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Apache Cassandra

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INTRODUCTION

Apache Cassandra is a high-performance, extremely scalable, fault-tolerant (i.e., no single point of failure), distributed non-relational database solution. Cassandra provides benefits similar to Google Bigtable and Amazon Dynamo to handle the types of database management needs that traditional RDBMS vendors cannot support.

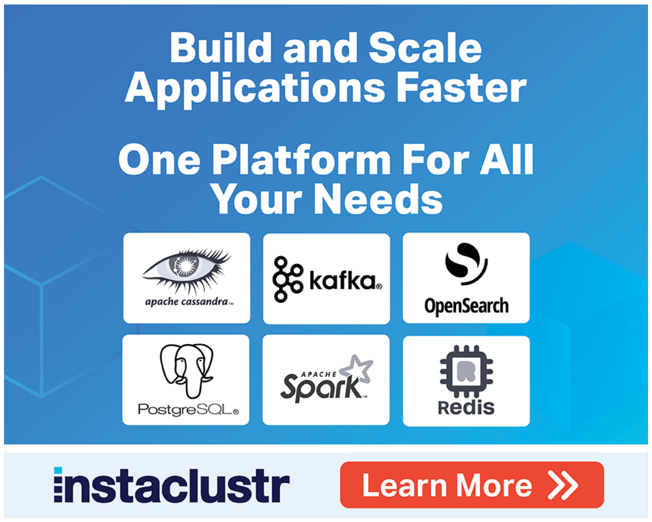
WHO IS USING CASSANDRA?

Cassandra is in use at Apple (75,000+ nodes), Spotify (3,000+ nodes), eBay, Capital One, Macy's, Bank of America, Netflix, Twitter, Urban Airship, Constant Contact, Reddit, Cisco, OpenX, Rackspace, Ooyala, and more companies that have large active data sets. The largest known Cassandra cluster has more than 300 TB of data across more than 400 machines (cassandra.apache.org).

RDBMS VS. CASSANDRA

	CASSANDRA	RDBMS
Atomicity	Success or failure for inserts/deletes in a single partition (one or more rows in a single partition).	Enforced at every scope, at the cost of performance and scalability.
Sharding	Native share-nothing architecture, inherently partitioned by a configurable strategy.	Often forced when scaling, partitioned by key or function.
Consistency	No tunable consistency in the ACID sense. Can be tuned to provide more consistency or to provide more availability. The consistency is configured per request. Since Cassandra is a distributed database, traditional locking and transactions are not possible.	Favors consistency over availability tunable via isolation levels.

(Table continues on Page 3)



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Durability	Writes are durable to a replica node being recorded in memory and the commit log before acknowledged. In the event of a crash, the commit log replays on restart to recover any lost writes before data is flushed to a disk.	Typically, data is written to a single master node, sometimes configured with synchronous replication at the cost of performance and cumbersome data restoration.
Multi-Datacenter Replication	Native and out-of-the-box capabilities for data replication over lower bandwidth, higher latency, and less reliable connections.	Typically, only limited long-distance replication to read-only followers receiving asynchronous updates.
Security	Coarse-grained and primitive, but authorization, authentication, roles, and data encryption are provided out of the box.	Fine-grained access control to objects.

DATA MODEL OVERVIEW

Cassandra has a tabular schema comprising keyspaces, tables, partitions, rows, and columns.

	DEFINITION	RDBMS ANALOGY	OBJECT EQUIVALENT
Schema/ Keyspace	A collection of tables	Schema/ Database	`Set`
Table/ Column Family	A set of partitions	Table	`Map`
Partition	A set of rows that share the same partition key	N/A	N/A
Row	An ordered (inside of a partition) set of columns	Row	`OrderedMap`
Column	A key-value pair and timestamp	Column (Name, Value)	(Key, Value, `Timestamp`)

SCHEMA

The keyspace is akin to a database or schema in RDBMS, contains a set of tables, and is used for replication. A keyspace and table is the unit for Cassandra's access control mechanism. When enabled, users must authenticate to access and manipulate data in a schema or table.

TABLE

A table, previously known as a column family, is a map of rows. Similar to RDBMS, a table is defined by a primary key. The primary key consists of a partition key and clustering columns. The partition key defines data locality in the cluster, and the data with the same partition key will be stored together on a single node. The clustering columns define how the data will be ordered on the disk within a partition. The client application provides rows that conform to the schema. Each row has the same fixed subset of columns.

As values for these properties, Cassandra provides the following CQL data types for columns (see the Apache Cassandra documentation):

TYPE	PURPOSE	STORAGE
`ascii`	Efficient storage for simple ASCII strings	Arbitrary number of ASCII bytes (i.e., values are 0-127)
`boolean`	True or false	Single byte
`blob`	Arbitrary byte content	Arbitrary number of bytes
`counter`	Used for counters, which are cluster-wide incrementing values	8 bytes
`timestamp`	Stores time in milliseconds	8 bytes
`time`	Value is encoded as a 64-bit signed integer representing the number of nanoseconds since midnight. Values can be represented as strings, such as 13:30:54.234.	64-bit signed integer
`date`	Value is a date with no corresponding time value; Cassandra encodes date as a 32-bit integer representing days since epoch (January 1, 1970). Dates can be represented in queries and inserts as a string, such as 2015-05-03 (yyyy-mm-dd).	32-bit integers
`decimal`	Stores `BigDecimals`	4 bytes to store the scale, plus an arbitrary number of bytes to store the value
`double`	Stores `Doubles`	8 bytes
`float`	Stores `Floats`	4 bytes
`tinyint`	Stores 1-byte integer	1 byte
`smallint`	Stores 2-byte integer	2 bytes
`int`	Stores 4-byte integer	4 bytes
`varint`	Stores variable precision integer	An arbitrary number of bytes used to store the value
`bigint`	Stores `Longs`	8 bytes

(Table continues on Next Page)

`text, varchar`	Stores text as UTF-8	UTF-8
`timeuuid`	Version 1 UUID only	16 bytes
`uuid`	Suitable for UUID storage	16 bytes
`frozen`	A frozen value serializes multiple components into a single value. Non-frozen types allow updates to individual fields. Cassandra treats the value of a frozen type as a blob. The entire value must be overwritten.	N/A
`inet`	IP address string in IPv4 or IPv6 format, used by the `python-cql` driver and CQL native protocols	N/A
`list`	A collection of one or more ordered elements: `[literal, literal, literal]`	N/A
`map`	A JSON-style array of literals: `{ literal : literal, literal : literal ... }`	N/A
`set`	A collection of one or more elements: `{ literal, literal, literal }`	N/A
`tuple`	A group of 2-3 fields	N/A

ROWS

Cassandra 3.x supports tables defined with composite primary keys. The first part of the primary key is a partition key. Remaining columns are clustering columns and define the order of the data on the disk. For example, let's say there is a table called `users_by_location` with the following primary key:

```
((country, town), birth_year, user_id)
```

In that case, the (`country, town`) pair is a partition key (a composite one). All users with the same (`country, town`) values will be stored together on a single node and replicated together based on the replication factor. The rows within the partition will be ordered by `birth_year` and then by `user_id`. The `user_id` column provides uniqueness for the primary key.

If the partition key is not separated by parentheses, then the first column in the primary key is considered a partition key. For example, if the primary key is defined by (`country, town, birth_year, user_id`), then `country` would be the partition key and town would be a clustering column.

COLUMNS

A column is a triplet: key, value, and timestamp. The validation and comparator on the column family define how Cassandra sorts and stores the bytes in column keys. The timestamp portion of the column is used to sequence mutations. The timestamp is defined and specified by the client. Newer versions of Cassandra drivers provide this functionality out of the box. Client application servers should have synchronized clocks.

Columns may optionally have a time-to-live (TTL), after which Cassandra asynchronously deletes them. Note that TTLs are defined per cell, so each cell in the row has an independent time-to-live and is handled by the Cassandra independently.

HOW DATA IS STORED ON DISK

Using the `sstabledump` tool, you can inspect how the data is stored on the disk. This is very important if you want to develop intuition about data modeling, reads, and writes in Cassandra. Given the table defined by:

```
CREATE TABLE IF NOT EXISTS symbol_history (
  symbol         text,
  year           int,
  month          int,
  day            int,
  volume         bigint,
  close          double,
  open           double,
  low            double,
  high           double,
  idx            text static,
  PRIMARY KEY ((symbol, year), month, day)
) with CLUSTERING ORDER BY (month desc, day desc);
```

The data (when deserialized into JSON using the `sstabledump` tool) is stored on the disk in this form:

```
[
  {
    "partition" : {
      "key" : [ "CORP", "2016" ],
      "position" : 0
    },
    "rows" : [
      {
        "type" : "static_block",
        "position" : 48,
        "cells" : [
          { "name" : "idx", "value" : "NASDAQ",
"tstamp" : 1457484225583260, "ttl" : 604800,
"expires_
 at" : 1458089025, "expired" : false }
        ]
      },
      {
        "type" : "row",
        "position" : 48,
        "clustering" : [ "1", "5" ],
        "deletion_info" : { "deletion_time" :
```

(Code continues on Next Page)

```
1457484273784615, "tstamp" : 1457484273 }
      },
      {
        "type" : "row",
        "position" : 66,
        "clustering" : [ "1", "4" ],
        "liveness_info" : { "tstamp" :
1457484225586933, "ttl" : 604800, "expires_at" :
1458089025, "expired" : false },
        "cells" : [
          { "name" : "close", "value" : "8.54" },
          { "name" : "high", "value" : "8.65" },
          { "name" : "low", "value" : "8.2" },
          { "name" : "open", "value" : "8.2" },
          { "name" : "volume", "value" : "1054342" }
        ]
      },
      {
        "type" : "row",
        "position" : 131,
        "clustering" : [ "1", "1" ],
        "liveness_info" : { "tstamp" :
1457484225583260, "ttl" : 604800, "expires_at" :
1458089025, "expired" : false },
        "cells" : [
          { "name" : "close", "value" : "8.2" },
          { "name" : "high", "deletion_time" :
1457484267, "tstamp" : 1457484267368678 },
          { "name" : "low", "value" : "8.02" },
          { "name" : "open", "value" : "9.33" },
          { "name" : "volume", "value" : "1055334" }
        ]
      }
    ]
  },
  {
    "partition" : {
      "key" : [ "CORP", "2015" ],
      "position" : 194
    },
    "rows" : [
      {
        "type" : "static_block",
        "position" : 239,
        "cells" : [
          { "name" : "idx", "value" : "NYSE",
"tstamp"
 : 1457484225578370, "ttl" : 604800, "expires_at" :
1458089025, "expired" : false }
        ]
      },
      {
        "type" : "row",
        "position" : 239,
        "clustering" : [ "12", "31" ],
        "liveness_info" : { "tstamp" :
1457484225578370, "ttl" : 604800, "expires_at" :
1458089025, "expired" : false },
        "cells" : [
          { "name" : "close", "value" : "9.33" },
```

(Code continues in Next Column)

```
            { "name" : "high", "value" : "9.57" },
            { "name" : "low", "value" : "9.21" },
            { "name" : "open", "value" : "9.55" },
            { "name" : "volume", "value" : "1054342" }
          ]
        }
      ]
    }
  ]
```

CASSANDRA ARCHITECTURE

Cassandra uses a masterless ring architecture. The ring represents a cyclic range of token values (i.e., the token space). Since Cassandra 2.0, each node is responsible for a number of small token ranges defined by the `num_tokens` property in `cassandra.yml`.

PARTITIONING

Keys are mapped into the token space by a partitioner. The important distinction between the partitioners is order preservation (OP). Users can define their own partitioners by implementing `IPartitioner`, or they can use one of the native partitioners.

	CASSANDRA	RDBMS	OP
`Murmur3Partitioner`	`MurmurHash`	64-bit hash value	No

MURMUR3 PARTITIONER

`Murmur3Partitioner` is the default partitioner since Cassandra 1.2. The `Murmur3Partitioner` provides faster hashing and improved performance than the `RandomPartitioner`. The `Murmur3Partitioner` can be used with vnodes.

REPLICATION

Cassandra provides continuous, high availability and fault tolerance through data replication. The replication uses the ring to determine nodes used for replication. Replication is configured on the keyspace level. Each keyspace has an independent replication factor, ***n***.

When writing information, the data is written to the target node as determined by the partitioner and ***n-1*** subsequent nodes along the ring.

There are two replication strategies: `SimpleStrategy` and `NetworkTopologyStrategy`.

SIMPLESTRATEGY

The `SimpleStrategy` is the default strategy and blindly writes the data to subsequent nodes along the ring. This strategy is NOT RECOMMENDED for a production environment.

In the previous example with a replication factor of ***2***, this would result in the following storage allocation:

ROW KEY	REPLICA 1 (AS DETERMINED BY PARTITIONER)	REPLICA 2 (FOUND BY TRAVERSING THE RING)
`collin`	3	1
`owen`	2	3
`lisa`	1	2

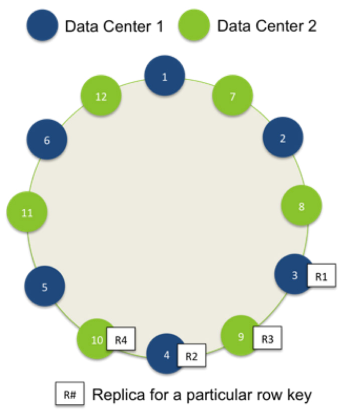
NETWORKTOPOLOGYSTRATEGY

The `NetworkTopologyStrategy` is useful when deploying to multiple datacenters. It ensures data is replicated across datacenters.

Effectively, the `NetworkTopologyStrategy` executes the `SimpleStrategy` independently for each datacenter, spreading replicas across distant racks. Cassandra writes a copy in each datacenter as determined by the partitioner.

Data is written simultaneously along the ring to subsequent nodes within that datacenter with preference for nodes in different racks to offer resilience to hardware failure. All nodes are peers and data files can be loaded through any node in the cluster, eliminating the single point of failure inherent in master-coordinator architecture and making Cassandra fully fault-tolerant and highly available.

See the following ring and deployment topology:



With blue nodes deployed to one datacenter (DC1), green nodes deployed to another datacenter (DC2), and a replication factor of two per each datacenter, one row will be replicated twice in Data Center 1 (R1, R2) and twice in Data Center 2 (R3, R4).

***Note:** Cassandra attempts to write data simultaneously to all target nodes, then waits for confirmation from the relevant number of nodes needed to satisfy the specified consistency level.*

CONSISTENCY LEVELS

One of the unique characteristics of Cassandra that sets it apart from other databases is its approach to consistency. Clients can specify the consistency level on both read and write operations, trading off between high availability, consistency, and performance.

WRITE

LEVEL	EXPECTATION
ANY	The write was written in at least one node's commit log. Provides low latency and a guarantee that a write never fails. Delivers the lowest consistency and continuous availability.
LOCAL_ONE	A write must be sent to, and successfully acknowledged by, at least one replica node in the local datacenter.
ONE	A write is successfully acknowledged by at least one replica (in any DC).
TWO	A write is successfully acknowledged by at least two replicas.
THREE	A write is successfully acknowledged by at least three replicas.
QUORUM	A write is successfully acknowledged by at least ***n*/2+1** replicas, where *n* is the replication factor.
LOCAL_QUORUM	A write is successfully acknowledged by at least ***n*/2+1** replicas within the local datacenter.
EACH_QUORUM	A write is successfully acknowledged by at least ***n*/2+1** replicas within each datacenter.
ALL	A write is successfully acknowledged by all *n* replicas. This is useful when absolute read consistency and/or fault tolerance are necessary (e.g., online disaster recovery).

READ

LEVEL	EXPECTATION
ONE	Returns a response from the closest replica, as determined by the snitch.
TWO	Returns the most recent data from two of the closest replicas.
THREE	Returns the most recent data from three of the closest replicas.
QUORUM	Returns the record after a quorum (***n*/2 +1**) of replicas from all datacenters that responded.
LOCAL_QUORUM	Returns the record after a quorum of replicas in the current datacenter, as the coordinator has reported. Avoids latency of communication among datacenters.
EACH_QUORUM	Not supported for reads.
ALL	The client receives the most current data once all replicas have responded.

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NETWORK TOPOLOGY

As input into the replication strategy and to efficiently route communication, Cassandra uses a ***snitch*** to determine the datacenter and rack of the nodes in the cluster. A snitch is a component that detects and informs Cassandra about the network topology of the deployment. The snitch dictates what is used in the strategy options to identify replication groups when configuring replication for a keyspace.

The following table shows the snitches provided by Cassandra and what you should use in your keyspace configuration for each snitch:

SNITCH	SPECIFY
SimpleSnitch	Specify only the replication factor in your strategy options.
PropertyFileSnitch	Specify the datacenter names from your properties file in the keyspace strategy options.
GossipingProperty FileSnitch	Returns the most recent data from three of the closest replicas.
RackInferring Snitch	Specify the second octet of the IPv4 address in your keyspace strategy options.
EC2Snitch	Specify the region name in the keyspace strategy options and dc_suffix in cassandra-rackdc.properties.
Ec2MultiRegion Snitch	Specify the region name in the keyspace strategy options and dc_suffix in cassandra-rackdc.properties.
GoogleCloudSnitch	Specify the region name in the keyspace strategy options.

SIMPLESNITCH

The SimpleSnitch provides Cassandra no information regarding racks or datacenters. It is the default setting and is useful for simple deployments where all servers are collocated. It is not recommended for a production environment, as it does not provide failure tolerance.

PROPERTYFILESNITCH

The PropertyFileSnitch allows users to be explicit about their network topology. The user specifies the topology in a properties file, cassandra-topology.properties. The file specifies which nodes belong to which racks and datacenters. Below is an example property file for our sample cluster:

```
# DC1
192.168.0.1=DC1:RAC1
192.168.0.2=DC1:RAC1
192.168.0.3=DC1:RAC2
```

(Code continues in Next Column)

```
# DC2
192.168.1.4=DC2:RAC3
192.168.1.5=DC2:RAC3
192.168.1.6=DC2:RAC4

# Default for nodes
default=DC3:RAC5
```

GOSSIPINGPROPERTYFILESNITCH

This snitch is recommended for production. It uses rack and datacenter information for the local node defined in the cassandra-rackdc.properties file and propagates this information to other nodes via gossip.

Unlike PropertyFileSnitch, which contains topology for the entire cluster on every node, GossipingPropertyFileSnitch contains DC and rack information only for the local node. Each node describes and gossips its location to other nodes.

Example contents of the cassandra-rackdc.properties files:

```
dc=DC1
rack=RACK1

RackInferringSnitch
```

THE RACKINFERRINGSNITCH

The RackInferringSnitch infers network topology by convention. From the IPv4 address (e.g., 9.100.47.75), the snitch uses the following convention to identify the datacenter and rack:

OCTET	EXAMPLE	INDICATES
1	9	Nothing
2	100	Datacenter
3	47	Rack
4	75	Node

EC2SNITCH

The EC2Snitch is useful for deployments to Amazon's EC2. It uses Amazon's API to examine the regions to which nodes are deployed. It then treats each region as a separate datacenter.

EC2MULTIREGIONSNITCH

Use this snitch for deployments on Amazon EC2 where the cluster spans multiple regions. This snitch treats datacenters and availability zones as racks within a datacenter and uses public IPs as broadcast_address to allow cross-region connectivity. Cassandra nodes in one EC2 region can bind to nodes in another region, thus enabling multi-datacenter support.

Hot tip: *Pay attention to which snitch you are using and which file you are using to define the topology. Some of the snitches use* `cassandra-topology.properties` *file and the other, newer ones use* `cassandra-rackdc.properties` *file.*

QUERYING/INDEXING

Cassandra provides simple primitives. Its simplicity allows it to scale linearly with continuous, high availability and very little performance degradation. That simplicity allows for extremely fast read and write operations for specific keys, but servicing more sophisticated queries that span keys requires pre-planning. Using the primitives that Cassandra provides, you can construct indexes that support exactly the query patterns of your application. Note, however, that queries may not perform well without properly designing your schema.

SECONDARY INDEXES

To satisfy simple query patterns, Cassandra provides a native indexing capability called secondary indexes. A column family may have multiple secondary indexes. A secondary index is hash-based and uses specific columns to provide a reverse lookup mechanism from a specific column value to the relevant row keys. Under the hood, Cassandra maintains hidden column families that store the index. The strength of secondary indexes is allowing queries by value.

Secondary indexes are built in the background automatically without blocking reads or writes. To create a secondary index using CQL is straightforward. For example, you can define a table of data about movie fans, then create a secondary index of states where they live:

```
CREATE TABLE fans ( watcherID uuid, favorite_actor
text, address text, zip int, state text PRIMARY KEY
(watcherID) );

CREATE INDEX watcher_state ON fans (state);
```

Hot tip: *Try to avoid indexes whenever possible. It is (almost) always a better idea to denormalize data and create a separate table that satisfies a particular query than it is to create an index.*

RANGE QUERIES

It is important to consider partitioning when designing your schema to support range queries.

RANGE QUERIES WITH ORDER PRESERVATION

Since order is preserved, order preserving partitioners better support range queries across a range of rows. Cassandra only needs to retrieve data from the subset of nodes responsible for that range. For example, if we are querying against a column family keyed by phone number and we want to find all phone numbers between that begin with ***215-555***, we could create a range query with start key ***215-555-0000*** and end key ***215-555-9999***.

To service this request with `OrderPreservingPartitioning`, it's possible for Cassandra to compute the two relevant tokens: token(***215-555-0000***) and token(***215-555-9999***). Then satisfying that querying simply means consulting nodes responsible for that token range and retrieving the rows/tokens in that range.

Hot tip: *Try to avoid queries with multiple partitions whenever possible. The data should be partitioned based on the access patterns, so it is a good idea to group the data in a single partition (or several) if such queries exist. If you have too many range queries that cannot be satisfied by looking into several partitions, you may want to rethink whether Cassandra is the best solution for your use case.*

RANGE QUERIES WITH RANDOM PARTITIONING

The `RandomPartitioner` provides no guarantees of any kind between keys and tokens. In fact, ideally row keys are distributed around the token ring evenly. Thus, the corresponding tokens for a start key and end key are not useful when trying to retrieve the relevant rows from tokens in the ring with the `RandomPartitioner`. Consequently, Cassandra must consult all nodes to retrieve the result. Fortunately, there are well-known design patterns to accommodate range queries. These are described next.

INDEX PATTERNS

There are a few design patterns to implement indexes. Each services different query patterns. The patterns leverage the fact that Cassandra columns are always stored in sorted order and all columns for a single row reside on a single host.

INVERTED INDEXES

First, let's consider the ***inverted index*** pattern. In an inverted index, columns in one row become row keys in another. Consider the following dataset, in which users IDs are row keys:

PARTITION KEY	ROWS/COLUMNS		
BONE42	{ name : "Brian"}	{ zip: 15283}	{dob : 09/19/1982}
LKEL76	{ name : "Lisa"}	{ zip: 98612}	{dob : 07/23/1993}
COW89	{ name : "Dennis"}	{ zip: 98612}	{dob : 12/25/2004}

Without indexes, searching for users in a specific zip code would mean scanning our Users column family row by row to find the users in the relevant zip code. Obviously, this does not perform well. To remedy the situation, we can create a table that represents the query we want to perform, inverting rows and columns. This would result in the following table:

(Table on Next Page)

PARTITION KEY	ROWS/COLUMNS		
98612	{ user_id : LKEL76 }		
	{ user_id : COW89 }		
15283	{ user_id : BONE42 }		

Since each partition is stored on a single machine, Cassandra can quickly return all user IDs within a single zip code by returning all rows within a single partition. Cassandra simply goes to a single host based on ***partition key (zip code)*** and returns the contents of that single partition.

TIME SERIES DATA

When working with time series data, consider partitioning data by time unit (hourly, daily, weekly, etc.), depending on the rate of events. That way, all the events in a single period (e.g., one hour) are grouped together and can be fetched and/or filtered based on the clustering columns. `TimeWindowCompactionStrategy` is specifically designed to work with time series data and is recommended in this scenario.

The `TimeWindowCompactionStrategy` compacts the all the SSTables in a single partition per time unit. This allows for extremely fast reads of the data in a single time unit because it guarantees that only one SSTable will be read.

DENORMALIZATION

Finally, it is worth noting that each of the indexing strategies as presented would require two steps to service a query if the request requires the actual column data (e.g., user name). The first step would retrieve the keys out of the index. The second step would fetch each relevant column by row key. We can skip the second step if we denormalize the data.

In Cassandra, denormalization is the norm. If we duplicate the data, the index becomes a true materialized view that is custom tailored to the exact query we need to support.

INSERTING/UPDATING/DELETING

Everything in Cassandra is an insert, typically referred to as a mutation. Since Cassandra is effectively a key-value store, operations are simply mutations of key-value pairs.

HINTED HANDOFF

Similar to read repair, hinted handoff is a background process that ensures data integrity and eventual consistency. If a replica is down in the cluster, the remaining nodes will collect and temporarily store the data that was intended to be stored on the downed node. If the downed node comes back online soon enough (configured by `max_hint_window_in_ms` option in `cassandra.yml`), other nodes will "hand off" the data to it. This way, Cassandra smooths out short network or other outages out of the box.

OPERATIONS AND MAINTENANCE

Cassandra provides tools for operations and maintenance. Some of the maintenance is mandatory because of Cassandra's eventually consistent architecture. Other facilities are useful to support alerting and statistics gathering. Use `nodetool` to manage Cassandra. You can read more about `nodetool` in the Cassandra documentation.

NODETOOL REPAIR

Cassandra keeps record of deleted values for some time to support the eventual consistency of distributed deletes. These values are called tombstones. Tombstones are purged after some time (GCGraceSeconds, which defaults to 10 days). Since tombstones prevent improper data propagation in the cluster, you will want to ensure that you have consistency before they get purged.

To ensure consistency, run:

```
>$CASSANDRA_HOME/bin/nodetool repair
```

The repair command replicates any updates missed due to downtime or loss of connectivity. This command ensures consistency across the cluster and obviates the tombstones. You will want to do this periodically on each node in the cluster (within the window before tombstone purge). The repair process is greatly simplified by using a tool called Cassandra Reaper (originally developed and open sourced by Spotify but taken over and improved by The Last Pickle).

MONITORING

Cassandra has support for monitoring via JMX, but the simplest way to monitor the Cassandra node is by using open source tools like Prometheus and Grafana. There is a free community edition as well as an enterprise edition that provides management of Apache SOLR and Hadoop. Simply download mx4j and execute the following:

```
cp $MX4J_HOME/lib/mx4j-tools.jar $CASSANDRA_HOME/lib
```

The following are key attributes to track per column family:

ATTRIBUTE	PROVIDES
Read Count	Frequency of reads against the column family.
Read Latency	Latency of reads against the column family.
Write Count	Frequency of writes against the column family.
Write Latency	Latency of writes against the column family.
Pending Tasks	Queue of pending tasks, informative to know if tasks are queuing.

BACKUP

Cassandra provides online backup facilities using `nodetool`. To take a snapshot of the data on the cluster, invoke:

```
$CASSANDRA_HOME/bin/nodetool snapshot
```

This will create a snapshot directory in each keyspace data directory. Restoring the snapshot is then a matter of shutting down the node, deleting the commitlogs and the data files in the keyspace, and copying the snapshot files back into the keyspace directory.

CLIENT LIBRARIES

Cassandra has a very active community developing libraries in different languages. Libraries are available for C3, C/C++, Python, REST, Ruby, Java, PHP CQL, and CQL. Some examples of client libraries include:

PYTHON

CLIENT	DESCRIPTION
Pycassa	Pycassa is the most well-known Python library for Cassandra: github.com/pycassa/pycassa

REST

CLIENT	DESCRIPTION
Virgil	Virgil is a Java-based REST client for Cassandra: github.com/hmsonline/virgil

RUBY

CLIENT	DESCRIPTION
Ruby Gem	Ruby has support for Cassandra via a gem: rubygems.org/gems/cassandra

JAVA

CLIENT	DESCRIPTION
Astyanax	Inspired by Hector, Astyanax is a client library developed by the folks at Netflix: github.com/Netflix/astyanax

PHP CQL

CLIENT	DESCRIPTION
Cassandra-PDO	A CQL (Cassandra Query Language) driver for PHP: code.google.com/a/apache-extras.org/p/cassandra-pdo

CQL

CLIENT	DESCRIPTION
CQL	Cassandra provides an SQL-like query language called the Cassandra Query Language (CQL). The CQL shell allows you to interact with Cassandra as if it were a SQL database. Start the shell with: `$CASSANDRA_HOME/bin/`

COMMAND LINE INTERFACE (CLI)

Cassandra also provides a Command Line Interface (CLI), through which you can perform all schema-related changes. It also allows you to manipulate data.

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