Redis

“It does not matter how slowly you go as long as you do not stop.”
- Confucius

RONIN™
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Outline

1. Introduction
2. How Redis Works?
    - Why is Redis So Fast?
    - How Redis store data?
    - Expired Deletion
    - Data Persistence
3. In Practices
    - Data Structures
    - Practices

1. Introduction

1.1. Definition

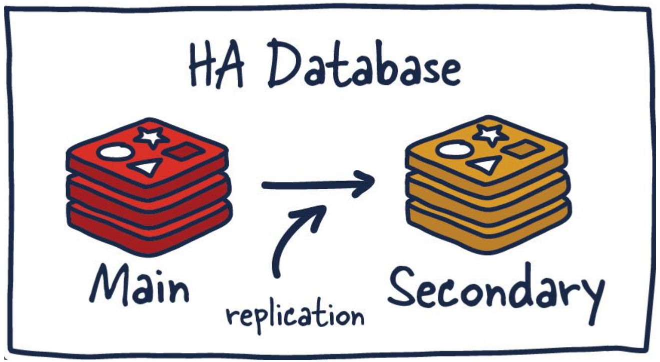
- Redis is an open-source, **in-memory** database.
- Redis provides **a variety of data structures** to support different business scenarios.
- Redis also **supports many features**: transactions, persistence, Lua scripts, multiple cluster solutions, publish/subscribe mode, memory elimination mechanism, …
- Use cases: caching, key-value database, message queue, …

1.2. Redis vs Memcached

- Similarities:
    - In-memory databases and generally used as cache.
    - Expiration policies
    - High performance
- Differences:
    - Redis (single-thread) runs on single core. Memcached runs multiple cores.
    - Redis is better on **read operations and memory efficient**.
      Memcached is better on write operations.
      > 16 GB impact to the performance of a single Redis instance.
    - Redis supports **more data structures.**
    - Redis supports **data persistence**. Memcached does not.
    - Redis supports **cluster mode**. Memcached does not.
    - Redis provides **other features**: transaction, pub/sub, lua script, …

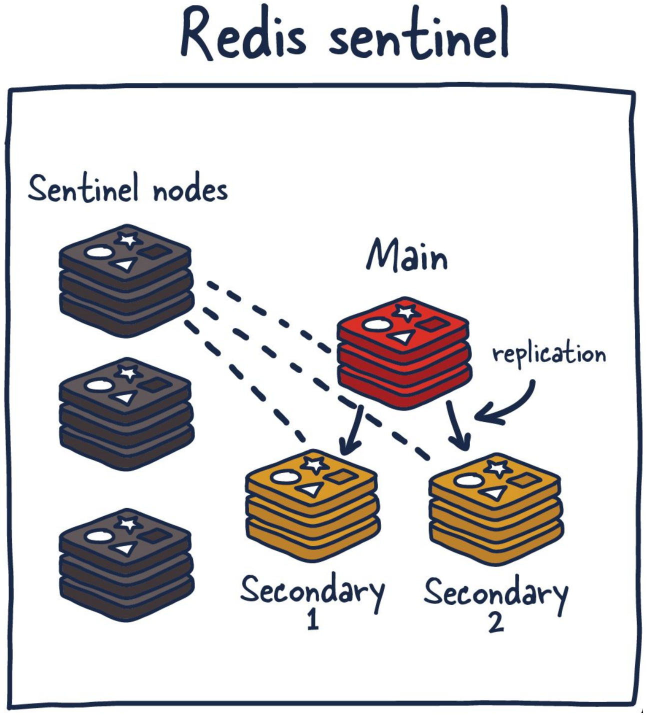
1.3.1. Architecture / Master-Slave

- Replication: Data is written to a master instance. The main instance sends copies of those commands to a replica asynchronously
- Pros:
    - Scalable for reads
- Cons:
    - Data inconsistency
    - **Failover. If master is down, which slave would become the new master?**
- To solve failover:
    - Sentinel
    - Cluster



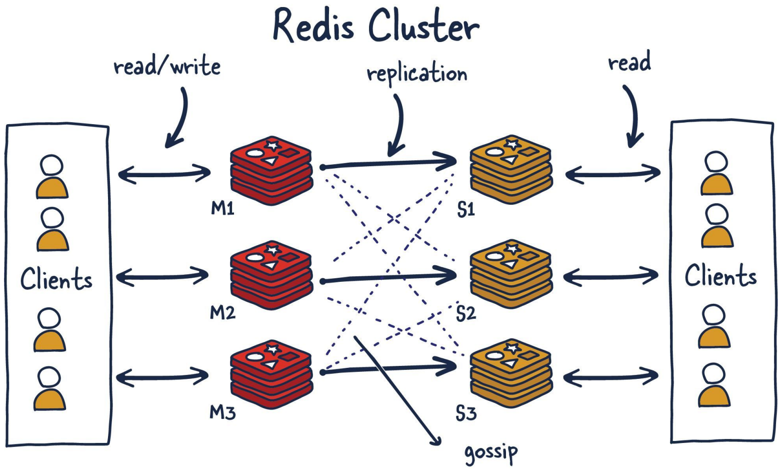
1.3.2. Architecture / Sentinel

- Sentinel mode can monitor the master and slave servers
- In addition, sentinel node serves a role in service discovery
- When master goes down, sentinels node elect 1 node as leader to decide which slave becomes master and configure other slaves to follow the new master.
- Pros:
  - Solve Failover
- Cons:
  - Data inconsistency
  - Operational Overhead
  - **Not scale for writes. All writes go to master**



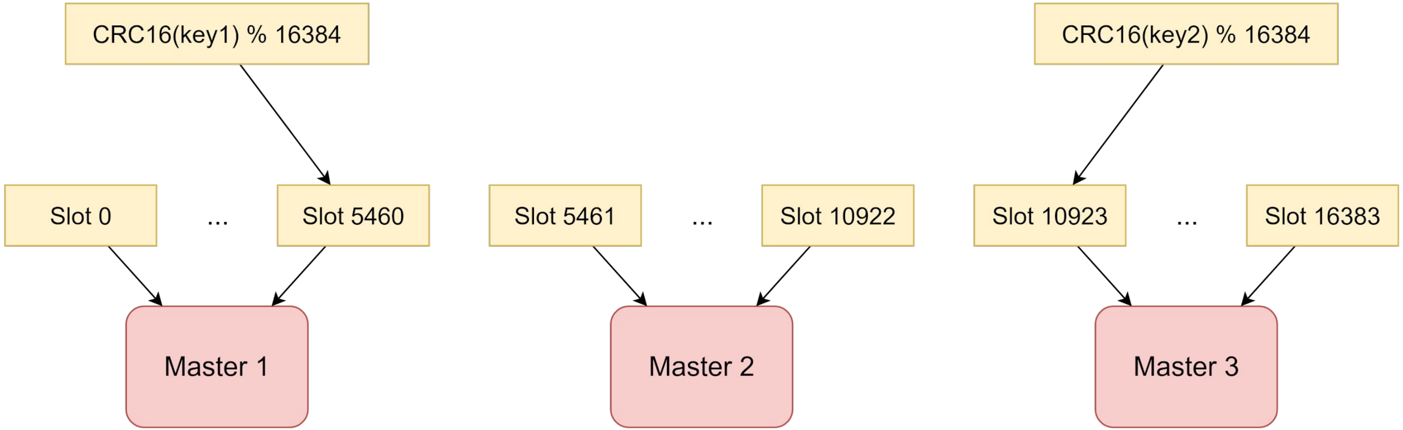
1.3.3. Architecture / Cluster

- Distributes the data on different servers
- Pros:
  - Solve Failover
  - Reduce the system's dependence on a single master node
  - Scalable for read and write
- Cons:
  - Data inconsistency
  - Operational Overhead
- Choose one of modes:
  - Master-Slave
  - Sentinel
  - **Cluster (recommended)**



1.3.3. Architecture / Cluster

- Hash Slots handle the mapping relationship between data and nodes
- A cluster has a total of **16384 hash slots**
- Even distribution on nodes in a cluster
- **One hash slots can have multiple keys**

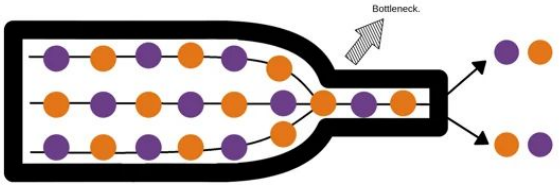


2. How Redis Works?

2.1. Why is Redis So Fast?

2.1.1. Redis Bottleneck

- What are **bottlenecks** of Redis?
    - **Memory**
    - **Network bandwidth**
    - **Not CPU**



2.1.2. Why is Redis So Fast?

- **In-Memory**
- **Single Thread Model**
  - CPU is not the bottleneck
  - Avoid context switching for multi-threads
  - Multi-threading app require locks or other synchronization mechanisms → complexity, bug prone → difficult to gain performance
- **Multiplexing I/O**
  - One thread processes multiple IO streams
- **Efficient Data Structures**

2.1.3. Note

- How to maximize CPU usage?
- Run multiple instances of Redis in the same server/machine
- After version 6.0, Redis is not single-threaded actually
    - Main thread execute commands
    - Other threads handle data persistence, network I/O

2.2. How Redis Store Data?

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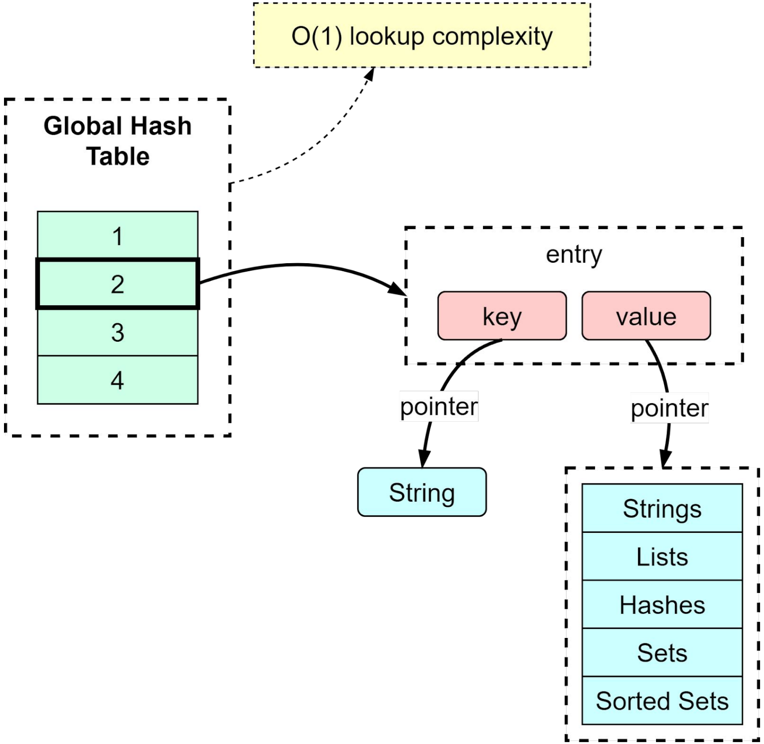
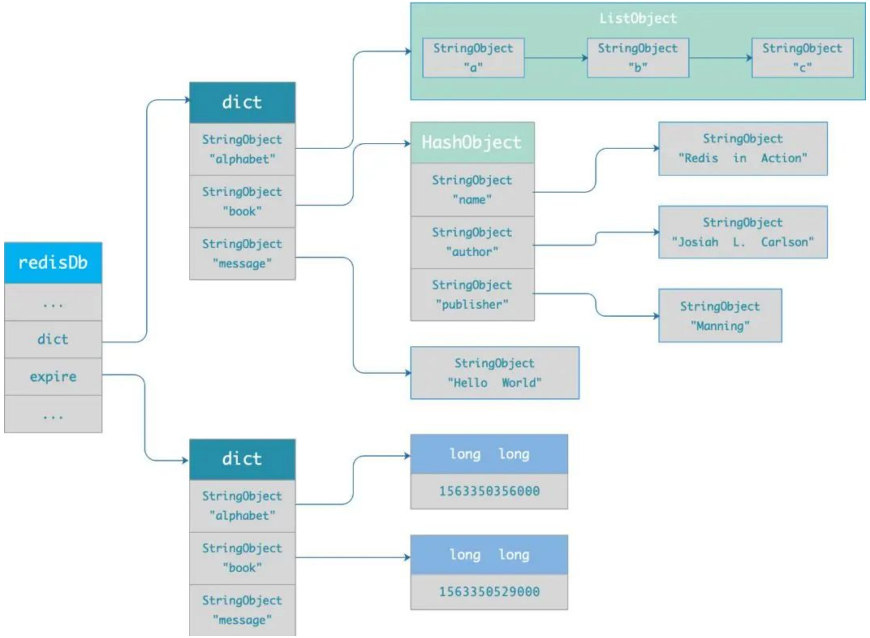
- A dictionary is a hash table → quick search O(1)



2.3. Expired Deletion

2.3.1. How to determine if the key has expired?

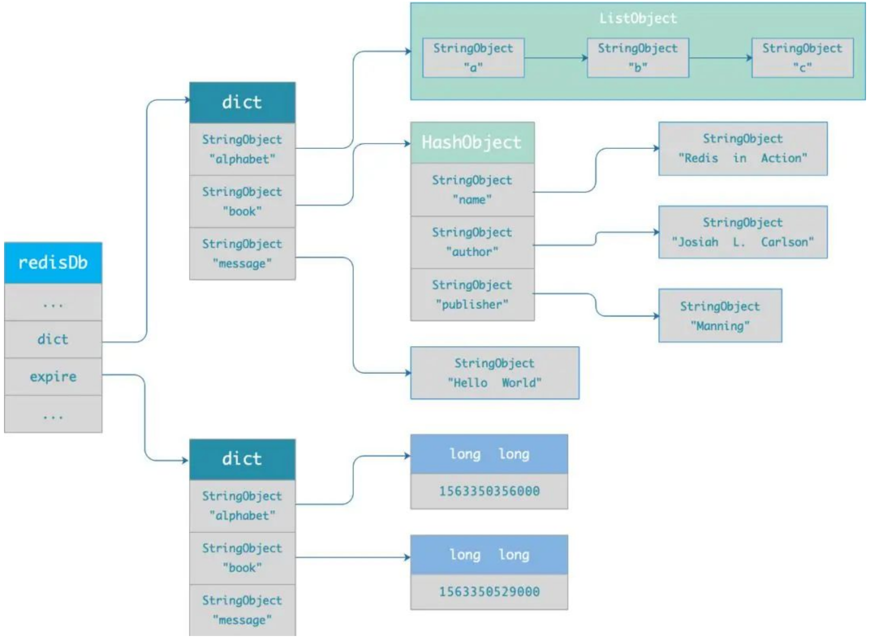
- 2 dictionaries:
  - Key dictionary
  - Expire dictionary
- When accessing a key, Redis first check if the key exists in the expire dictionary
  - If not, read the key value normally
  - If it exists, then compare with current time.
  - If it is smaller than the current time
    → expired
    → return null



2.3.2. What are the expiration deletion strategies?

- **Passive Way**:
  - Key is not deleted immediately right after expiration.
  - When the key is accessed, if it expires, then delete the key asynchronously.

→ Problem: some keys is never accessed after they are created
→ memory space wasted



2.3.2. What are the expiration deletion strategies?

- **Active Way**: Periodic job (activeExpireCycle): 10 times/s
  - Randomly select 20 keys from the expired dictionary
  - Check whether these 20 keys have expired and delete the expired keys
  - If the number of expired keys exceeds 25% of the number of randomly selected keys, continue to repeat step 1. If it does not, then the current job stops and wait for the next round

→ Problem: if the active job is long, active job will block other requests.

→ Set timeout for active jobs

2.3.2. What are the expiration deletion strategies?

- **Combine 2 ways: passive way + active way**
- **Problem:** Finding expired keys is not effective
- **New Approach**: Expiration of keys is stored in a Sorted Set (ZSET)
  → find expired keys more effectively

What happens when Redis memory is full?

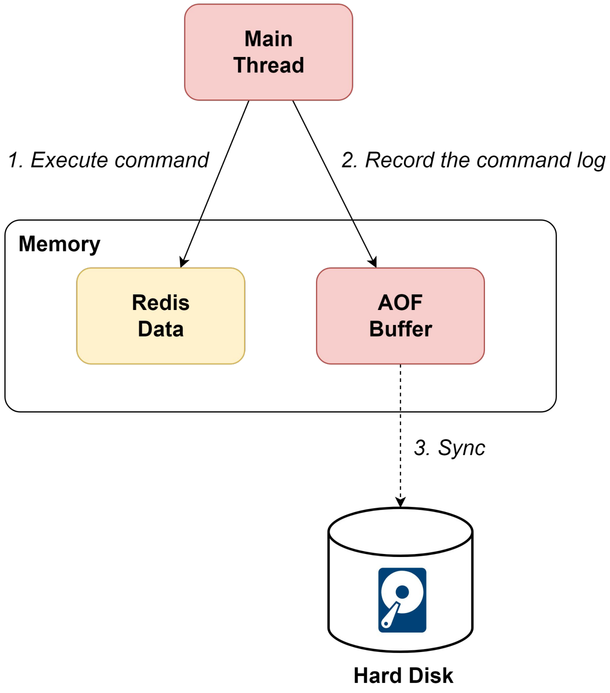
2.4. Memory Eviction

- Noeviction: The default memory eviction
- Random
- TTL: prioritize the elimination of key values that expire earlier
- LRU (Least Recently Used)
- LFU (Least Frequently Used)

2.4. Data Persistence

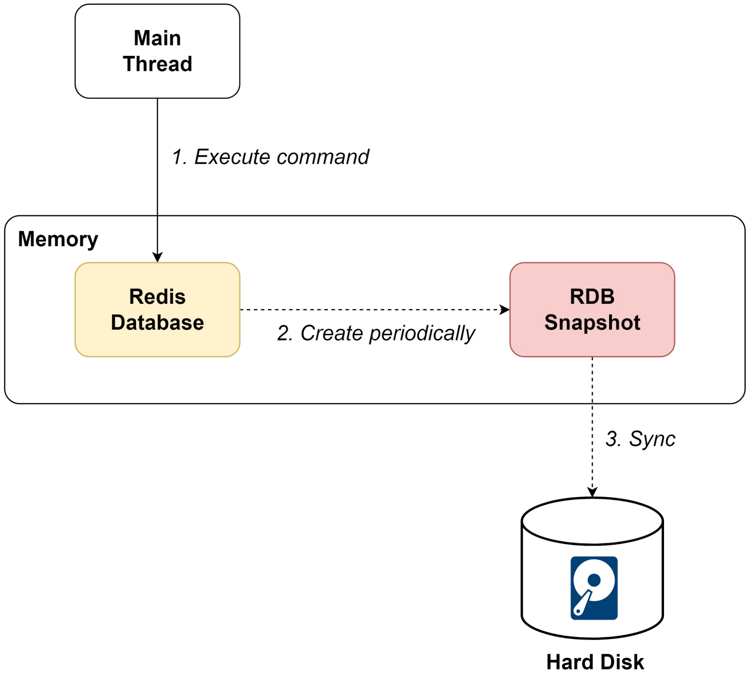
2.4.1. AOF (Append Only File)

- Pros:
  - Avoid additional checking overhead
  - Do not block the execution of the current write operation command
  - Less data loss
- Cons:
  - Data loss
  - May **block other operations**
  - If too many AOF logs → **slow recovery**



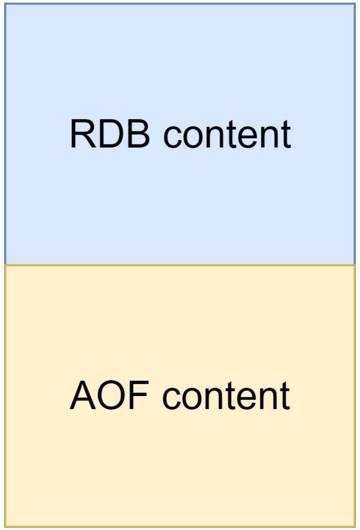
2.4.2. RDB (Redis Database)

- **The default mode**
- 2 ways to generate RDB files:
  - Save command: RDB is generated in the main thread → blocking the main thread
  - Bgsave command: a child process generates RDB → avoid blocking the main thread
- Pros:
  - Fast Recovery
- Cons:
  - **Data loss**
  - **A relatively heavy operation**



2.4.3. Hybrid

- Pros:
  - Less data loss
  - Fast recovery
- Cons:
  - Poor readability
  - Poor compatibility. Hybrid persistence AOF file cannot be used in versions prior to Redis 4.0



Hybrid Persistence

3. In Practices

3.1. Data Structures

3.0. Question

- User object: {uid, username, email, age}
- Requirements:
  - C1: access username only
  - C2: update age only
  - C3: get all fields
- Which data structure should we apply for the above 3 cases?
  - Hash
  - String Json

3.1.1. String

- Implementation: SDS (Simple Dynamic String)
  - **SDS can save not only text data, but also binary data**
  - SDS is **safe**, concatenating strings will not cause buffer overflow
- Applications
  - Cache objects (JSON)
  - Count
  - Share session
  - Distributed Lock*

3.1.2. List

- List is a simple list of strings, sorted in insertion order
- Elements can be added to the head or tail of List.
- Applications
  - Store list of elements
  - Message Queue
- Limitation:
  - The maximum length of List is 2^32 - 1
  - List does not support multiple consumers
  - Weak order preservation

3.1.3. Hash

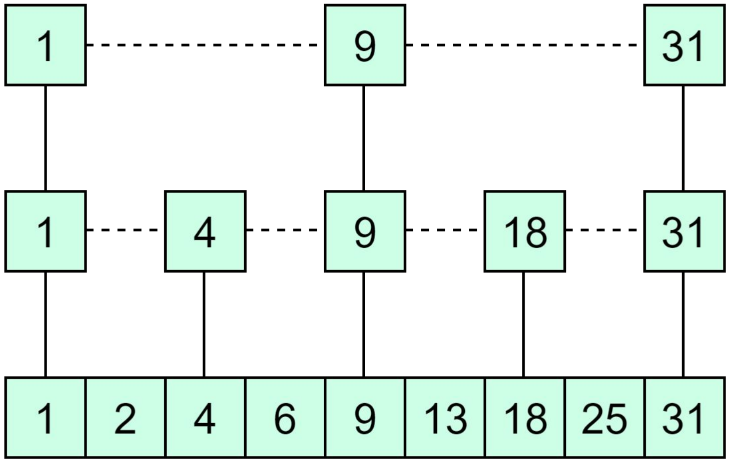
- Implementation: **hash table**
- Applications
  - Storing objects if frequently access or update attributes in objects
  - Shopping cart
    - Add item: HSET cart:{user_id} {product_id} 1
    - Increase Quantity: HINCRBY cart:{user_id} {product_id} 1
    - Total number of items: HLEN cart:{user_id}
    - Delete item: HDEL cart:{user_id} {product_id}
    - Get an item: HGET cart:{user_id} {product_id}
    - Get all items in the shopping cart: HGETALL cart:{user_id}

3.1.4. Set

- Set is an unordered and unique set of key values, and its storage order will not be stored in the order of insertion.
- Implementation: **hash table**
- Applications
  - Deduplication of data and ensuring the uniqueness
  - Function on sets: difference, union and intersection
  - Likes, common followers, …
- Limitations:
  - Max: 2^32-1 elements
  - The calculation complexity of functions on sets is relatively high. → block the main thread

3.1.5. Sorted Set (ZSET)

- Set is an ordered and unique set of key values, and its storage order will not be stored in the order of insertion.
- Implementation: **Skip List**
- Applications
  - Sorting
  - Ranking, Leaderboard



3.2. Practices

3.2.1. How to implement a delay task?

- Context:
  - When ordering a taxi, if there is no car owner to take the order within 10 minutes
  - The platform will cancel your order automatically
  - Remind you that there is no car owner to take the order at the moment
- **Use an sorted set (ZSet)**
- Add element:
  - Value: order_id
  - Score: expiration time
- Poll to get expires order

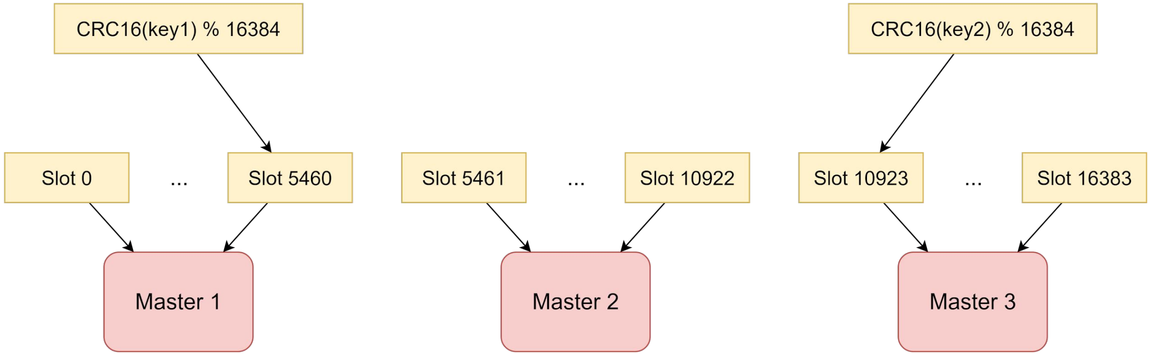
Key	Value	Score (timestamp)
o1	u1	1704790435
o2	u34	1704793232
o3	u88	1704797344

3.2.2. How to deal with big keys in Redis?

- Big key:
  - The value of type String is greater than 10 KB
  - The number of elements of Hash, List, Set, and ZSet types exceeds 5000
- Effects:
  - Time-consuming → timeout
  - Network congestion
  - Block the worker thread when deleting
  - Memory is unevenly distributed
- Approach:
  - Use the SCAN, HLEN, SCARD, MEMORY USAGE command to find the big key
  - Do not use DEL
  - Recommended: UNLINK. Asynchronous Deletion: Unlink + configure

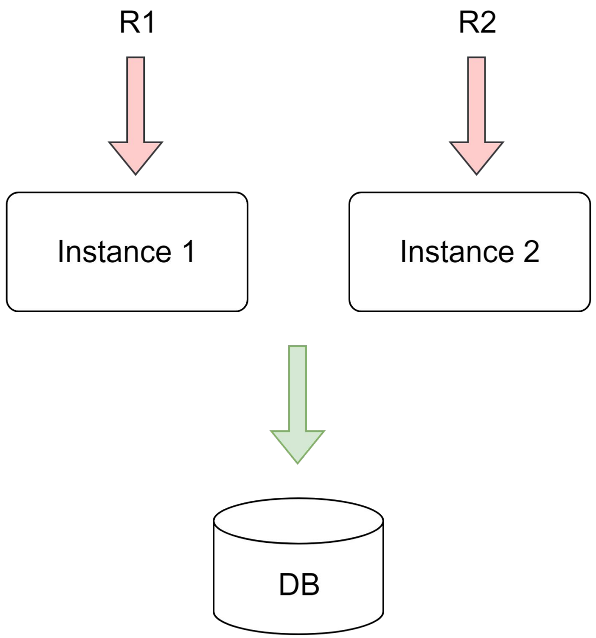
3.2.3. How to put different keys on a node?

- Limitation:
  - Functions on 2 sets on 2 different nodes → does not work
  - 2 sets in the same hash slot → works
- Use Hashtag
  - Key 1: User_profile:{34}
  - Key 2: User_session:{34}



3.2.4. How to implement distributed locks?

- Problem: Race condition
  - Context: 2 requests concurrently
  - Expectation: **1 request is processed at a time**
- **Use [SETNX]()**
- Process:
  - SET lock_key value NX PX 10000
  - DEL (UNLINK) lock_key



3.2.5. Best Practices

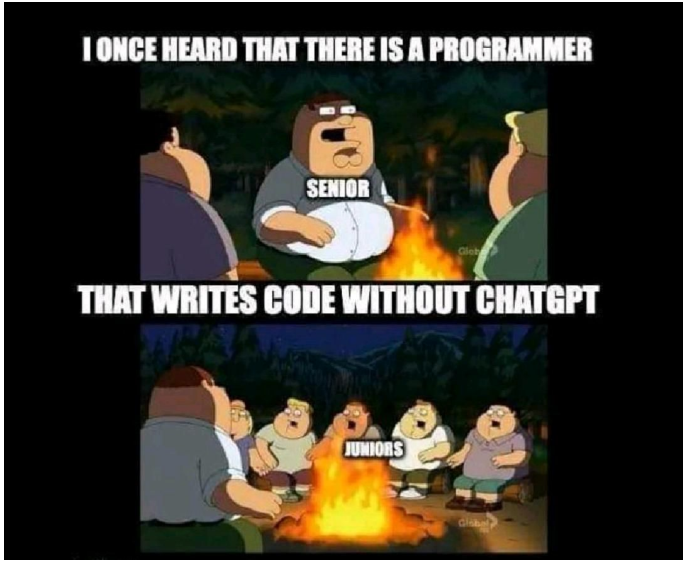
- Run Redis cluster
- Leverage multi get, pipelines
- Avoid long-run tasks
- Normally set short TTL
- Distribute TTL → avoid thundering herd
- Pick right data structures
- Leverage hashtag
- Understand the time complexity of each command
- [Performance Tuning Best Practices]
- …

Recap

- A cluster has a total of 16384 hash slots. Data is distributed into hash slots.
- CPU is not the bottleneck. Single thread model makes sense
- Leverage data structures and features. Specially care about distributed lock.

Homework

- Implement Distributed Lock
  - 2 requests booking the same seat (A34_S012C) on a flight (FA634)
  - No need to implement DB and booking logic



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