# MongoDB & Redis: NoSQL Big Data Management

Exploring basic theoretical notions regarding NoSQL, together with MongoDB and Redis as implementations and their storage models

# What is NoSQL?

- Informal definition: Not Only SQL
- Foundations laid in 2009 during a meetup in San Francisco
- A new databases paradigm that allows for schema-less, semi-structured data with distributed storage

# Why NoSQL?

- Traditional RDBMS struggle with huge workloads that occurr when dealing with Big Data

- NoSQL advocates claim that the horizontal scalability that comes with this technology, allow for better data management

- In addition, flexibility suits better agile environments where data structure can change over time

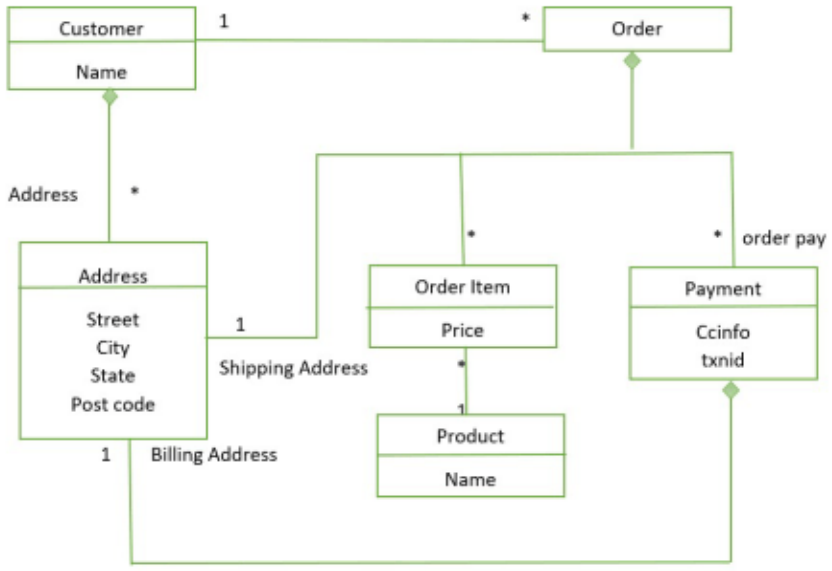
# CAP Theorem and NoSQL

- (C) Consistency, (A) Availability, (P) Partition Tolerance
- Proposed by Eric Brewer in 2000, it claims that between the above three properties on shared systems, only two can be achieved at once
- As we will see eventually, both Redis and MongoDB are considered CP systems, even if both now implement additional techniques

# NoSQL Data Models

| Type | DBMS Implementation | Storage Model |
|---|---|---|
| Key-Value | Redis | Key-Value pairs |
| Document | MongoDB | JSON-like documents |

# Aggregates and Schema Flexibility (1)



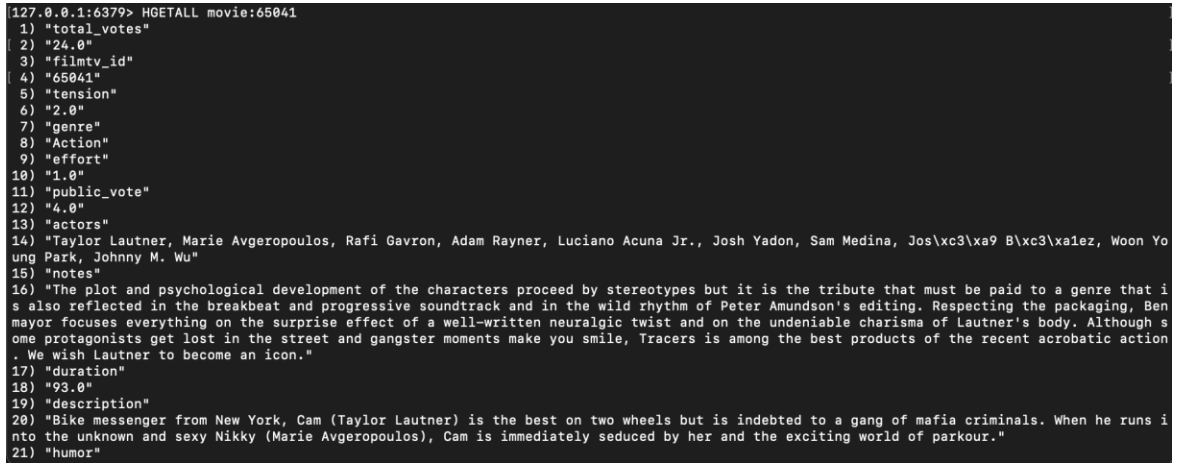

*Two main aggregates: Order and Customer*
*A single logical address appears 3 times in the data*

The foundational units in a NoSQL storage are identified as aggregates.

In the context of NoSQL, it is important to correctly identify aggregates in data when modelling information, so that querying and distribution can be performed efficiently

# Aggregates and Schema Flexibility (2)


In MongoDB, an aggregate is represented by a single document

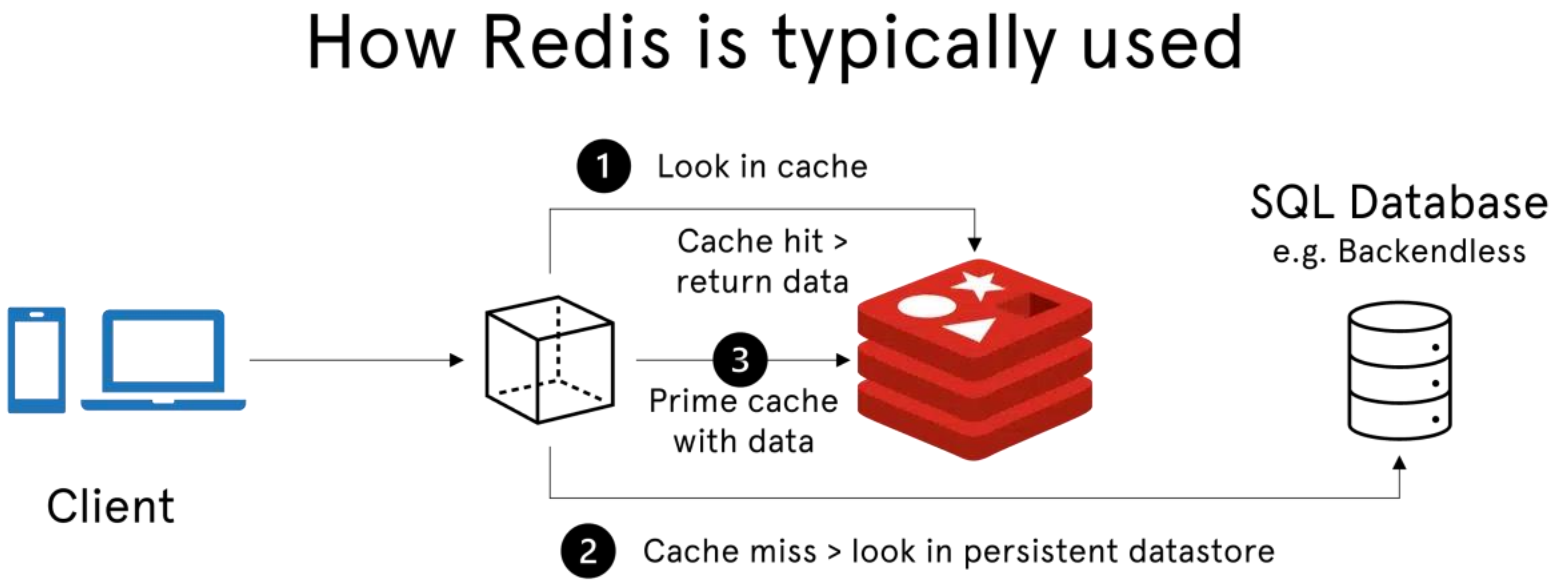



In Redis, an aggregate is a key-value pair

# Introduction to Key-Value Storage

- Key-Value stores allow for fast access to data via key lookups
- They work like a huge hash map, where data is stored and retrieved by means of a key
- They are mainly used in ambits like caching data, and session management for users

# Redis Typical Use Case



# How Redis Stores Data (1)

Redis,  in contrast to traditional DBMS, exploits an in-memory storage to fastly retrieve data.

Each blob of data (value) can be of multiple types:

- Simple strings
- Hashes, conceptually similar to dictionaries
- Lists and sets (also sorted)

# How Redis Stores Data (2)

```
127.0.0.1:6379> SET movie:99999 "hello"
OK
```

```
127.0.0.1:6379> HSET movie:99999 title "Test"
(integer) 1
127.0.0.1:6379> HGETALL movie:99999
1) "title"
2) "Test"
127.0.0.1:6379> HSET movie:99999 genre "Comedy
(integer) 1
127.0.0.1:6379> HGETALL movie:99999
1) "title"
2) "Test"
3) "genre"
4) "Comedy"
```

# How Redis Maintains Data (1)

Since Redis is an in-memory data storage, there must be a way to synchronize data to disk to prevent loss of information when the server is restarted.

Two main techniques are used to persist information: RDB and AOF.

# How Redis Maintains Data (2)

- RDB (Redis Database File): data is stored on disk with a snapshot of the dataset at configured intervals. It is enabled by default

```
127.0.0.1:6379> CONFIG get save
1) "save"
2) "3600 1 300 100 60 10000"
```

- AOF (Append-Only File): every write information is stored on a log file, and it can be replayed in case of data loss

```
127.0.0.1:6379> CONFIG get appendonly
1) "appendonly"
2) "no"
```

# How Redis Maintains Data (3)

In the basic setting, Redis runs on a single server with a single thread, hence it allows a good degree of consistency by exploiting the techniques of RDB and AOF.

However, it is also possible to increase availability, losing some degree of consistency in a trade-off for availability (CAP theorem)

# How Redis Ensures Consistency

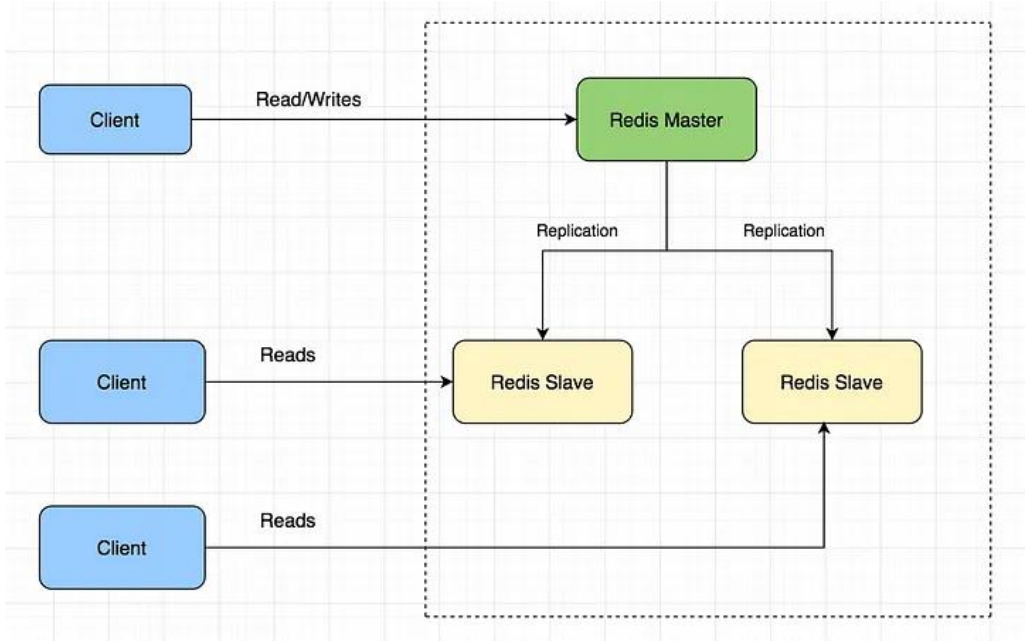
Consistency is ensured natively, since Redis is single-threaded and runs in the basic setting on only one server instance.

Nonetheless, when scaling horizontally with Redis Cluster or when increasing availability with Master-Replicas server, we may lose some degree of consistency.

Additionally, if we want to execute a sequence of commands without being interrupted by other clients' executions, Redis supports transactions.

# How Redis Ensures Availability (1)

When scaling horizontally, a server can be either run as a Master or a Replica (Slave):




In a typical setting, clients communicate with Master instances to write data, and the Master will **asynchronously** communicate with its replicas

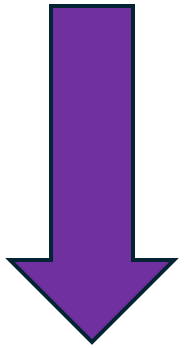
# How Redis Ensures Availability (2)

In the context of Availability, if one instance fails, we have two cases:

1. If a Replica Server fails, we simply create another replicating all data from the other Replica
2. If a Master Server fails, two approaches are possible
    1. We can add a new server as Redis Master
    2. We can ‘promote’ an existing Replica to the role of Master

# How Redis Ensures Availability (3)

Since the Master Server asynchronously updates its replicas when a write request comes from a server, in case a failure occurs during the Master-Replica update, the new data is lost



**No strong consistency guaranteed!**

# How Redis Performs Scaling (1)

Due to the need in Big Data Management to deal with large-sized information, Redis adopts a deployment topology called Redis Cluster that allows to scale horizontally.

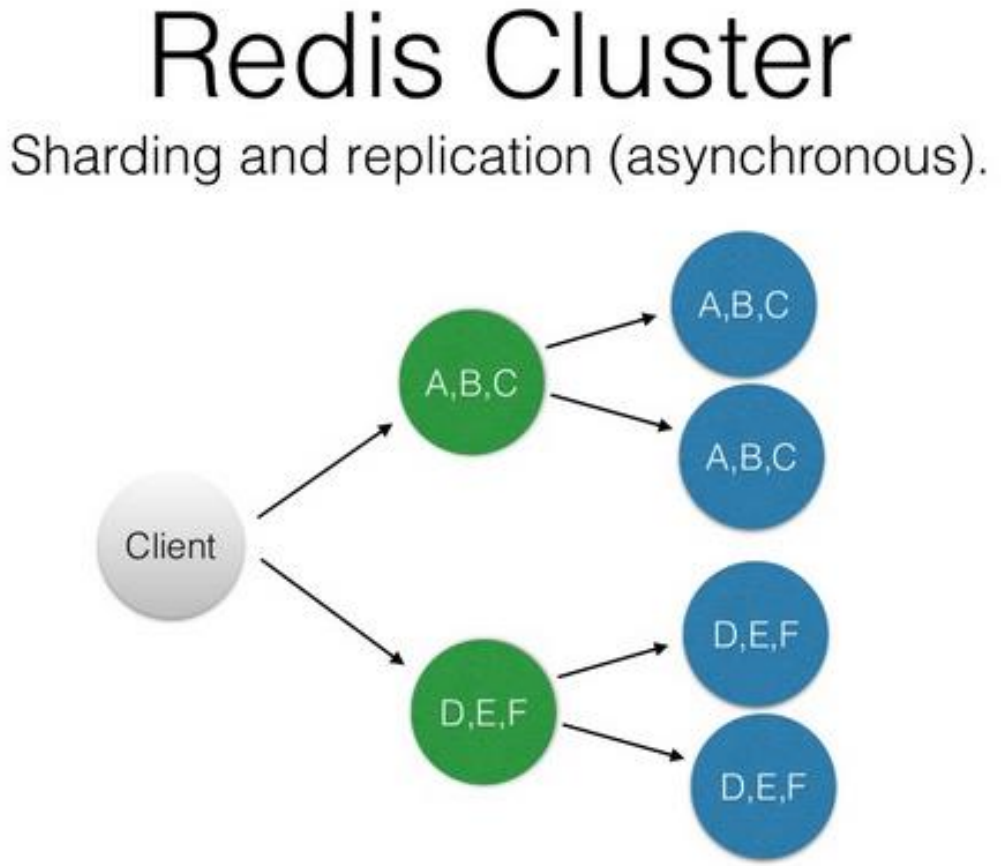
With Redis Cluster, it is possible to automatically split data in multiple nodes, increasing the overall throughput of the system.

# How Redis Performs Scaling (2)

Data is sharded through an hashing system, where every key is part of an hash slot computed by the modulo 16384 of the key.

Finally, it is also possible to integrate Redis Cluster with the Master-replica model in order to increase the level of availability.

# How Redis Performs Scaling (3)



# Redis indexing and queries (1)

Redis allows direct access to key-value pairs by knowing the key, which can be semantically meaningful (e.g. user:userId) with complexity O(1).

However, when dealing with hash values, access to secondary key is also possible, by exploiting Redis additional data structures.

# Redis indexing and queries (2)

There are two main types of indexes:

- Inverted index: used when indexing string fields inside hashes, for every term a specific list is maintained with the set of all documents containing this term

- Numeric index: a binary range tree where each numeric value is a node is maintained, so that also range operations can be performed

# Introduction to Document-Based Storage

- Similarly to key-value stores, also document-based storages store and retrieve data by means of an ID

- However, they were born to support structures such as array and data types inside every document

- Thus, it is is natively possible to perform queries and aggregations on single fields

# How MongoDB Stores Data (1)

In MongoDB, data records are stored as BSON documents


BSON is simply a binary representation of JSON documents, that extends some data types not available in JSON like dates, binary data, and also contains information like field length

# How MongoDB Stores Data (2)

Documents are gathered together in collections, which are ideally equivalent to RDBMS tables.
In turn, a collection is part of a single database.

MongoDB documents are:

- Polymorphic: fields can change from document to document within a single collection
- Self-describing: No need to declare fields priorly, they are described on-the-fly when creating and updating documents

# How MongoDB Stores Data (3)

Conversely to Redis, MongoDB stores data permanently on disk.

To ensure a greater level of data durability, however, it also exploits a system of checkpoints and data journal (similar to Redis AOF) which is also used during transactions to ensure consistency.

# How MongoDB Ensures Consistency

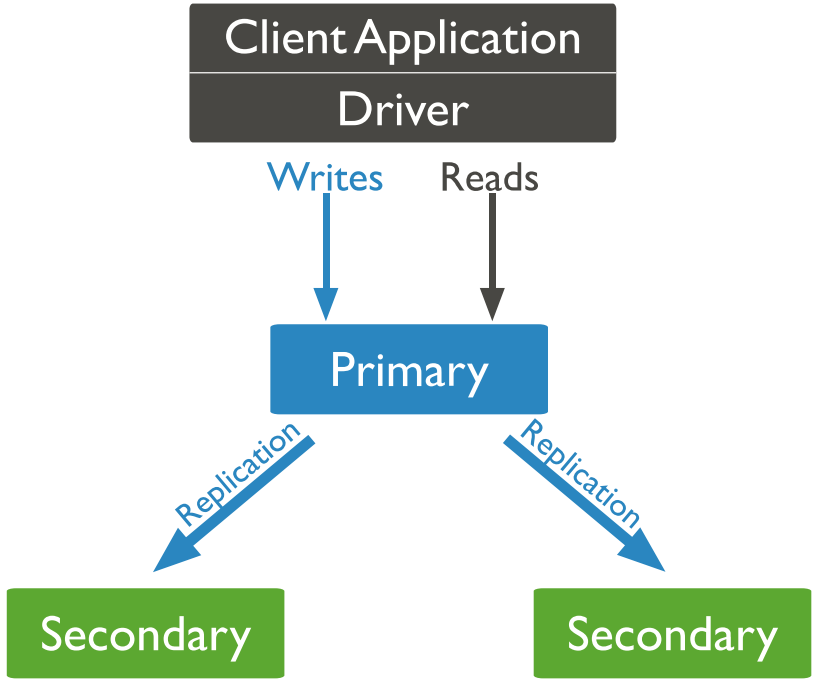
Operations that affect single documents within a collection are natively consistent.

For cases when an operation updates multiple documents within one or more collections, MongoDB supports transactions.

Transactions can also be executed on multiple Shards or Replica Sets.

# How MongoDB Ensures Availability (1)

Similarly to Redis, MongoDB provides increased data availability by replicating data inside a Replica Set



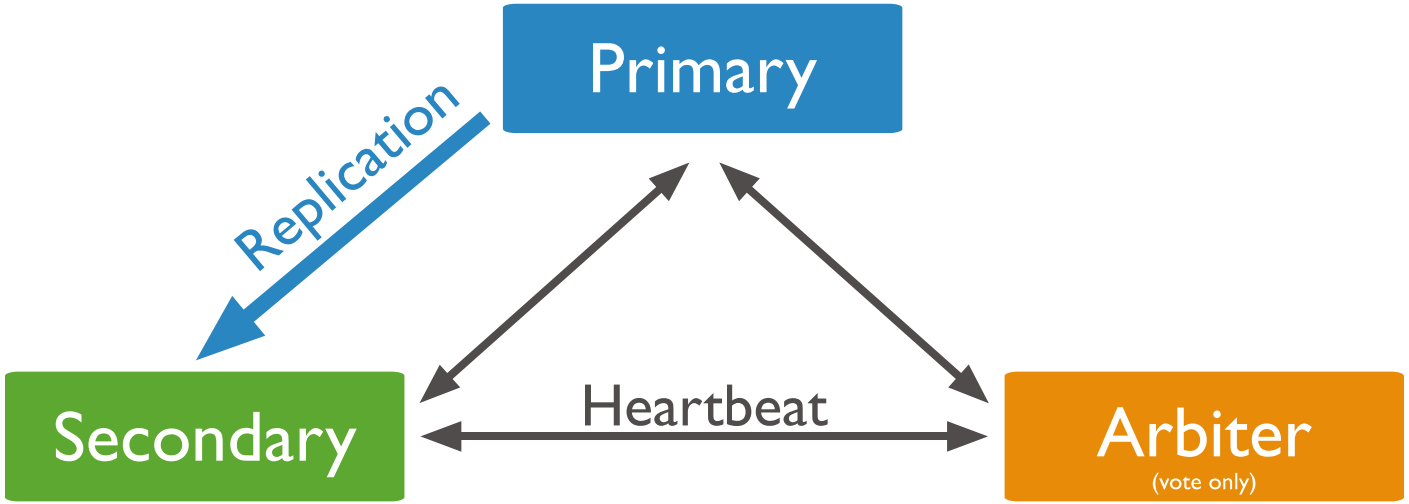
# How MongoDB Ensures Availability (2)

The primary node receives all read and write operations, while the secondary nodes only perform replicate these operations asynchronously such that their data set reflects the primary one.

When a primary node fails, a secondary node can ‘propose’ himself as the new primary, and elections are held.
A special type of node called Arbiter can be added, that doesn’t hold any data but can vote in an election.

# How MongoDB Ensures Availability (3)

Every two seconds, each member of the Replica Set can send an ‘heartbeat’ (ping) to every other member.
If a member does not answer, it is marked as inaccessible



# How MongoDB Performs Scaling (1)

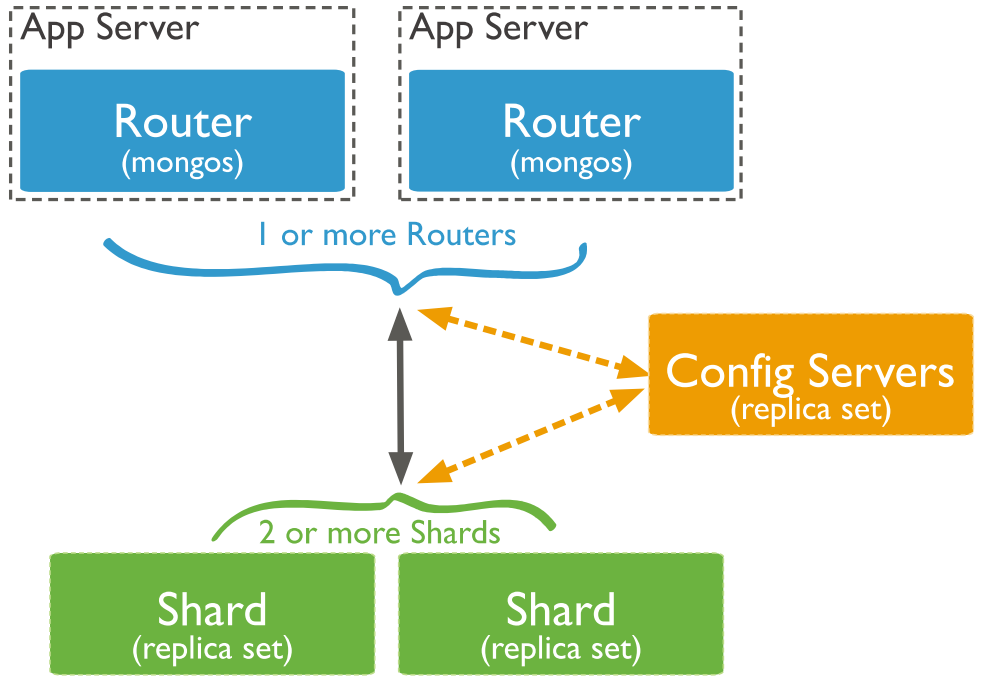
Just like Redis, MongoDB was developed with the clear goal of handling massive datasets that power Big Data use cases.

The same technical solution is implemented: horizontal scaling by means of sharding

# How MongoDB Performs Scaling (2)

Inside a sharded cluster, three main components are located:

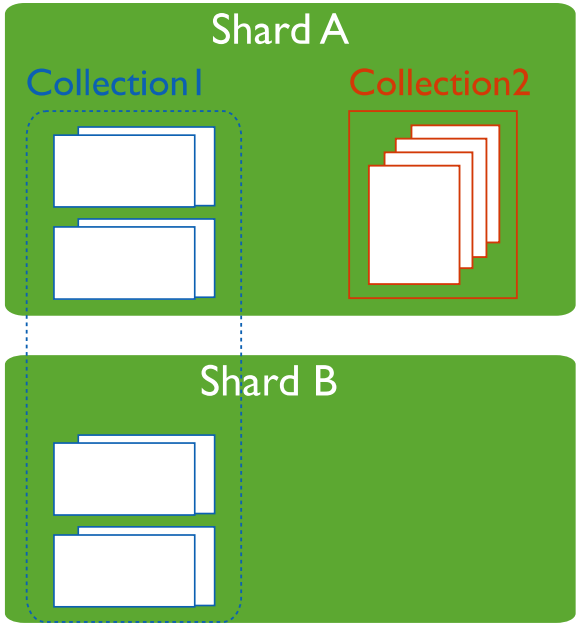
- Config servers: store metadata and settings for the cluster
- Mongos: Interface between application and shards, query router
- Shard: Actual Replica Set that contains data



# How MongoDB Performs Scaling (3)

MongoDB uses shard keys to distribute the documents of a collection across shards.

A shard key is composed by one or more document fields which are declared when sharding a collection.

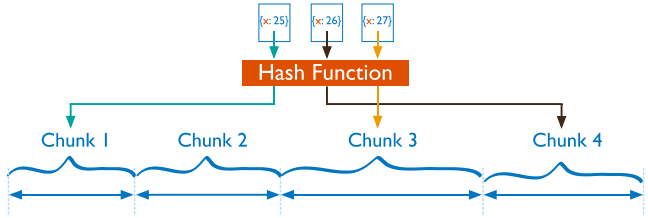



It is possible to have some sharded collections, whose content is distributed across partitions, while keeping unshared collections that can be located (entirely) on any shard.

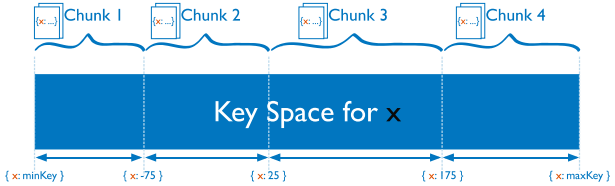
# How MongoDB Performs Scaling (4)

MongoDB supports two different strategies for distributing data between shards:

- Hashed sharding: computed by hashing the shardkey




- Ranged sharding: dividing data based on ranges defined on the shard key values



# Redis and MongoDB Recap (1)

| | Redis | MongoDB |
|---|---|---|
| Data Model | Key-Value | BSON Documents |
| Data Storage | In Memory | On Disk |
| Consistency | By default + transactions-like supported (multi-command ops) | By default + transactions supported (multi-collection ops) |
| Querying | Key lookups + optionally RediSearch, indexes specified priorly | Any field |
| Scalability | Yes, but harder to maintain with hashing | Yes, automatic data distribution |
| Availability | Possible, but no automatic failover detection | Natively supports automatic failover detection |

# Redis and MongoDB Recap (2)

- **Redis**: Best for **in-memory speed**, **caching**, **session management**, with **limited query support unless using RediSearch**

- **MongoDB**: Best for **flexible document storage**, **complex queries**, and **high write/read scalability** via **sharding**

# ...Thanks!

## References:

- Theoretical notions: LSDM Course taught by prof. Antonella Poggi
- Redis documentation
- MongoDB documentation
- GitHub: LSDM-Big-Data-Management