Administrator's Guide

Abstract

This books explains how to create and manage VoltDB databases and the clusters that run them.

V5.2

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Preface

This book explains how to manage VoltDB databases and the clusters that host them. It is intended for database administrators and operators, responsible for the ongoing management and maintenance of database infrastructure.

1. Structure of This Book

This book is divided into 7 chapters and 3 appendices:

- Chapter 1, *Managing VoltDB Databases*
- Chapter 2, *Preparing the Servers*
- Chapter 3, *Starting and Stopping the Database*
- Chapter 4, *Maintenance and Upgrades*
- Chapter 5, *Monitoring VoltDB Databases*
- Chapter 6, *Logging and Analyzing Activity in a VoltDB Database*
- Chapter 7, *What to Do When Problems Arise*
- Appendix A, *Server Configuration Options*
- Appendix B, *Snapshot Utilities*
- Appendix C, *Using Application Catalogs*

2. Related Documents

This book does not describe how to design or develop VoltDB databases. For a complete description of the development process for VoltDB and all of its features, please see the accompanying manual *Using VoltDB*. For new users, see the *VoltDB Tutorial*. These and other books describing VoltDB are available on the web from http://docs.voltdb.com/.

Chapter 1. Managing VoltDB Databases

VoltDB is a distributed, in-memory database designed from the ground up to maximize throughput performance on commodity servers. The VoltDB architecture provides many advantages over traditional database products while avoiding the pitfalls of NoSQL solutions:

- By partitioning the data and stored procedures, VoltDB can process multiple queries in parallel without sacrificing the consistency or durability of an ACID-compliant database.
- By managing all data in memory with a single thread for each partition, VoltDB avoids overhead such as record locking, latching, and device-contention inherent in traditional disk-based databases.
- VoltDB databases can scale up to meet new capacity or performance requirements simply by adding more nodes to the cluster.
- Partitioning is automated, based on the schema, so there is no need to manually shard or repartition the data when scaling up as with many NoSQL solutions.
- Finally, VoltDB Enterprise Edition provides features to ensure durability and high availability through command logging, locally replicating partitions (K-safety), and wide-area database replication.

Each of these features is described, in detail, in the *Using VoltDB* manual. This book explains how to use these and other features to manage and maintain a VoltDB database cluster from a database administrator's perspective.

1.1. Getting Started

To initialize a VoltDB database cluster, you need a deployment file. The *deployment file* defines:

- **The physical structure of the cluster** — including the number of nodes in the cluster and how many partitions each node manages.
- **The configuration of individual database features** — different elements of the deployment file let you enable and configure various database options including availability, durability, and security.

When using the VoltDB Enterprise Edition, you will also need a license file, often called `license.xml`. VoltDB automatically looks for the license file in the user's current working directory, the home directory, or the `voltdb/` subfolder where VoltDB is installed. If you keep the license file in a different directory or under a different name, you can use to `--license` argument on the **voltdb** command to specify the license file location.

Finally, to prepare the database for a specific application, you will need the database schema, including the DDL statements that describe the database's logical structure, and a JAR file containing stored procedure class files. In general, the database schema and stored procedures are produced as part of the database development process, which is described in the *Using VoltDB* manual.

This book assumes the schema and stored procedures have already been created. The deployment file, on the other hand, defines the run-time configuration of the cluster. Establishing the correct settings for the deployment file and physically managing the database cluster is the duty of the administrators who are responsible for maintaining database operations. This book is written for those individuals and covers the standard procedures associated with database administration.

1.2. Understanding the VoltDB Utilities

VoltDB provides several command line utilities, each with a different function. Familiarizing yourself with these utilities and their uses can make managing VoltDB databases easier. The three primary command line tools for creating, managing, and testing VoltDB databases are:

voltdb	Starts the VoltDB database process. The **voltdb** command can also collect log files for analyzing possible system errors (see Section 7.3.1, "Collecting Log Files Using the Command Line" for details). The **voltdb** command runs locally and does not require a running database.
voltadmin	Issues administrative commands to a running VoltDB database. You can use **voltadmin** to save and restore snapshots, pause and resume admin mode, and to shutdown the database, among other tasks. The **voltadmin** command can be run remotely, performs cluster-wide operations and requires a running database to connect to.
sqlcmd	Lets you issue SQL queries and invoke stored procedures interactively. The **sqlcmd** command is handy for testing database access without having to write a client application. The **sqlcmd** command can be run remotely and requires a running database to connect to.

In addition to the preceding general-purpose tools, VoltDB provides several other tools for specific tasks:

csvloader	Loads records from text files into an existing VoltDB database. The command's primary use is for importing data into VoltDB from CSV and other text-based data files that were exported from other data utilities, The **csvloader** command can be run remotely and requires a running database to connect to.
snapshotconvert	Converts native snapshot files to csv or tabbed text files. The **snapshotconvert** command is useful when exporting a snapshot in native format to text files for import into another data utility. (This utility is provided for legacy purposes. It is now possible to write snapshots directly to CSV format without post-processing, which is the recommended approach.) The **snapshotconvert** command runs locally and does not require a running database.
snapshotverify	Verifies that a set of native snapshot files are complete and valid. The **snapshotverify** command runs locally and does not require a running database.

Finally, VoltDB includes a browser-based management interface, the VoltDB Management Center, that lets you monitor the database cluster in realtime. See Section 5.1.1, "VoltDB Management Center" for more information about using the Management Center.

1.3. Management Tasks

Database administration responsibilities fall into five main categories, as described in Table 1.1, "Database Management Tasks". The following chapters are organized by category and explain how to perform each task for a VoltDB database.

Table 1.1. Database Management Tasks

Preparing the Servers	Before starting the database, you must make sure that the server hardware and software is properly configured. This chapter provides a checklist of tasks to perform before starting VoltDB.
Basic Database Operations	The basic operations of starting and stopping the database. This chapter describes the procedures needed to handle these fundamental tasks.
Maintenance and Upgrades	Over time, both the cluster and the database may require maintenance — either planned or emergency. This chapter explains the procedures for performing hardware and software maintenance, as well as standard maintenance, such as backing up the database and upgrading the hardware, the software, and the database schema.
Performance Monitoring	Another important role for many database administrators is monitoring database performance. Monitoring is important for several reasons: • Performance Analysis • Load Balancing • Fault Detection This chapter describes the tools available for monitoring VoltDB databases.
Problem Reporting & Analysis	If an error does occur and part or all of the database cluster fails, it is not only important to get the database up and running again, but to diagnose the cause of the problem and take corrective actions. VoltDB produces a number of log files that can help with problem resolution. This chapter describes the different logs that are available and how to use them to diagnose database issues.

Chapter 2. Preparing the Servers

VoltDB is designed to run on commodity servers, greatly reducing the investment required to operate a high performance database. However, out of the box, these machines are not necessarily configured for optimal performance of a dedicated, clustered application like VoltDB. This is especially true when using cloud-based services. This chapter provides best practices for configuring servers to maximize the performance and stability of your VoltDB installation.

2.1. Server Checklist

The very first step in configuring the servers is making sure you have sufficient memory, computing power, and system resources such as disk space to handle the expected workload. The *VoltDB Planning Guide* provides detailed information on how to size your server requirements.

The next step is to configure the servers and assign appropriate resources for VoltDB tasks. Specific server features that must be configured for VoltDB to perform optimally are:

- Install required software
- Configure memory management
- Turn off TCP Segmentation
- Configure NTP (time services)
- Define network addresses for all nodes in the cluster
- Assign network ports

2.2. Install Required Software

To start, VoltDB requires a recent release of the Linux operating system. The supported operating systems for running production VoltDB databases are:

- CentOS V6.3 or later. Including CentOS 7.0
- Red Hat (RHEL) V6.3 or later, including Red Hat 7.0
- Ubuntu 12.04, and 14.04

It may be possible to run VoltDB on other versions of Linux. Also, an official release for Macintosh OS X 10.7 and later is provided for development purposes. However, the preceding operating system versions are the only fulled tested and supported base platforms for running VoltDB in production.

In addition to the base operating system, VoltDB requires the following software at a minimum:

- Java 7 or 8
- NTP
- Python 2.4 or later

Sun Java SDK 8 is recommended. Sun Java SDK 7 and OpenJDK 7 or 8 are also supported. However, Java 7 is deprecated and support for Java 7 will be removed some time after it reaches end-of-life, which is currently scheduled for April 2015.

Note that although the VoltDB server requires Java 7 or 8, the Java client is also compatible with Java 6.

VoltDB requires the system clocks on all cluster nodes be synchronized to within 100 milliseconds. NTP, the Network Time Protocol, is recommended for achieving the necessary synchronization. NTP is installed and enabled by default on many operating systems. However, the configuration may need adjusting (see Section 2.5, “Configure NTP” for details) and in cloud instances where hosted servers are run in a virtual environment, NTP is not always installed or enabled by default. Therefore you need to do this manually.

Finally, VoltDB implements its command line interface through Python. Python 2.4 or later is required to use the VoltDB shell commands.

2.3. Configure Memory Management

Because VoltDB is an in-memory database, proper memory management is vital to the effective operation of VoltDB databases. Two important aspects of memory management are:

- Swapping
- Virtual memory

The following sections explain how best to configure these features for optimal performance of VoltDB.

2.3.1. Disable Swapping

Swapping is an operating system feature that optimizes memory usage when running multiple processes by swapping processes in and out of memory. However, any contention for memory, including swapping, will have a very negative impact on VoltDB performance and functionality. You should disable swapping when using VoltDB.

To disable swapping on Linux systems, use the `swapoff` command. If swapping cannot be disabled for any reason, you can reduce the likelihood of VoltDB being swapped out by setting the kernel parameter `vm.swappiness` to zero.

2.3.2. Enable Virtual Memory Mapping and Overcommit

Although swapping is bad for memory-intensive applications like VoltDB, the server does make use of virtual memory (VM) and there are settings that can help VoltDB make effective use of that memory. First, it is a good idea to enable VM overcommit. This avoids VoltDB encountering unnecessary limits when managing virtual memory. This is done on Linux by setting the system parameter `vm.overcommit_memory` to a value of "1".

```
$ sysctl -w vm.overcommit_memory=1
```

Second, for large memory systems, it is also a good idea to increase the VM memory mapping limit. So for servers with 64 Gigabytes or more of memory, the recommendation is to increase VM memory map count to 1048576. You do this on Linux with the system parameter `max_map_count`. For example:

```
$ sysctl -w vm.max_map_count=1048576
```

Remember that for both overcommit and the memory map count, the parameters are only active while the system is running and will be reset to the default on reboot. So be sure to add your new settings to the file `/etc/sysctl.conf` to ensure they are in effect when the system is restarted.

2.4. Turn off TCP Segmentation

Under certain conditions, the use of TCP segmentation offload (TSO) and generic receive offload (GRO) can cause nodes to randomly drop out of a cluster. The symptoms of this problem are that nodes timeout — that is, the rest of the cluster thinks they have failed — although the node is still running and no other network issues (such as a network partition) are the cause.

Disabling TSO and GRO is recommended for any VoltDB clusters that experience such instability. The commands to disable offloading are the following, where N is replaced by the number of the ethernet card:

```
ethtool -K ethN tso off
ethtool -K ethN gro off
```

Note that these commands disable offloading temporarily. You must issue these commands every time the node reboots or, preferably, put them in a startup configuration file.

2.5. Configure NTP

To orchestrate activities between the cluster nodes, VoltDB relies on the system clocks being synchronized. Many functions within VoltDB — such as cluster start up, nodes rejoining, and schema updates among others — are sensitive to variations in the time values between nodes in the cluster. Therefore, it is important to keep the clocks synchronized within the cluster. Specifically:

- The server clocks within the cluster must be synchronized to within 100 milliseconds of each other when the cluster starts. (Ideally, skew between nodes should be kept under 10 milliseconds.)
- Time must not move backwards

The easiest way to achieve these goals is to install and configure the NTP (Network Time Protocol) service to use a common time host server for synchronizing the servers. NTP is often installed by default but may require additional configuration to achieve acceptable synchronization. Specifically, listing only one time server (and the same one for all nodes in the cluster) ensures minimal skew between servers. You can even establish your own time server to facilitate this. All nodes in the cluster should also list each other as peers. For example, the following NTP configuration file uses a local time server (myntpsvr) and establishes all nodes in the cluster as peers:

```
server myntpsvr burst iburst minpoll 4 maxpoll 4

peer voltsvr1 burst iburst minpoll 4 maxpoll 4
peer voltsvr2 burst iburst minpoll 4 maxpoll 4
peer voltsvr3 burst iburst minpoll 4 maxpoll 4

server 127.127.0.1
```

See the chapter on Configuring NTP in the *Performance Guide* for more details on setting up NTP.

2.6. Configure the Network

It is also important to ensure that the network is configured correctly so all of the nodes in the VoltDB cluster recognize each other. If the DNS server does not contain entries for all of the servers in the cluster, an alternative is to add entries in the /etc/hosts file locally for each server in the cluster. For example:

```
12.24.48.101   voltsvr1
```

```
12.24.48.102   voltsvr2
12.24.48.103   voltsvr3
12.24.48.104   voltsvr4
12.24.48.105   voltsvr5
```

2.7. Assign Network Ports

VoltDB uses a number of network ports for functions such as internal communications, client connections, rejoin, database replication, and so on. For these features to perform properly, the ports must be open and available. Review the following list of ports to ensure they are open and available (that is, not currently in use).

Function	**Default Port Number**
Client Port	21212
Admin Port	21211
Web Interface Port (httpd)	8080
Internal Server Port	3021
Log Port	4560
JMX Port	9090
Replication Port	5555
Zookeeper port	7181

Alternately, you can reassign the port numbers that VoltDB uses. See Section A.5, “Network Ports” for a description of the ports and how to reassign them.

Chapter 3. Starting and Stopping the Database

The fundamental operations for database administration are starting and stopping the database. But before you start the database, you need to decide what database features you want to enable and how they should work. These features include the initial size of the cluster, what amount of replication you want to use to increase availability in case of server failure, and what level of durability is required for those cases where the database itself stops. These and other settings are defined in the deployment file, which you specify on the command line when you start the server.

This chapter explains how to configure the cluster's physical structure and features in the deployment file and how to start and stop the database.

3.1. Configuring the Cluster and Database

You specify the cluster configuration and what features to use in the deployment file, which is an XML file that you can create and edit manually. In the simplest case, the deployment file specifies how many servers the cluster has initially, how many partitions to create on each server, and what level of availability (K-safety) to use. For example:

```
<?xml version="1.0"?>
<deployment>
  <cluster hostcount="5"
           sitesperhost="4"
           kfactor="1"
  />
</deployment>
```

- The `hostcount` attribute specifies the number of servers the cluster will start with.
- The `sitesperhost` attribute specifies the number of partitions (or "sites") to create on each server. Set to eight by default, it is possible to optimize the number of sites per host in relation to the number of processors per machine. The optimal number is best determined by performance testing against the expected workload. See the chapter on "Benchmarking" in the *VoltDB Planning Guide* for details.
- The `kfactor` attribute specifies the K-safety value to use. The higher the K-safety value, the more node failures the cluster can withstand without affecting database availability. However, increasing the K-safety value increases the number of copies of each unique partition. High availability is a trade-off between replication to protect against node failure and the number of unique partitions, therefore throughput performance. See the chapter on availability in the *Using VoltDB* manual for more information on determining an optimal K-safety value.

In addition to the cluster configuration, you can use the deployment file to enable and configure specific database features such as export, command logging, and so on. The following table summarizes some of the key features that are settable in the deployment file.

Table 3.1. Configuring Database Features in the Deployment File

Feature	Example
Command Logging — Command logging provides durability by logging transactions to	`<commandlog enabled="true" synchronous="false">`

Feature	Example

disk so they can be replayed during a recovery. You can configure the type of command logging (synchronous or asynchronous), the log file size, and the frequency of the logs (in terms of milliseconds or number of transactions).	`  <frequency time="300"`
	`  transactions="1000"/>`
	`</commandlog>`

Snapshots — Automatic snapshot provide another form of durability by creating snapshots of the database contents, that can be restored later. You can configure the frequency of the snapshots, the unique file prefix, and how many snapshots are kept at any given time.	`<snapshot enabled="true"`
	`frequency="30m"`
	`prefix="mydb"`
	`retain="3" />`

Export — Export allows you to write selected records from the database to one or more external targets, which can be files, another database, or another service. VoltDB provides different export connectors for each protocol. You can configure the type of export for each stream as well as other properties, which are specific to the connector type. For example, the file connector requires a specific type (or format) for the files and a unique identifier called a "nonce".	`<export>`
	`  <configuration enabled="true" type="file">`
	`  <property name="type">csv</property>`
	`  <property name="nonce">mydb</property>`
	`  </configuration>`
	`</export>`

Security & Accounts — Security lets you protect your database against unwanted access by requiring all connections authenticate against known usernames and passwords. In the deployment file you can define the user accounts and passwords and what role or roles each user fulfills. Roles define what permissions the account has. Roles are defined in the database schema.	`<security enabled="true"/>`
	`<users>`
	`  <user name="admin"`
	`  password="superman"`
	`  roles="dev,ops"/>`
	`  <user name="mitty"`
	`  password="thurber"`
	`  roles="user"/>`
	`</users>`

File Paths — Paths define where VoltDB writes any files or other disc-based content. You can configure the default root for all files as well as specific paths for each type of service, such as snapshots, command logs, export overflow, etc.	`<paths>`
	`  <voltdbroot path="/tmp/vroot" />`
	`  <snapshots path="/opt/archive" />`
	`</paths>`

3.2. Starting the Database

Once you create the deployment file, you are ready to start a VoltDB database cluster[1] for the first time using the **voltdb create** command. You issue this command, specifying the same deployment file and host on each node of the cluster. For example:

```
$ voltdb create --deployment=deployment.xml \ ❶
                --host=voltsvr1 \             ❷
                --license=~/license.xml       ❸
```

[1]When testing with a single server, several of the command line arguments have defaults and can be left out. However, in production when starting a multi-node cluster, the arguments are required.

On the command line, you specify four arguments:

❶ The deployment file, which specifies the physical layout of the cluster and configures specific VoltDB features
❷ One node of the cluster identified as the "host", to coordinate the initial startup of the cluster
❸ The license file (when using the VoltDB Enterprise Edition)

What happens when you start the database is that each server contacts the named "host" server. The host then:

1. Waits until the necessary number of servers (as specified in the deployment file) are connected
2. Creates the network mesh between the servers
3. Distributes the deployment file to ensure all nodes are using the same configuration

At this point, the cluster is fully initialized and the "host" ends its special role and becomes a peer to all the other nodes. All nodes in the cluster then write an informational message to the console verifying that the database is ready:

```
Server completed initialization.
```

3.3. Loading the Database Definition

Responsibility for loading the database schema and stored procedures varies from company to company. In some cases, operators and administrators are only responsible for initiating the database; developers may load and modify the schema themselves. In other cases, the administrators are responsible for both starting the cluster and loading the correct database schema as well.

If you are responsible for establishing the correct schema, the next step is to load the Java stored procedures and the schema definition. Stored procedures are compiled into classes and then packaged into a JAR file, as described in the section on installing stored procedures in the *Using VoltDB* manual. To fully load the database definition you will need the JAR of stored procedure classes and a text file containing the data definition language (DDL) statements that declare the database schema.

The following example assumes these two files are `storedprocs.jar` and `dbschema.sql`. Once the database cluster has started, you can load the schema and stored procedures using the **sqlcmd** utility. To load them at the sqlcmd prompt, you can use the sqlcmd **load classes** and **file** directives:

```
$ sqlcmd
1> load classes storedprocs.jar;
2> file dbschema.sql;
```

Note that when loading the schema, you should always load the stored procedures first, so the class files are available for any CREATE PROCEDURE statements within the schema.

3.4. Stopping the Database

How you choose to stop a VoltDB depends on what features you have enabled. For example, if you do not have any durability features enabled (such as auto snapshots or command logging), it is strongly recommended that you pause the database and take a manual snapshot before shutting down, so you preserve the data across sessions.

If you have command logging enabled, a manual snapshot is not necessary. However, it is still a good idea to pause the database before shutting down to ensure that all active client queries have a chance to complete and return their results (and no new queries start) before the shutdown occurs.

To pause and shutdown the cluster you can use the **voltadmin pause** and **shutdown** commands:

```
$ voltadmin pause
$ voltadmin shutdown
```

As with all **voltadmin** commands, you can use them remotely by specifying one of the cluster servers on the command line:

```
$ voltadmin pause --host=voltsvr2
$ voltadmin shutdown --host=voltsvr2
```

If security is enabled, you will also need to specify a username and password for a user with admin permissions:

```
$ voltadmin pause --host=voltsvr2 -u root -p Suda51
$ voltadmin shutdown --host=voltsvr2 -u root -p Suda51
```

Finally, if you are not using the durability features of automatic snapshots or command logging, you should perform a manual snapshot using the **save** command after pausing and before shutting down. Use the `--blocking` flag to ensure the snapshot completes before the shutdown occurs:

```
$ voltadmin pause
$ voltadmin save --blocking /tmp/voltdb backup
$ voltadmin shutdown
```

3.5. Restarting the Database

Restarting a VoltDB database is different than starting it for the first time. How you restart the database depends on what durability features were in effect previously.

If you just use the **voltdb create** command, you create a new, empty database. Because VoltDB keeps its data in memory, to return the database to its last known state — including its content — you need to restore the data from a saved copy.

If you are using automatic snapshots or command logging, VoltDB can automatically reinstate the data when you use the **voltdb recover** command:

```
$ voltdb recover --deployment=deployment.xml \
                 --host=voltsvr1 \
                 --license=~/license.xml
```

Just as when starting a database for the first time, you must invoke the **recover** command on all nodes of the cluster before the database can start, You must also select one of the nodes as the "host" to facilitate startup and identify that node as the host on each of the servers when you issue the **voltdb recover** command.

When you recover a VoltDB database, the cluster performs the same initial coordination activities as when creating a new database: the host node facilitates establishing a quorum and ensures all nodes connect. Then the database servers restore the most recent snapshot plus (if command logging is enabled) the last logged transactions. Once the schema is loaded and all data is restored, the database enables client access.

If you are not using automatic snapshots or command logging, you must restore the last snapshot manually. You do this with the following procedure:

1. Start a new database using the **voltdb create** command on each server as described in Section 3.2, “Starting the Database”.

2. Use the **voltadmin pause** command to pause the database.

3. Load the stored procedures and schema definition, as described in Section 3.3, “Loading the Database Definition”.

4. Use the **voltadmin restore** command to restore the data from the manual snapshot.

5. Use the **voltadmin resume** command to resume client activity.

For example, if the last snapshot was saved in `/tmp/voltdb` using the unique ID *`backup`*, you can restore the data with the following commands:

```
$ voltadmin pause
$ sqlcmd
1> LOAD CLASSES storedprocs.jar
2> FILE dbschema.sql
   .  .  .
3> exit
$ voltadmin restore /tmp/voltdb backup
$ voltadmin resume
```

Chapter 4. Maintenance and Upgrades

Once the database is running, it is the administrator's role to keep it running. This chapter explains how to perform common maintenance and upgrade tasks, including:

- Database backups
- Schema and stored procedure updates
- Software and hardware upgrades

4.1. Backing Up the Database

It is a common safety precaution to backup all data associated with computer systems and store copies off-site in case of system failure or other unexpected events. Backups are usually done on a scheduled basis (every day, every week, or whatever period is deemed sufficient).

VoltDB provides several options for backing up the database contents. The easiest option is to save a native snapshot then backup the resulting snapshot files to removable media for archiving. The advantage of this approach is that native snapshots contain both a complete copy of the data and the schema. So in case of failure the snapshot can be restored to the current or another cluster using a single **voltadmin recover** command.

The key thing to remember when using native snapshots for backup is that each server saves its portion of the database locally. So you must fetch the snapshot files for all of the servers to ensure you have a complete set of files. The following example performs a manual snapshot on a five node cluster then uses scp to remotely copy the files from each server to a single location for archiving.

```
$ voltadmin save --blocking --host=voltsvr3 \
            /tmp/voltdb backup
$ scp -l 100 'voltsvr1:/tmp/voltdb/backup*' /tmp/archive/
$ scp -l 100 'voltsvr2:/tmp/voltdb/backup*' /tmp/archive/
$ scp -l 100 'voltsvr3:/tmp/voltdb/backup*' /tmp/archive/
$ scp -l 100 'voltsvr4:/tmp/voltdb/backup*' /tmp/archive/
$ scp -l 100 'voltsvr5:/tmp/voltdb/backup*' /tmp/archive/
```

Note that if you are using automated snapshots or command logging (which also creates snapshots), you can use the automated snapshots as the source of the backup. However, the automated snapshots use a programmatically generated file prefix, so your backup script will need some additional intelligence to identify the most recent snapshot and its prefix.

The preceding example also uses the scp limit flag (`-l 100`) to constrain the bandwidth used by the copy command to 100kbits/second. Use of the -l flag is recommended to avoid the copy operation blocking the VoltDB server process and impacting database performance.

Finally, if you wish to backup the data in a non-proprietary format, you can use the **voltadmin save --format=csv** command to create a snapshot of the data as comma-separated value (CSV) formatted text files. The advantage is that the resulting files are usable by more systems than just VoltDB. The disadvantage is that the CSV files only contain the data, not the schema. These files cannot be read directly into VoltDB, like a native snapshot can. Instead, you will need to create a new database, load the schema, then use the **csvloader** utility to load individual files into each table to restore the database completely.

4.2. Updating the Database Schema

As an application evolves, the database schema often needs changing. This is particularly true during the early stages of development and testing but also happens periodically with established applications, as the database is tuned for performance or adjusted to meet new requirements. In the case of VoltDB, these updates may involve changes to the table definitions, to the indexes, or to the stored procedures. The following sections explain how to:

- Perform live schema updates
- Change unique indexes and partitioning using save and restore

4.2.1. Performing Live Schema Updates

There are two ways to update the database schema for a VoltDB database: live updates and save/restore updates. For most updates, you can update the schema while the database is running. To perform this type of live update, you use the DDL CREATE, ALTER, and DROP statements to modify the schema interactively as described in the section on modifying the schema in the *Using VoltDB* manual.

You can make any changes you want to the schema as long as the tables you are modifying do not contain any data. The only limitations on performing live schema changes are that you cannot:

- Add or broaden unique constraints (such as indexes or primary keys) on tables with existing data
- Reduce the datatype size of columns on tables with existing data (for example, changing the datatype from INTEGER to TINYINT)

These limitations are in place to guarantee that the schema change will succeed without any pre-existing data violating the constraint. If you know that the data in the database does not violate the new constraints you can make these changes using the **save** and **restore** commands, as described in the following section.

4.2.2. Performing Updates Using Save and Restore

If you need to add unique indexes or reduce columns to database tables with existing data, you must use the **voltadmin save** and **restore** commands to perform the schema update. This requires shutting down and restarting the database to allow VoltDB to validate the existing data against the new constraints.

To perform a schema update using save and restore, use the following steps:

1. Create a new schema file containing the updated DDL statements.
2. Pause the database (**voltadmin pause**).
3. Create a snapshot of the database contents (**voltadmin save**).
4. Shutdown the database (**voltadmin shutdown**).
5. Create a new database using the **voltdb create** option and starting in admin mode (specified in the deployment file).
6. Load the stored procedures and new schema (using the sqlcmd **LOAD CLASSES** and **FILE** directives)
7. Restore the snapshot created in Step #3 (**voltadmin restore**).
8. Return the database to normal operations (**voltadmin resume**).

For example:

```
$ # Issue once
$ voltadmin pause
$ voltadmin save --blocking /opt/archive/  mydb
$ voltadmin shutdown

$ # Issue next command on all servers
$ voltdb create --deployment=deployment.xml \
                --host=voltsvr1 \
                --license=~/license.xml

$ # Issue only once
$ sqlcmd
1> load classes storedprocs.jar;
2> file newschema.sql;

3> exit
$ voltadmin restore /opt/archive  mydb
$ voltadmin resume
```

The key point to remember when adding new constraints is that there is the possibility that the restore operation will fail if existing records violate the new constraint. This is why it is important to make sure your database contents are compatible with the new schema before performing the update.

4.3. Upgrading the Cluster

Sometimes you need to update or reconfigure the server infrastructure on which the VoltDB database is running. Server upgrades are one example. A *server upgrade* is when you need to fix or replace hardware, update the operating system, or otherwise modify the underlying system. Server upgrades usually require stopping the VoltDB database process on the specific server being serviced.

Another example is when you want to reconfigure the cluster as a whole. Reasons for reconfiguring the cluster are because you want to add or remove servers from the cluster or you need to modify the number of partitions per server that VoltDB uses.

Adding servers to the cluster can happen without stopping the database. This is called *elastic scaling*. Removing servers or changing the number of sites per host requires restarting the cluster during a *maintenance window*.

The following sections describe three cases of cluster upgrades:

- Performing server upgrades
- Adding servers to a running cluster through elastic scaling
- Reconfiguring the cluster with a maintenance window

4.3.1. Performing Server Upgrades

If you need to upgrade or replace the hardware or software (such as the operating system) of the individual servers, this can be done without taking down the database as a whole. As long as the server is running with a K-safety value of one or more, it is possible to take a server out of the cluster without stopping the database. You can then fix the server hardware, upgrade software (other than VoltDB), even replace the server entirely with a new server, then bring the server back into the cluster.

To perform a server upgrade:

1. Stop the VoltDB server process on the server. As long as the cluster is K-safe, the rest of the cluster will continue running.

2. Perform the necessary upgrades.

3. Have the server rejoin the cluster using the **voltdb rejoin** command.

The rejoin command starts the database process on the server, contacts the database cluster, then copies the necessary partition content from other cluster nodes so the server can then participate as a full member of the cluster, While the server is rejoining, the other database servers remain accessible and actively process queries from client applications.

When rejoining a cluster you must specify a host server that the rejoining node will connect to. The host can be any server still in the cluster; it does not have to be the same host specified when the cluster was initially started. For example:

```
$ voltdb rejoin --host=voltsvr4 \
         --deployment=deployment.xml \
         --license=~/license.xml
```

If you need to upgrade all of the servers in the cluster (for example, if you are upgrading the operating system), the easiest method is to upgrade the servers one at a time, taking each server out of the cluster, upgrading it, then rejoining it to the cluster. This way the entire cluster can be upgraded without losing any availability to the database.

If the cluster is not K-safe — that is, the K-safety value is 0 — then you must follow the instructions in Section 4.3.3, “Reconfiguring the Cluster During a Maintenance Window” to upgrade the servers.

4.3.2. Adding Servers to a Running Cluster with Elastic Scaling

If you want to add servers to a VoltDB cluster — usually to increase performance and/or capacity — you can do this without having to restart the database. You add servers to the cluster with the **voltdb add** command, specifying one of the existing nodes with the `--host` flag. For example:

```
$ voltdb add --host=voltsvr4 \
         --license=~/license.xml
```

You must add a full complement of servers to match the K-safety value (K+1) before the servers can participate in the cluster. For example, if the K-safety value is 2, you must add 3 servers before they actually become part of the cluster and the cluster rebalances its partitions.

When you add servers to a VoltDB database, the cluster performs the following actions:

1. The new servers are added to the cluster configuration and sent copies of the schema, stored procedures, and deployment file.

2. Once sufficient servers are added, copies of all replicated tables and their share of the partitioned tables are sent to the new servers.

3. As the data is rebalanced, the new servers begin processing transactions for the partition content they have received.

4. Once rebalancing is complete, the new servers are full members of the cluster.

4.3.3. Reconfiguring the Cluster During a Maintenance Window

If you want to remove servers from the cluster permanently (as opposed to temporarily removing them for maintenance as described in Section 4.3, "Upgrading the Cluster") or you want to change other cluster-wide attributes, such as the number of partitions per server, you need to restart the server. Stopping the database temporarily to perform this sort of reconfiguration is known as a *maintenance window*.

The steps for reconfiguring the cluster with a maintenance window are:

1. Place the database in admin mode (**voltadmin pause**).
2. Perform a manual snapshot of the database (**voltadmin save**).
3. Shutdown the database (**voltadmin shutdown**).
4. Make the necessary changes to the deployment file.
5. Start a new database using the **voltdb create** option and the edited deployment file.
6. Reload the stored procedures and schema (with the sqlcmd **load classes** and **file** directives).
7. Restore the snapshot created in Step #2 (**voltadmin restore**).
8. Return the database to normal operations (**voltadmin resume**).

4.4. Upgrading VoltDB Software

Finally, as new versions of VoltDB become available, you will want to upgrade the VoltDB software on your database cluster. The steps for upgrading the VoltDB software on a database cluster are:

1. Place the database in admin mode (**voltadmin pause**).
2. Perform a manual snapshot of the database (**voltadmin save**).
3. Shutdown the database (**voltadmin shutdown**).
4. Upgrade VoltDB on all cluster nodes.
5. Start a new database using the **voltdb create** option and starting in admin mode (specified in the deployment file).
6. Reload the stored procedures and schema (with the sqlcmd **load classes** and **file** directives).
7. Restore the snapshot created in Step #2 (**voltadmin restore**).
8. Return the database to normal operations (**voltadmin resume**).

Chapter 5. Monitoring VoltDB Databases

Monitoring is an important aspect of systems administration. This is true of both databases and the infrastructure they run on. The goals for database monitoring include ensuring the database meets its expected performance target as well as identifying and resolving any unexpected changes or infrastructure events (such as server failure or network outage) that can impact the database. This chapter explains:

- How to monitor overall database health and performance using VoltDB
- How to integrate VoltDB monitoring with other enterprise monitoring infrastructures

5.1. Monitoring Overall Database Activity

VoltDB provides several tools for monitoring overall database activity. The following sections describe the two primary monitoring tools within VoltDB:

- VoltDB Management Center
- System Procedures

5.1.1. VoltDB Management Center

```
http://voltserver:8080/
```

The VoltDB Management Center provides a graphical display of key aspects of database performance, including throughput, memory usage, query latency, and partition usage. To use the Management Center, connect to one of the cluster nodes using a web browser, specifying the HTTP port (8080 by default) as shown in the example URL above. The Management Center shows graphs for cluster throughput and latency as well as CPU and memory usage for the current server. You can also use the Management Center to examine the database schema and to issue ad hoc SQL queries.

5.1.2. System Procedures

VoltDB provides callable system procedures that return detailed information about the usage and performance of the database. In particular, the @Statistics system procedure provides a wide variety of information depending on the selector keyword you give it. Some selectors that are particularly useful for monitoring include the following:

- **MEMORY** — Provides statistics about memory usage for each node in the cluster. Information includes the resident set size (RSS) for the server process, the Java heap size, heap usage, available heap memory, and more. This selector provides the type of information displayed by the Process Memory Report, except that it returns information for all nodes of the cluster in a single call.
- **PROCEDUREPROFILE** — Summarizes the performance of individual stored procedures. Information includes the minimum, maximum, and average execution time as well as the number of invocations, failures, and so on. The information is summarized from across the cluster as whole. This selector returns information similar to the latency graph in VoltDB Management Center.
- **TABLE** — Provides information about the size, in number of tuples and amount of memory consumed, for each table in the database. The information is segmented by server and partition, so you can use it to report the total size of the database contents or to evaluate the relative distribution of data across the servers in the cluster.

When using the @Statistics system procedure with the PROCEDUREPROFILE selector for monitoring, it is a good idea to set the second parameter of the call to "1" so each call returns information since the

last call. In other words, statistics for the interval since the last call. Otherwise, if the second parameter is "0", the procedure returns information since the database started and the aggregate results for minimum, maximum, and average execution time will have little meaning.

When calling @Statistics with the MEMORY or TABLE selectors, you can set the second parameter to "0" since the results are always a snapshot of the memory usage and table volume at the time of the call. For example, the following Python script uses @Statistics with the MEMORY and PROCEDUREPROFILE selectors to check for memory usage and latency exceeding certain limits. Note that the call to @Statistics uses a second parameter of 1 for the PROCEDUREPROFILE call and a parameter value of 0 for the MEMORY call.

```
import sys
from voltdbclient import *

nano = 1000000000.0
memorytrigger = 4 * (1024*1024)     # 4gbytes
avglatencytrigger = .01 * nano      # 10 milliseconds
maxlatencytrigger = 2 * nano        # 2 seconds

server = "localhost"
if (len(sys.argv) > 1): server = sys.argv[1]

client = FastSerializer(server, 21212)
stats = VoltProcedure( client, "@Statistics",
   [ FastSerializer.VOLTTYPE_STRING,
     FastSerializer.VOLTTYPE_INTEGER ] )

# Check memory
response = stats.call([ "memory", 0 ])
for t in response.tables:
   for row in t.tuples:
      print 'RSS for node ' + row[2] + "=" + str(row[3])
      if (row[3] > memorytrigger):
         print "WARNING: memory usage exceeds limit."

# Check latency
response = stats.call([ "procedureprofile", 1 ])
avglatency = 0
maxlatency = 0
for t in response.tables:
   for row in t.tuples:
      if (avglatency < row[4]): avglatency = row[4]
      if (maxlatency < row[6]): maxlatency = row[6]
print 'Average latency= ' + str(avglatency)
print 'Maximum latency= ' + str(maxlatency)
if (avglatency > avglatencytrigger):
   print "WARNING: Average latency exceeds limit."
if (maxlatency > maxlatencytrigger):
   print "WARNING: Maximum latency exceeds limit."

client.close()
```

The @Statistics system procedure is the the source for many of the monitoring options discussed in this chapter. Two other system procedures, @SystemCatalog and @SystemInformation, provide general in-

formation about the database schema and cluster configuration respectively and can be used in monitoring as well.

The system procedures are useful for monitoring because they let you customize your reporting to whatever level of detail you wish. The other advantage is that you can automate the monitoring through scripts or client applications that call the system procedures. The downside, of course, is that you must design and create such scripts yourself. As an alternative for custom monitoring, you can consider integrating VoltDB with existing third party monitoring applications, as described in next section.

5.2. Integrating VoltDB with Other Monitoring Systems

In addition to the tools and system procedures that VoltDB provides for monitoring the health of your database, you can also integrate this data into third-party monitoring solutions so they become part of your overall enterprise monitoring architecture. VoltDB supports integrating VoltDB statistics and status with the following monitoring systems:

- Ganglia
- JMX
- Nagios
- New Relic

5.2.1. Integrating with Ganglia

If you use Ganglia as your monitoring tool and the VoltDB Enterprise Manager as your database administration tool, the two products integrate seamlessly to provide VoltDB performance data to the Ganglia monitoring interface. Ganglia is a distributed monitoring system that provides a graphical interface to distributed clusters of systems. If Ganglia is present, VoltDB and the Enterprise Manager act as a data source for the Ganglia system.

To use VoltDB with Ganglia, make sure:

- The Ganglia Monitoring Daemon (gmond) is installed and configured on each VoltDB cluster node.
- The Ganglia Meta Daemon (gmetad) is installed and configured on the server running the VoltDB Enterprise Manager.

Having completed these steps, the VoltDB Enterprise Manager will automatically generate data for the Ganglia monitoring system. See the Ganglia web site (`http://ganglia.sourceforge.net/`) for more information about Ganglia.

5.2.2. Integrating Through JMX

VoltDB Enterprise Edition uses the Java Management Extensions (JMX) to send statistics from the database nodes to the VoltDB Enterprise Manager. The VoltDB JMX interface is also available to other monitoring frameworks that want to query for VoltDB statistics.

VoltDB Enterprise Edition servers open the JMX interface on port 9090 by default (you can change the port number, see Section A.5.6, “JMX Port” for details). Clients can either poll on this port for specific information or subscribe to messages that are sent approximately every second.

The information sent over the JMX interface is the same as that available through existing VoltDB system procedures, such as @SystemInformation, @Statitstics, and @SnapshotStatus. The easiest way to become familiar with the JMX interface is to connect to a running database using the Java Monitoring and Management Console (also known as Jconsole) and browse through the structures returned by the VoltDB servers.

5.2.3. Integrating with Nagios

If you use Nagios to monitor your systems and services, you can include VoltDB in your monitoring infrastructure. VoltDB Enterprise Edition provides Nagios plugins that let you monitor four key aspects of VoltDB. The plugins are included in a subfolder of the tools directory where VoltDB is installed. Table 5.1, "Nagios Plugins" lists each plugin and what it monitors.

Table 5.1. Nagios Plugins

Plugin	Monitors	Scope	Description
check_voltdb_ports	Availability	Server	Reports whether the specified server is reachable or not.
check_voltdb_memory	Memory usage	Server	Reports on the amount of memory in use by VoltDB for a individual node. You can specify the severity criteria as a percentage of total memory.
check_voltdb_cluster	K-safety	Cluster-wide	Reports on whether a K-safe cluster is complete or not. That is, whether the cluster has the full complement of nodes or if any have failed and not rejoined yet.
check_voltdb_replication	Database replication	Cluster-wide	Reports the status of database replication. Connect the plugin to one or more nodes on the master database.

Note that the httpd and JSON options must be enabled in the deployment file for the VoltDB database for the Nagios plugins to query the database status.

5.2.4. Integrating with New Relic

If you use New Relic as your monitoring tool, there is a VoltDB plugin to include monitoring of VoltDB databases to your New Relic dashboard. To use the New Relic plugin, you must:

- Define the appropriate configuration for your server.
- Start the voltdb-newrelic process that gathers and sends data to New Relic.

You define the configuration by editing and renaming the template files that can be found in the `/tools/monitoring/newrelic/config` folder where VoltDB is installed. The configuration files let you specify your New Relic license and which databases are monitored. A README file in the `/newrelic` folder provides details on what changes to make to the configuration files.

You start the monitoring process by running the script `voltdb-newrelic` that also can be found in the`/newrelic` folder. The script must be running for New Relic to monitor your databases.

Chapter 6. Logging and Analyzing Activity in a VoltDB Database

VoltDB uses Log4J, an open source logging service available from the Apache Software Foundation, to provide access to information about database events. By default, when using the VoltDB shell commands, the console display is limited to warnings, errors, and messages concerning the status of the current process. A more complete listing of messages (of severity INFO and above) is written to log files in the subfolder `/log`, relative to the user's current default location.

The advantages of using Log4J are:

- Logging is compiled into the code and can be enabled and configured at run-time.
- Log4J provides flexibility in configuring what events are logged, where, and the format of the output.
- By using Log4J in your client applications, you can integrate the logging and analysis of both the database and the application into a single consistent output stream.
- By using an open source logging service with standardized output, there are a number of different applications, such as Chainsaw, available for filtering and presenting the results.

Logging is important because it can help you understand the performance characteristics of your application, check for abnormal events, and ensure that the application is working as expected.

Of course, any additional processing and I/O will have an incremental impact on the overall database performance. To counteract any negative impact, Log4J gives you the ability to customize the logging to support only those events and servers you are interested in. In addition, when logging is not enabled, there is no impact to VoltDB performance. With VoltDB, you can even change the logging profile on the fly without having to shutdown or restart the database.

The following sections describe how to enable and customize logging of VoltDB using Log4J. This chapter is **not** intended as a tutorial or complete documentation of the Log4J logging service. For general information about Log4J, see the Log4J web site at http://wiki.apache.org/logging-log4j/.

6.1. Introduction to Logging

Logging is the process of writing information about application events to a log file, console, or other destination. Log4J uses XML files to define the configuration of logging, including three key attributes:

- **Where** events are logged. The destinations are referred to as *appenders* in Log4J (because events are appended to the destinations in sequential order).
- **What** events are logged. VoltDB defines named classes of events (referred to as *loggers*) that can be enabled as well as the severity of the events to report.
- **How** the logging messages are formatted (known as the *layout*),

6.2. Creating the Logging Configuration File

VoltDB ships with a default Log4J configuration file, voltdb/log4j.xml, in the installation directory. The sample applications and the VoltDB shell commands use this file to configure logging and it is recommended for new application development. This default Log4J file lists all of the VoltDB-specific logging

categories and can be used as a template for any modifications you wish to make. Or you can create a new file from scratch.

The following is an example of a Log4J configuration file:

```
<?xml version="1.0" encoding="UTF-8" ?>
<!DOCTYPE log4j:configuration SYSTEM "log4j.dtd">

<log4j:configuration xmlns:log4j="http://jakarta.apache.org/log4j/">

<appender name="Async" class="org.apache.log4j.AsyncAppender">
  <param name="Blocking" value="true" />
  <appender-ref ref="Console" />
  <appender-ref ref="File" />
</appender>

<appender name="Console" class="org.apache.log4j.ConsoleAppender">
  <param name="Target" value="System.out" />
  <layout class="org.apache.log4j.TTCCLayout" />
</appender>

<appender name="File" class="org.apache.log4j.FileAppender">
  <param name="File" value="/tmp/voltdb.log" />
  <param name="Append" value="true" />
  <layout class="org.apache.log4j.TTCCLayout" />
</appender>

<logger name="AUTH">
<!-- Print all VoltDB authentication messages -->
  <level value="trace" />
</logger>

<root>
      <priority value="debug" />
      <appender-ref ref="Async" />
</root>
</log4j:configuration>
```

The preceding configuration file defines three destinations, or appenders, called *Async*, *Console*, and *File*. The appenders define the type of output (whether to the console, to a file, or somewhere else), the location (such as the file name), as well as the layout of the messages sent to the appender. See the log4J documentation for more information about layout.

Note that the appender Async is a superset of Console and File. So any messages sent to Async are routed to both Console and File. This is important because for logging of VoltDB, you should always use an asynchronous appender as the primary target to avoid the processing of the logging messages from blocking other execution threads.

More importantly, you should not use any appenders that are susceptible to extended delays, blockages, or slow throughput, This is particularly true for network-based appenders such as SocketAppender and third-party log infrastructures including logstash and JMS. If there is any prolonged delay in writing to the appenders, messages can end up being held in memory causing performance degradation and, ultimately, possible out of memory errors.

The configuration file also defines a root class. The root class is the default logger and all loggers inherit the root definition. So, in this case, any messages of severity "debug" or higher are sent to the Async appender.

Finally, the configuration file defines a logger specifically for VoltDB authentication messages. The logger identifies the class of messages to log (in this case "AUTH"), as well as the severity ("trace"). VoltDB defines several different classes of messages you can log. Table 6.1, “VoltDB Components for Logging” lists the loggers you can invoke.

Table 6.1. VoltDB Components for Logging

Logger	Description
ADHOC	Execution of ad hoc queries
AUTH	Authentication and authorization of clients
COMPILER	Interpretation of SQL in ad hoc queries
CONSOLE	Informational messages intended for display on the console
DR	Database replication sending data
DRAGENT	Database replication receiving data
EXPORT	Exporting data
GC	Java garbage collection
HOST	Host specific events
NETWORK	Network events related to the database cluster
REJOIN	Node recovery and rejoin
SNAPSHOT	Snapshot activity
SQL	Execution of SQL statements
TM	Transaction management

6.3. Enabling Logging for VoltDB

Once you create your Log4J configuration file, you specify which configuration file to use by defining the variable LOG4J_CONFIG_PATH before starting the VoltDB database. For example:

```
$ LOG4J_CONFIG_PATH="$HOME/MyLog4jConfig.xml"
$ voltdb create -H localhost -d mydeployment.xml
```

6.4. Customizing Logging in the VoltDB Enterprise Manager

When using the VoltDB Enterprise Manager to manage your databases, the startup process is automated for you. There is no command line for specifying a Log4J configuration file.

Instead, the Enterprise Manager provides a Log4J properties file that is used to start each node in the cluster. You can change the logging configuration by modifying the properties file `server_log4j.properties` included in the `/management` subfolder of the VoltDB installation. The Enterprise Manager copies and uses this file to enable logging on all servers when it starts the database.

Note that the properties file used by the VoltDB Enterprise Manager is in a different format than the XML file used when configuring Log4J on the command line. However, both files let you configure the same logging attributes. In the case of the properties file, be sure to add your modifications to the end of the file so as not to interfere with the logging required by the Enterprise Manager itself.

6.5. Changing the Timezone of Log Messages

By default all VoltDB logging is reported in GMT (Greenwich Mean Time). If you want the logging to be reported using a different timezone, you can use extensions to the Log4J service to achieve this.

To change the timezone of log messages:

1. Download the extras kit from the Apache Extras for Apache Log4J website, http://logging.apache.org/log4j/extras/.

2. Unpack the kit and place the included JAR file in the `/lib/extension` folder of the VoltDB installation directory.

3. Update your Log4J configuration file to enable the Log4J extras and specify the desired timezone for logging for each appender.

You enable the Log4J extras by specifying `EnhancedPatternLayout` as the layout class for the appenders you wish to change. You then identify the desired timezone as part of the layout pattern. For example, the following XML fragment changes the timezone of messages written to the file appender to GMT minus four hours:

```
<appender name="file" class="org.apache.log4j.DailyRollingFileAppender">
    <param name="file" value="log/volt.log"/>
    <param name="DatePattern" value="'.'yyyy-MM-dd" />
    <layout class="org.apache.log4j.EnhancedPatternLayout">
        <param name="ConversionPattern" value="%d{ISO8601}{GMT-4}   %-5p [%t]
    </layout>
</appender>
```

You can use any valid ISO-8601 timezone specification, including named timezones, such as EST.

To customize the timezone when using the VoltDB Enterprise Manager, you must specify the layout class and pattern using the Log4J properties file in the `/management` folder. For example, the following code appended to the file `server_log4j.properties` would make the same change to the timezone for clusters started with the Enterprise Manager as the preceding example would when starting a server manually:

```
# Add your own log4j configurations below this line

log4j.appender.file.layout=org.apache.log4j.EnhancedPatternLayout
log4j.appender.file.layout.ConversionPattern=%d{ISO8601}{GMT-4}   %-5p [%t] %c: %m
```

6.6. Changing the Configuration on the Fly

Once the database has started, you can still start or reconfigure the logging without having to stop and restart the database. By calling the system procedure @UpdateLogging you can pass the configuration XML to the servers as a text string. For any appenders defined in the new updated configuration, the existing appender is removed and the new configuration applied. Other existing appenders (those not mentioned in the updated configuration XML) remain unchanged.

Chapter 7. What to Do When Problems Arise

As with any high performance application, events related to the database process, the operating system, and the network environment can impact how well or poorly VoltDB performs. When faced with performance issues, or outright failures, the most important task is identifying and resolving the root cause. VoltDB and the server produce a number of log files and other artifacts that can help you in the diagnosis. This chapter explains:

- Where to look for log files and other information about the VoltDB server process
- What to do when recovery fails
- How to collect the log files and other system information when reporting a problem to VoltDB

7.1. Where to Look for Answers

The first place to look when an unrecognized problem occurs with your VoltDB database is the console where the database process was started. VoltDB echoes key messages and errors to the console. For example, if a server becomes unreachable, the other servers in the cluster will report an error indicating which node has failed. Assuming the cluster is K-safe, the remaining nodes will then re-establish a quorum and continue, logging this event to the console as well.

However, not all messages are echoed on the console.[1] A more complete record of errors, warnings, and informational messages is written to a log file, `log/volt.log`, in a subfolder of the working directory where the VoltDB server process was started. The `volt.log` file can be extremely helpful for identifying unexpected but non-fatal events that occurred earlier and may identify the cause of the current issue.

If VoltDB encounters a fatal error and exits, shutting down the database process, it also attempts to write out a crash file in the current working directory. The crash file name has the prefix "voltdb_crash" followed by a timestamp identifying when the file is created. Again, this file can be useful in diagnosing exactly what caused the crash, since it includes the last error message, a brief profile of the server and a dump of the Java threads running in the server process before it crashed.

To summarize, when looking for information to help analyze system problems, three places to look are:

1. The console where the server process was started.
2. The log file in `log/volt.log`
3. The crash file named `voltdb_crash{timestamp}.txt` in the server process's working directory

7.2. Recovering in Safe Mode

After determining what caused the problem, the next step is often to get the database up and running again as soon as possible. When using snapshots or command logs, this is done using the **voltdb recover** command described in Section 3.5, “Restarting the Database”. However, in unusual cases, the resume itself may fail.

[1] Note that you can change which messages are echoed to the console and which are logged by modifying the Log4j configuration file. See the chapter on logging in the *Using VoltDB* manual for details.

There are several situations where an attempt to recover a database — either from a snapshot or command logs — may fail. For example, restoring a snapshot where a unique index has been added to a table can result in a constraint violation that causes the restore, and the database, to fail. Similarly, a command log may contain a transaction that originally succeeded but fails and raises an exception during playback.

In both of these situations, VoltDB issues a fatal error and stops the database to avoid corrupting the contents.

Although protecting you from an incomplete recovery is the appropriate default behavior, there may be cases where you want to recover as much data as possible, with full knowledge that the resulting data set does *not* match the original. VoltDB provides two techniques for performing partial recoveries in case of failure:

- Logging constraint violations during snapshot restore
- Performing command log recovery in safe mode

The following sections describe these techniques.

Warning

It is critically important to recognize that the techniques described in this section *do not* produce a complete copy of the original database or resolve the underlying problem that caused the initial recovery to fail. These techniques should never be attempted without careful consideration and full knowledge and acceptance of the risks associated with partial data recovery.

7.2.1. Logging Constraint Violations

There are several situations that can cause a snapshot restore to fail because of constraint violations. Rather than have the operation fail as a whole, you can request that constraint violations be logged to a file instead. This way you can review the tuples that were excluded and decide whether to ignore or replace their content manually after the restore completes.

To perform a manual restore that logs constraint violations rather than stopping when they occur, you use a special JSON form of the @SnapshotRestore system procedure. You specify the path of the log files in a JSON attribute, `duplicatePaths`. For example, the following commands perform a restore of snapshot files in the directory `/var/voltdb/snapshots/` with the unique identifier `myDB`. The restore operation logs constraint violations to the directory `/var/voltdb/logs`.

```
$ sqlcmd
1> exec @SnapshotRestore '{ "path":"/var/voltdb/snapshots/",
                            "nonce":"myDB",
                            "duplicatesPath":"/var/voltdb/logs/" }';
2> exit
```

Constraint violations are logged as needed, one file per table, to CSV files with the name *`{table}`*`-duplicates-`*`{timestamp}`*`.csv`.

7.2.2. Safe Mode Recovery

On rare occasions, recovering a database from command logs may fail. This can happen, for example, if a stored procedure introduces non-deterministic content. If a recovery fails, the specific error is known. However, there is no way for VoltDB to know the root cause or how to continue. Therefore, the recovery fails and the database stops.

When this happens, VoltDB logs the last successful transaction before the recovery failed. You can then ask VoltDB to recover up to but not including the failing transaction by performing a recovery in *safe mode*.

You request safe mode by adding the **--safemode** switch to the command line when starting the recovery operation, like so:

```
$ voltdb recover --safemode -license ~/license.xml
```

When VoltDB recovers from command logs in safe mode it enables two distinct behaviors:

- Snapshots are restored, logging any constraint violations
- Command logs are replayed up to the last valid transaction

This means that if you are recovering using an automated snapshot (rather than command logs), you can recover some data even if there are constraint violations during the snapshot restore. Also, when recovering from command logs, VoltDB will ignore constraint violations in the command log snapshot and replay all transactions that succeeded in the previous attempt.

It is important to note that to successfully use safe mode with command logs, you must perform a regular recovery operation first — and have it fail — so that VoltDB can determine the last valid transaction. Also, if the snapshot and the command logs contain both constraint violations and failed transactions, you may need to run recovery in safe mode twice to recover as much data as possible. Once to complete restoration of the snapshot, then a second time to recover the command logs up to a point before the failed transaction.

7.3. Collecting the Log Files

VoltDB includes a utility that collects all of the pertinent logs for a given server. The log collector retrieves the necessary system and process files from the server, creates a compressed archive file and, optionally, uploads it via SFTP to a support site. For customers requesting support from VoltDB, your support contact will often provide instructions on how and when to use the log collector and where to submit the files.

Note that the database does not need to be running to use the log collector. It can find and collect the log files based solely on the location of the VoltDB root directory where the database was run.

You can run the log collector from the command line, from within the VoltDB Enterprise Manager, or programmatically through the REST interface (for databases started through REST or the Enterprise Manager). The following sections describe how to run the log collector using the three different environments.

7.3.1. Collecting Log Files Using the Command Line

To collect the log files from the command line, use the **voltdb collect** command:

```
$ voltdb collect --prefix=mylogs /home/db/voltdbroot
```

When you run the command you must specify the location of the root directory for the database as an argument to the command. For example, if you are in the same working directory where the database was originally started, by default the root directory is the subdirectory `voltdbroot`.

```
$ voltdb collect --prefix=mylogs $(pwd)/voltdbroot
```

The archive file that the **collect** command generates is created in your current working directory.

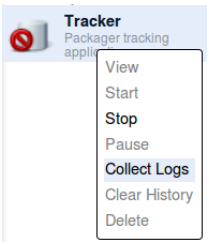
The **collect** command has optional arguments that let you control what data is collected, the name of the resulting archive file, as well as whether to upload the file to an FTP server. In the preceding example the `--prefix` flag specifies the prefix for the archive file name. If you are submitting the log files to an

FTP server via SFTP, you can use the `--upload`, `--username`, and `--password` flags to identify the target server and account. For example:

```
$ voltdb collect --prefix=mylogs \
     --upload=ftp.mycompany.com \
     --username=babbage
     --password=charles  /home/db/voltdbroot
```

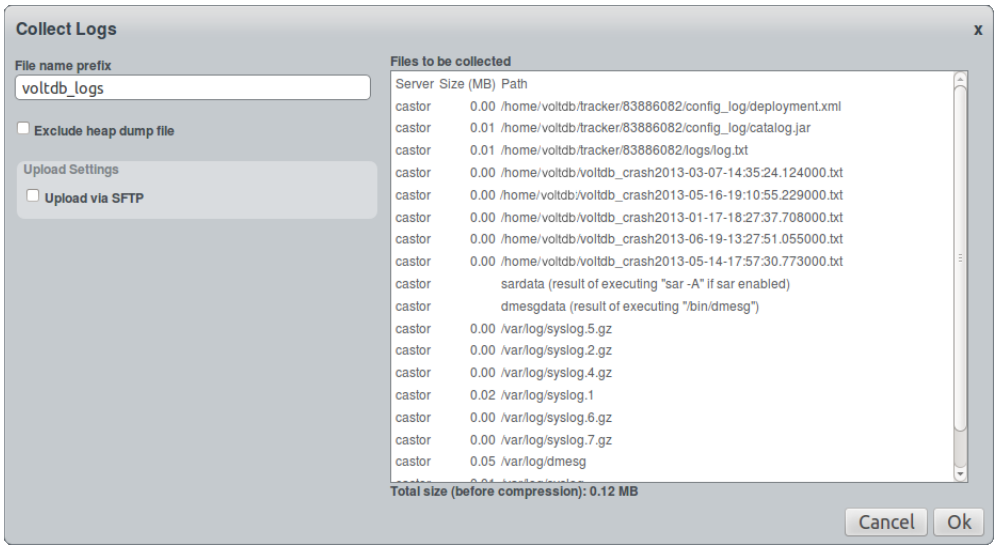
Note that the **voltdb collect** command collects log files for the current system only. To collect logs for all servers in a cluster, you will need to issue the **voltdb collect** command locally on each server separately. See the **voltdb collect** documentation in the *Using VoltDB* manual for details.

7.3.2. Collecting Log Files Using the Enterprise Manager



To collect the log files from a database cluster created and managed by the VoltDB Enterprise Manager, it is easiest to use the Enterprise Manager interface. Click on the name of the database on the database list to the left of the dashboard then select the item "Collect logs" from the popup menu.

This menu item brings up a dialog box showing a list of the files and command output that will be collected. The dialog box also has fields so you can control the resulting file prefix, include or exclude the heap dump file, and optionally upload the results via SFTP.



The major difference between using the Enterprise Manager interface and the shell command line is that the Enterprise Manager creates (and optionally uploads) archives for every server in the cluster at once. You do not need to collect logs for each server separately.

7.3.3. Collecting Log Files Using the REST Interface

Finally, it is possible to invoke the log collector using the REST interface. Invoking the log collector from REST has the same effect as invoking it from within the Enterprise Manager — it collects the logs on all of the servers of the cluster.

The method for collecting logs using the REST interface is `/mgmt/databases/{id}/collect`. Attributes of the method let you optionally customize the collection in the same way you can from the

command line or the Enterprise Manager interface. For example, the following REST call collects the logs from all of the servers associated with the database ID 12345, using the file prefix "MyLogs":

```
http://voltdbmgr:9000/man/api/1.0/mgmt
/databases/12345/collect?prefix=MyLogs
```

See the REST reference appendix in the *VoltDB Enterprise Manager Guide* for more information about the collect method and the supported attributes.

Appendix A. Server Configuration Options

There are a number of system, process, and application options that can impact the performance or behavior of your VoltDB database. You control these options when starting VoltDB. The configuration options fall into five main categories:

- Server configuration
- Process configuration
- Database configuration
- Path configuration
- Network ports used by the database cluster

This appendix describes each of the configuration options, how to set them, and their impact on the resulting VoltDB database and application environment.

A.1. Server Configuration Options

VoltDB provides mechanisms for setting a number of options. However, it also relies on the base operating system and network infrastructure for many of its core functions. There are operating system configuration options that you can adjust to to maximize your performance and reliability, including:

- Network configuration
- Time configuration

A.1.1. Network Configuration (DNS)

VoltDB creates a network mesh among the database cluster nodes. To do that, all nodes must be able to resolve the IP address and hostnames of the other server nodes. Make sure all nodes of the cluster have valid DNS entries or entries in the local hosts files.

For servers that have two or more network interfaces — and consequently two or more IP addresses — it is possible to assign different functions to each interface. VoltDB defines two sets of ports:

- External ports, including the client and admin ports. These are the ports used by external applications to connect to and communicate with the database.
- Internal ports, including all other ports. These are the ports used by the database nodes to communicate among themselves. These include the internal port, the zookeeper port, and so on. (See Section A.5, “Network Ports” for a complete listing of ports.)

You can specify which network interface the server expects to use for each set of ports by specifying the internal and external interface when starting the database. For example:

```
$ voltdb create -d deployment.xml \
  -H serverA -l license.xml \
  --externalinterface=10.11.169.10 \
  --internalinterface=10.12.171.14
```

Note that the default setting for the internal and external interface can be overridden for a specific port by including the interface and a colon before the port number when specifying a port on the command line. See Section A.5, “Network Ports” for details on setting specific ports.

A.1.2. Time Configuration (NTP)

Keeping VoltDB cluster nodes in close synchronization is important for the ongoing performance of your database. At a minimum, use of NTP to synchronize time across the cluster is recommended. If the time difference between nodes is too large (greater than three seconds) VoltDB refuses to start. It is also important to avoid having nodes adjust time backwards, or VoltDB will pause while it waits for time to "catch up" to its previous setting.

A.2. Process Configuration Options

In addition to system settings, there are configuration options pertaining to the VoltDB server process itself that can impact performance. Runtime configuration options are set as command line options when starting the VoltDB server process.

The key process configuration for VoltDB is the Java maximum heap size. It is also possible to pass other arguments to the Java Virtual Machine directly.

A.2.1. Maximum Heap Size

The heap size is a parameter associated with the Java runtime environment. Certain portions of the VoltDB server software use the Java heap. In particular, the part of the server that receives and responds to stored procedure requests uses the Java heap.

Depending upon how many transactions your application executes a second, you may need additional heap space. The higher the throughput, the larger the maximum heap needed to avoid running out of memory.

In general, a maximum heap size of two gigabytes (2048) is recommended. For production use, a more accurate measurement of the needed heap size can be calculated from the size of the schema (number of tables), number of sites per host, and what durability and availability features are in use. See the *VoltDB Planning Guide* for details.

It is important to remember that the heap size is not directly related to data storage capacity. Increasing the maximum heap size does not provide additional data storage space. In fact, quite the opposite. Needlessly increasing the maximum heap size reduces the amount of memory available for storage.

To set the maximum heap size when starting VoltDB, define the environment variable VOLTDB_HEAPMAX as an integer value (in megabytes) before issuing the **voltdb** command. For example, the following commands start VoltDB with a 3 gigabyte heap size (the default is 2 gigabytes):

```
$ export VOLTDB_HEAPMAX="3072"
$ voltdb create -d deployment.xml -H serverA
```

A.2.2. Other Java Runtime Options (VOLTDB_OPTS)

VoltDB sets the Java options — such as heap size and classpath — that directly impact VoltDB. There are a number of other configuration options available in the Java Virtual machine (JVM).

VoltDB provides a mechanism for passing arbitrary options directly to the JVM. If the environment variable VOLTDB_OPTS is defined, its value is passed as arguments to the Java command line.

- When starting VoltDB using the **voltdb** command, the contents of VOLTDB_OPTS are added to the Java command line on the current server.
- When starting the VoltDB Enterprise Manager, the contents of VOLTDB_OPTS are added to the invocation that the Enterprise Manager uses to start the VoltDB process on all remote servers.

In other words, when starting a cluster manually, you must define VOLTDB_OPTS on each server to have it take effect for all servers. When using the Enterprise Manager, you only need to define VOLTDB_OPTS once, before starting the Enterprise Manager, to have these JVM options take effect on all nodes that the Enterprise Manager starts.

Warning

VoltDB does not validate the correctness of the arguments you specify using VOLTDB_OPTS or their appropriateness for use with VoltDB. This feature is intended for experienced users only and should be used with extreme caution.

A.3. Database Configuration Options

Runtime configuration options are set either as part of the deployment file or as command line options when starting the VoltDB server process. These database configuration options are only summarized here. See the *Using VoltDB* manual for a more detailed explanation. The configuration options include:

- Sites per host
- K-Safety
- Network partition detection
- Automated snapshots
- Export
- Command logging
- Heartbeat
- Temp table size

A.3.1. Sites per Host

Sites per host specifies the number of unique VoltDB "sites" that are created on each physical database server. The section on "Determining How Many Partitions to Use" in the *Using VoltDB* manual explains how to choose a value for sites per host.

You set the value of sites per host using the `sitesperhost` attribute of the `<cluster>` tag in the deployment file.

A.3.2. K-Safety

K-safety defines the level of availability or durability that the database can sustain, by replicating individual partitions to multiple servers. K-safety is described in detail in the "Availability" chapter of the *Using VoltDB* manual.

You specify the level of K-safety that you want in the deployment file using the `kfactor` attribute of the `<cluster>` tag.

A.3.3. Network Partition Detection

Network partition detection protects a VoltDB cluster in environments where the network is susceptible to partial or intermittent failure among the server nodes. Partition detection is described in detail in the "Availability" chapter of the *Using VoltDB* manual.

Use of network partition detection is strongly recommended for production systems and therefore is enabled by default. You can enable or disable network partition detection in the deployment file using the <partition-detection> tag.

A.3.4. Automated Snapshots

Automated snapshots provide ongoing protection against possible database failure (due to hardware or software issues) by taking periodic snapshots of the database's contents. Automated snapshots are described in detail in the section on "Scheduling Automated Snapshots" in the *Using VoltDB* manual.

You enable and configure automated snapshots with the <snapshot> tag in the deployment file.

Snapshot activity involves both processing and disk I/O and so may have a noticeable impact on performance (in terms of throughput and/or latency) on a very busy database. You can control the priority of snapshots activity using the <snapshot/> tag within the <systemsettings> element of the deployment file. The snapshot priority is an integer value between 0 and 10, with 0 being the highest priority and 10 being the lowest. The closer to 10, the longer snapshots take to complete, but the less they can affect ongoing database work.

Note that snapshot priority affects all snapshot activity, including automated snapshots, manual snapshots, and command logging snapshots.

A.3.5. Export

The export function lets you automatically export selected data from your VoltDB database to an another target database or system using SQL INSERT statements to special export tables at runtime. This feature is described in detail in the chapter on "Exporting Live Data" in the *Using VoltDB* manual.

You enable and disable export using the <export> tag in the deployment file.

A.3.6. Command Logging

The command logging function saves a record of each transaction as it is initiated. These logs can then be "replayed" to recreate the database's last known state in case of intentional or accidental shutdown. This feature is described in detail in the chapter on "Command Logging and Recovery" in the *Using VoltDB* manual.

To enable and disable command logging, use the <commandlog> tag in the deployment file.

A.3.7. Heartbeat

The database servers use a "heartbeat" to verify the presence of other nodes in the cluster. If a heartbeat is not received within a specified time limit, that server is assumed to be down and the cluster reconfigures

itself with the remaining nodes (assuming it is running with K-safety). This time limit is called the "heartbeat timeout" and is specified as a integer number of seconds.

For most situations, the default value for the timeout (10 seconds) is appropriate. However, if your cluster is operating in an environment that is susceptible to network fluctuations or unpredictable latency, you may want to increase the heartbeat timeout period.

You can set an alternate heartbeat timeout using the `<heartbeat>` tag in the deployment file.

A.3.8. Temp Table Size

VoltDB uses temporary tables to store intermediate table data while processing transactions. The default temp table size is 100 megabytes. This setting is appropriate for most applications. However, extremely complex queries or many updates to large records could cause the temporary space to exceed the maximum size, resulting in the transaction failing with an error.

In these unusual cases, you may need to increase the temp table size. You can specify a different size for the temp tables using the `<temptables>` tag in the deployment file and specifying a whole number of megabytes. Note: since the temp tables are allocated as needed, increasing the maximum size can result in a Java out-of-memory error at runtime if the system is memory-constrained. Modifying the temp table size should be done with caution.

A.3.9. Query Timeout

In general, SQL queries execute extremely quickly. But it is possible, usually by accident, to construct a query that takes an unexpectedly long time to execute. This usually happens when the query is overly complex or accesses extremely large tables without the benefit of an appropriate filter or index.

There is no way to terminate individual queries once they start. However, you can set a limit on the length of time any read-only query (or batch of queries in the case of the voltExecuteSQL() method in a stored procedure) is allowed to run. This limit is called the query timeout and is specified in milliseconds. Setting the timeout value to zero is the equivalent of the default; that is, no timeout.

For example, the following deployment file sets a query timeout value of three seconds:

```
<systemsettings>
   <query timeout="3000"/>
</systemsettings>
```

If any query or batch of queries exceeds the query timeout, the query is interrupted and an error returned to the calling application. Note that the limit is applied to read-only ad hoc queries or queries in read-only stored procedures only. In a K-Safe cluster, queries on different copies of a partition may execute at different rates. Consequently the same query may timeout in one copy of the partition but not in another. To avoid possible non-deterministic changes, VoltDB does not apply the time out limit to any queries or procedures that may modify the database contents.

A.4. Path Configuration Options

The running database uses a number of disk locations to store information associated with runtime features, such as export, network partition detection, and snapshots. You can control which paths are used for these disk-based activities. The path configuration options include:

- VoltDB root

- Snapshots path
- Export overflow path
- Command log path
- Command log snapshots path

A.4.1. VoltDB Root

VoltDB defines a root directory for any disk-based activity which is required at runtime. This directory also serves as a root for all other path definitions that take the default or use a relative path specification.

By default, the VoltDB root is the directory `voltdbroot` created as a subfolder in the current working directory for the process that starts the VoltDB server process. (If the subfolder does not exist, VoltDB creates it on startup.) You can specify an alternate root in the deployment file using the `<voltdbroot>` element. However, if you explicitly name the root directory in the deployment file, the directory must exist or the database server cannot start. See the section on "Configuring Paths for Runtime Features" in the *Using VoltDB* manual for details.

When using the VoltDB Enterprise Manager, the VoltDB root directory is defined implicitly by the destination directory. You define the destination directory when you create the database. The VoltDB root becomes a subfolder of the destination directory, where the subfolder name is the same as the database ID of the current database. So, for example, if the destination directory is /`opt/voltdb` and the database ID is 12345, the resulting VoltDB root directory is `/opt/voltdb/12345`.

A.4.2. Snapshots Path

The snapshots path specifies where automated and network partition snapshots are stored. The default snapshots path is the "`snapshots`" subfolder of the VoltDB root directory. You can specify an alternate path for snapshots using the `<snapshots>` child element of the `<paths>` tag in the deployment file.

A.4.3. Export Overflow Path

The export overflow path specifies where overflow data is stored if the export queue gets too large. The default export overflow path is the "`export_overflow`" subfolder of the VoltDB root directory. You can specify an alternate path using the `<exportoverflow>` child element of the `<paths>` tag in the deployment file.

See the chapter on "Exporting Live Data" in the *Using VoltDB* manual for more information on export overflow.

A.4.4. Command Log Path

The command log path specifies where the command logs are stored when command logging is enabled. The default command log path is the "`command_log`" subfolder of the VoltDB root directory. However, for production use, it is strongly recommended that the command logs be written to a dedicated device, not the same device used for snapshotting or export overflow. You can specify an alternate path using the `<commandlog>` child element of the `<paths>` tag in the deployment file.

See the chapter on "Command Logging and Recovery" in the *Using VoltDB* manual for more information on command logging.

A.4.5. Command Log Snapshots Path

The command log snapshots path specifies where the snapshots created by command logging are stored. The default path is the "`command_log_snapshot`" subfolder of the VoltDB root directory. (Note that command log snapshots are stored separately from automated snapshots.) You can specify an alternate path using the `<commandlogsnapshot>` child element of the `<paths>` tag in the deployment file.

See the chapter on "Command Logging and Recovery" in the *Using VoltDB* manual for more information on command logging.

A.5. Network Ports

A VoltDB cluster opens network ports to manage its own operation and to provide services to client applications. When using the Enterprise Manager, most ports are configurable as part of the database definition. When using the command line, the network ports are configurable as part of the command that starts the VoltDB database process or through the deployment file. When specifying a port on the command line, you can specify just a port number or the network interface and the port number, separated by a colon.

Table A.1, “VoltDB Port Usage” summarizes the ports that VoltDB uses, their default value, and how to change the default. The following sections describe each port in more detail.

Table A.1. VoltDB Port Usage

Port	Default Value	Where to Set (Community Edition)
Client Port	21212	VoltDB command line
Admin Port	21211	VoltDB command line or deployment file
Web Interface Port (httpd)	8080	VoltDB command line or deployment file
Internal Server Port	3021	VoltDB command line
Log Port	4560	(Enterprise Manager only)
JMX Port	9090	VoltDB command line
Replication Port	5555	VoltDB command line
Zookeeper port	7181	VoltDB command line

A.5.1. Client Port

The client port is the port VoltDB client applications use to communicate with the database cluster nodes. By default, VoltDB uses port 21212 as the client port. You can change the client port. However, all client applications must then use the specified port when creating connections to the cluster nodes.

To specify a different client port on the command line, use the `--client` flag when starting the VoltDB database. For example, the following command starts the database using port 12345 as the client port:

```
$ voltdb create -l ~/license.xml \
         -d deployment.xml -H serverA \
         --client=12345
```

When using the Enterprise Manager, use the Edit Configuration dialog box to specify the port to use.

If you change the default client port, all client applications must also connect to the new port. The client interfaces for Java and C++ accept an additional, optional argument to the createConnection method for

this purpose. The following examples demonstrate how to connect to an alternate port using the Java and C++ client interfaces.

Java

```
org.voltdb.client.Client voltclient;
voltclient = ClientFactory.createClient();
voltclient.createConnection("myserver",12345);
```

C++

```
boost::shared_ptr<voltdb::Client> client = voltdb::Client::create();
client->createConnection("myserver", 12345);
```

A.5.2. Admin Port

The admin port is similar to the client port, it accepts and processes requests from applications. However, the admin port has the special feature that it continues to accept requests when the database enters admin mode.

By default, VoltDB uses port 21211 on the default external network interface as the admin port. You can change the port assignment in the deployment file using the <admin-mode> tag or on the command line using the `--admin` flag. For example, the following deployment file sets the admin port to 2222:

```
<deployment>
   ...
   <admin-mode port="2222" />
</deployment>
```

The same effect can be achieved using the --admin flag on the command line:

```
$ voltdb create -l ~/license.xml \
         -d deployment.xml -H serverA \
         --admin=2222
```

When the admin port is set in both the deployment file and on the command line, the command line setting supersedes the deployment file.

When using the Enterprise Manager, use the Edit Configuration dialog box to specify a different admin port.

A.5.3. Web Interface Port (httpd)

The web interface port is the port that VoltDB listens to for web-based connections from the JSON interface. There are two related settings associated with the JSON interface. The first setting is whether the port is enabled; the second is which port to use, if the interface is enabled.

When starting a VoltDB database manually, the web interface port (and the JSON interface) or disabled by default. When using the Enterprise Manager, both the web interface port and the JSON interface are enabled by default. The default httpd port is 8080.

If you plan on using the JSON interface from the community edition, be sure to include the <httpd> tag in the deployment file.

- To enable the httpd port but disable the JSON interface, specify the attribute `enabled="false"` in the `<jsonapi>` tag in the deployment file when starting VoltDB. If you are using the Enterprise Manager, there is a check box for enabling and disabling the JSON interface in the Edit Configuration dialog box.

- To change the web interface port, specify the alternate port using the `port` attribute to the `<httpd>` tag in the deployment file. Or, you can use the `--http` flag on the command line. If you are using the Enterprise Manager, use the httpd port field in the Edit Configuration dialog.

For example, the following deployment file fragment enables the web interface and the JSON interface, specifying the alternate port 8083.

```
<httpd port='8083'>
        <jsonapi enabled='true'/>
</httpd>
```

If you change the port number, be sure to use the new port number when connecting to the cluster using the JSON interface. For example, the following URL connects to the port 8083, instead of 8080:

```
http://athena.mycompany.com:8083/api/1.0/?Procedure=@SystemInformation
```

For more information about the JSON interface and specifying the appropriate port when connecting to the VoltDB cluster, see the section on "How the JSON Interface Works" in the *Using VoltDB* manual.

A.5.4. Internal Server Port

A VoltDB cluster uses ports to communicate among the cluster nodes. This port is internal to VoltDB and should not be used by other applications.

By default, the internal server port is port 3021 for all nodes in the cluster[1]. You can specify an alternate port using the `--internal` flag when starting the VoltDB process. For example, the following command starts the VoltDB process using an internal port of 4000:

```
$ voltdb create -l ~/license.xml \
         -d deployment.xml -H serverA \
          --internal=4000
```

A.5.5. Log Port

When using the Enterprise Manager to configure and run VoltDB, the resulting VoltDB cluster nodes open a port as an output stream for log4J messages. The Enterprise Manager uses the port to fetch log4J messages from the cluster nodes and display them in the management console.

By default, port 4560 is assigned as the log port. However, this port is only opened when using the Enterprise Manager. You can change the port number using the Edit Database dialog from within the VoltDB Enterprise Manager.

A.5.6. JMX Port

The VoltDB Enterprise Manager uses JMX to collect statistics from the cluster nodes at runtime. It does this using JMX.

[1] In the special circumstance where multiple VoltDB processes are started for one database, all on the same server, the internal server port is incremented from the initial value for each process.

The default JMX port is 9090. However, the JMX port is only opened when using the VoltDB Enterprise Edition. You can change the port number used by JMX by adding the Java argument -Dvolt.rmi.agent.port to the command line. You do that by defining the environment variable VOLTDB_OPTS before starting the server. For example, the following command assigns the JMX port to port number 2345:

```
$ export VOLTDB_OPTS="-Dvolt.rmi.agent.port=2345"
```

There is no JMX port when using the VoltDB Community Edition.

A.5.7. Replication Port

During database replication, the replica uses a dedicated port to connect to the master database. By default, the replication port is port 5555. You can use a different port by specifying a different port number either on the **voltdb** command line or in the deployment file.

- On the command line, use the `--replication` flag to specify a different port (and, optionally, a different network interface):

  ```
  $ voltdb create -l ~/license.xml \
           -d deployment.xml -H serverA \
          --replication=6666
  ```

- In the deployment file, specify the replication port number using the `port` attribute of the `<dr>` tag:

  ```
  <dr id="3" port="6666" />
  ```

Adding the replication port to the deployment file is useful when setting the port for all nodes in the cluster. Using the command line option is useful for changing the default port for only one node in the cluster or for specifying a specific network interface. If you specify the replication port in both the deployment file and on the command line, the command line argument takes precedence.

A.5.8. Zookeeper Port

VoltDB uses a version of Apache Zookeeper to communicate among supplementary functions that require coordination but are not directly tied to database transactions. Zookeeper provides reliable synchronization for functions such as command logging without interfering with the database's own internal communications.

VoltDB uses a network port bound to the local interface (127.0.0.1) to interact with Zookeeper. By default, 7181 is assigned as the Zookeeper port for VoltDB. You can specify a different port number using the `--zookeeper` flag when starting the VoltDB process. It is also possible to specify a different network interface, like with other ports. However, accepting the default for the zookeeper network interface is recommended where possible. For example:

```
$ voltdb create -l ~/license.xml \
         -d deployment.xml -H serverA \
         --zookeeper=2288
```

Appendix B. Snapshot Utilities

VoltDB provides two utilities for managing snapshot files. These utilities verify that a native snapshot is complete and usable and convert the snapshot contents to a text representation that can be useful for uploading or reloading data in case of severe errors.

It is possible, as the result of a design flaw or failed program logic, for a database application to become unusable. However, the data is still of value. In such emergency cases, it is desirable to extract the data from the database and possibly reload it. This is the function that save and restore performs within VoltDB.

But there may be cases when you want to use the data created by a VoltDB snapshot elsewhere. The goal of the utilities is to assist in that process. The snapshot utilities are:

- *SnapshotConverter* converts a snapshot (or part of a snapshot) into text files, creating one file for each table in the snapshot.
- *SnapshotVerifier* verifies that a VoltDB snapshot is complete and usable.

Unlike system procedures, that must be run within the context of an existing database connection, the snapshot utilities can be run from the command line without a running database present. However, the utilities are still dependent on the Java classes and library for VoltDB. So you must be sure to define your Java classpath and library path appropriately to invoke the classes.

To run either SnapshotVerifier or SnapshotConverter, use the Java command to invoke the class, specifying the appropriate classpath and library path based on where your VoltDB software is installed. For example, if VoltDB is installed in /opt/voltdb, the command to invoke SnapshotVerifier is as follows:

```
$ java -classpath "/opt/voltdb/voltdb/*:/opt/voltdb/lib/*" \
       -Djava.library.path=/opt/voltdb/voltdb \
       org.voltdb.utils.SnapshotVerifier
```

You may find it easier to add an alias to your shell script startup file to abbreviate these commands:

```
$ alias snapshotverify="java \
        -cp \"/opt/voltdb/voltdb/*:/opt/voltdb/lib/*\"  \
        -Djava.library.path=/opt/voltdb/voltdb \
         org.voltdb.utils.SnapshotVerifier "
$ alias snapshotconvert="java \
        -cp \"/opt/voltdb/voltdb/*:/opt/voltdb/lib/*\"  \
        -Djava.library.path=/opt/voltdb/voltdb \
        org.voltdb.utils.SnapshotConverter "
```

The following sections describing each command assume these aliases have been defined.

Each command accepts a different set of arguments. Use the `--help` argument to display a list the allowable arguments and qualifiers. For example:

```
$ snapshotverify --help
```

snapshotconvert

snapshotconvert — Converts the tables in a VoltDB snapshot into text files.

Syntax

```
snapshotconvert {snapshot-id} --type {csv|tsv} \
        --table {table} [...] [--dir {directory}]... \
        [--outdir {directory}]

snapshotconvert --help
```

Description

SnapshotConverter converts one or more tables in a valid snapshot into either comma-separated (csv) or tab-separated (tsv) text files, creating one file per table.

Where:

{snapshot-id} is the unique identifier specified when the snapshot was created. (It is also the name of the .digest file that is part of the snapshot.) You must specify a snapshot ID.

{csv|tsv} is either "csv" or "tsv" and specifies whether the output file is comma-separated or tab-separated. This argument is also used as the filetype of the output files.

{table} is the name of the database table that you want to export to text file. You can specify the `--table` argument multiple times to convert multiple tables with a single command.

{directory} is the directory to search for the snapshot (`--dir`) or where to create the resulting output files (`--outdir`). You can specify the `--dir` argument multiple times to search multiple directories for the snapshot files. Both `--dir` and `--outdir` are optional; they default to the current directory path.

Example

The following command exports two tables from a snapshot of the flight reservation example used in the *Using VoltDB* manual. The utility searches for the snapshot files in the current directory (the default) and creates one file per table in the user's home directory:

```
$ snapshotconvert flightsnap --table CUSTOMER --table RESERVATION \
                  --type csv -- outdir ~/
```

snapshotverify

snapshotverify — Verifies that the contents of one or more snapshot files are complete and usable.

Syntax

```
snapshotverify [snapshot-id] [--dir {directory}] ...

snapshotverify --help
```

Description

SnapshotVerifier verifies one or more snapshots in the specified directories.

Where:

[snapshot-id] is the unique identifier specified when the snapshot was created. (It is also the name of the .digest file that is part of the snapshot.) If you specify a snapshot ID, only snapshots matching that ID are verified. If you do not specify an ID, all snapshots found will be verified.

{directory} is the directory to search for the snapshot. You can specify the `--dir` argument multiple times to search multiple directories for snapshot files. If you do not specify a directory, the default is to search the current directory.

Examples

The following command verifies all of the snapshots in the current directory:

```
$ snapshotverify
```

This example verifies a snapshot with the unique identifier "flight" in either the directory `/etc/voltdb/save` or `~/mysaves`:

```
$ snapshotverify flight --dir /etc/voltdb/save/ --dir ~/mysaves
```

Appendix C. Using Application Catalogs

Warning: Deprecated

The features and capabilities described in this appendix are deprecated and may be removed in a future release of VoltDB. This information is provided for existing customers who wish to continue using application catalogs temporarily. However, we do recommend converting to use of interactive DDL at your earliest convenience (as described in Section C.5, "**Converting** Existing Catalogs for Use with Interactive DDL").

In previous versions of VoltDB, the database schema and stored procedures had to be precompiled into an application catalog before starting the database. This catalog was then specified on the command line when issuing the **voltdb create** command.

Catalogs are no longer needed and you can enter schema DDL interactively using the sqlcmd utility. This makes both creating your database and updating much easier. However, use of an application catalog — although deprecated — is still supported in VoltDB V5 for backwards compatibility.

This appendix provides information for customers with existing catalogs who wish to continue using catalogs to start and run their databases. The topics covered in the appendix are:

- Configuring the Database to Use an Application Catalog
- Compiling an Application Catalog
- Starting the Database With a Catalog
- Updating the Application Catalog
- **Converting** Existing Catalogs for Use with Interactive DDL

C.1. Configuring the Database to Use an Application Catalog

When starting a VoltDB database, you must choose between using an application catalog or using interactive DDL. The default is using interactive DDL. To use an application catalog, specify `schema="catalog"` in the `<cluster>` element of the deployment file. For example:

```
<cluster hostcount=5
         kfactor=2
         schema="catalog"
/>
```

Application catalogs and interactive DDL cannot be used together on the same running database. If you start a database using an application catalog, you cannot use interactive DDL to modify that catalog. You must use the **voltadmin update** command or the @UpdateApplicationCatalog system procedure. Similarly, if you start a database using interactive DDL, you must use interactive DDL to modify the schema. You cannot use **voltadmin update** or @UpdateApplicationCatalog to apply a compiled catalog.

C.2. Compiling an Application Catalog

To create an application catalog, you must compile the database schema and stored procedure class files into a single catalog file. To run the compiler, use the **`voltdb compile`** command, specifying three arguments:

1. The path to your compiled stored procedure classes
2. The name of the schema file to use as input
3. The name of the application catalog to create as output

For example, if your stored procedure classes are in a subfolder called `obj`, the command might be:

```
$ voltdb compile --classpath="obj" -o flight.jar flightschema.sql
```

If you do not specify an output file, the catalog is created as `catalog.jar` in the current working directory. The schema can include any data definition language (DDL) statements listed in the *Using VoltDB* manual appendix on "Supported DDL" that create or partition database objects. A compiled schema cannot contain any DDL statements for modifying the schema; that is, the schema cannot include any ALTER or DROP statements.

C.3. Starting the Database With a Catalog

To create a new database using an application catalog, specify the name of the catalog on the **voltdb create** command line. Be sure to also specify a deployment file that includes the schema="catalog" attribute. For example:

```
$ voltdb create flight.jar --deployment=deploycatalog.xml
```

C.4. Updating the Application Catalog

While the database is running, you can update the schema and/or stored procedures for a database schema that was started with a catalog by updating the catalog. Changes you can make in the catalog include:

- Adding, removing, or updating tables, columns, and indexes
- Adding or removing materialized views and export-only tables
- Adding, removing, or updating stored procedures and the security permissions for accessing them

Schema updates via application catalog are done by creating an updated application catalog and deployment file and telling the database process to use the new catalog. You do this with the @UpdateApplicationCatalog system procedure, or from the shell prompt using the **voltadmin update** command. The process is as follows:

1. Make the necessary changes to the source code for the stored procedures and the schema.
2. Recompile the class files and the application catalog as described in Section C.2, “Compiling an Application Catalog”.
3. Use the @UpdateApplicationCatalog system procedure or **voltadmin update** command to pass the new catalog and deployment file to the cluster.

For example:

```
$ voltdb compile -o mycatalog.jar  myschema.sql
$ voltadmin update mycatalog.jar deploycatalog.xml
```

C.5. Converting Existing Catalogs for Use with Interactive DDL

Although application catalogs are still supported in VoltDB V5.0, use of catalogs is deprecated and support will be removed in a future release. Therefore, we encourage customers to migrate their development and production processes towards use of interactive DDL.

C.5.1. Updating the Database Startup Process

Changing from application catalogs to interactive DDL is a relatively simple process. No changes are needed to the Java stored procedures and more often than not, no changes are needed to the DDL either. There are actually only two changes to your existing procedures:

- **Package stored procedures as a JAR file rather than compile them into an application catalog**

  Stored procedures still needed to be packaged into one or more JAR files before you can load them into the database. However, they do not need to be compiled with the schema anymore.

  Note that application catalogs *are* JAR files. So, if you have an existing application catalog, you can temporarily use that as the stored procedure JAR file — any extraneous content in the catalog will be ignored. However, in the long run it is better to update your processes to use the **jar** command to create your JAR files when migrating to interactive DDL.

- **Load the stored procedures and schema after the database starts rather than using a catalog when starting**

  When using interactive DDL, you create an empty database instance first then, once the database has started, load the stored procedures and schema. The easiest way to do this is using the sqlcmd **load classes** and **file** directives, as described in Section 3.3, “Loading the Database Definition”.

C.5.2. When to Modify the Schema DDL

In most cases, your existing schema files are valid input to the sqlcmd utility as is. There are only a few exceptions where you may need to edit the DDL:

- Replace IMPORT CLASSES with sqlcmd LOAD CLASSES

  If your application catalog contains additional Java helper classes beyond just stored procedures, you must use IMPORT CLASSES statements to tell the VoltDB compiler to add them to the catalog. When using interactive DDL, this is no longer necessary. Simply include the helper classes in the stored procedure JAR file and they will automatically be included when you load the classes using sqlcmd.

- Merge CREATE PROCEDURE and PARTITION PROCEDURE for single-partitioned procedures with complex queries

  In earlier versions of VoltDB, the statements to define a stored procedure and partition it, CREATE PROCEDURE and PARTITION PROCEDURE, were separate. These two statements are still supported and in most cases work perfectly well. However, there are some cases, with complex SQL queries, where the procedure is not valid as a multi-partition procedure. For example, joining two partitioned tables is not allowed in a multi-partition procedure. However, if the tables are joined on the partition column, they can be in a single-partitioned procedure.

  So, using two statements, the initial CREATE PROCEDURE command may fail to compile interactively. In this case, you can combine the two statements into a single CREATE PROCEDURE using

the PARTITION clause. For example, the following statements may fail if the procedure joins two or more partitioned tables:

```
CREATE PROCEDURE FROM CLASS acme.procs.GetStoreByRegion;
PARTITION PROCEDURE GetStoreByRegion ON TABLE store COLUMN region;
```

Instead, you can combine the two statements into a single CREATE PROCEDURE statement including the partitioning information in a PARTITION ON clause:

```
CREATE PROCEDURE PARTITION ON TABLE store COLUMN region
       FROM CLASS acme.procs.GetStoreByRegion;
```

The PARTITION ON clause can be used in both the CREATE PROCEDURE AS and CREATE PROCEDURE FROM CLASS statements.