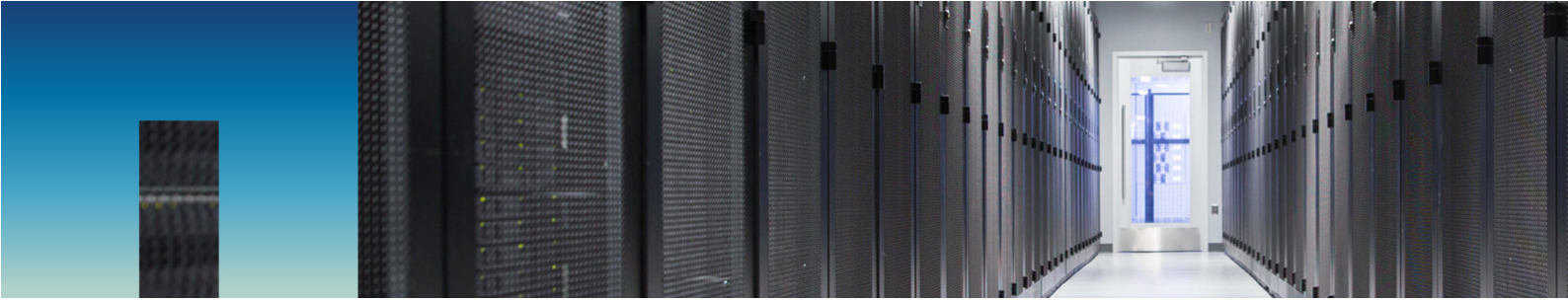


Technical Report

PostgreSQL Database on ONTAP

Best Practices

Anup Bharti, Ebin Kadavy, NetApp
May 2019 | TR-4770

Abstract

PostgreSQL comes with different variants that include PostgreSQL, PostgreSQL Plus, and EDB Postgres Advanced Server (EPAS). PostgreSQL is typically deployed as the back-end database for multitier applications. It is supported by common middleware packages (such as PHP, Java, Python, Tcl/TK, ODBC, and JDBC) and has historically been a popular choice for Open Source DBMS. This document covers the configuration requirements and guidance on tuning and storage configuration when deploying PostgreSQL on NetApp® ONTAP® data management software.

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

NetApp®

TABLE OF CONTENTS

LIST OF FIGURES

1 Introduction

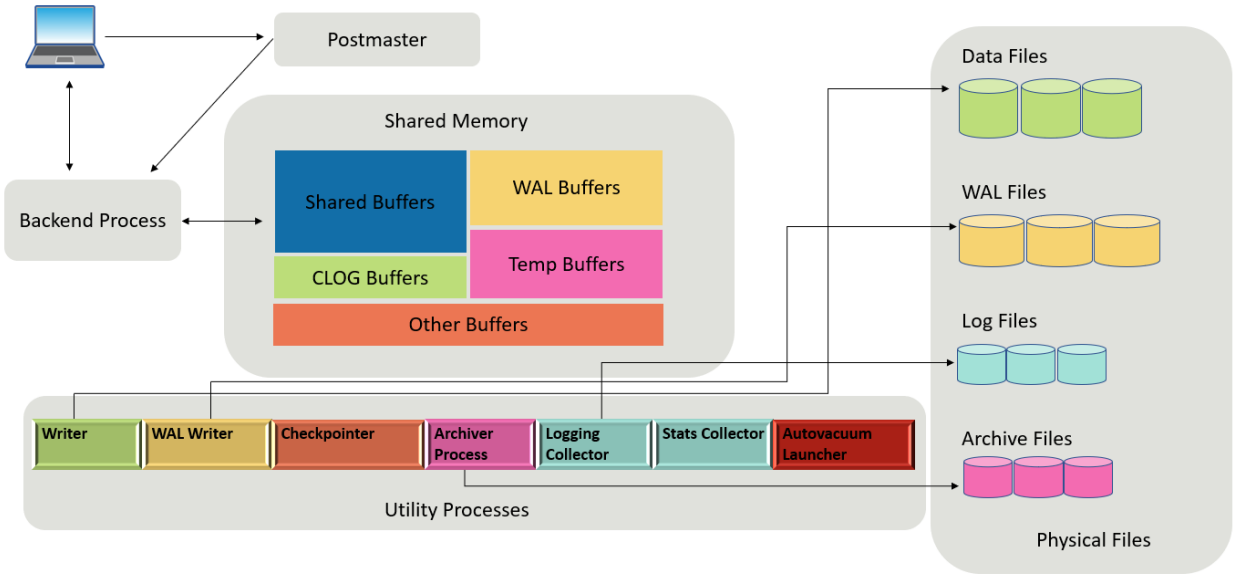
As data grows exponentially, data management becomes more complex for enterprises like yours. This complexity increases your licensing, operational, support, and maintenance costs. To reduce the overall TCO, you might consider switching from commercial to open-source databases with reliable, high-performing back-end storage. PostgreSQL is an advanced open-source database that is widely used in academic, commercial, and large enterprises. It comes with a new set of features that address the gaps in other relational database management systems (RDBMSs). The NetApp® ONTAP® proprietary software is used in storage disk arrays such as NetApp FAS and NetApp AFF, NetApp ONTAP Select, and NetApp Cloud Volumes ONTAP. With the release of ONTAP 9, you can unify data management across flash, disk, and cloud. This unification enables you to simplify your storage environment and build the foundation for a data fabric that makes it easy to move your data anywhere.

Note: This document is intended for customers who use PostgreSQL databases in both the physical and virtualized environments. It contains information about best practices for successfully deploying and managing PostgreSQL databases on ONTAP 9.x. The recommendations in this report are generic and are not specific to any configuration. Depending on your business needs, some suggestions might require changes. You must evaluate your environment against the official documentation for PostgreSQL, hypervisors, OS, and ONTAP storage.

2 PostgreSQL Architecture

PostgreSQL is an RDBMS based on client and server architecture. A PostgreSQL instance is known as a “database cluster” which is a collection of databases as opposed to a collection of servers. Figure 1 shows a brief overview of the PostgreSQL architecture.

Figure 1) Basic architecture of PostgreSQL.



There are three major elements in a PostgreSQL database: postmaster, front end (client), and back end. The client sends requests to the postmaster with information such as IP protocol and which database to connect to. Postmaster authenticates the connection and passes it to the back end process for further communication. The back end process executes the query and sends back results directly to the front end (client).

PostgreSQL instance is based on a multiprocess model instead of a multithreaded model. It spawns multiple processes for different jobs and each process has its own functionality. Some of the major processes include:

- When a client (foreground) process sends read or write requests to the PostgreSQL instance, it doesn't read or write data directly to the disk. It first buffers the data in shared buffers and WAL buffers.
- WAL writer process manipulates the content of the shared buffers and WAL buffers to write into the WAL logs. WAL logs are typically transaction logs of PostgreSQL and are sequentially written. Therefore, to improve the response time from the database, PostgreSQL first writes into the transaction logs and acknowledges the client.
- To put the database in a consistent state, the background writer process checks the shared buffer periodically for dirty pages. It then flushes the data onto the data files that are stored on NetApp volumes or LUNs.
- The checkpointer process also runs periodically (less frequently than background process) and prevents any modification to the buffers. It signals to the WAL writer process to write and flush the CHECKPOINT record to the end of WAL logs that are stored on the NetApp disk. It also signals the background writer process to write and flush all dirty pages to the disk.

3 Storage Design Considerations for PostgreSQL

This section addresses key topics of ONTAP storage design such as storage virtual machines (SVMs), logical interfaces (LIFs) design, volume layouts, storage efficiencies, and data protection for deploying a PostgreSQL database. For more information about ONTAP deployments and configurations, see the ONTAP Administration guide.

3.1 Storage Virtual Machines

Storage virtual machines (SVMs) contain data volumes and one or more LIFs through which they serve data to the clients. A cluster must have at least one SVM to serve data. SVMs securely isolate the shared virtualized data storage and network, and each SVM appears as a single dedicated server to the clients.

In a multitenant PostgreSQL environment, each tenant's data (database instance) can be given a dedicated SVM on ONTAP storage. NetApp recommends a limit of approximately 125 ONTAP SVMs per cluster node, but usually the LIF maximums are reached before the SVM limit is reached.

Multitenancy can also be achieved to some extent by having dedicated volumes from the same SVM but isolating them based on different network segments (LIFs, ports).

3.2 Logical Interface

When you create LIFs for a PostgreSQL database, consider the following aspects:

- **Performance**: is the network bandwidth sufficient?
- **Resiliency:** are there any single points of failure in the design?
- **Manageability:** can the network be scaled nondisruptively?

NFS LIF Design

Although NFS protocol has limited ability to define multiple paths to data, there are a few guidelines that help the database to achieve performance and resiliency over an NFS protocol.

Binding a LIF to a physical port results in more granular control over the 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. However, enabling Link Aggregation Control Protocol (LACP) and IP load balancing are the most common approaches for NFS databases running in larger environments. In scenarios where there are fewer NFS clients, enabling LACP and IP load balancing on the ONTAP interface groups doesn't seem to be efficient.

LIF Failover

The behavior of LIFs during network disruption is controlled by failover policies and failover groups. ONTAP enables management of LIF failover based on broadcast domains. Therefore, you can define all of the ports that have access to a given subnet and enable ONTAP to select an appropriate failover LIF. This approach 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. Therefore, NetApp recommends choosing individual ports for LIF failover.

Key Recommendations for LIF Failover

- Configure a failover group as user-defined.
- Populate the failover group with ports on the SFO partner controller. The LIFs then follow the aggregates during a storage failover which means you avoid creating indirect traffic.
- 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.

For more information about failover policies and failover groups, see the ONTAP Network Management Guide.

SAN LIF Design

All modern SAN implementations allow clients to use multipathing for accessing data over multiple network paths and to select the optimal paths for access. As a result, performance regarding 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.

You do not have 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.

Key Recommendations

- Do not create more paths than you need. Too many paths make overall management more complicated and can cause problems with path failover on some hosts.
- For a multipathing environment, it is better to have a NetApp LUN for the host zoned from different switches for high availability.
- In ONTAP 8.3 and later, the selective LUN-mapping (NetApp Service Level Manager (SLM) software) feature is the default. With SLM, any new LUN is automatically advertised from the node that owns the underlying aggregate and the node's HA partner. This arrangement removes the need to create port sets or configure zoning to limit port accessibility.
- It is better to avoid indirect traffic in an I/O-intensive database environment where every microsecond of latency is critical but the visible performance effect is negligible for typical workloads.
- Any 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.
- LUN mobility events (such as volume or LUN moves that involve moving a LUN from one HA pair in the cluster to another) should include a step to confirm that the LUN is being presented. This step can be done using the destination storage controllers before the mobility event is initiated.
- Modify selective LUN map reporting-nodes list before moving.

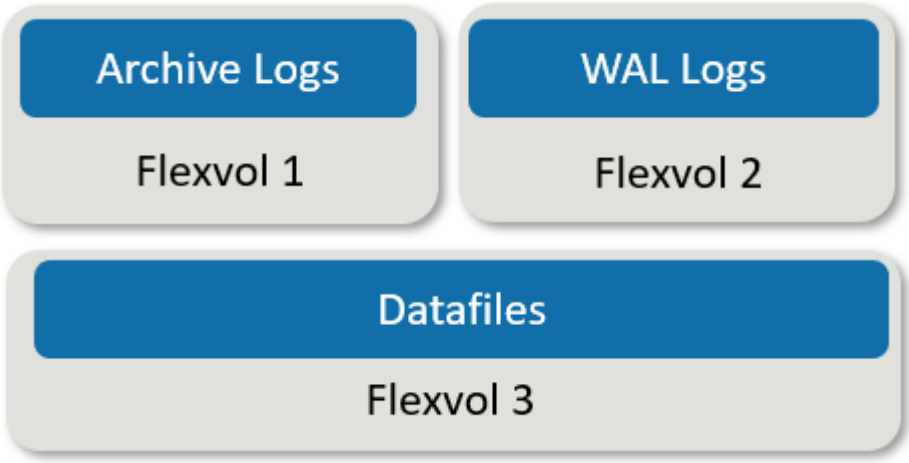
3.3 Volume Layout

A well-designed volume layout ensures great database performance and the easy management of the database. You should consider multiple factors when defining the volume layout for the database such as size of the database, growth rate of the database, and the backup frequency.

Dedicated Storage Layout

- In a mission critical environment, NetApp recommends keeping data files and WAL logs on dedicated volumes or LUNs for better performance in both the SAN and NFS layouts.
- Isolation of data files and WAL log volumes also enables faster recovery of the database.
- Multiple tablespaces of a PostgreSQL database can also be spread across dedicated volumes to get the individual database performance.
- If an aggregate is busy serving other applications in an ONTAP cluster, then you should isolate the PostgreSQL on a dedicated aggregate of a non-busy node (Figure 2).

Figure 2) Dedicated storage layout for PostgreSQL database.

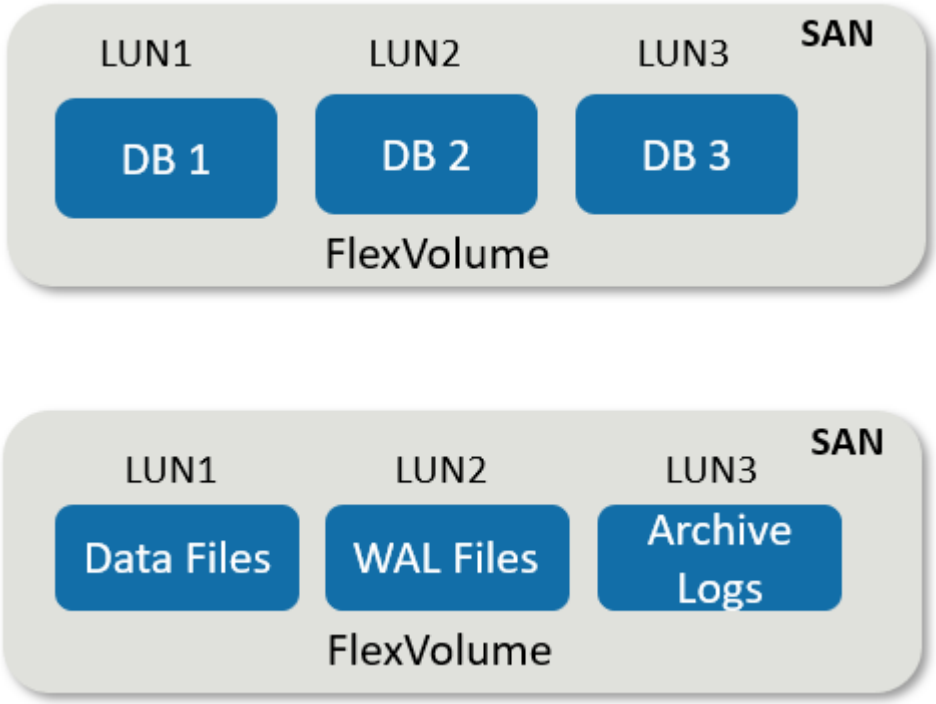


Shared Storage Layout

- For a noncritical environment, sharing multiple databases on the same volume or LUN helps to reduce the operational and management cost (Figure 3).
- Hosting data and WAL logs of multiple databases on single LUN or volume optimizes the NetApp Snapshot™ consolidation process by taking a single Snapshot copy for the entire dataset.

  Note: This might not be an ideal layout for mission critical systems.

Figure 3) Shared storage layout.



Virtualized Layout

When considering virtualization for your databases, you should make storage decisions based on business needs. Provisioning storage to a virtual machine (VM) can be of three different ways:

- iSCSI LUNs managed by the iSCSI initiator of the VM OR NFS file systems mounted directly on a guest VM.
- FC raw device mappings (RDMs)
- ONTAP volumes or LUNs managed by hypervisor (VMware) as NFS and VMFS datastores.

Figure 4) Virtualized database layouts with shared storage.

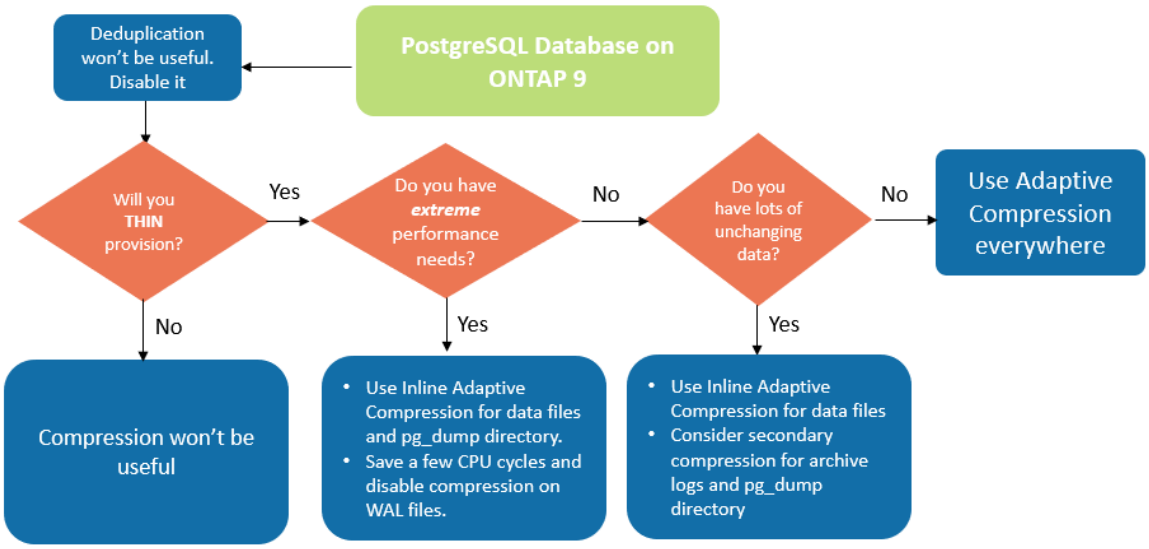
Key Recommendations

- When a VM owns its file systems, it is easier for you to identify the source of the file systems for their data.
- There can be a positive performance affect from channeling all I/Os through a hypervisor datastore.
- Choosing datastores might improve the overall manageability and operational overhead but it adds complexity because of the extra set of timeouts, parameters, log files, and potential bugs.
- Choosing NFS over VMware Virtual Machine File System (VMFS) datastore helps in using the NetApp SnapRestore technology in a disaster scenario.

3.4 Storage Efficiencies

Storage efficiency enables you to store the maximum amount of data within the smallest possible space at the lowest possible cost. However, enabling some of these technologies might affect the databases. The flowchart in Figure 5 discusses the considerations for storage efficiency.

Figure 5) Storage efficiency flowchart



Key Recommendations

- If there is no more than a single tenant sharing the storage dynamic disk pool (aggregate), it is a good practice to have thin provisioning enabled across volumes. On the contrary, in a multitenant environment when tenants are sharing the same storage pool (aggregate), there is a higher chance of running out of space due to uncertainty in the tenant's usage pattern. Therefore NetApp recommends that you use thick provisioning in the case of multitenant environments.
- If a volume is thick provisioned, you must completely disable all efficiency features for that volume, including compression and removal of deduplication using the `sis undo` command. The volume should not appear in the "volume efficiency show" output. If it does, then the volume is still partially configured for efficiency features and there is a chance you might run out of space, resulting in database I/O errors.
- In a virtualized layout, use either thin or thick lazy zeroed provisioning for datastores. See Appendix for more information about provisioning.
- For PostgreSQL workloads, NetApp recommends disabling deduplication for data and WAL log volumes. Enabling either deduplication or compression or both for `pg_dump` or tar file system backup volume might save space however it depends on the customer environment. For more information about workloads, see Appendix.
- LUN alignment refers to optimizing I/O for the underlying file system layout. On a NetApp system, storage is organized in 4KB units. Align an 8KB block on a PostgreSQL data file to exactly two 4KB blocks. If an error in LUN configuration shifts the alignment by 1KB in either direction, each 8KB PostgreSQL block would exist on three different 4KB storage blocks rather than two. This arrangement would cause increased latency and cause additional I/O to be performed within the storage system.

3.5 Data Protection

One of the major aspects of storage design is enabling protection for PostgreSQL volumes. Customers can protect their PostgreSQL database by either using dump approach or by using file system backups. This section explains the different approaches of backing up individual databases or the entire cluster using native approach and Snapshot technology.

Native Data Protection

There are three different approaches to backing up PostgreSQL data:

- SQL Server dump
- File system level backup
- Continuous archiving

The idea behind the **SQL Server dump** method is to generate a file with SQL Server commands that, when returned to the server, can re-create the database in the same state as it was at the time of the dump. PostgreSQL provides the utility programs `pg_dump and pg_dump_all` for taking individual and cluster level backup. These dumps are logical and do not contain enough information to be used by WAL replay.

An alternative backup strategy is to use **file system-level backup** where administrators can directly copy the files that PostgreSQL uses to store the data in the database. This method is done in offline mode where the database or cluster must be shut down. Another alternative is to use `pg_basebackup` and `pg_stop` to run hot streaming backup of the PostgreSQL database.

Snapshot Technology

NetApp has developed a full portfolio of technologies and tools to help organizations build or adapt their backup and recovery plans to respond to all business demands. With the NetApp Snapshot™ technology that is included in ONTAP software, you can create backups or execute restore operations of any size dataset in a matter of seconds. For PostgreSQL, must use Snapshot technology for data files, WAL files, and archived WAL files to provide full or point-in-time recovery.

For PostgreSQL databases, the average backup time with NetApp Snapshot copies is in the range of few seconds to a few minutes. This backup speed is 60 to 100 times faster than `PG_BASE_BACKUP` and other file system-based backup approaches.

Snapshot copy backups on NetApp storage can be both crash-consistent and application-consistent. A crash-consistent Snapshot copy is taken on storage without quiescing the database, whereas an application-consistent Snapshot copy is taken while the database is in backup mode. NetApp also ensures that subsequent Snapshot copies are incremental-forever backups to drive storage savings and network efficiency.

Because Snapshot copies are rapid and do not affect system performance, you can schedule multiple Snapshot copy backups daily instead of creating a single daily backup as with existing streaming backup technology. When a restore and recovery operation is necessary, the system downtime is reduced by two key features:

- NetApp SnapRestore® data recovery technology means that the restore operation is executed in seconds.
- Aggressive RPOs mean that fewer database logs must be applied and forward recovery is also accelerated.

For backing up PostgreSQL, you must ensure that the data volumes are copied simultaneously with (consistency-group) WAL and the archived logs. While you are using Snapshot technology to copy WAL files, make sure that you run `pg_stop` to flush all the WAL entries that must be archived. If you flush the WAL entries during the restore, then you only need to stop the database, unmount, or delete the existing data directory and perform storage SnapRestore. After the restore is done, you can mount and bring back the system to its current state. For point-in-time recovery, you can also restore WAL and archival logs, then PostgreSQL decides the most consistent point and recovers it automatically.

Storage Replication

Storage replication is suitable for low to medium recovery time objective (RTO) requirements. The Snapshot copies on primary storage can be replicated to secondary or tertiary storage, that is NetApp disaster recovery and backup destination (SnapMirror® and SnapVault®). This method works for a quick application-transparent failover and long-term retention of backups and clones.

NetApp SnapMirror® data replication software provides synchronous and asynchronous replication. The replication is configured on the storage **volume** level whereas NetApp MetroCluster™ high-availability and disaster recovery provides synchronous replication that works on the storage **system** level. MetroCluster integrates with SnapMirror® to support distance and SLA requirements for applications, and delivers zero data loss (RPO) and near-zero failover time (RTO under 120 seconds) for a distance up to 300 km.

NetApp SnapMirror offers you capabilities that are cost efficient compared to other traditional offerings. For example, if you want to protect thousands of PostgreSQL databases for a quick failover along with other workloads, SnapMirror technology is much more efficient and a superior alternative in terms of TCO compared to other individual application failover techniques.

NetApp's disaster recovery backup storage can be running either on-premises, in the cloud or in co-located data centers, enabling enterprises to easily move data anywhere in the data fabric with high transparency between copy infrastructures.

Data Protection Software

SnapCenter and SnapCreator integration in a PostgreSQL database combined with Snapshot and NetApp FlexClone® technologies, offers you benefits such as:

- Rapid backup and restore
- Space efficient clones
- The ability to build a speedy and effective disaster recovery system.
- A premium bundle that does not require separate licenses. Licenses are covered already as part of the NetApp SnapManager® suite license.

Note: You might prefer to choose NetApp's premium backup partners such as Veeam Software and Commvault under the following circumstances:

  - Managing workloads across a heterogenous environment
  - Storing backups to either cloud or tapes for long-term retention
  - Support for wide range of OS versions and types

4 PostgreSQL Database Best Practices

This section covers more best practices for using the PostgreSQL database.

4.1 Tablespace

- Two tablespaces are automatically created when the database cluster is initialized. The `pg_global` tablespace is used for shared system catalogs. The `pg_default` tablespace is the default tablespace of the template1 and template0 databases. If the partition or volume on which the cluster was initialized runs out of space and cannot be extended, a tablespace can be created on a different partition and used until the system can be reconfigured.
- An index which is heavily used can be placed on a fast, highly available disk, like a solid-state device. Also a table storing archived data which is rarely used or not performance critical could be stored on a less expensive, slower disk system like SAS or SATA drives.
- Tablespaces are a part of the database cluster and cannot be treated as an autonomous collection of data files. They depend on metadata contained in the main data directory, and therefore cannot be attached to a different database cluster or backed up individually. Similarly, if you lose a tablespace (through file deletion, disk failure, and so on), the database cluster might become unreadable or unable to start. Placing a tablespace on a temporary file system like a RAM disk risks the reliability of the entire cluster.
- After it is created, a tablespace can be used from any database provided the requesting user has sufficient privilege. PostgreSQL uses symbolic links to simplify the implementation of tablespaces. PostgreSQL adds a new row to the `pg_tablespace` table (a cluster-wide table) and assigns a new OID (object-id) to that row. Finally, the server uses the OID to create a symbolic link between

your cluster and the given directory. The directory `$PGDATA/pg_tblspc` contains symbolic links that point to each of the non-built-in tablespaces defined in the cluster.

- For better performance, NetApp recommends not to keep more than one tablespace per logical file system. Also, you cannot control the location of individual files within a logical file system. However, PostgreSQL does not enforce any such limitation, and it is not directly aware of the file system boundaries on your system. It just stores files in the directories you tell it to use.

4.2 File System Options

- NetApp recommends using V4 of the NFS protocol as it has an integrated locking feature that V3 was lacking. Also it has new features like statefulness, improved security, and strong authentication.
- Soft mounting of an NFS file system is not recommended by PostgreSQL.
- PostgreSQL also advises mounting the NFS file system synchronously to avoid a data inconsistency problem. See the PostgreSQL documentation for more details.
- Use following mount option while mounting NFS file system.

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

- NetApp recommends having four to eight LUNs to support data file I/O.
- NetApp LUN stores data in 4KB physical blocks. If we don't set up the same block size, I/O is not aligned with physical blocks correctly and might end up writing in two different disks in the RAID group. Writing to two disks results in latency and therefore NetApp recommends using 4KB block sizes to create the partition on discovered LUN.

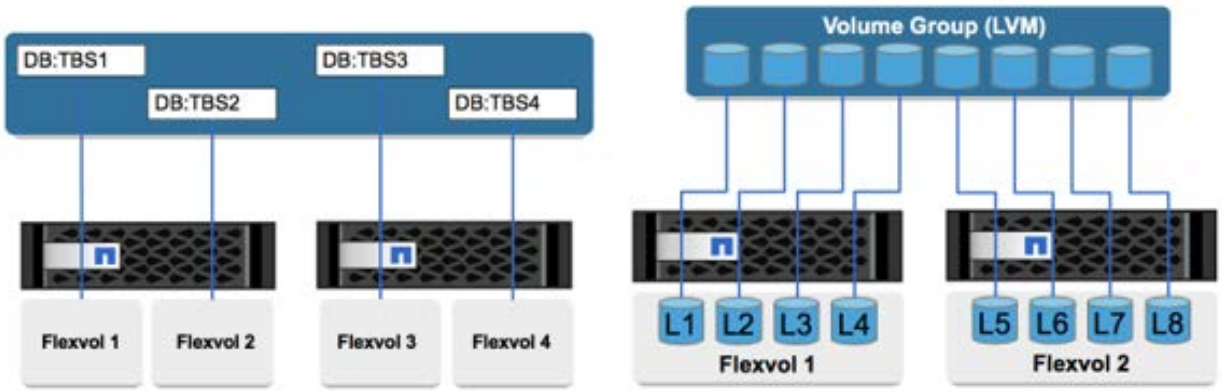
4.3 PostgreSQL Performance Best Practice

Designing an efficient and high performing database file system layout is important from both a performance and scalability perspective. Importantly, this is not dependent on the database size. In general, the perception is that huge size databases need high-performance disk architecture which is not true. Even if the database size is 50GB, you might be in need of a good disk architecture.

Following are some tips for designing the database layout:

- Ensure that the database has multiple tablespaces, with tables and indexes grouped based on the transaction rates.
- The tablespace must be placed across multiple disk file systems for balanced I/O. This balance is possible by using logical volume manager (LVM) or placing critical tables on different volumes or LUNs on the same or different aggregate. Placing tables in this way ensures that multiple CPUs come into play to perform transactions across multiple disks as described in Figure 6.

Figure 6) User-defined tablespaces stored on multiple disks (NFS, SAN).



- Consider placing the `pg_xlog` or `pg_wal` directory on a separate disk (volume or LUN) on a high-transaction database.

- If the application requires sub micro-second latency then choosing NetApp MAX Data and AFF A700, A800 with end-end NVMe technologies is recommended.
- Use I/O monitoring tools to understand the I/O statistics across all the disks and manage the database objects accordingly.

Database Configuration Best Practices

There are several PostgreSQL tuning configurations that can improve performance. The most commonly used parameters are as follows:

- `max_connections = <num>:` The maximum number of database connections to have at any one time. Use this -parameter to restrict swapping to disk and killing the performance. Depending on your application requirement, you can also tune this parameter for the connection pool settings.
- `shared_buffers = <num>:` The simplest method to improve the performance of your database server. The default is low for most modern hardware. It is set on deployment to approximately 25% of available RAM on the system. This parameter setting varies depending on how it works with particular database instances. Increase and decrease the values on a trial and error basis. However setting it high likely degrades performance.
- `effective_cache_size = <num>:` This value tells PostgreSQL's optimizer how much memory PostgreSQL has available for caching data and helps in determining whether to use an index or not. A larger value increases the likelihood of using an index. This should be set to the amount of memory allocated to `shared_buffers` plus the amount of OS cache available. Often this is more than 50% of the total system memory.
- `work_mem = <num>:` This parameter controls the amount of memory to be used in sort operations and hash tables. If you do heavy sorting in your application, you might need to increase the amount of memory, but you should be cautious. This isn't a system-wide parameter, but a per-operation one. If a complex query has several sort operations in it, it uses multiple `work_mem` units of memory and multiple back ends could be doing this simultaneously. This query can often lead your database server to swap if the value is too large. This option was previously called `sort_mem` in older versions of PostgreSQL.
- `max_fsm_pages = <num>:` This parameter helps to control the free-space map. When something is deleted from a table it isn't removed from the disk immediately, it is marked as "free" in the free space map. The space can then be reused for any new INSERTs that you do on the table. If your setup has a high rate of DELETEs and INSERTs, it might be necessary to increase this value to avoid table bloat.
- `fsync = <boolean>:` This parameter determines if all your WAL pages should be synched to disk using `fsync()` before a transaction is committed. Turning it off might improve write performance sometimes.
- `commit_delay = <num>` and `commit_siblings = <num>:` These options are used together to help improve performance by writing out multiple transactions that are committing at once. If there are several commit_siblings active at the instant your transaction is committing, then the server waits for `commit_delay` microseconds to try to commit multiple transactions at once.
- `random_page_cost = <num>:` This value controls the way PostgreSQL views nonsequential disk reads. A higher value means it is more likely to use a sequential scan instead of an index scan, indicating that your server has fast disks.
- `effective_io_concurrency= <num>:` This parameter sets the number of concurrent disk I/O operations that PostgreSQL expects can be executed simultaneously. Raising this value increases the number of I/O operations that any individual PostgreSQL session attempts to initiate in parallel. The allowed range is 1 to 1000, or zero to disable issuance of asynchronous I/O requests. Currently, this setting only affects bitmap heap scans. Solid-state drives (SSDs) and other memory-based storage (NVMe) can often process many concurrent requests, so the best value can be in hundreds.

See the PostgreSQL documentation for a complete list of PostgreSQL configuration parameters.

5 Best Practices Summary

The following tables summarizes the best practices and recommendation for deploying PostgreSQL on ONTAP data management software.

Best Practices
• In a multitenant PostgreSQL environment, each tenant's data (database or instance) can have a dedicated SVM on ONTAP storage. • Enabling LACP and IP load balancing is the most common approach during NFS LIF design. Otherwise, failover policies and groups should be configured in the regular method. • For a SAN multipathing environment, it is better to have a NetApp LUN host zoned from different switches to ensure high availability. • Any FC zone should never contain more than one initiator. Crosstalk between initiators eventually interferes with performance and stability. • During LUN or volume moves in a HA cluster, the LUN must be presented using the destination storage controllers before the mobility event is initiated. Modify the selective LUN map reporting-nodes list before moving. • In a mission critical environment, NetApp recommends keeping data files and WAL logs on dedicated volumes or LUNs for better performance. This applies to both the SAN and NFS layouts. • Isolation of data files and WAL logs in a dedicated volume also enables faster recovery of the database. • For better database performance, isolate the critical tablespaces on a dedicated volume or LUN. • Choosing datastores might improve the overall manageability and operational overhead. • Datastores might add extra layer of complexity by having another set of timeouts, parameters, log files, and potential bugs. • Choosing NFS over VMFS datastore helps when using the NetApp SnapRestore technology in a disaster scenario. • An index that is heavily used can be placed on a fast, highly available disk, such as an expensive solid-state device. Also, a table storing archived data that is rarely used or not performance critical could be stored on a less expensive, slower disk system. • Tablespaces are dependent on metadata contained in the main data directory, and therefore cannot be attached to a different database cluster or backed up individually. Similarly, if you lose a tablespace (through file deletion, disk failure, and so on), the database cluster might become unreadable or unable to start. Placing a tablespace on a temporary file system like a RAM disk risks the reliability of the entire cluster. • NetApp does not recommend making more than one tablespace per logical file system because you cannot control the location of individual files within a logical file system. • NetApp recommends using V4 of the NFS protocol as it has an integrated locking feature that V3 was lacking. Also, it has new features such as statefulness, improved security, and strong authentication. • Soft mounting of an NFS file system is not recommended by PostgreSQL. • PostgreSQL also advises mounting the NFS file system synchronously to avoid a data inconsistency problem. For more information, see the PostgreSQL documentation. • NetApp recommends having four to eight LUNs to support data file I/O. Fewer than four LUNs might create performance issues because of limitations in host SCSI/FC implementations. • Ensure that the database has multiple tablespaces, with tables and indexes grouped based on the transaction rates. • The tablespace must be placed across multiple disk file systems for balanced I/O. This balance ensures that multiple CPUs come into play to perform transactions across multiple disks.

Appendix A: Host Configuration

- Verify that FC host bus adapters (HBAs) in the ESX host are running with updated drivers, firmware, and the correct BIOS version.
- Install NetApp Host Utility kit on host to view direct and indirect paths for a given LUN. It also provides extended information about the LUN SVM information.
- Always use rescan SCSI bus script on host to:
  - Find new LUNs
  - Discard stale LUNs
  - Update new paths to LUN
- Install and configure multipathing software on the host operating system to establish multiple routes to the storage if there is path failure.
- If you are not using multipathing software, you should limit each LUN to a single path.
- Linux kernel allows low-level control over the scheduling of I/O to block devices. The defaults on Linux versions might vary considerably. NetApp customers and internal testing generally show better results with NoOps scheduler for databases. You should perform benchmarking to determine which I/O schedulers are optimal for your use case.

SELinux

Security-Enhanced Linux (SELinux) is a Linux Kernel security model that provides a mechanism for supporting access control security policies.

The `/etc/selinux/config` configuration file controls whether SELinux is enabled or disabled, and if enabled, whether SELinux operates in permissive mode or enforcing mode. 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 accesses that would be denied by policy are permitted but audited.
- The enforcing option enables the SELinux code and causes it to enforce access denials and audit them.

Most deployments observed errors while mounting an NFS file system on a Linux host or while starting the PostgreSQL daemon. Some common errors include:

```
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
```

These errors can be resolved by correcting the SELinux configuration files and verifying that the export options on ONTAP are correct. See the NetApp Knowledgebase for further troubleshooting steps here.

There are additional documents to help you learn more about FC configuration. All of the following documentation is available:

- SAN configuration
  Describes supported FC, iSCSI, and FCoE topologies for connecting host computers to storage controllers in clusters.
- SAN administration
  Describes how to configure and manage the iSCSI, FCoE, and FC protocols for clustered SAN environments, including configuration of LUNs, igroups, and targets.

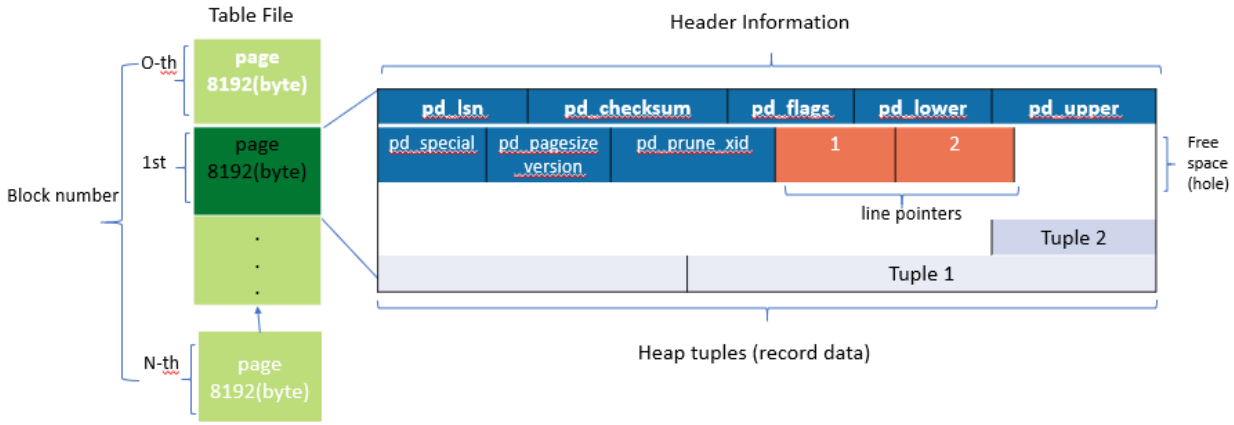
Appendix B: PostgreSQL Page and File System Layout

Every table and index is stored as an array of pages of a fixed size (usually 8kB), although a different page size can be selected by changing the configuration. Each page contains a header that stores

metadata about the block. The header provides details about checksum, start of free space and end of free space. The items after the header is an array identifier composed of (offset, length) pairs pointing to the actual items.

The structure used to store the table is a heap file. Heap files are lists of unordered records of variable size. The heap file is structured as a collection of pages (or block), each containing a collection of items. Figure 7 takes a closer look at how PostgreSQL stores data across rows and also within each page or block of a table.

Figure 7) Data storage in PostgreSQL



Toast

TOAST stands for The Oversized-Attribute Storage Technique. PostgreSQL uses a fixed page size (commonly 8kB) and does not allow tuples to span multiple pages. Therefore, it is not possible to store large field values directly. When you attempt to store a row that exceeds this size, TOAST breaks up the data of large columns into smaller "pieces" and stores them in a TOAST table.

The large values of toasted attributes are only pulled out (if selected at all) at the time the result set is sent to the client. The table itself is much smaller and can fit more rows into the shared buffer cache than it could without any out-of-line storage (TOAST).

Vacuum

In normal PostgreSQL operation, tuples that are deleted or obsoleted by an update are not physically removed from their table, they remain present until a VACUUM is done. Therefore you must do VACUUM periodically, especially on frequently updated tables.

The space it occupies must then be reclaimed for reuse by new rows, to avoid disk space outage. However, it does not return the space to the operating system.

The free space inside a page is not fragmented. VACUUM rewrites the entire block, efficiently packing the remaining rows and leaving a single contiguous block of free space in a page.

In contrast, VACUUM FULL actively compacts tables by writing a completely new version of the table file with no dead space. This minimizes the size of the table but can take a long time. It also requires extra disk space for the new copy of the table, until the operation completes. The goal of routine VACUUM is to avoid VACUUM FULL activity. This process not only keeps tables at their minimum size, but also maintains steady-state usage of disk space.

PostgreSQL File System Layout

New database cluster is created by using the initdb program. Initdb script creates the data files, system tables, and template databases (template0 and template1) that define the cluster. The template database represents a stock database. It contains definitions for system tables, standard

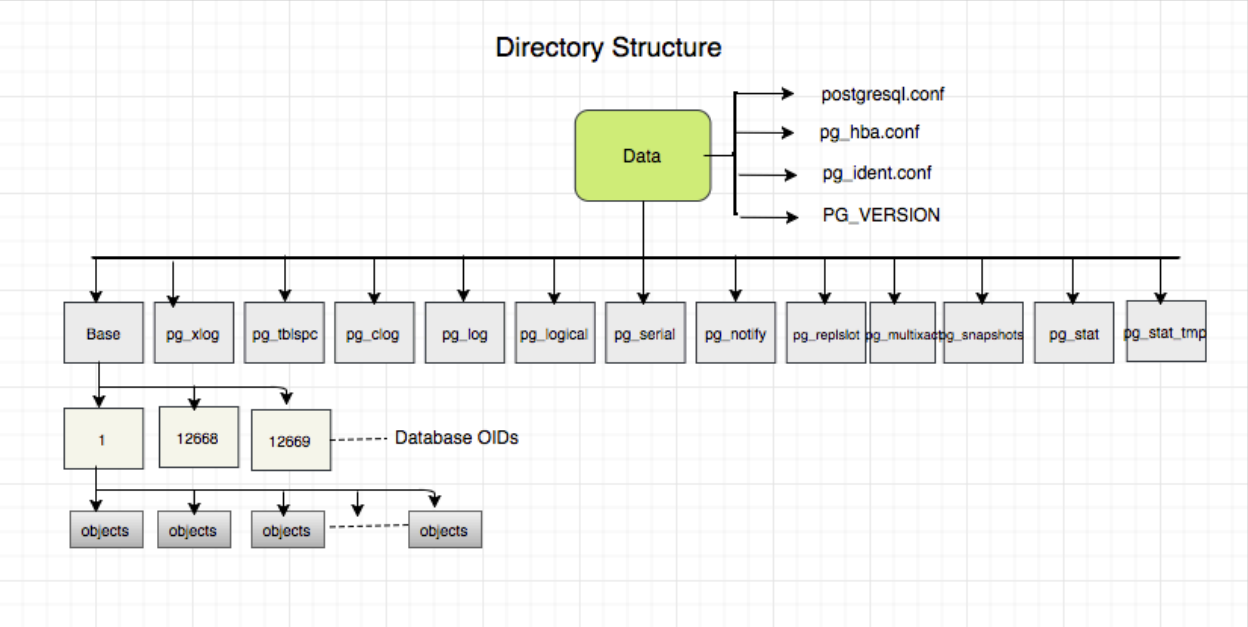
views, function, and data types. Pgdata acts as an argument to initdb script that specifies the location of the database cluster.

All the database objects in PostgreSQL are internally managed by respective object identifiers (OIDs). Tables and indexes are also managed by individual OID. The relationship between database objects and their respective OIDs is stored in appropriate system catalog tables, depending on the type of object. For example, OIDs of databases and heap tables are stored in pg_database and pg_class respectively. You can find out the OIDs you want to know by issuing the queries on PostgreSQL client.

Every database has its own individual tables and index files that are restricted to 1GB in size. Each table has two associated files, suffixed respectively with '_fsm' and '_vm'. They are referred to as free space map and visibility map. These files store the information about free space capacity and have visibility on each page within the table file. Indexes only have individual free space maps and don't have a visibility map.

The `pg_xlog/ pg_wal` directory contains the write-ahead logs. Write-ahead logs are used to improve database reliability and performance. Whenever you update a row within a table, PostgreSQL first writes the change to the write-ahead log, and later writes the modifications to the actual data pages to a disk. The `pg_xlog` directory usually contains several files, but initdb only creates the first one. Extra files are added as needed. Each xlog file is 16MB long.

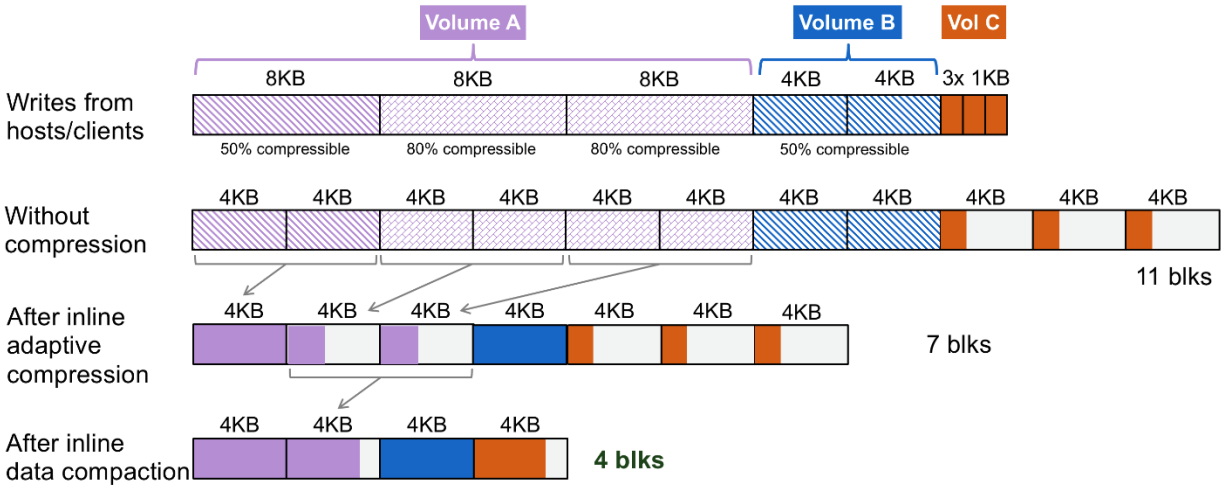
Figure 8) Directory structure.



Appendix C: Storage Efficiency

Figure 9 shows how compression and compaction works for databases on ONTAP storage.

Figure 9) Compression and compaction.



Where to Find Additional Information

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

- NetApp Documentation Centers
  https://www.netapp.com/us/documentation/index.aspx

Version History

Version	Date	Document Version History
Version 1.0	May 2019	Initial release.

Refer to the Interoperability Matrix Tool (IMT) on the NetApp Support site to validate that the exact product and feature versions described in this document are supported for your specific environment. The NetApp IMT defines the product components and versions that can be used to construct configurations that are supported by NetApp. Specific results depend on each customer's installation in accordance with published specifications.

Copyright Information

Trademark Information

