Technical Report

MySQL Database on NetApp ONTAP

Best Practices

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Abstract

MySQL and its variants, including MariaDB and Percona, are widely used for many enterprise applications. These applications range from global social networking sites and massive e-commerce systems to SMB hosting systems containing thousands of database instances. This document describes the configuration requirements and provides guidance on tuning and storage configuration for deploying MySQL on NetApp® ONTAP® data management software.

To determine whether the environment, configurations, and versions specified in this report support your environment, consult the Interoperability Matrix Tool (IMT).

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1 Introduction

NetApp® ONTAP® is powerful data-management software with native capabilities that include inline compression, nondisruptive hardware upgrades, and the ability to import a LUN from a foreign storage array. Up to 24 nodes can be clustered together, simultaneously serving data through NFS, CIFS, iSCSI, FC, and FC over Ethernet (FCoE) protocols. In addition, NetApp Snapshot™ technology is the basis for creating tens of thousands of online backups and fully operational database clones.

In addition to the rich feature set of ONTAP, there are many user requirements, including database size, performance requirements, and data protection needs. Known deployments of NetApp storage include everything from a virtualized environment of approximately 6,000 databases to single databases approaching the 1PB mark.

MySQL, including its derivatives such as MariaDB, is one of the most popular open-source databases across the globe. MySQL provides ultimate platform flexibility to enterprises that need more features and functions for their database servers, at a lower cost than proprietary closed-source databases. Enterprise features include an extensible, pluggable architecture, native high availability, and exceptionally simple management. Setting up the MySQL database server takes just 15 minutes from software download to installation. Recent MySQL versions also support many advanced features commonly found in NoSQL databases.

Enterprises using MySQL face several challenges when their data grows exponentially, and data management becomes difficult. This document details the best practices to follow for successful deployment of MySQL on ONTAP. These practices range from tuning options to data protection to proper use of efficiency features such as compression and compaction.

Note: This guide assumes that you have a basic understanding of the technology and operation of ONTAP software and the MySQL database.

2 NetApp ONTAP

For maximum performance and control of data, NetApp ONTAP remains the leading solution. It is the standard storage solution that thousands of customers have relied on for more than 20 years. ONTAP delivers solutions for any environment, ranging from mission-critical database deployments to instant restore scenarios.

ONTAP software is the foundation for advanced data protection and management. However, ONTAP is only the software portion of the solution. There are several hardware environments to choose from:

- ONTAP on NetApp AFF and FAS
- NetApp Private Storage for Cloud (NPS for Cloud)
- ONTAP Select
- NetApp Cloud Volumes ONTAP

Some hardware options offer better performance, others offer lower costs, and some run within hyperscale clouds. The core functions of ONTAP are unchanged, with multiple replication options available to bind different ONTAP systems into a single solution. As a result, data protection and disaster recovery strategies can be built on real-world needs, such as performance requirements, capital expenditure (capex), or operational expenditure (opex) considerations, and overall cloud strategy. The underlying storage technology runs anywhere in any environment.

2.1 ONTAP with AFF and FAS Controllers

For maximum performance and control of data, ONTAP on a physical AFF or FAS controller remains the leading solution. ONTAP delivers solutions for any environment, ranging from three mission-critical databases to 60,000-database service provider deployments, instant restores of petabyte-scale databases, and database as a service (DBaaS) environments involving hundreds of clones of a single database.

2.2 NPS for Cloud

NetApp introduced the NPS option to address the needs of data-intensive workloads in the public cloud. Although many public cloud storage options exist, most of them have limitations in terms of performance, control, or scale. For database workloads, the primary limitations are as follows:

- Many public cloud storage options do not scale to the IOPS levels required by modern database workloads in terms of cost, efficiency, or manageability.
- Even when the raw IOPS capabilities of a public cloud provider meet requirements, the I/O latencies are frequently unacceptable for database workloads. This limitation has become more prevalent as databases have migrated to all-flash storage arrays, and businesses have begun to measure latency in terms of microseconds, not milliseconds.
- Although public cloud storage availability is good overall, it does not yet meet the demands of most mission-critical environments.
- Public cloud storage services have backup and recovery capabilities, but in general, they cannot meet the zero recovery point objective (RPO) and near-zero recovery time objective (RTO) requirements of most databases. Data protection requires true instant backup and recovery based on Snapshot copies, not streaming backup and recovery to and from elsewhere in a cloud.
- Hybrid cloud environments must move data between on-premises and cloud storage systems, mandating a common foundation for storage management.
- Many governments have strict data sovereignty laws that prohibit relocating data outside national borders.

NPS systems deliver maximum storage performance, control, and flexibility to public cloud providers, including Amazon Web Services (AWS), Microsoft Azure, and IBM SoftLayer. This capability is delivered by AFF and FAS systems, including NetApp MetroCluster™ options, in data centers connected directly to public clouds. The full power of the hyperscaler compute layer can be used without the limitations of hyperscaler storage. Furthermore, NPS enables cloud-independent and multicloud architectures because the data, such as application binaries, databases, database backups, and archives, remains wholly within the NPS system. There is no need to expend time, bandwidth, or money moving data between cloud providers.

Notably, some NetApp customers have used the NPS model on their own initiative. In many locations, high-speed access to one of the hyperscaler providers is readily available to customer data center facilities. Elsewhere, customers use colocation facilities that are already capable of providing high-speed access to hyperscaler cloud providers. These facilities have led to the use of AWS, Azure, and SoftLayer as essentially on-demand, consumption-based sources of virtualized servers. In some cases, nothing has changed about the customers' day-to-day operations. They simply use the hyperscaler services as a more powerful, flexible, and cost-efficient replacement for their traditional virtualization infrastructure.

Options are also available for NPS as a service (NPSaaS). Often the demands of database environments are substantial enough to warrant purchasing an NPS system at a colocation facility. However, some customers prefer to use both cloud servers and cloud storage as an operational expenditure rather than a capital expenditure. In these cases, they want to use storage resources purely as an as-needed, on-demand service. Several providers now offer NPS as a service for such customers.

2.3 ONTAP Select

ONTAP Select runs on a customer's own virtualization infrastructure and delivers ONTAP intelligence and Data Fabric connectivity to the drives inside white box hardware. ONTAP Select allows ONTAP and guest operating systems to share physical hardware as a highly converged infrastructure. The best practices for running MySQL on ONTAP are not affected.

An ONTAP Select environment does not match the peak performance of a high-end AFF system, but most databases do not require 300K IOPS. Typical databases require only about 5K to 10K IOPS, a target that ONTAP Select can meet. Furthermore, most databases are limited more by storage latency than storage IOPS, a problem that you can address by deploying ONTAP Select on solid-state drives (SSDs).

2.4 Cloud Volumes

NetApp introduced Cloud Volumes to meet the advanced performance and management requirements in hyperscaler clouds, including AWS, Azure, and Google Cloud Platform. The Cloud Volumes solution is available in two forms: NetApp Cloud Volumes ONTAP and NetApp Cloud Volumes Service.

Cloud Volumes ONTAP

Cloud Volumes ONTAP is similar to ONTAP Select, except that it runs in a hyperscaler cloud environment, bringing intelligence and Data Fabric connectivity to hyperscaler storage volumes. The best practices for running MySQL on ONTAP are not affected. The primary considerations are performance and, to a lesser extent, cost.

Cloud Volumes ONTAP is partially limited by the performance of the underlying volumes managed by the cloud provider. The result is more manageable storage, and, in some cases, the caching capability of Cloud Volumes ONTAP offers a performance improvement. However, there are always some IOPS and latency limitations due to the reliance on the public cloud provider. These limitations do not make database performance unacceptable, but the performance ceiling is simply lower than the performance of a physical AFF system. Furthermore, the performance of storage volumes offered by the cloud providers that are used by Cloud Volumes ONTAP are continuously improving.

Cloud Volumes Service

NetApp Cloud Volumes Service is storage served by physical storage systems running ONTAP, delivering the best possible performance in the public cloud with enterprise-class availability and data protection. Storage is available on demand with pay-as-you-go and prepaid billing options. Many of the advanced features of ONTAP are available through hyperscaler portals, with more options becoming available all the time.

3 ONTAP Features

Some NetApp ONTAP features include:

- Flexible response to changing business requirements:
  - Accelerate SAN and NAS workloads with flash.
  - Scale to 24 nodes, and upgrade and service with zero downtime.
  - Connect easily to the cloud.
- Delivery of uptime, security, and cost efficiency:
  - Continuous availability.
  - Proven storage efficiency with built-in encryption.
  - Simplified management and deep application integration.
- Flexible, scalable storage; designed for business-critical and consolidated environments that require:
  - Rich data management.
  - Enterprise-grade capabilities.
  - Scalability for SAN and NAS workloads.
- Backups based on Snapshot technology:

- Use volume-based Snapshot technology to create entire volume backups.
  - Take advantage of very fast, crash-consistent Snapshot copy backups.
- Use of the NetApp Snap Creator® framework along with user-maintained scripts to custom-design your database backup solution.
- Recovery based on Snapshot copies:
  - Use volume-based NetApp SnapRestore® (VBSR) technology to restore your volume.
  - Perform instant recovery to an earlier point in time (PiT).
  - Use single-file SnapRestore if needed.
- Checksums and data integrity:
  - Data integrity is protected by use of checksums at multiple levels.
  - TCP layer rejects the packet data and requests retransmission if data inconsistency occurs at a network level.
  - Checksum errors can be detected and corrected.
  - RAID rebuild takes care of data integrity.
  - Data integrity is also maintained at the MySQL level through checksum at the InnoDB page level.

4 ONTAP Configuration

This section presents best practices for basic NetApp ONTAP configuration.

These best practices don't apply to large-scale MySQL deployments (200+ databases), which require a special architecture and design. Even small changes in data protection requirements can significantly affect storage design. For detailed configuration information, see TR-4591: Database Data Protection: Backup, Recovery, Replication, and DR. For comprehensive assistance with design, contact NetApp sales.

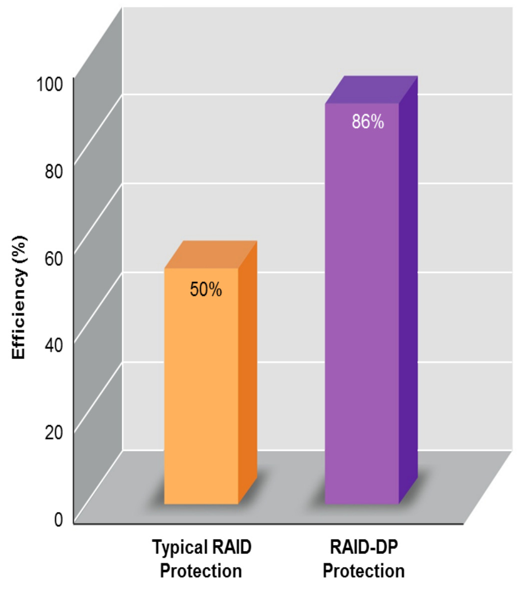
4.1 RAID Level

Disk redundancy is an important factor in decisions about storage layout for controllers. There are different RAID levels that measure disk redundancy; for example, RAID 4, RAID 3, RAID 5, RAID 6, NetApp RAID DP®, or NetApp RAID-TEC™.

With traditional single-parity RAID (RAID 3, 4, or 5) or even RAID 1 (mirroring), the entire volume and all its data is lost if a second drive fails or has an uncreatable bit error while another drive in the RAID group rebuilds. Most RAID implementations also have a drawback that affects write operations. Completion of a write operation on other RAID implementations requires multiple disk reads to regenerate the parity data, a process commonly called the RAID penalty.

However, NetApp RAID DP, a high-performance dual-parity version of RAID 6, protects against double disk failure, as shown in Figure 1. It provides higher availability than RAID 1 (mirroring), RAID 0+1 (striping and mirroring), and RAID 5 and incurs no performance penalty.

Figure 1) RAID DP offers protection and efficiency.



RAID DP is integrated with NetApp WAFL® to prevent performance bottlenecks with dedicated parity drives. Write operations are coalesced in RAM and prepared as a complete RAID stripe, including parity generation. There is no need to perform a read to complete a write, which means that ONTAP and WAFL avoid the RAID penalty. Performance for latency-critical operations, such as redo logging, is unimpeded, and random data-file writes do not incur any RAID penalty resulting from a need to regenerate parity. Therefore, NetApp recommends RAID DP as the default RAID group size.

In addition to having no single point of failure, RAID DP lets you expand or reconfigure storage while online. You can run your applications without interruption—even while adding more storage capacity or throughput.

4.2 Capacity Levels

To provide high and predictable performance on a storage array, some free space is required for metadata and data organizational tasks. Free space is defined as any space that is not used for actual data and includes unallocated space on the aggregate itself and unused space within the constituent volumes. Thin provisioning must also be considered. For example, a volume might contain a 1TB LUN of which only 50% is used by actual data. In a thinly provisioned environment, this LUN would correctly appear to be consuming 500GB of space. However, in a fully provisioned environment, the full capacity of 1TB appears to be in use, and the 500GB of unallocated space is hidden. This space is unused by actual data and should therefore be included in the calculation of total free space. The NetApp recommendations for storage systems used for databases are described in the sections that follow.

SSD Aggregates, Including AFF Systems

For SSD aggregates, including NetApp AFF systems, NetApp recommends a minimum of 10% free space. This percentage includes all unused space, free space within the aggregate or a volume, and any free space that is allocated because of full provisioning but is not used by actual data. The recommendation of 10% free space is conservative. SSD aggregates can support database workloads at even higher levels of utilization without any effect on performance. However, as the utilization of the aggregate increases, the risk of running out of space also increases if utilization is not monitored carefully.

HDD Aggregates, Including Flash Pool Aggregates

For HDD aggregates, including NetApp Flash Pool™ aggregates, NetApp recommends a minimum of 15% free space. This percentage includes all unused space, free space within the aggregate or a volume, and any free space that is allocated because of full provisioning but is not used by actual data. There should be no measurable performance effect when utilization is less than 85%. As utilization approaches 90%, some reduction in performance might become noticeable for certain workloads. As utilization reaches 95%, most database workloads experience a degradation in performance.

4.3 Read_realloc

Most write activity to the MySQL data file consists of random overwrites. As these overwrites occur, the changed data is placed on a new physical location within the storage system. This action has no effect on random I/O, which is typically the most performance-critical I/O type. However, it can affect sequential I/O throughput because the storage system is forced to perform more physical disk I/O operations to assemble the response to a multiblock read request and to perform read-ahead.

On an AFF system, the additional I/O operations are not significant. But on an array with spinning media, including Flash Pool aggregates, the additional drive head movement results in increased latency, which lowers throughput. Enabling the `read_realloc` option on a volume results in real-time optimization of the file system layout. When the data on a WAFL volume is poorly allocated, the bulk of the work required to address the problem is read activity. After the block reads are complete, writing the data back to disk in a single contiguous RAID stripe is a low-cost operation. The `read_realloc` option enables this process in a way that does not affect overall performance.

For example, suppose a full table scan is being performed, meaning that a data file is being read sequentially. If `read_realloc` detects blocks that were suboptimally organized on the disk, 90% of the work to address the problem is already complete. The blocks are already in RAM on the storage system; therefore, after servicing the read request from the database server, `read_realloc` performs the next step and writes them back to disk in an optimized format. The next time a full table scan is performed, the data is optimized. In the long term, the use of the `read_realloc` option creates a constant data cleanup process that optimizes the layout of the data files on a disk.

There are two `read_realloc` methods: general and space optimized. The general setting optimizes block layout for both the live file system and the blocks contained in a Snapshot copy. This approach can result in increased space consumption when Snapshot copies are present, but it offers improved performance during sequential reads on the live file system, Snapshot copies, and clones. If the space-optimized approach is used, the blocks contained in Snapshot copies are not reorganized. These parameters can be changed at any time; however, `read_realloc` should not be enabled across the entire environment at once because the additional work required could affect performance. Enabling it on one or two data-file–containing volumes per day is a safer approach.

NetApp recommends following best practices for the `read_realloc` option:

- Set `read_realloc` on volumes that contain the data files, and then monitor the space consumption. Enabling this option is unnecessary on volumes that contain an archive log, control file, or other data file, but doing so should not cause problems.
- If the Snapshot copies appear to cause excess space consumption, change the setting to space optimized.

As previously stated, `read_realloc` is not applicable to AFF systems.

5 Storage Virtual Machines and Logical Interfaces

As with other aspects of database architecture, the best options for storage virtual machine (SVM) and logical interface (LIF) designs depend heavily on scaling requirements and business needs.

This section provides an overview of key management principles of NetApp ONTAP data management software. For more comprehensive documentation, see the Network Management Guide for the version of ONTAP you are using.

5.1 SVMs

SVMs are the basic functional unit of storage, so it is useful to compare an SVM to a guest on a VMware ESXi server. When first installed, ESXi has no preconfigured capabilities, such as hosting a guest operating system or supporting an end-user application. It is an empty container until a virtual machine (VM) is defined. ONTAP data management software is similar. When first installed, ONTAP has no data-serving capabilities, and an SVM must be defined. It is the SVM personality that defines the data services.

Some customers operate one primary SVM for most of their day-to-day requirements but then create a small number of SVMs for special needs, including the following situations:

- An SVM for a critical business database managed by a specialist team.
- An SVM for a development group that has been granted administrative control to manage its own storage independently.
- An SVM for sensitive business data, such as human resources or financial reporting data, for which the administrative team must be limited.

  Note: In a multitenant environment, each tenant’s data can be given a dedicated SVM. The recommended limit for SVMs is approximately 125 per cluster node, but in general the LIF maximums are reached before the SVM limit is reached. There is a point at which a multitenant environment is best separated into network segments rather into isolated, dedicated SVMs.

5.2 LIF

From a functional perspective, LIFs can be divided into the following groups:

- **Cluster and node management LIFs.** LIFs used to manage the storage cluster.
- **SVM management LIFs.** Interfaces that permit access to an SVM through the ONTAP API (known as NetApp Manageability SDK) for functions such as Snapshot copy creation or volume resizing. Products such as NetApp SnapManager® for Oracle (SMO) must have access to an SVM management LIF.
- **Data LIFs.** Interfaces that carry FC, iSCSI, NFS, or CIFS data.

  Note: A data LIF used for NFS traffic can also be used for management. To do so, change the firewall policy from data to management or another policy that allows HTTP, HTTPS, or SSH. This change can simplify network configuration by avoiding the configuration of each host for access to both the NFS data LIF and a separate management LIF. You cannot configure an interface for both iSCSI and management traffic, even though both use an IP protocol. A separate management LIF is required in iSCSI environments.

For detailed information about LIF types, see the ONTAP Network Management Guide.

Consider the following primary topics when building a LIF strategy:

- **Performance.** Is the network bandwidth sufficient?
- **Resiliency.** Are there any single points of failure in the design?
- **Manageability.** Can the network be scaled nondisruptively?

These topics apply to the end-to-end solution, from the host through the switches to the storage system.

5.3 NFS LIF Design

In contrast to SAN protocols, NFSv3 and NFSv4 have a limited ability to define multiple paths to data. The parallel NFS (pNFS) extensions to NFSv4.1 address this limitation.

Performance and Resiliency

Although measuring SAN LIF performance is primarily a matter of calculating the total bandwidth from all primary paths, determining NFS LIF performance requires a closer look at the exact network configuration. For example, two 10Gb ports can be configured as raw physical ports, or they can be configured as a Link Aggregation Control Protocol (LACP) interface group. If they are configured as an interface group, multiple load-balancing policies are available that work differently depending on whether traffic is switched or routed. Finally, Direct NFS (DNFS) offers load-balancing configurations that do not exist in any currently operating system NFS clients.

Unlike SAN protocols, NFS file systems require resiliency at the protocol layer. For example, a LUN is always configured with multipathing enabled, meaning that multiple redundant channels are available to the storage system, each of which uses the FC protocol. An NFS file system, on the other hand, depends on the availability of a single TCP/IP channel that can be protected at the physical layer only. This arrangement is why options such as port failover and LACP port aggregation exist.

In an NFS environment, both performance and resiliency are provided at the network protocol layer. As a result, both topics are intertwined and must be discussed together.

Bind LIFs to Port Groups

To bind a LIF to a port group, associate the LIF IP address with a group of physical ports. The primary method for aggregating physical ports together is LACP. The fault-tolerance capability of LACP is fairly simple; each port in an LACP group is monitored and is removed from the port group if a malfunction occurs. There are, however, many misconceptions about how LACP works with respect to performance:

- LACP does not require the configuration on the switch to match the endpoint. For example, ONTAP can be configured with IP-based load balancing, whereas a switch can use MAC-based load balancing.
- Each endpoint using an LACP connection can independently choose the packet transmission port, but it cannot choose the port used for receipt. Therefore, traffic from ONTAP to a particular destination is tied to a particular port, and the return traffic could arrive on a different interface. This does not cause problems, however.
- LACP does not evenly distribute traffic all the time. In a large environment with many NFS clients, the result is typically even use of all ports in an LACP aggregation. However, any one NFS file system in the environment is limited to the bandwidth of only one port, not the entire aggregation.
- Although round-robin LACP policies are available on ONTAP, these policies do not address the connection from a switch to a host. For example, a configuration with a four-port LACP trunk on a host and a four-port LACP trunk on ONTAP is still only able to read a file system using a single port. Although ONTAP can transmit data through all four ports, no switch technologies are currently available that send from the switch to the host through all four ports. Only one is used.

The most common approach in larger environments consisting of many database hosts is to build an LACP aggregate of an appropriate number of 10Gb interfaces by using IP load balancing. This approach enables ONTAP to deliver even use of all ports, as long as enough clients exist. Load balancing breaks down when there are fewer clients in the configuration, because LACP trunking does not dynamically redistribute load.

When a connection is established, traffic in a particular direction is placed on only one port. For example, a database performing a full table scan against an NFS file system connected through a four-port LACP trunk reads data though only one network interface card (NIC). If only three database servers are in such an environment, it is possible that all three are reading from the same port, while the other three ports are idle.

Bind LIFs to Physical Ports

Binding a LIF to a physical port results in more granular control over network configuration because a given IP address on an ONTAP system is associated with only one network port at a time. Resiliency is then accomplished through the configuration of failover groups and failover policies.

Failover Policies and Failover Groups

The behavior of LIFs during network disruption is controlled by failover policies and failover groups. Configuration options have changed with the different versions of ONTAP. Consult the ONTAP Network Management Guide for specific details for the version of ONTAP being deployed.

Follow these general practices for Data ONTAP 8.2 and earlier:

1. Configure a failover group to be user defined.
2. Populate the failover group with ports on the storage failover (SFO) partner controller so that the LIFs follow the aggregates during an SFO. This configuration avoids the creation of indirect traffic.
3. Use failover ports with performance characteristics that match the original LIF. For example, a LIF on a single physical 10Gb port should include a failover group with a single 10Gb port. A four-port LACP LIF should fail over to another four-port LACP LIF.
4. Set the failover policy to priority.

Data ONTAP 8.3 allows management of LIF failover based on broadcast domains. Therefore, an administrator can define all the ports that have access to a given subnet and allow Data ONTAP to select an appropriate failover LIF. Some customers can use this approach, but it has limitations in a high-speed database storage network environment because of the lack of predictability. For example, an environment can include both 1Gb ports for routine file system access and 10Gb ports for data file I/O. If both types of ports exist in the same broadcast domain, LIF failover can result in moving data file I/O from a 10Gb port to a 1Gb port.

NetApp recommends using the Data ONTAP 8.2 approach, defining which ports can be used for LIF failover. In summary, consider the following practices:

1. Configure a failover group as user defined.
2. Populate the failover group with ports on the SFO partner controller so that the LIFs follow the aggregates during an SFO. This approach avoids creating indirect traffic.
3. Use failover ports with matching performance characteristics to the original LIF. For example, a LIF on a single physical 10Gb port should include a failover group with a single 10Gb port. A four-port LACP LIF should fail over to another four-port LACP LIF. These ports would be a subset of the ports defined in the broadcast domain.
4. Set the failover policy to SFO partner only. Doing so makes sure that the LIF follows the aggregate during failover.

Auto-Revert

Set the `auto-revert` parameter as desired. Most customers prefer to set this parameter to `true` to have the LIF revert to its home port. However, in some cases, customers have set this parameter to `false` so that they can investigate an unexpected failover before returning a LIF to its home port.

LIF-to-Volume Ratio

A common misconception is that there must be a 1:1 relationship between volumes and NFS LIFs. Although this configuration is required for moving a volume anywhere in a cluster without creating additional interconnect traffic, it is categorically not a requirement. Intercluster traffic must be considered, but the mere presence of intercluster traffic does not create problems. Many of the published benchmarks created for ONTAP include predominantly indirect I/O.

For example, a database project containing a relatively small number of performance-critical databases that only requires a total of 40 volumes might warrant a 1:1 volume to LIF strategy. This arrangement would require 40 IP addresses. Any volume could then be moved anywhere in the cluster along with the associated LIF, and traffic would always be direct, minimizing every source of latency even at microsecond levels.

As a counterexample, a 1:1 relationship between customers and LIFs might make a large hosted environment easier to manage. Over time, you might need to migrate a volume to a different node, which would cause some indirect traffic. However, you shouldn’t be able to detect the performance effect unless the network ports on the interconnect switch are saturating. If necessary, establish a new LIF on additional nodes and update the host at the next maintenance window to remove indirect traffic from the configuration.

5.4 SAN LIF Design

LIF design in a SAN environment is relatively simple for one reason: multipathing. All modern SAN implementations allow a client to access data over multiple network paths and select the best path or paths for access. As a result, performance with respect to LIF design is simpler to address because SAN clients automatically load-balance I/O across the best available paths. If a path becomes unavailable, the client automatically selects a different path. The resulting simplicity of design makes SAN LIFs more manageable. This does not mean that a SAN environment is always more easily managed, because there are many other aspects of SAN storage that are much more complicated than NFS. It simply means that SAN LIF design is easier.

Performance

The most important consideration with LIF performance in a SAN environment is bandwidth. For example, a four-node ONTAP cluster with two 16Gb FC ports per node allows up to 32Gb of bandwidth from each node. I/O is automatically balanced between ports, and all I/O is directed down the most optimal path.

Resiliency

SAN LIFs do not fail over. If a SAN LIF fails, the client’s multipathing ability detects the loss of a path and redirects I/O to a different LIF.

Manageability

LIF migration is a much more common task in an NFS environment, because LIF migration is often associated with relocating volumes around the cluster. There is no need to migrate a LIF in a SAN environment when volumes are relocated. After the volume move has completed, ONTAP sends a notification to the SAN about a change in paths, and the SAN clients automatically reoptimize. LIF migration with SAN is primarily associated with major physical hardware changes. For example, if a nondisruptive upgrade of the controllers is required, a SAN LIF is migrated to the new hardware. If an FC port is found to be faulty, a LIF can be migrated to an unused port.

Design Recommendations

NetApp makes the following primary recommendations:

- Do not create more paths than are required. Too many paths make overall management more complicated and can cause problems with path failover on some hosts. Furthermore, some hosts have unexpected path limitations for configurations such as SAN booting.

- Few LUNs should require more than four paths to storage. The value of having more than two nodes advertising paths to LUNs is limited because the aggregate hosting a LUN is inaccessible if the node that owns the LUN and its high-availability (HA) partner fail. Creating paths on nodes other than the primary HA pair is not helpful in such a situation.
- You can manage the number of visible LUN paths by selecting which ports are included in FC zones. However, it is usually easier to include all potential target points in the FC zone and control LUN visibility at the ONTAP level.
- In Data ONTAP 8.3 and later, the selective LUN-mapping feature is the default. With selective LUN mapping, any new LUN is automatically advertised from the node that owns the underlying aggregate and the node's HA partner. With this arrangement, you don't need to create port sets or configure zoning to limit port accessibility. Each LUN is available on the minimum number of nodes required for optimal performance and resiliency.
- If you must migrate a LUN outside the two controllers, you can add the additional nodes with the LUN-mapping `add-reporting-nodes` command so that the LUNs are advertised on the new nodes. Doing so creates additional SAN paths to the LUNs for LUN migration. However, the host must perform a discovery operation to use the new paths.
- Do not be overly concerned about indirect traffic. It is best to avoid indirect traffic in an I/O-intensive environment for which every microsecond of latency is critical, but the visible performance effect is negligible for typical workloads.
- An FC zone should never contain more than one initiator. Such an arrangement might appear to work initially, but crosstalk between initiators eventually interferes with performance and stability.

  Note: In general, multitarget zones are regarded as safe, although in rare circumstances the behavior of FC target ports from different vendors has caused problems. For example, avoid including the target ports from both a NetApp and an EMC storage array in the same zone. In addition, placing a NetApp storage system and a tape device in the same zone is even more likely to cause problems.

6 Additional ONTAP Considerations

The additional points described in this section must be considered while deploying a database solution on NetApp ONTAP.

6.1 LUN Considerations

LUN Misalignment Warnings

Database logging normally generates unaligned I/O that can cause misleading warnings about misaligned LUNs on ONTAP. The reason is that most databases perform a sequential write of the log file with writes of varying size. A log write operation that does not align to 4KB boundaries does not ordinarily cause performance problems, because the next log write operation completes the block. The result is that ONTAP is able to process almost all writes as complete 4KB blocks, even though the data in some 4KB blocks was written in two separate operations.

LUN Sizing

A LUN is a virtualized object on ONTAP that exists across all the spindles in the hosting aggregate. As a result, the LUN's performance is unaffected by its size, because the LUN draws on the full potential of the aggregate no matter which size is chosen.

NetApp discourages the practice of establishing a universal standard LUN size, because doing so can complicate manageability. For example, a standard LUN size of 100GB might work well when a database is in the range of 1TB to 2TB, but a database 20TB in size would require 200 LUNs. This means that server reboot times are longer, and there are more objects to manage in the various UIs. Using fewer, larger LUNs avoids such problems.

Notes:

- The LUN count is more important than the LUN size.
- LUN size is mostly controlled by LUN count requirements.

Avoid creating more LUNs than required.

LUN Resizing and LVM-Based Resizing

When a SAN-based file system has reached its capacity limit, there are two options for increasing the space available:

- Increase the size of the LUNs.
- Add a LUN to an existing volume group and expand the contained logical volumes.

Both options are supportable, but increasing a LUN size is usually more difficult and can be risky. Here are some of the considerations:

- LUNs created by ONTAP can be increased to approximately 10 times their original size. The limitation is based on the inherent structure of disk geometry. There are sometimes options to increase further, but this increase can involve partition table changes that require advanced understanding of disk configuration at the host level.
- NetApp recommends that you shut down the database before attempting to resize a LUN, and to create Snapshot copies as a fallback measure. Although this recommendation is not a requirement, there is some risk of disruption and user error when rediscovering the newly enlarged LUNs at the host OS level.
- NetApp SnapDrive® for Windows offers an exception to LUN resizing complications. SnapDrive for Windows provides a safe and nondisruptive method of increasing LUN sizes.

Although LUN resizing is an option to increase capacity, it is usually better to use a logical volume manager (LVM). One of the principal reasons LVMs exist is to avoid the need for a LUN resize. With an LVM, multiple LUNs are bonded together into a virtual pool of storage. The logical volumes carved out of this disk pool are managed by the LVM and can be resized easily. An LVM also avoids hotspots on a particular disk by distributing a given logical volume across all available LUNs. You can usually perform transparent migration by using the volume manager to relocate the underlying extents of a logical volume to new LUNs.

For these reasons, NetApp discourages a strategy involving resizing LUNs and encourages an LVM approach.

LUN Count

Unlike the LUN size, the LUN count does affect performance. Database performance is affected by the capability to perform parallel I/O through the SCSI layer. As a result, two LUNs offer better performance than a single LUN. Using a logical volume manager, such as Veritas Volume Manager (VxVM) or Linux LVM2, is the simplest method to increase parallelism.

NetApp customers have experienced minimal benefit from increasing the number of LUNs beyond eight, although testing of 100% SSD environments with very heavy random I/O has demonstrated further improvement up to 64 LUNs. NetApp recommends building a volume group with an extent size that enables the even distribution of I/O. For example, a 1TB volume group composed of 10 100GB LUNs and an extent size of 100MB would yield 10,000 extents in total (1,000 extents per LUN). The resulting I/O on a database placed on this 1TB volume group should be evenly distributed across all 10 LUNs.

Distributing a logical volume across extents is not the same as striping, although the concept is similar.

Logical volume managers break up LUNs into relatively large extents in order to make data management simpler. Larger extents are preferred because they deliver better efficiency of read-ahead operations. For example, an LVM2 extent of 64MB allows storage array read-ahead to assist transferring a full 64MB of data before the LVM moves to the next extent. Smaller extents mean that read-ahead must reset more often as read operations move from extent to extent.

The more important random I/O should still be evenly distributed across LUNs, even with a large extent size, unless the database has extremely concentrated I/O.

In contrast to distributed extents, true striping should be avoided. Striping mostly targeted relatively slow spinning disk technology. For example, if an application was known to read in 1MB chunks, a stripe set could be created with eight LUNs with a stripe width of 128KB. As a result, a 1MB operation could be executed as eight simultaneous 128KB I/O operations on each LUN. This technique is rarely beneficial with a modern database and storage system. Furthermore, incorrect tuning of a striped volume group decreases performance.

Most databases are limited by random I/O performance, not sequential performance If a data file exists across many extents, a large amount of I/O can be randomized across the extents. This arrangement means that all LUNs in the volume group are used evenly, and no individual LUN limits performance.

NetApp recommends the following:

- In general, four to eight LUNs are sufficient to support data file I/O. Fewer than four LUNs might limit performance because of limitations in host SCSI implementations.
- Do not use fine-grained striping. Instead, enable an LVM policy that distributes data across large extents on each LUN to ensure that each data file is spread across all available LUNs.

6.2 Cluster Operations—Takeover and Switchover

You must understand the storage takeover and switchover function to make sure that database operations are not disrupted by these operations:

- Under normal conditions, incoming writes to a controller are synchronously mirrored to its partner. In a NetApp MetroCluster environment, writes are also mirrored to a remote controller. Until a write is stored in nonvolatile media in all locations, it is not acknowledged to the host application.
- The media storing the write data is called NVMEM. It is sometimes referred to as NVRAM, and it can be thought of as a write cache, although it functions as a journal. In a normal operation, the data from NVMEM is not read; it is used only to protect data if software or hardware fails. When data is written to disk, the data is transferred from the RAM in the system, not from NVMEM.
- During a takeover operation, one node in an HA pair takes over the operations from its partner. A switchover is essentially the same, but it applies to MetroCluster configurations in which a remote node takes over the functions of a local node.

During routine maintenance operations, a storage takeover or switchover operation should be transparent, other than for a potential brief pause in database operations as the network paths change. Networking can be complicated, and it is easy to make errors, so NetApp strongly recommends testing takeover and switchover operations thoroughly with a database before putting a storage system into production. Doing so is the only way to be sure that all network paths are configured correctly. In a SAN environment, carefully check the output of the `sanlun lun show -p` command to make sure that all expected primary and secondary paths are available.

Take care when issuing a forced takeover or switchover. Forcing a change to storage configuration with these options means that the state of the controller that owns the disks is disregarded and the alternative node forcibly takes control of the disks. Incorrect forcing of a takeover can result in data loss or corruption, because a forced takeover or switchover can discard the contents of NVMEM. After the takeover or switchover is complete, the loss of that data means that the data stored on disk might revert to a slightly older state from the point of view of the database.

A forced takeover with a normal HA pair is rarely required. In almost all failure scenarios, a node shuts down and informs the partner so that an automatic failover takes place. There are some edge cases, such as a rolling failure in which the interconnect between nodes is lost and then one controller is lost, so a forced takeover is required. In such a situation, the mirroring between nodes is lost before the controller failure, which means that the surviving controller no longer has a copy of the writes in progress. The takeover then needs to be forced, which means that data potentially is lost.

The same logic applies to a MetroCluster switchover. In normal conditions, a switchover is nearly transparent. However, a disaster can result in a loss of connectivity between the surviving site and the disaster site. From the point of view of the surviving site, the problem could be nothing more than an interruption in connectivity between sites, and the original site might still be processing data. If a node cannot verify the state of the primary controller, only a forced switchover is possible.

NetApp recommends taking the following precautions:

- Do not accidentally force a takeover or a switchover. Normally, forcing should not be required, and forcing the change can cause data loss.
- If a forced takeover or switchover is required, make sure that the database is shut down, dismount all file systems, shut down any instances, and vary off any LVM volume groups.
- If a forced MetroCluster switchover occurs, fence off the failed node from all surviving storage resources. For more information, see the MetroCluster Management and Disaster Recovery Guide for the relevant version of ONTAP.

6.3 MetroCluster and Multiple Aggregates

MetroCluster is a synchronous replication technology that switches to asynchronous mode if connectivity is interrupted. Customers have requested this functionality, because guaranteed synchronous replication means that interruption in site connectivity leads to a complete stall of database I/O, taking the database out of service.

With MetroCluster, aggregates rapidly resynchronize after connectivity is restored. Unlike other storage technologies, MetroCluster should never require a complete remirroring after site failure. Only delta changes must be shipped.

In databases that span aggregates, there is a small risk that additional data recovery steps would be required in a rolling disaster scenario. Additional steps would be required if:

- Connectivity between sites is interrupted.
- Connectivity is restored.
- The aggregates reach a state in which some are synchronized, and some are not.
- The primary site is lost, which results in a surviving site in which the aggregates are not synchronized with one another.

In this scenario, parts of the database are synchronized with one another and you cannot bring up the database without recovery. If a database spans aggregates, NetApp strongly recommends using backups based on Snapshot copies. Use one of the many available tools to verify rapid recoverability in this unusual scenario.

6.4 NVFAIL

Databases are vulnerable to corruption if a failover or switchover is forced, because databases maintain large internal caches. If a forced failover occurs, previously acknowledged changes are effectively discarded. The contents of the storage array jump backward in time, and the state of the database cache no longer reflects the state of the data on disk. The result is data inconsistency.

An obvious use of caching is at the operating system’s file system layer. Blocks from a mounted NFS file system might be cached in the operating system, or a file system based on LUNs can cache data in the operating system buffer cache. A failure of NVRAM or a forced takeover in these situations could result in file system corruption.

ONTAP systems protect databases and operating systems from this scenario with NVFAIL and its associated parameters.

6.5 Overcommitting RAM

Overcommitting RAM means configuring more virtualized RAM on various hosts than exists on the physical hardware. Doing so can cause unexpected performance problems. When virtualizing a database, the underlying blocks of the database cache must not be swapped out to disk by the hypervisor, or performance becomes highly unstable.

6.6 Ethernet Flow Control

Ethernet flow control allows a client to request that a sender temporarily stop data transmission—usually because the receiver cannot process incoming data quickly enough. At one time, requesting that a sender cease transmission was less disruptive than having a receiver discard packets because buffers were full. This is no longer the case with the TCP stacks used in operating systems today. In fact, flow control causes more problems than it solves.

Performance problems caused by Ethernet flow control have been increasing in recent years. This is because Ethernet flow control operates at the physical layer. If a network configuration permits any database server to send an Ethernet flow control request to a storage system, I/O pauses for all connected clients. Because more clients are served by a single storage controller, the likelihood of these clients sending flow control requests increases. The problem has occurred frequently at customer sites with extensive operating system virtualization.

A NIC on a NetApp system should not receive flow-control requests. The method used to achieve this result varies according to the network switch manufacturer. Usually, you can set flow control on an Ethernet switch to `receive desired` or `receive on`, which means that a flow control request is not forwarded to the storage controller. If the network connection on the storage controller doesn't allow flow-control disabling, configure the clients to never send flow control requests. Change to either the NIC configuration on the database server itself or the switch ports to which the database server is connected.

NetApp Best Practice

Make sure that NetApp storage controllers do not receive Ethernet flow-control packets. If possible, set the switch ports to which the controller is attached; however, some switch hardware has limitations that might require client-side changes instead.

6.7 Jumbo Frames

The use of jumbo frames can improve performance somewhat in 1Gb networks by reducing CPU and network overhead, but the benefit usually isn't significant. Even so, NetApp recommends implementing jumbo frames when possible, to realize potential performance benefits and to future-proof the solution.

In 10Gb networks, using jumbo frames is almost mandatory. Without jumbo frames, most 10Gb implementations reach a packets-per-second limit before they reach the 10Gb mark. Using jumbo frames improves efficiency in TCP/IP processing, because it allows the database server, NICs, and the storage system to process fewer larger packets. The performance improvement varies from NIC to NIC, but it is significant.

Many people erroneously believe that in jumbo-frame implementations, all connected devices must support jumbo frames and that the maximum transmission unit (MTU) size must match end to end. Instead, the two network endpoints negotiate the highest mutually acceptable frame size when establishing a connection. In a typical environment, a network switch is set to an MTU size of 9216, the NetApp controller is set to 9000, and the clients are set to a mix of 9000 and 1514. Clients that can support an MTU of 9000 can use jumbo frames, and clients that can support only 1514 can negotiate a lower value.

Problems with this arrangement are rare in a completely switched environment. However, take care in a routed environment that no intermediate router is forced to fragment jumbo frames.

NetApp recommends the following best practices:

- With 1GbE, Jumbo frames are desirable but not required.
- With 10GbE, Jumbo frames are required for maximum performance.

6.8 TCP Parameters

Three settings are frequently misconfigured: TCP timestamps, selective acknowledgment (SACK), and TCP window scaling. Many out-of-date Internet documents recommend disabling these parameters to improve performance. There was some merit to this recommendation many years ago when CPU capabilities were much lower and it was advantageous to reduce TCP processing overhead whenever possible.

However, with modern operating systems, disabling any of these TCP features rarely results in any detectable benefit, and might damage performance. Performance damage is especially likely in virtualized networking environments, because these features are required for efficient handling of packet loss and changes in network quality.

NetApp recommends the following best practices:

- Enable TCP timestamps, SACK, and TCP window scaling on the host.

7 ONTAP QoS

The increased adoption of all-flash storage has also resulted in consolidation of database workloads. Storage arrays relying on spinning media tended to support only a limited number of databases because of the limited IOPS capabilities of older drive technology. One or two highly active databases would saturate the underlying disks long before the storage controllers reached their limits. This situation has changed. A performance capability of a relatively small number of SSDs can saturate even the most powerful storage controllers. You can use the full capabilities of the controllers without the fear of sudden performance collapse as spinning media latency spikes.

For example, a simple two-node HA AFF8080 system can service about 400K random IOPS before latency climbs above 1 millisecond. Less than 1% of databases would be expected to reach such levels, and allowing an AFF8080 to manage just 10K IOPS would be wasteful.

There are three types of quality of service (QoS) in NetApp ONTAP: IOPS, bandwidth, and guaranteed. QoS controls can be applied to SVMs, volumes, LUNs, and files.

7.1 IOPS QoS

An IOPS QoS control is based on the total IOPS of a given resource, but there are several aspects of IOPS QoS that might not be intuitive. Some customers have been puzzled by the apparent increase in latency when an IOPS threshold is reached. This IOPS QoS is the only viable method of limiting IOPS. Logically, it functions like a token system. For example, if a volume containing data files has a 10K IOPS limit, each I/O operation that arrives must first receive a token to continue processing. As long as no more than 10K tokens are consumed in a second, no delays are present.

7.2 Bandwidth QoS

Not all I/O sizes are the same. Databases might perform a large number of fully random block reads, which would result in the IOPS threshold being reached. But databases might also perform a full table scan operation, which would consist of few large block reads, consuming a lot of bandwidth, but relatively few IOPS.

7.3 Guaranteed QoS

Many customers seek a solution that includes guaranteed QoS, which is more difficult than it seems and potentially wasteful. For example, placing 10 databases with a 10K IOPS guarantee would require a system to be sized such that all 10 databases could simultaneously run at 10K IOPS, for a total of 100K. This scenario is highly unlikely, but if it is required, the best option is to guarantee performance through the sizing effort.

For example, each NetApp AFF8080 HA pair could constitute a 400K IOPS building block. The total guaranteed IOPS of all hosted databases should not add up to more than 400K IOPS. Furthermore, to prevent a database from consuming more than its allotted IOPS capability, it should have the standard QoS applied as a limit.

8 ONTAP Efficiency

Storage efficiency enables you to store the maximum amount of data within the smallest possible space and at the lowest possible cost. The NetApp storage efficiency technologies described in this section can help you realize maximum space savings.

8.1 Compression

Before all-flash storage systems were available, database compression was of limited value, because most databases required a large number of spindles to provide acceptable performance. Storage systems contained much more capacity than required as a side effect of the large number of drives. The scenario has changed with the rise of solid-state storage. You no longer need to vastly overprovision the drive count purely to obtain good performance. You can match the drive space in a storage system to actual capacity needs.

The increased IOPS capability of SSDs almost always yields cost savings compared to spinning drives, but compression can achieve further savings by increasing the effective capacity of solid-state media. Compression is available in MySQL, but it creates a load on the database server CPUs, which can damage performance. A better option is to offload the compression work to the storage system.

Adaptive Compression

Adaptive compression has been thoroughly tested with database workloads with no observed effect on performance, even in an all-flash environment in which latency is measured in microseconds. In initial testing, some customers have reported a performance increase with the use of compression.

NetApp ONTAP manages physical blocks in 4KB units. Therefore, the maximum possible compression ratio with adaptive compression alone is 2:1 with a database using an 8KB block. Early testing with real customer data has shown compression ratios approaching this level, but results vary according to the type of data stored.

The simplest approach for using compression is enabling adaptive compression for all database volumes. As stated previously, adaptive compression is suitable for all I/O patterns. Note the following exceptions:

- If a volume is not thin provisioned, do not enable compression; it provides no benefit.
- If a large number of binary logs are retained, moving them to a volume using secondary compression improves storage efficiency.

- Some databases have high redo logging (transaction logs) rates. Redo logs are comparatively small and are constantly overwritten, so any space savings from compression is negligible. This data should be moved to a volume without compression.
- If data files contain a significant amount of uncompressible data—for example, when compression is already enabled, or encryption is used—place this data on volumes without compression.

Secondary Compression

Secondary compression uses a larger block size that is fixed at 32KB. This feature allows ONTAP to compress data beyond 2:1, but secondary compression is primarily designed for data at rest or data that is written sequentially and requires maximum compression.

NetApp recommends secondary compression for datasets that include large amounts of unchanging data, such as binary logs, logical or physical backups, or exported data. These types of files are written sequentially and not updated. This point does not mean that adaptive compression is discouraged. However, if the volume of data being stored is large, then secondary compression delivers better savings when compared to adaptive compression.

Caution

Secondary compression and deduplication should not be used together with flat-file backups. Small changes to the backed-up data will affect the 32KB compression window. If the window shifts, the resulting compressed data will differ across the entire file. Deduplication occurs after compression, which means the deduplication engine will see each compressed backup differently. If deduplication of backups is required, don’t use secondary compression. Adaptive compression is preferable, because it works at a smaller block size and does not disrupt deduplication efficiency. For similar reasons, host-side compression also interferes with deduplication efficiency.

8.2 Alignment

Adaptive compression in a database environment requires some consideration of compression block alignment. Compression block is a concern only for data that is subject to random overwrites of specific blocks. This approach is similar in concept to overall file system alignment.

For example, an 8KB write to a data file is compressed only if it aligns with an 8KB boundary in the file system itself. This point means that the write operation must fall within the first 8KB of the file, the second 8KB of the file, and so forth. Data such as backups or binary logs consists of sequentially written operations that span multiple blocks, all of which are compressed. There is no need to consider alignment. The only I/O pattern of concern is the random overwrites of data files.

Alignment on an NFS Volume

With NFS, data files are aligned. Each block of the data file is aligned with respect to the start of the file.

Alignment on SAN (LUN)

SAN environments require data to be aligned to an 8KB boundary for optimum compression. There are two aspects of alignment for SAN: the LUN and the file system. The LUN must be configured as either a whole-disk device (no partition) or with a partition that aligns to an 8KB boundary.

The simplest approach is to use the whole-disk device, and skip creating any partitions. The file system is then aligned to the start of the LUN itself, and alignment is correct.

8.3 Inline Data Compaction

Inline data compaction, introduced in ONTAP 9, improves compression efficiency. As stated previously, adaptive compression alone can provide at best 2:1 savings, because it is limited to storing an 8K I/O in a 4K WAFL block. Compression methods such as secondary compression use a larger block size and deliver better efficiency but are not suitable for data that is subject to small block overwrites. Decompressing 32KB units of data, updating an 8KB portion, recompressing, and writing back to disk creates overhead.

Inline data compaction works by allowing multiple logical blocks to be stored within physical blocks. For example, a database with highly compressible data such as text or partially full blocks can compress from 8KB to 1KB. Without compaction, that 1KB of data would still occupy an entire 4KB block. Inline data compaction allows that 1KB of compressed data to be stored in just 1KB of physical space alongside other compressed data. It is not a compression technology; it is simply a more efficient way of allocating space on disk and therefore should not create any detectable performance impact.

The degree of savings varies. In general, data that is already compressed or encrypted cannot be further compressed, so such datasets do not benefit from compaction. The best way to evaluate potential savings is to use the NetApp Space Saving Estimation Tool (SSET) available on the NetApp Field Portal or through your NetApp representative.

8.4 Deduplication

Data deduplication cuts storage requirements by reducing redundancies in primary, backup, and archival data. Inline deduplication of zeros speeds up database performance by 20% to 30%. Further improvements to inline deduplication in ONTAP 9 provide additional efficiency by extending elimination of duplicate data to blocks in memory and SSDs.

8.5 Thin Provisioning

Efficiency features are forms of thin provisioning. For example, a 100GB LUN occupying a 100GB volume might compress down to 50GB. There are no actual savings realized yet, because the volume is still 100GB. The volume must first be reduced in size, so the space saved can be used elsewhere on the system. If later changes to the 100GB LUN result in the data becoming less compressible, the LUN grows and the volume could fill up.

NetApp strongly recommends thin provisioning, because it can simplify management while delivering a substantial improvement in usable capacity with associated cost savings. The reason is simple: Database environments frequently include a lot of empty space, a large number of volumes and LUNs, and compressible data. Thick provisioning results in reserving space on storage for volumes and LUNs in case they someday become full and contain 100% uncompressible data. This scenario is unlikely. Thin provisioning allows that space to be reclaimed and used elsewhere and allows capacity management to be based on the storage system itself rather than many smaller volumes and LUNs.

Some customers prefer to use thick provisioning, either for specific workloads or according to established operational practices.

Caution

If a volume is thick provisioned, take care to completely disable all efficiency features for that volume, including decompression and removal of deduplication, by using the `sis undo` command. The volume should not appear in `volume efficiency show` output. If it does, the volume is still partially configured for efficiency features. The result is overwriting, which increases the chance that configuration oversights cause the volume to unexpectedly run out of space, resulting in database I/O errors.

9 Native Data Protection

The most mission-critical data is usually found in databases. Any enterprise without its data becomes paralyzed and cannot run its business. This data must be protected. However, data protection is more than just ensuring a usable backup—it involves performing the backups quickly and reliably as well as storing backups safely. The other side of data protection is data recovery. When data is inaccessible, the enterprise is affected and might be inoperative until data is restored. This process must be quick and reliable. Finally, most databases must be protected against disasters, which means maintaining a replica of the database. The replica must be sufficiently up-to-date, and making the replica a fully operational database must be quick and simple.

A database data protection architecture should be defined by business requirements. These requirements include factors such as the speed of recovery, the maximum permissible data loss, and backup retention needs. The data protection plan must also consider various regulatory requirements for data retention and restoration. Finally, consider different data recovery scenarios, ranging from the typical recovery resulting from user or application errors up to disaster recovery scenarios that include the complete loss of a site. Small changes in data protection and recovery policies can significantly affect the overall architecture of storage, backup, and recovery. It is critical to define and document standards before starting design work to avoid complicating a data protection architecture. The following two sections describe two objectives of data protection to consider in your backup or recover strategy: RTO and RPO.

9.1 Recovery Time Objective

The recovery time objective (RTO) defines the maximum time allowed for the recovery of a service. For example, a human resources database might have an RTO of 24 hours because, although losing access to this data for a day would be inconvenient, the business can still operate. In contrast, a database supporting the general ledger of a bank would have an RTO measured in minutes or even seconds. An RTO of zero is not possible, because there must be a way to differentiate between an actual service outage and a routine event such as a lost network packet. However, a near-zero RTO is a typical requirement.

9.2 Recovery Point Objective

The recovery point objective (RPO) defines the maximum tolerable data loss. In a database context, the RPO is usually a question of how much uncommitted data can be lost in a specific situation. In a typical recovery scenario in which a database is damaged by a product bug or user error, the RPO should be zero—there should be no data loss. The recovery procedure involves restoring an earlier copy of the database files and then replaying the log files to bring the database state up to the desired PiT. The log files required for this operation should already be backed up.

In unusual scenarios, log data might be lost. For example, an accidental or malicious `rm -rf *` of database files could result in the deletion of all data. The only option would be to restore from backup, including log files, and some data would inevitably be lost. The only option to improve the RPO in a traditional backup environment would be to perform repeated backups of the log data. This option is limited, however, because of the constant data movement and the difficulty maintaining a backup system as a constantly running service. One of the benefits of advanced storage systems is the ability to protect data from accidental or malicious damage to files and thus deliver a better RPO without data movement.

9.3 NetApp Snapshot Technology

The foundation of NetApp ONTAP data protection software is NetApp Snapshot technology. The key values are as follows:

- **Simplicity.** A Snapshot copy is a read-only copy of a data container's contents at a specific PiT.
- **Efficiency.** Snapshot copies require no space at the moment of creation. Space is only consumed when data is changed.

- **Manageability.** A backup strategy based on Snapshot copies is easy to configure and manage, because Snapshot copies are a native part of the storage operating system. If the storage system is powered on, it is ready to create backups.
- **Scalability.** Up to 255 backups of a single container of files and LUNs can be preserved. For complex datasets, multiple containers of data can be protected by a single, consistent set of Snapshot copies.
- **No performance impact.** Performance is unaffected, whether a volume contains 250 Snapshot copies or none.

  As a result, protecting a database running on ONTAP is simple and highly scalable. Database backups do not require movement of data. Therefore, a backup strategy should be customized to the needs of the business rather than the limitations of network transfer rates, large number of tape drives, or disk staging areas.

To implement the data protection strategy with MySQL, it is important to design the storage layout accordingly. NetApp recommends that you create two volumes for MySQL:

- A volume to store all your data files, index files, and tablespace
- A volume to store all your logs (mainly redo logs and binary logs)

For detailed information about this recommendation, see section 12, “MySQL.”

You can create point-in-time recovery (PITR) consistent backups by completing the following steps:

1. Quiesce the I/O to stop MySQL writing on disk by running the `FLUSH TABLES WITH READ LOCK` command.
2. Create the Snapshot copy of both volumes.
3. Unquiesce the I/O to allow MySQL transactions by running the `UNLOCK TABLES` command.

Integrate these steps in the shell script for your daily and weekly backup solutions. NetApp Snapshot technology backs up terabytes and petabytes in a matter of seconds. This feature is helpful for the MySQL ecosystem where the traditional approach (logical or hot backup) of creating backups takes longer and uses more network and disk bandwidth.

9.4 NetApp SnapRestore Technology

Rapid data restoration in ONTAP from a Snapshot copy is delivered by NetApp SnapRestore technology. SnapRestore enables instantaneous restoration of Snapshot data. The reason SnapRestore works so quickly and efficiently is that a Snapshot copy is essentially a parallel read-only view of the contents of a volume at a specific PiT. The active blocks are the real blocks that can be changed, whereas the Snapshot copy is a read-only view into the state of the blocks that constitute the files and LUNs at the time the Snapshot copy was created. ONTAP permits read-only access to Snapshot data, but the data can be reactivated with SnapRestore. The Snapshot copy is reenabled as a read/write view of the data, returning the data to its prior state. SnapRestore can operate at the volume or file level. The technology is essentially the same with a few minor differences in behavior. The key values are as follows:

- Individual files or LUNs can be restored in seconds, whether it is a 2TB LUN or a 4KB file.
- An entire container (a NetApp FlexVol® volume) of LUNs and files can be restored in seconds, whether it is 10GB or 100TB of data.

When a critical database is down, critical business operations are down. Tapes can break, and even restore operations from disk-based backups can be slow to transfer across the network. SnapRestore prevents these problems by delivering near instantaneous restoration of databases. Even petabyte-scale databases can be completely restored with just a few minutes of effort.

With a two-volume approach and SnapRestore technology, it is easy to restore any backup size. Select the target data and log volumes to restore. The restore is an exact PiT, because all the logs (binary and transaction logs) are stored on the log volume. You can perform PITR by completing the following steps:

1. Stop the MySQL application.
2. Restore the volumes with SnapRestore technology.
3. Start the MySQL application.

After MySQL restarts, it automatically recovers by checking the transaction logs (IB logs).

Note: Manual recovery is not required for MySQL to bring the database back up. Database recovery depends on the size of the IB log file. The larger the size of the file, the longer the recovery time. For more information, see section 12.2, “MySQL File Structure.”

Snapshot and SnapRestore technologies are most useful when database refresh is required on dev/test systems. Most of the time the development and QA teams provide production data for their work. It is quite easy to restore daily backups on dev and QA systems with NetApp Snapshot, SnapRestore, and FlexClone® technologies. Also, you can restore the deleted rows or dropped tables from the Snapshot copy.

To recover deleted rows or dropped tables from the backup, complete the following steps:

1. Take a FlexClone volume from the Snapshot copy.
2. Split the FlexClone volume from its parent volume.
3. Attach the volume to another MySQL instance.
4. Restore individual rows or tables from the MySQL instance.

9.5 Data Replication and Disaster Recovery

Nearly every database requires data replication. At the most basic level, replication can mean a copy on tape stored off site or database-level replication to a standby database. Disaster recovery refers to the use of those replica copies to bring a service online if a catastrophic loss of service occurs. ONTAP offers multiple replication options to address various requirements natively within the storage array, covering a complete spectrum of needs. These options can range from simple replication of backups to a remote site up to a synchronous, fully automated solution that delivers disaster recovery and HA in the same platform.

The primary ONTAP replication technologies applicable to databases are the NetApp SnapMirror® and NetApp SyncMirror® technologies. These products are not add-ons but are fully integrated into ONTAP and activated by the simple addition of a license key. Storage-level replication is not the only option, either. Database-level replication, MySQL native replication, global transaction identifier (GTID) semi-sync replication, InnoDB clusters, and Percona XtraDB Cluster (PXC) can also be used as data protection strategies.

The right choice depends on the specific replication, recovery, and retention requirements.

ONTAP SnapMirror

SnapMirror is the NetApp asynchronous replication solution, ideally suited for protecting large, complicated, and dynamic datasets such as databases and their associated applications. Its key values are as follows:

- **Manageability.** SnapMirror is easy to configure and manage because it is a native part of the storage software. No add-on products are required. Replication relationships can be established in minutes and can be managed directly on the storage system.
- **Simplicity.** Replication is based on FlexVol volumes, which are containers of LUNs or files that are replicated as a single consistent group.
- **Efficiency.** After the initial replication relationship is established, only changes are replicated. Efficiency features such as deduplication and compression are preserved, further reducing the amount of data that must be transferred to a remote site.

- **Flexibility.** Mirrors can be temporarily broken to allow testing of disaster recovery procedures, and then the mirroring can be easily reestablished with no need for a complete remirroring. Only the changed data must be applied to bring the mirrors back into sync. Mirroring can also be reversed to allow a rapid resync after the disaster concludes and the original site is back in service. Finally, read/write clones of replicated data are available for testing and development.

ONTAP SyncMirror

SyncMirror provides an additional layer of synchronous data mirroring in ONTAP. At the simplest layer, SyncMirror creates two complete sets of RAID-protected data in two different locations. They can be in adjoining rooms within a data center, or they can be located many kilometers apart.

SyncMirror is fully integrated with ONTAP and operates just above the RAID level. Therefore, all the usual ONTAP features, such as Snapshot copies, SnapRestore, and FlexClone technology, work seamlessly.

NetApp MetroCluster manages ONTAP controllers by using SyncMirror technology. The primary purpose of MetroCluster is to provide HA access to synchronously mirrored data in various failure scenarios.

The key values of data protection with MetroCluster and SyncMirror are as follows:

- In normal operations, SyncMirror delivers synchronous mirroring across locations. A write operation is not acknowledged until it is present on nonvolatile media on both sites.
- If connectivity between sites fails, SyncMirror automatically switches into asynchronous mode to keep the primary site serving data until connectivity is restored. Then it delivers rapid resynchronization by efficiently updating the changes that have accumulated on the primary site. Full reinitialization is not required.

SnapMirror is also fully compatible with systems based on SyncMirror. For example, a primary database might be running on a MetroCluster cluster spread across two geographic sites. This database can also replicate backups to a third site as long-term archives or for the creation of clones in a DevOps environment.

For more information about database protection, see TR-4591: Database Data Protection: Backup, Recovery, and DR.

10 Linux Configuration

10.1 Slot Tables

NFS performance on Linux depends on a parameter called `tcp_slot_table_entries`. This parameter regulates the number of outstanding NFS operations that are permitted on a Linux operating system.

The default value in most 2.6-derived kernels, which includes RH5 and OL5, is 16. However, this default frequently causes performance problems. The opposite problem occurs on newer kernels in which the `tcp_slot_table_entries` value is uncapped and can cause storage problems by flooding the system with excessive requests. The solution is to set this value statically. Use a value of 128 for any Linux operating system using NetApp NFS storage with a MySQL database. To set this value in Red Hat Enterprise Linux 6.2 and earlier, place the following entry in `/etc/sysctl.conf`:

```
# sysctl -a | grep tcp.*.slot_table sunrpc.tcp_max_slot_table_entries = 128
sunrpc.tcp_slot_table_entries = 128
# sysctl -a | grep tcp.*.slot_table sunrpc.tcp_max_slot_table_entries = 128
sunrpc.tcp_slot_table_entries = 128
```

In addition, there is a bug in most Linux distributions using 2.6 kernels. The startup process reads the contents of /`etc/sysctl.conf` before the NFS client is loaded. As a result, when the NFS client is eventually loaded, it takes the default value of 16. To avoid this problem, edit /`etc/init.d/netfs` to call `/sbin/sysctl -p` in the first line of the script so that `tcp_slot_table_entries` is set to 128 before NFS mounts any file systems. To set this value in Red Hat Enterprise Linux 6.3 and later, apply the following modification in the RPC configuration file:

```
echo "options sunrpc udp_slot_table_entries=64 tcp_slot_table_entries=128
tcp_max_slot_table_entries=128" >> /etc/modprobe.d/sunrpc.conf
```

10.2 Security-Enhanced Linux

Security-Enhanced Linux (SELinux) is a Linux kernel security model that provides a mechanism for supporting access control security policies. The SELinux architecture supports the enforcement of many kinds of mandatory access control policies. This enforcement applies to users, daemons, files, and directories.

The `/etc/selinux/config` configuration file controls whether SELinux is enabled or disabled. The SELinux variable can be set to disabled, permissive, or enforcing mode. The disabled option completely disables the SELinux kernel and application code, leaving the system running without any SELinux protection. The permissive option enables the SELinux code but causes it to operate in a mode where policy-denied accesses are permitted but audited. The enforcing option enables the SELinux code and causes it to enforce and audit access denials. Permissive mode can yield a different set of denials than enforcing mode. Enforcing mode prevents an operation from proceeding past the first denial, and some application code will fall back to a less privileged mode of operation if denied access.

Most deployments observed errors while mounting an NFS file system on a Linux host or while starting the MySQL daemon. Some common errors are shown here:

```
Error message: not found; Error message: access denied;
Error message: Permission denied; Cannot mount / access an NFS volume or file system; Error
Message: Cannot find home Directory

[Warning] Can't create test file /mysqlvol/test/mysql/testmysql.lower-test
[Note] /usr/sbin/mysqld (mysqld 5.7.22-log) starting as process 5683 ...
[Warning] Can't create test file /mysqlvol/test/mysql/testmysql.lower-test
[Warning] Can't create test file /mysqlvol/test/mysql/testmysql.lower-test
[ERROR] Could not open file '/mysqlvol/test/mysql/mysql-error.log' for error logging: Permission
denied
```

You can resolve these errors by correcting the SELinux configuration files and making sure that the export options on NetApp ONTAP are configured correctly. For relevant troubleshooting information, see the steps in the NetApp Knowledgebase.

10.3 I/O Schedulers

The Linux kernel allows low-level control over the way that I/O to block devices is scheduled. The defaults on various distributions of Linux vary considerably. MySQL recommends that you use NoOps or a deadline I/O scheduler with native asynchronous I/O (AIO) on Linux. In general, NetApp customers and internal testing show better results with NoOps.

MySQL's InnoDB storage engine uses the asynchronous I/O subsystem (native AIO) on Linux to perform read-ahead and write requests for data file pages. This behavior is controlled by the `innodb_use_native_aio` configuration option, which is enabled by default. With native AIO, the type of I/O scheduler has greater influence on I/O performance. Conduct benchmarks to determine which I/O scheduler provides the best results for your workload and environment.

See the relevant Linux and MySQL documentation for instructions on configuring the I/O scheduler.

10.4 Multipathing

Some customers have encountered crashes during network disruption because the multipath daemon was not running on their system. On more recent versions of Linux, the installation process of the operating system and the multipathing daemon might leave these operating systems vulnerable to this problem. The packages are installed correctly, but they are not configured for automatic startup after a reboot.

You can verify the state of the multipath daemon by running the `systemctl` command. If the status is not `active`, the daemon is not running.

```
[root@jfs0 ~]# systemctl status multipathd.service
multipathd.service - Device-Mapper Multipath Device Controller
   Loaded: loaded (/usr/lib/systemd/system/multipathd.service; enabled; vendor preset: enabled)
   Active: active (running) since Mon 2018-06-25 13:05:05 EDT; 1 months 21 days ago
  Process: 583 ExecStart=/sbin/multipathd (code=exited, status=0/SUCCESS)
  Process: 579 ExecStartPre=/sbin/multipath -A (code=exited, status=0/SUCCESS)
  Process: 557 ExecStartPre=/sbin/modprobe dm-multipath (code=exited, status=0/SUCCESS)
 Main PID: 589 (multipathd)
   CGroup: /system.slice/multipathd.service
           └─589 /sbin/multipathd
```

10.5 Open File Limits

To run, the MySQL server needs file descriptors. It uses them to open new connections, store tables in the cache, create temporary tables to resolve complicated queries, and access persistent ones. If `mysqld` is not able to open new files when needed, it can stop functioning correctly. A common symptom of this issue is error 24, “Too many open files.” The number of file descriptors `mysqld` can open simultaneously is defined by the `open_files_limit` option set in the configuration file `(/etc/my.cnf`). But `open_files_limit` also depends on the limits of the operating system. This dependency makes setting the variable more complicated.

MySQL cannot set its `open_files_limit` option higher than what is specified under `ulimit 'open files'`. Therefore, you need to explicitly set these limits at the operating system level to allow MySQL to open files as needed. There are two ways to check the file limit in Linux:

- The `ulimit` command quickly gives you a detailed description of the parameters being allowed or locked. The changes made by running this command are not permanent and will erase after a system reboot.
- Changes to the `/etc/security/limit.conf` file are permanent and are not affected by a system reboot.

Make sure to change both the hard and soft limits for user `mysql`. The following excerpts are from the configuration:

```
mysql hard nofile 65535
mysql soft nofile 65353
```

In parallel, update the same configuration in `my.cnf` to fully use the open file limits.

11 Database and Virtualization

Virtualization of databases with VMware ESXi, Oracle Virtual Machine (OVM), or Kernel-Based Virtual Machine (KVM) is an increasingly common choice for NetApp customers who choose virtualization for even their most mission-critical databases.

11.1 Containers

Containerization of MySQL databases is becoming more prevalent. Low-level container management is almost always performed through Docker. Container management platforms such as OpenShift and Kubernetes make management of large container environments even simpler. The benefits of containerization include lower costs, because there is no need to license a hypervisor. Also, containers allow multiple databases to run isolated from one another while sharing the same underlying kernel and operating system. Containers can be provisioned in microseconds.

NetApp offers the Trident driver to provide advanced management capabilities of storage. For example, Trident allows a container created in Kubernetes to automatically provision its storage on the appropriate tier, apply export policies, set NetApp Snapshot policies, and even clone one container to another. For additional information, see Trident Storage Orchestrator for Containers.

11.2 Storage Presentation

Customers considering virtualization of their databases should base their storage decisions on their business needs. Although this statement applies to all IT decisions, it is especially important for virtualization, because the size and scope of projects vary considerably.

Regarding storage presentation, a storage resource should be managed directly by the VM guest. Therefore, use one of the following storage configurations:

- iSCSI LUNs managed by the iSCSI initiator on the VM, not the hypervisor
- NFS file systems mounted by the VM, not a Virtual Machine Disk (VMDK)
- FC raw device mappings (RDMs) when the VM guest manages the file system

As a general rule, avoid using datastores for database files. There are many reasons for this recommendation:

- **Transparency.** When a VM owns its file systems, it is easier for a database administrator (DBA) or a system administrator to identify the source of the file systems for their data.
- **Performance.** Testing has shown that channeling all I/O through a hypervisor datastore affects performance.
- **Manageability.** When a VM owns its file systems, the use or nonuse of a hypervisor layer affects manageability. The same procedures for provisioning, monitoring, data protection, and so on can be used across the entire estate, including virtualized and nonvirtualized environments.
- **Stability and troubleshooting.** When a VM owns its file systems, delivering good, stable performance and troubleshooting problems are much simpler because the entire storage stack is present on the VM. The hypervisor's only role is to transport FC or IP frames. When a datastore is included in a configuration, it complicates the configuration by introducing another set of timeouts, parameters, log files, and potential bugs.
- **Portability.** When a VM owns its file systems, the process of moving a database environment becomes much simpler. File systems can be easily moved between virtualized and nonvirtualized guests.
- **Vendor lock-in.** After data is placed in a datastore, using a different hypervisor or removing the data from the virtualized environment entirely becomes very difficult.
- **Snapshot enablement.** In some cases, backups in a virtualized environment can become a problem because of the relatively limited bandwidth. For example, a four-port 10GbE trunk might be sufficient to support day-to-day performance needs of many virtualized databases. However, such a trunk would be insufficient to perform backups using Oracle Recovery Manager (RMAN) or other backup products that require streaming a full-sized copy of the data.

  Using VM-owned file systems makes it easier to take advantage of Snapshot-based backups and restores. A VM-owned file system offloads the work of performing backups onto the storage system. There is no need to overbuild the hypervisor configuration purely to support the bandwidth and CPU requirements in the backup window.

  Note: For optimum performance and manageability, NetApp recommends that you avoid placing database data on a datastore. Use guest-owned file systems such as NFS, or use iSCSI file systems managed by the guest or by RDMs.

11.3 Para Virtualized Drivers

For optimum performance, using Para virtualized network drivers is critical. When a datastore is used, a Para virtualized SCSI driver is required. A Para virtualized device driver allows a guest to integrate more deeply into the hypervisor, as opposed to an emulated driver in which the hypervisor spends more CPU time mimicking the behavior of physical hardware.

The performance of most databases is limited by storage. Therefore, the extra latency introduced by a network or SCSI driver is particularly noticeable. NetApp Support has encountered many performance complaints that customers resolved by installing Para virtualized drivers. During one customer proof of concept, databases showed better performance under ESXi than with the same hardware running as bare metal. The tests were very I/O intensive, and the performance difference was attributed to the use of the ESXi Para virtualized network drivers.

Note: NetApp recommends that you use Para virtualized network drivers and SCSI drivers.

12 MySQL

MySQL Standard Edition enables you to deliver high-performance and scalable OLTP applications. It provides the ease of use that has made MySQL famous along with industrial-strength performance and reliability. MySQL Standard Edition includes InnoDB, making it a fully integrated, transaction-safe ACID-compliant database. In addition, MySQL replication allows you to deliver high-performance, scalable applications.

12.1 Why MySQL?

MySQL is the world’s most popular database because it has native-rich features. Some of the features are as follows:

- **Lower TCO.** MySQL is a powerful, free, open-source database management system that has been available for years. It is very stable. It has community support that helps maintain, debug, and add new features. If a web application requires more than a database, or requires load-balancing or sharding, you can easily set up database instances with only hardware costs, rather than commercial databases that require a single license for each instance.
- **Reliability, performance, and ease of use.** One of MySQL’s hallmarks is exceptional performance and scalability, which is why so many web-based businesses use it. MySQL uses several key strengths to deliver fast performance. Because competition is always a mouse click (or screen touch) away, rapid responses to customer inquiries and activities are paramount. The database serving web-based applications needs to provide extreme performance for both read (simple and complex queries) and write operations.
- **Database development, design, and administration.** MySQL Workbench provides an integrated development, design, and administration environment to make developers and DBAs more productive. Different developers look for different features in a database, and MySQL offers a range of features. It can run adequately on both a laptop and a desktop. It can easily adapt to the environment, ensuring that it does not collide with existing web servers or applications.
- **Comprehensive transactional support.** MySQL is one of the most robust transactional database engines available. It is the solution for full data integrity, offering features such as complete atomic, consistent, isolated, durable transaction support; multiversion transaction support; and unrestricted row-level locking. It provides instant deadlock identification through server-enforced referential integrity.
- **Data security.** MySQL is globally renowned for being the most secure and reliable database management system used in popular web applications such as WordPress, Drupal, Joomla, Facebook, Google, and Twitter. The data security and support for transactional processing that accompany the recent version of MySQL can benefit any business, especially e-commerce businesses that involve frequent money transfers.

- **Pluggable architecture.** The MySQL pluggable storage engine architecture enables a database professional to select a specialized storage engine for a particular application need without having to manage application coding requirements. The MySQL server architecture isolates the application programmer and DBA from all the low-level implementation details at the storage level, providing a consistent and easy application model and API. Although there are different capabilities across different storage engines, the application is shielded from these differences.

MySQL’s efficient and modular architecture provides huge benefits if you want to target a particular application need—such as data warehousing, transaction processing, or HA situations—while using interfaces and services that are independent of any one storage engine.

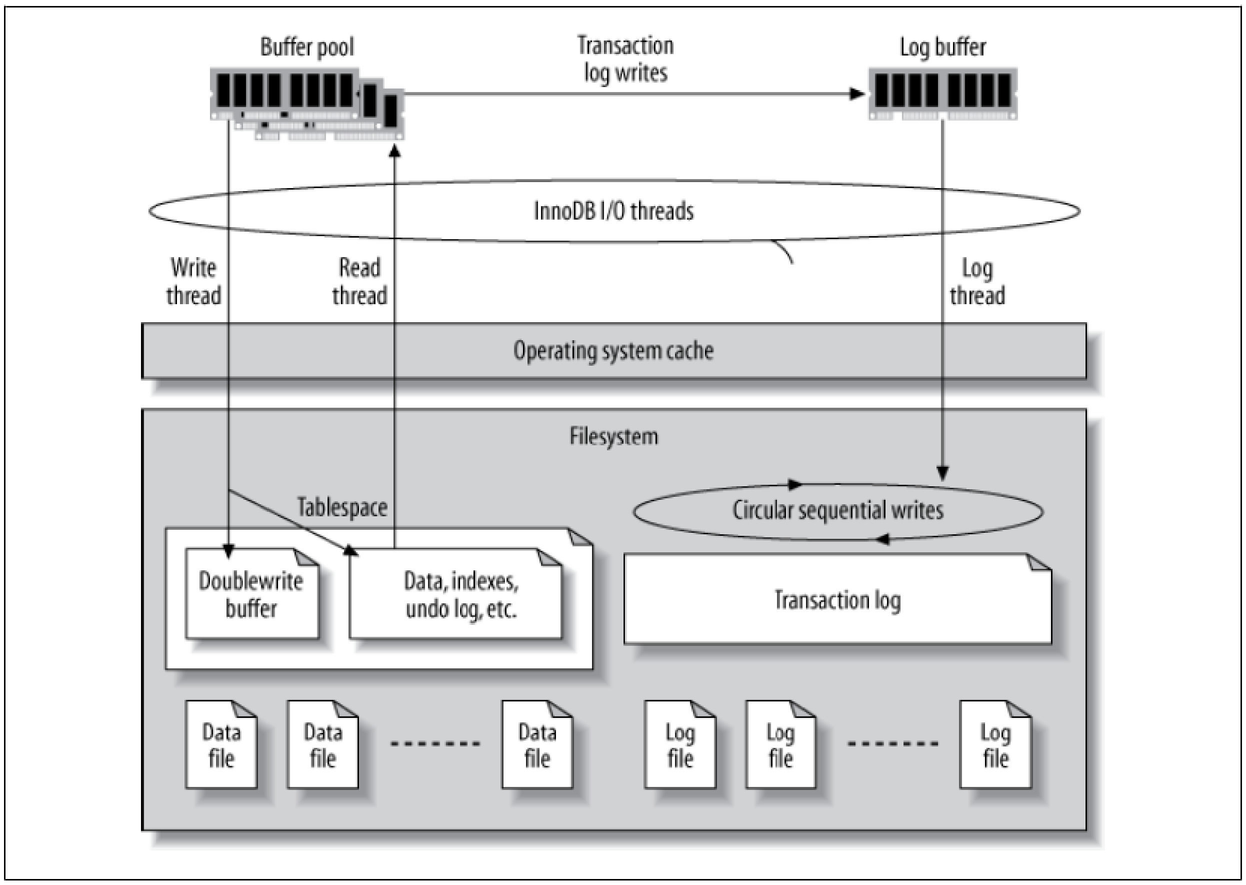
Before designing your storage solution for deploying MySQL on NetApp ONTAP, you should understand the MySQL architecture. The pluggable architecture divides work between MySQL common code (parser, optimizer) and the storage engine. The default storage engine for MySQL, InnoDB, is ACID compatible and is used mostly for OLTP workloads. Its features include:

- ACID transactions
- Row-level locking
- Foreign key constraints
- Automatic crash recovery
- Table compression (read/write)
- Spatial data types (no spatial indexes)

12.2 MySQL File Structure

InnoDB acts as the middle layer between disk storage and the MySQL server—it stores the data to disk. Figure 2 shows how InnoDB interacts with storage.

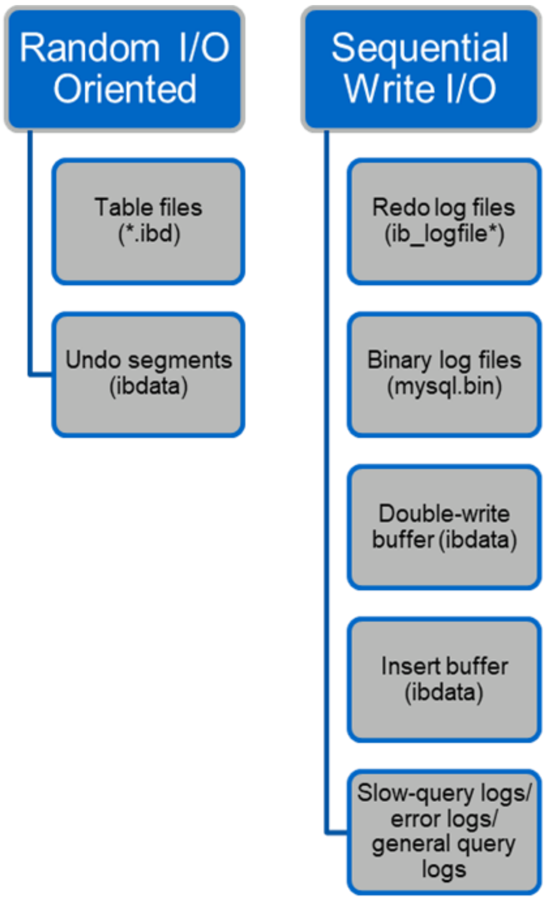
Figure 2) InnoDB engine architecture.



MySQL I/O is categorized into two types (as shown in Figure 3):

- Random file I/O
- Sequential file I/O

Figure 3) MySQL file system structure.


Random I/O Oriented
Table files (*.ibd)
Undo segments (ibdata)
Sequential Write I/O
Redo log files (ib_logfile*)
Binary log files (mysql.bin)
Double-write buffer (ibdata)
Insert buffer (ibdata)
Slow-query logs/ error logs/ general query logs

Data files are randomly read and overwritten, which results in high IOPS levels. Therefore, SSD storage is recommended.

Note: A battery-backed write cache is also very effective on SSD.

Redo log files and binary log files are transactional logs. They are sequentially written, so you can get good performance on HDD with the write cache. A sequential disk read happens on recovery, but it rarely causes a performance problem, because log file size is usually smaller than data files, and sequential reads are faster than random reads (occurring on data files).

The double-write buffer is a special feature of InnoDB. InnoDB first writes flushed pages to the double-write buffer, and then writes the pages to their correct positions on the data files. This process prevents page corruption. Without the double-write buffer, the page might become corrupted if a power failure occurs during the write-to-disks process. Because writing to the double-write buffer is sequential, it is highly optimized for HDDs. Sequential reads occur on recovery.

Because ONTAP NVRAM already provides write protection, double-write buffering is not required. MySQL has a parameter, `skip_innodb_doublewrite`, to disable the double-write buffer. This feature can substantially improve performance.

The insert buffer is also a special feature of InnoDB. If nonunique secondary index blocks are not in memory, InnoDB inserts entries into the insert buffer to avoid random disk I/O operations. Periodically, the insert buffer is merged into the secondary index trees in the database. The insert buffer reduces the number of disk I/O operations by merging I/O requests to the same block; random I/O operations can be sequential. The insert buffer is also highly optimized for HDDs. Both sequential writes and reads occur during normal operations.

Undo segments are random I/O oriented. To guarantee multiversion concurrency (MVCC), InnoDB must register old images in the undo segments. Reading previous images from the undo segments on disk requires random reads. If you run a long transaction with repeatable reads (such as `mysqldump`—single transaction) or run a long query, random reads can occur. Therefore, storing undo segments on SSDs is better in this instance. If you run only short transactions or queries, the random reads are not an issue.

Because of these InnoDB I/O characteristics, NetApp recommends the following storage design layout:

- One volume to store random and sequential I/O-oriented files of MySQL
- Another volume to store purely sequential I/O-oriented files of MySQL

Note: This layout also helps you design data protection policies and strategy.

12.3 MySQL Configuration

NetApp recommends a few important MySQL configuration parameters (listed in Table 1) to obtain optimal performance.

Table 1) MySQL configuration parameters.

Parameters	Values
`innodb_log_file_size`	256M
`innodb_flush_log_at_trx_commit`	2
`innodb_doublewrite`	0
`innodb_flush_method`	fsync
`innodb_buffer_pool_size`	11G
`innodb_io_capacity`	8192
`innodb_buffer_pool_instances`	8
`innodb_lru_scan_depth`	8192
`open_file_limit`	65535

To set the parameters described in this section, you must change them in the MySQL configuration file (`my.cnf`). The NetApp best practices are a result of the tests performed in-house. Detailed test results and the hardware configuration of the server are detailed in section 15, “Performance Results.”

innodb_log_file_size

Selecting the right size for the InnoDB log file size is important for the write operations and for having a decent recovery time after a server crash. Because so many transactions are logged in to the file, the log file size is important for write operations. When records are modified, the change is not immediately written back to the tablespace on the disk. Instead, the change is recorded at the end of the log file on disk and the page is marked as dirty. InnoDB uses its log to convert the random disk I/O into sequential I/O.

When the log is full, the dirty page is written out to the tablespace in sequence to free up space in the log file. For example, suppose a server crashes in the middle of a transaction, and the write operations are only recorded in the log file. Before the server can go live again, it must go through a recovery phase in which the changes recorded in the log file are replayed. The more entries that are in the log file, the longer it takes for the server to recover.

In this example, the log file size affects both the recovery time and the write performance. When choosing the right number for the log file size, balance the recovery time against write performance. Typically, anything between 128M and 512M is a good value.

innodb_flush_log_at_trx_commit

When there is a change to the data, the change is not immediately written to the disk. Instead, the data is recorded in a log buffer, which is a portion of memory that InnoDB allocates to buffer changes that are recorded in the log file. InnoDB flushes the buffer to the log file on disk when a transaction is committed, when the buffer gets full, or once per second, whichever event happens first. The configuration variable that controls this process is `innodb_flush_log_at_trx_commit`. The value options include:

- **0**: When you set `innodb_flush_log_trx_at_commit=0`, InnoDB writes the modified data (in the InnoDB buffer pool) to the log file (`ib_logfile`) and flushes the log file (write to disk) every second. However, it does not do anything when the transaction is committed. If there is a power failure or system crash, none of the unflushed data is recoverable because it is not written to either the log file or stored disk.
- **1**: When you set `innodb_flush_log_trx_commit=1`, InnoDB writes the log buffer to the transaction log and flushes to durable storage for every transaction. For example, for all transaction commits, InnoDB writes to the log and then writes to disk. Slower disk storage negatively affects performance; for example, the number of InnoDB transactions per second is reduced.
- **2**: When you set `innodb_flush_log_trx_commit=2`, InnoDB writes the log buffer to the log file at every commit; however, it doesn't write data to disk. InnoDB flushes data once every second. Even if there is a power failure or system crash, option 2 data is available in the log file and is recoverable.

If performance is the main goal, set the value to 2. Since InnoDB writes to disk once per second, not for every transaction commit, performance improves dramatically. If a power failure or crash occurs, data can be recovered from the transaction log.

If data safety is the main goal, set the value to 1 so that for every transaction commit, InnoDB flushes to disk. However, performance might be affected.

Note: For optimal performance from MySQL on ONTAP, set the value of this parameter to 2.

innodb_doublewrite

When this parameter is enabled (the default), InnoDB stores all data twice: first to the double-write buffer and then to the actual data files. You can turn off this parameter with `--skip-innodb_doublewrite` for benchmarks or when you're more concerned with top performance than data integrity or possible failures. InnoDB uses a file flush technique called double-write. Before it writes pages to the data files, InnoDB writes them to a contiguous area called the double-write buffer. After the write and the flush to the double-write buffer are complete, InnoDB writes the pages to their proper positions in the data file. If the operating system or a `mysqld` process crashes during a page write, InnoDB can later find a good copy of the page from the double-write buffer during crash recovery.

Best Practice
NetApp recommends disabling the double-write buffer, because it's an area in common tablespace and is already stored on ONTAP software. ONTAP NVRAM serves the same function.

innodb_buffer_pool_size

The InnoDB buffer pool is the most important part of any tuning activity. InnoDB relies heavily on the buffer pool for caching indexes and rowing the data, the adaptive hash index, the insert buffer, and many other data structures used internally. The buffer pool also buffers changes to data so that write operations don't have to be performed immediately on disk, thus improving their performance. The buffer pool is an integral part of InnoDB and its size must be adjusted accordingly. Consider the following factors when setting the buffer pool size:

- For a dedicated InnoDB-only machine, set the buffer pool size to 80% or more of available RAM.
- If it's not a MySQL dedicated server, set the size to 50% of RAM.

innodb_flush_method

The `innodb_flush_method` parameter specifies how InnoDB opens and flushes the log and data files. In InnoDB optimization, setting this parameter tweaks the database performance when applicable.

The following options are for flushing the files through InnoDB:

- **Fsync**. InnoDB uses the `fsync()` system call to flush both the data and log files. This option is the default setting.
- **O_DSYNC**. InnoDB uses the `O_DSYNC` option to open and flush the log files and `fsync()` to flush the data files. InnoDB does not use `O_DSYNC` directly, because there have been problems with it on many varieties of UNIX.
- **O_DIRECT.** InnoDB uses the `O_DIRECT` option (or `directio()` on Solaris) to open the data files and uses `fsync()` to flush both the data and log files. This option is available on some GNU/Linux versions, FreeBSD, and Solaris.
- **O_DIRECT_NO_FSYNC.** InnoDB uses the `O_DIRECT` option during flushing I/O; however, it skips the `fsync()` system call afterward. This option is unsuitable for some types of file systems (for example, XFS). If you are not sure if your file system requires an `fsync()` system call—for example, to preserve all file metadata—use the `O_DIRECT` option instead.

Observation

In the NetApp lab tests, the `fsync` default option was used on NFS and SAN, and it was a great performance improviser compared to `O_DIRECT`. While using the flush method as `O_DIRECT` with ONTAP, we observed that the client writes a lot of single-byte writes at the border of the 4096 block in serial fashion. These writes increased latency over the network and degraded performance.

innodb_io_capacity

In the InnoDB plug-in, a new parameter called `innodb_io_capacity` was added from MySQL 5.7. It controls the maximum number of IOPS that InnoDB performs (which includes the flushing rate of dirty pages as well as the insert buffer [ibuf] batch size). The `innodb_io_capacity` parameter sets an upper limit on IOPS by InnoDB background tasks, such as flushing pages from the buffer pool and merging data from the change buffer.

Set the `innodb_io_capacity` parameter to the approximate number of I/O operations that the system can perform per second. Ideally, keep the setting as low as possible, but not so low that background activities slow down. If the setting is too high, data is removed from the buffer pool and insert buffer too quickly for caching to provide a significant benefit. If you are using this setting over NFS, NetApp recommends that you analyze the test result of disk IOPS (SysBench/Fio) and set the parameter accordingly. Use the smallest value possible for flushing and purging to keep up unless you see more modified or dirty pages than you want in the InnoDB buffer pool. Do not use extreme values such as 20,000 or more unless you've proved that lower values are not sufficient for your workload. The

Innodb_IO_capacity parameter regulates flushing rates and related disk I/O. You can seriously harm performance by setting this parameter or the innodb_io_capacity_max parameter too high and wasting disk I/O operations with premature flushing.

innodb_lru_scan_depth

The innodb_lru_scan_depth parameter influences the algorithms and heuristics of the flush operation for the InnoDB buffer pool. This parameter is primarily of interest to performance experts tuning I/O-intensive workloads. For each buffer pool instance, this parameter specifies how far down in the least recently used (LRU) page list the page cleaner thread should continue scanning, looking for dirty pages to flush. This background operation is performed once per second.

You can adjust the value up or down to minimize the number of free pages. Don't set the value much higher than needed, because the scans can have a significant performance cost. Also, consider adjusting this parameter when changing the number of buffer pool instances, because innodb_lru_scan_depth *innodb_buffer_pool_instances defines the amount of work performed by the page cleaner thread each second.

A setting smaller than the default is suitable for most workloads. Consider increasing the value only if you have spare I/O capacity under a typical workload. Conversely, if a write-intensive workload saturates your I/O capacity, decrease the value, especially if you have a large buffer pool.

open_file_limits

The open_file_limits parameter determines the number of files that the operating system permits mysqld to open. The value of this parameter at run time is the real value permitted by the system and might be different from the value you specify at server startup. The value is 0 on systems where MySQL cannot change the number of open files. The effective open_files_limit value is based on the value that is specified at the system startup (if any) and the values of max_connections and table_open_cache by using these formulas:

- 10 + max_connections + (table_open_cache x 2)
- max_connections x 5
- Operating system limit if positive
- If the operating system limit is infinity: open_files_limit value is specified at startup; 5,000 if none

The server attempts to obtain the number of file descriptors using the maximum of these four values. If that many descriptors cannot be obtained, the server attempts to obtain as many as the system will permit.

13 Deployment Methods

There are different ways of accessing your data stored on disk. If it's a local disk, you can directly access the data over the cable. However, if the data is stored over a network, you must choose a protocol to fit your requirements. Storage protocols are broadly categorized into the following two parts:

- NAS protocols
- SAN protocols

A NAS unit is a single storage device that operates on files. It includes a dedicated hardware device that connects to a LAN, usually through an Ethernet connection. This NAS server authenticates clients and manages file operations in much the same manner as traditional file servers, through well-established network protocols. NAS uses file-based protocols such as NFS (popular on UNIX systems) or SMB (used with Microsoft Windows systems) to copy the blocks and files over a network.

SAN storage is usually an array of disks that are attached to the server through a special network. It is a block-level system with full server's access to the disk volume through fast protocols such as FC, FCoE, iSCSI, and so on. SANs provide block-level access to shared data storage. Block-level access refers to the specific blocks of data on a storage device as opposed to file-level access. One file contains several blocks.

SANs provide high availability and robust business continuity for critical data environments. SAN is faster in most cases, but the exact performance depends on the storage network and how the LUNs are defined within the SAN.

13.1 MySQL over NAS

NetApp used the NFSv4 protocol during lab tests because NFSv3 has file-locking issues. The most common issue with NFSv3 was the locked InnoDB log files after a power outage. Using time or switching log files solved this issue. However, NFSv4 has locking operations and keeps track of open files and delegations. The MySQL documentation also recommends that you use NFSv4. The following information is from the official MySQL documentation on the MySQL website.

> **Using NFS with MySQL**
>
> Caution is advised when considering using NFS with MySQL. The potential issues, which vary by operating system and NFS version, include:
>
> – MySQL data and log files placed on NFS volumes become locked and unavailable. Locking issues can occur in cases where multiple instances of MySQL access the same data directory or where MySQL is shut down improperly, due to a power outage, for example. NFS version 4 addresses underlying locking issues with the introduction of advisory and lease-based locking. However, sharing a data directory among MySQL instances is not recommended.
>
> – Data inconsistencies introduced due to messages received out of order or lost network traffic. To avoid this issue, use TCP with `hard` and `intr` mount options.
>
> – Maximum file size limitations. NFS Version 2 clients can only access the lowest 2GB of a file (signed 32 bit offset). NFS Version 3 clients support larger files (up to 64-bit offsets). The maximum supported file size also depends on the local file system of the NFS server.
>
> Using NFS within a professional SAN environment or other storage system tends to offer greater reliability than using NFS outside of such an environment. However, NFS within a SAN environment might be slower than directly-attached or bus-attached nonrotational storage.
>
> If you choose to use NFS, NFS Version 4 or later is recommended, as is testing your NFS setup thoroughly before deploying into a production environment.[1]

NetApp recommends the following NFSv4 `fstab` (`/etc/fstab`) configurations:

```
nfs4 rw, hard,nointr,bg,vers=4,proto=tcp,noatime,rsize=65536,wsize=65536
```

Note: Specify `hard` if users write to the mounted directory or to running programs located in it. When NFS tries to access a hard-mounted directory, it keeps trying until it succeeds or someone interrupts its attempts. If the server goes down, any processes using the mounted directory hang until the server comes back up and then continue processing without errors. Interruptible hard mounts might be interrupted with CTRL+C or `kill`.

[1] *MySQL 8.0 Reference Manual*, https://dev.mysql.com/doc/refman/8.0/en/disk-issues.html.

Specify `nointr` if users might damage critical data by manually interrupting an NFS request. It is better for the system to hang while the server is down than risk losing data between the client and the server.

13.2 MySQL over SAN

There are two options to configure MySQL with SAN using the previously described two-volume model. Smaller databases can be placed on a pair of standard LUNs as long as the I/O and capacity demands are within the limits of a single LUN file system. For example, a database that requires approximately 2K random IOPS can be hosted on a single file system on a single LUN. Likewise, a database that is only 100GB in size would fit on a single LUN without creating a management problem.

Larger databases require multiple LUNs. For example, a database that requires 100K IOPS would most likely need at least eight LUNs. A single LUN would become a bottleneck because of the inadequate number of SCSI channels to disk. A 10TB database would similarly be difficult to manage on a single 10TB LUN. Logical volume managers are designed to bond the performance and capacity capabilities of multiple LUNs together to improve performance and manageability.

In both cases, a pair of NetApp ONTAP volumes should be sufficient. With a simple configuration, the data file LUN would be placed in a dedicated volume, as would the log LUN. With a logical volume manager configuration, all the LUNs in the data file volume group would be in a dedicated volume, and the LUNs of the log volume group would be in a second dedicated volume.

NetApp recommends two file systems for MySQL deployments on SAN:

- The first file system stores all MySQL data including tablespace, data, and index.
- The second file system stores all logs (binary logs, slow logs, and transaction logs).

There are multiple reasons for separating data in this manner, including:

- The I/O patterns of data files and log files differ. Separating them would allow more options with QoS controls.
- Optimal use of Snapshot technology requires the ability to independently restore the data files. Comingling data files with log files interferes with data file restoration.
- NetApp SnapMirror technology can be used to provide a simple, low-RPO disaster recovery capability for a database; however, it requires different replication schedules for the data files and logs.

  Note: Use this basic two-volume layout to future-proof the solution so that all ONTAP features can be used if needed.

NetApp also recommends that you format your drive with the ext4 file system because of the following features:

- Extended approach to block management features used in the journaling file system (JFS) and delayed allocation features of the extended file system (XFS).
- Ext4 permits file systems of up to 1 exbibyte (2^60 bytes) and files of up to 16 tebibytes (16 * 2^40 bytes). In contrast, the ext3 file system supports only a maximum file system size of 16TB and a maximum file size of 2TB.
- In ext4 file systems, multiblock allocation (`mballoc`) allocates multiple blocks for a file in a single operation, instead of allocating them one by one, as in ext3. This configuration reduces the overhead of calling the block allocator several times, and it optimizes the allocation of memory.
- Although XFS is the default for many Linux distributions, it manages metadata differently and is not suitable for some MySQL configurations.

NetApp recommends using 4k block size options with the `mkfs` utility to align with existing block LUN size.

```
mkfs.ext4 -b 4096
```

NetApp LUNs store data in 4KB physical blocks, which yields eight 512-byte logical blocks.

If you do not set up the same block size, I/O will not be aligned with physical blocks correctly and could write in two different disks in a RAID group, resulting in latency.

It is important that you align I/O for smooth read/write operations. However, when the I/O begins at a logical block that is not at the start of a physical block, the I/O is misaligned. I/O operations are aligned only when they begin at a logical block—the first logical block in a physical block.

14 Performance Benchmarking

Most MySQL deployments undergo a performance benchmarking stage before going to the production. It is always a best practice to complete performance benchmarking of the system. Here are some of the important metrics to benchmark:

- Throughput
- Transactions/queries per second (TPS/QPS)
- Latency

This section describes tools that have been used to measure these metrics in the MySQL ecosystem.

14.1 SysBench

SysBench is a benchmark suite that allows you to quickly get an impression of system performance, which is important if you plan to run a database under intensive load. SysBench supports testing CPU, memory, file I/O, mutex performance, and even MySQL benchmarking. You can select the SysBench File I/O Workload option to measure the disk throughput. It also comes with a set of database workload Lua scripts (read/write, write only, and read only) to measure QPS/TPS metrics of MySQL. The tool also helps you measure the average latency of the queries. In summary, you can simulate different kinds of workloads as needed. For more information, refer to the Linux man page for the SysBench tool.

14.2 MySQL Slap

MySQL includes a diagnostic tool called `mysqlslap`; it's been available since version 5.1.4. It is a benchmarking tool that can help DBAs and developers load-test their database servers. The `mysqlslap` tool can emulate a large number of client connections to the database server at the same time. The load-testing parameters are fully configurable, and the results from different test runs can be used to fine-tune the database design or hardware resources. This tool runs in the following three stages:

1. Create schema, table, and, optionally, any stored programs or data to use for the test. This stage uses a single client connection.
2. Run the load test. This stage can use many client connections.
3. Clean up (disconnect, drop table if specified). This stage uses a single client connection.

A query that consumes too many database resources might be the result of designing tables incorrectly, selecting the wrong table type, or creating an inefficient query. When a query eats up a lot of database resources, it can negatively affect other application components. By using `mysqlslap` to stress-test a server in a nonpublic environment, you will discover these errors sooner, which prevents a database failure after your application goes live. To learn more, review the tool options on the MySQL site.

15 Performance Results

This section describes the tests and validations performed in the NetApp labs. All the parameters suggested in section 10, "Linux Configuration," and section 12, "MySQL," were tested in the NetApp lab. We used the SysBench utility to perform basic benchmarking of the disk and MySQL. The test results provide a basic idea of the tests performed and the numbers achieved. Actual results can vary depending on the server configuration and the parameters configured. Test results covered the benchmarking performed for NFS and iSCSI protocol.

15.1 Testing Considerations

Accurate testing of database storage performance is a complicated task. It requires not just an understanding of IOPS and throughput, but also an understanding of the difference between foreground and background I/O operations, the impact of latency on the database, and numerous operating system and network settings that affect storage performance. In addition, there are nonstorage database tasks to consider. There is a point where optimizing storage performance yields no useful benefits, because storage performance is no longer a limiting factor for performance.

Most database customers now select an all-flash array, which creates some additional considerations. As an example, consider performance testing on a two-node NetApp AFF8080 system:

- With a 75/25 read/write ratio, two AFF8080 nodes can deliver over 300K random database IOPS before latency even crosses the 1ms mark. This far exceeds the current performance demands of most databases, so it is difficult to predict the expected improvement. Storage would be largely erased as a bottleneck.
- Network bandwidth is an increasingly common source of performance limitations. For example, spinning disk solutions are often bottlenecks for database performance, because the I/O latency is very high. When latency limitations are removed by an all-flash array, the barrier frequently shifts to the network. This situation is especially notable with virtualized environments and blade systems where the true network connectivity is difficult to visualize. This limitation can complicate performance testing if the storage system itself cannot be fully utilized because of bandwidth limitations.
- In general, comparing the performance of an all-flash array with an array containing spinning disks is not possible because of the dramatically improved latency of all-flash arrays. Test results are typically not meaningful.
- Comparing peak IOPS performance with an all-flash array is frequently not a useful test, because databases are not limited by storage I/O. For example, assume that one array can sustain 500K random IOPS, whereas another can sustain 300K. The difference is irrelevant in the real world if a database is spending 99% of its time on CPU processing. The workloads never use the full capabilities of the storage array. In contrast, peak IOPS capabilities might be critical in a consolidation platform in which the storage array is expected to be loaded to its peak capabilities.
- Always consider latency as well as IOPS in any storage test. Many storage arrays in the market make claims of extreme levels of IOPS, but the latency renders those IOPS useless at such levels. The typical target with all-flash arrays is the 1ms mark. A better approach to testing is not to measure the maximum possible IOPS, but to determine how many IOPS a storage array can sustain before average latency is greater than 1ms.

Table 2 describes the test lab environment.

Table 2) Lab setup.

Lab Details	
Server details	Intel Xeon CPU E5-2630 0 @ 2.30GHz (4Core); 15GB RAM
Operating system	Red Hat Enterprise Linux 7.3 (64-bit)
Storage	Hybrid FAS8060; two volumes (data and logs)

Lab Details	
MySQL	MySQL 5.7
Workload	75% reads and 25% writes
SysBench options	• --range_size = 100 • --table_size = 10,000 • --tables = 2 • --threads = $ each • --events = 0 • --time = 15 • --rand-type = uniform • oltp_read_write.lua run for each in 1, 4, 8, 16, 32, and 64
MySQL configuration	Refer to the `my.cnf` variables included in Appendix A.
Protocols	NFSv4 and iSCSI

This SysBench test is a basic OLTP (read/write) test with connections ranging from 1 to 64 in loop on two tables of 10,000 records with 75% of reads and 25% writes. Data is uniformly distributed for a time frame of 15 seconds for each thread. Table 3 lists the test results.

Table 3) Test results on NFS.

Database Threads	Queries per Second (QPS)	TPS (Transactions)	Latency (ms)		
			Minimum	Average (All Threads)	Maximum
1	4,295	214	3.47	4.65	19.26
4	14,643	732	3.43	5.46	20.94
8	18,835	941	3.56	8.49	27.88
16	21,021	1,051	3.71	15.18	53.30
32	23,418	1,170	3.71	27.30	133.92
64	23,362	1,167	3.65	54.70	315.48

Table 4) Test results on NFS with compression and deduplication.

Database Threads	QPS	TPS	Latency (ms)		
			Minimum	Average (All Threads)	Maximum
1	4,128	206	3.73	4.84	9.08
4	14,016	700	3.73	5.70	19.19

Database Threads	QPS	TPS	Latency (ms)		
8	20,376	1,018	3.72	7.85	27.73
16	23,254	1,162	3.87	13.75	49.68
32	23,709	1,185	3.87	26.96	119.76
64	23,784	1,188	3.85	53.73	290.33

The results in Table 4 clearly show that there is not much of a performance impact after enabling deduplication and compression. For fewer threads, QPS and TPS are smaller, but as the threads increase, the numbers increase.

After activating storage efficiency, the initial numbers were less compared to now. After additional SysBench tests were performed (read only, write only) to warm up the buffers, the results looked favorable.

Table 5) Test results on iSCSI.

Database Threads	QPS	TPS	Latency (ms)		
			Minimum	Average (All Threads)	Maximum
1	7,087	354	2.47	2.82	8.31
4	28,850	1,442	2.43	2.77	15.83
8	29,177	1,458	2.44	5.48	180.02
16	26,544	1,327	2.46	12.04	159.23
32	24,720	1,236	2.47	25.84	246.27
64	23,944	1,197	2.47	53.25	628

Table 6) Test results on iSCSI with compression and deduplication.

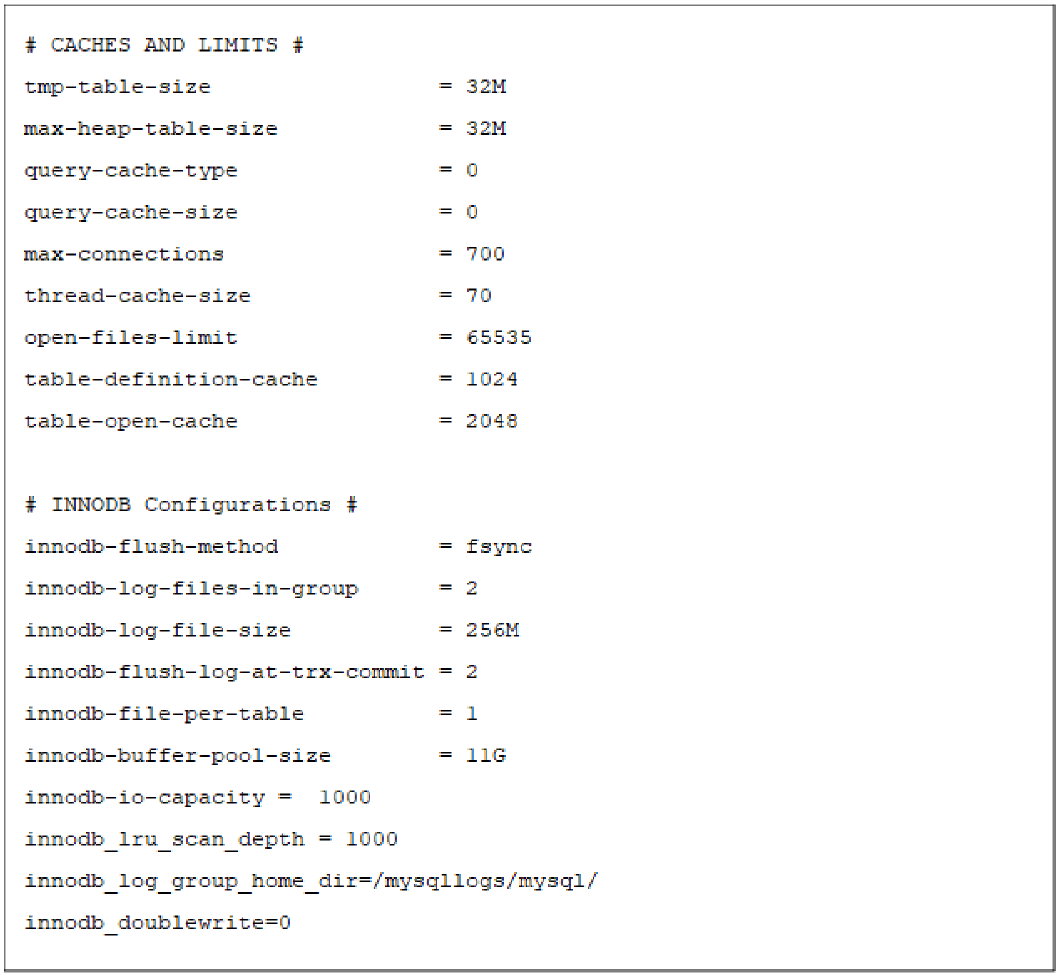
Database Threads	QPS	TPS	Latency (ms)		
			Minimum	Average (All Threads)	Maximum
1	5,359	267	2.43	3.72	1149
4	29,816	1,490	2.33	2.68	14.24
8	30,133	1,506	2.35	5.30	86.89
16	29,967	1,498	2.33	10.66	152.75
32	29,735	1,486	2.36	21.49	271.08
64	29,086	1,454	2.34	43.90	638.11

The test results shown in Table 6 are more favorable. After compression and deduplication, TPS and QPS numbers increased on block storage compared to file storage.

Appendix A: my.cnf Parameters

The important MySQL configuration parameters shown in Figure 4 were used in the NetApp labs to perform benchmark tests.

Figure 4) MySQL configuration parameters used for benchmark tests.



```
# CACHES AND LIMITS #
tmp-table-size                 = 32M
max-heap-table-size            = 32M
query-cache-type               = 0
query-cache-size               = 0
max-connections                = 700
thread-cache-size              = 70
open-files-limit               = 65535
table-definition-cache         = 1024
table-open-cache               = 2048

# INNODB Configurations #
innodb-flush-method            = fsync
innodb-log-files-in-group      = 2
innodb-log-file-size           = 256M
innodb-flush-log-at-trx-commit = 2
innodb-file-per-table          = 1
innodb-buffer-pool-size        = 11G
innodb-io-capacity =  1000
innodb_lru_scan_depth = 1000
innodb_log_group_home_dir=/mysqllogs/mysql/
innodb_doublewrite=0
```

Where to Find Additional Information

To learn more about the information that is described in this document, review the following documents and websites:

- AFF Resource page
  http://mysupport.netapp.com/aff/resources
- AFF and FAS System Documentation Center
  http://docs.netapp.com/platstor/index.jsp
- FAS Resources page
  http://mysupport.netapp.com/fas/resources
- ONTAP 9 Resource page
  http://mysupport.netapp.com/ontap/resources
- ONTAP 9 Documentation Center
  http://docs.netapp.com/ontap-9/index.jsp

- NetApp Product Documentation
  http://docs.netapp.com

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