Apache Cassandra

Topics

- Introduction
- Data Modeling
- Querying
- Administration
- DevOps

Introduction

- Overview
- Architecture
- Compare with Other Database

Apache Cassandra

- Distributed DBMS
  - Open-Source
  - Distributed
  - Decentralized
- Developed at Facebook
- Power the Facebook inbox search feature

Applications of Cassandra

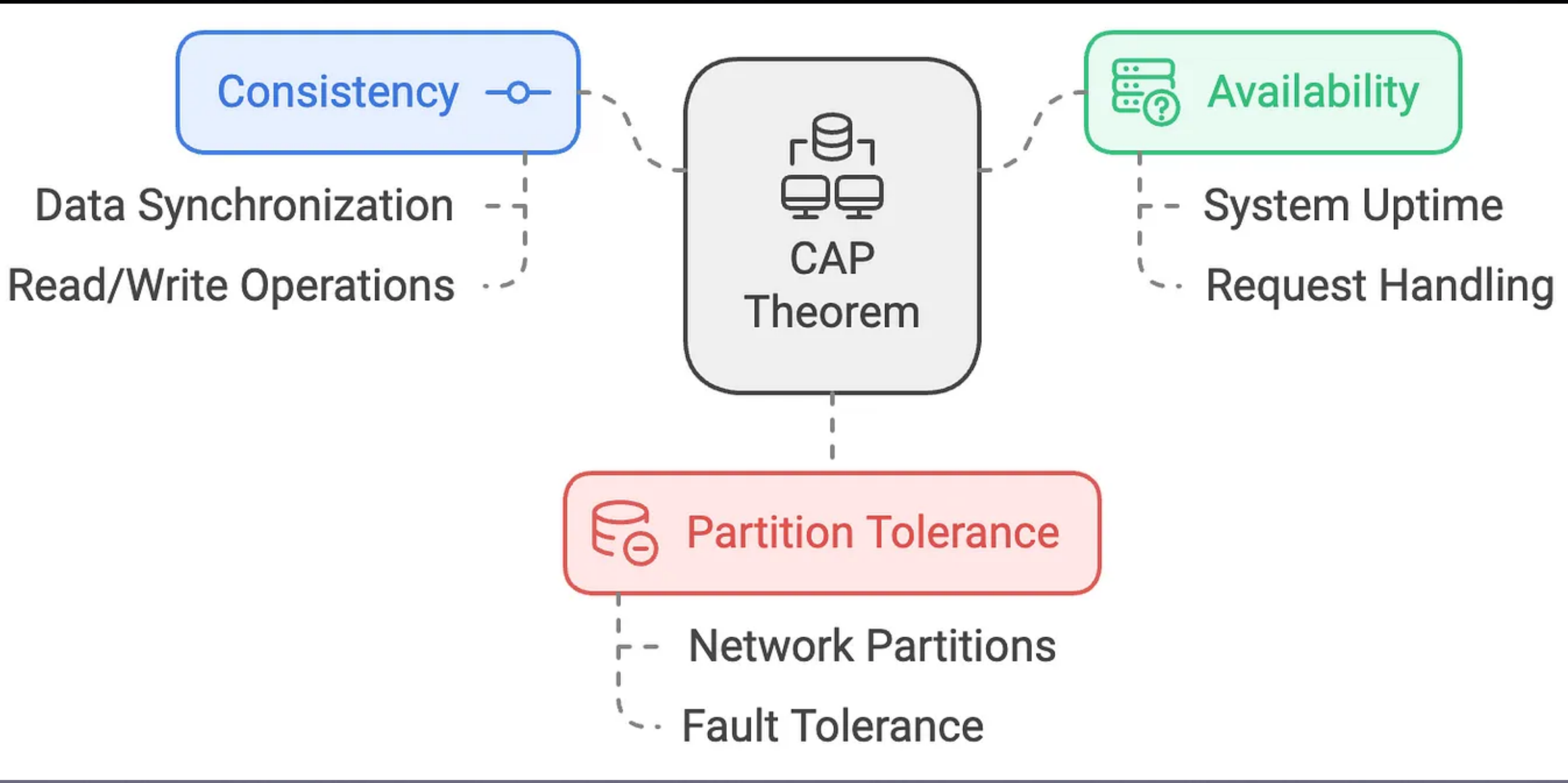
- Great Application where **Data** is collected at **High Speed** from **Different** kinds of **sources**
- Internet of Things
- Product & Retail apps
- Messaging
- Social Media Analytics
- Recommendation Engine

Traditional RDBMS vs Cassandra

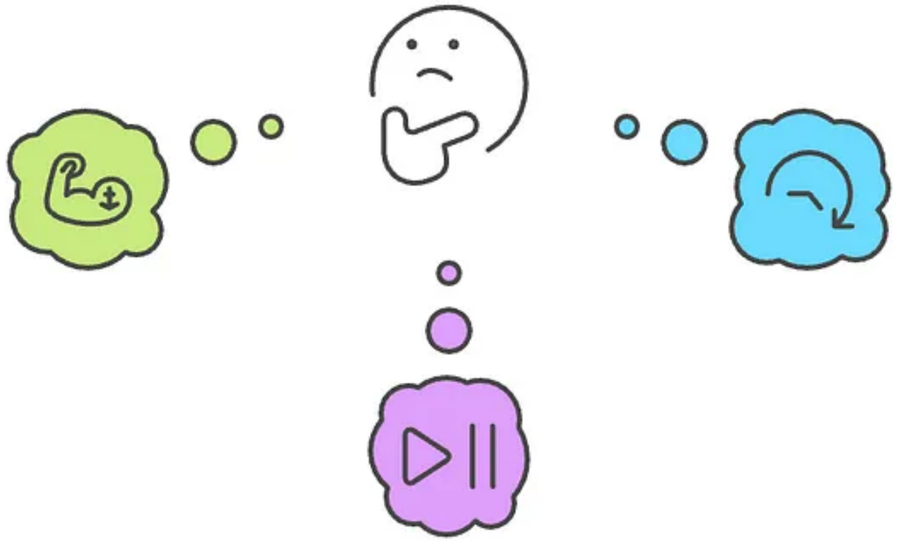
Feature	Traditional RDBMS	Cassandra
Data Model	Relational	NoSQL, flexible column families
Architecture	Centralized/Master-Slave	Distributed, Peer-to-peer
Scalability	Vertical, complex horizontal	Horizontal, easy to scale out
Consistency	Strong (ACID)	Tunable, often eventually consistent
Transactions	Complex, nested	Simple
Use Cases	Structured data, strong consistency	High availability, large datasets

The CAP Theorem

- **Consistency**
    - all nodes see the same data at the same time
- **Availability**
    - every request receives a response, even if some nodes are down
- **Partition Tolerance**
    - the system continues to function despite communication breaks between nodes


Consistency
Data Synchronization
Read/Write Operations
CAP Theorem
Availability
System Uptime
Request Handling
Partition Tolerance
Network Partitions
Fault Tolerance

Which consistency model to adopt for a database system?



Strong Consistency

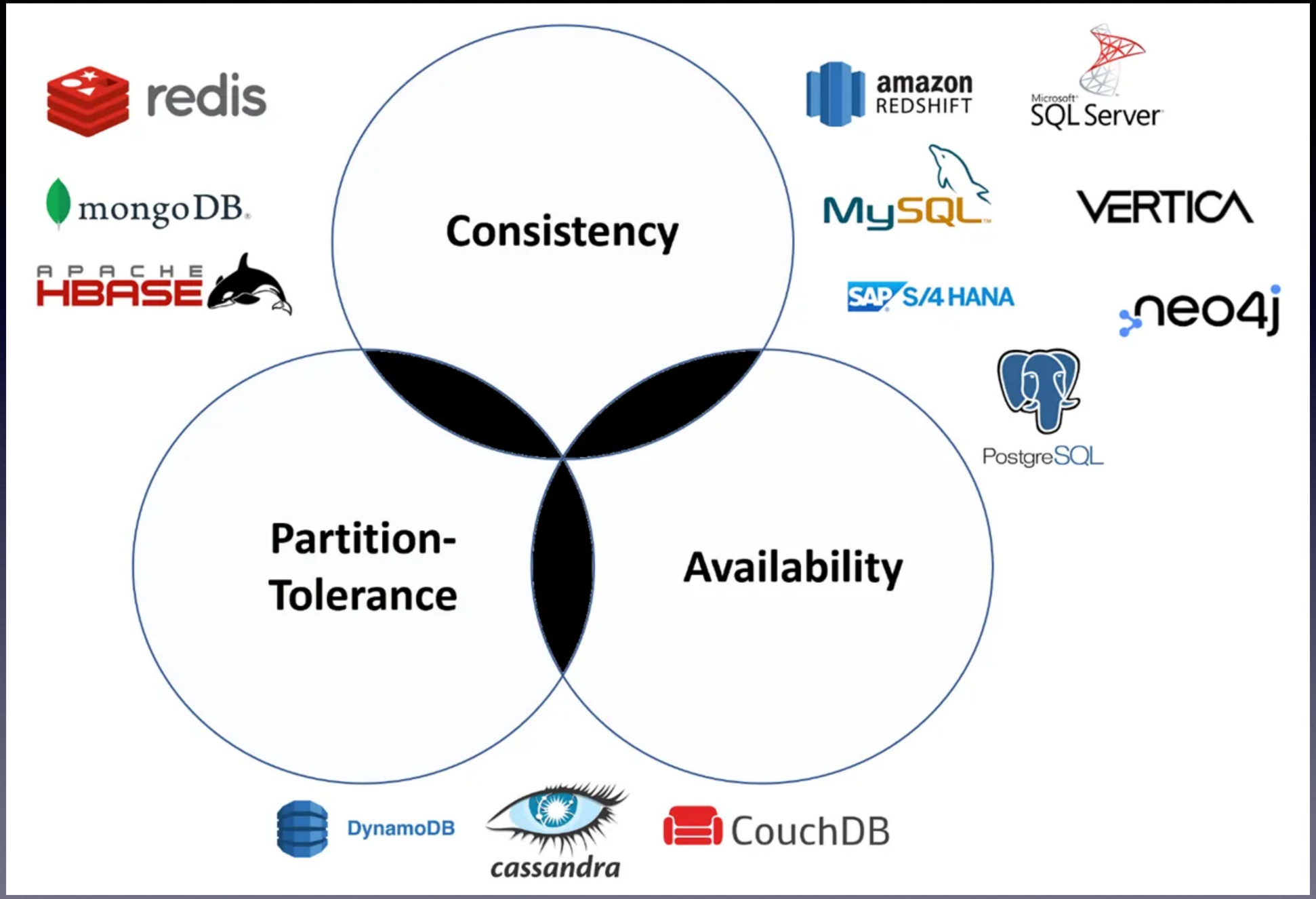
Ensures data accuracy and reliability, but may sacrifice performance and availability.

Eventual Consistency

Offers better performance and availability, but data may not be immediately accurate.

Tunable Consistency (Cassandra)

Provides flexibility to choose consistency level based on specific use cases, balancing accuracy, performance, and availability.


redis
mongoDB.
APACHE HBASE
amazon REDSHIFT
Microsoft SQL Server
MySQL
VERTICA
SAP S/4 HANA
neo4j
PostgreSQL
Consistency
Partition-Tolerance
Availability
DynamoDB
cassandra
CouchDB

CAP

- CA: The system prioritizes **consistency** and **availability** but doesn't handle network partitions well. In the case of a network partition, it might choose to become unavailable to maintain consistency.
- CP: The system prioritizes **consistency** and **partition tolerance** but sacrifices availability. In the face of a network partition, it will maintain consistency by refusing some requests.
- AP: The system prioritizes **availability** and **partition tolerance** but sacrifices strong consistency. It continues to operate and respond to requests even if it means returning stale data or data that is not consistent across all nodes.

BASE (NoSQL Philosophy)

- **[BASICALLY AVAILABLE]**
-  System mostly works
- **[SOFT STATE]**
-  May change over time
- **[EVENTUAL CONSISTENCY]**
-  Gets fixed later

Key Terms in Cassandra

- Nodes
- Data Center / Cluster
- Commit Log
- SSTable
- MemTable
- Replication

Cassandra Node

- A node is a basic unit of Cassandra,
- It is a system that is part of a cluster.
- Node is the main area where the data is stored.
- The units of a node is represented as computer/server

Cassandra Data Center / Cluster

- A data center is a collection of Cassandra nodes.
- The data in a data center is stored in the form of a cluster
- The cluster is also referred to as a collection of nodes.

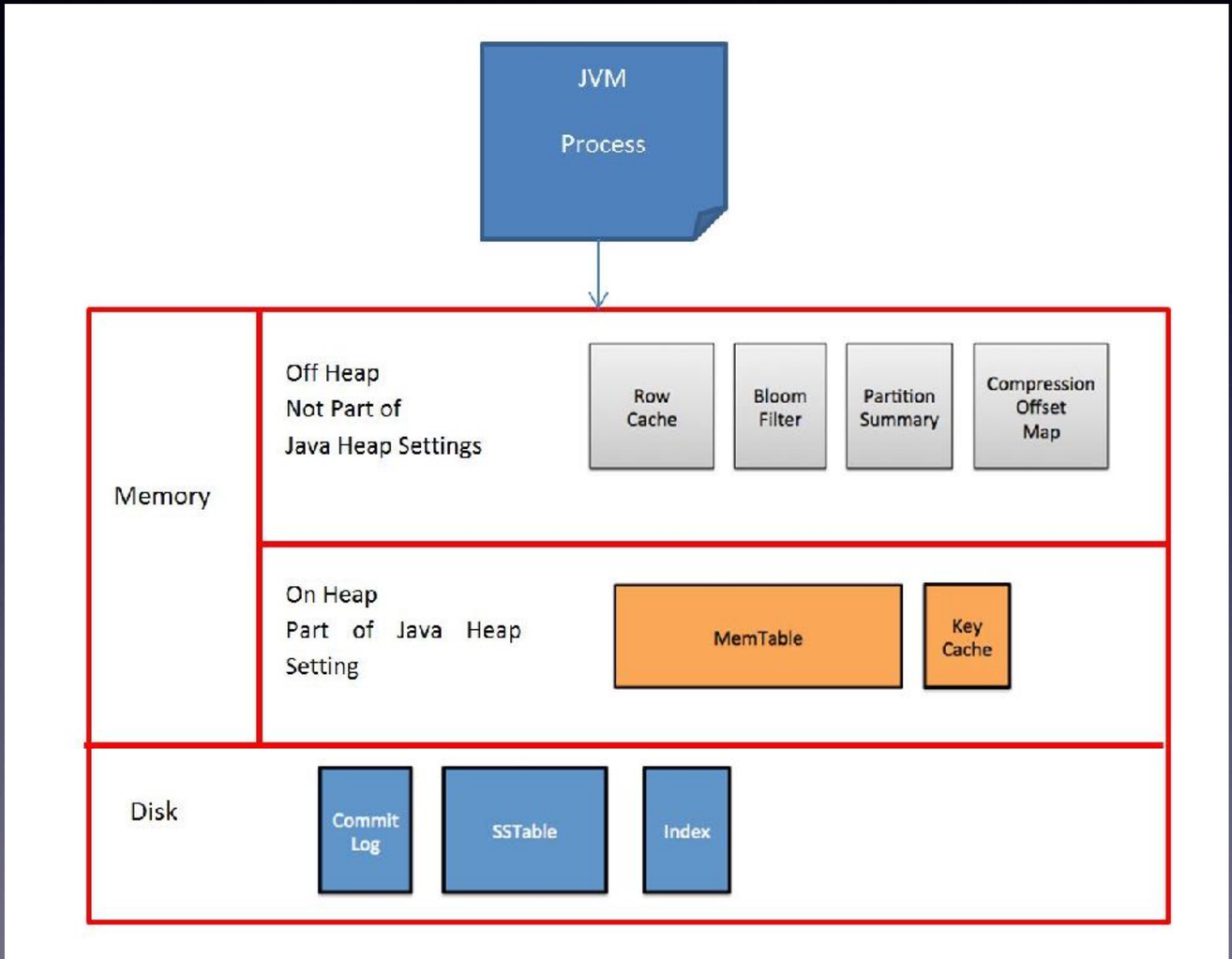
Cassandra MemTable

- MemTable is a location where data is written and stored temporarily.
- Data is written in memtable after the data is completed in the commit log.
- Memtable is a storage engine in Cassandra.
- Data in MemTable is classified into a key, and where the data is retrieved using the key as each column category has its own MemTable.
- When the write memory is full, it deletes the messages automatically.

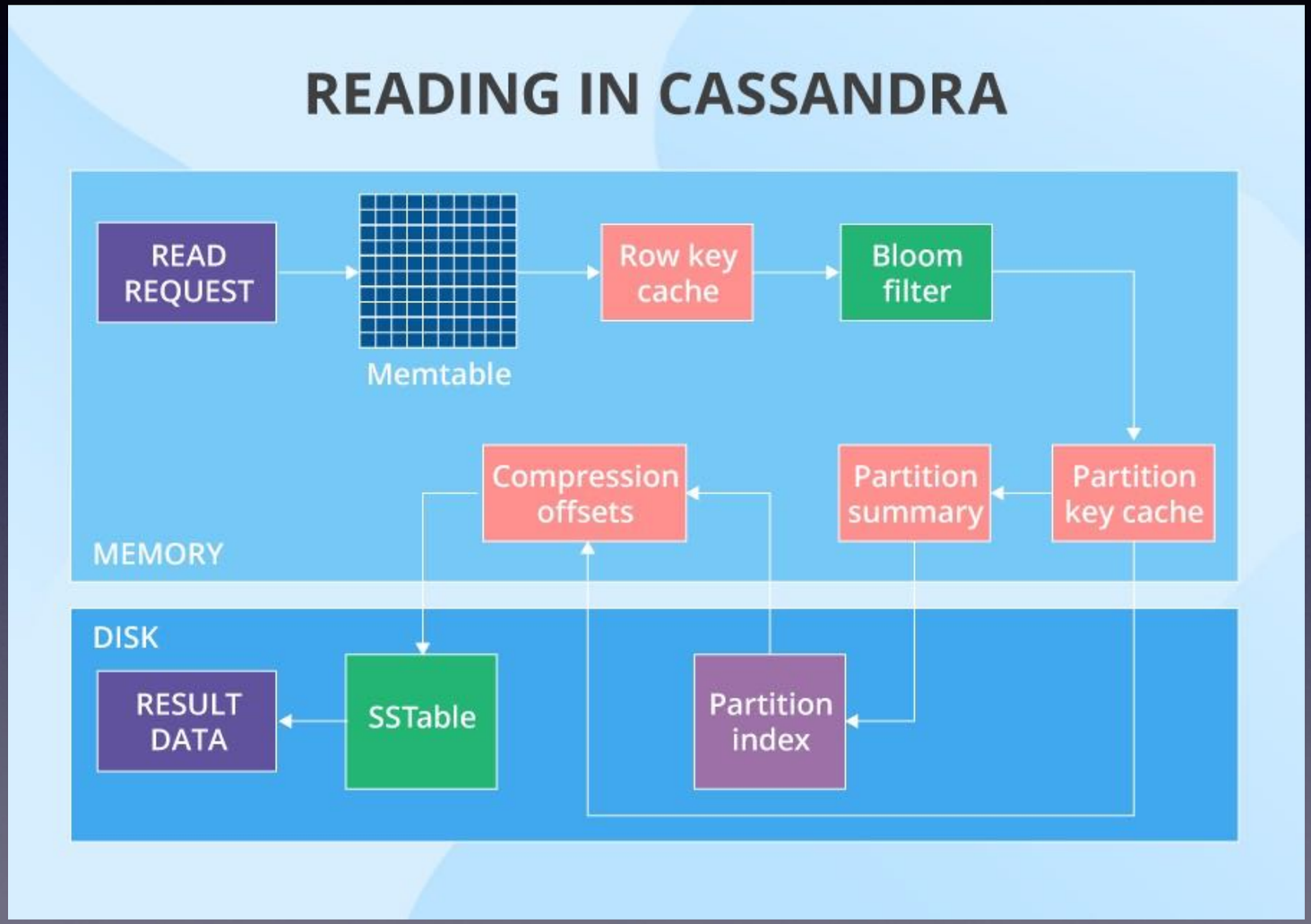
Cassandra SSTable

- SSTable also means 'Sorted String Table'.
- SSTable is a data file in Cassandra
- Its main function is to save data that is flushed from memtable.
- Unlike MemTable, SSTbale doesn't delete any data or lets any further addition once data is written.

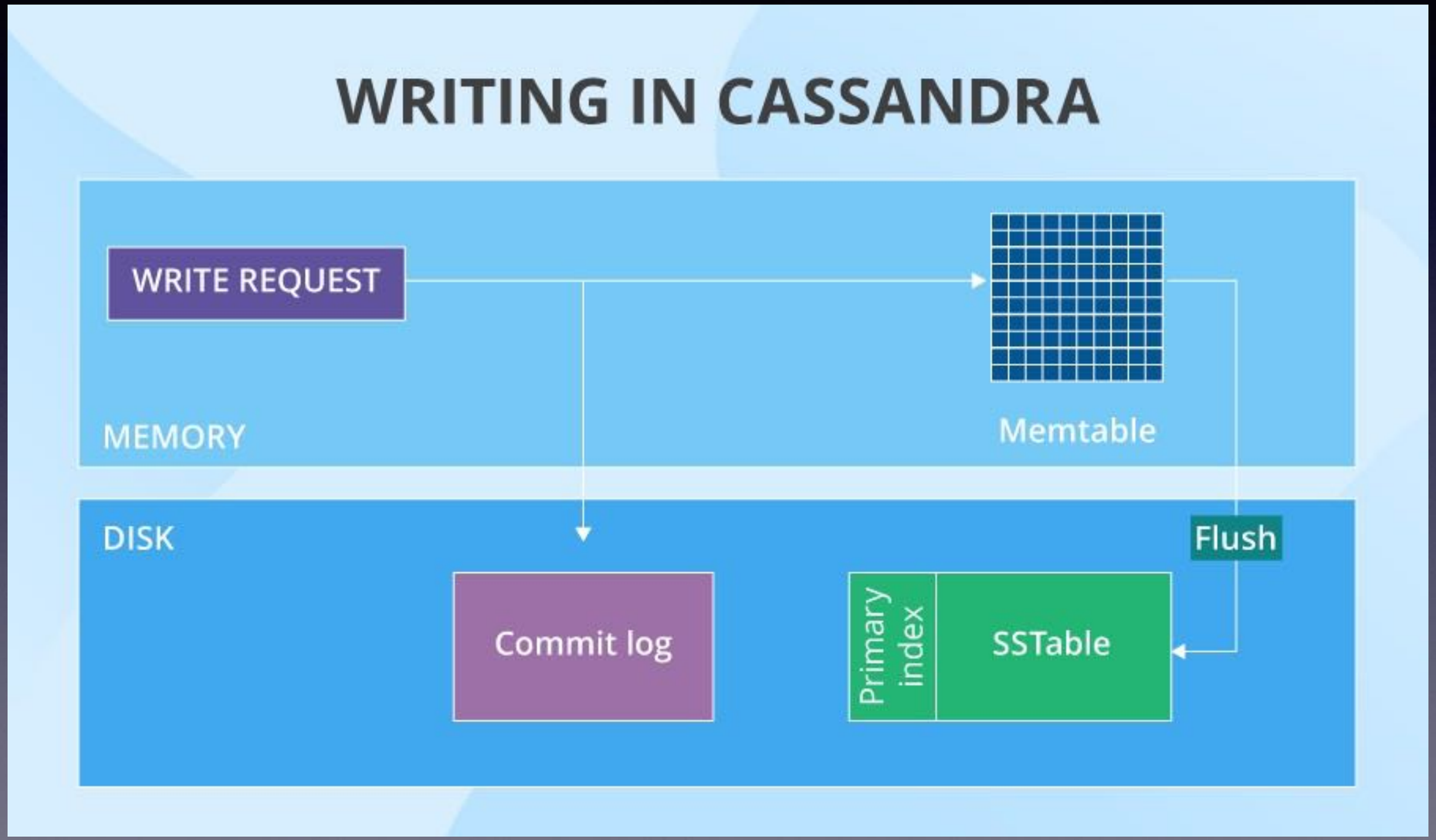
Architecture



Read Operation



Write Operation



Cassandra 5.0 Features

- Storage Attached Indexes (SAI): More flexible secondary indexing with better performance
- Vector search: Native support for AI/ML workloads with vector data type
- Unified Compaction Strategy (UCS): Adaptive compaction that optimizes automatically
- JDK 17 support: Up to 20% performance improvement from better memory management
- Trie-based storage: New memtable and SSTable formats for improved efficiency
- ACID transactions: Limited support for multi-partition transactions

Data Modeling

- Data Model
- Denormalization Strategies

What is Data Modeling

- Data modeling is the process of identifying entities and their relationships.
- In relational databases, data is placed in normalized tables with foreign keys used to reference related data in other tables.
- Queries that the application will make are driven by the structure of the tables and related data are queried as table joins.

What is Data Modeling

- In Cassandra, data modeling is Query-Driven.
- Queries are best designed to access a single table, which implies that all entities involved in a query must be in the same table to make data access (reads) very fast.
- Data is modeled to best suit a query or a set of queries. A table could have one or more entities as best suits a query. As entities do typically have relationships among them and queries could involve entities with relationships among them, a single entity may be included in multiple tables.

Query-Driven Modeling

- Unlike a relational database model in which queries make use of table joins to get data from multiple tables, joins are not supported in Cassandra so all required fields (columns) must be grouped together in a single table.
- Since each query is backed by a table, data is duplicated across multiple tables in a process known as denormalization.
- Data duplication and a high write throughput are used to achieve a high read performance.

Goals

- The choice of the **primary** key and **partition** key is important to distribute data evenly across the **cluster**.
- Keeping the number of partitions read for a query to a **minimum** is also important because different partitions could be located on different nodes and the coordinator would need to send a request to each node adding to the request overhead and latency.
- Even if the different partitions involved in a query are on the same node, fewer partitions make for a more efficient query.

Partitions

- Apache Cassandra is a distributed database that stores data across a cluster of nodes.
- A partition key is used to partition data among the nodes.
- Cassandra partitions data over the storage nodes using a variant of consistent hashing for data distribution.
- A partition key is generated from the first field (or group of fields) of a primary key.
- Data partitioned into hash tables using partition keys provides for rapid lookup.
- Fewer the partitions used for a query faster is the response time for the query.

Primary Key Components

- The primary key in Cassandra is always composed of:1.
  - **Partition** Key (mandatory)
    - Determines data distribution across nodes
  - **Clustering** Columns (optional)
    - Determines sorting within a partition

Partition Key

- The **first component** of the **primary** key
- Controls which node **stores** the data (via consistent hashing)
- All rows with the same partition key are stored together on the same node
- Data is spread across the cluster based on the partition key's hash value
- You must include the partition key in queries
- High cardinality partition keys distribute data more evenly

Partition Key

```
CREATE TABLE users (
    user_id UUID,
    name TEXT,
   email TEXT,
    PRIMARY KEY (user_id)  -- user_id is the partition key
);
```

Clustering Columns

- The **second** and **subsequent** components of the primary key
- Control the **sort order** of rows within a partition
- Determines the on-disk sort order of data within a partition
- Enable efficient **range queries** within a partition
- Contribute to row uniqueness within a partition

Clustering Columns

```
CREATE TABLE user_orders (
    user_id UUID,              -- Partition key
    order_date TIMESTAMP,      -- First clustering column
    order_id UUID,             -- Second clustering column
    amount DECIMAL,
    PRIMARY KEY (user_id, order_date, order_id)
) WITH CLUSTERING ORDER BY (order_date DESC);
```

Composite Partition Key

```
CREATE TABLE sensor_readings (
    sensor_type TEXT,
    sensor_id UUID,
    reading_time TIMESTAMP,
    value FLOAT,
    PRIMARY KEY ((sensor_type, sensor_id), reading_time)
);
```

Querying

- Cassandra Query language - CQL
- Query Optimization
- Advanced CQL Features

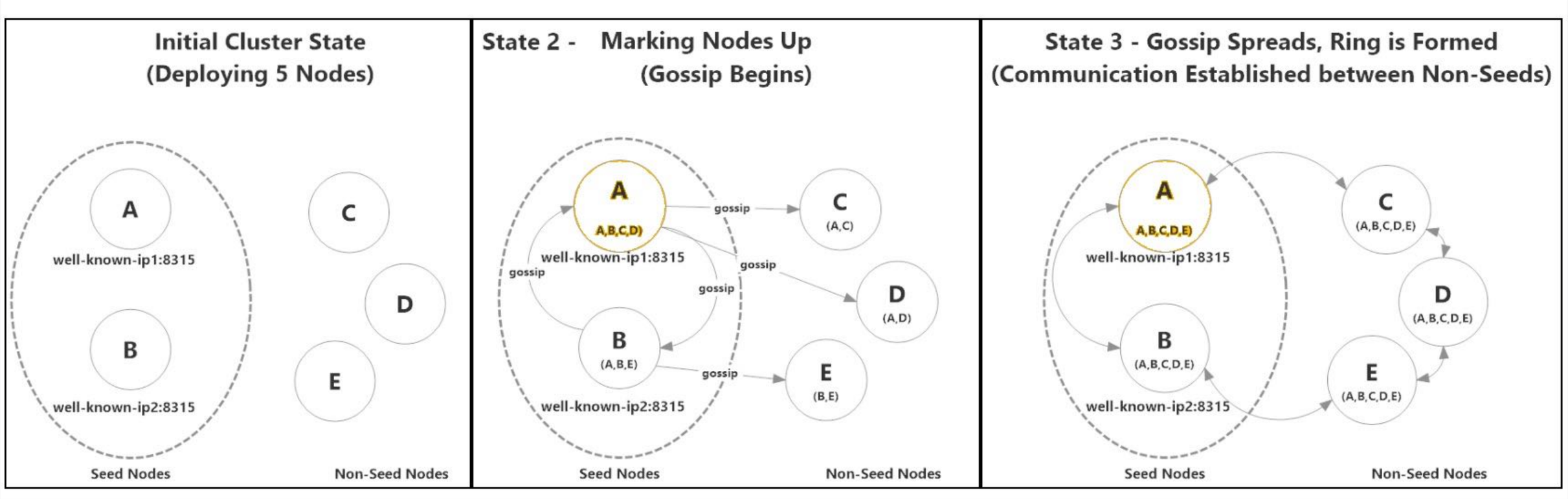
Administration

- Cluster Setup and Configuration
- Monitoring and Troubleshooting
- Backup and Recovery

Development

- Client Drivers
- Data Consistency and Durability
- Performance Optimization

High Availability



Direct vs Digest Requests

- Direct request involves the coordinator node directly contacting one replica for the data.
- Digest requests involve contacting multiple replicas and checking for data consistency by comparing digests (hashes) of the data

Direct vs Digest Requests

Feature	Direct Request	Digest Request
Primary Goal	Quickly retrieve data from one replica	Ensure data consistency across multiple replicas
Consistency	Limited consistency guarantees	Higher consistency guarantees
Performance	Potentially faster	Potentially slower due to additional network traffic and data comparison
Data Delivery	Full data retrieval	Digest (hash) of the data, not the full data
Consistency Verification	No direct verification	Uses digests to check for data consistency

Repair Request

- A repair request initiates the process of resolving data inconsistencies between replicas.
  - These inconsistencies can arise when nodes fail
  - When writes are not synchronized across all replicas.
- Repairs ensure data accuracy and consistency within the cluster, which is crucial for maintaining data integrity.

Read Repair vs Repair Request

- **Read Repair** is a process that occurs during a read operation to ensure data consistency across replicas if inconsistencies are detected.
- **Repair Request** is a broader term that refers to any request to reconcile data between replicas, whether it's during a read or as a separate maintenance task.

Repair Command

- ***`nodetool repair`***
  - Initiates an incremental repair.
- ***`nodetool repair --full`***
  - Initiates a full repair.
- ***`nodetool repair [keyspace_name]`***
  - Repairs a specific keyspace.
- ***`nodetool repair [keyspace_name] [table1] [table2]:`***
  - Repairs specific tables within a keyspace.

DevOps

- Integrating with DevOps Tools