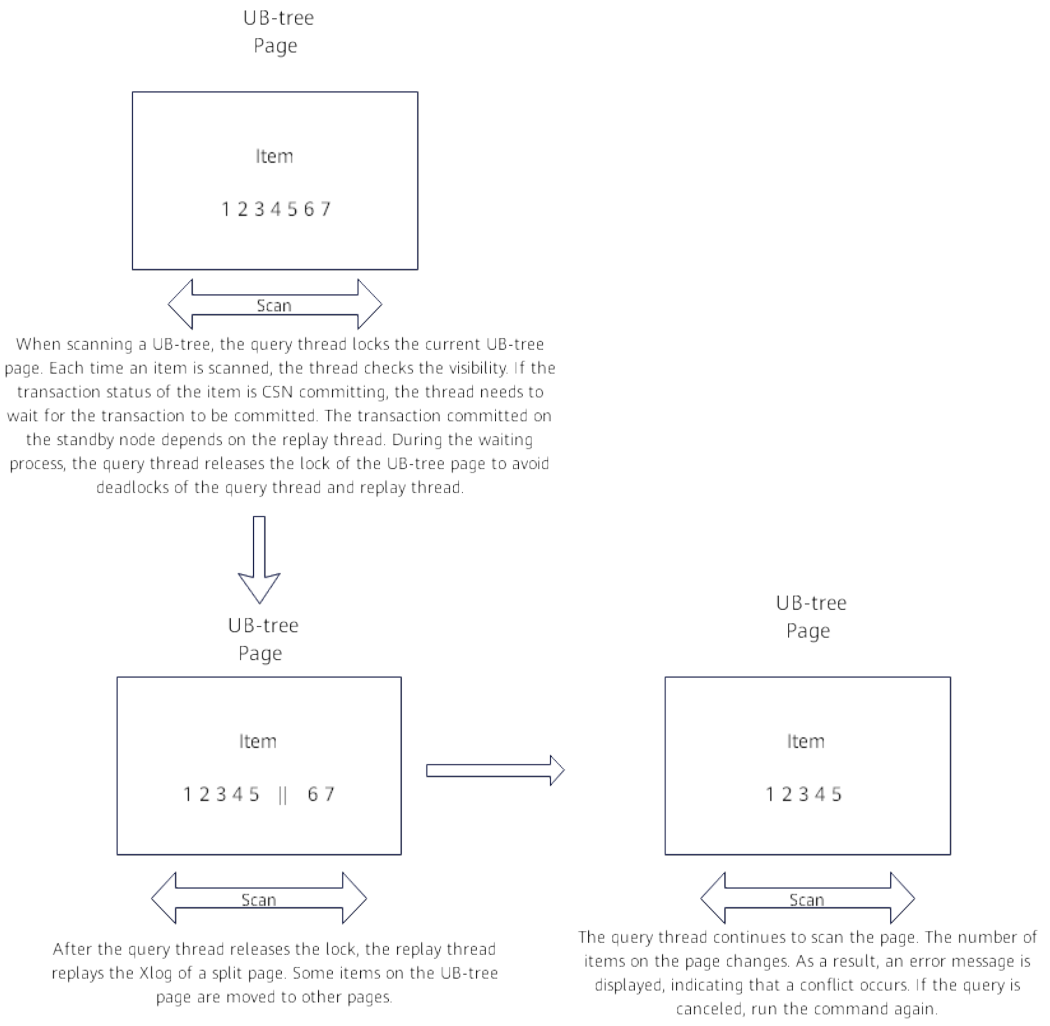
When parallel or serial replay is enabled (if the GUC parameters **recovery_parse_workers** and **recovery_max_workers** are both set to **1**, serial replay is enabled; if **recovery_parse_workers** is set to **1** and **recovery_max_workers** is greater than 1, parallel replay is enabled): If the query thread of the standby node scans indexes, a read lock is added to the index page. Each time a tuple is scanned, the visibility is checked. If the transaction corresponding to the tuple is in the committing state, the visibility is checked after the transaction is committed. Transaction committed on the standby node depends on the log replay thread. During this process, the index page is modified. Therefore, a lock is required. The query thread releases the lock of the index page during waiting. Otherwise, the query thread waits for the replay thread to commit the transaction, and the replay thread waits for the query thread to release the lock.

This error occurs only when the same index page needs to be accessed during query and replay. When the query thread releases the lock and waits for the transaction to end, the accessed page is modified.

NOTE

- When scanning tuples in the committing state, the standby node needs to wait for transaction to be committed because the transaction committing sequence and log generation sequence may be out of order. For example, the transaction of tx_1 on the primary node is committed earlier than that of tx_2, the commit log of tx_1 on the standby node is replayed after the commit log of tx_2. According to the transaction committing sequence, tx_1 should be visible to tx_2. Therefore, you need to wait for the transaction to be committed.
- When the standby node scans the index page, it is found that the number of tuples (including dead tuples) on the page changes and cannot be retried. This is because the scanning may be forward or reverse scanning. For example, after the page is split, some tuples are moved to the right page. In the case of reverse scanning, even if the retry is performed, the tuples can only be read from the left, the correctness of the result cannot be ensured, and the split or insertion cannot be distinguished. Therefore, retry is not allowed.

Figure 4-1 Analysis


UB-tree Page
Item
1 2 3 4 5 6 7
Scan
When scanning a UB-tree, the query thread locks the current UB-tree page. Each time an item is scanned, the thread checks the visibility. If the transaction status of the item is CSN committing, the thread needs to wait for the transaction to be committed. The transaction committed on the standby node depends on the replay thread. During the waiting process, the query thread releases the lock of the UB-tree page to avoid deadlocks of the query thread and replay thread.
UB-tree Page
Item
1 2 3 4 5 || 6 7
Scan
After the query thread releases the lock, the replay thread replays the Xlog of a split page. Some items on the UB-tree page are moved to other pages.
UB-tree Page
Item
1 2 3 4 5
Scan
The query thread continues to scan the page. The number of items on the page changes. As a result, an error message is displayed, indicating that a conflict occurs. If the query is canceled, run the command again.

Solution

If an error is reported, you are advised to retry the query. In addition, you are advised to select index columns that are not frequently updated and use the soft deletion mode (physical deletion is performed during off-peak hours) to reduce the probability of this error.