DataStax Enterprise Reference Architecture

White Paper

BY DATASTAX CORPORATION

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Abstract

This white paper outlines reference architectures for deploying Apache Cassandra™ and DataStax Enterprise (DSE) within an organization and establishes a starting point for users contemplating hardware choices to host DataStax solutions. This paper also provides guidance for system architects and system administrators during the planning stages of development, test and production environments, whether in-house or at a private or public data center. It explores common scenarios and configuration options for various deployments.

Introduction

Requirements of modern applications are progressing rapidly as businesses generate exponentially more data each year where end-users demand instant access independent of location. In addition, it is becoming increasingly important to search and gain insights from application data such as user recommendations and website traffic. As a result, decision makers face tremendous pressure to choose the right set of database tools and configuration to deliver these requirements in a cost efficient manner. DataStax Enterprise (DSE) addresses requirements of modern, online applications with its tightly integrated big data platform built on Apache Cassandra™ with enterprise search, analytics and in-memory capabilities.

Apache Cassandra is an open-source, NoSQL platform designed from the ground up to handle concurrent requests with fast writes and provide a low latency response for widely distributedusers. DataStax Enterprise built on Cassandra provides integrated batch analytics so that users can leverage Hadoop tools such as Hive, Pig and Mahout to carry out the analysis on Cassandra data. In addition, DSE's integrated search (built on Solr) delivers features such as full-text search, faceting, hit highlighting, and more.

Choosing the right database technology for an application is imperative for the success and scale of an online application. Planning for hardware and accompanying software ensure that the system remains robust when scaled. This whitepaper provides tips to configure and deploy a DataStax system. Remember, use cases play an important role in determining specific information system requirements, application access patterns and mix of workloads that will be present in the end result.

DataStax Enterprise Architecture

Built on a production-certified version of Apache Cassandra, DataStax Enterprise (DSE) encapsulates a distributed peer-to-peer architecture in which all nodes are equal ensuring cluster resilience to an arbitrary number of node or data center failures. DSE transparently distributes data across the cluster permitting cluster performance to scale linearly with the number of nodes, at a petabyte scale. Data is stored in a keyspace, a container similar to a schema in a relational database (Figure 1). Keyspaces are used to group column families together. Data is uniquely identified by a primary key that determines on which node in the cluster the data is stored.

Cassandra stores copies, called replicas, of each row based on the row key. The number of replicas is defined when a keyspace is created using replica placement strategy. This strategy sets the distribution of the replicas across the nodes in the cluster depending on the cluster's topology.

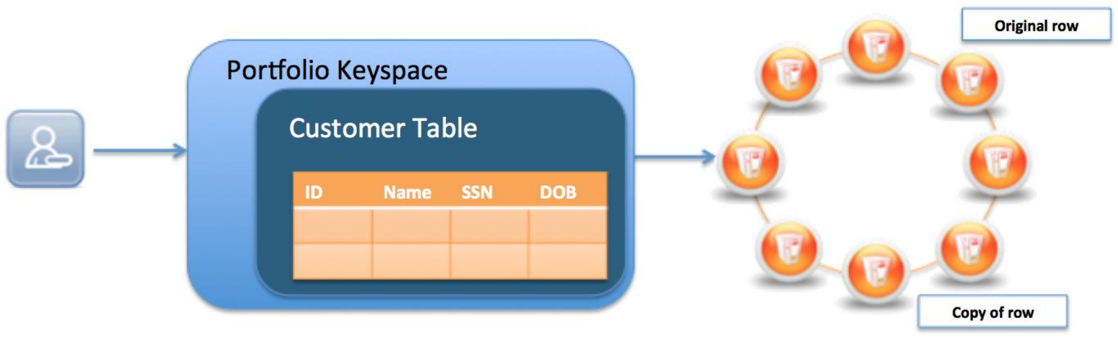


Figure 1 - Keyspace & Cassandra Ring

An insert operation is first written to the commit log for durability and then to a memtable as shown in Figure 2 below. It is later flushed to an SStable once the memtable is full.

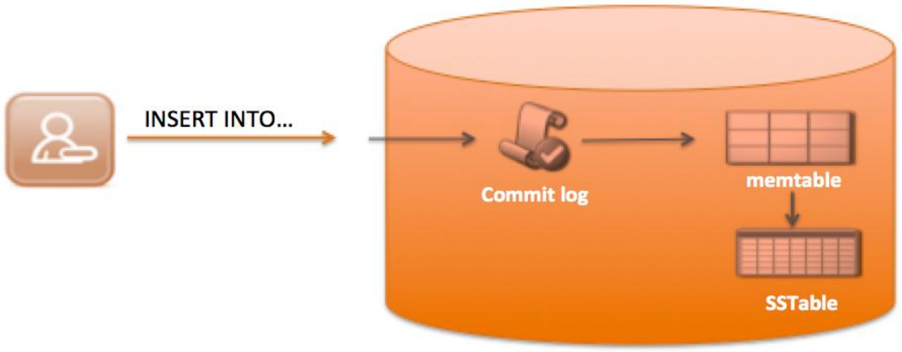


Figure 2 - Writes in Cassandra

Each node can be assigned a combination of dedicated functions from real-time, analytics, and search processing as shown in Figure 3 below. Data is distributed and replicated across the real-time / online and analytic groups. Solr nodes also utilize Cassandra for storage, with data inserted on Cassandra nodes being automatically replicated, indexed and made available for search operations on Solr nodes.

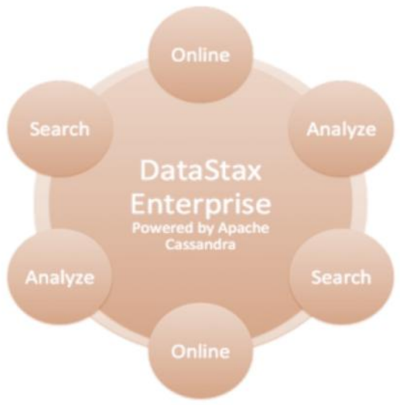


Figure 3 – DataStax Enterprise Cluster

Management Interface

DataStax OpsCenter is a management and monitoring tool that administers Cassandra and DSE clusters. Each node in a DSE cluster has a DataStax agent installed by default, which OpsCenter uses to manage and monitor the cluster. System and database activities are monitored through a web-based, visual interface.

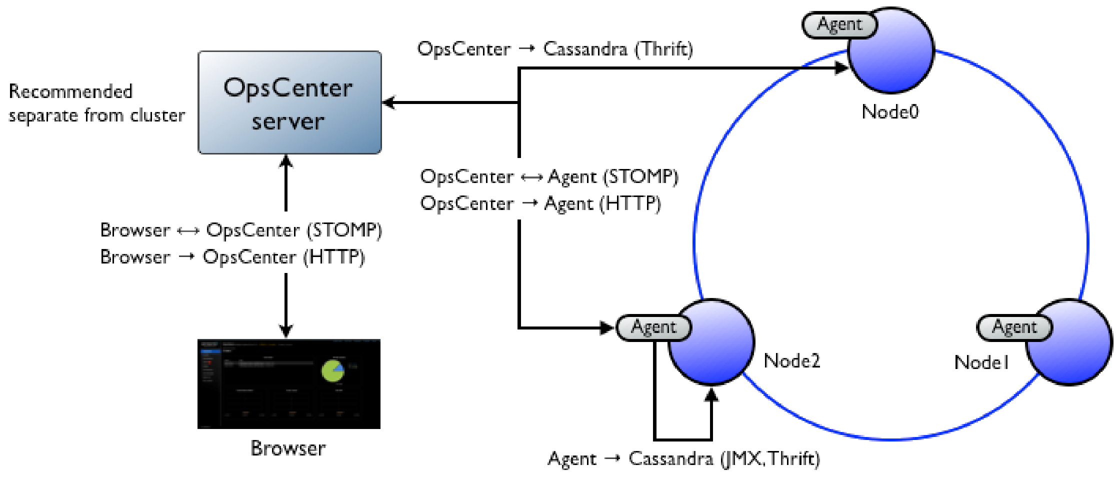

Recommended separate from cluster
OpsCenter server
OpsCenter → Cassandra (Thrift)
Agent
Node0
OpsCenter ↔ Agent (STOMP)
OpsCenter → Agent (HTTP)
Browser ↔ OpsCenter (STOMP)
Browser → OpsCenter (HTTP)
Agent
Node2
Agent
Node1
Browser
Agent → Cassandra (JMX, Thrift)

Figure 4 – OpsCenter Architecture

Capacity Planning

Storage, memory and CPU are key during the initial capacity-planning phase. Monitoring storage and memory usage on existing nodes and adding more capacity when needed can easily be done in a number of ways. Per-node data and memory usage is monitored visually with DataStax OpsCenter or via the command line with Cassandra's nodetool utility. Alerts notify administrators to take action when a predetermined threshold is met.

DSE's Capacity Service is an automated service using trend analysis to help monitor cluster performance within a cluster's current environment and workload. It uses historical data to determine future resource needs of a cluster. For example, using DSE's Capacity Service, users can forecast upcoming disk usage based on the prior three months of usage.

Storage

Estimating transaction arrival rates and retained data volume are key factors for computing data storage. SSD versus magnetic hard disk is a key lever for performance, and highly impactful. Selecting the type of storage medium is also important: SSD and magnetic hard disks have very different performance characteristics, and should be considered carefully based on your workload. The key point to acknowledge is the elimination of seek time and the penalty associated with non-contiguous data on physical media. While Cassandra mitigates these issues by writing sequentially only, SSD drives can scale up to cope with larger compaction overheads and simultaneously serve many random reads.

Free Disk Space Planning for Compaction

Operational storage requires the disk space remain available for Cassandra's compaction. Compaction improves data locality and flushes stale data from the system. The default compaction strategy is "size-tiered" (STCS), which may temporarily require up to double the size of the table it is compacting. Since multiple tables may be compacted simultaneously, it is prudent to keep free space in excess of your live data volume to ensure optimal performance.

Leveled Compaction Strategy (LCS) dramatically reduces the temporary disk space usage requirement, while providing tighter bounds on the latency of read operations. The tradeoff is that LCS generally produces twice as many I/O operations over time. LCS is generally not recommended for write-heavy workloads and it is possible to forecast compaction I/O impact in 2.x Cassandra releases if you have a running cluster to use as a basis for estimation. Please contact DataStax Technical Support to discuss your LCS-based use case and determine the best free disk space headroom estimate.

Hadoop workloads often create large volumes of intermediate results stored in the Cassandra File System (CFS). If you plan to use Analytics/Hadoop nodes, you will want to review the CFS Compaction strategy and compare with your analytics workloads.   On a per-table basis, free disk space headroom for the CFS use case is no worse in magnitude than the LCS use case.

Free Disk Space Planning for Snapshots

Cassandra backs up data by taking a snapshot of all on-disk data files (SSTables files) stored in the data directory. Users can take a snapshot of all keyspaces, a single keyspace, or a single table while the system is online. Snapshots can be taken automatically depending on your configuration and can be actively managed. (Refer to auto_snapshot and snapshot_before_compaction settings in cassandra.yaml.) Administrators need to factor in sufficient storage capacity for the length and frequency of retention required.

Secondary Indexes and Solr Index Overhead

Though highly dependent on schema design, secondary indexes on Cassandra tables require disk space proportional to the columns indexed. In the worst case, if each column had a secondary index, one might need double the normal disk space.

For Search/Solr nodes, indexed content is stored in Cassandra column families, so roughly twice the disk space is needed for storing the content alone. This is due to the space needed for a Lucene keyword index on each node. DataStax Customer Operations or Technical Support helps customers arrive at reasonable per-node data storage targets for their particular use case.

CPU

Insert-heavy workloads are CPU-bound in Cassandra before becoming memory-bound. This means that all writes go to the commit log. The processing power of the CPU determines limitations. Cassandra is highly concurrent and uses as many CPU cores as available. Hence, if your application uses search/Solr nodes, increased CPU consumption comes at indexing time, where an index backlog is constructed from unique keys of data stored in Cassandra. One or more CPU cores will be fully utilized when the indexing service works off the backlog. The indexing is a multi-threaded operation and can be configured in terms of the maximum number of allowed index operation in queue.

Memory

It is important to ensure that sufficient RAM is available on a per-node basis. RAM is used by Java Virtual Machine (VM), filesystem buffer cache, operating system and by Cassandra. Some of the big data structures to be aware of include the bloom filter, row cache, key cache, compression metadata and memtable. The operating system, Java VM and DSE all have fixed overhead. For memory capacity planning purposes, 4 GB should be allocated as fixed overhead. A general guideline is to allow plenty of memory for the filesystem buffer cache. Another rule of thumb is to devote half the server memory to the Java VM used by Cassandra, with a cap of 8 GB.

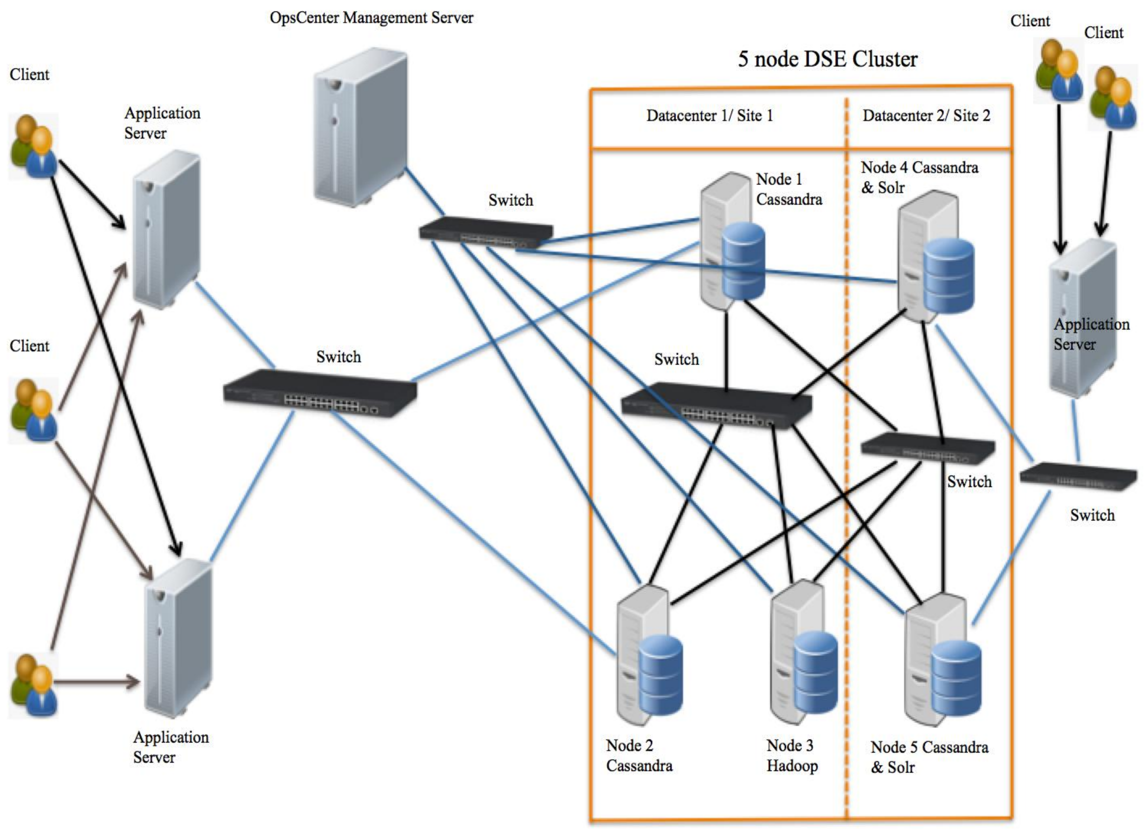
The bloom filter size is directly proportional to the number of unique row keys in the Cassandra database. For any given node and table, the local hash-table-based bloom filter is checked for the possible existence of a row given its row key value. If present in the bloom filter, the index cache and/or file are read and finally the row is read from the SSTable on disk. Bloom filter, index and row cache sizes are tunable.
When considering the transient memory needed for a given mix of workloads, it will be best to engage with DataStax Customer Operations or Technical Support to formulate the best advice for a particular situation. The following guidelines are generalizations and meant as qualitative advice:

- 32 GB or more are practical server memory capacities for Cassandra use cases
- 32 GB to 64 GB are appropriate server memory capacities for many search use cases
- 32 GB, 64 GB and 128 GB are appropriate memory capacities for light, moderate and heavy analytics use cases, respectively
- Depending on the number of map and reduce workers configured per node, 8 GB to 32 GB can be needed for analytics
- To keep Java VM "garbage collection runs" to a manageable time frame (under a quarter of a second), it is advantageous to target an 8 GB or smaller heap.
- With reference to configuring DataStax OpsCenter, having dedicated hardware for the core service is recommended with 2 cores and 2 GB of RAM

DSE Reference Architecture

This portion of the document will guide you through common architecture deployments either as dedicated hardware systems or in the cloud.

Physical Architecture (On-premise deployment)



More nodes (Node 6, Node 7…Node N) can be added to the architecture for additional capacity and throughput. These nodes can span different racks across different data centers. Data centers can either be in the same physical location (for failover/upgrades etc.) or can span different physical locations.
Cassandra & Solr (node 4 & node 5) are running in the same JVM.

Dedicated Components

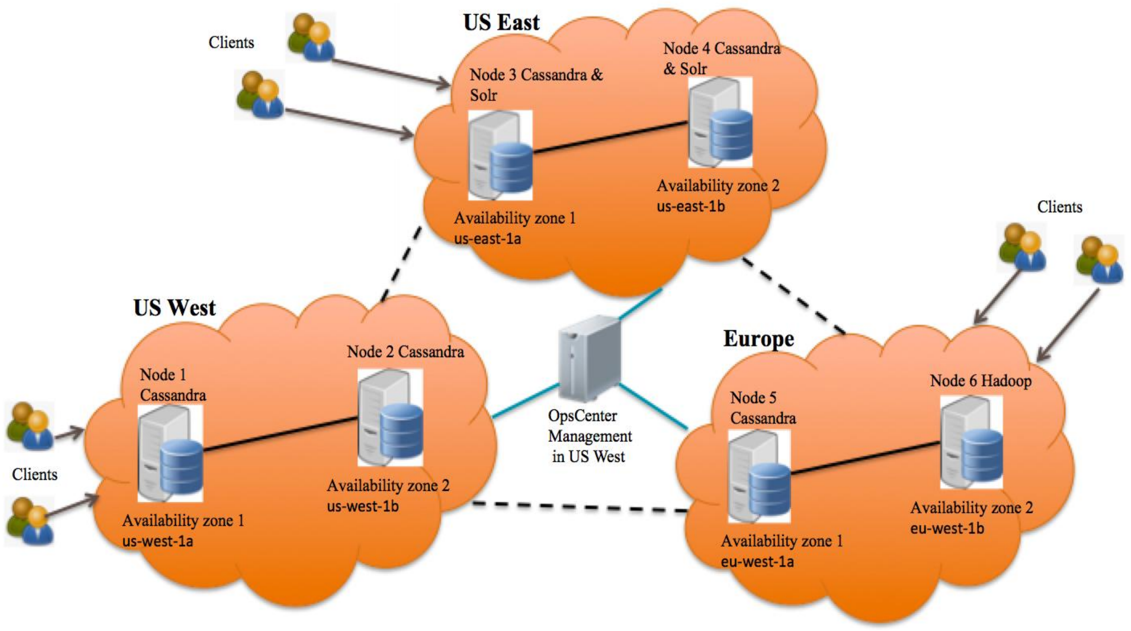
Hardware Components
Intel Xeon or AMD processor based (64 bit)
1 GbE or 10 GbE switch
SATA3 or SAS or SSD for storage

SATA3 or SAS for commit log

Software Components
Cassandra 2.x, DataStax Enterprise 3.2 or beyond
OpsCenter 4.0 or beyond
CentOS/Debian/Ubuntu/Red Hat/Suse/Oracle Linux

Platforms support
http://www.datastax.com/what-we-offer/products-services/datastax-enterprise/platforms

Physical Architecture (Cloud Deployment)



Cloud Components

Hardware Components
m1.XLarge instance or more
1 GbE or 10 GbE switch
Regular or SSD for storage

Software Components
Cassandra 2.x or DataStax Enterprise 3.2 or beyond
OpsCenter 4.0 or beyond
CentOS/Rad Hat/Debian/Ubuntu

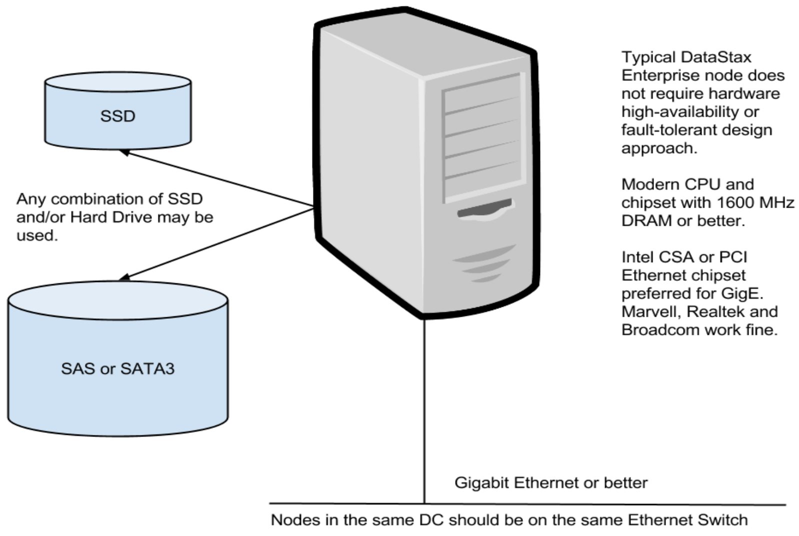
Deployment Scenarios

Low End Specification (Cassandra only)

Server	Intel Xeon or AMD modern processor (64 bit) 4 cores or more
RAM	**16 GB to 32 GB of ECC DRAM per node
Storage	SATA III hard disks or SAS drives
Network	Gigabit Ethernet
Data Size	30 GB to 500 GB per node on SATA III Up to 1 TB per node on SAS

** Some users report good results with 16GB, but DataStax recommends 32GB as minimum RAM support for production workload.

A typical cluster running Cassandra may have four or more nodes, with a replication factor of 3 (RF=3). The replicated data often spans two physically separated data centers.
Given the low-specification hardware mentioned above, when file systems are striped across additional SATA III hard drives, architects will need to manage a data size of 500 GB (including the extra copies due to replication factor) per node.


SSD
Any combination of SSD and/or Hard Drive may be used.
SAS or SATA3
Typical DataStax Enterprise node does not require hardware high-availability or fault-tolerant design approach.
Modern CPU and chipset with 1600 MHz DRAM or better.
Intel CSA or PCI Ethernet chipset preferred for GigE. Marvell, Realtek and Broadcom work fine.
Gigabit Ethernet or better
Nodes in the same DC should be on the same Ethernet Switch

Up to 1 TB per node is achievable with SAS drives because SAS drives are lower capacity and more spindles will likely be used relative to SATA. SAS drives typically perform better with lower latency and higher throughput than SATA counterparts. Three-way striping is recommended if volume management is utilized.

Rotating magnetic hard drives should be striped three ways or more. DSE supports distributing I/O across multiple data directories when volume management is not utilized.
Please note that RAID 1 or RAID 1+0 can be used if RF=1. If RF=3 or higher, the system administrator can generally rely on database-level replication for data durability.
Solid State Disk (SSD) may be striped two ways, however, separate PCI-e controllers must be used for each SSD. SSD's typically outperform their mechanical counterparts but are used more in performance-oriented, higher-specification examples as mentioned below.

High End Specification (Cassandra only)

Server	Intel Xeon or AMD modern processors (64 bit) 8 cores or more
RAM	128 GB or 256 GB ECC DRAM per node
Storage	SATA III hard disks or SAS drives or SSDs
Network	10-Gigabit Ethernet
Data Size	300 GB to 1 TB or more per node Up to 5 TB per node using SSD exclusively, for key-based access pattern

Demanding applications are frequently focused on minimal latency for end-user requests, or maximum throughput for batch processing. Both approaches typically result in the selection of high end, state-of-the-art equipment.

DataStax recommends using Solid State Disk (SSD). 400 MB/sec or better can be expected for a modern SSD drive. Additionally, DataStax recommends striping across more than one SATA controller for the most demanding applications. Use of a multi-lane SATA controller (PCIe 2.0 x4 or better) may be worth the premium to ensure maximum disk throughput, especially with multiple SSDs. Solid State Disk (SSD) may be striped two ways, but separate PCI-e SATA controllers must be used for each SSD.

Transactional volume per cluster depends on the use case (like average record or row size). Users must estimate and calculate the number records and size of each record to come to a conclusion on transaction rate.

Cloud Specification (Cassandra only)

This section covers the basics of sizing in cloud deployments. A cloud specification assumes low performance hardware on a per-server or per blade basis. Examples below are for Public Clouds - r Amazon AWS EC2 and Google Cloud Compute Engine (GCE).

Amazon AWS EC2

Data per node	Instance Type	Memory	Disk	Network Performance
< 100 GB	m1.xlarge	15 GB	Ephemeral	High
< 100 GB	c3.2xlarge	15 GB	SSD	High
< 1 TB	i2.2xlarge	60 GB	SSD	High

Google Cloud Compute Engine

Data per node	Instance Type	Memory	Disk
< 200 GB	n1-standard-8	30 GB	2 TB persistent disk
< 1 TB	n1-highmem-16	104 GB	4 TB persistent disk

Private Cloud Hardware

Data per node	CPU/Chipset	Memory	Disk	Network
< 500 GB	4 physical core, single socket motherboard	32 GB	SSD	GigE e.g. 1000base-T

< 1 TB	2 socket motherboard, Ivy Bridge 4 physical core	64 GB	SSD	GigE e.g. 1000base T or GBIC
< 5 TB	4 socket, Sandy Bridge, 6 physical core	128 GB	Multi-controller, SSD	10GbE e.g. 10GBase-x, SFP+

Workload-Specific Examples (DSE)

DataStax Enterprise addresses different needs depending upon the application requirement and its usage for DSE-Cassandra, DSE-Search and DSE-Analytics.

	DSE/Cassandra
Workload	**Writes/second:** From thousands per node to millions per cluster, depending on row size, block I/O subsystem performance and CPU integer performance. **Queries:** Sub-second to sub-millisecond response times **Data sizing:** Hundreds of TB, up to PB range
Use Case	High transaction-rate, write-mostly or balanced read and write transaction workloads characterize real-time use cases. This is the typical web application object persistence mechanism for many modern and larger-scale web apps. For example, Netflix streaming media metadata, including users, accounts, genres, preferences, sessions, bookmarks—but not movie content—are managed in DSE/Cassandra, supporting terabytes of streaming media (30% of the internet on Friday nights), at write speeds exceeding 15M writes/second. Reference customers - http://www.datastax.com/customers.
Simple scale-out patterns	Cassandra was originally optimized for x86 commodity servers. The storage engine leverages log structured merge trees, which result in purely sequential writes to maximize performance, and inter-node operations enable fast interactions across commodity networks. Leverage these basic building blocks to grow/shrink deployments in stepwise manner for both on-premise & cloud deployments. **Scaling**: Auto-scale based on transaction arrival rates first, then the data storage volume as you learn the data access patterns and how they depend on data volume.
High-density patterns	Cassandra customers looking to achieve operational efficiency, minimize energy usage and floor space, typically deploy non-redundant hardware and utilize high-capacity SSD exclusively.

	DSE/Search (with Solr)
Workload	**Documents**: Hundreds to billions **Queries**: Sub-second on down to sub-millisecond response times **Data sizing:** Tens of TB
Use Case	Current Solr use cases can be broadly characterized as either write-heavy or read-heavy. For example, a major U.S. retailer supports a universal product catalog (every SKU, every currency, every language, with 40% change per day). All searches on their website now traverse DSE/Solr.
Simple scale-out patterns	DSE/Solr exerts high CPU demands and memory (heap and OS buffers) due to ingest/indexing and for complex queries. The benefit of smaller nodes is that Solr auto-scales/auto-shards as the DSE cluster grows/shrinks. Avoid vnodes (num_tokens > 1) on any DSE/Search nodes.
Storage-density patterns	100 GB per node or more is a good target for nominal hardware running DSE Search. An equal amount of room must be dedicated to the Solr/Lucene search index as well as to data in Cassandra.

	DSE/Analytics (with Hadoop)
Workload	**Batch-based job processing:** Hours of elapsed time to compute analytics **Data sizing:** Tens of TB
Use Case	Analytics workload requirements vary by data model and by the question asked. Summary rollups, statistical measures or multivariate regression (trend determination) are familiar patterns with a predictable workload characteristic - a full scan of all data is needed and elapsed time should be proportional to the number of rows in the dataset. Any automatable task can be realized in Java, compiled and submitted as a Hadoop job, which then iterates over a dataset. Constant Contact, for example, uses DSE/Analytics to refine a customer's email campaign through a broad array of batch analytics.
Simple scale-out patterns	DSE/Analytics uses the Cassandra File System (CFS) as a foundation for Hadoop support and Hadoop is provided to run batch analytics on Cassandra data. This capability should ideally not be used as a general Hadoop data warehouse with cold storage. CFS is an alternative to HDFS and not a replacement. DataStax performance is a function of the algorithm executed and typically characterized by high memory demands. Typical Java-based Hadoop jobs are implemented in Java and run in a separate Java VM alongside the DSE/Cassandra VM. High CPU demands may also be present depending on the nature of the Map/Reduce algorithm.
High-density patterns	Large DSE customers run analytics on massive scale typically have a purpose-built Hadoop clusters running alongside with DSE. DSE interoperates well with Hadoop and other batch analytics frameworks through integrations such as Hadoop connectors (Hive and Pig), ODBC/JDBC drivers, and bulk output format data integration and ETL tools.

Conclusion

This reference architecture paper delivers a foundation for choosing hardware components and educates users on the right deployment strategy for specific use cases. DataStax recommends engaging with our technical experts for support and guidance on specific scenarios.

About DataStax

DataStax provides a massively scalable enterprise NoSQL platform to run mission-critical business applications for some of the world's most innovative and data-intensive enterprises. Powered by the open source Apache Cassandra™ database, DataStax delivers a fully distributed, continuously available platform that is faster to deploy and less expensive to maintain than other database platforms.

DataStax has more than 400 customers in 38 countries including leaders such as Netflix, Rackspace, Pearson Education, and Constant Contact, and spans verticals including web, financial services, telecommunications, logistics, and government. Based in San Mateo, Calif., DataStax is backed by industry-leading investors including Lightspeed Venture Partners, Meritech Capital, and Crosslink Capital.

For more information, visit www.datastax.com.