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ApsaraDB for RDS

Proprietary AliSQL

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Document conventions

Style	Description	Example
Danger	A danger notice indicates a situation that will cause major system changes, faults, physical injuries, and other adverse results.	**Danger:** Resetting will result in the loss of user configuration data.
Warning	A warning notice indicates a situation that may cause major system changes, faults, physical injuries, and other adverse results.	**Warning:** Restarting will cause business interruption. About 10 minutes are required to restart an instance.
Notice	A caution notice indicates warning information, supplementary instructions, and other content that the user must understand.	**Notice:** If the weight is set to 0, the server no longer receives new requests.
Note	A note indicates supplemental instructions, best practices, tips, and other content.	**Note:** You can use Ctrl + A to select all files.
>	Closing angle brackets are used to indicate a multi-level menu cascade.	Click **Settings**> **Network**> **Set network type**.
Bold	Bold formatting is used for buttons , menus, page names, and other UI elements.	Click **OK**.
`Courier font`	Courier font is used for commands	Run the `cd /d C:/window` command to enter the Windows system folder.
Italic	Italic formatting is used for parameters and variables.	`bae log list --instanceid` *Instance_ID*
[] or [a|b]	This format is used for an optional value, where only one item can be selected.	`ipconfig [-all|-t]`
{} or {a|b}	This format is used for a required value, where only one item can be selected.	`switch {active|stand}`

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1.Overview of AliSQL features

This topic provides an overview of the features that are provided by AliSQL. This topic also provides a comparison between AliSQL and other MySQL versions.

Introduction to AliSQL

AliSQL is an independent MySQL branch that is developed by Alibaba Cloud. AliSQL provides all the features of the MySQL Community Edition. AliSQL also provides some similar features that you can find in the MySQL Enterprise Edition. These similar features include enterprise-grade backup and restoration, thread pool, and parallel query. In addition, AliSQL provides Oracle-compatible features, such as the Sequence engine. ApsaraDB RDS for MySQL with AliSQL provides all features of MySQL and a wide range of advanced features that are developed by Alibaba Cloud. These advanced features include enterprise-grade security, backup and restoration, monitoring, performance optimization, and read-only instances.

Features and MySQL versions

Category	Feature	Description	MySQL 8.0	MySQL 5.7	MySQL 5.6
Functionality	Native Flashback	The native flashback feature allows you to query or restore the data at a specified point in time by executing SQL statements. This way, you can obtain the historical data at your earliest opportunity after accidental operations.	Supported	Not supported	Not supported
	Thread Pool	The thread pool feature separates threads from sessions. If a large number of sessions are created on your RDS instance, ApsaraDB RDS can run a small number of threads to process the tasks in all active sessions.	Supported	Supported	Supported
	Statement outline	The statement outline feature allows ApsaraDB RDS to stably run query plans by using optimizer hints and index hints. You can install the DBMS_OUTLN package to use this feature.	Supported	Supported	Not supported
	Sequence Engine	The Sequence engine simplifies the generation of sequence values on your RDS instance.	Supported	Supported	Supported
	Returning	This returning feature allows DML statements to return result sets. You can install the DBMS_TRANS package to use this feature.	Supported	Not supported	Not supported
	Lizard transaction system	The Lizard transaction system can further increase the throughput of your RDS instance. It also supports distributed transactions and global consistency.	Supported	Not supported	Not supported

Category	Feature	Description	MySQL 8.0	MySQL 5.7	MySQL 5.6
Performance	Fast query cache	The fast query cache is a query cache that is developed by Alibaba Cloud based on the native MySQL query cache. The fast query cache uses a new design and a new implementation mechanism to increase the query performance of your RDS instance.	Not supported	Supported	Not supported
	Binlog in Redo	The Binlog in Redo feature allows ApsaraDB RDS to write binary logs to the redo log file when transactions are committed. This reduces the operations on the disk and increases the performance of your RDS instance.	Supported	Not supported	Not supported
	Statement Queue	The statement queue feature allows statements to queue in the same bucket. These statements may be executed on the same resources. For example, these statements are executed on the same row of a table. This feature reduces the overheads that are caused by potential conflicts.	Supported	Supported	Not supported
	Inventory Hint	The inventory hint feature can be used in combination with the returning feature and the statement queue feature to commit and roll back transactions at fast speeds. This increases the throughput of your application.	Supported	Supported	Supported
Stability	Faster DDL	The faster DDL feature provides an optimized buffer pool management mechanism. This mechanism reduces the impact of DDL operations on the performance of your RDS instance. This mechanism also increases the number of concurrent DDL operations that are allowed.	Supported	Supported	Supported
	Statement concurrency control	The concurrency control (CCL) feature allows ApsaraDB RDS to control the concurrency of statements based on syntax rules. You can install the DBMS_CCL package to use this feature.	Supported	Supported	Not supported
	Performance Agent	The performance agent feature is provided as a plug-in for MySQL. This feature is used to calculate and analyze the performance metrics of your RDS instance.	Supported	Supported	Supported

Category	Feature	Description	MySQL 8.0	MySQL 5.7	MySQL 5.6
	Purge Large File Asynchronously	The Purge Large File Asynchronously feature allows ApsaraDB RDS to asynchronously delete files from your RDS instance. This ensures the stability of your RDS instance.	Supported	Supported	Supported
	Performance Insight	The performance insight feature supports load monitoring, association analysis, and performance optimization at the instance level. You can evaluate the loads on your RDS instance and resolve performance issues. This increases the stability of your RDS instance.	Supported	Supported	Not supported
Security	Recycle bin	The recycle bin feature allows ApsaraDB RDS to temporarily store deleted tables. It also allows you to specify a retention period within which you can retrieve the deleted tables. You can install the DBMS_RECYCLE package to use this feature.	Supported	Not supported	Not supported

Features

Category	Feature	MySQL Community Edition	MySQL Enterprise Edition	AliSQL (MySQL 5.7 and MySQL 8.0)	ApsaraDB RDS for MySQL
Enterprise-grade value-added services	24/7 support	Not supported	Supported	Supported	Supported
	Emergency troubleshooting	Not supported	Supported	Supported	Supported
	Expert support	Not supported	Supported	Supported	Supported
	MySQL Database Server	Supported	Supported	Supported	Supported
	MySQL Document Store	Supported	Supported	Supported for MySQL 8.0	Supported for MySQL 8.0
	MySQL Connectors	Supported	Supported	Supported for public versions	Supported for public versions
	MySQL Replication	Supported	Supported	Supported	Supported

MySQL Features Category	Feature	MySQL Community Edition	MySQL Enterprise Edition	AliSQL (MySQL 5.7 and MySQL 8.0)	ApsaraDB RDS for MySQL
	MySQL Router	Supported	Supported	MaxScale supported for MySQL 8.0	Shared proxies supported
	MySQL Partitioning	Supported	Supported	Supported	Supported
	Storage Engine	InnoDB MyISAM NDB	InnoDB MyISAM NDB	InnoDB X-Engine	InnoDB X-Engine
Oracle Compatibility	Sequence Engine	Not supported	Not supported	Supported for MySQL 8.0	Supported for MySQL 8.0
MySQL Enterprise Monitor	Enterprise Dashboard	Not supported	Supported	Under development	Enhanced Monitor
	Query Analyzer	Not supported	Supported	Under development	Performance Insight
	Replication Monitor	Not supported	Supported	Under development	Supported
	Enhanced OS Metrics	Not supported	Not supported	Not supported	Enhanced Monitor
MySQL Enterprise Backup	Hot backup for InnoDB	Not supported	Supported	Supported	Supported
	Full, Incremental, Partial, Optimistic Backups	Not supported	Supported	Supported	Database- and table-level backup supported
	Full, Partial, Selective, Hot Selective restore	Not supported	Supported	Supported	Database- and table-level restoration supported
	Point-In-Time-Recovery	Not supported	Supported	Supported	Supported
	Cross-Region Backup	Not supported	Not supported	Not supported	Cross-region backup supported
	Recycle bin	Not supported	Not supported	Supported for MySQL 8.0	Supported for MySQL 8.0

Category	Feature	MySQL Community Edition	MySQL Enterprise Edition	AliSQL (MySQL 5.7 and MySQL 8.0)	ApsaraDB RDS for MySQL
	Flashback	Not supported	Not supported	Supported	Supported
MySQL Enterprise Security	Enterprise TDE	Local key replacement supported	Supported	BYOK-based TDE and key rotation supported	BYOK-based TDE and key rotation supported
	Enterprise Disk Data Encryption at Rest	Not supported	Not supported	Not supported	BYOK-based disk encryption supported
	Enterprise Encryption	SSL	Supported	SSL	SSL
	SQL Explorer	Not supported	Supported	SQL Explorer	SQL Explorer
	SM4 encryption algorithm	Not supported	Not supported	Supported	Supported
MySQL Enterprise Scalability	Thread Pool	Not supported	Supported	Supported for MySQL 8.0	Supported for MySQL 8.0
	Enterprise Readonly Request Extention	Not supported	Not supported	Supported	Read-only instances supported
MySQL Enterprise Reliability	Statement outline	Not supported	Not supported	Supported	Supported
	Inventory Hint	Not supported	Not supported	Supported	Supported
	Statement concurrency control	Not supported	Not supported	Supported	Supported
	Hot SQL Firewall	Not supported	Not supported	Supported	Supported
MySQL Enterprise High-Availability	Enterprise Automatic Failover Switch	Not supported	Not supported	Third-party high-availability mechanism required	Supported for the RDS High-availability Edition
	Multi-Source Replication	Supported	Supported	Supported	Highly available read-only instances supported

2.X-Engine

2.1. Introduction to X-Engine

X-Engine is an online transaction processing (OLTP) database-oriented storage engine that is developed by the Database Products Business Unit of Alibaba Cloud. X-Engine is widely used in a number of business systems within Alibaba Group to reduce costs. These systems include the transaction history database and the DingTalk chat history database. In addition, X-Engine is a crucial database technology that empowers Alibaba Group to withstand bursts of traffic that can surge to hundreds of times greater than average during Double 11, a shopping festival in China.

Background information

X-Engine is designed to help Alibaba Group run internal workloads. Alibaba Group has been deploying MySQL databases at scale since 2010. However, a large volume of data that grows exponentially year by year continues to impose the following challenges on these databases:

- To process highly concurrent transactions.
- To store large amounts of data.

You can increase the processing and storage capabilities by adding servers on which you can create more databases. However, this is not an efficient approach. Alibaba Cloud aims to use technical means to maximize performance with minimal resources.

The performance of the conventional database architecture is carefully studied. Michael Stonebreaker, a leader in the database field and a winner of the Turing Award, wrote a paper titled *OLTP Through the Looking Glass, and What We Found There* on this topic. In the paper, he points out that conventional general-purpose relational databases spend less than 10% of the time in actually processing data. The remaining 90% of the time is wasted on other work, such as waiting for locked resources to be released, managing buffers, and synchronizing logs.

This situation is caused by significant changes to the hardware systems on which we depend over recent years. These include multi-core and many-core CPUs, new processor architectures such as the cache-only memory architecture (COMA) and the non-uniform memory access (NUMA), various heterogeneous computing devices such as GPUs and field-programmable gate arrays (FPGAs). However, database software that is built on top of these hardware systems has barely changed. Such software includes the mechanism that fixes page sizes based on B-tree indexing, the mechanism that processes transactions and restores data by using the recovery and isolation exploiting semantics (ARIES) algorithms, and the concurrency control mechanism that is based on independent lock managers. These software mechanisms are designed based on slow disks. Therefore, the preceding hardware systems cannot unleash their full potential to deliver optimal performance.

Alibaba Cloud developed X-Engine to support the requirements of the hardware systems that are used today.

Architecture

With the pluggable storage engine of MySQL, X-Engine can be seamlessly integrated with MySQL and use the tiered storage architecture.

X-Engine is designed to store large amounts of data, increase the capability of processing concurrent transactions, and reduce storage costs. In most scenarios with large amounts of data, the data is not evenly accessed. Frequently accessed data, which is called hot data, accounts for only a small proportion. X-Engine divides data into multiple levels based on the access frequency. In addition, X-Engine determines storage structures and writes the data to appropriate storage devices based on the access characteristics of each level of data.

X-Engine uses the log-structured merge-tree (LSM tree) architecture that is redesigned for tiered storage.

- X-Engine stores hot data and updated data in the memory by using a number of memory database technologies to expedite the execution of transactions. These technologies include lock-free index structures and append-only data structures.
- X-Engine uses a transaction processing pipeline mechanism to run multiple transaction processing stages in parallel. This significantly increases throughput.
- Less frequently accessed data, which is called cold data, is gradually deleted or merged to persistent storage levels, and stored in tiered storage devices, such as NVMs, SSDs, and HDDs.
- A number of improvements are made to compactions that impose a significant impact on performance.
  - The data storage granularity is refined based on the concentration of data update hotspots. This ensures that data is reused as much as possible in the compaction process.
  - The hierarchy of the LSM tree is refined to reduce I/O and computing costs and to minimize the storage that is consumed by compactions.
- More fine-grained access control and caching mechanisms are used to optimize read performance.

> **Note** The architecture and optimization technologies of X-Engine are summarized in a paper titled *X-Engine: An Optimized Storage Engine for Large-scale E-Commerce Transaction Processing*. The paper was presented at the 2019 SIGMOD Conference, an international academic conference in the database field. This was the first time that a company from the Chinese mainland published technological achievements in OLTP database engines at an international academic conference.

Highlights

- FPGA hardware is used to accelerate compactions and further maximize the performance of database systems. This marks the first time that hardware acceleration is applied to the storage engine of an OLTP database. The achievement is summarized in a paper titled *FPGA-Accelerated Compactions for LSM-based Key Value Store*. The paper was accepted by the 18th USENIX Conference on File and Storage Technologies (FAST'20) in 2020.
- The data reuse technology is used to reduce the costs of compactions and mitigate the performance jitters that are caused by data deletion from the cache.
- Queued multi-transaction processing and pipeline processing are used to reduce the thread context switching overheads and calculate the task ratio in each stage. This streamlines the entire pipeline and increases transaction processing performance by more than 10 times compared with other similar storage engines such as RocksDB.
- The copy-on-write technique is used to prevent data pages from being updated when the data pages are read. This allows read-only data pages to be encoded and compressed. This also reduces storage usage by 50% to 90% compared with conventional storage engines such as InnoDB.
- A Bloom filter is used to quickly determine whether the requested data exists, a succinct range filter (SuRF) is used to determine whether the range data exists, and a row cache is used to cache hot data

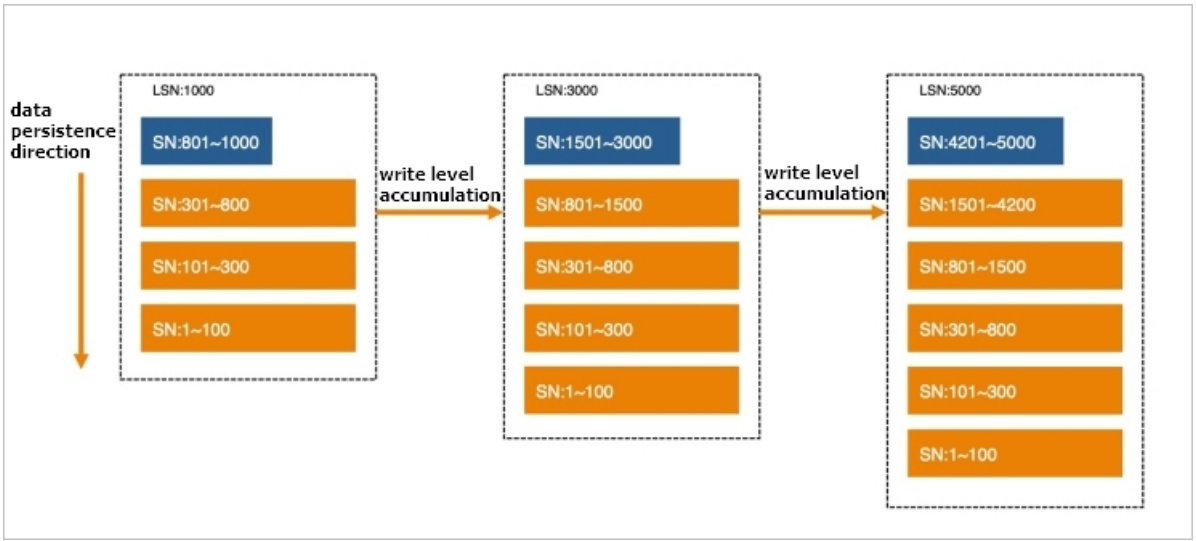
rows to accelerate read operations.

Basic logic of LSM

All LSM-based write operations write data by appending the data to the memory. When the amount of data that is written reaches a specific amount, the data is frozen as a level and then flushed to the persistent storage. All rows to which data is written are sorted based on primary keys, regardless of whether the data is stored in the memory or in the persistent storage. In the memory, data is stored in a sorted in-memory data structure, such as a skip list or a B-tree. In the persistent storage, data is stored in a read-only, fully sorted persistent storage structure.

To allow a common storage engine to support transaction processing in common storage systems, you must add a temporal factor, based on which an independent view can be built for each transaction. These views are not affected in the event of concurrent transactions. For example, the storage engine sorts the transactions, assigns sequence numbers (SNs) that monotonically and globally increase to the transactions, and logs the SN of each transaction. This way, the storage engine can determine visibility among independent transactions and isolate transactions.

If data is continuously written to the LSM storage structure and no other operations are performed, the LSM storage structure eventually becomes the structure that is shown in the following figure.



This structure facilitates write operations. A write operation is considered complete after the data is appended to the latest memory table. For crash recovery purposes, the data needs only to be recorded in the redo log. New data does not overwrite old data, and therefore appended records form a natural multi-SN structure.

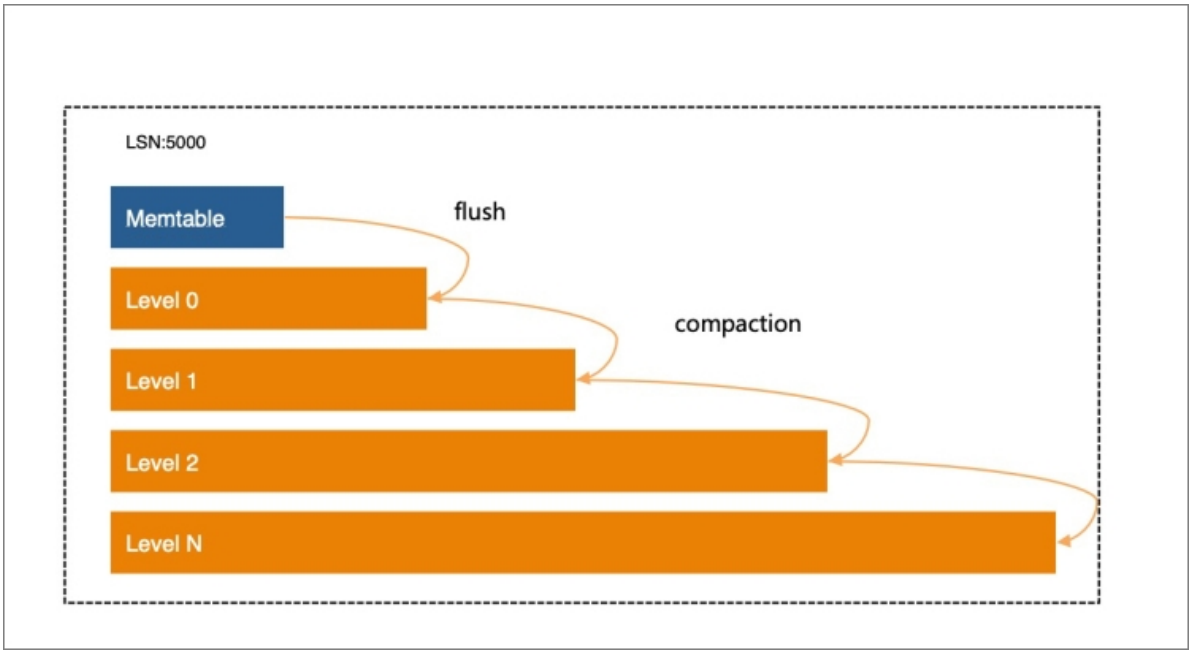
However, when more persistence levels of data are accumulated and frozen, query performance decreases. The multi-SN records that are generated for different transaction commits but have the same primary key are distributed across different levels, as are the records that have different keys. In this case, read operations need to search all levels of data and merge the found data to obtain the final results.

Compactions are introduced to LSM to resolve this issue. Compactions in LSM have two objectives:

- Control the hierarchy of LSM

  In most cases, the data volume increases in proportion with the decrease of the LSM level to improve read performance.

Data access in a storage system is localized, and a large proportion of access traffic is concentrated on a small portion of data. This is the basic prerequisite for effective operations in the cache system. In the LSM storage structure, you can store hot data at a high LSM level on high-speed storage devices, such as NVMs and DRAMs, and cold data at a low level on low-speed storage devices that are provided at lower costs. This is the basis of hot and cold data separation in X-Engine.



- Merge data

  Compactions continuously merge data at adjacent LSM levels and write the merged data to the lower LSM levels. During the compaction process, the system reads the data to be merged from two or more adjacent levels and then sorts the data based on keys. If multiple records with the same key have different SNs, the system retains only the record with the latest SN, discards the records with earlier SNs, and writes the record with the latest SN to a new level. The latest SN is greater than the earliest SN of the current transaction that is being executed. This process consumes a large number of resources.

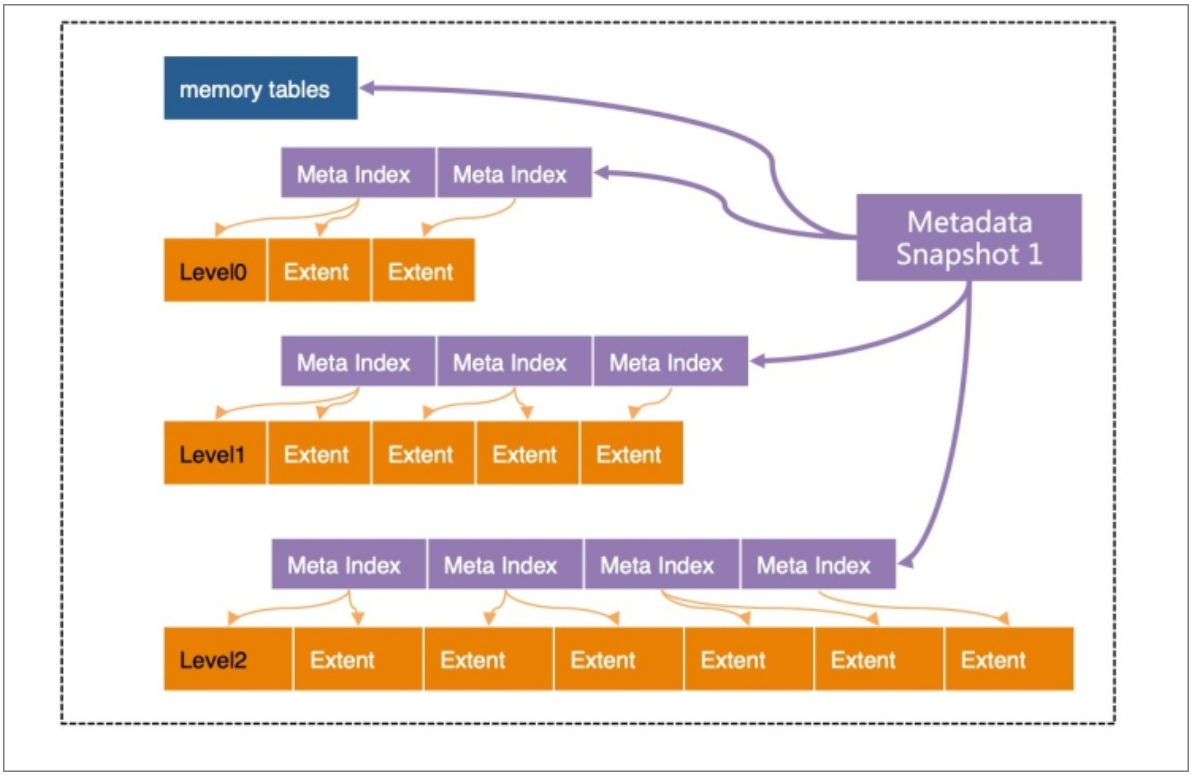
  In addition to the separation of hot data and cold data, factors such as the data update frequency must also be considered during compactions. Queries for a large number of multi-SN records waste more I/O and CPU resources. Therefore, records that have the same key but different SNs must be preferably merged to reduce the number of SNs. Alibaba Cloud designs a proprietary compaction scheduling mechanism for X-Engine.

Highly optimized LSM

In X-Engine, lock-free skip lists are used in the memory tables to accelerate highly concurrent read and write queries. A data structure must be planned at each LSM level to ensure the efficient organization of data at persistence levels.

- Data structuring

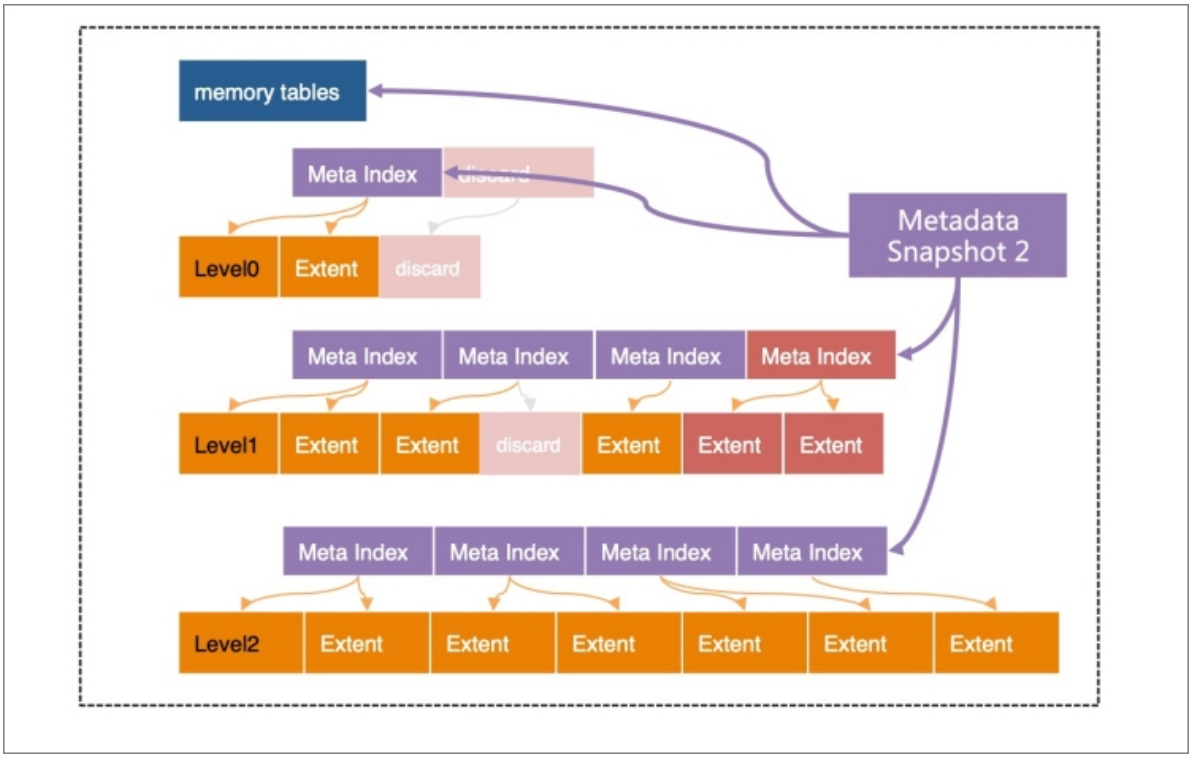
  In X-Engine, each level is divided into extents of a fixed size. An extent stores the data with a continuous key range at the level. A set of metadata indexes are created for the extents at each level. All of these indexes together with all of the active and immutable memory tables form a metadata tree. The metadata tree has a structure similar to the structure of the B-tree, and the root nodes of the metadata tree are metadata snapshots. The metadata tree helps quickly locate extents.



Except for the active memory tables to which data is being written, all structures in X-Engine are read-only and cannot be modified. When a point in time is specified, for example, when the log sequence number (LSN) is 1000, the structure that is referenced by metadata snapshot 1 in the preceding figure contains all data that is logged until LSN 1000. This is also why this structure is called a snapshot.

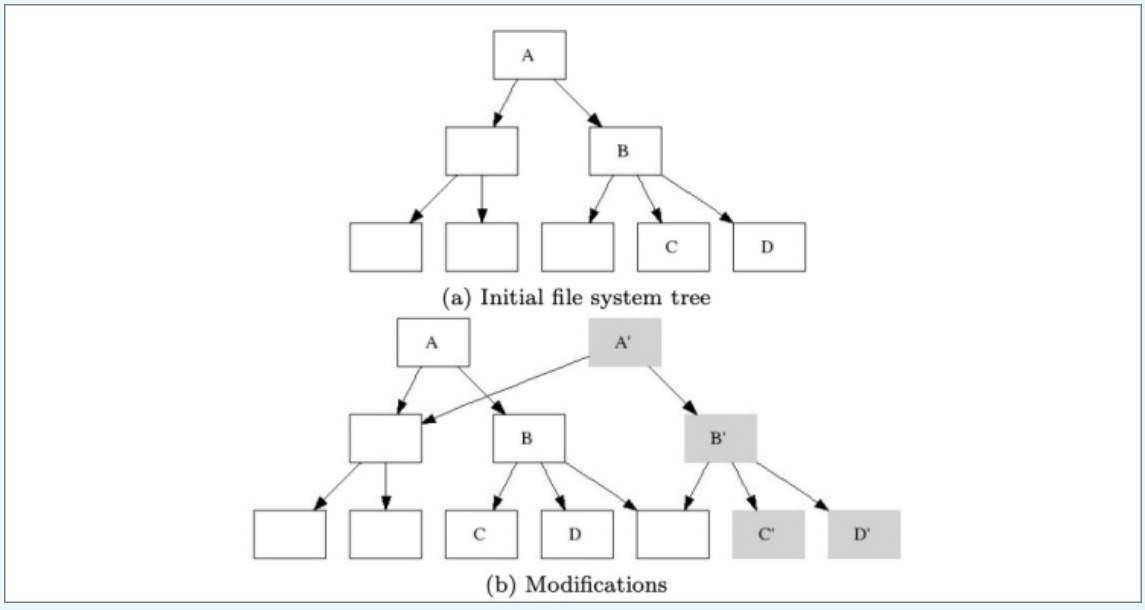
The metadata structure itself does not change after it is generated. All read operations start from this snapshot structure. This is the basis on which X-Engine implements snapshot-level isolation. The copy-on-write technique is used to perform all operations such as compactions and memory table freezes. The result of each modification is written to a new extent. Then, a new metadata index structure is generated. Finally, a new metadata snapshot is generated.

For example, each compaction generates a new metadata snapshot, as shown in the following figure.



In this example, metadata snapshot 2 is slightly different from metadata snapshot 1. Only the leaf nodes and index nodes that change are modified.

Note This data structuring technology is similar to the technology that is presented in the paper titled B-trees, Shadowing, and Clones. You can read the paper to better understand this process.



- Transaction processing

With a lightweight write mechanism, LSM has significant advantages in processing write operations. However, transaction processing is not as simple as writing updated data to a system and requires complicated processing phases to ensure atomicity, consistency, isolation, and durability (ACID). X-Engine divides the transaction processing process into two phases:

i. Read and write phase

   In the read and write phase, X-Engine checks for write-write conflicts and read-write conflicts and determines whether the transaction can be executed, rolled back, or locked. If no conflicts are detected, all modified data is written to the transaction buffer.

ii. Commit phase

   The commit phase includes the entire process of writing data to the write-ahead logging (WAL) file, writing data to the memory tables, committing data, and returning results to the user. This process involves I/O operations and CPU operations. I/O operations are performed to log operations and return results. CPU operations are performed to copy logs and write data to memory tables.

To increase the throughput during transaction processing, the system concurrently processes a large number of transactions. A single I/O operation requires high costs. Therefore, most storage engines preferably commit a number of transactions at a time, which is called "group commit." This allows you to combine I/O operations. However, the transactions that are to be committed at a time still need to wait for a long period of time. For example, when logs are being written to the disk, nothing else is done except to wait for the data to be flushed to the disk.

To further increase the throughput during transaction processing, X-Engine adopts a pipeline technology that divides the commit phase into four independent, more fine-grained stages:

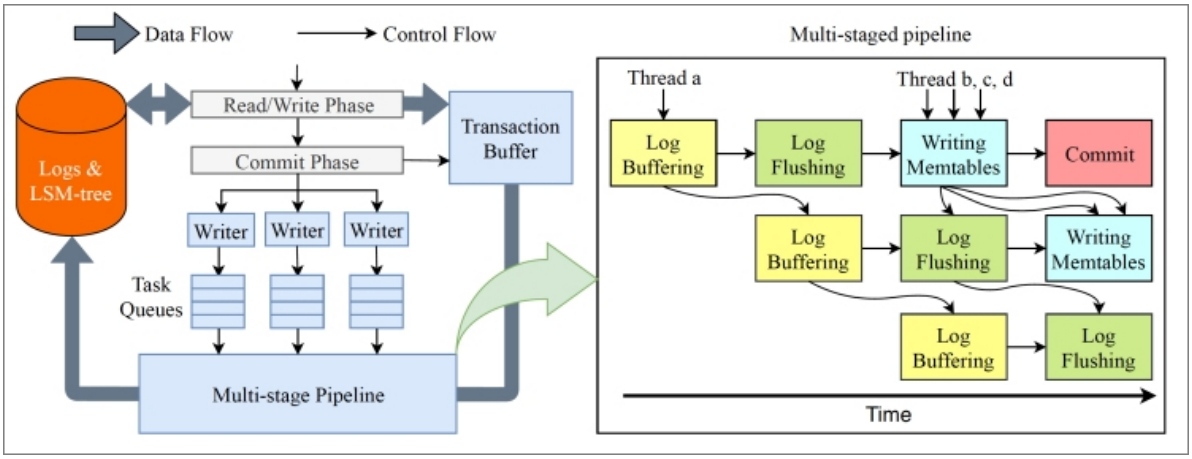
i. Copying logs to the log buffer

ii. Flushing logs to the disk

iii. Writing data to the memory tables

iv. Committing data

When a transaction commit thread enters the commit phase, it can freely choose any stages of the pipeline to process the data. This way, threads can concurrently process data at different stages. If the tasks for each stage are properly divided based on sizes, all stages of the pipeline can be nearly fully loaded. In addition, transaction processing threads rather than background threads are used in the commit phase. Each phase either executes tasks in a stage or processes requests. This process does not involve waiting or switching, and therefore the capabilities of each thread are fully utilized.



- Read operations

In LSM, if multiple records with the same key have different SNs, the records with later SNs are appended to the record with the earliest SN. Records that have the same key but different SNs may be stored at different levels. The system must identify the appropriate SN of each requested record in compliance with the visibility rules that are defined based on the transaction isolation levels. In most cases, the system searches for records with the latest SNs from the highest level to the lowest level.

For single-record queries, the query process ends after the single record is found. If the record is located at a high level, for example, in a memory table, the record is quickly returned. If the record is located at a low level, for example, at a level used for random reading, the system must search downwards level by level. In this case, a bloom filter can be used to skip some levels to expedite the query. However, this involves more I/O operations. A row cache is used in X-Engine to expedite single-row queries. The row cache stores data above all persistent data levels. If a single-row query does not hit the requested data in the memory tables, the single-row query can hit the requested data in the row cache. The row cache needs to store each record with the latest SN at all persistence levels. However, the records in the row cache may change. For example, every time after a read-only memory table is flushed to a persistence level, the records in the row cache must be updated accordingly. This operation is subtle and requires a careful design.

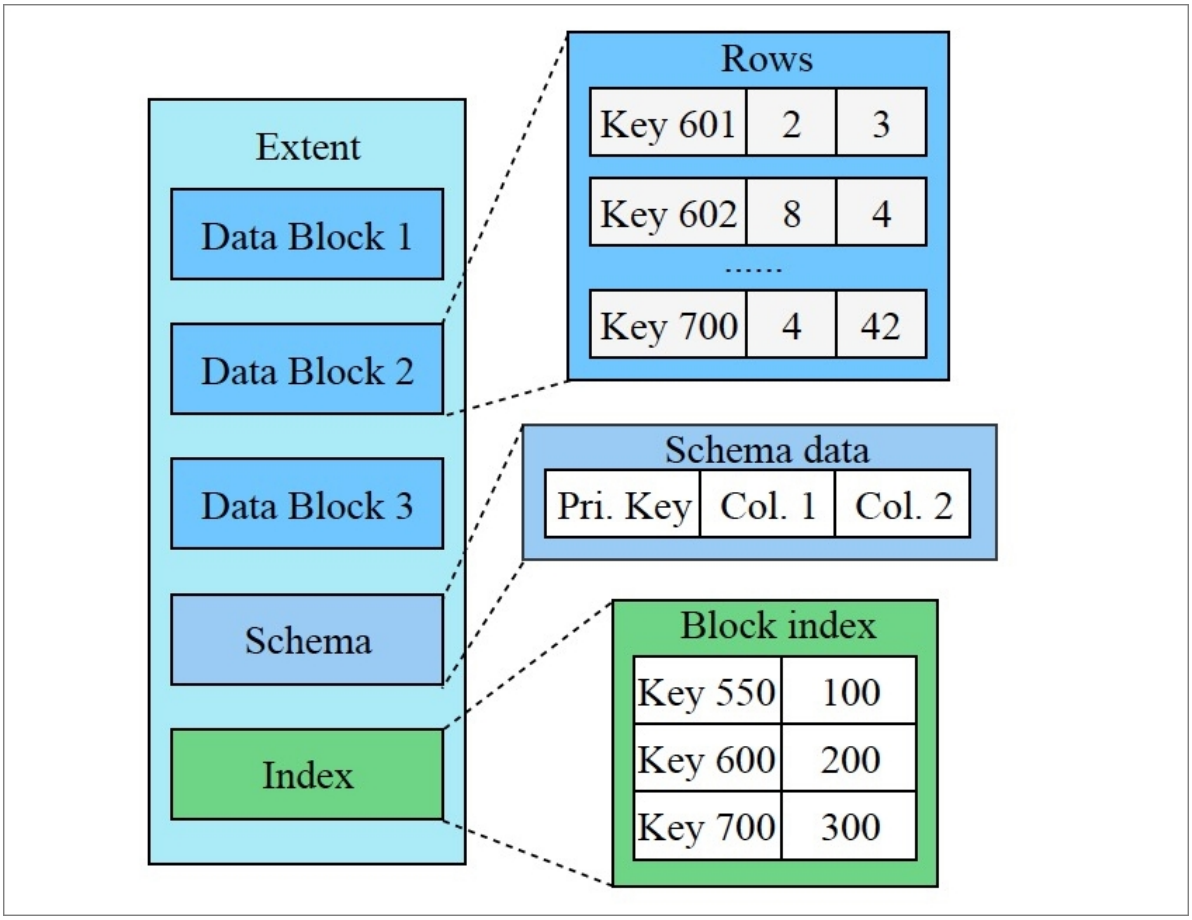
For range scans, the level at which the data associated with a specific key range is stored cannot be determined. In this case, the final result can be returned only after all levels are scanned for the data and the data is merged. X-Engine provides various methods to address this issue. For example, SuRF presented at the best paper at the 2018 SIGMOD Conference provides a range scan filter to reduce the number of levels to be scanned. The asynchronous I/O and prefetching mechanism are also provided to address this issue.

The core to read operations is the cache design. A row cache handles single-row queries. A block cache handles the requests that cannot be hit in the row cache or the range scan requests. However, in LSM, a compaction incurs updates to a large number of data blocks at a time. As a result, a large amount of data in the block cache expires within a short period of time, and a sharp performance jitter occurs. The following optimizations are made to address this issue:

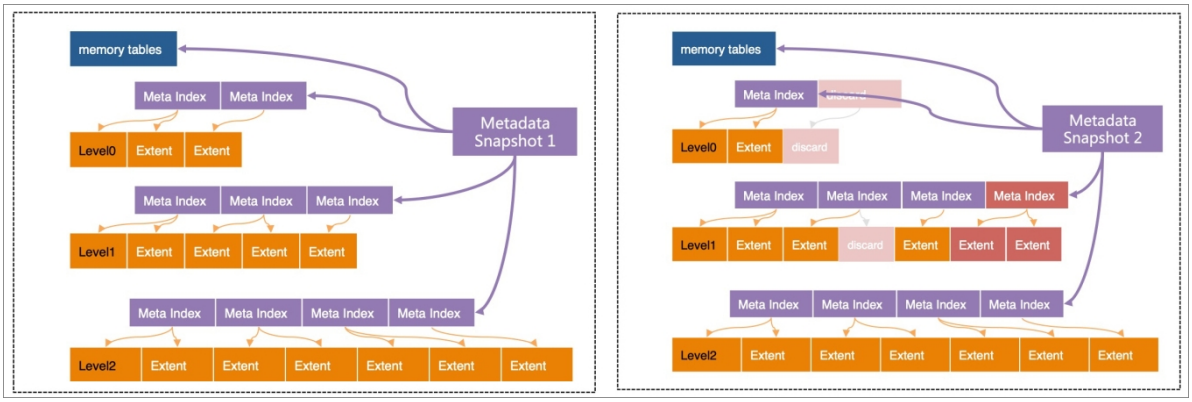
- Reduce the granularity of compaction.
- Reduce the amount of data that is modified during each compaction.
- Update the existing cached data only when the data is modified during each compaction.

- Compaction

  Compactions are important. The system needs to read data associated with overlapped key ranges from adjacent levels, merge the data, and write the merged data to a new level. This is the cost of simple write operations. The storage architecture of X-Engine is redesigned to optimize compactions.



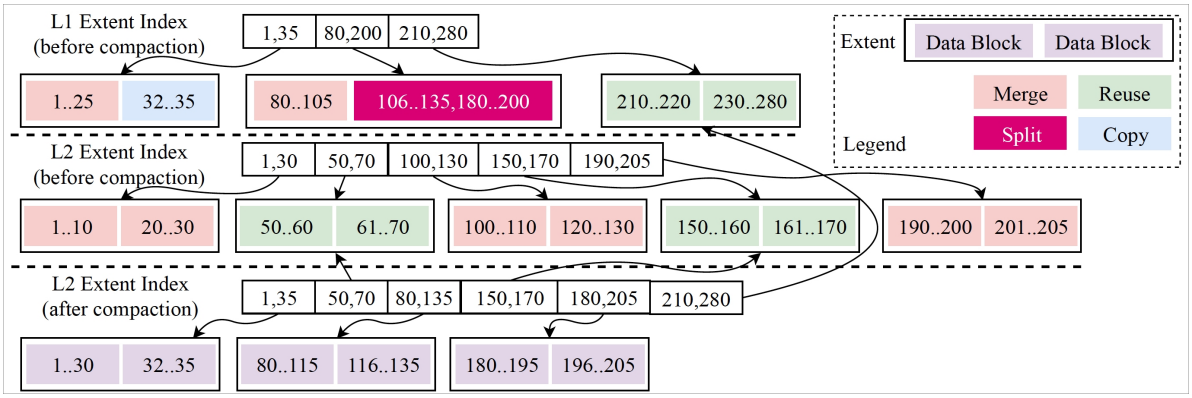
As previously mentioned, X-Engine divides each level of data into extents of a fixed-size. An extent is equivalent to a small but complete Sorted String Table (SSTable), which stores the data with a continuous key range at the level. A key range is further divided into smaller continuous segments, which are called data blocks. Data blocks are equivalent to pages in conventional databases, except that data blocks are read-only and their lengths are not fixed.



A comparison between metadata snapshot 1 and metadata snapshot 2 helps you understand the intent of the extent design. Only a small portion of overlapped data and the metadata index node need to be modified during each modification. The structures of metadata snapshot 1 and metadata snapshot 2 share a large number of data structures. This is called data reuse, and the extent size is a crucial factor that determines the data reuse rate. As a completely reusable physical structure, the extent size is minimized to reduce the amount of overlapped data. However, the extent size must be appropriate. If the extent size is abnormally small, a large number of indexes are required, which increases management costs.

In X-Engine, the data reuse rate is high in compactions. For example, you want to merge the extents that contain overlapped key ranges at level 1 and level 2. In this case, the merge algorithm scans the data row by row. All physical structures, including data blocks and extents, that do not overlap with the data at other levels can be reused. The difference between the reuse of extents and the reuse of data blocks is that the metadata indexes of extents can be modified while data blocks can only be copied. Data blocks are not recommended, although they can help significantly reduce CPU utilization.

The following figure shows a typical data reuse process in a compaction.



Row-by-row iteration is used to complete the data reuse process. However, this fine-grained data reuse causes data fragmentation.

Data reuse benefits the compaction itself, reduces I/O and CPU consumption during the compaction, and improves the overall performance of the system. For example, in the compaction process, data does not need to be completely rewritten, which significantly reduces the storage that is occupied by the written data. In addition, most data remains unchanged, and therefore the cached data remains valid after data updates. This reduces read performance jitters that are caused by the expiration of the cached data during the compaction.

In fact, optimizations to compactions are only part of what X-Engine does. X-Engine also optimizes the compaction scheduling policies, specifies the type of extent, and defines the granularity of compactions and the execution priorities of the specified compactions. These all affect the performance of the system. Although no perfect policies exist, X-Engine has accumulated valuable experience and defined a number of rules to define proper compaction scheduling policies.

Scenarios

For more information, see Best practices of X-Engine.

Get started with X-Engine

For more information, see Usage notes.

Follow-up development

As a storage engine for MySQL, X-Engine must be continuously improved in terms of compatibility with MySQL systems. Based on the most urgent needs, some features such as foreign keys will be gradually enhanced, and more data structures and index types will be supported.

The core value of X-Engine lies in cost-effectiveness. The continuous improvement of performance at lower costs is a long-term fundamental goal. Alibaba Cloud continues its exploration for new approaches that make X-Engine more efficient on operations, such as compaction scheduling, cache management and optimization, data compression, and transaction processing.

2.2. Usage notes

This topic describes the X-Engine storage engine supported by ApsaraDB RDS for MySQL. This engine can process transactions and reduce disk usage.

Introduction

X-Engine is an online transaction processing (OLTP) database storage engine developed by the Database Products Business Unit of Alibaba Cloud to suit the needs of ApsaraDB PolarDB. This storage engine is widely used in many business systems of Alibaba Group to reduce costs. These systems include the transaction history database and DingTalk chat history database. In addition, X-Engine is a crucial database technology that empowers Alibaba Group to withstand bursts of traffic that may surge to hundreds of times greater than usual during the Double 11 shopping festival in China.

X-Engine is optimized for large-scale e-commerce transaction processing. The paper *X-Engine: An Optimized Storage Engine for Large-scale E-Commerce Transaction Processing* written by the X-Engine R&D team describes the pioneering work X-Engine has achieved in the database engine field. This paper was accepted by the Industrial Track of SIGMOD 2019.

Unlike the InnoDB storage engine, X-Engine adopts the log-structured merge-tree (LSM tree) architecture for tiered storage. LSM tree has the following significant advantages:

- The small size of hotspot datasets that require indexes improves write performance.
- The bottom-layer persistent data pages are read-only. In addition, they are stored in a compact format and are compressed by default to reduce storage costs.

In addition to the advantages of LSM tree, X-Engine brings the following innovations in engineering implementation:

- Continuously optimized write performance: Continuous optimization allows X-Engine to deliver write performance that is over 10 times higher than the write performance of RocksDB that runs in the LSM tree architecture.
- Data reuse at the storage layer: Data reuse optimizes the performance of compaction operations and reduces the impact of compaction operations on system resources in the traditional LSM tree architecture. This allows you to keep system performance stable.
- Hybrid storage: You can deploy various storage media, such as SSDs and HDDs. These storage media provide different I/O capabilities on the same RDS instance. The hybrid storage architecture works with the tiered storage architecture of X-Engine to intelligently store hot and cold data separately. This allows you to reduce overall costs without compromising performance.
- Multi-level caching, refilling, and prefetching: These allow X-Engine to use the fine-grained access mechanism and cache technology to make up for the read performance shortcomings of the engines that adopt the LSM tree architecture.

The preceding optimizations make X-Engine an alternative to the traditional InnoDB storage engine. In addition to supporting transactions, X-Engine can also reduce occupied storage space by up to 90% and thus lower storage costs. X-Engine is especially suitable for businesses that have a large data volume and require high read/write performance.

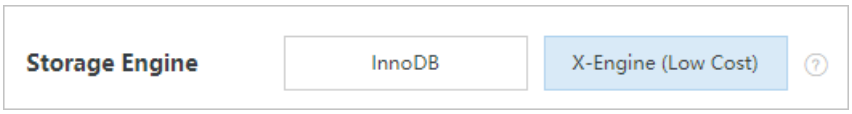
> **Note** For more information about the use scenarios of X-Engine, see Best practices of X-Engine.

Prerequisites

Your RDS instance runs MySQL 8.0 on High-availability Edition or Basic Edition.

Purchase an RDS instance that uses X-Engine

If you want to use X-Engine for your RDS instance, select MySQL 8.0 for Database Engine on the **Basic Configuration** page and select **X-Engine (Low Cost)** for Storage Engine on the **Instance Configuration** page when you purchase an RDS instance. For more information about other parameters, see Create an ApsaraDB RDS for MySQL instance.



> **Note**
>
> - If you want to use X-Engine for an RDS instance that runs MySQL 5.5, 5.6, or 5.7, you must migrate the data of the RDS instance to a new RDS instance that runs MySQL 8.0. For more information, see Migrate data between RDS instances.
> - If you want to convert the storage engine of an RDS instance to X-Engine, see Convert tables from InnoDB, TokuDB, or MyRocks to X-Engine.

Create X-Engine tables

If you select X-Engine when you create an instance, the table created within the instance uses X-Engine by default. Execute the following statement to view the default engine used by an instance:

```
show variables like '%default_storage_engine%';
```

```
mysql> show variables like '%default_storage_engine%';
+------------------------+---------+
| Variable_name          | Value   |
+------------------------+---------+
| default_storage_engine | XENGINE |
+------------------------+---------+
1 row in set (0.00 sec)
```

If the default engine is X-Engine, you do not need to specify the storage engine in the table creation statement.

```
mysql> create table tt(id int primary key, c1 int, c2 varchar(100));
Query OK, 0 rows affected (0.01 sec)

mysql> show create table tt;
+-------+-----------------------------------------------------------------------------------------
| Table | Create Table
+-------+-----------------------------------------------------------------------------------------
| tt    | CREATE TABLE `tt` (
  `id` int(11) NOT NULL,
  `c1` int(11) DEFAULT NULL,
  `c2` varchar(100) DEFAULT NULL,
  PRIMARY KEY (`id`)
) ENGINE=XENGINE DEFAULT CHARSET=utf8 |
+-------+-----------------------------------------------------------------------------------------
1 row in set (0.01 sec)
```

After you have created a table, data is stored in X-Engine.

> **Note** You can create tables that use the InnoDB engine in an instance that uses X-Engine. If you use Data Transmission Service (DTS) to migrate an InnoDB table to an X-Engine instance, the destination table also uses InnoDB. For more information, see Solution 2 in Convert the storage engine from InnoDB, TokuDB, or MyRocks to X-Engine.

Limits

- Limits on resource allocations if X-Engine and InnoDB are used together

  When you use X-Engine for an instance, 95% of the memory is used as the write cache and block cache to speed up reading and writing. The InnoDB buffer pool does not occupy much memory. Do not use tables that use InnoDB to store a large volume of data within an instance that uses X-Engine. Otherwise, the X-Engine performance may deteriorate due to a low cache hit ratio. We recommend that you use only a single engine type for tables within an ApsaraDB for RDS instance that runs MySQL 8.0.

- Limits on engine features

  X-Engine has some limits on features. Some features are in development. Other features that are not listed in the following table are the same as those of InnoDB.

Category	Feature	X-Engine	Remarks
SQL features	Foreign key	Not supported.	None
	Temporary table	Not supported.	None
	Partition table	Not supported. X-Engine does not support the creation, addition, deletion, modification, or query of partitions.	None
	Generated Column	Not supported.	None
	Handler API	Not supported.	None
	Maximum column size (LONGBLOB/LONGTEXT/JSON)	32 MB	None

Category	Feature	X-Engine	Remarks
Column properties	GIS data type	Not supported. X-Engine does not support the following GIS data types: GEOMETRY, POINT, LINESTRING, POLYGON, MULTIPOINT, MULTILINESTRING, MULTIPOLYGON, and GEMOMETRYCOLLECTION.	None
Indexes	Hash index	Not supported.	None
	Spatial index	Not supported. X-Engine does not support the creation and use of full-text indexes.	None
Transactions	Transaction isolation level	Two isolation levels are provided: ○ Read Committed (RC) ○ Repeatable Read (RR)	None
	Maximum transaction size	32 MB	Support for larger transactions is under development.
	Savepoint	Not supported.	None
	XA transaction	Not supported.	Support for XA transactions is under development.
Locks	Lock granularity	○ Table-level locks supported. ○ Row-level locks supported. ○ Gap locks not supported.	None
	Skip Locked Lock Nowait	Not supported.	None
	Character sets supported by non-indexed columns	Supported.	None

Category	Feature	X-Engine	Remarks
Character sets	Character sets supported by indexed columns	○ Latin1 (latin1_bin) ○ GBK (gbk_chinese_ci and gbk_bin) ○ UTF-8 (utf8_general_ci and utf8_bin) ○ UTF-8MB4 (utf8mb4_0900_ai_ci, utf8mb4_general_ci, and utf8mb4_bin)	None
Primary/secondary replication	Binary log formats	stmt/row/mixed **Note** The default binary log format is the row-based format. The statement-based and row-based log formats may lead to data security issues in specific concurrency scenarios.	None

- Limits on large transactions

  X-Engine does not support large transactions. If a transaction modifies a large number of rows, X-Engine uses the commit in middle feature. For example, if you use a transaction to modify more than 10,000 rows, X-Engine commits this transaction and starts a new transaction. However, the commit in middle feature cannot strictly follow atomicity, consistency, isolation, durability (ACID). Exercise caution when you use the commit in middle feature. Examples:

  ○ Start a transaction to insert more than 10,000 rows. During the insertion, a portion of the committed data can be queried by other requests.

- Start a transaction to modify more than 10,000 rows. If a portion of the data is committed in the middle of the transaction, you cannot roll the transaction back.

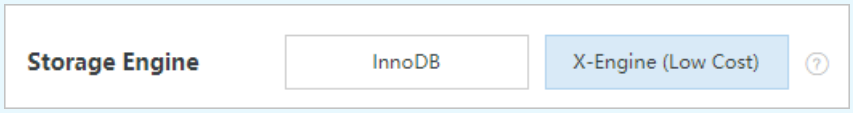
```
drop table t1;
create table t1(c1 int primary key , c2 int)ENGINE=xengine;
begin;
call insert_data(12000); // 12,000 rows is inserted, and a commit in middle operation i
s triggered. As a result, the first 10,000 rows of data are committed.
rollback;// Only the last 2,000 rows can be rolled back.
select count(*) from t1; // The committed 10,000 rows of data can be queried.
+----------+
| count(*) |
+----------+
|    10000 |
+----------+
1 row in set (0.00 sec)
```

- Start a transaction to delete or modify more than 10,000 rows. Some rows are omitted.

```
drop table t1;
create table t1(c1 int primary key , c2 int)ENGINE=xengine;
call insert_data(10000);
begin;
insert into t1 values(10001,10001), (10002,10002);
delete from t1 where c1 >= 0;// The deletion triggers a commit in middle operation, and
the two rows of data inserted by the current transaction are not deleted.
commit;
select * from t1;
+-------+-------+
| c1    | c2    |
+-------+-------+
| 10001 | 10001 |
| 10002 | 10002 |
+-------+-------+
2 rows in set (0.00 sec)
```

Parameters

Note When you create an RDS instance, you can select X-Engine as the default storage engine. You can also adjust the parameter template based on the parameters described in the following table to suit your business requirements. For more information, see Create an ApsaraDB RDS for MySQL instance.



Category	Parameter	Description	Remarks

Category	Parameter	Description	Remarks
Performance	xengine_arena_block_size	The unit used when a memory table requests new memory from the operating system and the external memory management system of jemalloc.	Read-only after startup.
	xengine_batch_group_max_group_size	The maximum number of groups of a transaction pipeline.	Read-only after startup.
	xengine_batch_group_max_leader_wait_time_us	The maximum wait time of a transaction pipeline.	Read-only after startup.
	xengine_batch_group_slot_array_size	The maximum batch size of a transaction pipeline.	Read-only after startup.
Memory	xengine_block_cache_size	The size of the read block cache.	This parameter cannot be modified.
	xengine_row_cache_size	The size of the row cache.	This parameter cannot be modified.
	xengine_write_buffer_size	The maximum size of a single memory table.	This parameter cannot be modified.
	xengine_block_size	The size of the data block on a disk.	Read-only after initialization. Read-only after startup.
	xengine_db_write_buffer_size	The maximum size of the active memory tables in all subtables.	This parameter cannot be modified.
	xengine_db_total_write_buffer_size	The maximum size of the active memory tables and immutable memory tables in all subtables.	This parameter cannot be modified.
	xengine_scan_add_blocks_limit	The number of blocks that can be added to the block cache during each range-based scan request.	This parameter cannot be modified.

Category	Parameter	Description	Remarks
compaction	xengine_flush_delete_percent_trigger	If the number of records in a memory table exceeds the value of this parameter, the xengine_flush_delete_record_trigger parameter takes effect on the memory table.	None
Lock	xengine_max_row_locks	The maximum number of rows that can be locked in a single SQL request.	This parameter cannot be modified.
	xengine_lock_wait_timeout	The timeout period of lock wait.	This parameter cannot be modified.

Running status metrics

The following table shows the running status metrics of X-Engine.

Metric	Description
xengine_rows_deleted	The number of rows deleted.
xengine_rows_inserted	The number of rows written.
xengine_rows_read	The number of rows read.
xengine_rows_updated	The number of rows updated.
xengine_system_rows_deleted	The number of deletion operations on an X-Engine system table.
xengine_system_rows_inserted	The number of insert operations on an X-Engine system table.
xengine_system_rows_read	The number of read operations on an X-Engine system table.
xengine_system_rows_updated	The number of updates on an X-Engine system table.
xengine_block_cache_add	The number of add operations on the block cache.
xengine_block_cache_data_hit	The number of hits in read data blocks.
xengine_block_cache_data_miss	The number of misses in read data blocks.
xengine_block_cache_filter_hit	The number of hits in filter blocks.
xengine_block_cache_filter_miss	The number of misses in filter blocks.

Metric	Description
xengine_block_cache_hit	The number of hits in the block cache. The value of this metric is calculated by using the following formula: The value of this metric= The value of the data_hit metric + The value of index_hit metric.
xengine_block_cache_index_hit	The number of hits in index blocks.
xengine_block_cache_index_miss	The number of misses in index blocks.
xengine_block_cache_miss	The number of misses in the block cache. The value of this metric is calculated by using the following formula: The value of this metric= The value of the data_hit metric + The value of the index_hit metric.
xengine_block_cachecompressed_miss	The number of misses in the compressed block cache.
xengine_bytes_read	The number of bytes on the read physical disk.
xengine_bytes_written	The number of bytes that are added to the block cache.
xengine_memtable_hit	The number of hits in memory tables.
xengine_memtable_miss	The number of misses in memory tables.
xengine_number_block_not_compressed	The number of uncompressed blocks.
xengine_number_keys_read	The number of times that keys are read.
xengine_number_keys_updated	The number of times that keys are updated.
xengine_number_keys_written	The number of times that keys are written.
xengine_number_superversion_acquires	The number of times that Superversion is applied for references.
xengine_number_superversion_cleanups	The number of times that Superversion is cleared. If Superversion is not referenced, it is cleared.
xengine_number_superversion_releases	The number of times that the referenced Superversion is released. If Superversion is not referenced, it is cleared.
xengine_snapshot_conflict_errors	The number of times that an error is reported due to snapshot version conflicts at the RR isolation level.
xengine_wal_bytes	The size of redo logs that are flushed into the disk. Unit: bytes.

Metric	Description
xengine_wal_group_syncs	The number of times that GroupCommit is executed by redo logs.
xengine_wal_synced	The number of times that redo logs are synchronized.
xengine_write_other	The number of times that a follower commits transactions in a transaction pipeline.
xengine_write_self	The number of times that a leader commits transactions in a transaction pipeline.
xengine_write_wal	The number of times that redo logs are written.

2.3. Convert tables from InnoDB, TokuDB, or MyRocks to X-Engine

ApsaraDB RDS for MySQL 8.0 supports X-Engine. X-Engine provides better data compression capabilities and reduces disk space costs. This topic describes how to convert tables from InnoDB, TokuDB, or MyRocks to X-Engine.

Context

X-Engine is an online transaction processing (OLTP) database storage engine that is developed by Alibaba Cloud to suit the needs of PolarDB. X-Engine now is widely used in a number of business systems of Alibaba Group to reduce costs. These include the transaction history database and DingTalk chat history database. In addition, X-Engine is a crucial database technology that empowers Alibaba Group to withstand bursts of traffic that may surge by hundreds of times than usual during Double 11, a shopping festival in China.

For more information, see the following topics:

- Usage notes
- Best practices of X-Engine

> **Note** When you create an RDS instance that is designed to run MySQL 8.0, we recommend that you specify X-Engine as the default storage engine. After the RDS instance is created, you can also specify X-Engine for the RDS instance by setting the engine parameter to xengine. For more information, see Usage notes.

Precautions

- If the tables that you want to convert uses InnoDB, make sure that the remaining disk space of your RDS instance is twice the data volume of the tables. After the conversion to X-Engine, the disk space that is occupied by the tables decreases to 10% to 50% of the original disk space that is occupied by the tables before the conversion.
- If you use Solution 1 in this topic to perform the conversion, you must reconfigure parameters and restart your RDS instance. Stop your database service before you perform the conversion.

- If you use Solution 2 in this topic to migrate all data from your RDS instance to a new RDS instance, you must update the endpoints on your application. We recommend that you perform the migration during off-peak hours.
- Before the conversion, make sure that X-Engine is compatible with SQL.
- After the conversion, change the value of the **default_storage_engine** parameter to **xengine**. This ensures that all of the tables that are created later use X-Engine.

Solution recommendations

- If your RDS instance runs MySQL 8.0 (with a minor engine version of 20200229 or later), we recommend that you use Solution 1. This way, you do not need to configure various tools.

  > **Note** If the minor engine version of your RDS instance does not meet your business requirements, you can update the minor engine version on the **Basic Information** page in the ApsaraDB RDS console. In the Configuration Information section of the Basic Information page, check whether the Upgrade Kernel Version button exists. If the button exists, you can click the button to view and update the minor engine version. If the button does not exist, you are using the latest minor engine version. For more information, see Update the minor engine version of an ApsaraDB RDS for MySQL instance.

- If your RDS instance runs MySQL 5.6 or 5.7, we recommend that you use Solution 2.

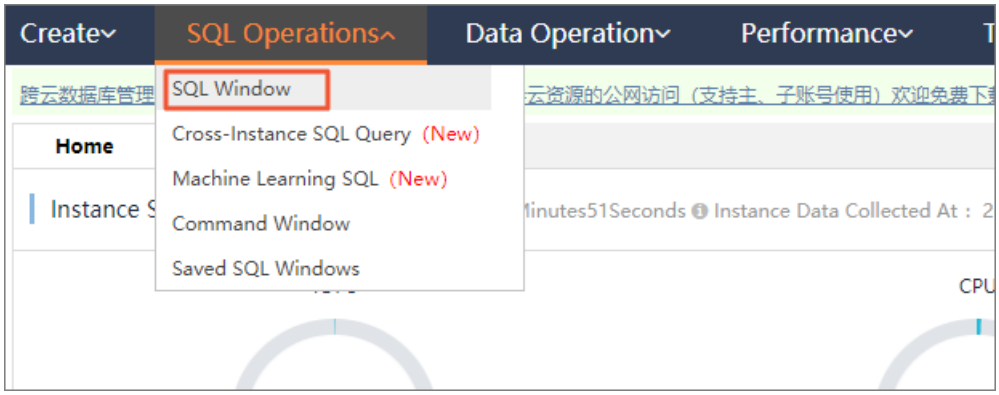
Solution 1

This solution allows you to enable X-Engine by using a parameter template. Then, you can use data definition language (DDL) statements to convert tables to X-Engine. This solution is easy and fast, but requires a restart of your RDS instance. In addition, data manipulation language (DML) operations may be blocked, and the conversion of large-sized tables is time-consuming.

1.
2. In the left-side navigation pane, click **Parameters**.
3. In the upper-left corner of the Editable Parameters tab, click **Apply Template**. In the dialog box that appears, select **MySQL_8.0_X-Engine_High-availability_Default Parameter Template** from the Apply Template drop-down list and click **OK**.

   > **Note** This operation triggers a restart of your RDS instance. After the restart, 95% of the memory resources are allocated to X-Engine. Do not use X-Engine and InnoDB at the same time.

4. Log on to your RDS instance by using Data Management (DMS). For more information, see Use DMS to log on to an ApsaraDB RDS instance.
5. In the top navigation bar, choose **SQL Operations > SQL Window**.



6. Run the following command to convert a table:

```
alter table <The name of the database where the table resides>. <The name of the table>
engine xengine;
```

Example:

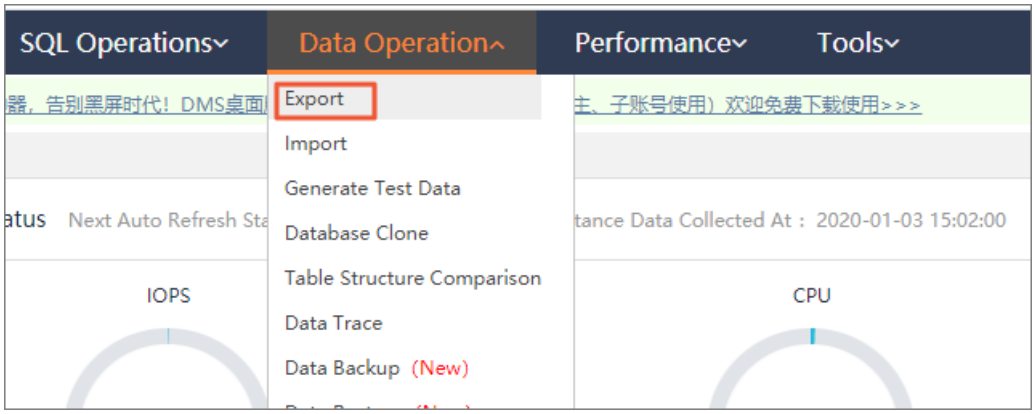
```
alter table test.sbtest1 engine xengine;
```

Solution 2

This solution allows you to synchronize the data of tables in real time from your RDS instance to a new RDS instance by using Data Transmission Service (DTS). After the data synchronization is complete, you can switch over your workloads to the new RDS instance.

> **Note** The new RDS instance inherits the storage engine of your RDS instance by default. You must export the SQL statements that are used to create tables. In addition, you must change the storage engine to X-Engine in these SQL statements. Then, you can migrate the data to the new X-Engine tables.

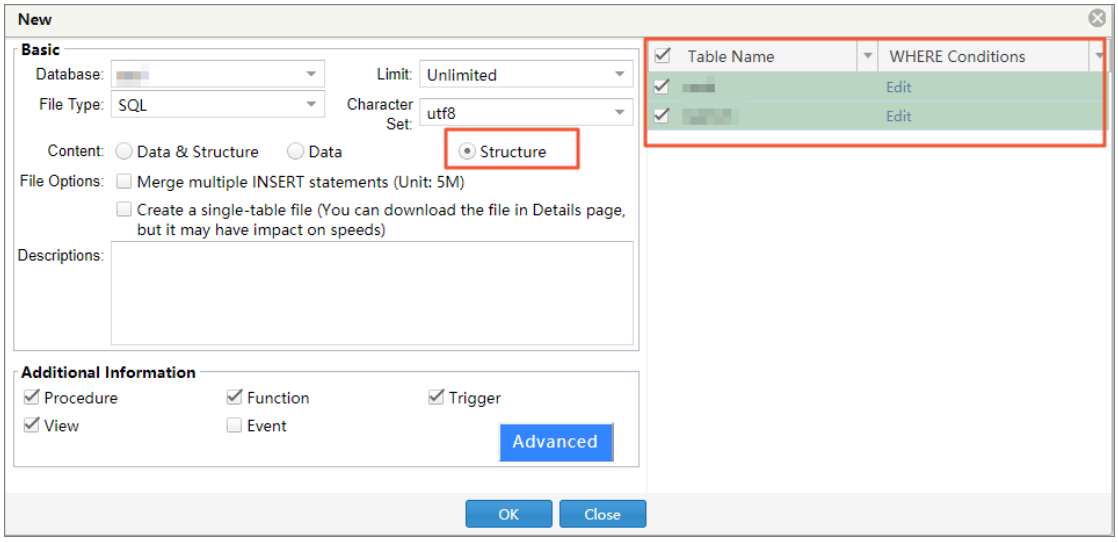
1. Perform the following steps to export all the schemas of your RDS instance:
   i. Log on to your RDS instance by using DMS. For more information, see Use DMS to log on to an ApsaraDB RDS instance.
   ii. In the top navigation bar, choose **Data Operation > Export**.



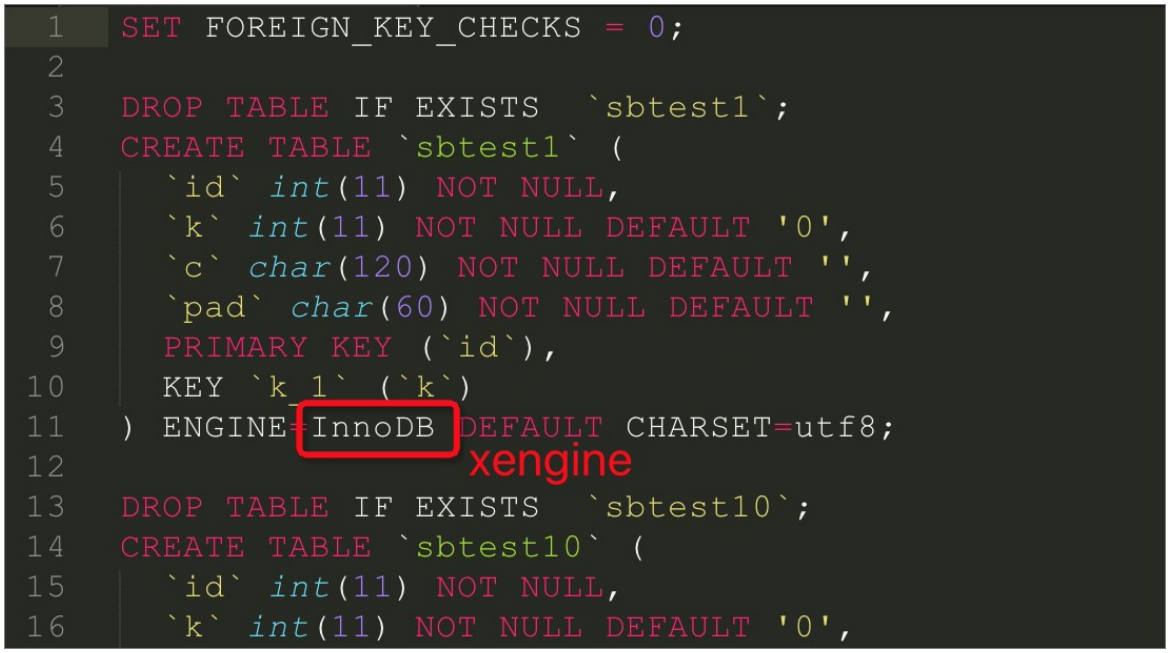
   iii. Choose **New > Export Database**.

iv. Configure the parameters and click **OK**. In the message that appears, click **Yes**.

> **Note** The message appears because **Extended Options** is selected in the **Advanced Options** dialog box. You can ignore the message.



2. Decompress the schemas and change InnoDB or TokuDB to X-Engine.



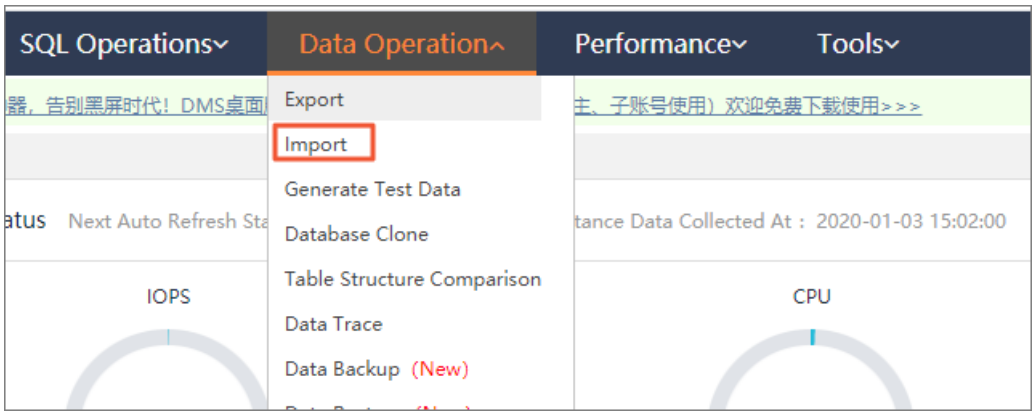
3. Purchase a new RDS instance that runs MySQL 8.0 and has the same specifications as your RDS instance. Make sure that you select the X-Engine parameter template.

> **Note** When you create the new RDS instance, you can use the default X-Engine parameter template to specify X-Engine as the default storage engine. For more information, see Create an ApsaraDB RDS for MySQL instance.

4. Perform the following steps to import the schemas into the new RDS instance.

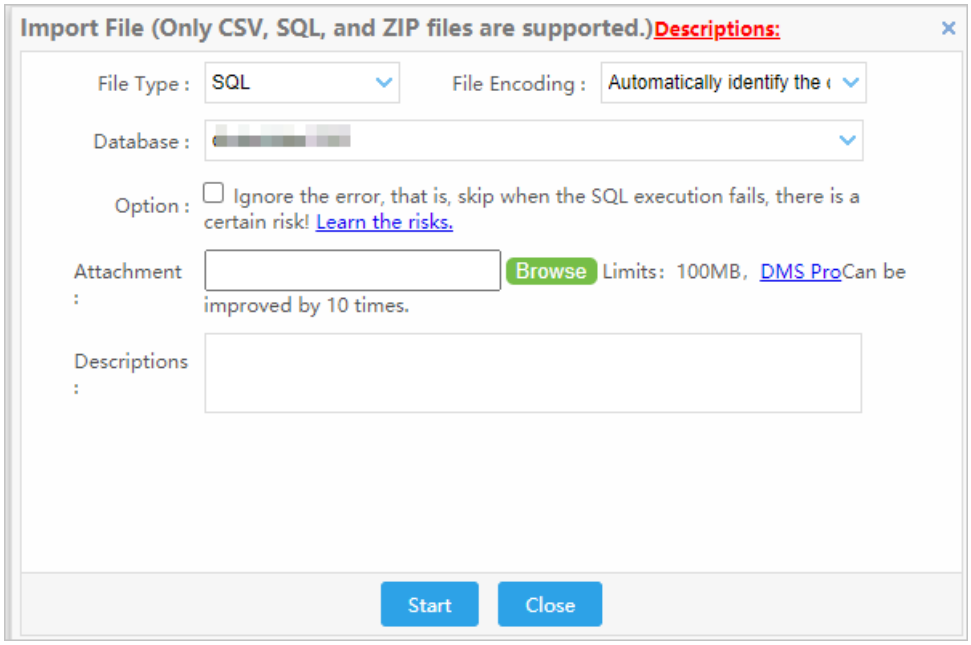
i. Log on to the new RDS instance by using DMS. For more information, see Use DMS to log on to an ApsaraDB RDS instance.

ii. In the top navigation bar, choose **Data Operation > Import**.



iii. On the page that appears, click **New Task**.

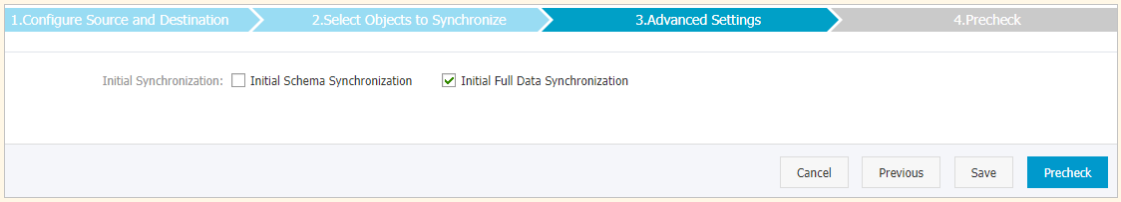
iv. In the dialog box that appears, configure the parameters and click **Start**.



> **Note** After the schemas are imported, you can run the following command to verify that a table uses X-Engine: `show create table <The name of the table>;`.

5. Synchronize data from your RDS instance to the new RDS instance. For more information, see Configure two-way data synchronization between MySQL instances.

> **Warning** In the Advanced Settings step, do not select **Initial Schema Synchronization**.



Result

After the synchronization is complete, you can check whether the data synchronization is successful. Then, you can test the compatibility between X-Engine and SQL. If X-Engine is compatible with SQL, you can convert tables to X-Engine.

2.4. Benefits of X-Engine

This topic describes the benefits of X-Engine. X-Engine provides the same performance as InnoDB at 50% lower costs for storage.

Background information

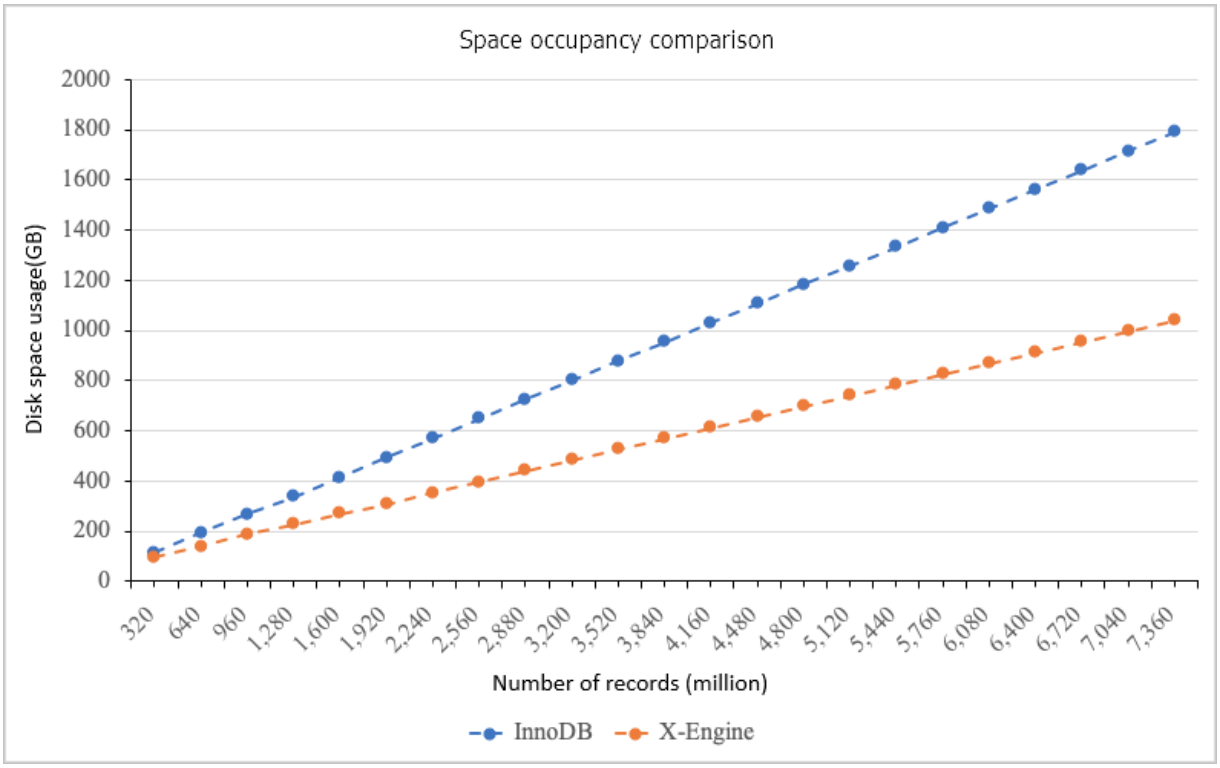
X-Engine is a storage engine that is developed by Alibaba Cloud to reduce the disk usage and overall database costs of ApsaraDB RDS for MySQL. X-Engine stores data in a tiered storage architecture and uses the Zstandard algorithm to compress data at a high compression ratio. You can understand the advantages of X-Engine over InnoDB and TokuDB by comparing their storage costs and performance.

> **Note** The major technological innovations of X-Engine have been released at three top academic conferences: ACM SIGMOD 2019 and VLDB2020 in the database field and the USENIX Conference on File and Storage Technologies (FAST) 2020 in the storage field.

Test environment

The RDS instance used for testing is created with the rds.mysql.s3.large instance type and a storage capacity of 2 TB. This instance type supports four CPU cores and 8 GB of memory.

50% lower storage costs than InnoDB



This figure compares disk usage between X-Engine and InnoDB.

Both X-Engine and InnoDB use their default configurations and the default schema that is provided by Sysbench. Each table contains 10 million data records, and the total number of tables increases from 32 to 736. As the data volume increases, the disk usage of X-Engine increases at a lower speed compared with InnoDB. The disk usage of X-Engine is up to 42% less than that of InnoDB. In addition, X-Engine requires less disk space to store large-sized individual data records. For example, after an image database is migrated to X-Engine, it occupies only 14% of the disk space that is required in InnoDB.

InnoDB does not compress data in most of its business scenarios. If data compression is enabled, the disk usage of InnoDB decreases by about 33%, but the query performance also decreases. For example, the performance for updates based on primary keys decreases by about 90%. This interrupts your business. X-Engine can compress data to reduce storage costs and maintain stable performance. The following tests are run by using Sysbench.

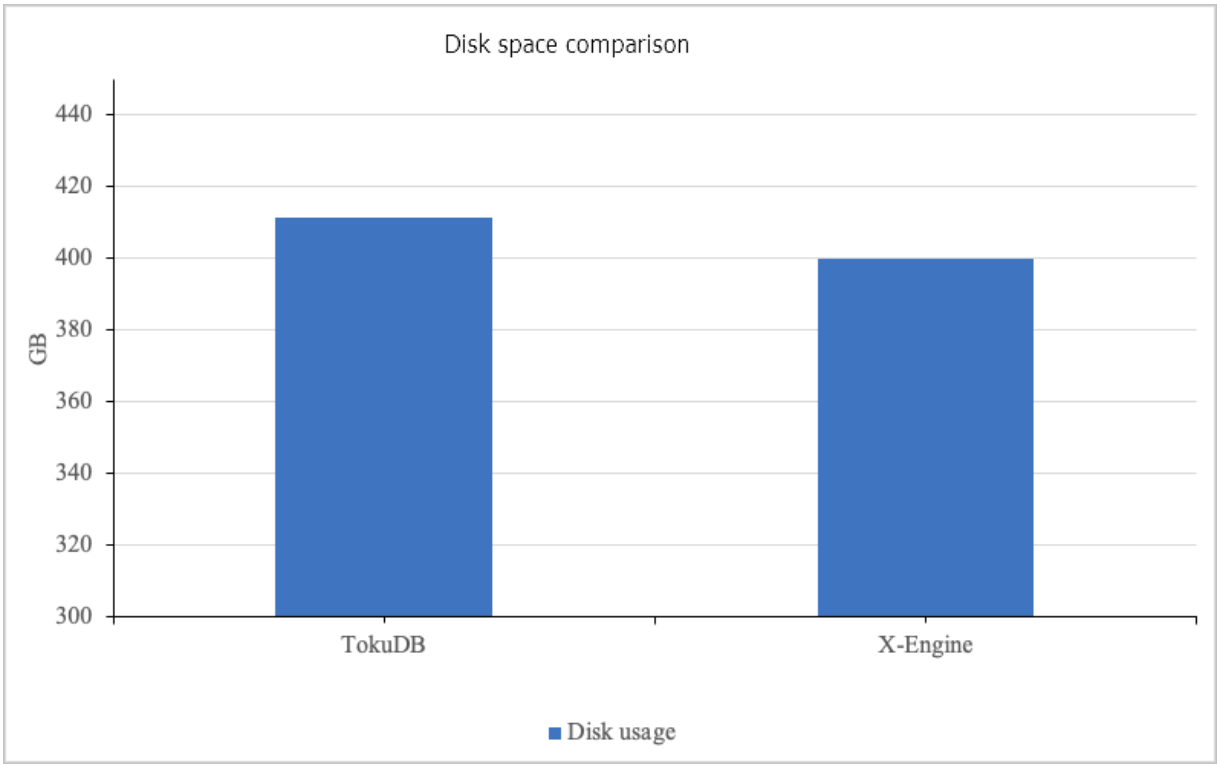
Run the following commands to test the performance:

```
# For an ApsaraDB RDS for MySQL instance that runs InnoDB
sysbench /usr/share/sysbench/oltp_update_index.lua\
    --mysql-host=[The endpoint of the RDS instance]\
    --mysql-user=sbtest\
    --mysql-password=sbtest\
    --mysql-db=sbtest\
    --threads=32\
    --tables=[32-736]\
    --table_size=10000000\
    --mysql-storage_engine=INNODB\
    prepare
# For an ApsaraDB RDS for MySQL instance that runs X-Engine
sysbench /usr/share/sysbench/oltp_update_index.lua\
    --mysql-host=[The endpoint of the RDS instance]\
    --mysql-user=sbtest\
    --mysql-password=sbtest\
    --mysql-db=sbtest\
    --threads=32\
    --tables=[32-736]\
    --table_size=10000000\
    --mysql-storage_engine=XENGINE\
    prepare
```

Lower storage costs than TokuDB

TokuDB no longer offers low cost storage options. Also, Percona no longer offers support, maintenance, and updates for TokuDB. However, X-Engine offers lower storage costs than TokuDB. We recommend that you change the storage engine of your ApsaraDB RDS for MySQL instance from TokuDB to X-Engine.

TokuDB uses a fractal tree structure. This structure consists of more leaf nodes than the B+-tree structure that is used by InnoDB. These leaf nodes are populated with data records and stored as data blocks. Therefore, TokuDB supports a higher data compression ratio than InnoDB. However, the fractal tree structure does not support tiered storage. The tiered storage architecture of X-Engine not only consists of blocks that are populated with data records but also offers optimized storage. This reduces the storage costs of X-Engine.



This figure compares disk usage between X-Engine and TokuDB.

A total of 32 tables are created on the RDS instance used for testing. Each table contains 100 million data records. These data records occupy 411 GB of disk space in TokuDB and 400 GB of disk space in X-Engine. This proves the improvements and advantages of X-Engine over TokuDB in terms of storage costs.

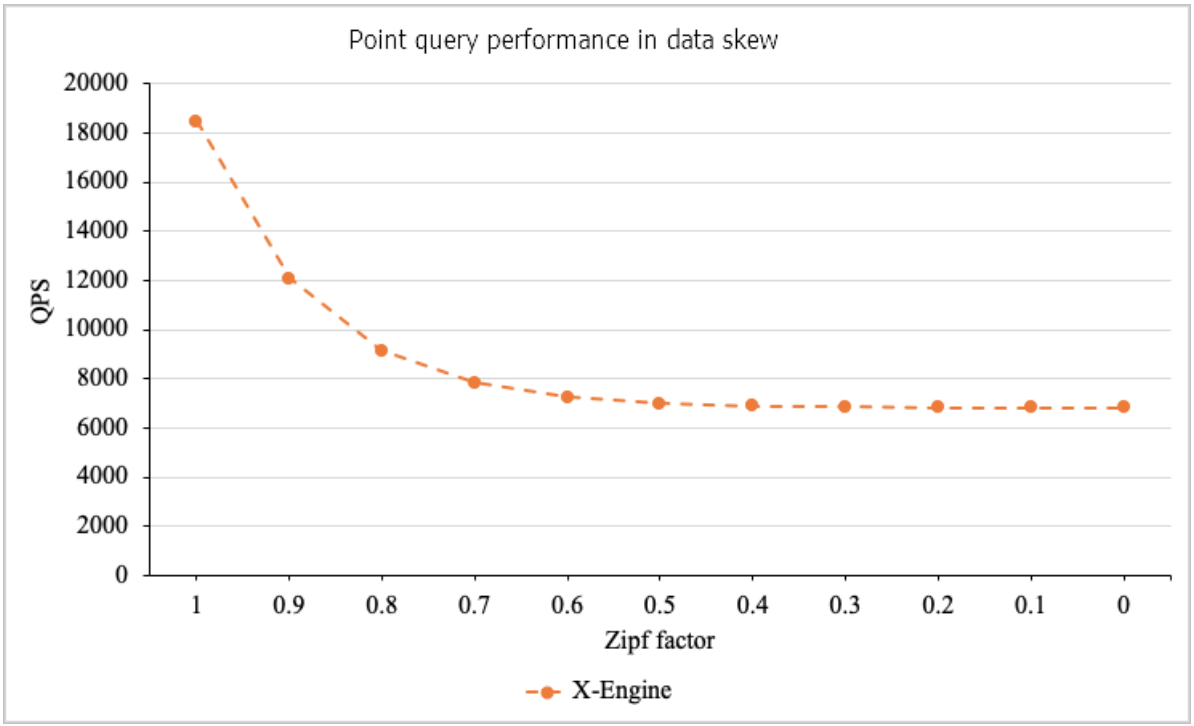
Run the following commands to test the performance:

```
# For an ApsaraDB RDS for MySQL instance that runs TokuDB
sysbench /usr/share/sysbench/oltp_update_index.lua\
    --mysql-host=[The endpoint of the RDS instance]\
    --mysql-user=sbtest\
    --mysql-password=sbtest\
    --mysql-db=sbtest\
    --threads=32\
    --tables=[32-736]\
    --table_size=1000000000\
    --mysql-storage_engine=TokuDB\
    prepare
# For an ApsaraDB RDS for MySQL instance that runs X-Engine
sysbench /usr/share/sysbench/oltp_update_index.lua\
    --mysql-host=[The endpoint of the RDS instance]\
    --mysql-user=sbtest\
    --mysql-password=sbtest\
    --mysql-db=sbtest\
    --threads=32\
    --tables=[32-736]\
    --table_size=1000000000\
    --mysql-storage_engine=XENGINE\
    prepare
```

Tiered storage and tiered access to increase QPS

X-Engine reduces the disk usage for cold data to lower the overall storage costs and maintains a stable rate of queries per second (QPS) for hot data. The following content describes how X-Engine increases the QPS and reduces storage costs:

- The tiered storage architecture of X-Engine allows you to store hot and cold data at different tiers and compress cold data by default.
- X-Engine applies technologies such as prefix encoding to every data record. This reduces storage costs.
- In most of the actual business scenarios, data is skewed because the volume of hot data is smaller than that of cold data. The tiered access architecture of X-Engine allows you to increase the QPS.



This figure shows the performance of X-Engine for processing point queries on skewed data.

This test uses the popular method of Zipf distribution to control the degree of data skew. If the degree of data skew (namely, the Zipf factor) is high, more point queries hit hot data in the cache instead of cold data on disks. This decreases the access latency and increases the QPS. In addition, the compression of cold data only has a small impact on the QPS.

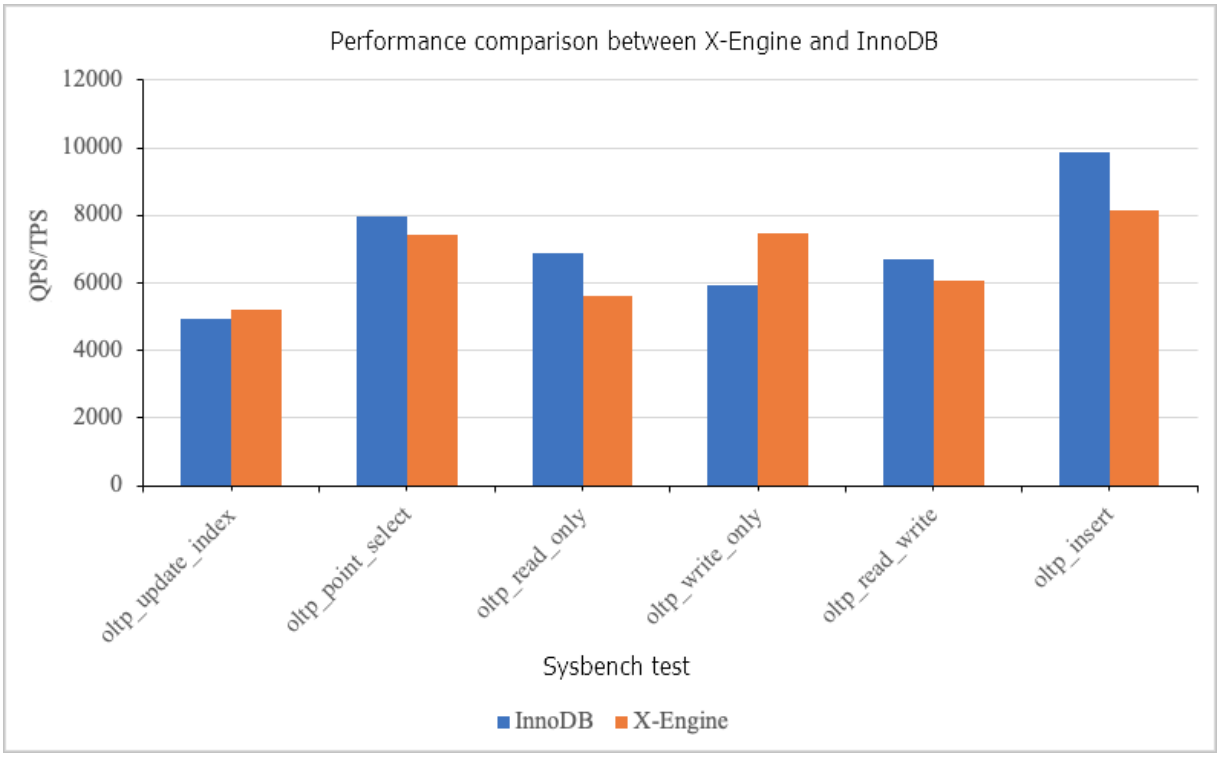
The tiered storage and tiered access architectures of X-Engine reduces the probability that SQL statements for hot data hit cold data. These architectures increase the QPS by 2.7 times than when all data is evenly accessed.

Run the following commands to test the performance:

```
sysbench /usr/share/sysbench/oltp_point_select.lua\
    --mysql-host=[The endpoint of the RDS instance]\
    --mysql-user=sbtest\
    --mysql-password=sbtest\
    --time=3600\
    --mysql-db=sbtest\
    --tables=32\
    --threads=512\
    --table_size=10000000\
    --rand-type=zipfian\
    --rand-zipfian-exp=[0-1]\
    --report-interval=1\
    run
```

Equally matched performance of X-Engine and InnoDB for cold data queries

X-Engine and InnoDB offer an equally matched QPS and transactions per second (TPS) for processing queries to a large volume of cold data, especially archived and historical data.



This figure compares cold data query performance between InnoDB and X-Engine.

In most of the online transactional processing (OLTP) scenarios, X-Engine and InnoDB offer equally matched performance for processing frequent updates (oltp_update_index and oltp_write_only) and point queries (oltp_point_select).

However, when X-Engine queries data for a specific time range or checks the uniqueness of a single data record, it performs a scan or access to multiple storage tiers. As a result, X-Engine processes range queries (oltp_read_only) and inserts (OLTP_insert) at a slightly lower speed than InnoDB.

X-Engine processes data reads and writes (oltp_read_write) at the same speed as InnoDB.

Run the following commands to test the performance:

```
# oltp_read_only is used as an example.
sysbench /usr/share/sysbench/oltp_read_only.lua\
    --mysql-host=[The endpoint of the RDS instance]\
    --mysql-user=sbtest\
    --mysql-password=sbtest\
    --mysql-db=sbtest\
    --time=3600\
    --tables=32\
    --threads=512\
    --table_size=10000000\
    --rand-type=uniform\
    --report-interval=1\
    run
```

Summary

X-Engine is a storage engine that is tailored to the cost-effectiveness requirements of ApsaraDB RDS for MySQL. It offers performance that is comparable to InnoDB but at lower storage costs. X-Engine has been used in a number of core business of Alibaba Group. These include DingTalk chat history databases, Taobao image databases, and Taobao transaction history databases. For more information, see Introduction to X-Engine.

Get started with X-Engine

- If you are new to ApsaraDB RDS for MySQL, select X-Engine as the storage engine when you create an RDS instance. For more information, see Create an ApsaraDB RDS for MySQL instance.
- You can also change the storage engine of your RDS instance to X-Engine. For more information, see Convert tables from InnoDB, TokuDB, or MyRocks to X-Engine.

3.Feature

3.1. Native Flashback

This topic describes the native flashback feature. This feature allows you to query or restore the data at a specified point in time by executing SQL statements. This way, you can obtain the historical data at your earliest opportunity after accidental operations.

Background information

Accidental operations during database O&M may have a serious impact on your business. You can restore the data from binary log files. This restoration method is complicated, time-consuming, and prone to errors. You can also restore the data from data backup files. This restoration method requires additional database resources and may require a long period of time if you want to restore a large amount of data.

The native flashback feature of AliSQL is supported by InnoDB. You can query or restore the historical data within a short period of time by executing simple SQL statements. This way, you can ensure the stability of your database service.

Prerequisites

- Your RDS instance runs MySQL 8.0 on RDS High-availability Edition or RDS Basic Edition.
- The minor engine version of your RDS instance is 20210930 or later. For more information about how to view or update the minor engine version, see Update the minor engine version of an ApsaraDB RDS for MySQL instance.

Precautions

- The native flashback feature is supported only for InnoDB tables.
- The native flashback feature consumes undo tablespaces. You can configure the INNODB_UNDO_SPACE_SUPREMUM_SIZE parameter to specify an undo tablespace. For more information, see the "Parameters" section of this topic.
- The query results provided by the native flashback feature are the data at the point in time that is closest to the specified point in time. The native flashback feature cannot ensure that the query results exactly match the data at the specified point in time.
- You cannot use the native flashback feature to query or restore the data of tables on which DDL operations have been performed. For example, you cannot use the native flashback feature to query the data of a deleted table.

Syntax

The native flashback feature provides a new `AS OF` syntax, which is used to specify the point in time to which you want to roll back a table. The AS OF syntax has the following rules:

```
SELECT ... FROM <The name of the table>
  AS OF TIMESTAMP <Expression>;
```

The expression specifies the point in time to which you want to roll back a table and supports multiple formats. Examples:

```
SELECT ... FROM tablename
  AS OF TIMESTAMP '2020-11-11 00:00:00';
SELECT ... FROM tablename
  AS OF TIMESTAMP now();
SELECT ... FROM tablename
  AS OF TIMESTAMP (SELECT now());
SELECT ... FROM tablename
  AS OF TIMESTAMP DATE_SUB(now(), INTERVAL 1 minute);
```

Parameters

The following table describes the parameters of the native flashback feature.

Parameter	Description
INNODB_RDS_FLASHBACK_TASK_ENABLED	• This parameter specifies whether to enable the native flashback feature. • Command format: `--innodb-rds-flashback-task-enabled=#`. • Parameter range: a global parameter. • Data type: BOOLEAN. • Default value: OFF. • Valid values: ON and OFF. **Note** If you want to disable the native flashback feature, you must set this parameter to OFF and set the INNODB_UNDO_RETENTION parameter to 0.
INNODB_UNDO_RETENTION	• This parameter specifies the retention period of undo records. Undo records that are generated after the retention period elapses cannot be queried. Unit: seconds. • Command format: `--innodb-undo-retention=#`. • Parameter range: a global parameter. • Data type: INTEGER. • Default value: 0. • Valid values: 0 to 4294967295. **Note** • A larger value of this parameter indicates that the native flashback feature supports queries of earlier historical data and a larger amount of storage is occupied by the undo tablespace. • If you set the INNODB_RDS_FLASHBACK_TASK_ENABLED parameter to OFF, you must also set the INNODB_UNDO_RETENTION parameter to 0.

Parameter	Description
INNODB_UNDO_SPACE_SUPREMUM_SIZE	• This parameter specifies the maximum disk space that can be occupied by the undo tablespace. Unit: MB. When the maximum size is reached, the undo records are forcibly deleted regardless of the value of the `INNODB_UNDO_RETENTION` parameter. • Command format: `--innodb-undo-space-supremum-size=#` . • Parameter range: a global parameter. • Data type: INTEGER. • Default value: 10240. • Valid values: 0 to 4294967295.
INNODB_UNDO_SPACE_RESERVED_SIZE	• This parameter specifies the amount of disk space that is reserved for the undo tablespace. Unit: MB. If the value of the `INNODB_UNDO_RETENTION` parameter is not 0, a larger value of the INNODB_UNDO_SPACE_RESERVED_SIZE parameter indicates more undo records that can be reserved in the undo tablespace. • Command format: `--innodb-undo-space-reserved-size=#` . • Parameter range: a global parameter. • Data type: INTEGER. • Default value: 0. • Valid values: 0 to 4294967295. **Note** If you set this parameter to a large value, a large number of undo records are reserved. As a result, the performance of your RDS instance decreases. We recommend that you set this parameter to 0.

Examples

```
# Obtain a point in time.
MySQL [mytest]> select now();
+---------------------+
| now()               |
+---------------------+
| 2020-10-14 15:44:09 |
+---------------------+
1 row in set (0.00 sec)
# Query the data of a table.
MySQL [mytest]> select * from mt1;
+----+------+
| id | c1   |
+----+------+
|  1 |    1 |
|  2 |    2 |
```

```
|  3 |    3 |
|  4 |    4 |
|  5 |    5 |
+----+------+
5 rows in set (0.00 sec)
# Perform an update operation that does not contain the WHERE clause.
MySQL [mytest]> update mt1 set c1 = 100;
Query OK, 5 rows affected (0.00 sec)
Rows matched: 5  Changed: 5  Warnings: 0
MySQL [mytest]> select * from mt1;
+----+------+
| id | c1   |
+----+------+
|  1 |  100 |
|  2 |  100 |
|  3 |  100 |
|  4 |  100 |
|  5 |  100 |
+----+------+
5 rows in set (0.00 sec)
# Query the historical data at a point in time. A result is successfully returned.
MySQL [mytest]> select * from mt1 AS OF timestamp '2020-10-14 15:44:09';
+----+------+
| id | c1   |
+----+------+
|  1 |    1 |
|  2 |    2 |
|  3 |    3 |
|  4 |    4 |
|  5 |    5 |
+----+------+
5 rows in set (0.00 sec)
# Query the historical data at a point in time that is not within the retention period of h
istorical data. An error message is returned.
MySQL [mytest]> select * from mt1 AS OF timestamp '2020-10-13 14:44:09';
ERROR 7545 (HY000): The snapshot to find is out of range
# Restore the data of a table.
MySQL [mytest]> create table mt1_tmp like mt1; # Create a temporary table that uses the sam
e schema as the original table.
Query OK, 0 rows affected (0.03 sec)
MySQL [mytest]> insert into mt1_tmp
             -> select * from mt1 AS OF
             -> TIMESTAMP '2020-10-14 15:44:09'; # Write historical data from the original
table to the temporary table.
Query OK, 5 rows affected (0.01 sec)
Records: 5  Duplicates: 0  Warnings: 0
MySQL [mytest]> select * from mt1_tmp; # Verify the data in the temporary table.
+----+------+
| id | c1   |
+----+------+
|  1 |    1 |
|  2 |    2 |
|  3 |    3 |
|  4 |    4 |
|  5 |    5 |
```

```
+----+------+
5 rows in set (0.00 sec)
MySQL [mytest]> rename table mt1 to mt1_bak,
             -> mt1_tmp to mt1; #(Before you perform this operation, you must stop the read
and write operations on the original table.) Change the name of the original table to mt1_b
ak and change the name of the temporary table to the original name of the original table. T
he restoration process is complete.
Query OK, 0 rows affected (0.02 sec)
MySQL [mytest]> select * from mt1; # Verify that the data is correct after the restoration
process.
+----+------+
| id | c1   |
+----+------+
|  1 |    1 |
|  2 |    2 |
|  3 |    3 |
|  4 |    4 |
|  5 |    5 |
+----+------+
5 rows in set (0.01 sec)
```

3.2. Thread Pool

ApsaraDB for RDS provides the Thread Pool feature to maximize performance. This feature separates threads from sessions. It allows sessions to share threads and complete more tasks with less threads.

Benefits

By default, each session creates an exclusive thread in MySQL. If a large number of sessions are active, they will compete for resources. In addition, your database system needs to process a heavy workload of thread scheduling, and a large amount of data in the cache becomes invalid. This decreases your database performance.

The thread pool of ApsaraDB for RDS grants priorities to SQL statements based on the statement types. The thread pool also provides a concurrency control mechanism to limit the number of connections. This ensures high database performance in the event of a large number of highly concurrent connections. The benefits of the thread pool are as follows:

- When a large number of threads are running concurrently, the thread pool automatically limits the number of concurrent threads to a proper range. Within this range, your database system processes a moderate workload of thread scheduling, and most of the data in the cache remains valid.
- When a large number of transactions are executed concurrently, the thread pool automatically grants different priorities to SQL statements and transactions. Based on the priorities, the thread pool limits the number of concurrent statements and transactions separately. This mitigates resource competition.
- The thread pool grants high priorities to SQL statements that are used to manage data and ensures that these statements are preferentially executed. This delivers stable execution of operations such as connection establishment, management, and monitoring even if your database system is heavily loaded.
- The thread pool grants low priorities to complicated SQL statements that are used to query data and limits the maximum number of concurrent statements. This prevents a large number of

complicated SQL statements from exhausting resources and making the database service unavailable.

Prerequisites

Your RDS instance is running MySQL 5.6, 5.7, or 8.0.

Use the thread pool

The following table describes the parameters of the thread pool. You can configure these parameters in the ApsaraDB for RDS console. For more information, see Modify the parameters of an ApsaraDB RDS for MySQL instance.

Parameter	Description
thread_pool_enabled	Specifies whether to enable the Thread Pool feature. Valid values: • ON • OFF Default value: ON. **Note** • You can enable or disable the Thread Pool feature only by using this parameter. The **thread_handling** parameter has phased out. • Enabling or disabling the Thread Pool feature does not require an instance restart.
thread_pool_size	The number of groups in the thread pool. Default value: 4. Threads in the thread pool are evenly divided into groups and managed by group.
thread_pool_oversubscribe	The number of active threads allowed per group. Default value: 32. A thread is active if it is executing an SQL statement. However, if the SQL statement is in one of the following states, the thread is inactive: • The SQL statement is waiting for disk I/O. • The SQL statement is waiting for the involved transaction to be committed.

Query the status of the thread pool

Run the following command to query the status of the thread pool:

```
show status like "thread_pool%";
```

Example:

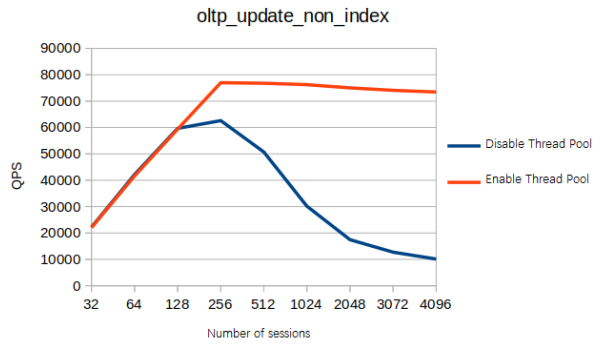
```
mysql> show status like "thread_pool%";
+----------------------------+-------+
| Variable_name              | Value |
+----------------------------+-------+
| thread_pool_active_threads | 1     |
| thread_pool_big_threads    | 0     |
| thread_pool_dml_threads    | 0     |
| thread_pool_idle_threads   | 19    |
| thread_pool_qry_threads    | 0     |
| thread_pool_total_threads  | 20    |
| thread_pool_trx_threads    | 0     |
| thread_pool_wait_threads   | 0     |
+----------------------------+-------+
8 rows in set (0.00 sec)
```

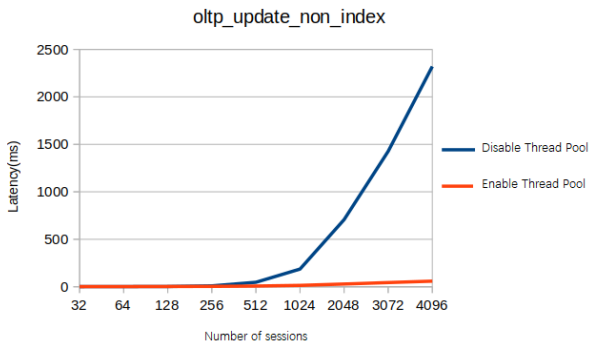
The following table describes the parameters that describe the status of the thread pool.

Parameter	Description
thread_pool_active_threads	The number of active threads in the thread pool.
thread_pool_big_threads	The number of threads that are executing complicated SQL statements in the thread pool. Complicated SQL statements contain subqueries, aggregate functions, and clauses such as GROUP BY and LIMIT.
thread_pool_dml_threads	The number of threads that are executing data manipulation language (DML) statements in the thread pool.
thread_pool_idle_threads	The number of idle threads in the thread pool.
thread_pool_qry_threads	The number of threads that are executing simple SQL statements in the thread pool.
thread_pool_total_threads	The total number of threads in the thread pool.
thread_pool_trx_threads	The number of threads that are executing transactions in the thread pool.
thread_pool_wait_threads	The number of threads that are waiting for disk I/O and those that are waiting for transactions to be committed in the thread pool.

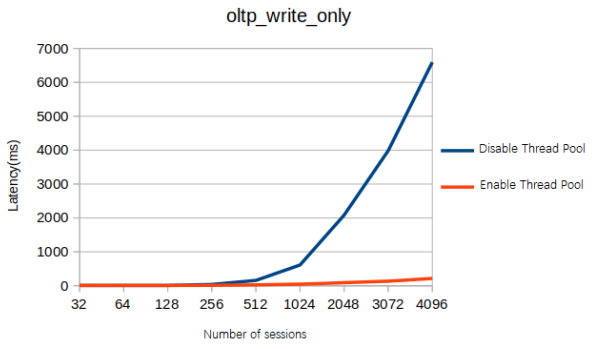
Use SysBench to test the thread pool

The following figures show comparisons of performance between business scenarios with the thread pool enabled and disabled. Based on the test results, the thread pool significantly increases your database performance in the event of a large number of highly concurrent sessions.

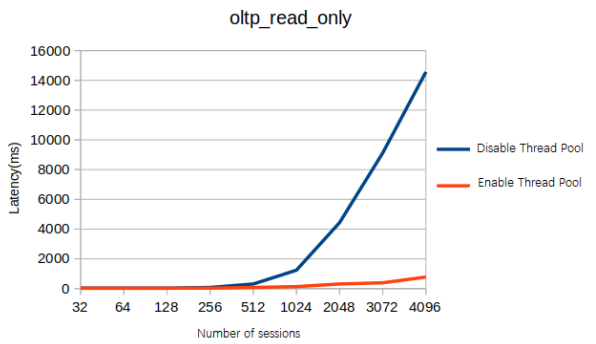

oltp_update_non_index
QPS
Number of sessions
Disable Thread Pool
Enable Thread Pool

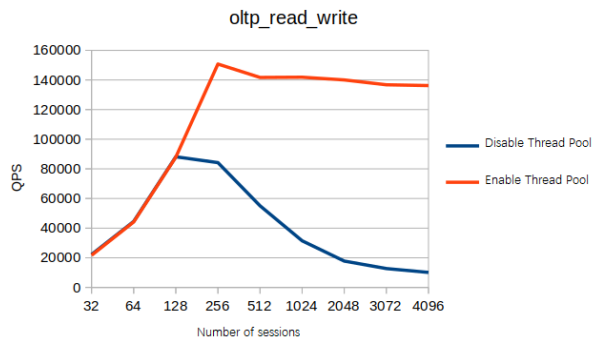

oltp_update_non_index
Latency(ms)
Number of sessions
Disable Thread Pool
Enable Thread Pool

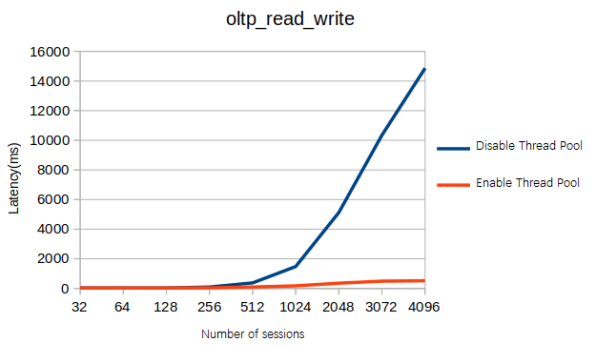

oltp_write_only
QPS
Number of sessions
Disable Thread Pool
Enable Thread Pool

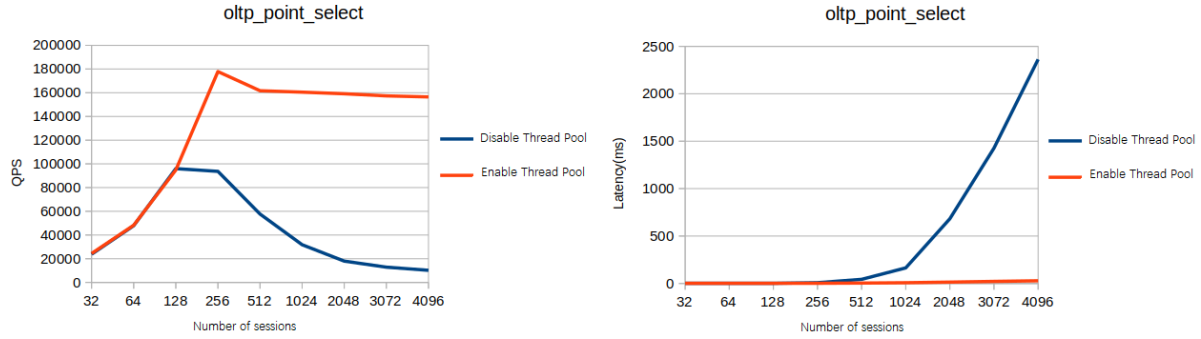

oltp_write_only
Latency(ms)
Number of sessions
Disable Thread Pool
Enable Thread Pool


oltp_read_only
QPS
Number of sessions
Disable Thread Pool
Enable Thread Pool


oltp_read_only
Latency(ms)
Number of sessions
Disable Thread Pool
Enable Thread Pool


oltp_read_write
QPS
Number of sessions
Disable Thread Pool
Enable Thread Pool


oltp_read_write
Latency(ms)
Number of sessions
Disable Thread Pool
Enable Thread Pool



3.3. Statement outline

Databases may be unstable because the execution plan of SQL statements is constantly changing. Alibaba Cloud provides the statement outline feature to make stable execution plans by using optimizer and index hints. The DBMS_OUTLN package can be installed to use the statement outline feature.

Prerequisites

The RDS instance version is one of the following:

- MySQL 8.0
- MySQL 5.7

Feature design

The statement outline feature supports the following types of hints provided by MySQL 8.0.

- Optimizer hint

  Optimizer hints are classified by scope and object, and are divided into various types, such as global level hint, table level hint, index level hint, and JOIN_ORDER hint. For more information, see Optimizer Hints.

- Index hint

  Index hints are classified by scope and type. For more information, see Index Hints.

Introduction to the outline table

AliSQL uses a system table named outline to store hints. The instance system automatically creates the table when the system is started. You can refer to the following statements that create the outline table.

```
CREATE TABLE `mysql`.`outline` (
  `Id` bigint(20) NOT NULL AUTO_INCREMENT,
  `Schema_name` varchar(64) COLLATE utf8_bin DEFAULT NULL,
  `Digest` varchar(64) COLLATE utf8_bin NOT NULL,
  `Digest_text` longtext COLLATE utf8_bin,
  `Type` enum('IGNORE INDEX','USE INDEX','FORCE INDEX','OPTIMIZER') CHARACTER SET utf8 COLL
ATE utf8_general_ci NOT NULL,
  `Scope` enum('','FOR JOIN','FOR ORDER BY','FOR GROUP BY') CHARACTER SET utf8 COLLATE utf8
_general_ci DEFAULT '',
  `State` enum('N','Y') CHARACTER SET utf8 COLLATE utf8_general_ci NOT NULL DEFAULT 'Y',
  `Position` bigint(20) NOT NULL,
  `Hint` text COLLATE utf8_bin NOT NULL,
  PRIMARY KEY (`Id`)
) /*! 50100 TABLESPACE `mysql` */ ENGINE=InnoDB
DEFAULT CHARSET=utf8 COLLATE=utf8_bin STATS_PERSISTENT=0 COMMENT='Statement outline'
```

The following table describes the parameters.

Parameter	Description
Id	The ID of the outline table.
Schema_name	The name of the database.
Digest	The 64-byte hash string calculated from **Digest_text** during the hash calculation.
Digest_text	The digest of the SQL statement.
Type	• The hint type of optimizer hints is OPTIMIZER. • The hint type of index hints is USE INDEX, FORCE INDEX, or IGNORE INDEX.
Scope	This parameter is only specified for index hints. Valid values: • FOR GROUP BY • FOR ORDER BY • FOR JOIN An empty string indicates index hints of all types.
State	Specifies whether to enable the statement outline.
Position	• For optimizer hints, the Position parameter is the position of the keyword in query blocks because all optimizer hints are applied to query blocks. The value of Position indicates the order of the keyword that is applied by hints. The valid values of Position starts from 1. • For index hints, the Position parameter is the position of the table. The value of Position indicates the order of the table that is applied by hints. The valid value starts from 1.

Parameter	Description
Hint	• For optimizer hints, Hint indicates an integrated hint string, such as `/*+ MAX_EXECUTION_TIME(1000) */`. • For index hints, Hint indicates a list of index names, such as `ind_1,ind_2`.

Manage the statement outline

AliSQL provides six management interfaces in the DBMS_OUTLN package. They are described as follows:

- add_optimizer_outline

  Adds optimizer hints. The statement is as follows:

  ```
  dbms_outln.add_optimizer_outline('<Schema_name>','<Digest>','<query_block>','<hint>','<query>');
  ```

  > **Note** You can enter either of the Digest or Query SQL statements. If you enter the query statement, DBMS_OUTLN calculates the values of Digest and Digest_text.

  Example:

  ```
  CALL DBMS_OUTLN.add_optimizer_outline("outline_db", '', 1, '/*+ MAX_EXECUTION_TIME(1000) */',
                                        "select * from t1 where id = 1");
  ```

- add_index_outline

  Adds index hints. The statement is as follows:

  ```
  dbms_outln.add_index_outline('<Schema_name>','<Digest>',<Position>,'<Type>','<Hint>','<Scope>','<Query>');
  ```

  > **Note** You can enter either of the Digest or Query SQL statements. If you enter the query statement, DBMS_OUTLN calculates the values of Digest and Digest_text.

  Example:

  ```
  call dbms_outln.add_index_outline('outline_db', '', 1, 'USE INDEX', 'ind_1', '',
                                    "select * from t1 where t1.col1 =1 and t1.col2 ='xpchild'
  ");
  ```

- preview_outline

  Queries the status of the SQL statement matching the statement outline, which can be used for manual verification. The statement is as follows:

  ```
  dbms_outln.preview_outline('<Schema_name>','<Query>');
  ```

  Example:

```
mysql> call dbms_outln.preview_outline('outline_db', "select * from t1 where t1.col1 =1 a
nd t1.col2 ='xpchild'");
+------------+----------------------------------------------------------------------+--------
----+------------+-------+---------------------+
| SCHEMA     | DIGEST                                                               | BLOCK_T
YPE | BLOCK_NAME | BLOCK | HINT                |
+------------+----------------------------------------------------------------------+--------
----+------------+-------+---------------------+
| outline_db | b4369611be7ab2d27c85897632576a04bc08f50b928a1d735b62d0a140628c4c | TABLE
| t1         |     1 | USE INDEX (`ind_1`) |
+------------+----------------------------------------------------------------------+--------
----+------------+-------+---------------------+
1 row in set (0.00 sec)
```

- show_outline

  Displays the in-memory hit rate of the statement outline. The statement is as follows:

  ```
  dbms_outln.show_outline();
  ```

  Example:

```
mysql> call dbms_outln.show_outline();
+------+------------+-----------------------------------------------------------------+-
----------+-------+------+-------------------------------------------------------------+------+
----------+-------------------------------------------------------------------------------
-------+
| ID   | SCHEMA     | DIGEST                                                                |
TYPE      | SCOPE | POS  | HINT                                                        | HIT  |
OVERFLOW | DIGEST_TEXT
|
+------+------------+-----------------------------------------------------------------+-
----------+-------+------+-------------------------------------------------------------+------+
----------+-------------------------------------------------------------------------------
-------+
|   33 | outline_db | 36bebc61fce7e32b93926aec3fdd790dad5d895107e2d8d3848d1c60b74bcde6 |
OPTIMIZER |       |    1 | /*+ SET_VAR(foreign_key_checks=OFF) */                      |    1 |
0 | SELECT * FROM `t1` WHERE `id` = ?                                                   |
|   32 | outline_db | 36bebc61fce7e32b93926aec3fdd790dad5d895107e2d8d3848d1c60b74bcde6 |
OPTIMIZER |       |    1 | /*+ MAX_EXECUTION_TIME(1000) */                             |    2 |
0 | SELECT * FROM `t1` WHERE `id` = ?                                                   |
|   34 | outline_db | d4dcef634a4a664518e5fb8a21c6ce9b79fccb44b773e86431eb67840975b649 |
OPTIMIZER |       |    1 | /*+ BNL(t1,t2) */                                           |    1 |
0 | SELECT `t1` . `id` , `t2` . `id` FROM `t1` , `t2`                                   |
|   35 | outline_db | 5a726a609b6fbfb76bb8f9d2a24af913a2b9d07f015f2ee1f6f2d12dfad72e6f |
OPTIMIZER |       |    2 |  /*+ QB_NAME(subq1) */                                      |    2 |
0 | SELECT * FROM `t1` WHERE `t1` . `col1` IN ( SELECT `col1` FROM `t2` )               |
|   36 | outline_db | 5a726a609b6fbfb76bb8f9d2a24af913a2b9d07f015f2ee1f6f2d12dfad72e6f |
OPTIMIZER |       |    1 | /*+ SEMIJOIN(@subq1 MATERIALIZATION, DUPSWEEDOUT) */  |    2 |
0 | SELECT * FROM `t1` WHERE `t1` . `col1` IN ( SELECT `col1` FROM `t2` )               |
|   30 | outline_db | b4369611be7ab2d27c85897632576a04bc08f50b928a1d735b62d0a140628c4c |
USE INDEX |       |    1 | ind_1                                                       |    3 |
0 | SELECT * FROM `t1` WHERE `t1` . `col1` = ? AND `t1` . `col2` = ?                    |
|   31 | outline_db | 33c71541754093f78a1f2108795cfb45f8b15ec5d6bff76884f4461fb7f33419 |
USE INDEX |       |    2 | ind_2                                                       |    1 |
0 | SELECT * FROM `t1` , `t2` WHERE `t1` . `col1` = `t2` . `col1` AND `t2` . `col2` = ? |
+------+------------+-----------------------------------------------------------------+-
----------+-------+------+-------------------------------------------------------------+------+
----------+-------------------------------------------------------------------------------
-------+
7 rows in set (0.00 sec)
```

The following table describes the HIT and OVERFLOW parameters.

Parameter	Description
HIT	The number of times that the statement outline finds the destination query block or table.
OVERFLOW	The number of times that the statement outline does not find the destination query block or table.

- del_outline

  Deletes a statement outline from the memory and the table. The statement is as follows:

```
dbms_outln.del_outline(<Id>);
```

Example:

```
mysql> call dbms_outln.del_outline(32);
```

> **Note** If the statement outline that you want to delete does not exist, the system displays a corresponding error. You can execute the `SHOW WARNINGS;` statement to view the error message.

```
mysql> call dbms_outln.del_outline(1000);
Query OK, 0 rows affected, 2 warnings (0.00 sec)
mysql> show warnings;
+---------+------+-----------------------------------------------+
| Level   | Code | Message                                       |
+---------+------+-----------------------------------------------+
| Warning | 7521 | Statement outline 1000 is not found in table |
| Warning | 7521 | Statement outline 1000 is not found in cache |
+---------+------+-----------------------------------------------+
2 rows in set (0.00 sec)
```

- flush_outline

  If you modify the statement outline in the outline table, you need to execute the following statement so that the statement outline takes effect again. The statement is as follows:

  ```
  dbms_outln.flush_outline();
  ```

  Example:

  ```
  mysql> update mysql.outline set Position = 1 where Id = 18;
  Query OK, 1 row affected (0.00 sec)
  Rows matched: 1  Changed: 1  Warnings: 0
  mysql> call dbms_outln.flush_outline();
  Query OK, 0 rows affected (0.01 sec)
  ```

Feature test

There are two methods to verify whether the statement outline takes effect.

- Use the preview_outline interface.

```
mysql> call dbms_outln.preview_outline('outline_db', "select * from t1 where t1.col1 =1 a
nd t1.col2 ='xpchild'");
+------------+----------------------------------------------------------------------+--------
----+------------+-------+---------------------+
| SCHEMA     | DIGEST                                                               | BLOCK_T
YPE | BLOCK_NAME | BLOCK | HINT                |
+------------+----------------------------------------------------------------------+--------
----+------------+-------+---------------------+
| outline_db | b4369611be7ab2d27c85897632576a04bc08f50b928a1d735b62d0a140628c4c | TABLE
| t1         |     1 | USE INDEX (`ind_1`) |
+------------+----------------------------------------------------------------------+--------
----+------------+-------+---------------------+
1 row in set (0.01 sec)
```

- Execute the EXPLAIN statement.

```
mysql> explain select * from t1 where t1.col1 =1 and t1.col2 ='xpchild';
+----+-------------+-------+------------+------+---------------+-------+---------+-------
+------+----------+-------------+
| id | select_type | table | partitions | type | possible_keys | key   | key_len | ref
| rows | filtered | Extra       |
+----+-------------+-------+------------+------+---------------+-------+---------+-------
+------+----------+-------------+
|  1 | SIMPLE      | t1    | NULL       | ref  | ind_1         | ind_1 | 5       | const
|    1 |   100.00 | Using where |
+----+-------------+-------+------------+------+---------------+-------+---------+-------
+------+----------+-------------+
1 row in set, 1 warning (0.00 sec)
mysql> show warnings;
+-------+------+-----------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------+
| Level | Code | Message
|
+-------+------+-----------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------+
| Note  | 1003 | /* select#1 */ select `outline_db`.`t1`.`id` AS `id`,`outline_db`.`t1`.`
col1` AS `col1`,`outline_db`.`t1`.`col2` AS `col2` from `outline_db`.`t1` USE INDEX (`ind
_1`) where ((`outline_db`.`t1`.`col1` = 1) and (`outline_db`.`t1`.`col2` = 'xpchild')) |
+-------+------+-----------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------+
1 row in set (0.00 sec)
```

3.4. Sequence Engine

AliSQL provides the Sequence Engine feature. This feature allows you to use a Sequence engine on your ApsaraDB RDS instance to generate sequence values in an efficient manner.

Introduction

In most cases, unique sequence values that monotonically increase are required for primary keys in a single-node persistent database system, for globally unique identifiers (GUIDs) in a distributed persistent database system, and for idempotence among multiple persistent database systems. Each database engine uses a unique method to ensure that sequence values are unique. For example, MySQL provides the AUTO_INCREMENT attribute, and Oracle and SQL Server provide the SEQUENCE attribute.

In MySQL databases, the process of using the AUTO_INCREMENT attribute to encapsulate unique sequence values, such as dates and usernames, is time-consuming. The following methods can be used to generate unique sequence values in an efficient manner:

- Use an application or a proxy to generate sequence values. A drawback of this method lies in that the statuses of the sequence values are sent to the application. This drawback makes scaling more complicated.
- Use a simulated table to generate sequence values. This method requires you to install middleware. The middleware is used to encapsulate and simplify the logic that is used to obtain the generated sequence values.

A Sequence engine is compatible with various database engines and can help generate sequence values in a more efficient manner.

A Sequence engine is compatible with various storage engines that are used with MySQL. However, the underlying persistent data is still stored by using existing storage engines, such as InnoDB and MyISAM. This ensures compatibility with third-party tools, such as XtraBackup. Therefore, a Sequence engine is used only as a logical engine.

A Sequence engine uses Sequence Handler to access sequence objects. This way, you can increase the value of a sequence by using the NEXTVAL operator and manage the cached data. The data is sent to the underlying base table engine. You can access the data from the underlying base table engine based on your business requirements.

Prerequisites

Your RDS instance runs one of the following MySQL versions and RDS editions:

- MySQL 8.0 in a minor engine version of 20190816 or later
- MySQL 5.7 in a minor engine version of 20210430 or later
- MySQL 5.6 in a minor engine version of 20170901 or later

> **Note** The Sequence Engine feature is not supported for RDS instances that run RDS Enterprise Edition.

Limits

- A Sequence engine does not support subqueries or JOIN queries.
- You can use the `SHOW CREATE TABLE` or `SHOW CREATE SEQUENCE` statement to access a sequence. You cannot use the `SHOW CREATE SEQUENCE` statement to access a regular table.
- When you create a table, you cannot specify a Sequence engine. If you want to specify a Sequence engine for a table, you must execute the statement that is described in the "Create a sequence" section of this topic.

Create a sequence

To create a sequence, execute the following statement:

```
CREATE SEQUENCE [IF NOT EXISTS] <Database name>.<Sequence name>
   [START WITH <constant>]
   [MINVALUE <constant>]
   [MAXVALUE <constant>]
   [INCREMENT BY <constant>]
   [CACHE <constant> | NOCACHE]
   [CYCLE | NOCYCLE]
  ;
```

Note When you execute the preceding statement, you must configure the parameters that are enclosed in brackets ([]).

The following table describes the parameters.

Parameter	Description
START	The start value of the sequence.
MINVALUE	The minimum value of the sequence.
MAXVALUE	The maximum value of the sequence. **Note** If the NOCYCLE option is specified for the sequence, the following error is reported when the maximum value is reached: `ERROR HY000: Sequence 'db.seq' has been run out.`
INCREMENT BY	The increment at which the value of the sequence increases.
CACHE/NOCACHE	The size of the cache. You can specify a larger cache size to improve the performance of your RDS instance. If your RDS instance is restarted, the sequence values that are stored in the cache are lost.
CYCLE/NOCYCLE	Specifies whether the value of the sequence is reset to the minimum value that is specified by the MINVALUE parameter after the maximum value is reached. Valid values: • CYCLE: The value of the sequence is reset to the minimum value after the maximum value is reached. • NOCYCLE: The value of the sequence is not reset to the minimum value after the maximum value is reached.

Example:

```
create sequence s
       start with 1
       minvalue 1
       maxvalue 9999999
       increment by 1
       cache 20
       cycle;
```

If you want to use the mysqldump plug-in to back up your RDS instance, you can create a sequence table and insert an initial row into the sequence table. Example:

```
CREATE TABLE schema.sequence_name (  `currval` bigint(21) NOT NULL COMMENT 'current value',
  `nextval` bigint(21) NOT NULL COMMENT 'next value',
  `minvalue` bigint(21) NOT NULL COMMENT 'min value',
  `maxvalue` bigint(21) NOT NULL COMMENT 'max value',
  `start` bigint(21) NOT NULL COMMENT 'start value',
  `increment` bigint(21) NOT NULL COMMENT 'increment value',
  `cache` bigint(21) NOT NULL COMMENT 'cache size',
  `cycle` bigint(21) NOT NULL COMMENT 'cycle state',
  `round` bigint(21) NOT NULL COMMENT 'already how many round'
) ENGINE=Sequence DEFAULT CHARSET=latin1;
INSERT INTO schema.sequence_name VALUES(0,0,1,9223372036854775807,1,1,10000,1,0);
COMMIT;
```

Introduction to sequence tables

Sequences are stored in the tables that are created by using the default storage engine. When you query sequences, the system returns the tables that are created by using the default storage engine. Example:

```
SHOW CREATE TABLE schema.sequence_name;
CREATE TABLE schema.sequence_name (
  `currval` bigint(21) NOT NULL COMMENT 'current value',
  `nextval` bigint(21) NOT NULL COMMENT 'next value',
  `minvalue` bigint(21) NOT NULL COMMENT 'min value',
  `maxvalue` bigint(21) NOT NULL COMMENT 'max value',
  `start` bigint(21) NOT NULL COMMENT 'start value',
  `increment` bigint(21) NOT NULL COMMENT 'increment value',
  `cache` bigint(21) NOT NULL COMMENT 'cache size',
  `cycle` bigint(21) NOT NULL COMMENT 'cycle state',
  `round` bigint(21) NOT NULL COMMENT 'already how many round'
) ENGINE=Sequence DEFAULT CHARSET=latin1
```

Syntax

A Sequence engine supports the following syntaxes:

- `SELECT nextval(<Sequence name>),currval(<Sequence name>) FROM <Sequence name>;`

  > **Note** This syntax is supported for MySQL 8.0 and MySQL 5.7.

- `SELECT <Sequence name>.currval, <Sequence name>.nextval FROM dual;`

> **Note** This syntax is supported for MySQL 8.0, MySQL 5.7, and MySQL 5.6.

Example:

```
mysql> SELECT test.currval, test.nextval from dual;
+--------------+--------------+
| test.currval | test.nextval |
+--------------+--------------+
|           24 |           25 |
+--------------+--------------+
1 row in set (0.03 sec)
```

> **Note** Before you query the values of a new sequence, you must execute the following statement. Otherwise, the system reports the "`Sequence 'xxx' is not yet defined in current session`" error message.
>
> Example:
>
> ```
> SELECT <Sequence name>.nextval FROM dual;
> ```

3.5. Returning

This topic describes the Returning feature of AliSQL. This feature enables data manipulation language (DML) statements to return result sets and provides the DBMS_TRANS package for you to track the execution of DML statements.

Context

The execution results of MySQL statements are divided into three types: result sets, OK packets, and ERR packets. An OK or ERR packet contains attributes such as the number of affected and the number of scanned records. However, the execution of a DML statement (INSERT, UPDATE, or DELETE) is often followed by the execution of the SELECT statement to query current records. In such cases, the Returning feature enables the server to respond to the client only once by combining the execution results of the two statements into a result set.

Prerequisites

Your RDS instance is running MySQL 8.0.

Syntax

```
DBMS_TRANS.returning(<Field_list>,<Statement>);
```

The following table describes the parameters that you need to configure.

Parameter	Description
Field_list	The fields to return. If you enter more than one field, separate them with commas (,). Native fields and wildcards (*) in the specified table are supported. However, operations such as calculation and aggregation are not supported.

Parameter	Description
Statement	The DML statement to execute. Only the INSERT, UPDATE, and DELETE statements are supported.

Precautions

`dbms_trans.returning()` is not a transactional statement. It inherits the context of the specified transaction based on the DML statement that you want to execute. To terminate the transaction, you must explicitly commit it or roll it back.

INSERT Returning

The server returns the records that were inserted into the specified table by using the INSERT statement.

Example:

```
CREATE TABLE `t` (
  `id` int(11) NOT NULL AUTO_INCREMENT,
  `col1` int(11) NOT NULL DEFAULT '1',
  `col2` timestamp NOT NULL DEFAULT CURRENT_TIMESTAMP,
  PRIMARY KEY (`id`)
) ENGINE=InnoDB;
mysql> call dbms_trans.returning("*", "insert into t(id) values(NULL),(NULL)");
+----+------+---------------------+
| id | col1 | col2                |
+----+------+---------------------+
|  1 |    1 | 2019-09-03 10:39:05 |
|  2 |    1 | 2019-09-03 10:39:05 |
+----+------+---------------------+
2 rows in set (0.01 sec)
```

Note

- If you do not specify the Field_list parameter, the server returns an OK or ERR packet.

```
mysql> call dbms_trans.returning("", "insert into t(id) values(NULL),(NULL)");
Query OK, 2 rows affected (0.01 sec)
Records: 2  Duplicates: 0  Warnings: 0
mysql> select * from t;
+----+------+---------------------+
| id | col1 | col2                |
+----+------+---------------------+
|  1 |    1 | 2019-09-03 10:40:55 |
|  2 |    1 | 2019-09-03 10:40:55 |
|  3 |    1 | 2019-09-03 10:41:06 |
|  4 |    1 | 2019-09-03 10:41:06 |
+----+------+---------------------+
4 rows in set (0.00 sec)
```

- The Returning feature only supports statements that are similar to `INSERT VALUES`. It does not support statements such as `CREATE AS` and `INSERT SELECT`.

```
mysql> call dbms_trans.returning("", "insert into t select * from t");
ERROR 7527 (HY000): Statement didn't support RETURNING clause
```

UPDATE Returning

The server returns the records that were updated in the specified table by the using UPDATE statement.

Example:

```
mysql> call dbms_trans.returning("id, col1, col2", "update t set col1 = 2 where id >2");
+----+------+---------------------+
| id | col1 | col2                |
+----+------+---------------------+
|  3 |    2 | 2019-09-03 10:41:06 |
|  4 |    2 | 2019-09-03 10:41:06 |
+----+------+---------------------+
2 rows in set (0.01 sec)
```

Note The Returning feature does not allow the UPDATE statement to be executed on more than one table.

DELETE Returning

The server returns the records that were deleted from the specified table by using the DELETE statement.

Example:

```
mysql> call dbms_trans.returning("id, col1, col2", "delete from t where id < 3");
+----+------+---------------------+
| id | col1 | col2                |
+----+------+---------------------+
|  1 |    1 | 2019-09-03 10:40:55 |
|  2 |    1 | 2019-09-03 10:40:55 |
+----+------+---------------------+
2 rows in set (0.00 sec)
```

3.6. Lizard transaction system

This topic describes the Lizard transaction system that is launched for ApsaraDB RDS for MySQL 8.0 instances.

Background information

The performance of MySQL 8.0 is significantly enhanced thanks to the continuous improvement in the locking service and redo logging mechanism by the MySQL community. However, the transaction system of the InnoDB storage engine suffers problems such as interference between read and write requests and unstable XA transactions. To increase the throughput of ApsaraDB RDS for MySQL databases and allow them to support distributed transactions and global consistency, Alibaba Cloud launches the Lizard transaction system for ApsaraDB RDS for MySQL 8.0.22 (with a minor version of 20201231). The following section describes the benefits of the Lizard system:

- Improved performance in high-concurrency scenarios
- Native flashback query
- Support for XA transactions and global consistency

Improved performance in high-concurrency scenarios

The InnoDB engine of the official MySQL version uses a global transaction system. Changes of the transaction status in data manipulation language (DML) processes and read views in queries all require access to the global transaction system. This causes severe read/write interference and limits the system throughput. However, Lizard bypasses the transaction system by not maintaining the read views used to implement multi-version concurrency control (MVCC) during queries. This allows MySQL databases to better utilize multi-core CPU resources and substantially enhances the transaction throughput in high-concurrency scenarios that involve both read and write requests.

In the following section, SysBench tests are performed to compare the performance of the official MySQL version and ApsaraDB RDS for MySQL. The test environment and test results are described.

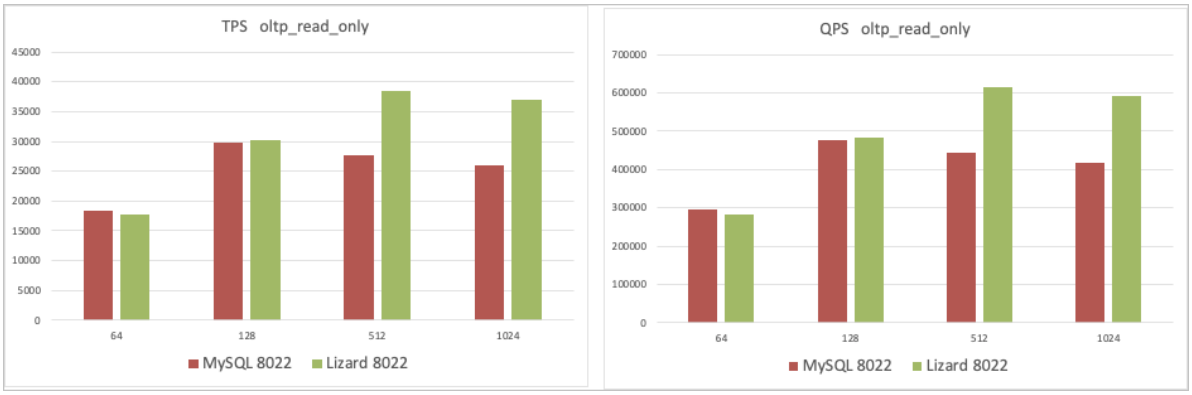
- Test environment
  - CPU: Intel(R) Xeon(R) Platinum 8163, with 96 cores and a 2.5 GHz base frequency

- MySQL configuration:
  - innodb_buffer_pool_size: 50 GB
  - `sync_binlog = 0`: When a transaction is committed, binlogs are written to the cache, but not immediately to the disk. The system determines when to write binlogs to the disk.
  - `innodb_flush_log_at_trx_commit = 2`: When a transaction is committed, redo logs are written to the cache, but not immediately to the disk. A flush operation is performed once per second to write redo logs to the disk.

> **Note** `sync_binlog = 0` and `innodb_flush_log_at_trx_commit = 2` can reduce the interference of I/O subsystems, facilitate the utilization of multi-core CPU resources in high-concurrency scenarios, and eliminate concurrent contentions.

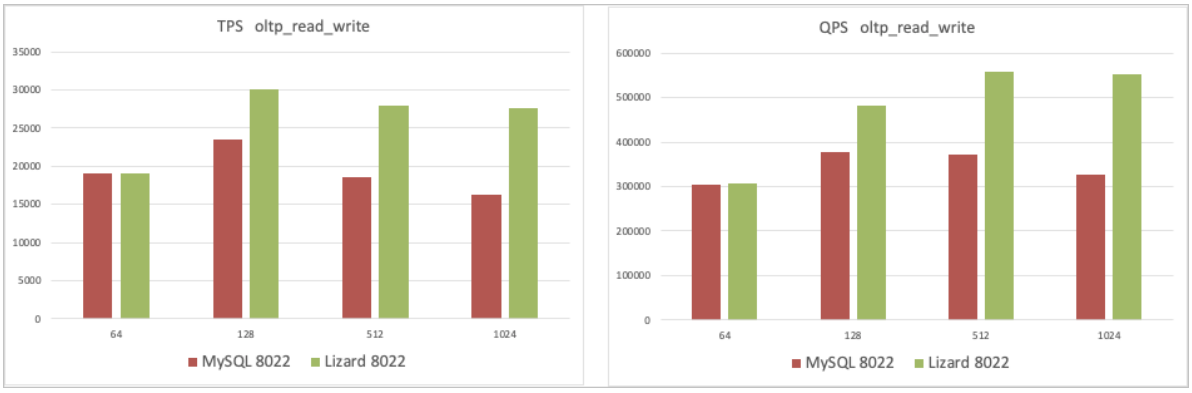
- Test data amount: 30 GB (20 tables with 5 million records in each table)

- Test scenario 1: SysBench OLTP Read_only



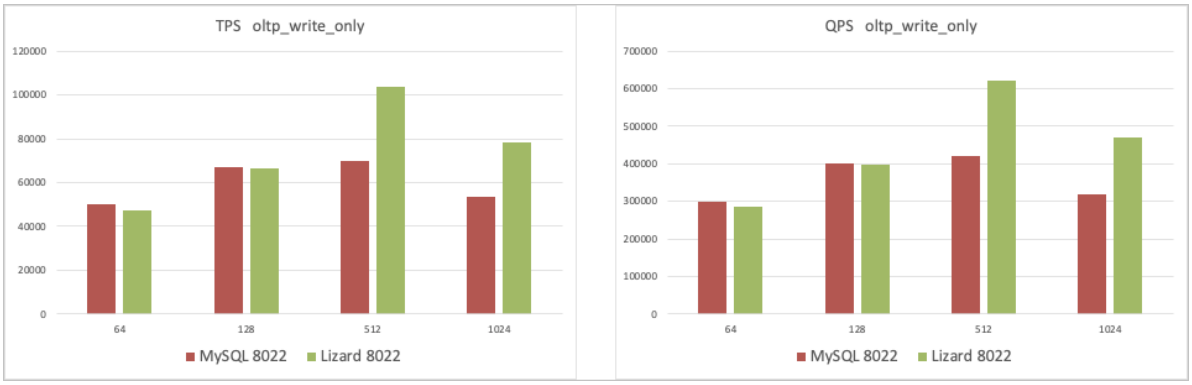
> **Note** The queries per second (QPS) of ApsaraDB RDS for MySQL is up to 42.2% higher than that of the official MySQL version.

- Test scenario 2: SysBench OLTP Read_write



> **Note** The QPS of ApsaraDB RDS for MySQL is up to 69.9% higher than that of the official MySQL version.

- Test scenario 3: SysBench OLTP Write_only



> **Note** The QPS of ApsaraDB RDS for MySQL is up to 48.1% higher than that of the official MySQL version.

According to the preceding test results, ApsaraDB RDS for MySQL that uses Lizard can eliminate concurrent contentions that occur in high-concurrency scenarios to improve the system throughput.

Native flashback query

During daily O&M of ApsaraDB RDS for MySQL databases, you may encounter accidental changes or unexpected data modifications. After you commit a transaction, you may not be able to roll it back. This issue can be solved by using Lizard. Its native flashback query feature allows you to have a consistent view of data as of an earlier point in time.

The following code shows the flashback query syntax:

```
SELECT ... FROM tablename
  AS OF [SCN | TIMESTAMP] expr;
```

Examples

- Initialize data

```
mysql> CREATE TABLE tab (
    -> id int PRIMARY KEY AUTO_INCREMENT,
    -> version int,
    -> gmt_modify timestamp
    -> );
mysql> INSERT INTO tab VALUES (1, 1, now()),(2, 1, now());
mysql> COMMIT;
mysql> SELECT * FROM tab;
+----+---------+---------------------+
| id | version | gmt_modify          |
+----+---------+---------------------+
|  1 |       1 | 2020-12-17 16:40:38 |
|  2 |       1 | 2020-12-17 16:40:39 |
+----+---------+---------------------+
```

- Update data

```
mysql> UPDATE tab SET version = version + 1, gmt_modify = now();
mysql> COMMIT;
mysql> SELECT * FROM tab;
+----+---------+---------------------+
| id | version | gmt_modify          |
+----+---------+---------------------+
|  1 |       2 | 2020-12-17 16:40:54 |
|  2 |       2 | 2020-12-17 16:40:54 |
+----+---------+---------------------+
```

- Retrieve data by using flashback query

```
mysql> SELECT * FROM tab AS OF TIMESTAMP '2020-12-17 16:40:40';
+----+---------+---------------------+
| id | version | gmt_modify          |
+----+---------+---------------------+
|  1 |       1 | 2020-12-17 16:40:38 |
|  2 |       1 | 2020-12-17 16:40:39 |
+----+---------+---------------------+
mysql> SELECT * FROM tab AS OF TIMESTAMP '2020-12-17 16:40:55';
+----+---------+---------------------+
| id | version | gmt_modify          |
+----+---------+---------------------+
|  1 |       2 | 2020-12-17 16:40:54 |
|  2 |       2 | 2020-12-17 16:40:54 |
+----+---------+---------------------+
```

Note If you query data as of an earlier point in time when undo records have been truncated, an `ERROR 7546 (HY000): Snapshot too old` error is returned.

ApsaraDB RDS for MySQL provides the following parameters to facilitate the management of flashback query.

Parameter	INNODB_UNDO_RETENTION	INNODB_UNDO_SPACE_SUPREMUM_SIZE	INNODB_UNDO_SPACE_RESERVED_SIZE
Description	The maximum period of time for which InnoDB retains the undo records. The value must be greater than 0. Unit: seconds. The longer the period, the earlier the records supported by flashback query, and the more space the undo tables occupy.	The maximum size of undo tablespaces used by InnoDB. Unit: MB. When the specified threshold is reached, the undo records are forcibly deleted regardless of the INNODB_UNDO_RETENTION value.	The space reserved for the undo tablespaces used by InnoDB. Unit: MB. Within the period specified by INNODB_UNDO_RETENTION, the space reserved by INNODB_UNDO_SPACE_RESERVED_SIZE is used to store as many undo records as possible.
Command syntax	--innodb-undo-retention=#	--innodb-undo-space-supremum-size=#	--innodb-undo-space-reserved-size=#

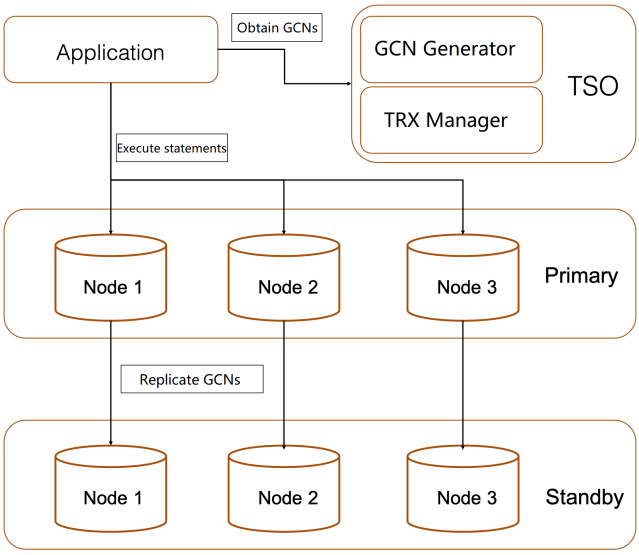
Parameter	INNODB_UNDO_RETENTION	INNODB_UNDO_SPACE_SUPREMUM_SIZE	INNODB_UNDO_SPACE_RESERVED_SIZE
Parameter range	Global	Global	Global
Dynamic	Yes	Yes	Yes
Prompts for value change	No	No	No
Data type	Integer	Integer	Integer
Default value	0	102400	0
Valid values	0 - 4294967295	0 - 4294967295	0 - 4294967295

Support for XA transactions and global consistency

To provide comprehensive support for XA transactions and global consistency, Lizard supports the assignment of global commit numbers (GCNs). The following section describes the methods to use this feature:

- During the commit phase, a transaction can be assigned a GCN and committed by using the COMMT/XA COMMIT by GCN statement.
- During the query phase, a transaction can be assigned a GCN and committed by using the SELECT by GCN statement.

The following figure shows a simple distributed architecture and scenario. In the example, a global Time Sharing Option (TSO) node is maintained and three ApsaraDB RDS for MySQL instances on High-availability Edition are created.



The following section shows the sample commands:

- Node 1

```
XA BEGIN $xid;
UPDATE account SET balance = balance + 10 WHERE user = 'Johnson';
XA END;
XA PREPARE $xid;
XA COMMIT $xid $GCN;
```

- Node 2

```
XA BEGIN $xid
UPDATE account SET balance = balance - 10 WHERE user = 'Lisa';
XA END;
XA PREPARE $xid;
XA COMMIT $xid $GCN;
```

- Query statements
  - Node 1

    ```
    SELECT * FROM account AS OF GCN $GCN where user ='Johnson';
    ```

  - Node 2

    ```
    SELECT * FROM account AS OF GCN $GCN where user ='Lisa';
    ```

Note ApsaraDB RDS for MySQL supports GCN-related syntax. This feature is in public preview. To use this feature, submit a .

4.Performance

4.1. Fast query cache

The fast query cache is a query cache that is developed by Alibaba Cloud based on the native MySQL query cache. The fast query cache uses a new design and a new implementation mechanism to increase the query performance of your ApsaraDB RDS instance.

Prerequisites

- Your RDS instance runs MySQL 5.7 with a minor engine version of 20200331 or later.
- The dedicated proxy service is disabled for your RDS instance. For more information, see Disable the dedicated proxy service for an ApsaraDB RDS for MySQL instance.

Background information

A query cache is designed to save CPU resources and accelerate queries. It stores the text of each qualified statement with the returned result set. If an identical SQL statement is received later, the database system directly retrieves the result set from the query cache. This eliminates the need to analyze, optimize, and execute the SQL statement again.

The native MySQL query cache has the following drawbacks in terms of design and implementation:

- It cannot process a large number of concurrent queries at high performance. If multiple CPU cores are configured, a larger number of concurrent queries may indicate lower performance.
- It cannot efficiently utilize memory resources or quickly reclaim memory resources. This causes a waste of memory resources.
- If the cache hit ratio is low, query performance does not increase and may even significantly decrease.

Due to the preceding drawbacks, the native MySQL query cache is not widely used. It is no longer provided in the latest MySQL version 8.0. In contrast, the fast query cache has the following benefits:

- Optimized concurrency control

  The global locking mechanism removed. This mechanism is used in the native MySQL query cache to synchronize the running of threads. The fast query cache uses a redesigned synchronization mechanism. This mechanism allows ApsaraDB RDS to exploit the configuration of multiple CPU cores and process a large number of concurrent queries at high performance.

- Optimized memory management

  The memory preallocation mechanism of the native MySQL query cache is removed. The fast query cache uses a dynamic, more flexible memory allocation mechanism. This mechanism allows ApsaraDB RDS to quickly reclaim invalid memory resources. This increases memory usage.

- Optimized caching

  The fast query cache dynamically monitors cache usage. Then, the fast query cache adjusts the cache policy based on the obtained cache usage. This prevents performance decreases when the cache hit ratio is low or when your RDS instance processes both read and write requests.

The fast query cache can be used in a wide range of business scenarios to increase query performance. However, the native MySQL query cache does not provide the same support.

Enable the fast query cache

You can enable the fast query cache by configuring the **query_cache_type** and **query_cache_size** parameters in the ApsaraDB RDS console.

Parameter	Description
query_cache_type	The switch that is used to control the fast query cache. Valid values: • 0: disables the fast query cache. This is the default value. • 1: enables the fast query cache. You can use the SQL_NO_CACHE option to skip the caching for SQL statements. • 2: disables the fast query cache. You can use the SQL_CACHE option to cache the texts and result sets of only the specified SQL statements.
query_cache_size	The size of the memory space that is allocated to the fast query cache. Valid values: 0 to 10485760000. The value must be a multiple of 1024. Unit: bytes.

The fast query cache occupies extra memory space. When you configure the fast query cache, we recommend that you also reconfigure the **innodb_buffer_pool_size** parameter:

1. Set the **innodb_buffer_pool_size** parameter to 90% of the original value of this parameter. The reduced 10% of memory space is used as the query cache size that is specified by the **query_cache_size** parameter. For example, if the original value of the innodb_buffer_pool_size parameter is **{DBInstanceClassMemory*7/10}**, set this parameter to **{DBInstanceClassMemory*63/100}**. For more information, see Change the size of the InnoDB buffer pool for an ApsaraDB RDS for MySQL instance.
2. Set the **query_cache_size** parameter. For more information, see Modify the parameters of an ApsaraDB RDS for MySQL instance.
   - If you can accurately estimate the result set size, you can set the **query_cache_size** parameter to a value that is equal to `20% of the result set size`.
   - If you cannot accurately estimate the result set size, you can set the **query_cache_size** parameter to a value that is equal to `10% of the value of the innodb_buffer_pool_size parameter`.

   > **Note** When you change the specifications of your RDS instance, the value of the **query_cache_size** parameter does not change based on the new specifications. After the specification change is applied, you must immediately reconfigure this parameter.
3. Set the **query_cache_type** parameter to **1**. This allows you to enable the fast query cache. For more information, see Modify the parameters of an ApsaraDB RDS for MySQL instance.

Compare the performance of the native MySQL query cache and the fast query cache

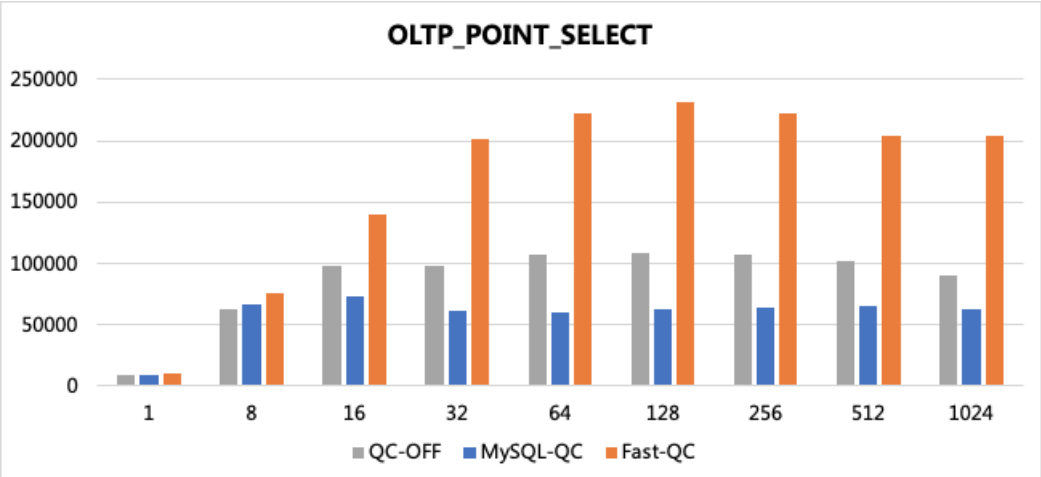
Compare the queries per second (QPS) with different query cache configurations under the same conditions in various test cases. These query cache configurations are QC-OFF (no query cache is enabled), MySQL-QC (the native MySQL query cache is enabled), and Fast-QC (the fast query cache is enabled).

- Test environment: a dedicated RDS instance with 4 CPU cores and 8 GB of memory
- Test tool: SysBench
- Test data size: 250 MB (25 tables in total, 40,000 records per table)
- Test case 1: Test the QPS for read queries with a cache hit ratio of 100%.

  The oltp_point_select script is used. Execute only the POINT SELECT statements that are based on primary keys. Additionally, make sure that you set the query cache size to 512 MB. This size is greater than the test data size and allows the cache hit ratio to reach 100%. In this test case, focus on how much the QPS increases based on the number of concurrent queries.

  QPS for read queries with a cache hit ratio of 100%

Number of concurrent queries	QC-OFF	MySQL-QC (QPS increase compared with QC-OFF)	Fast-QC (QPS increase compared with QC-OFF)
1	8,093	8,771 (8.38%)	9,261 (14.43%)
8	62,262	65,686 (5.50%)	75,313 (20.96%)
16	97,083	73,027 (-24.78%)	139,323 (43.51%)
32	97,337	60,567 (-37.78%)	200,978 (106.48%)
64	106,,283	60,216 (-43.34%)	221,659 (108.56%)
128	107781	62,844 (-41.69%)	231,409 (114.70%)
256	106,694	63,832 (-40.17%)	222,187 (108.25%)
512	101,733	64,866 (-36.24%)	203,789 (100.32%)
1024	89,548	62,291 (-30.44%)	203,542 (127.30%)



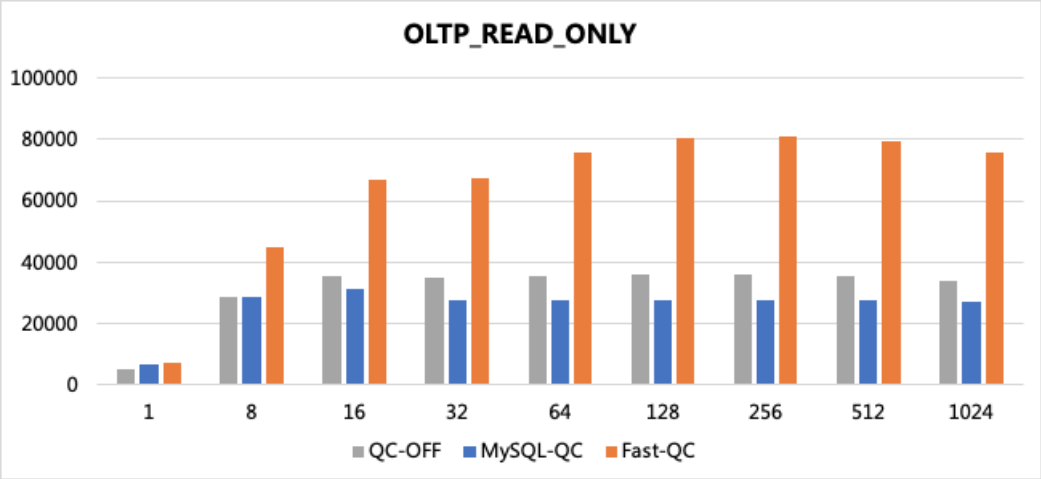
> **Note** Based on the test result, as the number of concurrent queries increases, the QPS of the native MySQL query cache significantly decreases. However, the QPS of the fast query cache does not decrease and can even increase by up to 100%.

- Test case 2: Test the QPS for read queries with a cache hit ratio higher than 80%.

  The oltp_read_only script is used. Run queries including range queries that each return multiple records. Additionally, make sure that you set the query cache size to 512 MB. This size ensures sufficient memory space and allows the cache hit ratio to reach more than 80%. In this test case, focus on how much the QPS increases based on the number of concurrent queries.

  QPS for read queries with a cache hit ratio higher than 80%

Number of concurrent queries	QC-OFF	MySQL-QC (QPS increase compared with QC-OFF)	Fast-QC (QPS increase compared with QC-OFF)
1	5,099	6,467 (26.83%)	7,022 (37.71%)
8	28,782	28,651 (-0.46%)	45,017 (56.41%)
16	35,333	31,099 (-11.98%)	66,770 (88.97%)
32	34,864	27,610 (-20.81%)	67,623 (93.96%)
64	35,503	27,518 (-22.49%)	75,981 (114.01%)
128	35,744	27,733 (-22.41%)	80,396 (124.92%)
256	35,685	27,738 (-22.27%)	80,925 (126.78%)
512	35,308	27,398 (-22.40%)	79,323 (124.66%)
1024	34,044	26,861 (-22.10%)	75,742 (122.48%)



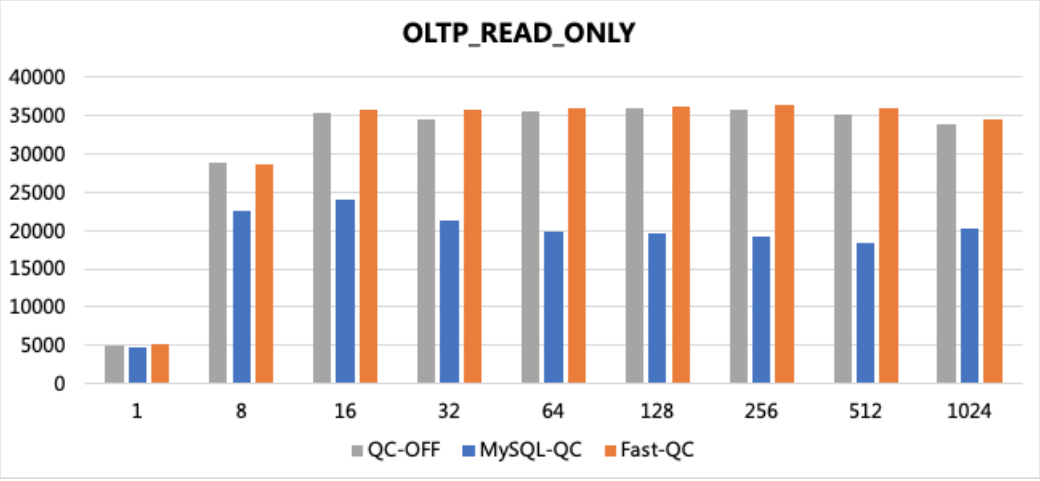
> **Note** Based on the test result, as the number of concurrent queries increases, the QPS of the native MySQL query cache significantly decreases. However, the QPS of the fast query cache can increase by more than 100%.

- Test case 3: Test the QPS for read queries with a cache hit ratio of about 10%

  The oltp_read_only script is used. Run queries including range queries that each return multiple records. Additionally, make sure that you set the query cache size to 16 MB. This size results in insufficient memory space and the deletion of a large amount of cached data. This allows the cache hit ratio to decrease to about 10%. In this test case, focus on how much the QPS decreases based on the number of concurrent queries.

  QPS for read queries with a cache hit ratio of about 10%

Number of concurrent queries	QC-OFF	MySQL-QC (QPS increase compared with QC-OFF)	Fast-QC (QPS increase compared with QC-OFF)
1	5,004	4,727 (-5.54%)	5,199 (3.90%)
8	28,795	22,542 (-21.72%)	28,578 (-0.75%)
16	35,455	24,064 (-32.13%)	35,682 (0.64%)
32	34,526	21,330 (-38.22%)	35,871 (3.90%)
64	35,514	19,791 (-44.27%)	36,051 (1.51%)
128	35,983	19,519 (-45.75%)	36,253 (0.75%)
256	35,695	19,168 (-46.30%)	36,337 (1.80%)
512	35,182	18,420 (-47.64%)	35,972 (2.25%)
1024	33,915	20,168 (-40.53%)	34,546 (1.86%)



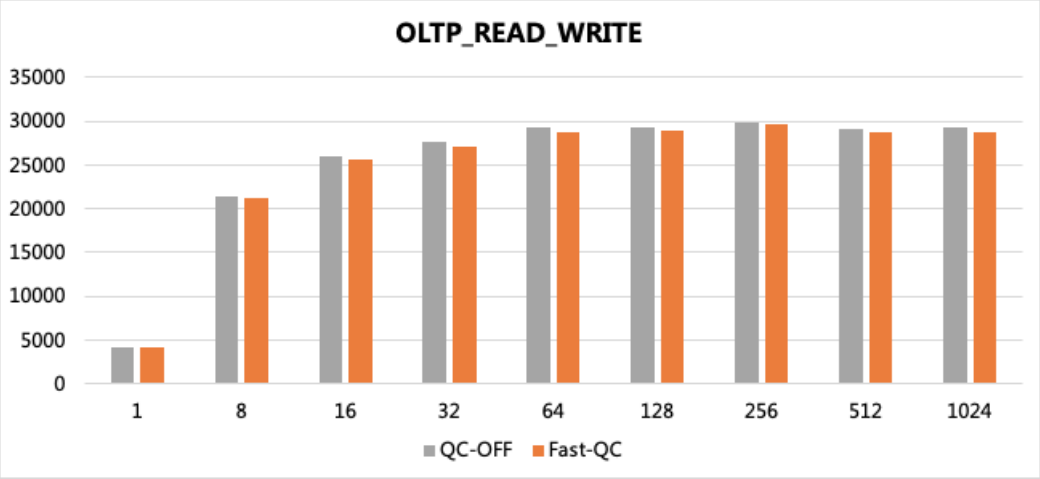
> **Note** Based on the test result, as the number of concurrent queries increases, the QPS of the native MySQL query cache significantly decreases. The decrease nears 50% at most. However, the QPS of the fast query cache decreases only by a small amount.

- Test case 4: Test the QPS for read and write queries.

  The oltp_read_write script is used. Run transactions that contain updates to tables. These frequent updates result in the deletion of cached data. Consequently, the configured query cache is considered invalid. In this test case, focus on how much the QPS decreases based on the number of concurrent queries.

  QPS for read and write queries

Number of concurrent queries	QC-OFF	Fast-QC (QPS increase compared with QC-OFF)
1	4,152	4,098 (-1.30%)
8	21,359	21,195 (-0.77%)
16	26,020	25,548 (-1.81%)
32	27,595	26,996 (-2.17%)
64	29,229	28,733 (-1.70%)
128	29,265	28,828 (-1.49%)
256	29,911	29,616 (-0.99%)
512	29,148	28,816 (-1.14%)
1024	29,204	28,824 (-1.30%)



> **Note** Based on the test result, as the number of concurrent read and write queries increases, the QPS of the fast query cache decreases only by a small amount.

Practice guidelines

If you can accurately estimate the result set size, you can evaluate the QPS by using the preceding test cases. This includes when you enable the fast query cache on a specified table by using the SQL_CACHE option. The following tips provide more information about how to use the fast query cache:

- Enable the fast query cache in various scenarios.
  - The fast query cache aims to increase the QPS for read queries. If your RDS instance processes a large number of read queries but a small number of write queries, we recommend that you enable the fast query cache. Otherwise, we recommend that you use the SQL_CACHE option to enable the fast query cache only for the tables that receive a large number of read queries but a small number of write queries. If your RDS instance processes a small number of read queries but a large number of write queries, the data of your RDS instance is frequently updated. In this case, the fast query cache may cause a small QPS decrease.
  - The QPS increase that is brought by the fast query cache varies based on the cache hit ratio. Before you enable the fast query cache for your RDS instance, we recommend that you obtain the hit ratio of the InnoDB buffer pool. If the hit ratio is lower than 80%, we recommend that you do not enable the fast query cache. The hit ratio of the InnoDB buffer pool is calculated by using the following formula: Hit ratio = (1 - The value of the Innodb_buffer_pool_reads parameter/The value of the Innodb_buffer_pool_read_requests parameter) x 100%. You can also obtain the read/write ratio of each table from the TABLE_STATISTICS table. If a table has a high read/write ratio, you can enable the fast query cache for the table by using the SQL_CACHE option. For more information about how to view the TABLE_STATISTICS table, see Performance Insight.
- Manage the fast query cache by using the **query_cache_type** parameter.

  You can set the **query_cache_type** parameter for a specific session based on your business scenario.
  - If your RDS instance processes a small number of read queries but a large number of write queries, the data of your RDS instance is frequently updated. In this case, we recommend that you globally set the **query_cache_type** parameter to 0.
  - If your RDS instance has a small data size, fixed query types, and a high hit ratio, we recommend that you globally set the **query_cache_type** parameter to 1.
  - If your RDS instance has a large data size, changing query types, and an unstable hit ratio, we recommend that you set the **query_cache_type** parameter to 2. Additionally, we recommend that you use the SQL_CACHE option to enable the fast query cache only for specified SQL statements.
- Specify a proper query cache size by using the **query_cache_size** parameter.

  The **query_cache_size** parameter is closely related to SQL statements. If you want to cache the results of queries that each return multiple records, you may need to specify a query cache size that is a few times greater than the data size. If you do not run range queries, you can perform the following test to evaluate the relationship between the data size and the **query_cache_size** parameter:
  - Test environment: a dedicated RDS instance with 4 CPU cores and 8 GB of memory (The size of the InnoDB buffer pool is set to 6 GB by using the innodb_buffer_pool_size parameter.)
  - Test tool: SysBench
  - Test data size: 10 GB (100 tables in total, 400,000 records per table)

Test case: Specify different cache sizes by using the query_cache_size parameter and execute the oltp_point_select script for each cache size. Make sure that 64 threads concurrently run to query data. In this case, the test data includes 20% hot data. This way, you can obtain the impacts of different cache sizes (**query_cache_size**) on the QPS. The actual result set size is 2.5 GB based on the test data size.

QPS with different cache sizes

query_cache_size (MB)	QC-OFF	Fast-QC hit ratio	Fast-QC (QPS increase compared with QC-OFF)
64	98,236	22%	99,440 (1.23%)
128	98,236	45%	114,155 (16.21%)
256	98,236	72%	140,668 (43.19%)
512	98,236	82%	151,260 (53.98%)
1024	98,,236	84%	153,866 (56.63%)
2048	98236	87%	159,597 (62.46%)
4096	98,236	92%	169,412 (72.45%)

The performance of the fast query cache does not decrease regardless of the value of the **query_cache_size** parameter. Specifically, the fast query cache provides significantly higher performance than the native MySQL query cache for primary key queries regardless of the cache hit ratio. In some circumstances, the performance can even increase by more than 90%. If the cache hit ratio is less than 90%, the fast query cache provides higher performance than the native MySQL query cache and saves a large number of CPU resources for range queries and for the queries that contain the `ORDER BY` clause.

4.2. Binlog in Redo

The Binlog in Redo function synchronously writes binary logs to the redo log file when a transaction is committed. This reduces operations on disks and improves database performance.

Prerequisites

Your RDS instance runs MySQL 8.0 (with a kernel version of 20200430 or later).

Context

To ensure data security in crucial MySQL business scenarios, the system stores both binary and redo logs when a transaction is committed. Both the following parameters must be set to 1:

```
sync_binlog = 1;
innodb_flush_log_at_trx_commit = 1;
```

Each time a transaction is committed, the system performs two I/O operations. One is to write the binary logs to disks, and the other is to write the redo logs to disks. Although Group Commit is enabled for binary logs, the system must still wait for the two I/O operations to complete. This affects the efficiency of transaction processing, especially when standard or enhanced SSDs are used. The performance of I/O merging is based on the number of concurrent transactions that are committed at the same time. When the number of concurrent transactions is small, the performance is low. For example, when a small number of write transactions are committed, the system response is slow.

To increase the efficiency of committing transactions, AliSQL provides the Binlog in Redo function. You can enable the function by setting the `persist_binlog_to_redo` parameter to on. When a transaction is committed, the system synchronously writes binary logs to the redo log file and stores only the redo log file to disks. This reduces I/O consumption. The binary log files are then asynchronously stored to disks by using a separate thread at regular intervals. If a restart operation is triggered upon an exception, the system uses the binary logs in the redo log file to complement the binary log files. In this way, the database performance improves and the system response is faster. Also, the number of times that the binary log files are stored is reduced. This significantly relieves the pressure on the file system while increasing performance. This pressure can be resulted from the calls of the fsync functions that are triggered by file updates in real time. The fsync function synchronizes files to disks.

Binlog in Redo does not change the format of binary logs. Replication and third-party tools that are based on binary logs are not affected.

Parameters

- persist_binlog_to_redo

  The switch that is used to enable or disable the Binlog in Redo function. This parameter is a global system variable. Valid values: on and off. The parameter change immediately takes effect. You do not need to restart your RDS instance.

  > **Note** If you want to enable Binlog in Redo, you only need to set the `persist_binlog_to_redo` parameter to on. You do not need to modify the settings of other parameters. The setting `sync_binlog = 1` automatically becomes invalid.

- sync_binlog_interval

  The interval at which binary logs are asynchronously stored. This parameter is a global system variable. It takes effect only when the `persist_binlog_to_redo` parameter is set to on. Default value: 50. Unit: milliseconds (ms). In normal cases, the default value is recommended. The parameter change immediately takes effect. You do not need to restart your RDS instance.

Stress testing

- Test environment
  - Application server: an Alibaba Cloud ECS instance
  - RDS instance type: 32 CPU cores, 64 GB of memory, and enhanced SSDs
  - RDS edition: High-availability Edition with asynchronous data replication
- Test cases

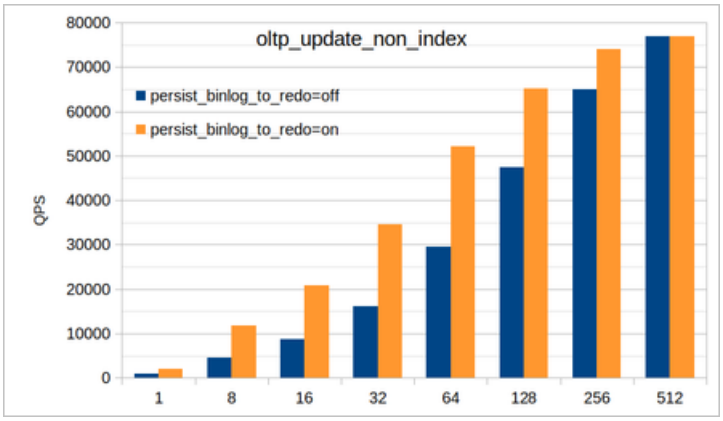
  Sysbench provides the following test cases:

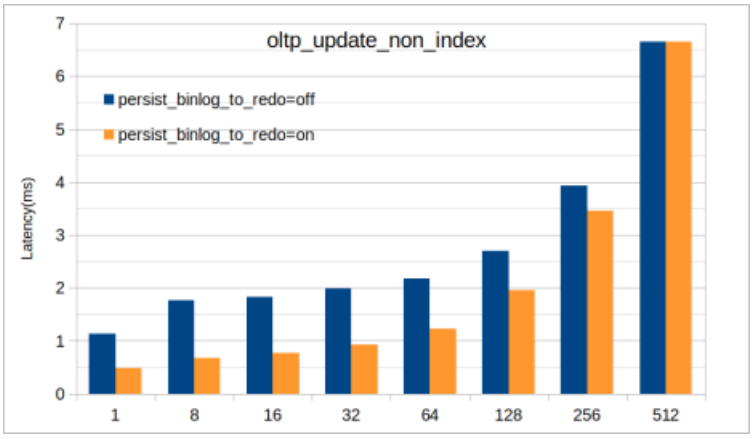
  - oltp_update_non_index

- oltp_insert
- oltp_write_only

- Test results
  - oltp_update_non_index

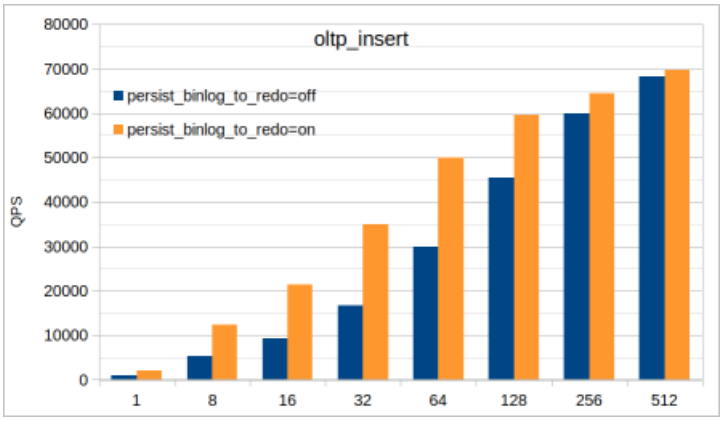
    After Binlog in Redo is enabled, the queries per second (QPS) significantly increases and the latency is low when the number of concurrent queries is small.

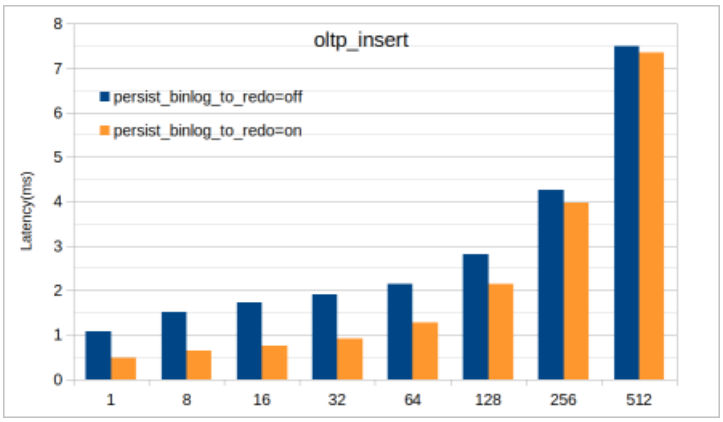




- oltp_insert

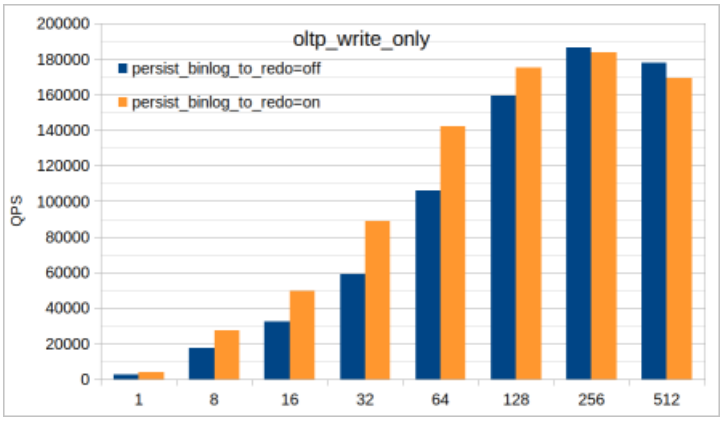
  After Binlog in Redo is enabled, the QPS significantly increases and the latency is low when the number of concurrent queries is small.

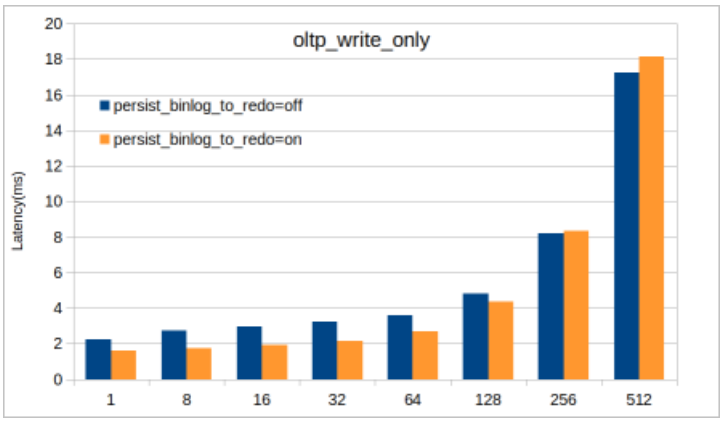




- oltp_write_only

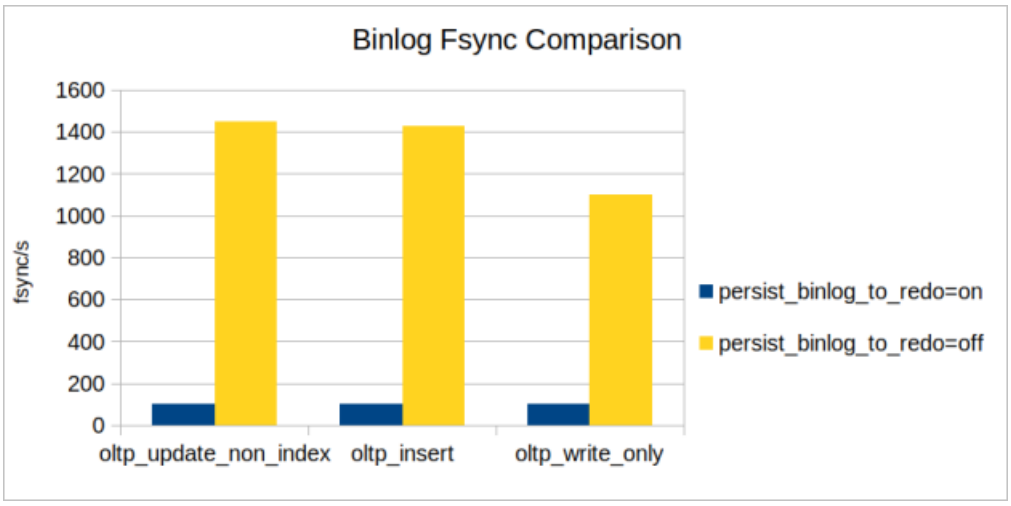
  After Binlog in Redo is enabled, the QPS slightly increases and the latency is low when the number of concurrent queries is small.





- Number of times that the fsync function is called for binary logs

  After Binlog in Redo is enabled, the number of times is significantly reduced.



Test conclusion

- oltp_update_non_index and oltp_insert test single-statement transactions, and the transactions are committed on a frequent basis. oltp_write_only tests multi-statement transactions, and the transactions are committed on a less frequent basis. This type of transaction contains two UPDATE statements, one DELETE statement, and one INSERT statement. Performance improvement in

oltp_update_non_index and oltp_insert is more notable than that in oltp_write_only.

- When the number of concurrent transactions is less than 256, Binlog in Redo significantly improves database performance and reduces latency. In most scenarios, Binlog in Redo provides significant benefits.
- Binlog in Redo significantly reduces the number of times that the fsync function is called for binary logs. This improves the performance of the file system.

4.3. Statement Queue

The statement queue feature allows statements to queue in the same bucket. These statements may be executed on the same resource. For example, these statements are executed on the same row of a table. This feature reduces overheads that are caused by potential conflicts.

Context

During the execution of concurrent statements, the MySQL server and engine may conflict with each other in some serial operations. For example, transactional lock conflicts are common during the execution of DML statements. The InnoDB storage engine supports resource locking accurate to rows. If multiple DML statements are concurrently executed on a row, serious conflicts may occur. The overall throughput of your database system decreases in proportion with the number of concurrent DML statements. The statement queue feature reduces overheads that are caused by these conflicts and increases the performance of your database system.

Prerequisites

The RDS instance runs one of the following SQL Server versions and RDS editions:

- MySQL 8.0 with a minor engine version of 20191115 or later on RDS Basic Edition or RDS High-availability Edition
- MySQL 5.7 with a minor engine version of 20200630 or later on RDS Basic Edition or RDS High-availability Edition

Benefits

AliSQL executes concurrent UPDATE statements on a single row four times faster than native MySQL.

Variables

AliSQL provides two variables that are used to define the bucket quantity and size of a statement queue:

- ccl_queue_bucket_count: the number of buckets that are allowed in the statement queue. Valid values: 1 to 64. Default value: 4.
- ccl_queue_bucket_size: the number of concurrent statements that are allowed per bucket. Valid values: 1 to 4096. Default value: 64.

> **Note** You can reconfigure the variables in the ApsaraDB RDS console. For more information, see Modify the parameters of an ApsaraDB RDS for MySQL instance.

Syntax

AliSQL supports two hints:

- ccl_queue_value

  AliSQL uses a hash algorithm to determine the bucket into which each statement is placed based on the value of a specified field.

  Syntax:

  ```
  /*+ ccl_queue_value([int | string]) */
  ```

  Example:

  ```
  update /*+ ccl_queue_value(1) */ t set c=c+1 where id = 1;
  update /*+ ccl_queue_value('xpchild') */ t set c=c+1 where name = 'xpchild';
  ```

- ccl_queue_field

  AliSQL uses a hash algorithm to determine the bucket into which each statement is placed based on the value of the field that is specified in the WHERE clause.

  Syntax:

  ```
  /*+ ccl_queue_field(string) */
  ```

  Example:

  ```
  update /*+ ccl_queue_field(id) */ t set c=c+1 where id = 1 and name = 'xpchild';
  ```

  > **Note** In the ccl_queue_field hint, the WHERE clause supports binary operators only on raw fields. These raw fields have not been altered by using functions or computation operations. In addition, the right operand of such a binary operator must be a number or a string.

Functions

AliSQL provides two functions that are used to query the status of a statement queue:

- dbms_ccl.show_ccl_queue()

  This function is used to query the status of the current statement queue.

  ```
  mysql> call dbms_ccl.show_ccl_queue();
  +------+-------+-------------------+---------+---------+----------+
  | ID   | TYPE  | CONCURRENCY_COUNT | MATCHED | RUNNING | WAITTING |
  +------+-------+-------------------+---------+---------+----------+
  |    1 | QUEUE |                64 |       1 |       0 |        0 |
  |    2 | QUEUE |                64 |   40744 |      65 |        6 |
  |    3 | QUEUE |                64 |       0 |       0 |        0 |
  |    4 | QUEUE |                64 |       0 |       0 |        0 |
  +------+-------+-------------------+---------+---------+----------+
  4 rows in set (0.01 sec)
  ```

  The following table describes the parameters in the result that is returned.

Parameter	Description
CONCURRENCY_COUNT	The maximum number of concurrent statements that are allowed.

Parameter	Description
MATCHED	The total number of statements that hit the specified rules.
RUNNING	The number of statements that are being concurrently executed.
WAITTING	The number of statements that are waiting in queue.

- dbms_ccl.flush_ccl_queue()

  This function is used to delete the data about a statement queue from the memory and query the status of the statement queue.

```
mysql> call dbms_ccl.flush_ccl_queue();
Query OK, 0 rows affected (0.00 sec)
mysql> call dbms_ccl.show_ccl_queue();
+------+-------+-------------------+---------+---------+----------+
| ID   | TYPE  | CONCURRENCY_COUNT | MATCHED | RUNNING | WAITTING |
+------+-------+-------------------+---------+---------+----------+
|    1 | QUEUE |                64 |       0 |       0 |        0 |
|    2 | QUEUE |                64 |       0 |       0 |        0 |
|    3 | QUEUE |                64 |       0 |       0 |        0 |
|    4 | QUEUE |                64 |       0 |       0 |        0 |
+------+-------+-------------------+---------+---------+----------+
4 rows in set (0.00 sec)
```

Practices

Statement queue can work with Statement outline to support online updates of your application code. In the following example, SysBench is used to execute the update_non_index.lua script:

- Test environment
  - Schema

```
CREATE TABLE `sbtest1` (
  `id` int(10) unsigned NOT NULL AUTO_INCREMENT,
  `k` int(10) unsigned NOT NULL DEFAULT '0',
  `c` char(120) NOT NULL DEFAULT '',
  `pad` char(60) NOT NULL DEFAULT '',
  PRIMARY KEY (`id`),
  KEY `k_1` (`k`)
) ENGINE=InnoDB AUTO_INCREMENT=2 DEFAULT CHARSET=utf8 MAX_ROWS=1000000;
```

  - Statement

```
UPDATE sbtest1 SET c='xpchild' WHERE id=0;
```

- Script

```
./sysbench
--mysql-host= {$ip}
--mysql-port= {$port}
--mysql-db=test
--test=./sysbench/share/sysbench/update_non_index.lua
--oltp-tables-count=1
--oltp_table_size=1
--num-threads=128
--mysql-user=u0
```

- Procedure

i. Create a statement outline in online mode.

```
mysql> CALL DBMS_OUTLN.add_optimizer_outline('test', '', 1,
                                             ' /*+ ccl_queue_field(id) */ ',
                          "UPDATE sbtest1 SET c='xpchild' WHERE id=0");
Query OK, 0 rows affected (0.01 sec)
```

ii. View the statement outline that you created.

```
mysql> call dbms_outln.show_outline();
+------+--------+-----------------------------------------------------------------------+-
----------+-------+------+--------------------------------+------+----------+--------
-------------------------------------+
| ID   | SCHEMA | DIGEST                                                                |
TYPE      | SCOPE | POS  | HINT                           | HIT  | OVERFLOW | DIGEST_
TEXT                                |
+------+--------+-----------------------------------------------------------------------+-
----------+-------+------+--------------------------------+------+----------+--------
-------------------------------------+
|    1 | test   | 7b945614749e541e0600753367884acff5df7e7ee2f5fb0af5ea58897910f023 |
OPTIMIZER |       |    1 |  /*+ ccl_queue_field(id) */  |    0 |        0 | UPDATE `s
btest1` SET `c` = ? WHERE `id` = ? |
+------+--------+-----------------------------------------------------------------------+-
----------+-------+------+--------------------------------+------+----------+--------
-------------------------------------+
1 row in set (0.00 sec)
```

iii. Verify that the statement outline has taken effect.

```
mysql> explain UPDATE sbtest1 SET c='xpchild' WHERE id=0;
+----+-------------+---------+------------+-------+---------------+---------+--------
-+--------+------+----------+-------------+
| id | select_type | table   | partitions | type  | possible_keys | key     | key_len
| ref   | rows | filtered | Extra       |
+----+-------------+---------+------------+-------+---------------+---------+--------
-+--------+------+----------+-------------+
|  1 | UPDATE      | sbtest1 | NULL       | range | PRIMARY       | PRIMARY | 4
| const |    1 |   100.00 | Using where |
+----+-------------+---------+------------+-------+---------------+---------+--------
-+--------+------+----------+-------------+
1 row in set, 1 warning (0.00 sec)
mysql> show warnings;
+-------+------+-----------------------------------------------------------------------------
-------------------------------------------------------+
| Level | Code | Message
|
+-------+------+-----------------------------------------------------------------------------
-------------------------------------------------------+
| Note  | 1003 | update /*+ ccl_queue_field(id) */ `test`.`sbtest1` set `test`.`sbtes
t1`.`c` = 'xpchild' where (`test`.`sbtest1`.`id` = 0) |
+-------+------+-----------------------------------------------------------------------------
-------------------------------------------------------+
1 row in set (0.00 sec)
```

iv. Query the status of the statement queue that is used.

```
mysql> call dbms_ccl.show_ccl_queue();
+------+-------+------------------+---------+---------+----------+
| ID   | TYPE  | CONCURRENCY_COUNT | MATCHED | RUNNING | WAITTING |
+------+-------+------------------+---------+---------+----------+
|    1 | QUEUE |               64 |       0 |       0 |        0 |
|    2 | QUEUE |               64 |       0 |       0 |        0 |
|    3 | QUEUE |               64 |       0 |       0 |        0 |
|    4 | QUEUE |               64 |       0 |       0 |        0 |
+------+-------+------------------+---------+---------+----------+
4 rows in set (0.00 sec)
```

v. Start the test.

```
sysbench
--mysql-host= {$ip}
--mysql-port= {$port}
--mysql-db=test
--test=./sysbench/share/sysbench/update_non_index.lua
--oltp-tables-count=1
--oltp_table_size=1
--num-threads=128
--mysql-user=u0
```

vi. Verify the test result.

```
mysql> call dbms_ccl.show_ccl_queue();
+------+-------+------------------+---------+---------+----------+
| ID   | TYPE  | CONCURRENCY_COUNT | MATCHED | RUNNING | WAITTING |
+------+-------+------------------+---------+---------+----------+
|    1 | QUEUE |                64 |   10996 |      63 |        4 |
|    2 | QUEUE |                64 |       0 |       0 |        0 |
|    3 | QUEUE |                64 |       0 |       0 |        0 |
|    4 | QUEUE |                64 |       0 |       0 |        0 |
+------+-------+------------------+---------+---------+----------+
4 rows in set (0.03 sec)
mysql> call dbms_outln.show_outline();
+------+--------+-----------+-----------+-------+------+-----------------------------
---+--------+----------+-----------------------------------------------+
| ID   | SCHEMA | DIGEST    | TYPE      | SCOPE | POS  | HINT
| HIT    | OVERFLOW | DIGEST_TEXT                                    |
+------+--------+-----------+-----------+-------+------+-----------------------------
---+--------+----------+-----------------------------------------------+
|    1 | test   | xxxxxxxxx | OPTIMIZER |       |    1 |  /*+ ccl_queue_field(id) */
| 115795 |        0 | UPDATE `sbtest1` SET `c` = ? WHERE `id` = ? |
+------+--------+-----------+-----------+-------+------+-----------------------------
---+--------+----------+-----------------------------------------------+
1 row in set (0.00 sec)
```

Note Based on the query results, a total of 115,795 statements hit the rules for the statement outline, a total of 10,996 statements hit the rules for the statement queue, a total of 63 statements are being concurrently executed, and four statements are waiting in queue.

4.4. Inventory Hint

This topic describes the Inventory Hint feature provided by AliSQL. This feature can work with the Returning and Statement Queue features to commit and roll back transactions rapidly.

Background information

In business scenarios such as seckilling, inventory reduction is a common task model that requires high concurrency and serialization. In this model, AliSQL uses queues and transactional hints to control concurrency and commit or roll back transactions. This increases the throughput of your business.

Prerequisites

The RDS instance version is one of the following:

- MySQL 8.0
- MySQL 5.7
- MySQL 5.6

Syntax

The following three hints are introduced to specify tables in SELECT, UPDATE, INSERT, and DELETE statements.

- COMMIT_ON_SUCCESS and ROLLBACK_ON_FAIL

These are two transactional hints.

- COMMIT_ON_SUCCESS: specifies to commit the transaction if the execution of the statement to which this hint is applied succeeds.
- ROLLBACK_ON_FAIL: specifies to roll the transaction back if the execution of the statement to which this hint is applied fails.

Syntax:

```
/*+ COMMIT_ON_SUCCESS */
/*+ ROLLBACK_ON_FAIL */
```

Example:

```
UPDATE /*+ COMMIT_ON_SUCCESS ROLLBACK_ON_FAIL */ T
SET c = c - 1
WHERE id = 1;
```

- TARGET_AFFECT_ROW(NUMBER)

  This is a conditional hint. After you apply it to a statement, the execution of the statement succeeds only when the number of affected rows is the same as the number specified in this hint.

  Syntax:

```
/*+ TARGET_AFFECT_ROW(NUMBER) */
```

  Example:

```
UPDATE /*+ TARGET_AFFECT_ROW(1) */ T
SET c = c - 1
WHERE id = 1;
```

Precautions

- The transactional hints do not support the autocommit mode. If you use a transactional hint in a statement with the autocommit mode, an error is reported. Example:

```
mysql> UPDATE /*+ commit_on_success rollback_on_fail target_affect_row(1) */ t
    -> SET col1 = col1 + 1
    -> WHERE id = 1;
ERROR 7531 (HY000): Inventory transactinal hints didn't allowed in autocommit mode
```

- Transactional hints cannot be used in substatements. If you use a transactional hint in a substatement, an error is reported. Example:

```
  mysql> CREATE TRIGGER tri_1
    -> BEFORE INSERT ON t
    -> FOR EACH ROW
    -> BEGIN
    -> INSERT /*+ commit_on_success */ INTO t1 VALUES (1);
    -> end//
mysql> INSERT INTO t VALUES (2, 1);
ERROR HY000: Inventory transactional hints didn't alllowed in stored procedure
```

- The conditional hint cannot be used in a SELECT or EXPLAIN statement. If you use the conditional hint in a SELECT or EXPLAIN statement, an error is reported. Example:

```
mysql> EXPLAIN UPDATE /*+ commit_on_success rollback_on_fail target_affect_row(1) */ t
    -> SET col1 = col1 + 1
    -> WHERE id = 1;
ERROR 7532 (HY000): Inventory conditional hints didn't match with result
```

Note You can specify an invalid number in the TARGET_AFFECT_ROW hint and check whether the system reports errors:

```
mysql> EXPLAIN UPDATE /*+ commit_on_success rollback_on_fail target_affect_row(-1) */
t
    -> SET col1 = col1 + 1
    -> WHERE id = 1;
+----+-------------+-------+------------+-------+---------------+---------+---------+
-------+------+----------+-------------+
| id | select_type | table | partitions | type  | possible_keys | key     | key_len |
ref   | rows | filtered | Extra       |
+----+-------------+-------+------------+-------+---------------+---------+---------+
-------+------+----------+-------------+
|  1 | UPDATE      | t     | NULL       | range | PRIMARY       | PRIMARY | 4       |
const |    1 |   100.00 | Using where |
+----+-------------+-------+------------+-------+---------------+---------+---------+
-------+------+----------+-------------+
1 row in set, 2 warnings (0.00 sec)
mysql> show warnings;
+---------+------+-----------------------------------------------------------------------
-----------------------------------------------------------------------+
| Level   | Code | Message
|
+---------+------+-----------------------------------------------------------------------
-----------------------------------------------------------------------+
| Warning | 1064 | Optimizer hint syntax error near '-1) */ t set col1=col1+1 where i
d =1' at line 1                                                        |
| Note    | 1003 | update /*+ COMMIT_ON_SUCCESS ROLLBACK_ON_FAIL */ `test`.`t` set `t
est`.`t`.`col1` = (`test`.`t`.`col1` + 1) where (`test`.`t`.`id` = 1) |
+---------+------+-----------------------------------------------------------------------
-----------------------------------------------------------------------+
2 rows in set (0.00 sec)
```

Work with Returning

You can use Inventory Hint with Returning for the system to return real-time result sets. Example:

```
mysql> CALL dbms_trans.returning("*", "update /*+ commit_on_success rollback_on_fail target
_affect_row(1) */ t
                                       set col1=col1+1 where id=1");
+----+------+
| id | col1 |
+----+------+
|  1 |   13 |
+----+------+
1 row in set (0.00 sec)
mysql> CALL dbms_trans.returning("*", "insert /*+ commit_on_success rollback_on_fail target
_affect_row(1) */ into
                                       t values(10,10)");
+----+------+
| id | col1 |
+----+------+
| 10 |   10 |
+----+------+
1 row in set (0.01 sec)
```

Work with Statement Queue

You can use Inventory Hint with Statement Queue for the system to queue statements. Example:

```
mysql> UPDATE /*+ ccl_queue_field(id) commit_on_success rollback_on_fail target_affect_row(
1) */ t
    -> SET col1 = col1 + 1
    -> WHERE id = 1;
Query OK, 1 row affected (0.00 sec)
Rows matched: 1  Changed: 1  Warnings: 0
mysql> UPDATE /*+ ccl_queue_value(1) commit_on_success rollback_on_fail target_affect_row(1
) */ t
    -> SET col1 = col1 + 1
    -> WHERE id = 1;
Query OK, 1 row affected (0.00 sec)
Rows matched: 1  Changed: 1  Warnings: 0
```

5.Stability

5.1. Faster DDL

This topic describes the faster DDL feature that provides an optimized buffer pool management mechanism. This mechanism allows you to reduce the impact of data definition language (DDL) operations and increase the number of concurrent DDL operations that are allowed.

Prerequisites

Your RDS instance runs one of the following MySQL versions:

- MySQL 8.0 (with a minor engine version of 20200630 or later.)
- MySQL 5.7 (with a minor engine version of 20200630 or later.)
- MySQL 5.6 (with a minor engine version of 20200630 or later.)

Context

DDL operations are common for RDS instances. When you use your RDS instance, you may encounter issues related to DDL operations. For example, you may encounter the following issues:

- When you add indexes, why does a performance jitter occur and interrupt the read and write operations on your RDS instance?
- Why does it require more than 10 minutes to perform a DDL operation on a table whose size is less than 1 GB?
- When a connection that generates temporary tables is closed, why does a performance jitter occur?

The database engine team of ApsaraDB for RDS has performed in-depth analyses and intensive tests to locate these issues. Based on the analysis and test results, the team has identified defects in the cache maintenance logic that is used to manage DDL operations. To fix these issues, the team has developed the faster DDL feature. The optimized buffer pool management mechanism provided by this feature reduces competition for locks that are triggered by DDL operations. When your RDS instance processes a normal number of workloads, this allows you to ensure the performance of your RDS instance during DDL operations.

Enable faster DDL

You can enable the faster DDL feature by setting the **loose_innodb_rds_faster_ddl** parameter to **ON** in the ApsaraDB for RDS console. For more information, see Modify the parameters of an ApsaraDB RDS for MySQL instance.

Test with DDL operations

- Test scenario

  Use the in-place algorithm to perform online DDL operations by executing the following MySQL 8.0-supported statements: CREATE INDEX and OPTIMIZE TABLE. The CREATE INDEX statement creates an index on a table without the need to rebuild the table. The OPTIMIZE TABLE statement creates an index on a table with the need to rebuild the table.

Operation	Instant	In-place	Rebuilds table	Permits concurrent DML operations	Only modifies metadata
CREATE INDEX	No	Yes	No	Yes	No
OPTIMIZE TABLE	No	Yes	Yes	Yes	No

- Test instance

  The RDS instance that is used for the test runs MySQL 8.0. It provides 8 CPU cores and 64 GB of memory. The size of the table on which you perform DDL operations is 600 MB.

- Test procedure

  Use SysBench to perform a stress test. In this test, perform online DDL operations and compare the operation results.

- Test result

Operation	Average execution duration (with faster DDL disabled)	Average execution duration (with faster DDL enabled)	Performance increase times
CREATE INDEX	56 seconds	4.9 seconds	11.4
OPTIMIZE TABLE	220 seconds	17 seconds	12.9

- Test summary

  The faster DDL feature enables ApsaraDB RDS for MySQL with AliSQL to reduce the execution duration of a DDL operation by more than 90% compared with the MySQL Community Edition.

Test with temporary tables

Temporary tables are common in MySQL. For example, the system creates temporary tables that are used to query tables from the information_schema database or to expedite the execution of complex SQL statements. When a thread exits, all of the related temporary tables are deleted. This is known as a specific type of DDL operation that causes a performance jitter on your RDS instance. For more information, see Temp ibt tablespace truncation at disconnection stuck InnoDB under large BP.

- Test instance

  The RDS instance that is used for the test runs MySQL 8.0. It provides 8 CPU cores and 64 GB of memory.

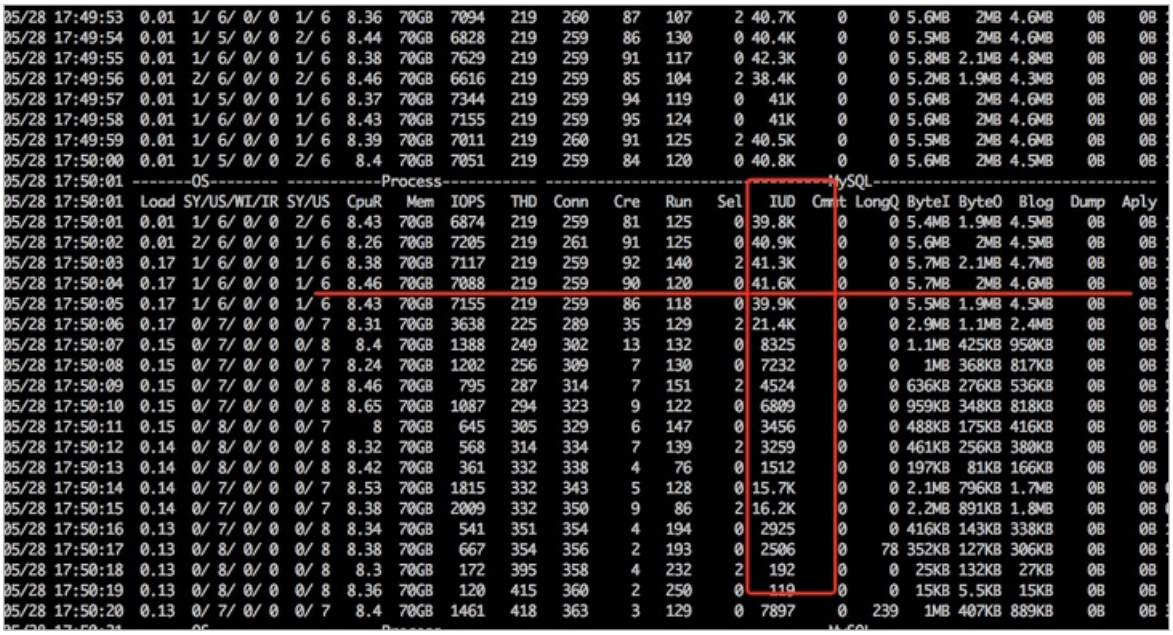
- Test procedure

  Use tpcc-mysql to perform a stress test. In this test, run queries to make sure that the buffer pool reaches near full capacity. Then, initiate single-threaded requests over short-lived connections to generate temporary tables.

- Test result

Comparison item	DDL operations not included	Faster DDL enabled	Faster DDL disabled
Transactions per second (TPS)	42,000	40,000	< 10,000

The following figure shows the second-level performance data that is obtained from the stress test. The red highlighted parts indicate the TPSs that are supported by the RDS instance when the faster DDL feature is disabled.



```
05/28 17:49:53  0.01  1/ 6/ 0/ 0  1/ 6  8.36  70GB  7094   219   260    87   107     2 40.7K     0      0 5.6MB    2MB 4.6MB    0B    0B
05/28 17:49:54  0.01  1/ 5/ 0/ 0  2/ 6  8.44  70GB  6828   219   259    86   130     0 40.4K     0      0 5.5MB    2MB 4.6MB    0B    0B
05/28 17:49:55  0.01  1/ 6/ 0/ 0  1/ 6  8.38  70GB  7629   219   259    91   117     0 42.3K     0      0 5.8MB  2.1MB 4.8MB    0B    0B
05/28 17:49:56  0.01  2/ 6/ 0/ 0  2/ 6  8.46  70GB  6616   219   259    85   104     2 38.4K     0      0 5.2MB  1.9MB 4.3MB    0B    0B
05/28 17:49:57  0.01  1/ 5/ 0/ 0  1/ 6  8.37  70GB  7344   219   259    94   119     0   41K     0      0 5.6MB    2MB 4.6MB    0B    0B
05/28 17:49:58  0.01  1/ 6/ 0/ 0  1/ 6  8.43  70GB  7155   219   259    95   124     0   41K     0      0 5.6MB    2MB 4.6MB    0B    0B
05/28 17:49:59  0.01  1/ 6/ 0/ 0  1/ 6  8.39  70GB  7011   219   260    91   125     2 40.5K     0      0 5.5MB    2MB 4.6MB    0B    0B
05/28 17:50:00  0.01  1/ 5/ 0/ 0  2/ 6   8.4  70GB  7051   219   259    84   120     0 40.8K     0      0 5.6MB    2MB 4.5MB    0B    0B
05/28 17:50:01 -------OS-------- ----------Process---------- ---------------------------------MySQL---------------------------------
05/28 17:50:01  Load SY/US/WI/IR SY/US  CpuR   Mem  IOPS  THD  Conn   Cre   Run   Sel   IUD  Cmit LongQ ByteI ByteO  Blog  Dump  Aply
05/28 17:50:01  0.01  1/ 6/ 0/ 0  2/ 6  8.43  70GB  6874   219   259    81   125     0 39.8K     0      0 5.4MB  1.9MB 4.5MB    0B    0B
05/28 17:50:02  0.01  2/ 6/ 0/ 0  1/ 6  8.26  70GB  7205   219   261    91   125     0 40.9K     0      0 5.6MB    2MB 4.5MB    0B    0B
05/28 17:50:03  0.17  1/ 6/ 0/ 0  1/ 6  8.38  70GB  7117   219   259    92   140     2 41.3K     0      0 5.7MB  2.1MB 4.7MB    0B    0B
05/28 17:50:04  0.17  1/ 6/ 0/ 0  1/ 6  8.46  70GB  7088   219   259    90   120     0 41.6K     0      0 5.7MB    2MB 4.6MB    0B    0B
05/28 17:50:05  0.17  1/ 6/ 0/ 0  1/ 6  8.43  70GB  7155   219   259    86   118     0 39.9K     0      0 5.5MB  1.9MB 4.5MB    0B    0B
05/28 17:50:06  0.17  0/ 7/ 0/ 0  0/ 7  8.31  70GB  3638   225   289    35   129     2 21.4K     0      0 2.9MB  1.1MB 2.4MB    0B    0B
05/28 17:50:07  0.15  0/ 7/ 0/ 0  0/ 8   8.4  70GB  1388   249   302    13   132     0  8325     0      0 1.1MB  425KB  950KB    0B    0B
05/28 17:50:08  0.15  0/ 7/ 0/ 0  0/ 7  8.24  70GB  1202   256   309     7   130     0  7232     0      0   1MB  368KB  817KB    0B    0B
05/28 17:50:09  0.15  0/ 7/ 0/ 0  0/ 8  8.46  70GB   795   287   314     7   151     2  4524     0      0 636KB  276KB  536KB    0B    0B
05/28 17:50:10  0.15  0/ 7/ 0/ 0  0/ 8  8.65  70GB  1087   294   323     9   122     0  6809     0      0 959KB  348KB  818KB    0B    0B
05/28 17:50:11  0.15  0/ 8/ 0/ 0  0/ 7     8  70GB   645   305   329     6   147     0  3456     0      0 488KB  175KB  416KB    0B    0B
05/28 17:50:12  0.14  0/ 8/ 0/ 0  0/ 8  8.32  70GB   568   314   334     7   139     2  3259     0      0 461KB  256KB  380KB    0B    0B
05/28 17:50:13  0.14  0/ 8/ 0/ 0  0/ 8  8.42  70GB   361   332   338     4    76     0  1512     0      0 197KB   81KB  166KB    0B    0B
05/28 17:50:14  0.14  0/ 7/ 0/ 0  0/ 7  8.53  70GB  1815   332   343     5   128     0 15.7K     0      0 2.1MB  796KB  1.7MB    0B    0B
05/28 17:50:15  0.14  0/ 7/ 0/ 0  0/ 7  8.38  70GB  2009   332   350     9    86     2 16.2K     0      0 2.2MB  891KB  1.8MB    0B    0B
05/28 17:50:16  0.13  0/ 7/ 0/ 0  0/ 8  8.34  70GB   541   351   354     4   194     0  2925     0      0 416KB  143KB  338KB    0B    0B
05/28 17:50:17  0.13  0/ 8/ 0/ 0  0/ 8  8.38  70GB   667   354   356     2   193     0  2506     0     78 352KB  127KB  306KB    0B    0B
05/28 17:50:18  0.13  0/ 8/ 0/ 0  0/ 8   8.3  70GB   172   395   358     4   232     2   192     0      0  25KB  132KB   27KB    0B    0B
05/28 17:50:19  0.13  0/ 8/ 0/ 0  0/ 8  8.36  70GB   120   415   360     2   250     0   119     0      0  15KB  5.5KB   15KB    0B    0B
05/28 17:50:20  0.13  0/ 7/ 0/ 0  0/ 7   8.4  70GB  1461   418   363     3   129     0  7897     0    239   1MB  407KB  889KB    0B    0B
```

- Test summary

  Every time when a thread that generates temporary tables exits, the native MySQL causes a severe performance jitter. The jitter decreases the TPS by more than 70%. After the faster DDL feature is enabled, the TPS decrease is reduced to 5%.

Optimization effect

The faster DDL feature supports MySQL 5.6, 5.7, and 8.0. However, the supported DDL operations can vary based on the selected MySQL version.

Category	DDL operation	MySQL 5.6	MySQL 5.7	MySQL 8.0
In-place DDL	For more information, see MySQL 8.0 Online DDL Operations and MySQL 5.7 Online DDL Operations.	No	Yes	Yes
Tablespace management	Enables or disables tablespace encryption.	No	Yes	Yes
	Releases or deletes a tablespace.	No	Yes	Yes
	Discards a tablespace.	Yes	Yes	Yes
Table deletion	Releases or deletes a table.	Yes	Yes	Yes

Category	DDL operation	MySQL 5.6	MySQL 5.7	MySQL 8.0
Undo operation	Releases or deletes an undo tablespace.	No	No	Yes
Table refresh	Refreshes a table and its dirty pages.	Yes	Yes	Yes

Defects fixed by faster DDL

The faster DDL feature fixes the following defects:

- Bug #95582: DDL using bulk load is very slow under long flush_list
- Bug #98869: Temp ibt tablespace truncation at disconnection stuck InnoDB under large BP
- Bug #99021: BUF_REMOVE_ALL_NO_WRITE is not needed for undo tablespace
- Bug #98974: InnoDB temp table could hurt InnoDB perf badly

5.2. Statement concurrency control

Alibaba Cloud provides the concurrency control (CCL) feature to ensure the stability of ApsaraDB RDS MySQL instances in case of unexpected request traffic, resource-consuming statements, and SQL access model changes. The DBMS_CCL package can be installed to use the CCL feature.

Prerequisites

The RDS instance version is one of the following:

- MySQL 8.0
- MySQL 5.7

Precautions

- CCL operations only affect the current instance because no binlogs are generated. For example, CCL operations performed on the primary instance are not synchronized to the secondary instance, read-only instance, or disaster recovery instance.
- CCL includes a timeout mechanism which resolves transaction deadlocks caused by DML statements. The waiting threads also respond to the transaction timeout and kill threads to prevent deadlocks.

Feature design

The CCL provides features based on the following dimensions:

- SQL command

  The types of SQL statements, such as SELECT, UPDATE, INSERT, and DELETE.

- Object

  The objects managed by SQL statements, such as tables and views.

- keywords

  The keywords of SQL statements.

Create a CCL table

AliSQL uses a system table named concurrency_control to store CCL rules. The instance system automatically creates the table when the system is started. You can refer to the following statements that create the concurrency_control table.

```
CREATE TABLE `concurrency_control` (
  `Id` bigint(20) NOT NULL AUTO_INCREMENT,
  `Type` enum('SELECT','UPDATE','INSERT','DELETE') NOT NULL DEFAULT 'SELECT',
  `Schema_name` varchar(64) COLLATE utf8_bin DEFAULT NULL,
  `Table_name` varchar(64) COLLATE utf8_bin DEFAULT NULL,
  `Concurrency_count` bigint(20) DEFAULT NULL,
  `Keywords` text COLLATE utf8_bin,
  `State` enum('N','Y') NOT NULL DEFAULT 'Y',
  `Ordered` enum('N','Y') NOT NULL DEFAULT 'N',
  PRIMARY KEY (`Id`)
) /*! 50100 TABLESPACE `mysql` */ ENGINE=InnoDB
DEFAULT CHARSET=utf8 COLLATE=utf8_bin
STATS_PERSISTENT=0 COMMENT='Concurrency control'
```

Parameter	Description
Id	The ID of the CCL rule.
Type	The type of the SQL statement.
Schema_name	The name of the database.
Table_name	The name of the table in the database.
Concurrency_count	The number of concurrent threads.
Keywords	The keyword. Multiple keywords are separated by semicolons (;).
State	Specifies whether to enable the CCL rule.
Ordered	Specifies whether to match multiple keywords in sequence.

Manage CCL rules

AliSQL provides four management interfaces in the DBMS_CCL package. They are described as follows:

- add_ccl_rule

  Use the following statement to create a rule.

  ```
  dbms_ccl.add_ccl_rule('<Type>','<Schema_name>','<Table_name>',<Concurrency_count>,'<Keywords>');
  ```

  Example:

  The number of concurrent threads of the SELECT statement is 10.

  ```
  mysql> call dbms_ccl.add_ccl_rule('SELECT', '', '', 10, '');
  ```

  The number of concurrent threads of the SELECT statement is 20, and the keyword of the statement is key1.

```
mysql> call dbms_ccl.add_ccl_rule('SELECT', '', '', 20, 'key1');
```

The number of concurrent threads of the SELECT statement in the test.t table is 20.

```
mysql> call dbms_ccl.add_ccl_rule('SELECT', 'test', 't', 20, '');
```

> **Note** The rule with a larger Id has higher priority.

- del_ccl_rule

  Use the following statement to delete a rule.

  ```
  dbms_ccl.del_ccl_rule(<Id>);
  ```

  Example:

  Delete the CCL rule whose ID is 15.

  ```
  mysql> call dbms_ccl.del_ccl_rule(15);
  ```

  > **Note** If the CCL rule that you want to delete does not exist, the system displays an error. You can execute the `SHOW WARNINGS;` statement to view the error message.

  ```
  mysql> call dbms_ccl.del_ccl_rule(100);
    Query OK, 0 rows affected, 2 warnings (0.00 sec)
  mysql> show warnings;
  +---------+------+-----------------------------------------------------+
  | Level   | Code | Message                                             |
  +---------+------+-----------------------------------------------------+
  | Warning | 7514 | Concurrency control rule 100 is not found in table |
  | Warning | 7514 | Concurrency control rule 100 is not found in cache |
  +---------+------+-----------------------------------------------------+
  ```

- show_ccl_rule

  Use the following statement to view the enabled rules in the memory.

  ```
  dbms_ccl.show_ccl_rule();
  ```

  Example:

```
mysql> call dbms_ccl.show_ccl_rule();
+------+--------+--------+-------+-------+-------+-------------------+---------+---------
+----------+----------+
| ID   | TYPE   | SCHEMA | TABLE | STATE | ORDER | CONCURRENCY_COUNT | MATCHED | RUNNING
| WAITTING | KEYWORDS |
+------+--------+--------+-------+-------+-------+-------------------+---------+---------
+----------+----------+
|   17 | SELECT | test   | t     | Y     | N     |                30 |       0 |       0
|        0 |          |
|   16 | SELECT |        |       | Y     | N     |                20 |       0 |       0
|        0 | key1     |
|   18 | SELECT |        |       | Y     | N     |                10 |       0 |       0
|        0 |          |
+------+--------+--------+-------+-------+-------+-------------------+---------+---------
+----------+----------+
```

The following table describes the MATCHED, RUNNING, and WAITTING parameters.

Parameter	Description
MATCHED	The number of times the rule is matched.
RUNNING	The number of concurrent threads under the rule.
WAITTING	The number of threads to be run under the rule.

- flush_ccl_rule

  If you modify the rules in the concurrency_control table, you must execute the following statement to validate the rules again.

  ```
  dbms_ccl.flush_ccl_rule();
  ```

  Example:

  ```
  mysql> update mysql.concurrency_control set CONCURRENCY_COUNT = 15 where Id = 18;
  Query OK, 1 row affected (0.00 sec)
  Rows matched: 1  Changed: 1  Warnings: 0
  mysql> call dbms_ccl.flush_ccl_rule();
  Query OK, 0 rows affected (0.00 sec)
  ```

Feature test

- Test rules

  Execute the following statements to create the rules for three dimensions.

  ```
  call dbms_ccl.add_ccl_rule('SELECT', 'test', 'sbtest1', 3, '');  // The SELECT statement
  manages the sbtest1 table and the number of concurrent threads is 3.
  call dbms_ccl.add_ccl_rule('SELECT', '', '', 2, 'sbtest2');       // The keyword of the S
  ELECT statement is sbtest2 and the number of concurrent threads is 2.
   call dbms_ccl.add_ccl_rule('SELECT', '', '', 2, '');            // The number of concurr
  ent threads of the SELECT statement is 2.
  ```

- Test scenarios

Use sysbench to test in the following scenarios:

- 64 threads
- 4 tables
- select.lua

- Test results

  Execute the following statement to view the number of concurrent threads under the rules.

```
mysql> call dbms_ccl.show_ccl_rule();
+------+--------+--------+---------+-------+-------+-------------------+---------+-------
--+----------+----------+
| ID   | TYPE   | SCHEMA | TABLE   | STATE | ORDER | CONCURRENCY_COUNT | MATCHED | RUNNIN
G | WAITTING | KEYWORDS |
+------+--------+--------+---------+-------+-------+-------------------+---------+-------
--+----------+----------+
|   20 | SELECT | test   | sbtest1 | Y     | N     |                 3 |     389 |
3 |        9 |          |
|   21 | SELECT |        |         | Y     | N     |                 2 |     375 |
2 |       14 | sbtest2  |
|   22 | SELECT |        |         | Y     | N     |                 2 |     519 |
2 |       34 |          |
+------+--------+--------+---------+-------+-------+-------------------+---------+-------
--+----------+----------+
3 rows in set (0.00 sec)
```

  The numbers displayed in the **RUNNING** column are the same as the numbers specified when you create the rules.

5.3. Performance Agent

This topic describes the Performance Agent feature that is provided by AliSQL. This feature allows you to collect statistics about the performance of an ApsaraDB RDS for MySQL instance.

Background information

A memory table named PERF_STATISTICS is added for Performance Agent. This table is stored in the information_schema system database. This table stores the performance data that is generated over the most recent period of time. You can query performance data from this table.

Prerequisites

Your RDS instance runs one of the following MySQL versions and RDS editions:

- MySQL 8.0 with a minor engine version of 20200229 or later
- MySQL 5.7 with a minor engine version of 20200229 or later
- MySQL 5.6 with a minor engine version of 20200630 or later

> **Note** For more information about how to update the minor engine version of an RDS instance, see Update the minor engine version of an ApsaraDB RDS for MySQL instance.

Parameters

The following table describes the parameters that you must configure for the Performance Agent feature.

Parameter	Description
performance_agent_enabled	Specifies whether to enable the Performance Agent feature. Valid values: ON and OFF. Default value: ON.
performance_agent_interval	Specifies the interval at which ApsaraDB RDS collects performance data. Unit: seconds. Default value: 1.
performance_agent_perfstat_volume_size	Specifies the maximum number of data records that are allowed in the PERF_STATISTICS memory table. Default value: 3600. If you set the performance_agent_interval parameter to 1, ApsaraDB RDS retains the performance data that is generated over the previous hour.

Note The parameters that are described in the preceding table are not displayed in the ApsaraDB RDS console. You can execute the `SHOW VARIABLES LIKE '<Parameter name>';` statement to view the value of each of these parameters.

Schema

The PERF_STATISTICS memory table uses the following schema:

```
CREATE TEMPORARY TABLE `PERF_STATISTICS` (
  `TIME` datetime NOT NULL DEFAULT '0000-00-00 00:00:00',
  `PROCS_MEM_USAGE` double NOT NULL DEFAULT '0',
  `PROCS_CPU_RATIO` double NOT NULL DEFAULT '0',
  `PROCS_IOPS` double NOT NULL DEFAULT '0',
  `PROCS_IO_READ_BYTES` bigint(21) NOT NULL DEFAULT '0',
  `PROCS_IO_WRITE_BYTES` bigint(21) NOT NULL DEFAULT '0',
  `MYSQL_CONN_ABORT` int(11) NOT NULL DEFAULT '0',
  `MYSQL_CONN_CREATED` int(11) NOT NULL DEFAULT '0',
  `MYSQL_USER_CONN_COUNT` int(11) NOT NULL DEFAULT '0',
  `MYSQL_CONN_RUNNING` int(11) NOT NULL DEFAULT '0',
  `MYSQL_LOCK_IMMEDIATE` int(11) NOT NULL DEFAULT '0',
  `MYSQL_LOCK_WAITED` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_INSERT` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_UPDATE` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_DELETE` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_SELECT` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_COMMIT` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_ROLLBACK` int(11) NOT NULL DEFAULT '0',
  `MYSQL_COM_PREPARE` int(11) NOT NULL DEFAULT '0',
  `MYSQL_LONG_QUERY` int(11) NOT NULL DEFAULT '0',
  `MYSQL_TCACHE_GET` bigint(21) NOT NULL DEFAULT '0',
  `MYSQL_TCACHE_MISS` bigint(21) NOT NULL DEFAULT '0',
  `MYSQL_TMPFILE_CREATED` int(11) NOT NULL DEFAULT '0',
  `MYSQL_TMP_TABLES` int(11) NOT NULL DEFAULT '0',
  `MYSQL_TMP_DISKTABLES` int(11) NOT NULL DEFAULT '0',
  `MYSQL_SORT_MERGE` int(11) NOT NULL DEFAULT '0',
  `MYSQL_SORT_ROWS` int(11) NOT NULL DEFAULT '0',
  `MYSQL_BYTES_RECEIVED` bigint(21) NOT NULL DEFAULT '0',
  `MYSQL_BYTES_SENT` bigint(21) NOT NULL DEFAULT '0',
  `MYSQL_BINLOG_OFFSET` int(11) NOT NULL DEFAULT '0',
  `MYSQL_IOLOG_OFFSET` int(11) NOT NULL DEFAULT '0',
  `MYSQL_RELAYLOG_OFFSET` int(11) NOT NULL DEFAULT '0',
  `EXTRA` json NOT NULL DEFAULT 'null'
) ENGINE=InnoDB DEFAULT CHARSET=utf8;
```

Column	Description
TIME	The time when the performance data of the RDS instance is collected. The time is in the yyyy-MM-dd HH:mm:ss format.
PROCS_MEM_USAGE	The size of physical memory that is occupied by the RDS instance. Unit: bytes.
PROCS_CPU_RATIO	The CPU utilization of the RDS instance.
PROCS_IOPS	The number of I/O operations that are performed.
PROCS_IO_READ_BYTES	The amount of data that is read by I/O operations. Unit: bytes.
PROCS_IO_WRITE_BYTES	The amount of data that is written by I/O operations. Unit: bytes.

Column	Description
MYSQL_CONN_ABORT	The number of closed connections.
MYSQL_CONN_CREATED	The number of new connections.
MYSQL_USER_CONN_COUNT	The total number of connections.
MYSQL_CONN_RUNNING	The number of active connections.
MYSQL_LOCK_IMMEDIATE	The number of locks that are held.
MYSQL_LOCK_WAITED	The number of lock wait events.
MYSQL_COM_INSERT	The number of statements that are executed to insert data.
MYSQL_COM_UPDATE	The number of statements that are executed to update data.
MYSQL_COM_DELETE	The number of statements that are executed to delete data.
MYSQL_COM_SELECT	The number of statements that are executed to query data.
MYSQL_COM_COMMIT	The number of transactions that are explicitly committed.
MYSQL_COM_ROLLBACK	The number of transactions that are rolled back.
MYSQL_COM_PREPARE	The number of statements that are pre-processed.
MYSQL_LONG_QUERY	The number of slow queries.
MYSQL_TCACHE_GET	The number of cache hits.
MYSQL_TCACHE_MISS	The number of cache misses.
MYSQL_TMPFILE_CREATED	The number of temporary files that are created.
MYSQL_TMP_TABLES	The number of temporary tables that are created.
MYSQL_TMP_DISKTABLES	The number of temporary disk tables that are created.
MYSQL_SORT_MERGE	The number of times that data is merged and sorted.
MYSQL_SORT_ROWS	The number of rows that are sorted.
MYSQL_BYTES_RECEIVED	The amount of data that is received. Unit: bytes.
MYSQL_BYTES_SENT	The amount of data that is sent. Unit: bytes.
MYSQL_BINLOG_OFFSET	The size of the binary log file that is generated. Unit: bytes.
MYSQL_IOLOG_OFFSET	The size of the binary log file that is sent by the RDS instance to its secondary RDS instance. Unit: bytes.

Column	Description
MYSQL_RELAYLOG_OFFSET	The size of the binary log file that is applied by the secondary RDS instance. Unit: bytes.
EXTRA	The statistics about InnoDB. The value of the EXTRA parameter consists of multiple fields and is in the JSON format. For more information, see the "Fields in the value of the EXTRA parameter" section of this topic. **Note** The values of the metrics in the InnoDB statistics are the same as the values that are obtained by executing the `SHOW STATUS` statement.

Fields in the value of the EXTRA parameter

Field	Description
INNODB_TRX_CNT	The number of transactions.
INNODB_DATA_READ	The amount of data that is read. Unit: bytes.
INNODB_IBUF_SIZE	The number of pages that are merged.
INNODB_LOG_WAITS	The number of times that InnoDB waits to write log data.
INNODB_MAX_PURGE	The number of transactions that are deleted.
INNODB_N_WAITING	The number of locks for which InnoDB waits.
INNODB_ROWS_READ	The number of rows that are read.
INNODB_LOG_WRITES	The number of times that log data is written by InnoDB.
INNODB_IBUF_MERGES	The number of times that data is merged by InnoDB.
INNODB_DATA_WRITTEN	The amount of data that is written. Unit: bytes.
INNODB_DBLWR_WRITES	The number of doublewrite operations.
INNODB_IBUF_SEGSIZE	The size of data that is inserted into the buffer.
INNODB_ROWS_DELETED	The number of rows that are deleted.
INNODB_ROWS_UPDATED	The number of rows that are updated.
INNODB_COMMIT_TRXCNT	The number of transactions that are committed.
INNODB_IBUF_FREELIST	The length of the idle list.
INNODB_MYSQL_TRX_CNT	The number of MySQL transactions.
INNODB_ROWS_INSERTED	The number of rows that are inserted.

Field	Description
INNODB_ACTIVE_TRX_CNT	The number of active transactions.
INNODB_OS_LOG_WRITTEN	The amount of log data that is written. Unit: bytes.
INNODB_ACTIVE_VIEW_CNT	The number of active views.
INNODB_RSEG_HISTORY_LEN	The length of the TRX_RSEG_HISTORY table.
INNODB_AVG_COMMIT_TRXTIME	The average amount of time that is taken to commit a transaction.
INNODB_MAX_COMMIT_TRXTIME	The maximum amount of time that is taken to commit a transaction.
INNODB_DBLWR_PAGES_WRITTEN	The number of writes that are completed by doublewrite operations.

Use Performance Agent

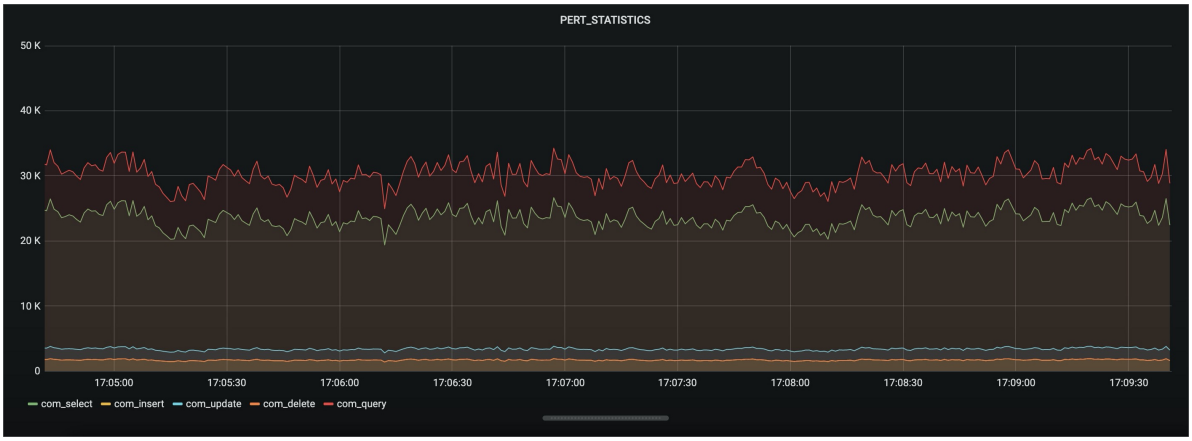
- Query performance data from the system table.
  - Query the CPU utilization and memory usage over the previous 30 seconds. Example:

```
MySQL> select TIME, PROCS_MEM_USAGE, PROCS_CPU_RATIO from information_schema.PERF_STATI
STICS order by time DESC limit 30;
+---------------------+-----------------+-----------------+
| TIME                | PROCS_MEM_USAGE | PROCS_CPU_RATIO |
+---------------------+-----------------+-----------------+
| 2020-02-27 11:15:36 |       857812992 |           18.55 |
| 2020-02-27 11:15:35 |       857808896 |           18.54 |
| 2020-02-27 11:15:34 |       857268224 |           19.64 |
| 2020-02-27 11:15:33 |       857268224 |           21.06 |
| 2020-02-27 11:15:32 |       857264128 |           20.39 |
| 2020-02-27 11:15:31 |       857272320 |           20.32 |
| 2020-02-27 11:15:30 |       857272320 |           21.35 |
| 2020-02-27 11:15:29 |       857272320 |            28.8 |
| 2020-02-27 11:15:28 |       857268224 |           29.08 |
| 2020-02-27 11:15:27 |       857268224 |           26.92 |
| 2020-02-27 11:15:26 |       857268224 |           23.84 |
| 2020-02-27 11:15:25 |       857264128 |           13.76 |
| 2020-02-27 11:15:24 |       857264128 |           15.12 |
| 2020-02-27 11:15:23 |       857264128 |           14.76 |
| 2020-02-27 11:15:22 |       857264128 |           15.38 |
| 2020-02-27 11:15:21 |       857260032 |           13.23 |
| 2020-02-27 11:15:20 |       857260032 |           12.75 |
| 2020-02-27 11:15:19 |       857260032 |           12.17 |
| 2020-02-27 11:15:18 |       857255936 |           13.22 |
| 2020-02-27 11:15:17 |       857255936 |           20.51 |
| 2020-02-27 11:15:16 |       857255936 |           28.74 |
| 2020-02-27 11:15:15 |       857251840 |           29.85 |
| 2020-02-27 11:15:14 |       857251840 |           29.31 |
| 2020-02-27 11:15:13 |       856981504 |           28.85 |
| 2020-02-27 11:15:12 |       856981504 |           29.19 |
| 2020-02-27 11:15:11 |       856977408 |           29.12 |
| 2020-02-27 11:15:10 |       856977408 |           29.32 |
| 2020-02-27 11:15:09 |       856977408 |            29.2 |
| 2020-02-27 11:15:08 |       856973312 |           29.36 |
| 2020-02-27 11:15:07 |       856973312 |           28.79 |
+---------------------+-----------------+-----------------+
30 rows in set (0.08 sec)
```

- Query the rows that are read and written by InnoDB over the previous 30 seconds. Example:

```
MySQL> select TIME, EXTRA->'$.INNODB_ROWS_READ', EXTRA->'$.INNODB_ROWS_INSERTED' from i
nformation_schema.PERF_STATISTICS order by time DESC limit 30;
+---------------------+-----------------------------+--------------------------------+
| TIME                | EXTRA->'$.INNODB_ROWS_READ' | EXTRA->'$.INNODB_ROWS_INSERTED' |
+---------------------+-----------------------------+--------------------------------+
| 2020-02-27 11:22:17 | 39209                       | 0                              |
| 2020-02-27 11:22:16 | 36098                       | 0                              |
| 2020-02-27 11:22:15 | 38035                       | 0                              |
| 2020-02-27 11:22:14 | 37384                       | 0                              |
| 2020-02-27 11:22:13 | 38336                       | 0                              |
| 2020-02-27 11:22:12 | 33946                       | 0                              |
| 2020-02-27 11:22:11 | 36301                       | 0                              |
| 2020-02-27 11:22:10 | 36835                       | 0                              |
| 2020-02-27 11:22:09 | 36900                       | 0                              |
| 2020-02-27 11:22:08 | 36402                       | 0                              |
| 2020-02-27 11:22:07 | 39672                       | 0                              |
| 2020-02-27 11:22:06 | 39316                       | 0                              |
| 2020-02-27 11:22:05 | 37830                       | 0                              |
| 2020-02-27 11:22:04 | 36396                       | 0                              |
| 2020-02-27 11:22:03 | 34820                       | 0                              |
| 2020-02-27 11:22:02 | 37350                       | 0                              |
| 2020-02-27 11:22:01 | 39463                       | 0                              |
| 2020-02-27 11:22:00 | 38419                       | 0                              |
| 2020-02-27 11:21:59 | 37673                       | 0                              |
| 2020-02-27 11:21:58 | 35117                       | 0                              |
| 2020-02-27 11:21:57 | 36140                       | 0                              |
| 2020-02-27 11:21:56 | 37592                       | 0                              |
| 2020-02-27 11:21:55 | 39765                       | 0                              |
| 2020-02-27 11:21:54 | 35553                       | 0                              |
| 2020-02-27 11:21:53 | 35882                       | 0                              |
| 2020-02-27 11:21:52 | 37061                       | 0                              |
| 2020-02-27 11:21:51 | 40699                       | 0                              |
| 2020-02-27 11:21:50 | 39608                       | 0                              |
| 2020-02-27 11:21:49 | 39317                       | 0                              |
| 2020-02-27 11:21:48 | 37413                       | 0                              |
+---------------------+-----------------------------+--------------------------------+
30 rows in set (0.08 sec)
```

- Connect to a monitoring platform to monitor your database performance in real time. For example, connect to Grafana.



5.4. Purge Large File Asynchronously

This topic describes how to use the Purge Large File Asynchronously feature to asynchronously delete large files from an ApsaraDB RDS instance that runs AliSQL. This feature helps ensure the stability of your database service.

Context

If your RDS instance runs with the InnoDB storage engine, the deletion of large files from the instance compromises the stability of your POSIX file system. Therefore, InnoDB starts a background thread to asynchronously delete large files. Before InnoDB deletes a tablespace, InnoDB renames the data files in the tablespace to mark them as temporary files. Then, InnoDB asynchronously deletes the data files from the tablespace at low speeds.

> **Note** AliSQL provides a log to record the file deletion operations. The log helps you ensure the atomicity of DDL statements.

Procedure

1. Execute the following statement to view the global variable settings of your RDS instance:

   ```
   SHOW GLOBAL VARIABLES LIKE '%data_file_purge%';
   ```

   The following result is returned:

   ```
   +----------------------------------------+-------+
   | Variable_name                          | Value |
   +----------------------------------------+-------+
   | innodb_data_file_purge                 | ON    |
   | innodb_data_file_purge_all_at_shutdown | OFF   |
   | innodb_data_file_purge_dir             |       |
   | innodb_data_file_purge_immediate       | OFF   |
   | innodb_data_file_purge_interval        | 100   |
   | innodb_data_file_purge_max_size        | 128   |
   | innodb_print_data_file_purge_process   | OFF   |
   +----------------------------------------+-------+
   ```

   The following table describes these global variables.

Variable	Description
innodb_data_file_purge	Specifies whether to enable the Purge Large File Asynchronously feature.
innodb_data_file_purge_all_at_shutdown	Specifies whether to delete all files when the host on which your RDS instance resides is shut down.
innodb_data_file_purge_dir	Specifies the directory that stores temporary files.
innodb_data_file_purge_immediate	Specifies whether to retain data files and only revoke the links of the data files.
innodb_data_file_purge_interval	Specifies the intervals at which InnoDB deletes files. Unit: milliseconds.
innodb_data_file_purge_max_size	Specifies the maximum size of a single file that can be deleted. Unit: MB.
innodb_print_data_file_purge_process	Specifies whether to display the file deletion progress.

Note We recommend that you configure the following variables to the values that are provided in the example:

```
set global INNODB_DATA_FILE_PURGE = on;
set global INNODB_DATA_FILE_PURGE_INTERVAL = 100;
set global INNODB_DATA_FILE_PURGE_MAX_SIZE = 128;
```

2. Run the following command to view the file deletion progress:

```
select * from information_schema.innodb_purge_files;
```

The following result is returned:

```
+--------+---------------------+--------------------+---------------+------------------
-------+--------------+
| log_id | start_time          | original_path      | original_size | temporary_path
| current_size |
+--------+---------------------+--------------------+---------------+------------------
-------+--------------+
|      0 | 2021-05-14 14:40:01 | ./file_purge/t.ibd |     146800640 | ./#FP_210514 14:4
0:01_9 |     79691776 |
+--------+---------------------+--------------------+---------------+------------------
-------+--------------+
```

The following table describes the parameters in the return result.

Parameter	Description
start_time	The point in time at which InnoDB starts to delete data files.

Parameter	Description
original_path	The original path in which the data files are stored before they are deleted.
original_size	The original size of the data files before they are deleted. Unit: bytes.
temporary_path	The path that stores the temporary files during the deletion progress.
current_size	The size of the remaining temporary files that are to be deleted. Unit: bytes.

5.5. Performance Insight

This topic describes how to use the Performance Insight function for load monitoring, association analysis, and optimizing performance. This function helps you quickly evaluate the loads of your ApsaraDB for RDS instance and locate performance problems to ensure database stability.

Prerequisites

- Your RDS instance runs one of the following database engine versions:
  - MySQL 8.0
  - MySQL 5.7
- The kernel version of your RDS instance is 20190915 or later.

> **Note** Log on to the ApsaraDB for RDS console, find the target RDS instance, and navigate to the **Basic Information** page. Then in the **Configuration Information** section, check whether the **Upgrade Kernel Version** button is available. If the button is available, click it to view the kernel version of your RDS instance. If the button is not available, you are already using the latest kernel version. For more information, see Update the minor engine version of an ApsaraDB RDS for MySQL instance.

Overview

The Performance Insight function consists of the following two parts:

- Object Statistics

  Object Statistics queries statistics from indexes and the following two tables:

  - TABLE_STATISTICS: records rows with read and modified data.
  - INDEX_STATISTICS: records rows with data read from indexes.

- Performance Point

  Performance Point collects performance details of your RDS instance. Using these details, you can quantify the overheads of SQL statements faster and more accurately. Performance Point measures database performance using the following three dimensions:

  - CPU: includes but is not limited to the total time spent executing an SQL statement and the time spent by CPU executing an SQL statement.
  - Lock: includes the time occupied by locks such as metadata locks on the server, storage transaction locks, mutual exclusions (mutexes) (in debugging mode only), and readers-writer locks.

- I/O: includes the time taken to perform operations such as reading and writing data files, writing log files, reading binary logs, reading redo logs, and asynchronously reading redo logs.

Use Object Statistics

1. Check that the values of the OPT_TABLESTAT and OPT_INDEXSTAT parameters are ON. Example:

```
mysql> show variables like "opt_%_stat";
  +---------------+-------+
  | Variable_name | Value |
  +---------------+-------+
  | opt_indexstat | ON    |
  | opt_tablestat | ON    |
  +---------------+-------+
```

> **Note** If these parameters cannot be found or their values are not ON, check that your RDS instance is running MySQL 5.7.

2. Query the TABLE_STATISTICS or INDEX_STATISTICS table in the information_schema database to obtain table or index statistics. Examples:

```
mysql> select * from TABLE_STATISTICS limit 10;
  +--------------+--------------+-----------+--------------+-----------------------+--
------------+--------------+--------------+
  | TABLE_SCHEMA | TABLE_NAME   | ROWS_READ | ROWS_CHANGED | ROWS_CHANGED_X_INDEXES | R
OWS_INSERTED | ROWS_DELETED | ROWS_UPDATED |
  +--------------+--------------+-----------+--------------+-----------------------+--
------------+--------------+--------------+
  | mysql        | db           |         2 |            0 |                     0 |
0 |            0 |            0 |
  | mysql        | engine_cost  |         2 |            0 |                     0 |
0 |            0 |            0 |
  | mysql        | proxies_priv |         1 |            0 |                     0 |
0 |            0 |            0 |
  | mysql        | server_cost  |         6 |            0 |                     0 |
0 |            0 |            0 |
  | mysql        | tables_priv  |         2 |            0 |                     0 |
0 |            0 |            0 |
  | mysql        | user         |         7 |            0 |                     0 |
0 |            0 |            0 |
  | test         | sbtest1      |      1686 |          142 |                   184 |
112 |           12 |           18 |
  | test         | sbtest10     |      1806 |          125 |                   150 |
105 |            5 |           15 |
  | test         | sbtest100    |      1623 |          141 |                   182 |
110 |           10 |           21 |
  | test         | sbtest11     |      1254 |          136 |                   172 |
110 |           10 |           16 |
  +--------------+--------------+-----------+--------------+-----------------------+--
------------+--------------+--------------+
  mysql> select * from INDEX_STATISTICS limit 10;
  +--------------+--------------+------------+-----------+
  | TABLE_SCHEMA | TABLE_NAME   | INDEX_NAME | ROWS_READ |
  +--------------+--------------+------------+-----------+
  | mysql        | db           | PRIMARY    |         2 |
  | mysql        | engine_cost  | PRIMARY    |         2 |
  | mysql        | proxies_priv | PRIMARY    |         1 |
  | mysql        | server_cost  | PRIMARY    |         6 |
  | mysql        | tables_priv  | PRIMARY    |         2 |
  | mysql        | user         | PRIMARY    |         7 |
  | test         | sbtest1      | PRIMARY    |      2500 |
  | test         | sbtest10     | PRIMARY    |      3007 |
  | test         | sbtest100    | PRIMARY    |      2642 |
  | test         | sbtest11     | PRIMARY    |      2091 |
  +--------------+--------------+------------+-----------+
```

The following table describes parameters of the responses to the sample query requests.

Parameter	Description
TABLE_SCHEMA	The name of a database.
TABLE_NAME	The name of a table.

Parameter	Description
ROWS_READ	The number of rows read from a table.
ROWS_CHANGED	The number of rows modified in a table.
ROWS_CHANGED_X_INDEXES	The number of rows modified by using indexes in a table.
ROWS_INSERTED	The number of rows inserted into a table.
ROWS_DELETED	The number of rows deleted from a table.
ROWS_UPDATED	The number of rows updated in a table.
INDEX_NAME	The name of an index.

Use Performance Point

1. View the global variable settings of your RDS instance, as shown in the following example:

```
mysql> show variables like "%performance_point%";
  +----------------------------------------+-------+
  | Variable_name                          | Value |
  +----------------------------------------+-------+
  | performance_point_dbug_enabled         | OFF   |
  | performance_point_enabled              | ON    |
  | performance_point_iostat_interval      | 2     |
  | performance_point_iostat_volume_size   | 10000 |
  | performance_point_lock_rwlock_enabled | ON    |
  +----------------------------------------+-------+
```

> **Note** If these variables cannot be found, check that your RDS instance is running MySQL 5.7.

2. Query the events_statements_summary_by_digest_supplement table in the performance_schema database to obtain the top 10 SQL statements in various dimensions. Example:

```
mysql> select * from events_statements_summary_by_digest_supplement limit 10;
  +--------------------+----------------------------------+----------------------------
--------------+--------------+
  | SCHEMA_NAME        | DIGEST                           | DIGEST_TEXT
| ELAPSED_TIME | ......
  +--------------------+----------------------------------+----------------------------
--------------+--------------+
  | NULL               | 6b787dd1f9c6f6c5033120760a1a82de | SELECT @@`version_comment`
LIMIT ?        |          932 |
  | NULL               | 2fb4341654df6995113d998c52e5abc9 | SHOW SCHEMAS
|         2363 |
  | NULL               | 8a93e76a7846384621567fb4daa1bf95 | SHOW VARIABLES LIKE ?
|        17933 |
  | NULL               | dd148234ac7a20cb5aee7720fb44b7ea | SELECT SCHEMA ( )
|         1006 |
  | information_schema | 2fb4341654df6995113d998c52e5abc9 | SHOW SCHEMAS
|         2156 |
  | information_schema | 74af182f3a2bd265678d3dadb53e08da | SHOW TABLES
|         3161 |
  | information_schema | d3a66515192fcb100aaef6f8b6e45603 | SELECT * FROM `TABLE_STATIS
TICS` LIMIT ?  |         2081 |
  | information_schema | b3726b7c4c4db4b309de2dbc45ff52af | SELECT * FROM `INDEX_STATIS
TICS` LIMIT ?  |         2384 |
  | information_schema | dd148234ac7a20cb5aee7720fb44b7ea | SELECT SCHEMA ( )
|          129 |
  | test               | 2fb4341654df6995113d998c52e5abc9 | SHOW SCHEMAS
|          342 |
  +--------------------+----------------------------------+----------------------------
--------------+--------------+
```

The following table describes parameters of the response to the sample query request.

Parameter	Description
SCHEMA_NAME	The name of a database.
DIGEST	The 64-byte hash string obtained from the **DIGEST_TEXT** parameter.
DIGEST_TEXT	The digest of an SQL statement.
ELAPSED_TIME	The total time spent executing an SQL statement. Unit: μs.
CPU_TIME	The time spent by CPU executing an SQL statement. Unit: μs.
SERVER_LOCK_TIME	The time occupied by metadata locks on the server during the execution of an SQL statement. Unit: μs.
TRANSACTION_LOCK_TIME	The time occupied by storage transaction locks during the execution of an SQL statement. Unit: μs.
MUTEX_SPINS	The number of mutex spins triggered during the execution of an SQL statement.

Parameter	Description
MUTEX_WAITS	The number of spin waits triggered by mutexes during the execution of an SQL statement.
RWLOCK_SPIN_WAITS	The number of spin waits triggered by readers-write locks during the execution of an SQL statement.
RWLOCK_SPIN_ROUNDS	The number of rounds in which the background thread looped in the spin-wait cycles triggered by readers-write locks during the execution of an SQL statement.
RWLOCK_OS_WAITS	The number of operating system waits triggered by readers-write locks during the execution of an SQL statement.
DATA_READS	The number of times the system read data from data files during the execution of an SQL statement.
DATA_READ_TIME	The time spent reading data from data files during the execution of an SQL statement. Unit: μs.
DATA_WRITES	The number of times the system wrote data into data files during the execution of an SQL statement.
DATA_WRITE_TIME	The time spent writing data into data files during the execution of an SQL statement. Unit: μs.
REDO_WRITES	The number of times the system wrote data into log files during the execution of an SQL statement.
REDO_WRITE_TIME	The time spent writing data into log files during the execution of an SQL statement. Unit: μs.
LOGICAL_READS	The number of times the system read logical pages during the execution of an SQL statement.
PHYSICAL_READS	The number of times the system read physical pages during the execution of an SQL statement.
PHYSICAL_ASYNC_READS	The number of times system read physical asynchronous pages during the execution of an SQL statement.

3. Query the IO_STATISTICS table in the information_schema database to obtain information about recent data read and write operations: Example:

```
mysql> select * from IO_STATISTICS limit 10;
  +---------------------+-----------+----------------+
  | TIME                | DATA_READ | DATA_READ_TIME | ......
  +---------------------+-----------+----------------+
  | 2019-08-08 09:56:53 |        73 |            983 |
  | 2019-08-08 09:56:57 |         0 |              0 |
  | 2019-08-08 09:59:17 |         0 |              0 |
  | 2019-08-08 10:00:55 |      4072 |          40628 |
  | 2019-08-08 10:00:59 |         0 |              0 |
  | 2019-08-08 10:01:09 |       562 |           5800 |
  | 2019-08-08 10:01:11 |       606 |           6910 |
  | 2019-08-08 10:01:13 |       609 |           6875 |
  | 2019-08-08 10:01:15 |       625 |           7077 |
  | 2019-08-08 10:01:17 |       616 |           5800 |
  +---------------------+-----------+----------------+
```

The following table describes parameters of the response to the query request.

Parameter	Description
TIME	The point in time at which data read and write operations were performed.
DATA_READ	The number of times the system read data.
DATA_READ_TIME	The total time spent reading data. Unit: μs.
DATA_READ_MAX_TIME	The maximum time spent reading data. Unit: μs.
DATA_READ_BYTES	The total amount of data read. Unit: bytes.
DATA_WRITE	The number of times the system wrote data.
DATA_WRITE_TIME	The total time spent writing data. Unit: μs.
DATA_WRITE_MAX_TIME	The maximum time spent writing data. Unit: μs.
DATA_WRITE_BYTES	The total amount of data written. Unit: bytes.

6.Security

6.1. Recycle bin

Data definition language (DDL) statements cannot be rolled back. For example, if developers or operations and maintenance (O&M) engineers drop a table by using a DROP TABLE statement, the data of the table may be lost. Alibaba Cloud provides the recycle bin feature, which allows you to temporarily store the tables that are dropped. You can specify a retention period within which you can retrieve the dropped tables. Alibaba Cloud also provides the DBMS_RECYCLE package to help you manage the dropped tables in the recycle bin.

Prerequisites

Your RDS instance runs one of the following database engine versions:

- MySQL 8.0 (with a minor engine version of 20191225 or later)
- MySQL 5.7 (with a minor engine version of 20210430 or later)

Parameters

The following table describes the parameters that you can configure for the recycle bin feature.

Parameter	Description
loose_recycle_bin	Specifies whether to enable the recycle bin feature. You can enable this feature for your RDS instance or for a specific session. You can reconfigure this parameter in the ApsaraDB RDS console. Default value: OFF.
loose_recycle_bin_retention	The period for which you want to retain tables in the recycle bin. Unit: seconds. Default value: 604800. The default value indicates seven days. You can reconfigure this parameter in the ApsaraDB RDS console.
loose_recycle_scheduler	Specifies whether to enable the thread that is used to asynchronously delete tables from the recycle bin. You can reconfigure this parameter in the ApsaraDB RDS console. Default value: OFF.
loose_recycle_scheduler_interval	The polling interval followed by the thread that is used to asynchronously delete tables from the recycle bin. Unit: seconds. Default value: 30. This parameter is temporarily unavailable.
loose_recycle_scheduler_purge_table_print	Specifies whether to log the operations performed by the thread that is used to asynchronously delete tables from the recycle bin. This parameter is temporarily unavailable.

Note To prevent disk space from being exhausted, we recommend that you set the loose_recycle_bin_retention parameter to an optimal value and the loose_recycle_scheduler parameter to ON.

Introduction

- Recycling and deletion

- Recycling

  When you execute a `TRUNCATE TABLE` statement to truncate a table, ApsaraDB RDS moves the truncated table to the recycle bin. Then, ApsaraDB RDS creates an empty table in the original location of the truncated table by using the same schema as the truncated table.

  > **Note** The recycling mechanism is supported only when your RDS instance runs MySQL 8.0 (with a minor engine version of 20200331 or later).

  When you execute a `DROP TABLE or DROP DATABASE` statement to drop a table or a database, ApsaraDB RDS moves only the dropped tables to the recycle bin. ApsaraDB RDS manages all the other objects based on the following policies:

  - If no relationships are established between an object and the dropped tables, ApsaraDB RDS determines whether to retain the object based on the executed statement. ApsaraDB RDS does not move the objects to the recycle bin.
  - If an object is based on the dropped tables and may cause modifications to the data in these tables, ApsaraDB RDS deletes the object. These objects include triggers and foreign keys. ApsaraDB RDS does not delete column statistics. These statistics are stored to the recycle bin with the dropped tables.

- Deletion

  The recycle bin starts a background thread to asynchronously delete tables from the recycle bin. These tables are stored in the recycle bin longer than the period of time that is specified by the **recycle_bin_retention** parameter. If the size of a table in the recycle bin is large, ApsaraDB RDS starts another background thread to asynchronously delete the table.

- Permission control

  When you start your RDS instance, a database named __recycle_bin__ is created to store the data that is moved to the recycle bin. The __recycle_bin__ database is a system database, which cannot be modified or deleted.

  You cannot execute `DROP TABLE` statements to delete tables from the recycle bin. However, you can use the `call dbms_recycle.purge_table('<TABLE>');` method to delete tables from the recycle bin.

  > **Note** The account that you use must have the permissions to execute DROP statements on both your RDS instance and the recycle bin.

- Table naming in the recycle bin

  Tables in the __recycle_bin__ database originate from different databases and may have the same name. To ensure that each table has a unique name in the recycle bin, ApsaraDB RDS implements the following naming conventions:

  ```
  "__" + <Storage Engine> + <SE private id>
  ```

  The following table describes the parameters in the naming conventions.

Parameter	Description
Storage Engine	The name of the storage engine that is used by the table.

Parameter	Description
SE private id	The unique value that is generated by the storage engine to identify the table. For example, the unique value that is used to identify an InnoDB table is the ID of the table.

- Independent recycling

  The configurations of a recycle bin for an RDS instance apply only to that RDS instance. The configurations of the recycle bin for the primary RDS instance do not apply to the secondary, read-only, or disaster recovery RDS instances to which binary logs are replicated. For example, you can specify a 7-day retention period on your primary RDS instance and a 14-day retention period on the secondary RDS instances.

  > **Note** The storage usage of an RDS instance varies based on the retention period that you specify on the instance.

Precautions

- If the __recycle_bin__ database and a table reside in different file systems, ApsaraDB RDS may migrate the related data file from the tablespace that stores the table after you execute a `DROP TABLE` statement to drop the table. This process is time-consuming.
- A general tablespace can store more than one table. If you execute a DROP TABLE statement to drop a table from a general tablespace, ApsaraDB RDS does not migrate the related data file from the general tablespace.

Manage the recycle bin

AliSQL provides the following management methods in the DBMS_RECYCLE package:

- show_tables

  This method is used to display all the tables that are temporarily stored in the recycle bin. To use this method, run the following command:

  ```
  call dbms_recycle.show_tables();
  ```

  Example:

```
mysql> call dbms_recycle.show_tables();
+-----------------+---------------+--------------+-------------+---------------------+-
--------------------+
| SCHEMA          | TABLE         | ORIGIN_SCHEMA | ORIGIN_TABLE | RECYCLED_TIME       |
PURGE_TIME          |
+-----------------+---------------+--------------+-------------+---------------------+-
--------------------+
| __recycle_bin__ | __innodb_1063 | product_db    | t1           | 2019-08-08 11:01:46 |
2019-08-15 11:01:46 |
| __recycle_bin__ | __innodb_1064 | product_db    | t2           | 2019-08-08 11:01:46 |
2019-08-15 11:01:46 |
| __recycle_bin__ | __innodb_1065 | product_db    | parent       | 2019-08-08 11:01:46 |
2019-08-15 11:01:46 |
| __recycle_bin__ | __innodb_1066 | product_db    | child        | 2019-08-08 11:01:46 |
2019-08-15 11:01:46 |
+-----------------+---------------+--------------+-------------+---------------------+-
--------------------+
4 rows in set (0.00 sec)
```

Parameter	Description
SCHEMA	The name of the database that stores the table after the table is moved to the recycle bin.
TABLE	The name of the table after the table is moved to the recycle bin.
ORIGIN_SCHEMA	The name of the database that stores the table before the table is moved to the recycle bin.
ORIGIN_TABLE	The name of the table before the table is moved to the recycle bin.
RECYCLED_TIME	The time when the table was moved to the recycle bin.
PURGE_TIME	The time when the table is expected to be deleted from the recycle bin.

- purge_table

  This method is used to manually delete a table from the recycle bin. To use this method, run the following command:

  ```
  call dbms_recycle.purge_table('<TABLE>');
  ```

  > **Note**
  > - The TABLE parameter specifies the name of the table after the table is moved to the recycle bin.
  > - The account that you use must have the permissions to execute DROP statements on both your RDS instance and the recycle bin.

  Example:

  ```
  call dbms_recycle.purge_table('__innodb_1063');
  ```

- restore_table

  This method is used to restore a table from the recycle bin. To use this method, run the following command:

```
call dbms_recycle.restore_table('<RECYCLE_TABLE>','<DEST_DB>','<DEST_TABLE>');
```

  The following table describes the parameters for this method.

Parameter	Description
RECYCLE_TABLE	The name of the table in the recycle bin. **Note** If you configure only this parameter, ApsaraDB RDS restores data to the original table.
DEST_DB	The name of the destination database to which you want to restore the table.
DEST_TABLE	The name of the destination table to which you want to restore the table.

  Note Super-user credentials are required to run the restore_table command. Therefore, you cannot run this command. If you need this command to be run, you must submit a .

  Example:

```
mysql> call dbms_recycle.restore_table('__innodb_1063','testDB','testTable');
```

7.Best practices

7.1. Convert the storage engine of DRDS from InnoDB to X-Engine

This topic describes how to convert the storage engine of DRDS from InnoDB to X-Engine.

Context

Most users of existing ApsaraDB for RDS instances want to use X-Engine. These users have the following characteristics:

- Most RDS instances run MySQL 5.6 or MySQL 5.7. Few RDS instances run MySQL 8.0.
- A single instance has a large volume of data, which reaches the upper limit of disk space supported by the instance type. For example, an RDS instance with 4 CPU cores and 8 GB of memory supports up to 2 TB of local SSDs.
- The users also use DRDS. In addition, some users use an old version of DRDS and have customized functions, such as SQL passthrough.

To address the user requirements, Alibaba Cloud allows you to convert the storage engine of DRDS from InnoDB to X-Engine by following the procedure in this topic.

> **Note** For more information about X-Engine, see Introduction to X-Engine.

Conversion plan

RDS for MySQL 8.0 instances provide consistent API operations and user experience regardless of whether they use InnoDB or X-Engine. In this situation, after a DRDS upgrade, we recommend that you convert the storage engines for the RDS instances from InnoDB to X-Engine one by one. For example, if a DRDS instance has eight RDS instances, first convert the storage engine for one of the eight RDS instances. Monitor the instance running for a period of time. If you confirm that no compatibility or performance issues occur, convert the storage engines for the remaining seven RDS instances.

Compression ratio verification before conversion

Before conversion, we recommend that you purchase an RDS instance that is powered by X-Engine with the same specifications as the existing RDS instance that is powered by the InnoDB storage engine. Then, you can use Alibaba Cloud Data Transmission Service (DTS) to import data from the existing RDS instance to the purchased instance. This way, you can check the compression efficiency. The compression efficiency allows you to determine the following items:

- Instance storage capacity

  Based on the compression efficiency, you can determine the instance specifications that you need to purchase after you convert a storage engine from InnoDB to X-Engine. For example, if the space required after compression is below 30% of the original space, you can purchase an RDS instance with 1 TB of disk space after you convert the storage engine of an RDS instance that originally requires 3 TB of disk space. Alternatively, you can purchase an RDS instance with the same specifications to reserve storage space for future business development.

- Number of database shards

After storage space is reduced, you can reduce the number of database shards. For example, you can merge databases that are distributed across instances to one instance. This reduces costs.

> **Note** You can release the RDS instance that is powered by X-Engine after you complete the verification, or you can clear the instance for official conversion later.

Conversion procedure

1. Upgrade DRDS to a version later than V5.4.2-15744202.

   > **Note**
   > - If the DRDS version is later than v5.4.2-15744202, skip this step.
   > - To ensure compatibility, you must adjust the service code. This applies if your business is based on specific API operations that are provided in an earlier version of DRDS, for example, the SQL passthrough function for performance optimization.

2. Select an RDS instance with the InnoDB storage engine from DRDS as the first instance for conversion. Export table creation statements and change the engine type to X-Engine. Then, create an RDS instance with the target specifications and X-Engine. Alternatively, use the RDS instance that you created when you verify the compression efficiency and import the table structure scripts into this instance.
   - For more information about how to create an RDS instance, see Create an ApsaraDB RDS for MySQL instance.
   - For more information about how to import and export table creation statements, see Convert the storage engine from InnoDB, TokuDB, or MyRocks to X-Engine.

   > **Note** If you use DTS to migrate data, the engine type of the source instance is inherited by default. You must separately export the table creation statements and change the engine type to X-Engine before you can migrate data to the destination instance that is powered by X-Engine.

3. Use DTS to synchronize data from the RDS instance with the InnoDB storage engine to the RDS instance with X-Engine. For more information about data synchronization, see Configure two-way data synchronization between MySQL instances.

   > **Note** You can use the two-way synchronization function of DTS to ensure data consistency between the two RDS instances.

4. Modify DRDS routing rules and redirect the access requests to the RDS instance with the InnoDB storage engine to the RDS instance with X-Engine. If you want to modify the DRDS routing rules, submit a .

> **Note** Run the first RDS instance with X-Engine for five days. Monitor the instance running and consider the request processing time, exception information, and two-way synchronization progress. If an exception occurs, you must make sure that services can be switched back to the original RDS instance with the InnoDB storage engine. For more information, see View the resource metrics, engine metrics, and deployment metrics of an ApsaraDB RDS for MySQL instance.

5. After you confirm that the first RDS instance with X-Engine is running as normal, proceed with the conversion for 30% to 50% of the remaining RDS instances and then monitor the instance running for three to five days. In this case, repeat the preceding steps 2 to 4.

   > **Note** Do not release or bring the original RDS instances with InnoDB offline because these instances are required to perform DTS two-way synchronization with new RDS instances with X-Engine.

6. Perform the conversion for all the remaining RDS instances. After you complete the conversion for all the instances of DRDS, monitor the instance running for three to five days. If the new instances run as normal, release all DTS synchronization links and the original RDS instances with InnoDB.

7.2. DingTalk secures App Store top rank with X-Engine

This topic describes how X-Engine of ApsaraDB for RDS helps reduce the costs of DingTalk and implement online collaborative offices.

Context

DingTalk is a leading enterprise-grade instant messaging (IM) tool in China. It serves hundreds of millions of users across China. Its basic functions include video conferences and daily reports. DingTalk Open Platform also provides various office automation (OA) applications to facilitate communication between co-workers.

In 2020, COVID-19 is a serious problem. To avoid the risk of infection caused by work in centralized offices, a large number of employees have opted to work from home. The demand for collaborative office tools suddenly increases. In this situation, DingTalk is quickly elevated to the top of the App Store download list. This results in a sharp increase in DingTalk access. DingTalk is based on the elastic infrastructure provided by Alibaba Cloud. This ensures that all the traffic peaks are smoothly handled.

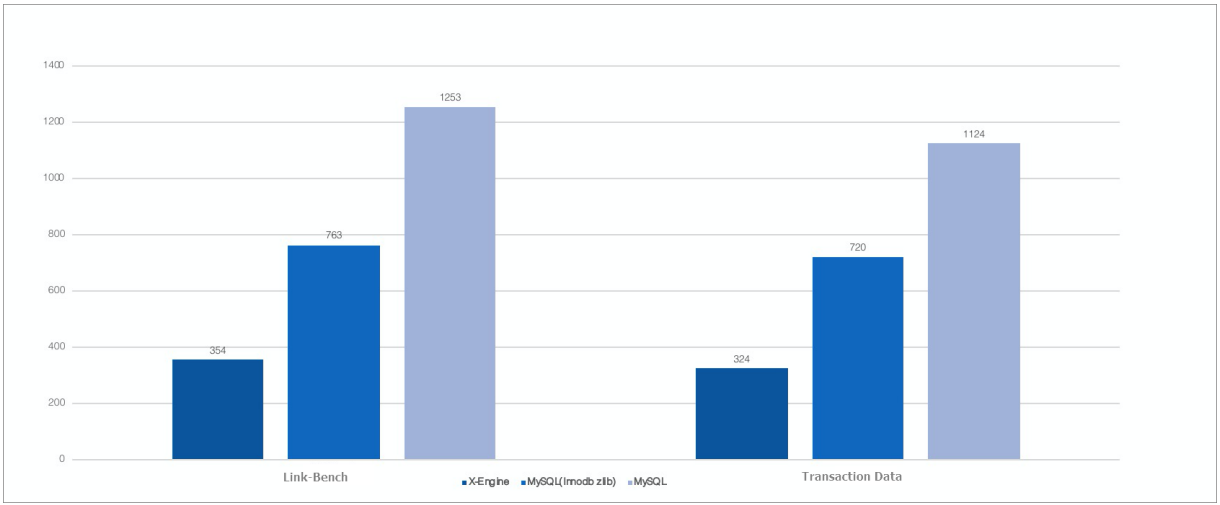
To serve a large number of users, DingTalk must ensure the timely and correct delivery of messages, and provide specific functions, such as read and unread messages. Unlike user-level IM tools such as WeChat, enterprise-grade IM tools must include the permanent storage of chat records and provide the multi-terminal roaming function. This function allows users to receive messages from multiple terminals. As the number of users sharply increases, DingTalk faces challenges in the costs incurred by the permanent storage of chat records while ensuring the performance of read and write operations on the chat records.

To address these challenges, DingTalk uses X-Engine as the storage engine for messages. This achieves a balance between the costs and performance. X-Engine has the following advantages:

- The storage space required by X-Engine is about 62% less than that required by the InnoDB storage engine.

- Specific database functions such as transactions and secondary indexes are supported.
- Service code can be migrated to RDS instances that are powered by X-Engine without changes.
- X-Engine separates hot and cold data to accelerate the processing of current messages. It also implements the most efficient compression algorithm for historical messages.

X-Engine storage efficiency is tested on two datasets: Link-Bench and Alibaba internal transaction business. In the test, X-Engine requires 2-fold less storage space than the InnoDB storage engine with compression enabled, and 3- to 5-fold less storage space than the InnoDB engine with compression disabled.



Low costs achieved by X-Engine

X-Engine adopts the following technologies to ensure low costs:

- Compact pages

  X-Engine uses the Copy-on-write technology to write new data to new pages without updating the original pages. The new pages are read-only and cannot be directly updated. These pages are stored in a compact manner, and the data is compressed by using specific algorithms, such as prefix encoding. This improves the storage efficiency. You can use the compaction operation to clear invalid records. This ensures a compact arrangement of valid records. X-Engine requires only 10% to 50% of the storage space compared with conventional storage engines, such as InnoDB.

- Data compression and cleaning of invalid records

  Pages after encoding can be compressed by using general compression algorithms, such as zlib, zstd, and snappy. Data at a low level of a log-structured merge-tree (LSM tree) is compressed by default.

  Data compression sacrifices computing resources for storage space. We recommend that you select compression algorithms that provide a low compression ratio and a high speed of compression and decompression. After a large number of comparative tests, X-Engine selects zstd as the default compression algorithm with additional support for other compression algorithms.

  In addition, the compaction operation is introduced to delete invalid records. This way, only valid records are retained. The more frequently the compaction operation is performed, the lower the proportion of invalid records, and the higher the storage efficiency. Therefore, you must perform the compaction operation at a suitable frequency.

The X-Engine team also develops the field-programmable gate array (FPGA) compaction technology to reduce the computing resource consumption of the compaction operation. This technology uses heterogeneous computing hardware to accelerate the compaction process. It streamlines compaction and compression operations by using FPGA hardware. On a host without FPGA hardware, X-Engine can use a suitable scheduling algorithm to save storage space at a lower performance cost.

- Intelligent separation between hot and cold data

  In normal access to a storage system, most access requests direct to a small portion of data. This is why the cache works. In an LSM tree structure, frequently accessed data is stored at a high level to a fast storage device, such as NVM and DRAM. Infrequently accessed data is stored at a low level to a slow storage device. This is the hot and cold data separation in X-Engine.

  The separation algorithm completes the following tasks:

  - In the compaction operation, the pages and records that are least likely to be accessed are selected and moved to the bottom of the LSM tree.
  - Current hot data is selected and backfilled to memory (BlockCache and RowCache) in the compaction or dump process. This prevents compromised performance from jitters in cache hit rates.
  - The AI algorithm recognizes data that may be accessed in the future and pre-reads it into memory. This increases the hit rates for accessing cache at the first time.

  Hot data and cold data are accurately identified to avoid computing resource waste due to invalid compression or decompression. This improves system throughput.

For more information, see Introduction to X-Engine.

Related papers

- X-Engine: An Optimized Storage Engine for Large-scale E-commerce Transaction Processing
- FPGA-Accelerated Compactions for LSM-based Key-Value Store

7.3. Storage engine that processes trillions of Taobao orders

Taobao historical orders are supported by a PolarDB-X cluster based on X-Engine. This fixes the known issues caused by the use of HBase databases, reduces storage costs, and allows users to query orders at all times.

Context

Taobao is the largest online shopping platform in China. It serves more than 700 million active users and tens of millions of sellers.

The large platform provides support for about 100 million transactions on physical and virtual commodities every day. Each transaction process involves different phases, such as member information verification, commodity library inquiry, order creation, inventory reduction, discounts, order payment, logistics information update, and payment confirmation. Each phase involves database record creation and status update. The entire process requires hundreds of database transactions, and the entire database cluster performs tens of billions of transaction read and write operations every day. The database team faces the challenge of huge storage costs incurred by the increasing volume of data every day while ensuring the stable performance of the database system.

Orders are the most critical information in the entire transaction process and must be permanently stored in databases. If a transaction dispute arises, the order records must be provided for users to query. Over the last nearly 17 years since Taobao was founded in 2003, the total number of database records related to orders has reached the trillion level, and the disk space occupied by these records has exceeded the PB level.

The following sections describe how Taobao ensures low latency every time that users query orders without increasing storage costs.

Architecture evolution

The architecture of transaction order databases has evolved through four phases as the traffic increases.

- Phase 1

  In this initial phase, the traffic was low, and Taobao used an Oracle database to store all order information. Order creation and historical order queries were performed on the same database.

- Phase 2

  As the volume of historical order data increased, the single database can no longer meet the performance and capacity requirements at the same time. Therefore, the database was split into an online database and a historical database. Historical orders that were generated three months ago were migrated to the historical database. However, the historical database contained too much data to allow queries. In this phase, users can only query historical orders for the last three months.

- Phase 3

  To fix the issues related to storage costs and historical order queries, Taobao migrated historical orders to an HBase database.

  HBase provides both primary and indexing tables. Users can query the primary tables for order details and the indexing tables for order IDs based on the IDs of buyers or sellers. In this situation, orders may not be migrated to the historical order database in chronological order, and many types of orders are not migrated to this database. As a result, the order list is not sorted by time, and users cannot search for orders by using the listed sequence of orders.

- Phase 4

  The historical order database is built in a PolarDB-X cluster based on X-Engine. This reduces storage costs and fixes the out-of-time-order issue.

Business pain points

The architecture evolution shows that the business team and the database team have suffered from the following pain points over the last 10 years since the historical order database was introduced:

- Storage costs

  A large volume of data is written every day and the data is never deleted. Low-cost storage is required.

- Query performance

  Diversified query functions are required to meet specific requirements, such as query by time and query by order type. Databases must support secondary indexes that can ensure data consistency and performance.

- Query latency

The query latency must be low to ensure user experience. For example, queries on historical orders of 90 days ago are much fewer than those in the last 90 days, but these queries still require low latency.

Historical order database solution based on X-Engine

The transaction order system has been iterated for 10 years in terms of the architecture, where online and historical databases are separated. Most service code is compatible with this architecture, which is also inherited in this solution. This architecture mitigates risks caused by the reconstruction and migration of service code. Initially, the HBase cluster is replaced with the PolarDB-X cluster that is based on X-Engine.

- The online database is still deployed in a MySQL cluster that is based on the InnoDB storage engine, and stores only orders for the last 90 days. The data volume is small, which ensures a high cache hit rate and reduces read/write latency.
- Orders that were generated 90 days ago are migrated from the online database to the historical database through data synchronization and are deleted from the online database.
- The storage engine of the historical database is converted to X-Engine. This database stores all orders that were generated 90 days ago. If you want to perform read or write operations on these orders, access the historical database.

After this new solution is used, the storage costs are the same as those incurred by the use of the HBase database. The historical database is compatible with the online database, and identical indexes can be created on the two databases. This fixes the out-of-time-order issue. In the historical database, hot data is separated from cold data to reduce read latency.

Summary

The transaction order records on Taobao are stored in the streamline mode. Recently written records are frequently accessed at first, and the access frequency sharply decreases over time. X-Engine separates hot and cold data and is suitable for this type of access. A single database cluster based on X-Engine is sufficient for these access scenarios.

Assume that a new or existing business needs to store a large number of streamline records. If hot data and cold data are not separated on the business layer, we recommend that you use the distributed PolarDB-X cluster based on X-Engine to ensure scalability without increasing storage costs.

Alibaba Cloud has launched X-Engine. You can purchase it if required. For more information, see Create an ApsaraDB RDS for MySQL instance.

7.4. Best practices for X-Engine testing

This topic describes how to use SysBench to test the performance of X-Engine used with ApsaraDB RDS for MySQL. This helps you evaluate the performance of X-Engine.

Prerequisites

- The default storage engine of your RDS instance is X-Engine.

Note If X-Engine is used, the value of the XENGINE parameter must be DEFAULT in the Support column.

```
MySQL [(none)]> show storage engines;
+--------------------+---------+------------------------------------------------------------
-----------+--------------+------+------------+
| Engine             | Support | Comment
| Transactions | XA   | Savepoints |
+--------------------+---------+------------------------------------------------------------
-----------+--------------+------+------------+
| FEDERATED          | NO      | Federated MySQL storage engine
| NULL         | NULL | NULL       |
| BLACKHOLE          | YES     | /dev/null storage engine (anything you write to it d
isappears) | NO           | NO   | NO         |
| XENGINE            | DEFAULT | X-Engine storage engine
| YES          | YES  | YES        |
| MEMORY             | YES     | Hash based, stored in memory, useful for temporary t
ables      | NO           | NO   | NO         |
| InnoDB             | YES     | Supports transactions, row-level locking, and foreig
n keys     | YES          | YES  | YES        |
| PERFORMANCE_SCHEMA | YES     | Performance Schema
| NO           | NO   | NO         |
| Sequence           | YES     | Sequence Storage Engine Helper
| NO           | NO   | NO         |
| MyISAM             | YES     | MyISAM storage engine
| NO           | NO   | NO         |
| MRG_MYISAM         | YES     | Collection of identical MyISAM tables
| NO           | NO   | NO         |
| CSV                | YES     | CSV storage engine
| NO           | NO   | NO         |
| ARCHIVE            | YES     | Archive storage engine
| NO           | NO   | NO         |
+--------------------+---------+------------------------------------------------------------
-----------+--------------+------+------------+
11 rows in set (0.00 sec)
```

- The table used for testing is stored in X-Engine.

Note In this example, the table used for testing is created with the ENGINE parameter set to XENGINE. If you set the ENGINE parameter to INNODB or another storage engine, the table used for testing is stored in the specified storage engine rather than X-Engine.

```
MySQL [sbtest]> show create table sbtest1;
+---------+-------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
------------------------------+
| Table   | Create Table
|
+---------+-------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
------------------------------+
| sbtest1 | CREATE TABLE `sbtest1` (
  `id` int(11) NOT NULL AUTO_INCREMENT,
  `k` int(11) NOT NULL DEFAULT '0',
  `c` char(120) COLLATE utf8mb4_general_ci NOT NULL DEFAULT '',
  `pad` char(60) COLLATE utf8mb4_general_ci NOT NULL DEFAULT '',
  PRIMARY KEY (`id`),
  KEY `k_1` (`k`)
) ENGINE=XENGINE AUTO_INCREMENT=2001 DEFAULT CHARSET=utf8mb4 COLLATE=utf8mb4_general_
ci |
+---------+-------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------
------------------------------+
1 row in set (0.01 sec)
```

Note We recommend that you use SysBench 1.1.0 or later.

Use DTS to test storage space usage

We recommend that you use Alibaba Cloud Data Migration Service (DTS) to migrate your actual database data to your RDS instance and then check the disk usage of X-Engine. In this case, the test results are more close to your actual business situation. X-Engine adopts technologies such as space-friendly storage format, prefix encoding, tiered storage, and efficient compression algorithms to reduce disk usage. The actual effect of these technologies varies based on schemas and record length in your databases. Therefore, using your actual database data allows you to obtain more accurate test results.

DTS does not support an automatic conversion of the storage engine during data migration. You must manually create databases and tables on your RDS instance that runs X-Engine, set the ENGINE parameter to XENGINE in the table creation statements as described in the "Prerequisites" section, and migrate data by using DTS. Do not migrate the schemas.

We recommend that you do not execute SQL statements immediately after the data import is complete. You can monitor the CPU utilization and input/output operations per second (IOPS) usage of your RDS instance in the ApsaraDB for RDS console. After the CPU utilization and IOPS approach zero, you can execute SQL statements to test the performance of X-Engine. In this case, the disk usage is calculated more accurately. This is because the log-structured merge-tree (LSM tree) architecture used by X-Engine depends on background asynchronous tasks to implement functions such as data compression. These functions reduce storage costs. The background asynchronous tasks take some time and consume CPU and IOPS resources.

For more information, see Migrate data between ApsaraDB RDS for MySQL instances.

Use SysBench to test the storage space usage

To fully test the compression efficiency of X-Engine, we recommend that you set the table_size parameter in the following command to a large value within the disk size range allowed for your RDS instance.

We recommend that you monitor the CPU utilization and IOPS usage of your RDS instance in the ApsaraDB for RDS console. After the CPU utilization and IOPS approach zero, the space usage is calculated more accurately.

Run the following command to test the storage space usage:

```
sysbench /usr/share/sysbench/oltp_update_index.lua \
  -- mysql-host=[The endpoint of your RDS instance] \
  --mysql-user=sbtest \
  --mysql-password=sbtest@888 \
  --mysql-db=sbtest \
  --threads=32 \
  --tables=32 \
  --table_size=1000000000 \
  --mysql-storage-engine=XENGINE \
  prepare
```

Use SysBench to test performance

If you use SysBench for performance testing, we recommend that you set the rand-type parameter to zipfian and the rand-zipfian-exp parameter to 0.9.

- rand-type: specifies the type of the distribution that is used to generate random numbers in SQL statements.
- Zipfian distribution: a common data distribution with hot spots. When the rand-zipfian-exp parameter is set to 0.9, the random numbers generated by using Zipfian distribution are closer to those generated in the real world. The test results are more valuable in comparison to those generated by using the default uniform distribution.

We recommend that you conduct a single test for a long period of time, such as 3,600 seconds. The test results of average performance obtained from a long-time test is more valuable and less affected by potential interference factors.

We recommend that you use a large number of threads, for example, 512 threads, to test the throughput.

To improve the performance of X-Engine by configuring parameters, contact your Alibaba Cloud account manager or after-sales engineers. You can also submit a to receive consulting services.

Run the following command to test the performance:

```
sysbench /usr/share/sysbench/oltp_point_select.lua \
  -- mysql-host=[The endpoint of your RDS instance] \
  --mysql-user=sbtest \
  --mysql-password=sbtest@888 \
  --time=3600 \
  --mysql-db=sbtest \
  --tables=32 \
  --threads=512 \
  --table_size=10000000 \
  --rand-type=zipfian \
  --rand-zipfian-exp=0.9 \
  --report-interval=1 \
  run
```

Use a Python script to perform multiple tests at a time

If you want to perform multiple tests at a time by using SysBench, we recommend that you use a Python script that can automatically perform the tests and record the test results. When you execute the script, you are prompted to enter the endpoint of your RDS instance. Example:

```
import subprocess
import time
import sys
def execute_test(test_name, db_conn_string):
  # setup sysbench parameters
  mysql = "--mysql-host=%s" % db_conn_string
  user = "--mysql-user=sbtest"
  password = "--mysql-password=*********"
  time = "--time=3600"
  database = "--mysql-db=sbtest"
  tables = "--tables=32"
  threads = "--threads=512"
  table_size = "--table_size=1000000"
  distribution = "--rand-type=pareto --rand-pareto-h=0.9"
  # formulate the sysbench command
  cmd = 'sysbench ' + test_name + " " + mysql + " " + user+ " " + password + " " + time+ "
" + database+ " " + tables + " " + threads + " " + table_size+ " " + distribution+ " " + "-
-report-interval=1"+ " " +'run'
  # execute
  out = subprocess.check_output(cmd,
    stderr = subprocess.STDOUT, shell=True)
  # output sysbench outputs to a file
  output_file_name = "xengine_result_"+test_name[20:len(test_name)]
  output_file = open(output_file_name, "w")
  output_file.write(out)
  output_file.close()
if __name__ == '__main__':
  # the connection string for the MySQL (X-Engine) instance to be tested
  db_conn_string = sys.argv[1]
  test = [
    "/usr/share/sysbench/oltp_update_index.lua",
    "/usr/share/sysbench/oltp_point_select.lua",
    "/usr/share/sysbench/oltp_read_only.lua",
    "/usr/share/sysbench/oltp_write_only.lua",
    "/usr/share/sysbench/oltp_read_write.lua",
    "/usr/share/sysbench/oltp_insert.lua"
  ]
  for atest in test:
    print("start test:\t%s\t%s" % (atest, time.ctime()))
    execute_test(atest, db_conn_string)
    print("end test:\t%s\t%s" % (atest, time.ctime()))
    # sleep foe some seconds
    # after a period of testing with inserts/updates/deletes, x-engine needs some time to c
omplete
    # its asynchronous background compactions.
    time.sleep(1000)
```

7.5. Use DMS to archive data to X-Engine