MySQL Backup and Recovery
Abstract

This is the MySQL Backup and Recovery extract from the MySQL 5.7 Reference Manual.

For legal information, see the Legal Notices.

For help with using MySQL, please visit the MySQL Forums, where you can discuss your issues with other MySQL users.

Document generated on: 2020-04-03 (revision: 65614)
# Table of Contents

Preface and Legal Notices ........................................................................................................... v

1 Backup and Recovery ............................................................................................................... 1
  1.1 Backup and Recovery Types ............................................................................................... 2
  1.2 Database Backup Methods ............................................................................................... 5
  1.3 Example Backup and Recovery Strategy ........................................................................... 7
    1.3.1 Establishing a Backup Policy ..................................................................................... 7
    1.3.2 Using Backups for Recovery .................................................................................... 9
    1.3.3 Backup Strategy Summary ....................................................................................... 10
  1.4 Using mysqldump for Backups ....................................................................................... 10
    1.4.1 Dumping Data in SQL Format with mysqldump ...................................................... 10
    1.4.2 Reloading SQL-Format Backups ............................................................................. 11
    1.4.3 Dumping Data in Delimited-Text Format with mysqldump ................................. 12
    1.4.4 Reloading Delimited-Text Format Backups ............................................................ 13
    1.4.5 mysqldump Tips ...................................................................................................... 13
  1.5 Point-in-Time (Incremental) Recovery Using the Binary Log ........................................ 15
    1.5.1 Point-in-Time Recovery Using Event Times ............................................................ 17
    1.5.2 Point-in-Time Recovery Using Event Positions ..................................................... 17
  1.6 MyISAM Table Maintenance and Crash Recovery ......................................................... 18
    1.6.1 Using myisamchk for Crash Recovery .................................................................. 18
    1.6.2 How to Check MyISAM Tables for Errors .............................................................. 19
    1.6.3 How to Repair MyISAM Tables ............................................................................. 20
    1.6.4 MyISAM Table Optimization .................................................................................. 22
    1.6.5 Setting Up a MyISAM Table Maintenance Schedule ............................................. 23

2 Using Replication for Backups .............................................................................................. 25
  2.1 Backing Up a Slave Using mysqldump ........................................................................... 25
  2.2 Backing Up Raw Data from a Slave ................................................................................ 26
  2.3 Backing Up a Master or Slave by Making It Read Only ................................................. 27

3 InnoDB Backup ....................................................................................................................... 29
Preface and Legal Notices

This is the MySQL Backup and Recovery extract from the MySQL 5.7 Reference Manual.

Licensing information—MySQL 5.7. This product may include third-party software, used under license. If you are using a Commercial release of MySQL 5.7, see the MySQL 5.7 Commercial Release License Information User Manual for licensing information, including licensing information relating to third-party software that may be included in this Commercial release. If you are using a Community release of MySQL 5.7, see the MySQL 5.7 Community Release License Information User Manual for licensing information, including licensing information relating to third-party software that may be included in this Community release.

Licensing information—MySQL NDB Cluster 7.5. This product may include third-party software, used under license. If you are using a Commercial release of NDB Cluster 7.5, see the MySQL NDB Cluster 7.5 Commercial Release License Information User Manual for licensing information relating to third-party software that may be included in this Commercial release. If you are using a Community release of NDB Cluster 7.5, see the MySQL NDB Cluster 7.5 Community Release License Information User Manual for licensing information relating to third-party software that may be included in this Community release.

Licensing information—MySQL NDB Cluster 7.6. If you are using a Commercial release of MySQL NDB Cluster 7.6, see the MySQL NDB Cluster 7.6 Community Release License Information User Manual for licensing information, including licensing information relating to third-party software that may be included in this Commercial release. If you are using a Community release of MySQL NDB Cluster 7.6, see the MySQL NDB Cluster 7.6 Community Release License Information User Manual for licensing information, including licensing information relating to third-party software that may be included in this Community release.

Legal Notices

Copyright © 1997, 2020, Oracle and/or its affiliates. All rights reserved.

This software and related documentation are provided under a license agreement containing restrictions on use and disclosure and are protected by intellectual property laws. Except as expressly permitted in your license agreement or allowed by law, you may not use, copy, reproduce, translate, broadcast, modify, license, transmit, distribute, exhibit, perform, publish, or display any part, in any form, or by any means. Reverse engineering, disassembly, or decompilation of this software, unless required by law for interoperability, is prohibited.

The information contained herein is subject to change without notice and is not warranted to be error-free. If you find any errors, please report them to us in writing.

If this is software or related documentation that is delivered to the U.S. Government or anyone licensing it on behalf of the U.S. Government, then the following notice is applicable:

U.S. GOVERNMENT END USERS: Oracle programs, including any operating system, integrated software, any programs installed on the hardware, and/or documentation, delivered to U.S. Government end users are "commercial computer software" pursuant to the applicable Federal Acquisition Regulation and agency-specific supplemental regulations. As such, use, duplication, disclosure, modification, and adaptation of the programs, including any operating system, integrated software, any programs installed on the hardware, and/or documentation, shall be subject to license terms and license restrictions applicable to the programs. No other rights are granted to the U.S. Government.

This software or hardware is developed for general use in a variety of information management applications. It is not developed or intended for use in any inherently dangerous applications, including applications that may create a risk of personal injury. If you use this software or hardware in dangerous applications, then you shall be responsible to take all appropriate fail-safe, backup, redundancy, and
other measures to ensure its safe use. Oracle Corporation and its affiliates disclaim any liability for any damages caused by use of this software or hardware in dangerous applications.

Oracle and Java are registered trademarks of Oracle and/or its affiliates. Other names may be trademarks of their respective owners.

Intel and Intel Xeon are trademarks or registered trademarks of Intel Corporation. All SPARC trademarks are used under license and are trademarks or registered trademarks of SPARC International, Inc. AMD, Opteron, the AMD logo, and the AMD Opteron logo are trademarks or registered trademarks of Advanced Micro Devices. UNIX is a registered trademark of The Open Group.

This software or hardware and documentation may provide access to or information about content, products, and services from third parties. Oracle Corporation and its affiliates are not responsible for and expressly disclaim all warranties of any kind with respect to third-party content, products, and services unless otherwise set forth in an applicable agreement between you and Oracle. Oracle Corporation and its affiliates will not be responsible for any loss, costs, or damages incurred due to your access to or use of third-party content, products, or services, except as set forth in an applicable agreement between you and Oracle.

This documentation is NOT distributed under a GPL license. Use of this documentation is subject to the following terms:

You may create a printed copy of this documentation solely for your own personal use. Conversion to other formats is allowed as long as the actual content is not altered or edited in any way. You shall not publish or distribute this documentation in any form or on any media, except if you distribute the documentation in a manner similar to how Oracle disseminates it (that is, electronically for download on a Web site with the software) or on a CD-ROM or similar medium, provided however that the documentation is disseminated together with the software on the same medium. Any other use, such as any dissemination of printed copies or use of this documentation, in whole or in part, in another publication, requires the prior written consent from an authorized representative of Oracle. Oracle and/or its affiliates reserve any and all rights to this documentation not expressly granted above.

Documentation Accessibility

For information about Oracle's commitment to accessibility, visit the Oracle Accessibility Program website at https://www.oracle.com/corporate/accessibility/.

Access to Oracle Support

Oracle customers that have purchased support have access to electronic support through My Oracle Support. For information, visit https://www.oracle.com/corporate/accessibility/learning-support.html#support-tab.
Chapter 1 Backup and Recovery

Table of Contents

1.1 Backup and Recovery Types ......................................................... 2
1.2 Database Backup Methods ....................................................... 5
1.3 Example Backup and Recovery Strategy ......................................... 7
  1.3.1 Establishing a Backup Policy .................................................. 7
  1.3.2 Using Backups for Recovery ..................................................... 9
  1.3.3 Backup Strategy Summary ........................................................ 10
1.4 Using mysqldump for Backups .................................................... 10
  1.4.1 Dumping Data in SQL Format with mysqldump .............................. 10
  1.4.2 Reloading SQL-Format Backups ............................................... 11
  1.4.3 Dumping Data in Delimited-Text Format with mysqldump ............... 12
  1.4.4 Reloading Delimited-Text Format Backups ................................... 13
  1.4.5 mysqldump Tips ..................................................................... 13
1.5 Point-in-Time (Incremental) Recovery Using the Binary Log .................. 15
  1.5.1 Point-in-Time Recovery Using Event Times ................................... 17
  1.5.2 Point-in-Time Recovery Using Event Positions ............................... 17
1.6 MyISAM Table Maintenance and Crash Recovery ................................. 18
  1.6.1 Using myisamchk for Crash Recovery .......................................... 18
  1.6.2 How to Check MyISAM Tables for Errors ..................................... 19
  1.6.3 How to Repair MyISAM Tables .................................................... 20
  1.6.4 MyISAM Table Optimization ....................................................... 22
  1.6.5 Setting Up a MyISAM Table Maintenance Schedule .......................... 23

It is important to back up your databases so that you can recover your data and be up and running again in case problems occur, such as system crashes, hardware failures, or users deleting data by mistake. Backups are also essential as a safeguard before upgrading a MySQL installation, and they can be used to transfer a MySQL installation to another system or to set up replication slave servers.

MySQL offers a variety of backup strategies from which you can choose the methods that best suit the requirements for your installation. This chapter discusses several backup and recovery topics with which you should be familiar:

- Types of backups: Logical versus physical, full versus incremental, and so forth.
- Methods for creating backups.
- Recovery methods, including point-in-time recovery.
- Backup scheduling, compression, and encryption.
- Table maintenance, to enable recovery of corrupt tables.

Additional Resources

Resources related to backup or to maintaining data availability include the following:

- Customers of MySQL Enterprise Edition can use the MySQL Enterprise Backup product for backups. For an overview of the MySQL Enterprise Backup product, see MySQL Enterprise Backup Overview.
- Details for mysqldump can be found in MySQL Programs.
1.1 Backup and Recovery Types

This section describes the characteristics of different types of backups.

Physical (Raw) Versus Logical Backups

Physical backups consist of raw copies of the directories and files that store database contents. This type of backup is suitable for large, important databases that need to be recovered quickly when problems occur.

Logical backups save information represented as logical database structure (CREATE DATABASE, CREATE TABLE statements) and content (INSERT statements or delimited-text files). This type of backup is suitable for smaller amounts of data where you might edit the data values or table structure, or recreate the data on a different machine architecture.

Physical backup methods have these characteristics:

- The backup consists of exact copies of database directories and files. Typically this is a copy of all or part of the MySQL data directory.
- Physical backup methods are faster than logical because they involve only file copying without conversion.
- Output is more compact than for logical backup.
- Because backup speed and compactness are important for busy, important databases, the MySQL Enterprise Backup product performs physical backups. For an overview of the MySQL Enterprise Backup product, see MySQL Enterprise Backup Overview.
- Backup and restore granularity ranges from the level of the entire data directory down to the level of individual files. This may or may not provide for table-level granularity, depending on storage engine. For example, InnoDB tables can each be in a separate file, or share file storage with other InnoDB tables; each MyISAM table corresponds uniquely to a set of files.
- In addition to databases, the backup can include any related files such as log or configuration files.
- Data from MEMORY tables is tricky to back up this way because their contents are not stored on disk. (The MySQL Enterprise Backup product has a feature where you can retrieve data from MEMORY tables during a backup.)
Online Versus Offline Backups

- Backups are portable only to other machines that have identical or similar hardware characteristics.
- Backups can be performed while the MySQL server is not running. If the server is running, it is necessary to perform appropriate locking so that the server does not change database contents during the backup. MySQL Enterprise Backup does this locking automatically for tables that require it.
- Physical backup tools include the `mysqlbackup` of MySQL Enterprise Backup for InnoDB or any other tables, or file system-level commands (such as `cp`, `scp`, `tar`, `rsync`) for MyISAM tables.
  
  For restore:
  - MySQL Enterprise Backup restores InnoDB and other tables that it backed up.
  - `ndb_restore` restores NDB tables.
  - Files copied at the file system level can be copied back to their original locations with file system commands.

Logical backup methods have these characteristics:

- The backup is done by querying the MySQL server to obtain database structure and content information.
- Backup is slower than physical methods because the server must access database information and convert it to logical format. If the output is written on the client side, the server must also send it to the backup program.
- Output is larger than for physical backup, particularly when saved in text format.
- Backup and restore granularity is available at the server level (all databases), database level (all tables in a particular database), or table level. This is true regardless of storage engine.
- The backup does not include log or configuration files, or other database-related files that are not part of databases.
- Backups stored in logical format are machine independent and highly portable.
- Logical backups are performed with the MySQL server running. The server is not taken offline.
- Logical backup tools include the `mysqldump` program and the `SELECT ... INTO OUTFILE` statement. These work for any storage engine, even `MEMORY`.
- To restore logical backups, SQL-format dump files can be processed using the `mysql` client. To load delimited-text files, use the `LOAD DATA` statement or the `mysqlimport` client.

Online Versus Offline Backups

Online backups take place while the MySQL server is running so that the database information can be obtained from the server. Offline backups take place while the server is stopped. This distinction can also be described as "hot" versus "cold" backups; a "warm" backup is one where the server remains running but locked against modifying data while you access database files externally.

Online backup methods have these characteristics:

- The backup is less intrusive to other clients, which can connect to the MySQL server during the backup and may be able to access data depending on what operations they need to perform.
- Care must be taken to impose appropriate locking so that data modifications do not take place that would compromise backup integrity. The MySQL Enterprise Backup product does such locking automatically.
Offline backup methods have these characteristics:

- Clients can be affected adversely because the server is unavailable during backup. For that reason, such backups are often taken from a replication slave server that can be taken offline without harming availability.

- The backup procedure is simpler because there is no possibility of interference from client activity.

A similar distinction between online and offline applies for recovery operations, and similar characteristics apply. However, it is more likely that clients will be affected for online recovery than for online backup because recovery requires stronger locking. During backup, clients might be able to read data while it is being backed up. Recovery modifies data and does not just read it, so clients must be prevented from accessing data while it is being restored.

### Local Versus Remote Backups

A local backup is performed on the same host where the MySQL server runs, whereas a remote backup is done from a different host. For some types of backups, the backup can be initiated from a remote host even if the output is written locally on the server host.

- `mysqldump` can connect to local or remote servers. For SQL output (`CREATE` and `INSERT` statements), local or remote dumps can be done and generate output on the client. For delimited-text output (with the `--tab` option), data files are created on the server host.

- `SELECT ... INTO OUTFILE` can be initiated from a local or remote client host, but the output file is created on the server host.

- Physical backup methods typically are initiated locally on the MySQL server host so that the server can be taken offline, although the destination for copied files might be remote.

### Snapshot Backups

Some file system implementations enable “snapshots” to be taken. These provide logical copies of the file system at a given point in time, without requiring a physical copy of the entire file system. (For example, the implementation may use copy-on-write techniques so that only parts of the file system modified after the snapshot time need be copied.) MySQL itself does not provide the capability for taking file system snapshots. It is available through third-party solutions such as Veritas, LVM, or ZFS.

### Full Versus Incremental Backups

A full backup includes all data managed by a MySQL server at a given point in time. An incremental backup consists of the changes made to the data during a given time span (from one point in time to another). MySQL has different ways to perform full backups, such as those described earlier in this section. Incremental backups are made possible by enabling the server’s binary log, which the server uses to record data changes.

### Full Versus Point-in-Time (Incremental) Recovery

A full recovery restores all data from a full backup. This restores the server instance to the state that it had when the backup was made. If that state is not sufficiently current, a full recovery can be followed by recovery of incremental backups made since the full backup, to bring the server to a more up-to-date state.

Incremental recovery is recovery of changes made during a given time span. This is also called point-in-time recovery because it makes a server’s state current up to a given time. Point-in-time recovery is based on the binary log and typically follows a full recovery from the backup files that restores the server to its state when the backup was made. Then the data changes written in the binary log files are applied as incremental recovery to redo data modifications and bring the server up to the desired point in time.
Table Maintenance

Data integrity can be compromised if tables become corrupt. For InnoDB tables, this is not a typical issue. For programs to check MyISAM tables and repair them if problems are found, see Section 1.6, “MyISAM Table Maintenance and Crash Recovery.”

Backup Scheduling, Compression, and Encryption

Backup scheduling is valuable for automating backup procedures. Compression of backup output reduces space requirements, and encryption of the output provides better security against unauthorized access of backed-up data. MySQL itself does not provide these capabilities. The MySQL Enterprise Backup product can compress InnoDB backups, and compression or encryption of backup output can be achieved using file system utilities. Other third-party solutions may be available.

1.2 Database Backup Methods

This section summarizes some general methods for making backups.

Making a Hot Backup with MySQL Enterprise Backup

Customers of MySQL Enterprise Edition can use the MySQL Enterprise Backup product to do physical backups of entire instances or selected databases, tables, or both. This product includes features for incremental and compressed backups. Backing up the physical database files makes restore much faster than logical techniques such as the mysqldump command. InnoDB tables are copied using a hot backup mechanism. (Ideally, the InnoDB tables should represent a substantial majority of the data.) Tables from other storage engines are copied using a warm backup mechanism. For an overview of the MySQL Enterprise Backup product, see MySQL Enterprise Backup Overview.

Making Backups with mysqldump

The mysqldump program can make backups. It can back up all kinds of tables. (See Section 1.4, “Using mysqldump for Backups”.)

For InnoDB tables, it is possible to perform an online backup that takes no locks on tables using the --single-transaction option to mysqldump. See Section 1.3.1, “Establishing a Backup Policy”.

Making Backups by Copying Table Files

For storage engines that represent each table using its own files, tables can be backed up by copying those files. For example, MyISAM tables are stored as files, so it is easy to do a backup by copying files (*.frm, *.MYD, and *.MYI files). To get a consistent backup, stop the server or lock and flush the relevant tables:

```
FLUSH TABLES tbl_list WITH READ LOCK;
```

You need only a read lock; this enables other clients to continue to query the tables while you are making a copy of the files in the database directory. The flush is needed to ensure that the all active index pages are written to disk before you start the backup. See LOCK TABLES and UNLOCK TABLES Statements, and FLUSH Statement.

You can also create a binary backup simply by copying all table files, as long as the server isn’t updating anything. (But note that table file copying methods do not work if your database contains InnoDB tables. Also, even if the server is not actively updating data, InnoDB may still have modified data cached in memory and not flushed to disk.)

Making Delimited-Text File Backups

To create a text file containing a table’s data, you can use SELECT * INTO OUTFILE 'file_name' FROM tbl_name. The file is created on the MySQL server host, not the client host. For this statement,
the output file cannot already exist because permitting files to be overwritten constitutes a security risk. See SELECT Statement. This method works for any kind of data file, but saves only table data, not the table structure.

Another way to create text data files (along with files containing CREATE TABLE statements for the backed up tables) is to use mysqldump with the --tab option. See Section 1.4.3, “Dumping Data in Delimited-Text Format with mysqldump”.

To reload a delimited-text data file, use LOAD DATA or mysqlimport.

**Making Incremental Backups by Enabling the Binary Log**

MySQL supports incremental backups: You must start the server with the --log-bin option to enable binary logging; see The Binary Log. The binary log files provide you with the information you need to replicate changes to the database that are made subsequent to the point at which you performed a backup. At the moment you want to make an incremental backup (containing all changes that happened since the last full or incremental backup), you should rotate the binary log by using FLUSH LOGS. This done, you need to copy to the backup location all binary logs which range from the one of the moment of the last full or incremental backup to the last but one. These binary logs are the incremental backup; at restore time, you apply them as explained in Section 1.5, “Point-in-Time (Incremental) Recovery Using the Binary Log”. The next time you do a full backup, you should also rotate the binary log using FLUSH LOGS or mysqldump --flush-logs. See mysqldump — A Database Backup Program.

**Making Backups Using Replication Slaves**

If you have performance problems with your master server while making backups, one strategy that can help is to set up replication and perform backups on the slave rather than on the master. See Chapter 2, Using Replication for Backups.

If you are backing up a slave replication server, you should back up its master info and relay log info repositories (see Replication Relay and Status Logs) when you back up the slave's databases, regardless of the backup method you choose. These information files are always needed to resume replication after you restore the slave's data. If your slave is replicating LOAD DATA statements, you should also back up any SQL_LOAD-* files that exist in the directory that the slave uses for this purpose. The slave needs these files to resume replication of any interrupted LOAD DATA operations. The location of this directory is the value of the slave_load_tmpdir system variable. If the server was not started with that variable set, the directory location is the value of the tmpdir system variable.

**Recovering Corrupt Tables**

If you have to restore MyISAM tables that have become corrupt, try to recover them using REPAIR TABLE or myisamchk -r first. That should work in 99.9% of all cases. If myisamchk fails, see Section 1.6, “MyISAM Table Maintenance and Crash Recovery”.

**Making Backups Using a File System Snapshot**

If you are using a Veritas file system, you can make a backup like this:

1. From a client program, execute FLUSH TABLES WITH READ LOCK.
2. From another shell, execute mount vxfs snapshot.
3. From the first client, execute UNLOCK TABLES.
4. Copy files from the snapshot.
5. Unmount the snapshot.

Similar snapshot capabilities may be available in other file systems, such as LVM or ZFS.
1.3 Example Backup and Recovery Strategy

This section discusses a procedure for performing backups that enables you to recover data after several types of crashes:

- Operating system crash
- Power failure
- File system crash
- Hardware problem (hard drive, motherboard, and so forth)

The example commands do not include options such as `--user` and `--password` for the `mysqldump` and `mysql` client programs. You should include such options as necessary to enable client programs to connect to the MySQL server.

Assume that data is stored in the InnoDB storage engine, which has support for transactions and automatic crash recovery. Assume also that the MySQL server is under load at the time of the crash. If it were not, no recovery would ever be needed.

For cases of operating system crashes or power failures, we can assume that MySQL's disk data is available after a restart. The InnoDB data files might not contain consistent data due to the crash, but InnoDB reads its logs and finds in them the list of pending committed and noncommitted transactions that have not been flushed to the data files. InnoDB automatically rolls back those transactions that were not committed, and flushes to its data files those that were committed. Information about this recovery process is conveyed to the user through the MySQL error log. The following is an example log excerpt:

```
InnoDB: Database was not shut down normally.
InnoDB: Starting recovery from log files...
InnoDB: Starting log scan based on checkpoint at
InnoDB: log sequence number 0 13739520
InnoDB: Doing recovery: scanned up to log sequence number 0 13805056
InnoDB: Doing recovery: scanned up to log sequence number 0 13870592
InnoDB: Doing recovery: scanned up to log sequence number 0 13936128
... 
InnoDB: Doing recovery: scanned up to log sequence number 0 20555264
InnoDB: Doing recovery: scanned up to log sequence number 0 20620800
InnoDB: Doing recovery: scanned up to log sequence number 0 20664692
InnoDB: 1 uncommitted transaction(s) which must be rolled back
InnoDB: Starting rollback of uncommitted transactions
InnoDB: Rolling back trx no 16745
InnoDB: Rolling back of trx no 16745 completed
InnoDB: Rollback of uncommitted transactions completed
InnoDB: Starting an apply batch of log records to the database...
InnoDB: Apply batch completed
InnoDB: Started
mysqld: ready for connections
```

For the cases of file system crashes or hardware problems, we can assume that the MySQL disk data is not available after a restart. This means that MySQL fails to start successfully because some blocks of disk data are no longer readable. In this case, it is necessary to reformat the disk, install a new one, or otherwise correct the underlying problem. Then it is necessary to recover our MySQL data from backups, which means that backups must already have been made. To make sure that is the case, design and implement a backup policy.

1.3.1 Establishing a Backup Policy

To be useful, backups must be scheduled regularly. A full backup (a snapshot of the data at a point in time) can be done in MySQL with several tools. For example, MySQL Enterprise Backup can perform a physical backup of an entire instance, with optimizations to minimize overhead and avoid disruption
Establishing a Backup Policy

when backing up InnoDB data files; mysqldump provides online logical backup. This discussion uses mysqldump.

Assume that we make a full backup of all our InnoDB tables in all databases using the following command on Sunday at 1 p.m., when load is low:

```shell
mysqldump --all-databases --master-data --single-transaction > backup_sunday_1_PM.sql
```

The resulting .sql file produced by mysqldump contains a set of SQL INSERT statements that can be used to reload the dumped tables at a later time.

This backup operation acquires a global read lock on all tables at the beginning of the dump (using FLUSH TABLES WITH READ LOCK). As soon as this lock has been acquired, the binary log coordinates are read and the lock is released. If long updating statements are running when the FLUSH statement is issued, the backup operation may stall until those statements finish. After that, the dump becomes lock-free and does not disturb reads and writes on the tables.

It was assumed earlier that the tables to back up are InnoDB tables, so --single-transaction uses a consistent read and guarantees that data seen by mysqldump does not change. (Changes made by other clients to InnoDB tables are not seen by the mysqldump process.) If the backup operation includes nontransactional tables, consistency requires that they do not change during the backup. For example, for the MyISAM tables in the mysql database, there must be no administrative changes to MySQL accounts during the backup.

Full backups are necessary, but it is not always convenient to create them. They produce large backup files and take time to generate. They are not optimal in the sense that each successive full backup includes all data, even that part that has not changed since the previous full backup. It is more efficient to make an initial full backup, and then to make incremental backups. The incremental backups are smaller and take less time to produce. The tradeoff is that, at recovery time, you cannot restore your data just by reloading the full backup. You must also process the incremental backups to recover the incremental changes.

To make incremental backups, we need to save the incremental changes. In MySQL, these changes are represented in the binary log, so the MySQL server should always be started with the --log-bin option to enable that log. With binary logging enabled, the server writes each data change into a file while it updates data. Looking at the data directory of a MySQL server that was started with the --log-bin option and that has been running for some days, we find these MySQL binary log files:

- rw-rw---- 1 guilhem guilhem 1277324 Nov 10 23:59 gbichot2-bin.000001
- rw-rw---- 1 guilhem guilhem 4 Nov 10 23:59 gbichot2-bin.000002
- rw-rw---- 1 guilhem guilhem 79 Nov 11 11:06 gbichot2-bin.000003
- rw-rw---- 1 guilhem guilhem 508 Nov 11 11:08 gbichot2-bin.000004
- rw-rw---- 1 guilhem guilhem 220047446 Nov 12 16:47 gbichot2-bin.000005
- rw-rw---- 1 guilhem guilhem 998412 Nov 14 10:08 gbichot2-bin.000006
- rw-rw---- 1 guilhem guilhem 361 Nov 14 10:07 gbichot2-bin.index

Each time it restarts, the MySQL server creates a new binary log file using the next number in the sequence. While the server is running, you can also tell it to close the current binary log file and begin a new one manually by issuing a FLUSH LOGS SQL statement or with a mysqladmin flush-logs command. mysqldump also has an option to flush the logs. The .index file in the data directory contains the list of all MySQL binary logs in the directory.

The MySQL binary logs are important for recovery because they form the set of incremental backups. If you make sure to flush the logs when you make your full backup, the binary log files created afterward contain all the data changes made since the backup. Let's modify the previous mysqldump command a bit so that it flushes the MySQL binary logs at the moment of the full backup, and so that the dump file contains the name of the new current binary log:

```shell
mysqldump --single-transaction --flush-logs --master-data=2 --all-databases > backup_sunday_1_PM.sql
```

After executing this command, the data directory contains a new binary log file, gbichot2-bin.000007, because the --flush-logs option causes the server to flush its logs. The --master-
Using Backups for Recovery

The `mysqldump` command made a full backup, those lines mean two things:

- The dump file contains all changes made before any changes written to the `gbichot2-bin.000007` binary log file or higher.
- All data changes logged after the backup are not present in the dump file, but are present in the `gbichot2-bin.000007` binary log file or higher.

On Monday at 1 p.m., we can create an incremental backup by flushing the logs to begin a new binary log file. For example, executing a `mysqladmin flush-logs` command creates `gbichot2-bin.000008`. All changes between the Sunday 1 p.m. full backup and Monday 1 p.m. will be in the `gbichot2-bin.000008` file. This incremental backup is important, so it is a good idea to copy it to a safe place. (For example, back it up on tape or DVD, or copy it to another machine.) On Tuesday at 1 p.m., execute another `mysqladmin flush-logs` command. All changes between Monday 1 p.m. and Tuesday 1 p.m. will be in the `gbichot2-bin.000008` file (which also should be copied somewhere safe).

The MySQL binary logs take up disk space. To free up space, purge them from time to time. One way to do this is by deleting the binary logs that are no longer needed, such as when we make a full backup:

```shell
mysqldump --single-transaction --flush-logs --master-data=2 --all-databases --delete-master-logs > backup_sunday_1_PM.sql
```

Note: Deleting the MySQL binary logs with `mysqldump --delete-master-logs` can be dangerous if your server is a replication master server, because slave servers might not yet fully have processed the contents of the binary log. The description for the `PURGE BINARY LOGS` statement explains what should be verified before deleting the MySQL binary logs. See `PURGE BINARY LOGS Statement`.

1.3.2 Using Backups for Recovery

Now, suppose that we have a catastrophic crash on Wednesday at 8 a.m. that requires recovery from backups. To recover, first we restore the last full backup we have (the one from Sunday 1 p.m.). The full backup file is just a set of SQL statements, so restoring it is very easy:

```shell
mysql < backup_sunday_1_PM.sql
```

At this point, the data is restored to its state as of Sunday 1 p.m.. To restore the changes made since then, we must use the incremental backups; that is, the `gbichot2-bin.000007` and `gbichot2-bin.000008` binary log files. Fetch the files if necessary from where they were backed up, and then process their contents like this:

```shell
mysqlbinlog gbichot2-bin.000007 gbichot2-bin.000008 | mysql
```

We now have recovered the data to its state as of Tuesday 1 p.m., but still are missing the changes from that date to the date of the crash. To not lose them, we would have needed to have the MySQL server store its MySQL binary logs into a safe location (RAID disks, SAN, ...) different from the place where it stores its data files, so that these logs were not on the destroyed disk. (That is, we can start the server with a `--log-bin` option that specifies a location on a different physical device from the one on which the data directory resides. That way, the logs are safe even if the device containing the directory is lost.) If we had done this, we would have the `gbichot2-bin.000009` file (and any
subsequent files) at hand, and we could apply them using `mysqlbinlog` and `mysql` to restore the most recent data changes with no loss up to the moment of the crash:

```
$ mysqlbinlog gbichot2-bin.000009 ... | mysql
```

For more information about using `mysqlbinlog` to process binary log files, see Section 1.5, “Point-in-Time (Incremental) Recovery Using the Binary Log”.

### 1.3.3 Backup Strategy Summary

In case of an operating system crash or power failure, InnoDB itself does all the job of recovering data. But to make sure that you can sleep well, observe the following guidelines:

- Always run the MySQL server with the `--log-bin` option, or even `--log-bin=log_name`, where the log file name is located on some safe media different from the drive on which the data directory is located. If you have such safe media, this technique can also be good for disk load balancing (which results in a performance improvement).

- Make periodic full backups, using the `mysqldump` command shown earlier in Section 1.3.1, “Establishing a Backup Policy”, that makes an online, nonblocking backup.

- Make periodic incremental backups by flushing the logs with `FLUSH LOGS` or `mysqladmin flush-logs`.

### 1.4 Using mysqldump for Backups

This section describes how to use `mysqldump` to produce dump files, and how to reload dump files. A dump file can be used in several ways:

- As a backup to enable data recovery in case of data loss.
- As a source of data for setting up replication slaves.
- As a source of data for experimentation:
  - To make a copy of a database that you can use without changing the original data.
  - To test potential upgrade incompatibilities.

`mysqldump` produces two types of output, depending on whether the `--tab` option is given:

- Without `--tab`, `mysqldump` writes SQL statements to the standard output. This output consists of `CREATE` statements to create dumped objects (databases, tables, stored routines, and so forth), and `INSERT` statements to load data into tables. The output can be saved in a file and reloaded later using `mysql` to recreate the dumped objects. Options are available to modify the format of the SQL statements, and to control which objects are dumped.

- With `--tab`, `mysqldump` produces two output files for each dumped table. The server writes one file as tab-delimited text, one line per table row. This file is named `tbl_name.txt` in the output directory. The server also sends a `CREATE TABLE` statement for the table to `mysqldump`, which writes it as a file named `tbl_name.sql` in the output directory.

#### 1.4.1 Dumping Data in SQL Format with mysqldump

This section describes how to use `mysqldump` to create SQL-format dump files. For information about reloading such dump files, see Section 1.4.2, “Reloading SQL-Format Backups”.

By default, `mysqldump` writes information as SQL statements to the standard output. You can save the output in a file:

```
$ mysqldump [arguments] > file_name
```
To dump all databases, invoke `mysqldump` with the `--all-databases` option:

```shell
shell> mysqldump --all-databases > dump.sql
```

To dump only specific databases, name them on the command line and use the `--databases` option:

```shell
shell> mysqldump --databases db1 db2 db3 > dump.sql
```

The `--databases` option causes all names on the command line to be treated as database names. Without this option, `mysqldump` treats the first name as a database name and those following as table names.

With `--all-databases` or `--databases`, `mysqldump` writes `CREATE DATABASE` and `USE` statements prior to the dump output for each database. This ensures that when the dump file is reloaded, it creates each database if it does not exist and makes it the default database so database contents are loaded into the same database from which they came. If you want to cause the dump file to force a drop of each database before recreating it, use the `--add-drop-database` option as well. In this case, `mysqldump` writes a `DROP DATABASE` statement preceding each `CREATE DATABASE` statement.

To dump a single database, name it on the command line:

```shell
shell> mysqldump --databases test > dump.sql
```

In the single-database case, it is permissible to omit the `--databases` option:

```shell
shell> mysqldump test > dump.sql
```

The difference between the two preceding commands is that without `--databases`, the dump output contains no `CREATE DATABASE` or `USE` statements. This has several implications:

- When you reload the dump file, you must specify a default database name so that the server knows which database to reload.
- For reloading, you can specify a database name different from the original name, which enables you to reload the data into a different database.
- If the database to be reloaded does not exist, you must create it first.
- Because the output will contain no `CREATE DATABASE` statement, the `--add-drop-database` option has no effect. If you use it, it produces no `DROP DATABASE` statement.

To dump only specific tables from a database, name them on the command line following the database name:

```shell
shell> mysqldump test t1 t3 t7 > dump.sql
```

### 1.4.2 Reloading SQL-Format Backups

To reload a dump file written by `mysqldump` that consists of SQL statements, use it as input to the `mysql` client. If the dump file was created by `mysqldump` with the `--all-databases` or `--databases` option, it contains `CREATE DATABASE` and `USE` statements and it is not necessary to specify a default database into which to load the data:

```shell
shell> mysql < dump.sql
```

Alternatively, from within `mysql`, use a `source` command:

```shell
mysql> source dump.sql
```

If the file is a single-database dump not containing `CREATE DATABASE` and `USE` statements, create the database first (if necessary):

```shell
shell> mysqladmin create db1
```
Then specify the database name when you load the dump file:

```bash
shell> mysql db1 < dump.sql
```

Alternatively, from within `mysql`, create the database, select it as the default database, and load the dump file:

```sql
mysql> CREATE DATABASE IF NOT EXISTS db1;
mysql> USE db1;
mysql> source dump.sql
```

**Note**

For Windows PowerShell users: Because the "<" character is reserved for future use in PowerShell, an alternative approach is required, such as using quotes:

```cmd
cmd.exe /c "mysql < dump.sql"
```

### 1.4.3 Dumping Data in Delimited-Text Format with `mysqldump`

This section describes how to use `mysqldump` to create delimited-text dump files. For information about reloading such dump files, see Section 1.4.4, “Reloading Delimited-Text Format Backups”.

If you invoke `mysqldump` with the `--tab=dir_name` option, it uses `dir_name` as the output directory and dumps tables individually in that directory using two files for each table. The table name is the base name for these files. For a table named `t1`, the files are named `t1.sql` and `t1.txt`. The `.sql` file contains a `CREATE TABLE` statement for the table. The `.txt` file contains the table data, one line per table row.

The following command dumps the contents of the `db1` database to files in the `/tmp` database:

```bash
shell> mysqldump --tab=/tmp db1
```

The `.txt` files containing table data are written by the server, so they are owned by the system account used for running the server. The server uses `SELECT ... INTO OUTFILE` to write the files, so you must have the `FILE` privilege to perform this operation, and an error occurs if a given `.txt` file already exists.

The server sends the `CREATE` definitions for dumped tables to `mysqldump`, which writes them to `.sql` files. These files therefore are owned by the user who executes `mysqldump`.

It is best that `--tab` be used only for dumping a local server. If you use it with a remote server, the `--tab` directory must exist on both the local and remote hosts, and the `.txt` files will be written by the server in the remote directory (on the server host), whereas the `.sql` files will be written by `mysqldump` in the local directory (on the client host).

For `mysqldump --tab`, the server by default writes table data to `.txt` files one line per row with tabs between column values, no quotation marks around column values, and newline as the line terminator. (These are the same defaults as for `SELECT ... INTO OUTFILE`.)

To enable data files to be written using a different format, `mysqldump` supports these options:

- `--fields-terminated-by=str`
  The string for separating column values (default: tab).

- `--fields-enclosed-by=char`
  The character within which to enclose column values (default: no character).

- `--fields-optionally-enclosed-by=char`
  The character within which to enclose non-numeric column values (default: no character).
Reloaded Delimited-Text Format Backups

• --fields-escaped-by=char
  The character for escaping special characters (default: no escaping).

• --lines-terminated-by=\r\n
  The line-termination string (default: newline).

Depending on the value you specify for any of these options, it might be necessary on the command line to quote or escape the value appropriately for your command interpreter. Alternatively, specify the value using hex notation. Suppose that you want mysqldump to quote column values within double quotation marks. To do so, specify double quote as the value for the --fields-enclosed-by option. But this character is often special to command interpreters and must be treated specially. For example, on Unix, you can quote the double quote like this:

```
--fields-enclosed-by='"'
```

On any platform, you can specify the value in hex:

```
--fields-enclosed-by=0x22
```

It is common to use several of the data-formatting options together. For example, to dump tables in comma-separated values format with lines terminated by carriage-return/newline pairs (\r\n), use this command (enter it on a single line):

```
shell> mysqldump --tab=/tmp --fields-terminated-by=,
   --fields-enclosed-by='"' --lines-terminated-by=0x0d0a db1
```

Should you use any of the data-formatting options to dump table data, you will need to specify the same format when you reload data files later, to ensure proper interpretation of the file contents.

### 1.4.4 Reloading Delimited-Text Format Backups

For backups produced with mysqldump --tab, each table is represented in the output directory by an .sql file containing the CREATE TABLE statement for the table, and a .txt file containing the table data. To reload a table, first change location into the output directory. Then process the .sql file with mysql to create an empty table and process the .txt file to load the data into the table:

```
shell> mysql db1 < t1.sql
shell> mysqlimport db1 t1.txt
```

An alternative to using mysqlimport to load the data file is to use the LOAD DATA statement from within the mysql client:

```
mysql> USE db1;
mysql> LOAD DATA INFILE 't1.txt' INTO TABLE t1;
```

If you used any data-formatting options with mysqldump when you initially dumped the table, you must use the same options with mysqlimport or LOAD DATA to ensure proper interpretation of the data file contents:

```
shell> mysqlimport --fields-terminated-by=,
   --fields-enclosed-by='"' --lines-terminated-by=0x0d0a db1 t1.txt
```

Or:

```
mysql> USE db1;
mysql> LOAD DATA INFILE 't1.txt' INTO TABLE t1
   FIELDS TERMINATED BY ',' FIELDS ENCLOSED BY '"'
   LINES TERMINATED BY '\r\n';
```

### 1.4.5 mysqldump Tips

This section surveys techniques that enable you to use mysqldump to solve specific problems:
• How to make a copy a database
• How to copy a database from one server to another
• How to dump stored programs (stored procedures and functions, triggers, and events)
• How to dump definitions and data separately

1.4.5.1 Making a Copy of a Database

```
shell> mysqldump db1 > dump.sql
shell> mysqladmin create db2
shell> mysql db2 < dump.sql
```

Do not use `--databases` on the `mysqldump` command line because that causes `USE db1` to be included in the dump file, which overrides the effect of naming `db2` on the `mysql` command line.

1.4.5.2 Copy a Database from one Server to Another

On Server 1:

```
shell> mysqldump --databases db1 > dump.sql
```

Copy the dump file from Server 1 to Server 2.

On Server 2:

```
shell> mysql < dump.sql
```

Use of `--databases` with the `mysqldump` command line causes the dump file to include `CREATE DATABASE` and `USE` statements that create the database if it does exist and make it the default database for the reloaded data.

Alternatively, you can omit `--databases` from the `mysqldump` command. Then you will need to create the database on Server 2 (if necessary) and specify it as the default database when you reload the dump file.

On Server 1:

```
shell> mysqldump db1 > dump.sql
```

On Server 2:

```
shell> mysqladmin create db1
shell> mysql db1 < dump.sql
```

You can specify a different database name in this case, so omitting `--databases` from the `mysqldump` command enables you to dump data from one database and load it into another.

1.4.5.3 Dumping Stored Programs

Several options control how `mysqldump` handles stored programs (stored procedures and functions, triggers, and events):

• `--events`: Dump Event Scheduler events
• `--routines`: Dump stored procedures and functions
• `--triggers`: Dump triggers for tables

The `--triggers` option is enabled by default so that when tables are dumped, they are accompanied by any triggers they have. The other options are disabled by default and must be specified explicitly to dump the corresponding objects. To disable any of these options explicitly, use its skip form: `--skip-events`, `--skip-routines`, or `--skip-triggers`. 

14
1.4.5.4 Dumping Table Definitions and Content Separately

The --no-data option tells mysqldump not to dump table data, resulting in the dump file containing only statements to create the tables. Conversely, the --no-create-info option tells mysqldump to suppress CREATE statements from the output, so that the dump file contains only table data.

For example, to dump table definitions and data separately for the test database, use these commands:

```shell
mysqldump --no-data test > dump-defs.sql
mysqldump --no-create-info test > dump-data.sql
```

For a definition-only dump, add the --routines and --events options to also include stored routine and event definitions:

```shell
mysqldump --no-data --routines --events test > dump-defs.sql
```

1.4.5.5 Using mysqldump to Test for Upgrade Incompatibilities

When contemplating a MySQL upgrade, it is prudent to install the newer version separately from your current production version. Then you can dump the database and database object definitions from the production server and load them into the new server to verify that they are handled properly. (This is also useful for testing downgrades.)

On the production server:

```shell
mysqldump --all-databases --no-data --routines --events > dump-defs.sql
```

On the upgraded server:

```shell
mysql < dump-defs.sql
```

Because the dump file does not contain table data, it can be processed quickly. This enables you to spot potential incompatibilities without waiting for lengthy data-loading operations. Look for warnings or errors while the dump file is being processed.

After you have verified that the definitions are handled properly, dump the data and try to load it into the upgraded server.

On the production server:

```shell
mysqldump --all-databases --no-create-info > dump-data.sql
```

On the upgraded server:

```shell
mysql < dump-data.sql
```

Now check the table contents and run some test queries.

1.5 Point-in-Time (Incremental) Recovery Using the Binary Log

Point-in-time recovery refers to recovery of data changes made since a given point in time. Typically, this type of recovery is performed after restoring a full backup that brings the server to its state as of the time the backup was made. (The full backup can be made in several ways, such as those listed in Section 1.2, "Database Backup Methods".) Point-in-time recovery then brings the server up to date incrementally from the time of the full backup to a more recent time.

---

**Note**

Many of the examples here use the mysql client to process binary log output produced by mysqlbinlog. If your binary log contains \0 (null) characters, that
Point-in-Time (Incremental) Recovery Using the Binary Log

Point-in-time recovery is based on these principles:

- The source of information for point-in-time recovery is the set of incremental backups represented by the binary log files generated subsequent to the full backup operation. Therefore, the server must be started with the \(--log-bin\) option to enable binary logging (see The Binary Log).

To restore data from the binary log, you must know the name and location of the current binary log files. By default, the server creates binary log files in the data directory, but a path name can be specified with the \(--log-bin\) option to place the files in a different location. The Binary Log.

To see a listing of all binary log files, use this statement:

```
mysql> SHOW BINARY LOGS;
```

To determine the name of the current binary log file, issue the following statement:

```
mysql> SHOW MASTER STATUS;
```

- The `mysqlbinlog` utility converts the events in the binary log files from binary format to text so that they can be executed or viewed. `mysqlbinlog` has options for selecting sections of the binary log based on event times or position of events within the log. See `mysqlbinlog — Utility for Processing Binary Log Files`.

- Executing events from the binary log causes the data modifications they represent to be redone. This enables recovery of data changes for a given span of time. To execute events from the binary log, process `mysqlbinlog` output using the `mysql` client:

```
shell> mysqlbinlog binlog_files | mysql -u root -p
```

- Viewing log contents can be useful when you need to determine event times or positions to select partial log contents prior to executing events. To view events from the log, send `mysqlbinlog` output into a paging program:

```
shell> mysqlbinlog binlog_files | more
```

Alternatively, save the output in a file and view the file in a text editor:

```
shell> mysqlbinlog binlog_files > tmpfile
shell> ... edit tmpfile ...
```

- Saving the output in a file is useful as a preliminary to executing the log contents with certain events removed, such as an accidental DROP DATABASE. You can delete from the file any statements not to be executed before executing its contents. After editing the file, execute the contents as follows:

```
shell> mysql -u root -p < tmpfile
```

If you have more than one binary log to execute on the MySQL server, the safe method is to process them all using a single connection to the server. Here is an example that demonstrates what may be unsafe:

```
shell> mysqlbinlog binlog.000001 | mysql -u root -p # DANGER!!
shell> mysqlbinlog binlog.000002 | mysql -u root -p # DANGER!!
```

Processing binary logs this way using different connections to the server causes problems if the first log file contains a CREATE TEMPORARY TABLE statement and the second log contains a statement that uses the temporary table. When the first `mysql` process terminates, the server drops the temporary table. When the second `mysql` process attempts to use the table, the server reports “unknown table.”

To avoid problems like this, use a single connection to execute the contents of all binary logs that you want to process. Here is one way to do so:
Another approach is to write all the logs to a single file and then process the file:

```
shell> mysqlbinlog binlog.000001 > /tmp/statements.sql
shell> mysqlbinlog binlog.000002 >> /tmp/statements.sql
shell> mysql -u root -p -e "source /tmp/statements.sql"
```

When writing to a dump file while reading back from a binary log containing GTIDs (see Replication with Global Transaction Identifiers), use the `--skip-gtids` option with `mysqlbinlog`, like this:

```
shell> mysqlbinlog --skip-gtids binlog.000001 > /tmp/dump.sql
shell> mysqlbinlog --skip-gtids binlog.000002 >> /tmp/dump.sql
shell> mysql -u root -p -e "source /tmp/dump.sql"
```

### 1.5.1 Point-in-Time Recovery Using Event Times

To indicate the start and end times for recovery, specify the `--start-datetime` and `--stop-datetime` options for `mysqlbinlog`, in `DATETIME` format. As an example, suppose that exactly at 10:00 a.m. on April 20, 2005 an SQL statement was executed that deleted a large table. To restore the table and data, you could restore the previous night's backup, and then execute the following command:

```
shell> mysqlbinlog --stop-datetime="2005-04-20 9:59:59" \ 
/var/log/mysql/bin.123456 | mysql -u root -p
```

This command recovers all of the data up until the date and time given by the `--stop-datetime` option. If you did not detect the erroneous SQL statement that was entered until hours later, you will probably also want to recover the activity that occurred afterward. Based on this, you could run `mysqlbinlog` again with a start date and time, like so:

```
shell> mysqlbinlog --start-datetime="2005-04-20 10:01:00" \ 
/var/log/mysql/bin.123456 | mysql -u root -p
```

In this command, the SQL statements logged from 10:01 a.m. on will be re-executed. The combination of restoring the previous night's dump file and the two `mysqlbinlog` commands restores everything up until one second before 10:00 a.m. and everything from 10:01 a.m. on.

To use this method of point-in-time recovery, you should examine the log to be sure of the exact times to specify for the commands. To display the log file contents without executing them, use this command:

```
shell> mysqlbinlog /var/log/mysql/bin.123456 > /tmp/mysql_restore.sql
```

Then open the `/tmp/mysql_restore.sql` file with a text editor to examine it.

Excluding specific changes by specifying times for `mysqlbinlog` does not work well if multiple statements executed at the same time as the one to be excluded.

### 1.5.2 Point-in-Time Recovery Using Event Positions

Instead of specifying dates and times, the `--start-position` and `--stop-position` options for `mysqlbinlog` can be used for specifying log positions. They work the same as the start and stop date options, except that you specify log position numbers rather than dates. Using positions may enable you to be more precise about which part of the log to recover, especially if many transactions occurred around the same time as a damaging SQL statement. To determine the position numbers, run `mysqlbinlog` for a range of times near the time when the unwanted transaction was executed, but redirect the results to a text file for examination. This can be done like so:

```
shell> mysqlbinlog --start-datetime="2005-04-20 9:55:00" \ 
--stop-datetime="2005-04-20 10:05:00" \ 
/var/log/mysql/bin.123456 > /tmp/mysql_restore.sql
```
This command creates a small text file in the /tmp directory that contains the SQL statements around the time that the deleterious SQL statement was executed. Open this file with a text editor and look for the statement that you do not want to repeat. Determine the positions in the binary log for stopping and resuming the recovery and make note of them. Positions are labeled as log_pos followed by a number. After restoring the previous backup file, use the position numbers to process the binary log file. For example, you would use commands something like these:

```bash
shell> mysqlbinlog --stop-position=368312 /var/log/mysql/bin.123456 \
       | mysql -u root -p
shell> mysqlbinlog --start-position=368315 /var/log/mysql/bin.123456 \
       | mysql -u root -p
```

The first command recovers all the transactions up until the stop position given. The second command recovers all transactions from the starting position given until the end of the binary log. Because the output of `mysqlbinlog` includes `SET TIMESTAMP` statements before each SQL statement recorded, the recovered data and related MySQL logs will reflect the original times at which the transactions were executed.

### 1.6 MyISAM Table Maintenance and Crash Recovery

This section discusses how to use `myisamchk` to check or repair MyISAM tables (tables that have `.MYD` and `.MYI` files for storing data and indexes). For general `myisamchk` background, see `myisamchk — MyISAM Table-Maintenance Utility`. Other table-repair information can be found at Rebuilding or Repairing Tables or Indexes.

You can use `myisamchk` to check, repair, or optimize database tables. The following sections describe how to perform these operations and how to set up a table maintenance schedule. For information about using `myisamchk` to get information about your tables, see Obtaining Table Information with `myisamchk`.

Even though table repair with `myisamchk` is quite secure, it is always a good idea to make a backup before doing a repair or any maintenance operation that could make a lot of changes to a table.

`myisamchk` operations that affect indexes can cause MyISAM FULLTEXT indexes to be rebuilt with full-text parameters that are incompatible with the values used by the MySQL server. To avoid this problem, follow the guidelines in `myisamchk General Options`.

MyISAM table maintenance can also be done using the SQL statements that perform operations similar to what `myisamchk` can do:

- To check MyISAM tables, use `CHECK TABLE`.
- To repair MyISAM tables, use `REPAIR TABLE`.
- To optimize MyISAM tables, use `OPTIMIZE TABLE`.
- To analyze MyISAM tables, use `ANALYZE TABLE`.

For additional information about these statements, see Table Maintenance Statements.

These statements can be used directly or by means of the `mysqlcheck` client program. One advantage of these statements over `myisamchk` is that the server does all the work. With `myisamchk`, you must make sure that the server does not use the tables at the same time so that there is no unwanted interaction between `myisamchk` and the server.

### 1.6.1 Using myisamchk for Crash Recovery

This section describes how to check for and deal with data corruption in MySQL databases. If your tables become corrupted frequently, you should try to find the reason why. See What to Do If MySQL Keeps Crashing.
For an explanation of how MyISAM tables can become corrupted, see MyISAM Table Problems.

If you run mysqld with external locking disabled (which is the default), you cannot reliably use myisamchk to check a table when mysqld is using the same table. If you can be certain that no one will access the tables through mysqld while you run myisamchk, you only have to execute mysqladmin flush-tables before you start checking the tables. If you cannot guarantee this, you must stop mysqld while you check the tables. If you run myisamchk to check tables that mysqld is updating at the same time, you may get a warning that a table is corrupt even when it is not.

If the server is run with external locking enabled, you can use myisamchk to check tables at any time. In this case, if the server tries to update a table that myisamchk is using, the server will wait for myisamchk to finish before it continues.

If you use myisamchk to repair or optimize tables, you must always ensure that the mysqld server is not using the table (this also applies if external locking is disabled). If you do not stop mysqld, you should at least do a mysqladmin flush-tables before you run myisamchk. Your tables may become corrupted if the server and myisamchk access the tables simultaneously.

When performing crash recovery, it is important to understand that each MyISAM table tbl_name in a database corresponds to the three files in the database directory shown in the following table.

<table>
<thead>
<tr>
<th>File</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>tbl_name.frm</td>
<td>Definition (format) file</td>
</tr>
<tr>
<td>tbl_name.MYD</td>
<td>Data file</td>
</tr>
<tr>
<td>tbl_name.MYI</td>
<td>Index file</td>
</tr>
</tbody>
</table>

Each of these three file types is subject to corruption in various ways, but problems occur most often in data files and index files.

myisamchk works by creating a copy of the .MYD data file row by row. It ends the repair stage by removing the old .MYD file and renaming the new file to the original file name. If you use --quick, myisamchk does not create a temporary .MYD file, but instead assumes that the .MYD file is correct and generates only a new index file without touching the .MYD file. This is safe, because myisamchk automatically detects whether the .MYD file is corrupt and aborts the repair if it is. You can also specify the --quick option twice to myisamchk. In this case, myisamchk does not abort on some errors (such as duplicate-key errors) but instead tries to resolve them by modifying the .MYD file. Normally the use of two --quick options is useful only if you have too little free disk space to perform a normal repair. In this case, you should at least make a backup of the table before running myisamchk.

### 1.6.2 How to Check MyISAM Tables for Errors

To check a MyISAM table, use the following commands:

- **myisamchk tbl_name**
  
  This finds 99.99% of all errors. What it cannot find is corruption that involves only the data file (which is very unusual). If you want to check a table, you should normally run myisamchk without options or with the -s (silent) option.

- **myisamchk -m tbl_name**
  
  This finds 99.999% of all errors. It first checks all index entries for errors and then reads through all rows. It calculates a checksum for all key values in the rows and verifies that the checksum matches the checksum for the keys in the index tree.

- **myisamchk -e tbl_name**
  
  This does a complete and thorough check of all data (-e means "extended check"). It does a check-read of every key for each row to verify that they indeed point to the correct row. This may take a
long time for a large table that has many indexes. Normally, `myisamchk` stops after the first error it finds. If you want to obtain more information, you can add the `-v` (verbose) option. This causes `myisamchk` to keep going, up through a maximum of 20 errors.

- `myisamchk -e -i tbl_name`

This is like the previous command, but the `-i` option tells `myisamchk` to print additional statistical information.

In most cases, a simple `myisamchk` command with no arguments other than the table name is sufficient to check a table.

### 1.6.3 How to Repair MyISAM Tables

The discussion in this section describes how to use `myisamchk` on MyISAM tables (extensions `.MYI` and `.MYD`).

You can also use the `CHECK TABLE` and `REPAIR TABLE` statements to check and repair MyISAM tables. See `CHECK TABLE Statement`, and `REPAIR TABLE Statement`.

Symptoms of corrupted tables include queries that abort unexpectedly and observable errors such as these:

- `tbl_name.frm` is locked against change
- Can't find file `tbl_name.MYI` (Errcode: `nnn`)
- Unexpected end of file
- Record file is crashed
- Got error `nnn` from table handler

To get more information about the error, run `perror nnn`, where `nnn` is the error number. The following example shows how to use `perror` to find the meanings for the most common error numbers that indicate a problem with a table:

```
shell> perror 126 127 132 134 135 136 141 144 145
MySQL error code 126 = Index file is crashed
MySQL error code 127 = Record-file is crashed
MySQL error code 132 = Old database file
MySQL error code 134 = Record was already deleted (or record file crashed)
MySQL error code 135 = No more room in record file
MySQL error code 136 = No more room in index file
MySQL error code 141 = Duplicate unique key or constraint on write or update
MySQL error code 144 = Table is crashed and last repair failed
MySQL error code 145 = Table was marked as crashed and should be repaired
```

Note that error 135 (no more room in record file) and error 136 (no more room in index file) are not errors that can be fixed by a simple repair. In this case, you must use `ALTER TABLE` to increase the `MAX_ROWS` and `AVG_ROW_LENGTH` table option values:

```
ALTER TABLE `tbl_name` MAX_ROWS=xxx AVG_ROW_LENGTH=yyy;
```

If you do not know the current table option values, use `SHOW CREATE TABLE`.

For the other errors, you must repair your tables. `myisamchk` can usually detect and fix most problems that occur.

The repair process involves up to four stages, described here. Before you begin, you should change location to the database directory and check the permissions of the table files. On Unix, make sure that they are readable by the user that `mysql` runs as (and to you, because you need to access the files you are checking). If it turns out you need to modify files, they must also be writable by you.
This section is for the cases where a table check fails (such as those described in Section 1.6.2, “How to Check MyISAM Tables for Errors”), or you want to use the extended features that myisamchk provides.

The myisamchk options used for table maintenance with are described in myisamchk — MyISAM Table-Maintenance Utility. myisamchk also has variables that you can set to control memory allocation that may improve performance. See myisamchk Memory Usage.

If you are going to repair a table from the command line, you must first stop the mysqld server. Note that when you do mysqladmin shutdown on a remote server, the mysqld server is still available for a while after mysqladmin returns, until all statement-processing has stopped and all index changes have been flushed to disk.

Stage 1: Checking your tables

Run myisamchk *.MYI or myisamchk -e *.MYI if you have more time. Use the -s (silent) option to suppress unnecessary information.

If the mysqld server is stopped, you should use the --update-state option to tell myisamchk to mark the table as “checked.”

You have to repair only those tables for which myisamchk announces an error. For such tables, proceed to Stage 2.

If you get unexpected errors when checking (such as out of memory errors), or if myisamchk crashes, go to Stage 3.

Stage 2: Easy safe repair

First, try myisamchk -r -q tbl_name (-r -q means “quick recovery mode”). This attempts to repair the index file without touching the data file. If the data file contains everything that it should and the delete links point at the correct locations within the data file, this should work, and the table is fixed.

Start repairing the next table. Otherwise, use the following procedure:

1. Make a backup of the data file before continuing.

2. Use myisamchk -r tbl_name (-r means “recovery mode”). This removes incorrect rows and deleted rows from the data file and reconstructs the index file.

3. If the preceding step fails, use myisamchk --safe-recover tbl_name. Safe recovery mode uses an old recovery method that handles a few cases that regular recovery mode does not (but is slower).

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you want a repair operation to go much faster, you should set the values of the sort_buffer_size and key_buffer_size variables each to about 25% of your available memory when running myisamchk.</td>
</tr>
</tbody>
</table>

If you get unexpected errors when repairing (such as out of memory errors), or if myisamchk crashes, go to Stage 3.

Stage 3: Difficult repair

You should reach this stage only if the first 16KB block in the index file is destroyed or contains incorrect information, or if the index file is missing. In this case, it is necessary to create a new index file. Do so as follows:

1. Move the data file to a safe place.

2. Use the table description file to create new (empty) data and index files:
MyISAM Table Optimization

3. Copy the old data file back onto the newly created data file. (Do not just move the old file back onto the new file. You want to retain a copy in case something goes wrong.)

   Important
   If you are using replication, you should stop it prior to performing the above procedure, since it involves file system operations, and these are not logged by MySQL.

Go back to Stage 2. `myisamchk -r -q` should work. (This should not be an endless loop.)

You can also use the `REPAIR TABLE tbl_name USE_FRM` SQL statement, which performs the whole procedure automatically. There is also no possibility of unwanted interaction between a utility and the server, because the server does all the work when you use `REPAIR TABLE`. See `REPAIR TABLE Statement`.

Stage 4: Very difficult repair

You should reach this stage only if the `.frm` description file has also crashed. That should never happen, because the description file is not changed after the table is created:

1. Restore the description file from a backup and go back to Stage 3. You can also restore the index file and go back to Stage 2. In the latter case, you should start with `myisamchk -r`.

2. If you do not have a backup but know exactly how the table was created, create a copy of the table in another database. Remove the new data file, and then move the `.frm` description and `.MYI` index files from the other database to your crashed database. This gives you new description and index files, but leaves the `.MYD` data file alone. Go back to Stage 2 and attempt to reconstruct the index file.

1.6.4 MyISAM Table Optimization

To coalesce fragmented rows and eliminate wasted space that results from deleting or updating rows, run `myisamchk` in recovery mode:

```
shell> myisamchk -r tbl_name
```

You can optimize a table in the same way by using the `OPTIMIZE TABLE` SQL statement. `OPTIMIZE TABLE` does a table repair and a key analysis, and also sorts the index tree so that key lookups are faster. There is also no possibility of unwanted interaction between a utility and the server, because the server does all the work when you use `OPTIMIZE TABLE`. See `OPTIMIZE TABLE Statement`.

`myisamchk` has a number of other options that you can use to improve the performance of a table:

- `--analyze` or `-a`: Perform key distribution analysis. This improves join performance by enabling the join optimizer to better choose the order in which to join the tables and which indexes it should use.
- `--sort-index` or `-S`: Sort the index blocks. This optimizes seeks and makes table scans that use indexes faster.
- `--sort-records=index_num` or `-R index_num`: Sort data rows according to a given index. This makes your data much more localized and may speed up range-based `SELECT` and `ORDER BY` operations that use this index.

For a full description of all available options, see `myisamchk — MyISAM Table-Maintenance Utility.`
1.6.5 Setting Up a MyISAM Table Maintenance Schedule

It is a good idea to perform table checks on a regular basis rather than waiting for problems to occur. One way to check and repair MyISAM tables is with the `CHECK TABLE` and `REPAIR TABLE` statements. See Table Maintenance Statements.

Another way to check tables is to use `myisamchk`. For maintenance purposes, you can use `myisamchk -s`. The `-s` option (short for `--silent`) causes `myisamchk` to run in silent mode, printing messages only when errors occur.

It is also a good idea to enable automatic MyISAM table checking. For example, whenever the machine has done a restart in the middle of an update, you usually need to check each table that could have been affected before it is used further. (These are “expected crashed tables.”) To cause the server to check MyISAM tables automatically, start it with the `myisam_recover_options` system variable set. See Server System Variables.

You should also check your tables regularly during normal system operation. For example, you can run a cron job to check important tables once a week, using a line like this in a crontab file:

```
35 0 * * 0 /path/to/myisamchk --fast --silent /path/to/datadir/*//*.MYI
```

This prints out information about crashed tables so that you can examine and repair them as necessary.

To start with, execute `myisamchk -s` each night on all tables that have been updated during the last 24 hours. As you see that problems occur infrequently, you can back off the checking frequency to once a week or so.

Normally, MySQL tables need little maintenance. If you are performing many updates to MyISAM tables with dynamic-sized rows (tables with `VARCHAR`, `BLOB`, or `TEXT` columns) or have tables with many deleted rows you may want to defragment/reclaim space from the tables from time to time. You can do this by using `OPTIMIZE TABLE` on the tables in question. Alternatively, if you can stop the mysqld server for a while, change location into the data directory and use this command while the server is stopped:

```
shell> myisamchk -r -s --sort-index --myisam_sort_buffer_size=16M */*.MYI
```
Chapter 2 Using Replication for Backups

Table of Contents

2.1 Backing Up a Slave Using mysqldump ................................................................. 25
2.2 Backing Up Raw Data from a Slave ................................................................. 26
2.3 Backing Up a Master or Slave by Making It Read Only ..................................... 27

To use replication as a backup solution, replicate data from the master to a slave, and then back up the data slave. The slave can be paused and shut down without affecting the running operation of the master, so you can produce an effective snapshot of “live” data that would otherwise require the master to be shut down.

How you back up a database depends on its size and whether you are backing up only the data, or the data and the replication slave state so that you can rebuild the slave in the event of failure. There are therefore two choices:

- If you are using replication as a solution to enable you to back up the data on the master, and the size of your database is not too large, the `mysqldump` tool may be suitable. See Section 2.1, “Backining Up a Slave Using mysqldump”.

- For larger databases, where `mysqldump` would be impractical or inefficient, you can back up the raw data files instead. Using the raw data files option also means that you can back up the binary and relay logs that will enable you to recreate the slave in the event of a slave failure. For more information, see Section 2.2, “Backing Up Raw Data from a Slave”.

Another backup strategy, which can be used for either master or slave servers, is to put the server in a read-only state. The backup is performed against the read-only server, which then is changed back to its usual read/write operational status. See Section 2.3, “Backing Up a Master or Slave by Making It Read Only”.

### 2.1 Backing Up a Slave Using mysqldump

Using `mysqldump` to create a copy of a database enables you to capture all of the data in the database in a format that enables the information to be imported into another instance of MySQL Server (see `mysqldump — A Database Backup Program`). Because the format of the information is SQL statements, the file can easily be distributed and applied to running servers in the event that you need access to the data in an emergency. However, if the size of your data set is very large, `mysqldump` may be impractical.

When using `mysqldump`, you should stop replication on the slave before starting the dump process to ensure that the dump contains a consistent set of data:

1. Stop the slave from processing requests. You can stop replication completely on the slave using `mysqladmin`:

   ```
   shell> mysqladmin stop-slave
   ```

   Alternatively, you can stop only the slave SQL thread to pause event execution:

   ```
   shell> mysql -e 'STOP SLAVE SQL_THREAD;'
   ```

   This enables the slave to continue to receive data change events from the master’s binary log and store them in the relay logs using the I/O thread, but prevents the slave from executing these events and changing its data. Within busy replication environments, permitting the I/O thread to run during backup may speed up the catch-up process when you restart the slave SQL thread.

2. Run `mysqldump` to dump your databases. You may either dump all databases or select databases to be dumped. For example, to dump all databases:
3. Once the dump has completed, start slave operations again:

```shell
mysqladmin start-slave
```

In the preceding example, you may want to add login credentials (user name, password) to the commands, and bundle the process up into a script that you can run automatically each day.

If you use this approach, make sure you monitor the slave replication process to ensure that the time taken to run the backup does not affect the slave's ability to keep up with events from the master. See Checking Replication Status. If the slave is unable to keep up, you may want to add another slave and distribute the backup process. For an example of how to configure this scenario, see Replicating Different Databases to Different Slaves.

### 2.2 Backing Up Raw Data from a Slave

To guarantee the integrity of the files that are copied, backing up the raw data files on your MySQL replication slave should take place while your slave server is shut down. If the MySQL server is still running, background tasks may still be updating the database files, particularly those involving storage engines with background processes such as InnoDB. With InnoDB, these problems should be resolved during crash recovery, but since the slave server can be shut down during the backup process without affecting the execution of the master it makes sense to take advantage of this capability.

To shut down the server and back up the files:

1. Shut down the slave MySQL server:

   ```shell
   mysqladmin shutdown
   ```

2. Copy the data files. You can use any suitable copying or archive utility, including `cp`, `tar` or WinZip. For example, assuming that the data directory is located under the current directory, you can archive the entire directory as follows:

   ```shell
   tar cf /tmp/dbbackup.tar ./data
   ```

3. Start the MySQL server again. Under Unix:

   ```shell
   mysqld_safe &
   ```

   Under Windows:

   `C:\> "C:\Program Files\MySQL\MySQL Server 5.7\bin\mysqld"

Normally you should back up the entire data directory for the slave MySQL server. If you want to be able to restore the data and operate as a slave (for example, in the event of failure of the slave), then in addition to the slave's data, you should also back up the slave status files, the master info and relay log info repositories, and the relay log files. These files are needed to resume replication after you restore the slave's data.

If you lose the relay logs but still have the `relay-log.info` file, you can check it to determine how far the SQL thread has executed in the master binary logs. Then you can use `CHANGE MASTER TO` with the `MASTER_LOG_FILE` and `MASTER_LOG_POS` options to tell the slave to re-read the binary logs from that point. This requires that the binary logs still exist on the master server.

If your slave is replicating `LOAD DATA` statements, you should also back up any `SQL_LOAD-*` files that exist in the directory that the slave uses for this purpose. The slave needs these files to resume replication of any interrupted `LOAD DATA` operations. The location of this directory is the value of the `slave_load_tmpdir` system variable. If the server was not started with that variable set, the directory location is the value of the `tmpdir` system variable.
2.3 Backing Up a Master or Slave by Making It Read Only

It is possible to back up either master or slave servers in a replication setup by acquiring a global read lock and manipulating the `read_only` system variable to change the read-only state of the server to be backed up:

1. Make the server read-only, so that it processes only retrievals and blocks updates.
2. Perform the backup.
3. Change the server back to its normal read/write state.

**Note**
The instructions in this section place the server to be backed up in a state that is safe for backup methods that get the data from the server, such as `mysqldump` (see `mysqldump — A Database Backup Program`). You should not attempt to use these instructions to make a binary backup by copying files directly because the server may still have modified data cached in memory and not flushed to disk.

The following instructions describe how to do this for a master server and for a slave server. For both scenarios discussed here, suppose that you have the following replication setup:

- A master server M1
- A slave server S1 that has M1 as its master
- A client C1 connected to M1
- A client C2 connected to S1

In either scenario, the statements to acquire the global read lock and manipulate the `read_only` variable are performed on the server to be backed up and do not propagate to any slaves of that server.

**Scenario 1: Backup with a Read-Only Master**

Put the master M1 in a read-only state by executing these statements on it:

```sql
mysql> FLUSH TABLES WITH READ LOCK;
mysql> SET GLOBAL read_only = ON;
```

While M1 is in a read-only state, the following properties are true:

- Requests for updates sent by C1 to M1 will block because the server is in read-only mode.
- Requests for query results sent by C1 to M1 will succeed.
- Making a backup on M1 is safe.
- Making a backup on S1 is not safe. This server is still running, and might be processing the binary log or update requests coming from client C2

While M1 is read only, perform the backup. For example, you can use `mysqldump`.

After the backup operation on M1 completes, restore M1 to its normal operational state by executing these statements:

```sql
mysql> SET GLOBAL read_only = OFF;
mysql> UNLOCK TABLES;
```

Although performing the backup on M1 is safe (as far as the backup is concerned), it is not optimal for performance because clients of M1 are blocked from executing updates.
This strategy applies to backing up a master server in a replication setup, but can also be used for a single server in a nonreplication setting.

**Scenario 2: Backup with a Read-Only Slave**

Put the slave S1 in a read-only state by executing these statements on it:

```mysql
mysql> FLUSH TABLES WITH READ LOCK;
mysql> SET GLOBAL read_only = ON;
```

While S1 is in a read-only state, the following properties are true:

- The master M1 will continue to operate, so making a backup on the master is not safe.
- The slave S1 is stopped, so making a backup on the slave S1 is safe.

These properties provide the basis for a popular backup scenario: Having one slave busy performing a backup for a while is not a problem because it does not affect the entire network, and the system is still running during the backup. In particular, clients can still perform updates on the master server, which remains unaffected by backup activity on the slave.

While S1 is read only, perform the backup. For example, you can use `mysqldump`.

After the backup operation on S1 completes, restore S1 to its normal operational state by executing these statements:

```mysql
mysql> SET GLOBAL read_only = OFF;
mysql> UNLOCK TABLES;
```

After the slave is restored to normal operation, it again synchronizes to the master by catching up with any outstanding updates from the binary log of the master.
Chapter 3 InnoDB Backup

The key to safe database management is making regular backups. Depending on your data volume, number of MySQL servers, and database workload, you can use these backup techniques, alone or in combination: hot backup with MySQL Enterprise Backup; cold backup by copying files while the MySQL server is shut down; logical backup with mysqldump for smaller data volumes or to record the structure of schema objects. Hot and cold backups are physical backups that copy actual data files, which can be used directly by the mysqld server for faster restore.

Using MySQL Enterprise Backup is the recommended method for backing up InnoDB data.

Note

InnoDB does not support databases that are restored using third-party backup tools.

Hot Backups

The mysqlbackup command, part of the MySQL Enterprise Backup component, lets you back up a running MySQL instance, including InnoDB tables, with minimal disruption to operations while producing a consistent snapshot of the database. When mysqlbackup is copying InnoDB tables, reads and writes to InnoDB tables can continue. MySQL Enterprise Backup can also create compressed backup files, and back up subsets of tables and databases. In conjunction with the MySQL binary log, users can perform point-in-time recovery. MySQL Enterprise Backup is part of the MySQL Enterprise subscription. For more details, see MySQL Enterprise Backup Overview.

Cold Backups

If you can shut down the MySQL server, you can make a physical backup that consists of all files used by InnoDB to manage its tables. Use the following procedure:

1. Perform a slow shutdown of the MySQL server and make sure that it stops without errors.
2. Copy all InnoDB data files (ibdata files and .ibd files) into a safe place.
3. Copy all the .frm files for InnoDB tables to a safe place.
4. Copy all InnoDB log files (ib_logfile files) to a safe place.
5. Copy your my.cnf configuration file or files to a safe place.

Logical Backups Using mysqldump

In addition to physical backups, it is recommended that you regularly create logical backups by dumping your tables using mysqldump. A binary file might be corrupted without you noticing it. Dumped tables are stored into text files that are human-readable, so spotting table corruption becomes easier. Also, because the format is simpler, the chance for serious data corruption is smaller. mysqldump also has a --single-transaction option for making a consistent snapshot without locking out other clients. See Section 1.3.1, “Establishing a Backup Policy”.

Replication works with InnoDB tables, so you can use MySQL replication capabilities to keep a copy of your database at database sites requiring high availability. See InnoDB and MySQL Replication.