Caching Design

“A man who doesn't spend time with his family can never be a real man.”
- Mario Puzo, The Godfather

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What are Cache Challenges in Your Work?

Outline

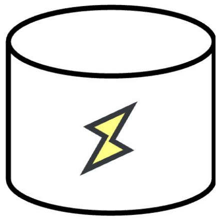
The journey of Dũng, my best friend.

Good Habit: Ask “What is it? Why?” always

1. Cache Introduction

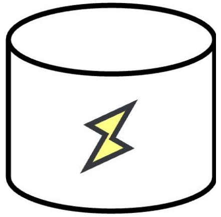
1.1. Cache Introduction

- A cache is a hardware or software component that **temporarily stores data**
- Future requests for that data can **be served faster**
- The data in cache:
  - **A copy** of data from data source
  - The result of an **earlier computation**
- Cache is a shield for DB

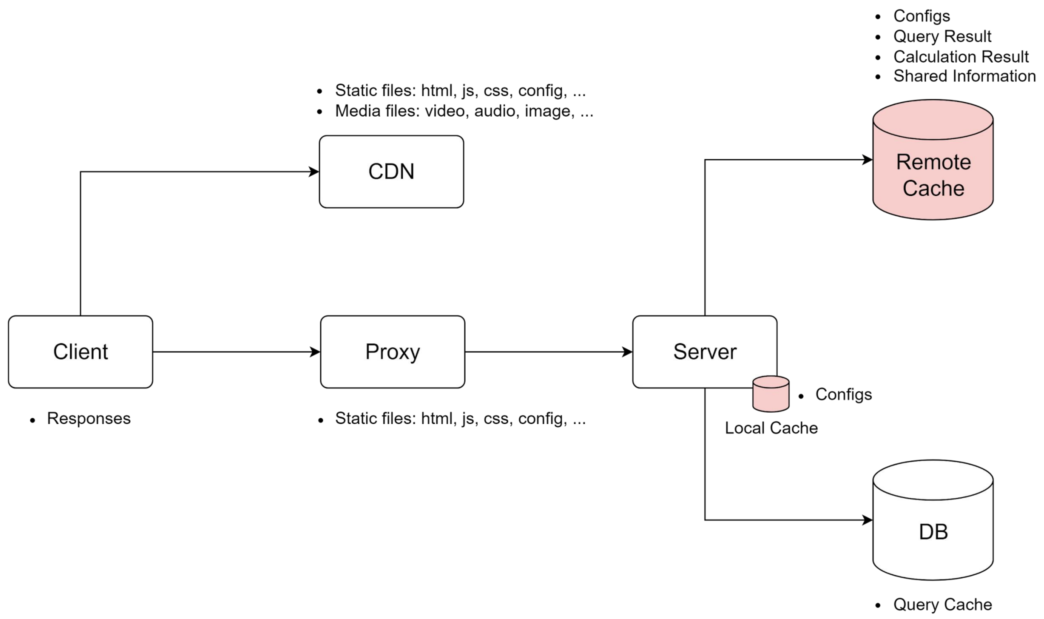


1.1. Cache Note

- Trade-off
  - **Performance vs Cost (Space, Operation)**
  - **Performance vs Consistency (sometime)**
- Cache is more suitable for hotspot data.
- The cache hit rate is the most important metric for caching.
  - Follow 80/20 principles to achieve a high hit rate.
- Cache != buffer
  - The buffer is an area for temporary storage (memory or disk) of data, which will be transmitted to other component later.
  - Buffer is like a queue.



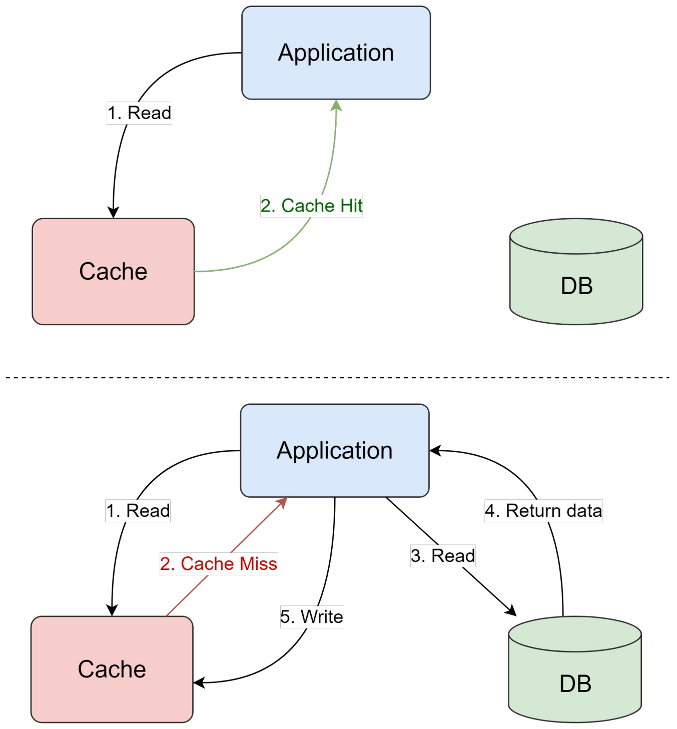
1.2. Where Is Cache Used



2. Cache Strategies

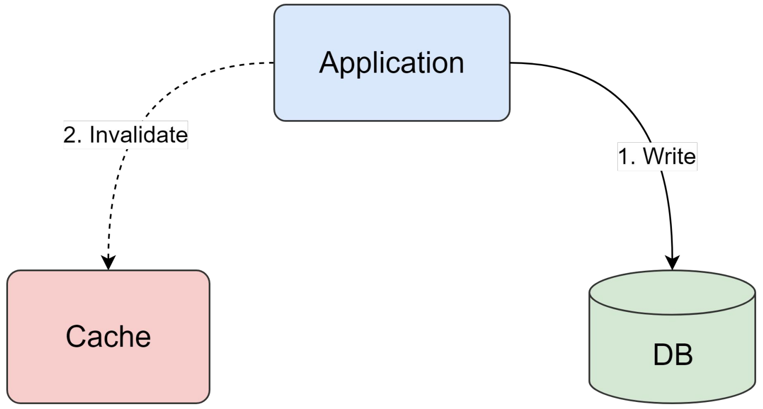
2.1. Read Strategies

- Read strategies
  - Read-Through
  - **Read-Aside**
- Read-Aside
  - Pros:
    - **Tolerate cache failures**
    - **Flexible for data models**
  - Cons:
    - Complex for app
    - Data inconsistency



2.2. Write Strategies

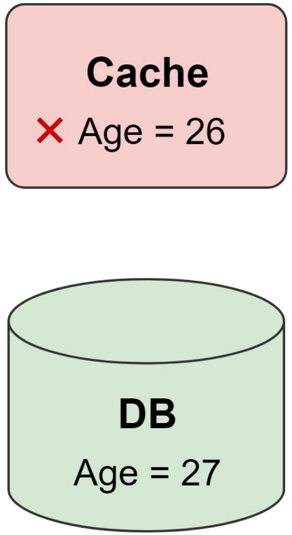
- Write strategies:
  - Write-Through
  - Write-Back (computer architecture)
  - **Write-Around**
- Write-Around
  - **Invalid cache asynchronously**
  - Pros:
    - **Decoupling cache and storage systems**
  - Cons:
    - Inefficient for Frequently Updated Data
    - Data inconsistency



What is The Common Problem?

2.3. Data Inconsistency

- The common problem: Data Inconsistency
- **Solution: Cache Invalidation**
- Cache Invalidation is removing data that is no longer valid or useful
- Types of Cache Invalidation:
    - **Time-based**
    - **Command-based**
    - **Event-based**
    - Group-based



2.3. Why Cache Invalidation is Hard?

The reason is the complexity of:

- Timing
  - How long enough for Time-To-Live (TTL)?
- Concurrency
  - **Race condition**
- Data relationships
- **Unlike Database, Cache can be everywhere and anywhere.**
- **Hard to finding root causes.**
  - Things can go wrong in a million different ways …

Let’s Try to Solve Data Inconsistency

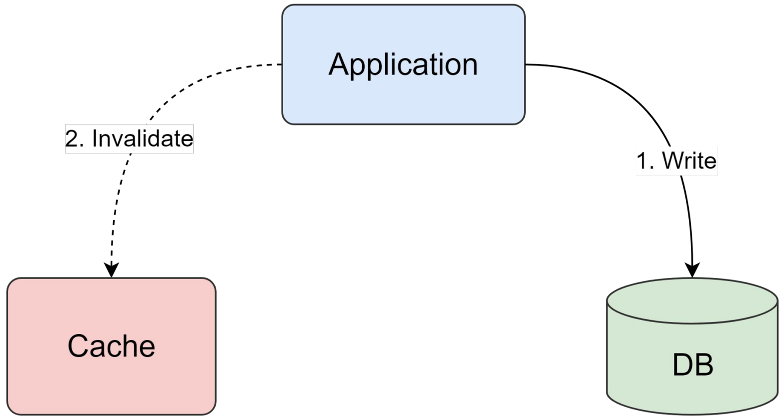
No more deal with Read-Aside

Dive into Write-Around

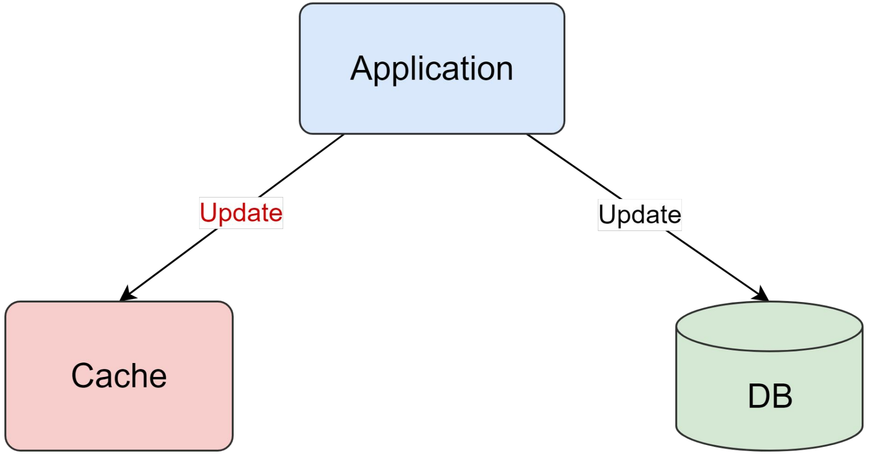
2.4. Write-Around

- Command-based Cache Invalidation (OR):
  - Update (replace)
  - Delete

→ The First Try: Update Cache



2.5. The First Try: Update Cache



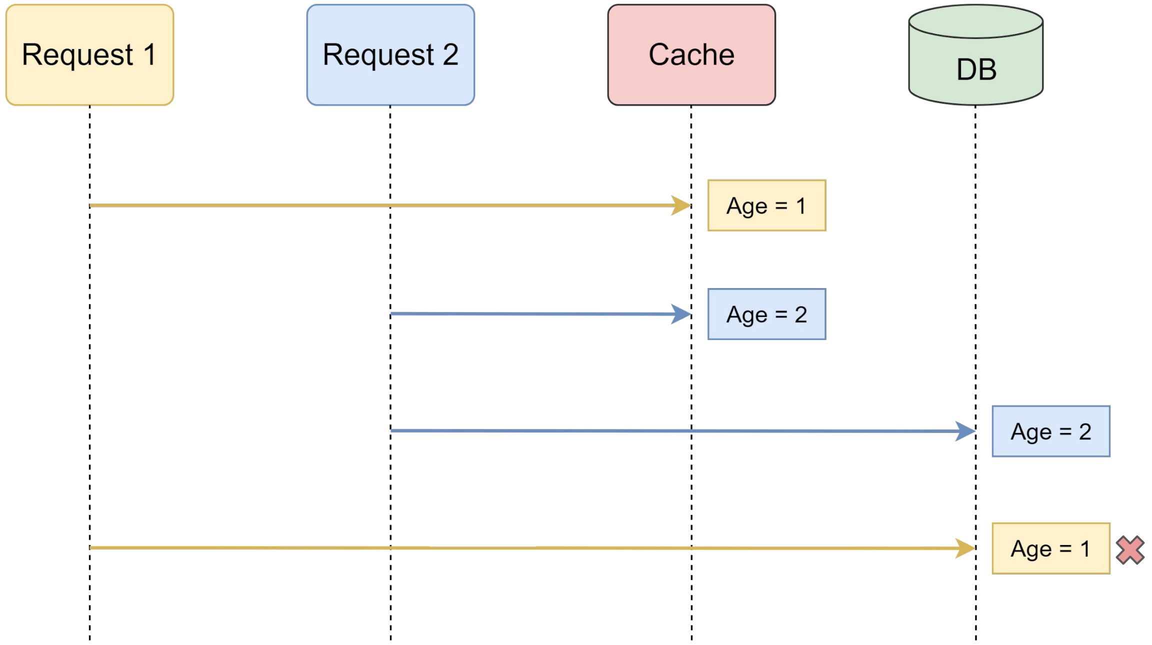
Update Cache First or Update Cache Later?

2.5.1. Update Cache First

Race condition:

- 2 write requests

→ **DB is wrong**

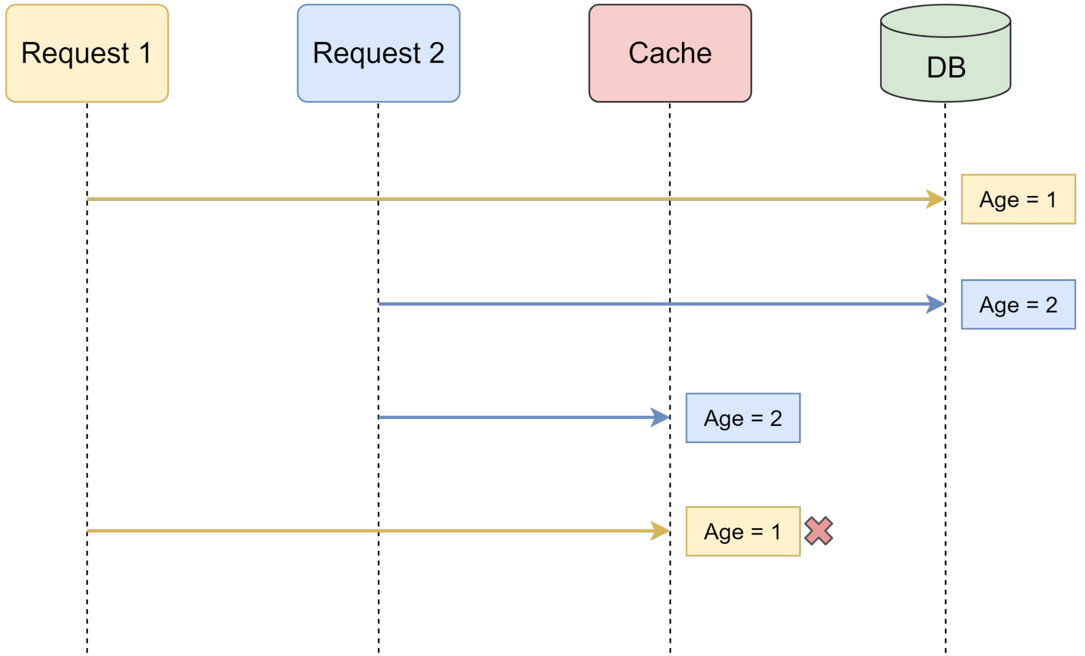


2.5.2. Update Cache Later

Race condition:

- 2 write requests

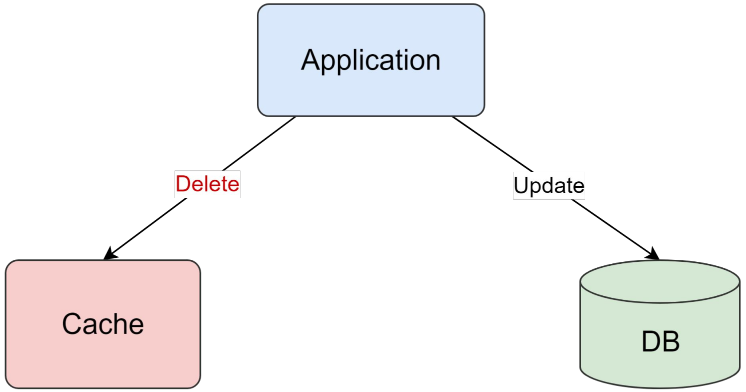
→ **Cache is wrong**



2.5.3. The First Try: Update Cache

→ Updating cache first or later **does not solve the problem Data Inconsistency at all.**

→ The Second Try: Delete cache?

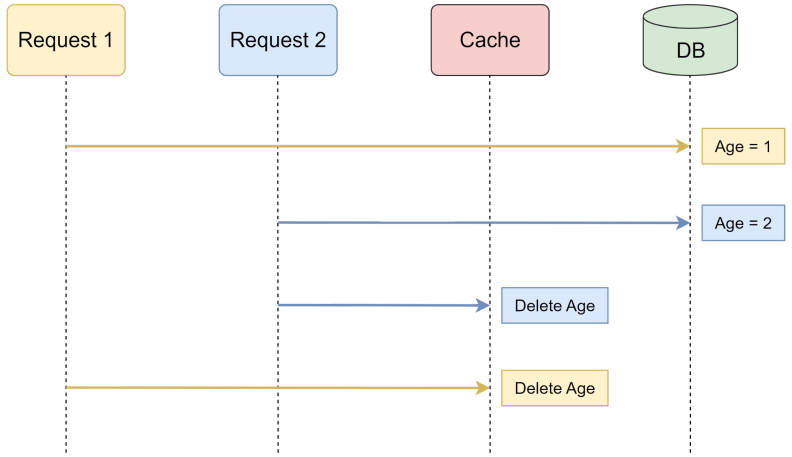


2.6. The Second Try: Delete cache

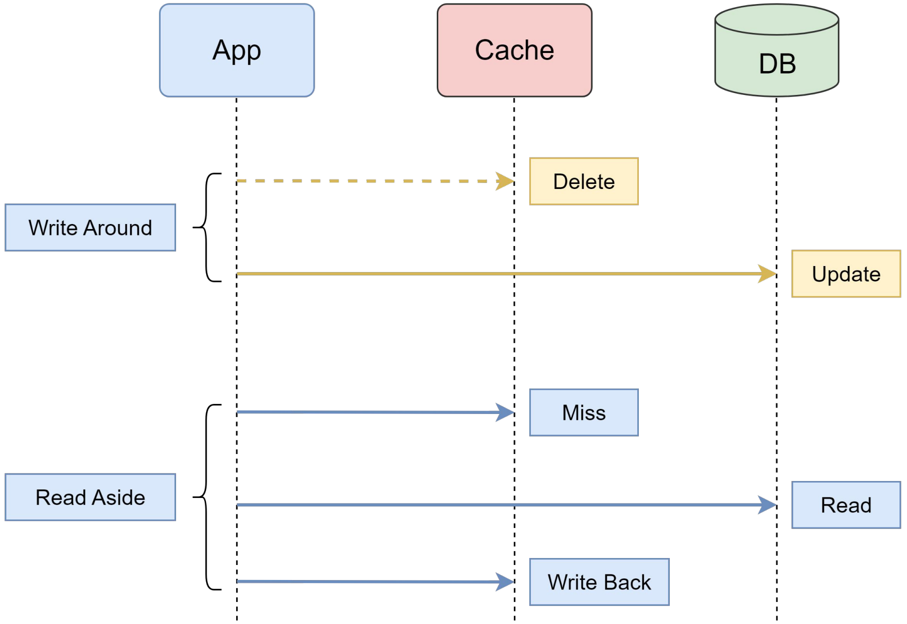
- 2 write-around requests in a race condition with deleting cache in any order

→ **DB is right, no data in cache** after 2 writes

→ The third try: Read-Aside + Write-Around with Deleting cache (called RA+DWA)



2.7. The Third Try: Read Aside + Delete Write Around

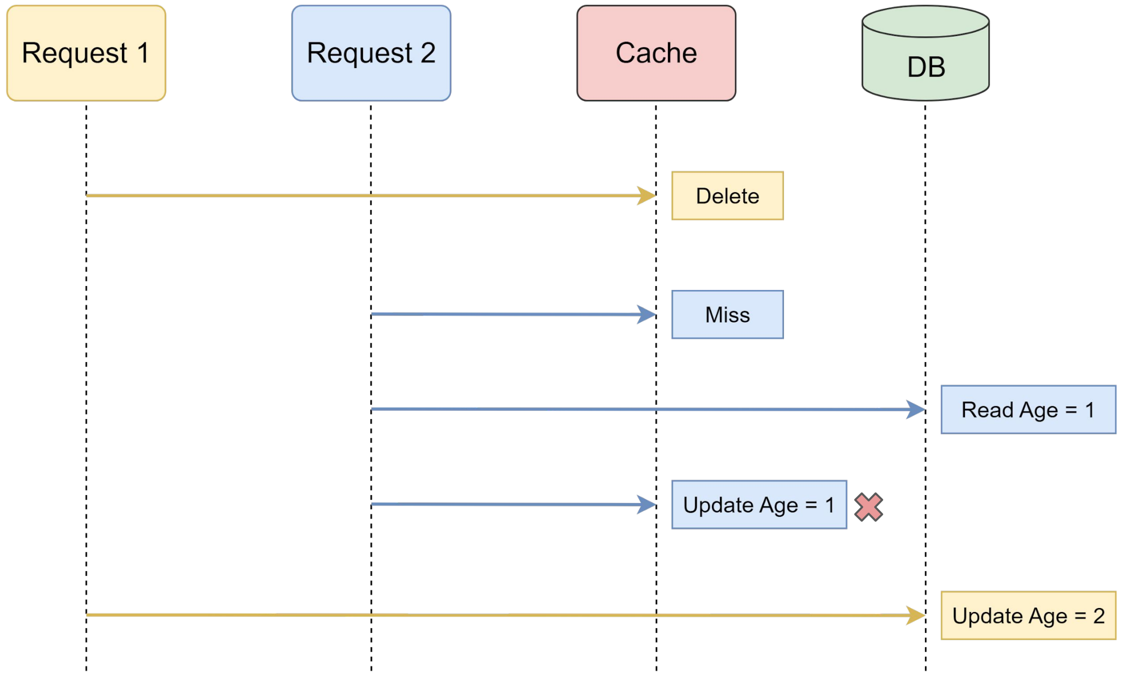


2.7. The Third Try: Delete Cache First

Race Condition:

- Request 1: Write
- Request 2: Read

→ **DB is right, cache is wrong**

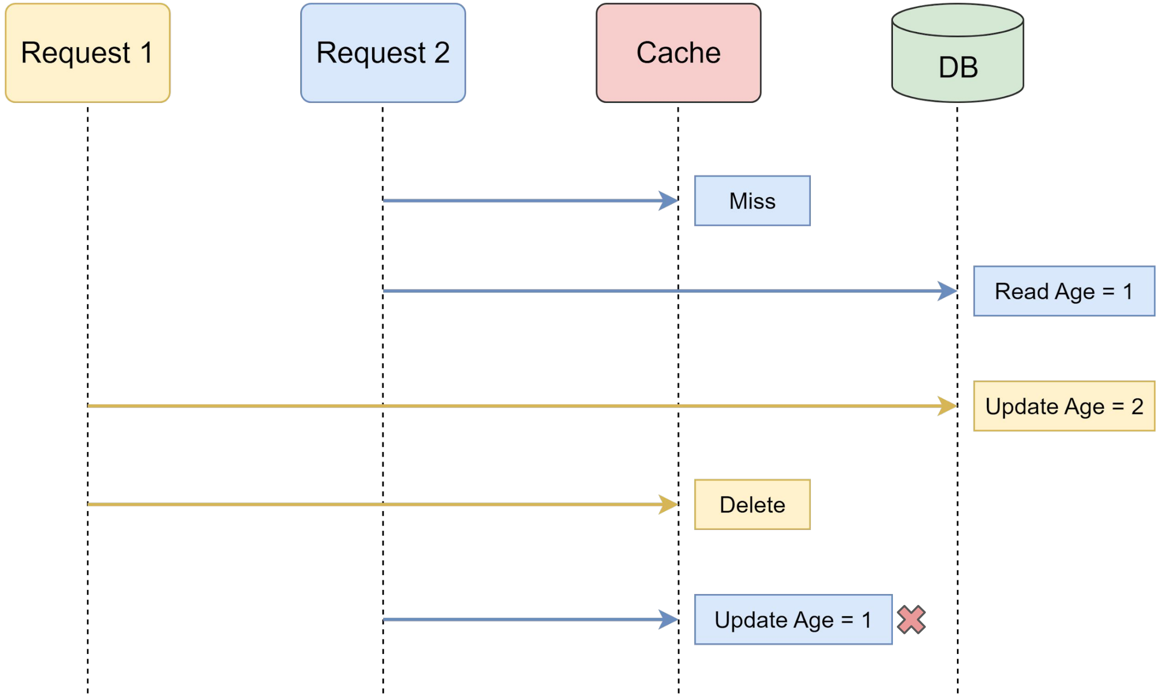


2.7. The Third Try: Delete Cache Later

Race Condition:

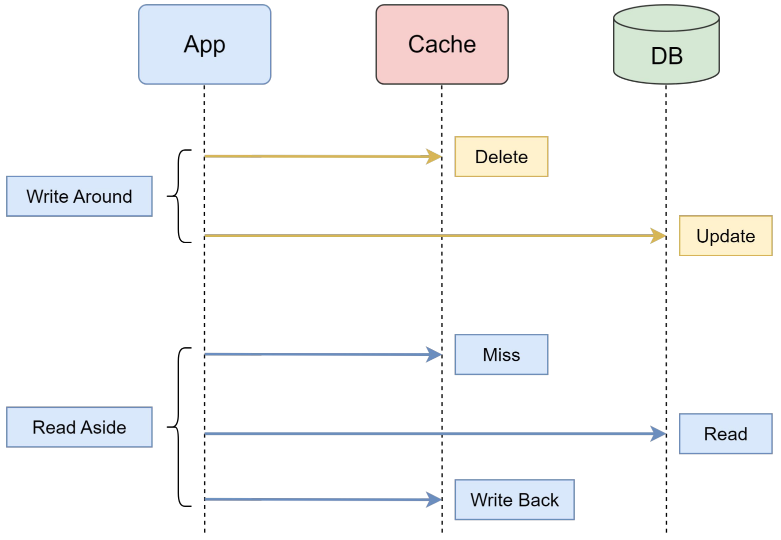
- Request 1: Write
- Request 2: Read

→ **DB is right, cache is wrong**



2.7. The Third Try: DWA+RA

- Data Inconsistency still!
- Choose one appropriate write strategy? **Why?**



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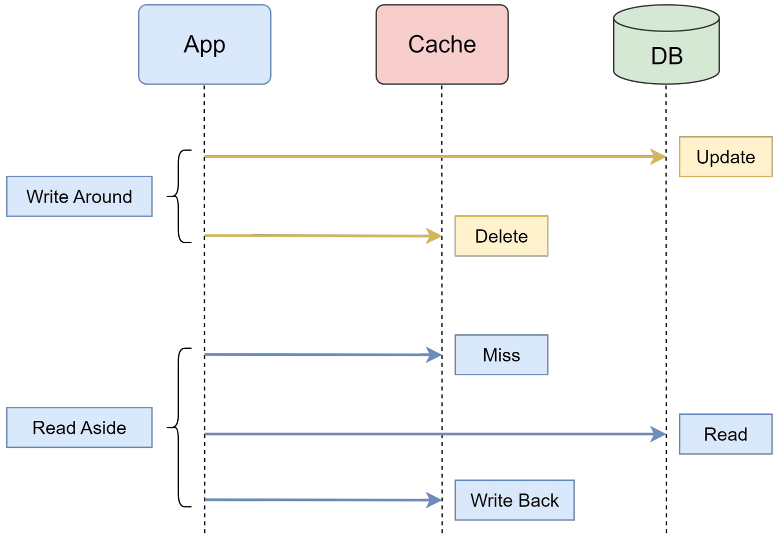

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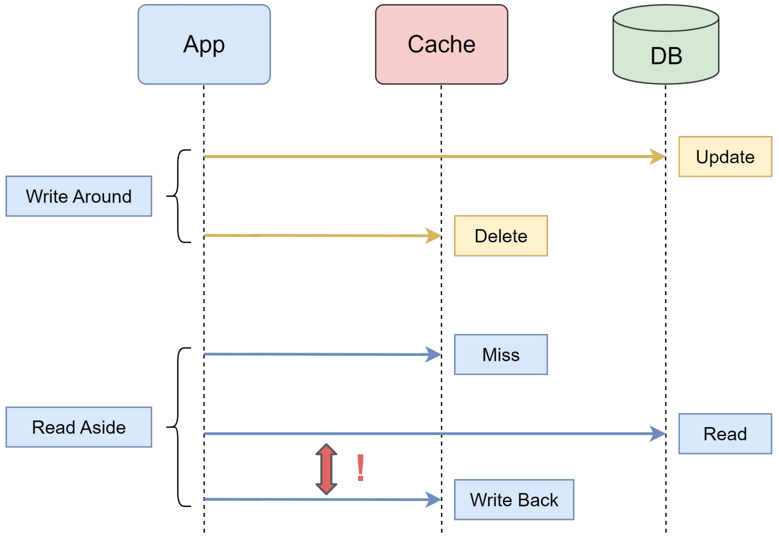
2.7. The Third Try: RA+DWA

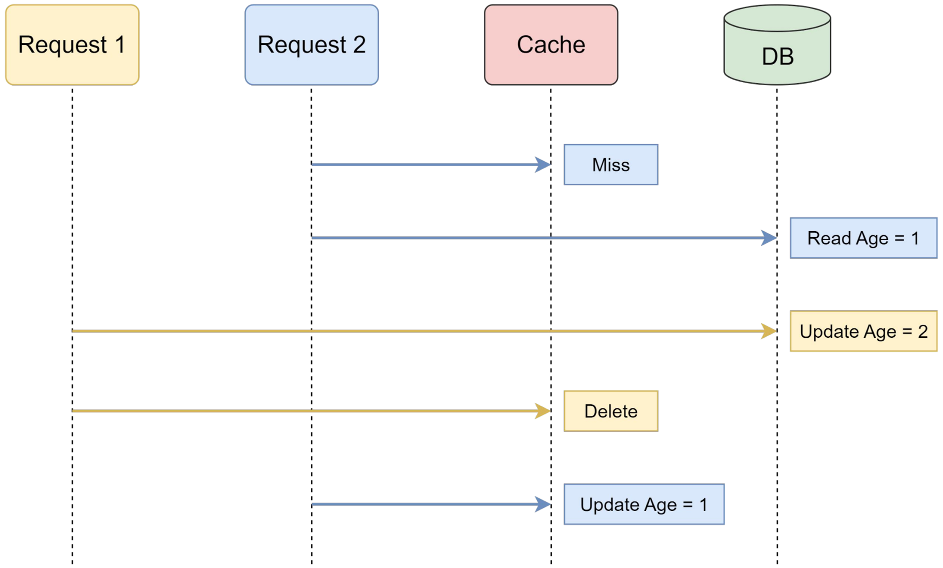
Answer:

- Update DB first, delete cache later
- Popular combination: Read Aside + Write Around (deleting cache)
- Because in practice, cache writes are usually much faster than DB writes
  → the probability that write operators is between read operators is **very low**



2.7. The Third Try: RA+DWA

- How can we mitigate the impact?
- Add **short TTL** to cache data



3. Challenges

3.1. Reliability Challenges

3.1.1. Problem 01: No Atomicity

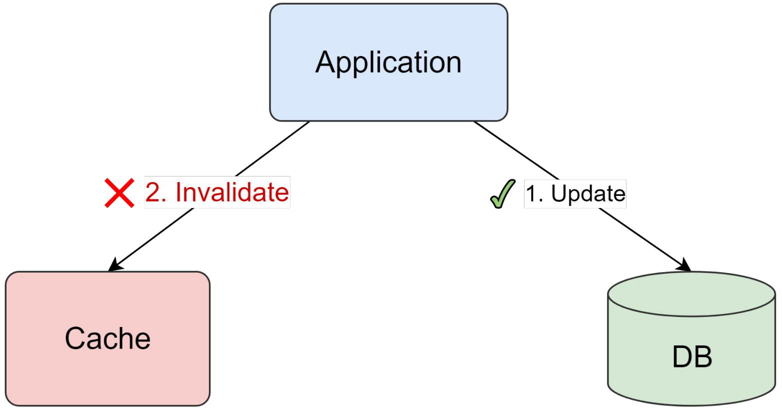
Problem Context:

- Customer X updates age from 33 → 34
- But customer X complains that it needs some time to take effect.
- Use Read-Aside + Write-Around
- The profile of customer X in cache

Cause: Updating DB is done, but invalidating cache **failed.**
→ Old value is in cache still, taking some time to take effect due to TTL

Solutions:

- **Retry**
- Subscribe to binlog of DB



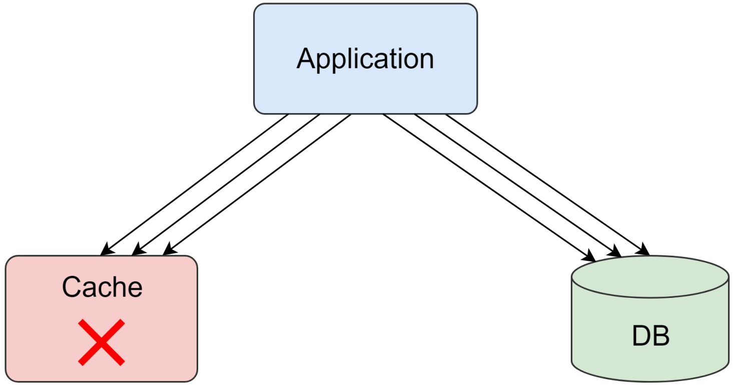
3.1.2. Problem 02: Cache Avalanche

Problem:

- Cache goes down for some reason
- There are a large number of requests at this time → DB down

Solutions:

- **Cache Cluster** → High Availability
- Rate Limit / Circuit breaker
- Cache Recovery



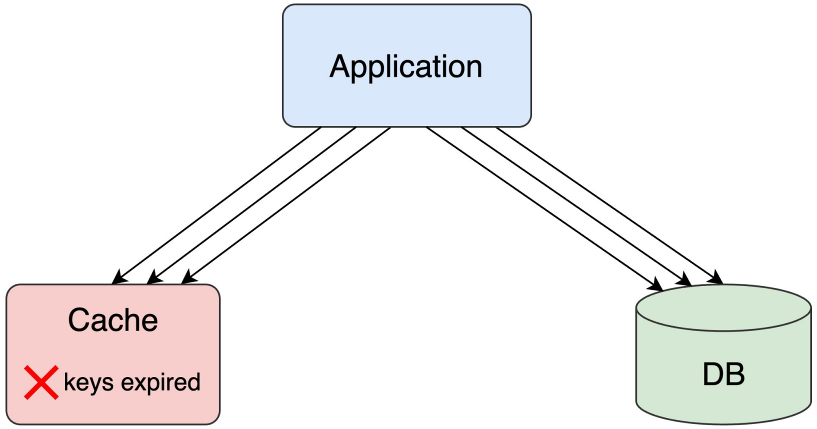
3.1.2. Problem 02: Cache Avalanche

Problem:

- A large amount of cached data expires at the same time
- There are a large number of requests at this time → DB down

Solutions:

- **Even distribution** for the expiration time



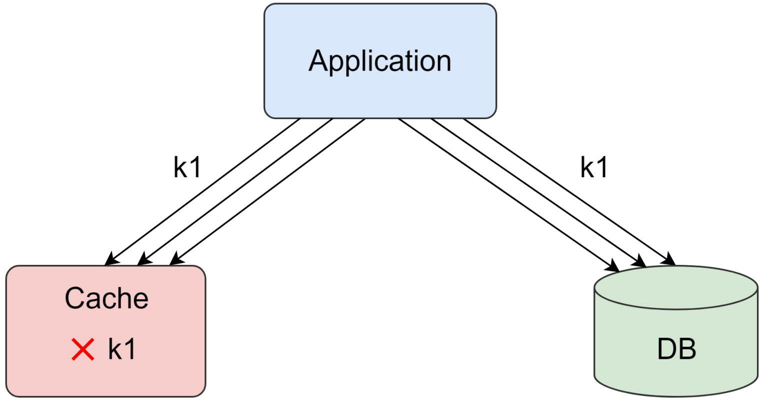
3.1.3. Problem 03: Cache Breakdown

Problem:

- A hotspot data in the cache expires → DB down

Solutions:

- Do not set an expiration time for the hotspot data
- **Background job to update cache periodically** or before the cache expires
- Locking / Mutex

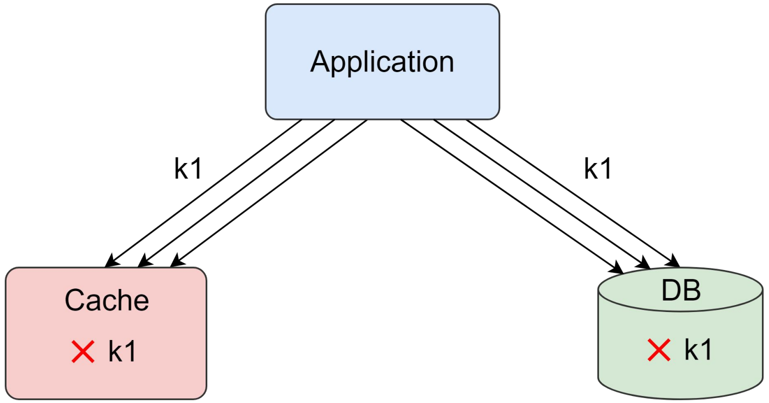


3.1.4. Problem 04: Cache Penetration

Problem: There is data neither in cache nor in DB. When a large number of requests hit that data (maybe made by attacker)
→ cache miss → DB miss → DB down

Solutions:

- **Set default value**. Example: 0
- Validate requests
- Use the Bloom filter to quickly determine whether the data does not exist



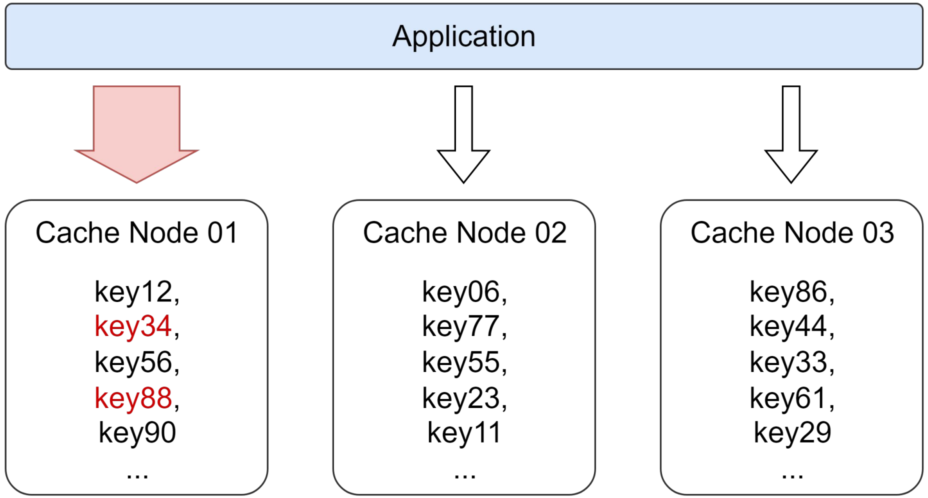
3.2. High Traffic Challenges

3.2.1. Problem 05: Hot Keys

Problem: A few keys have a lot of traffic

Solutions:

- Copy a hot key into multiple keys and distribute the keys across multiple nodes
- **Local cache to hot keys**

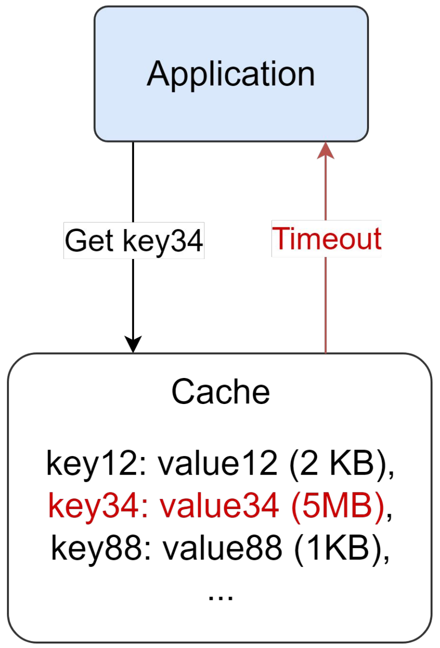


3.2.2. Problem 06: Large Key

Problem: The size of value is significantly large

Solutions:

- **Compress**
- Split
- Set a longer TTL for large keys
- Limit the number of large keys
- **Choose the right storage for large keys**

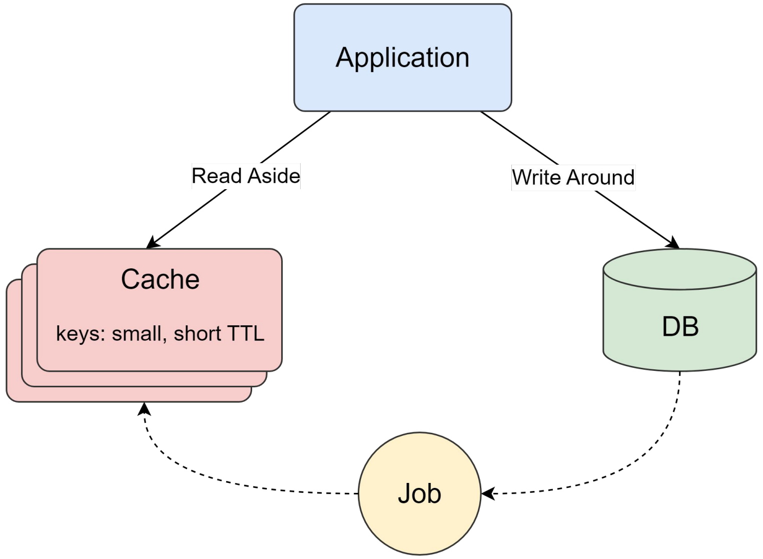


3.3. Cache Replacement

- What if the cache is running out of memory?
- Least Recently Used (LRU)
  - Use case: hot keys
- Least Frequently Used (LFU)
  - Use case: hot tweets
- LRU + LFU

Recap

- Evaluate data access patterns first
- Popular combination: Read Aside + Write Around
- Cache Invalidation is hard because of the complexity in many aspects:
    - Timing
    - Concurrency
    - Cache can be anywhere
    - …



References

- https://redis.com/glossary/cache-invalidation/
- https://blog.the-pans.com/cache-invalidation/

Homework

Implement local cache:

- Content: List of Airports (Code, Name) with TTL
- Allow to use libs
- No need a source DB
- Read Aside

Thank you 🙏

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