Large Scale Systems
CS 410 / 510

Lecture 7:

Deterministic Databases

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Assignment 2 is Out!

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- Please work with your groups to understand the underlying system.
- Assignment 2 report **deadline** → April 30, 2026 at 11:59pm.

Last Class

- Last class we looked at:

- Replication
- Distributed Consistency Levels
- Isolation Levels

How do Modern systems look like?

- Are modern distributed systems fully replicated or sharded?

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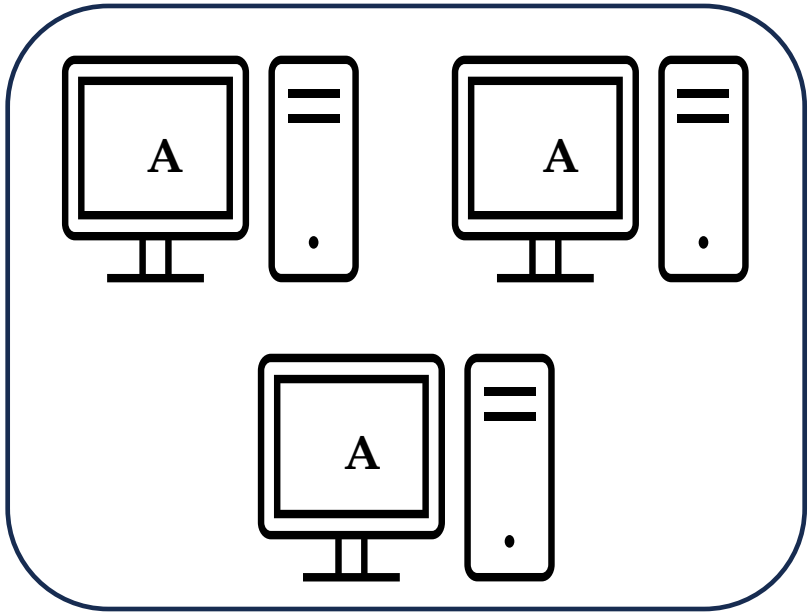
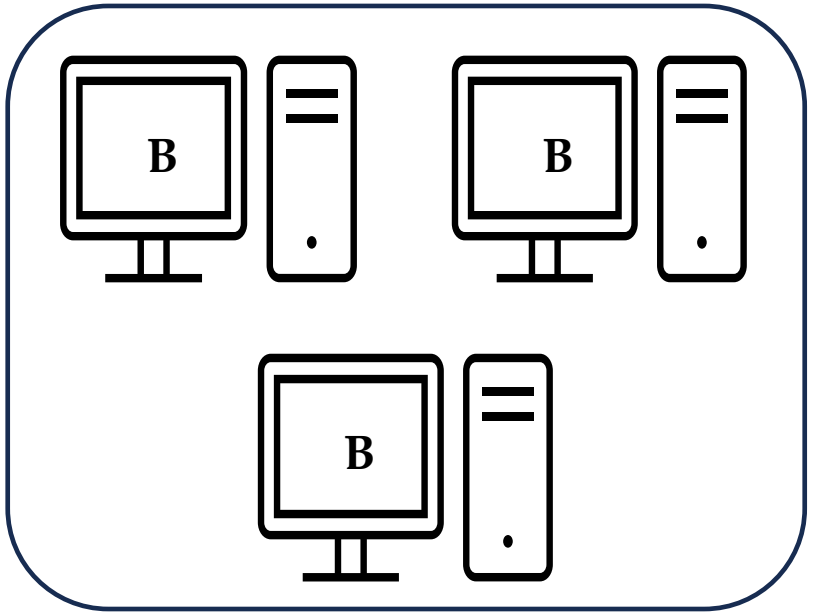
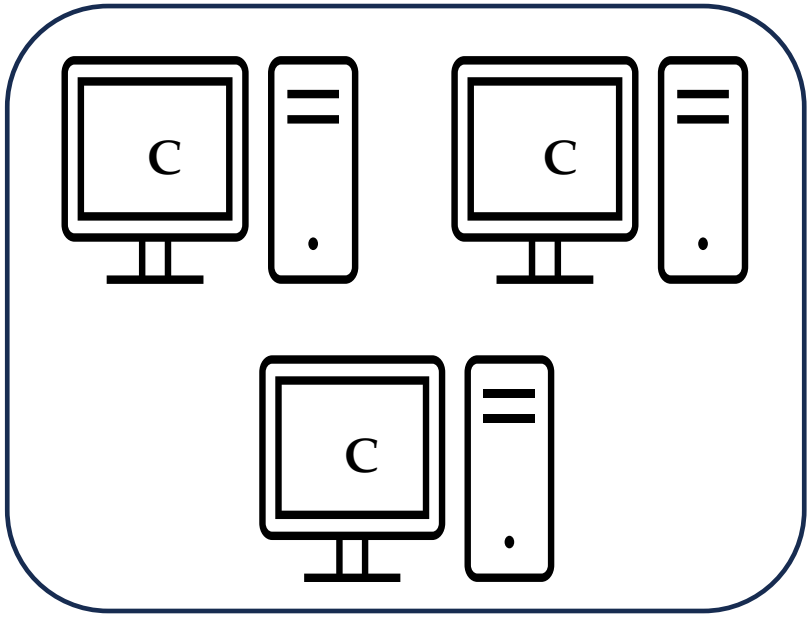
- Are modern distributed systems fully replicated or sharded?

- A combination of both:
  - Sharded Replicated
  - Replicated Sharded

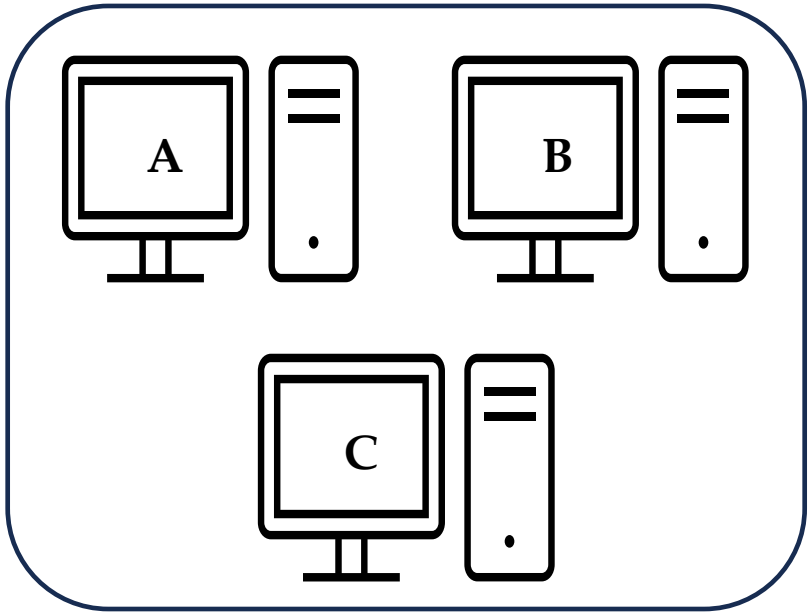
Sharded Replicated Systems

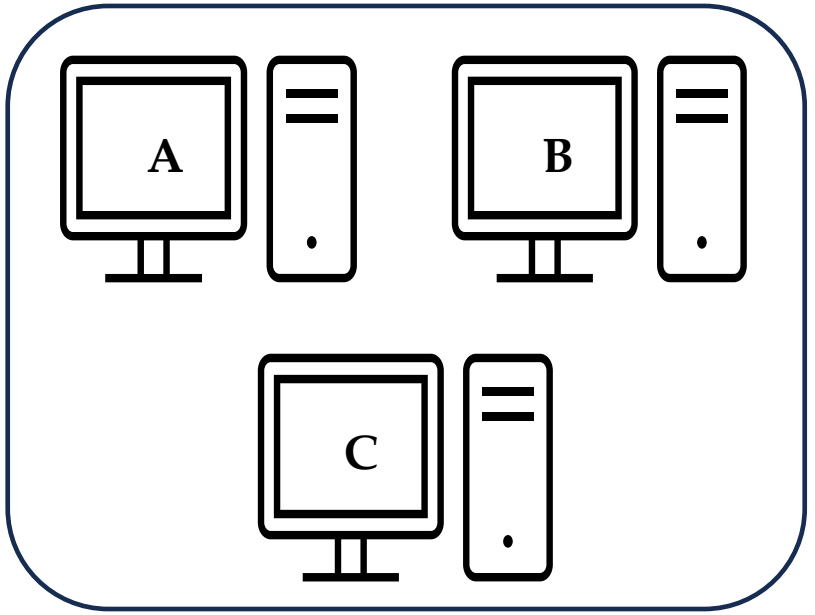


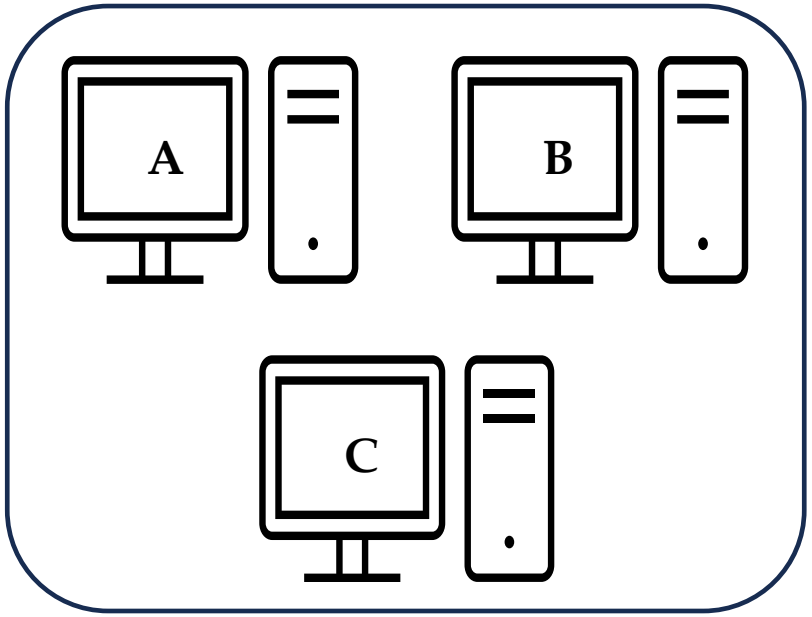




Replicated Sharded Systems







Disadvantage of Commit Protocols

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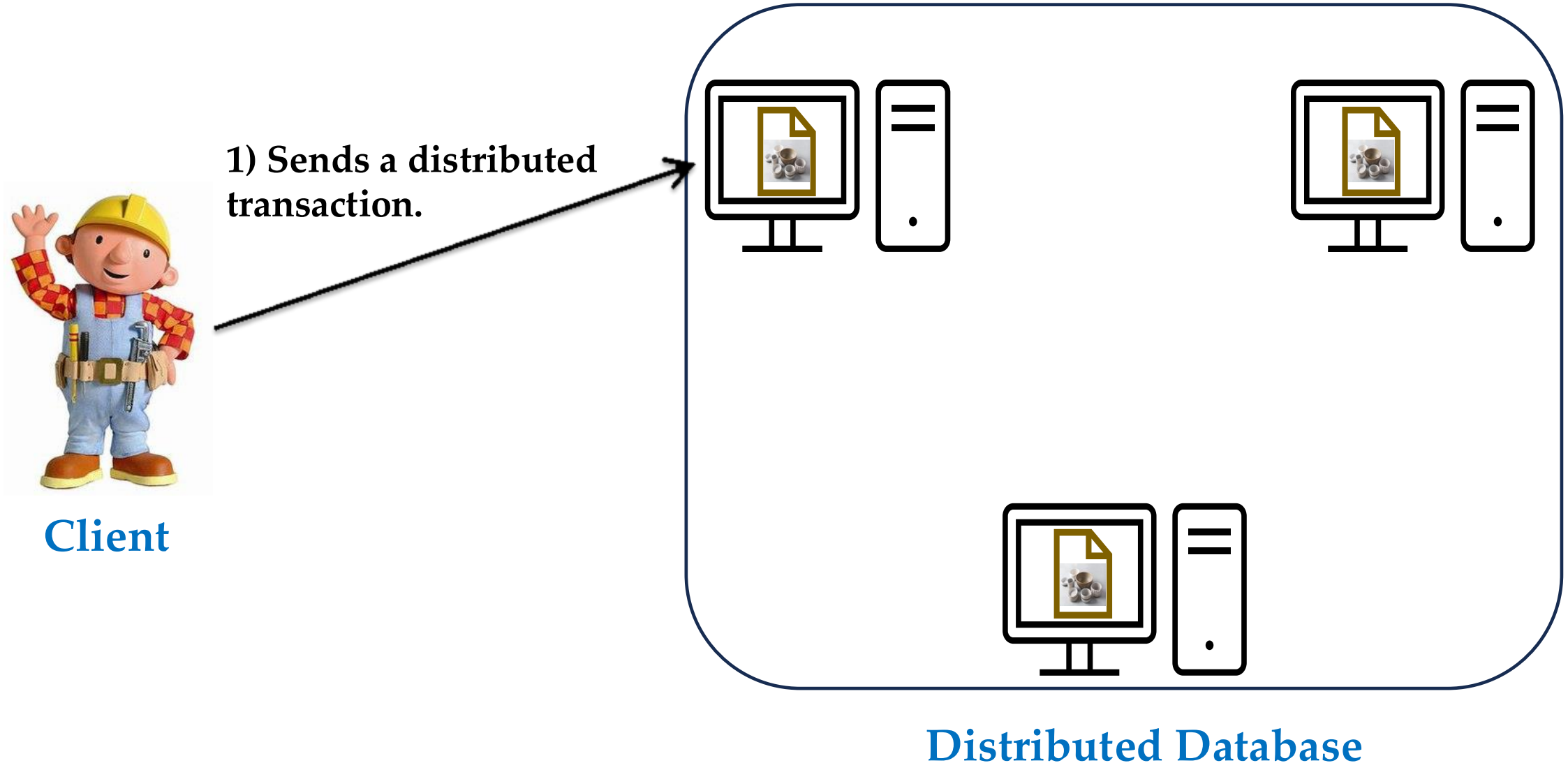
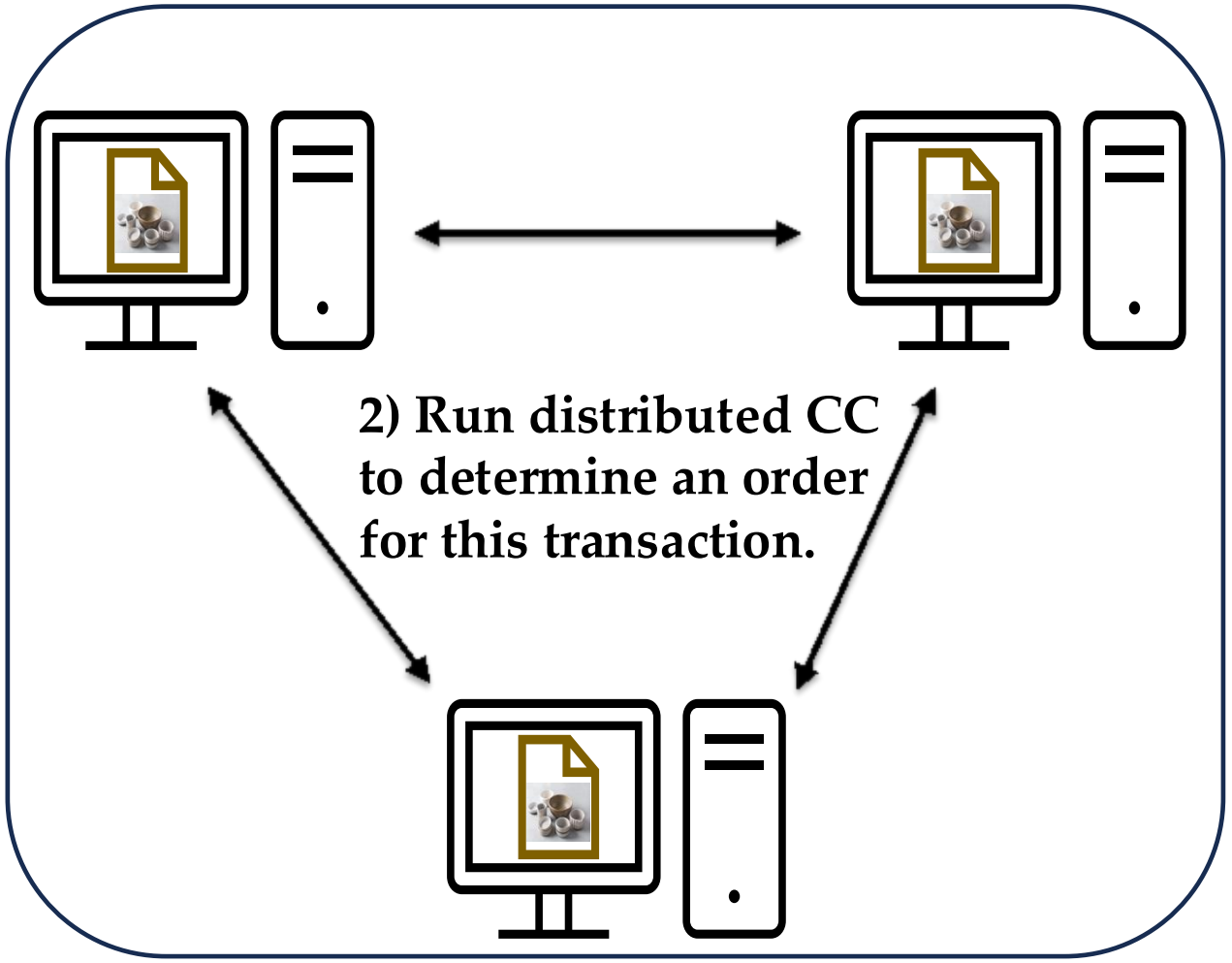
1) 2PC is blocking.
2) 3PC is non-blocking but requires three network round trips.
3) Running a commit protocol by itself is expensive! Why?

Cost of running Commit Protocols



Cost of running Commit Protocols

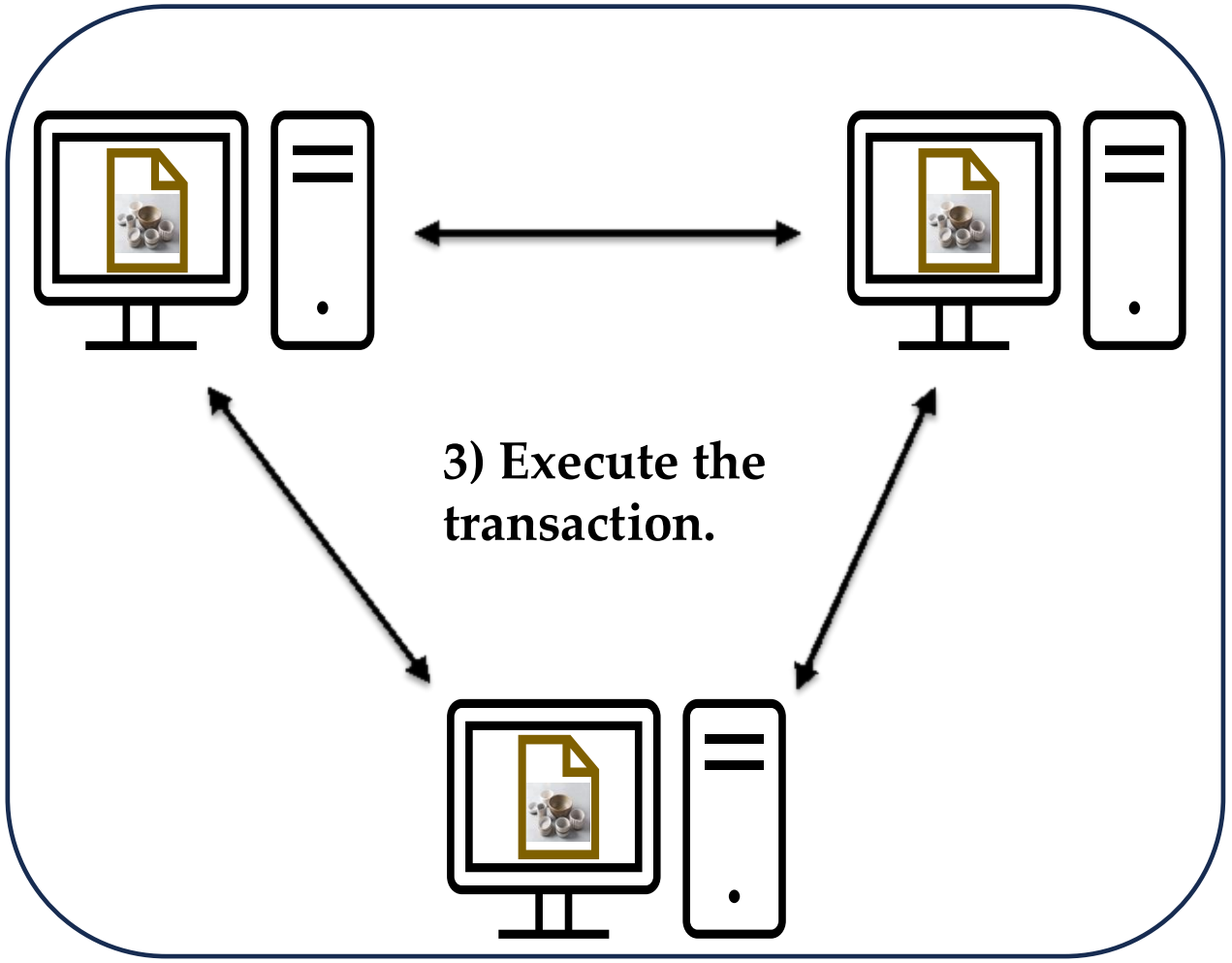
Client



Distributed Database

Cost of running Commit Protocols

Client



Distributed Database

Cost of running Commit Protocols

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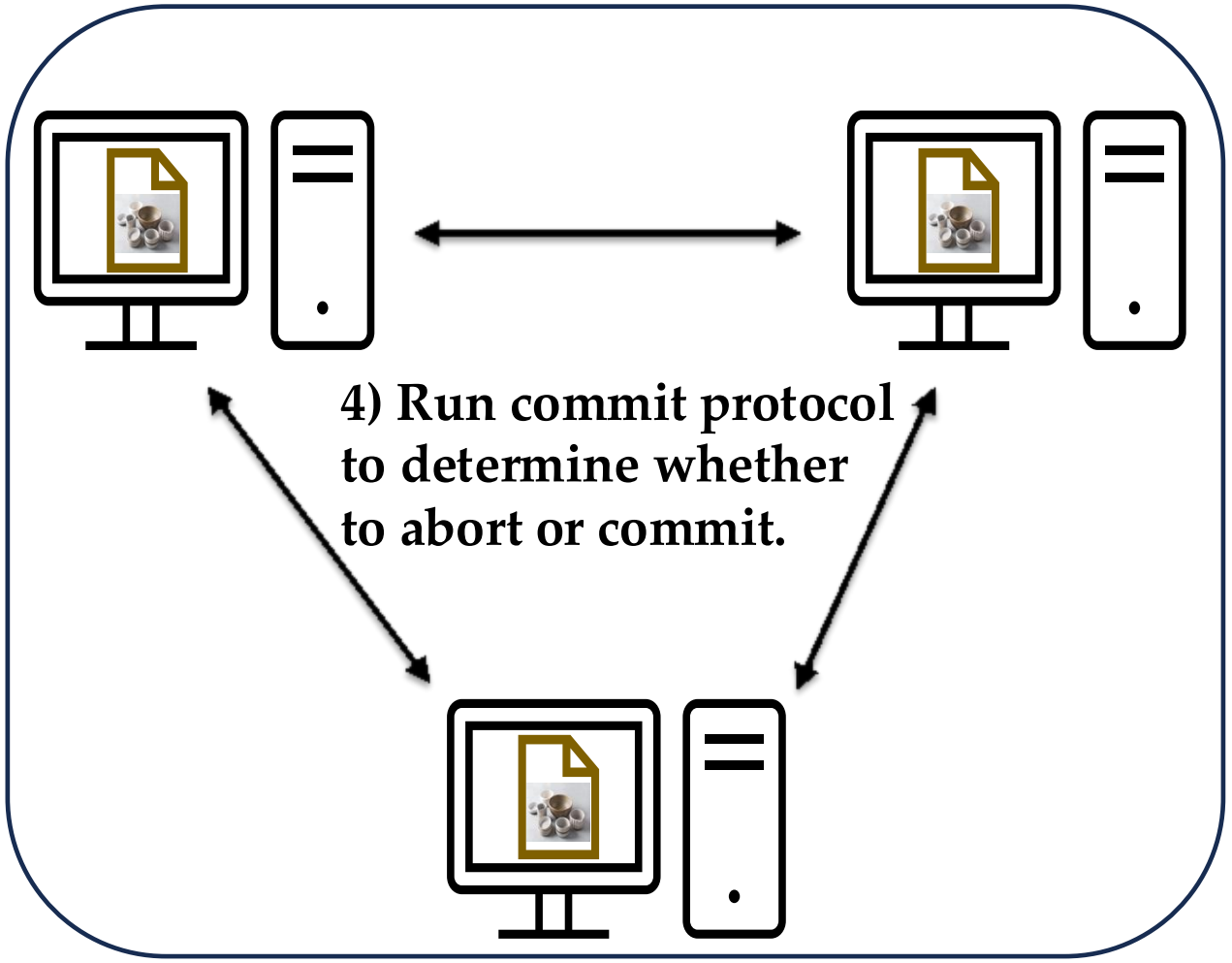

Distributed Database

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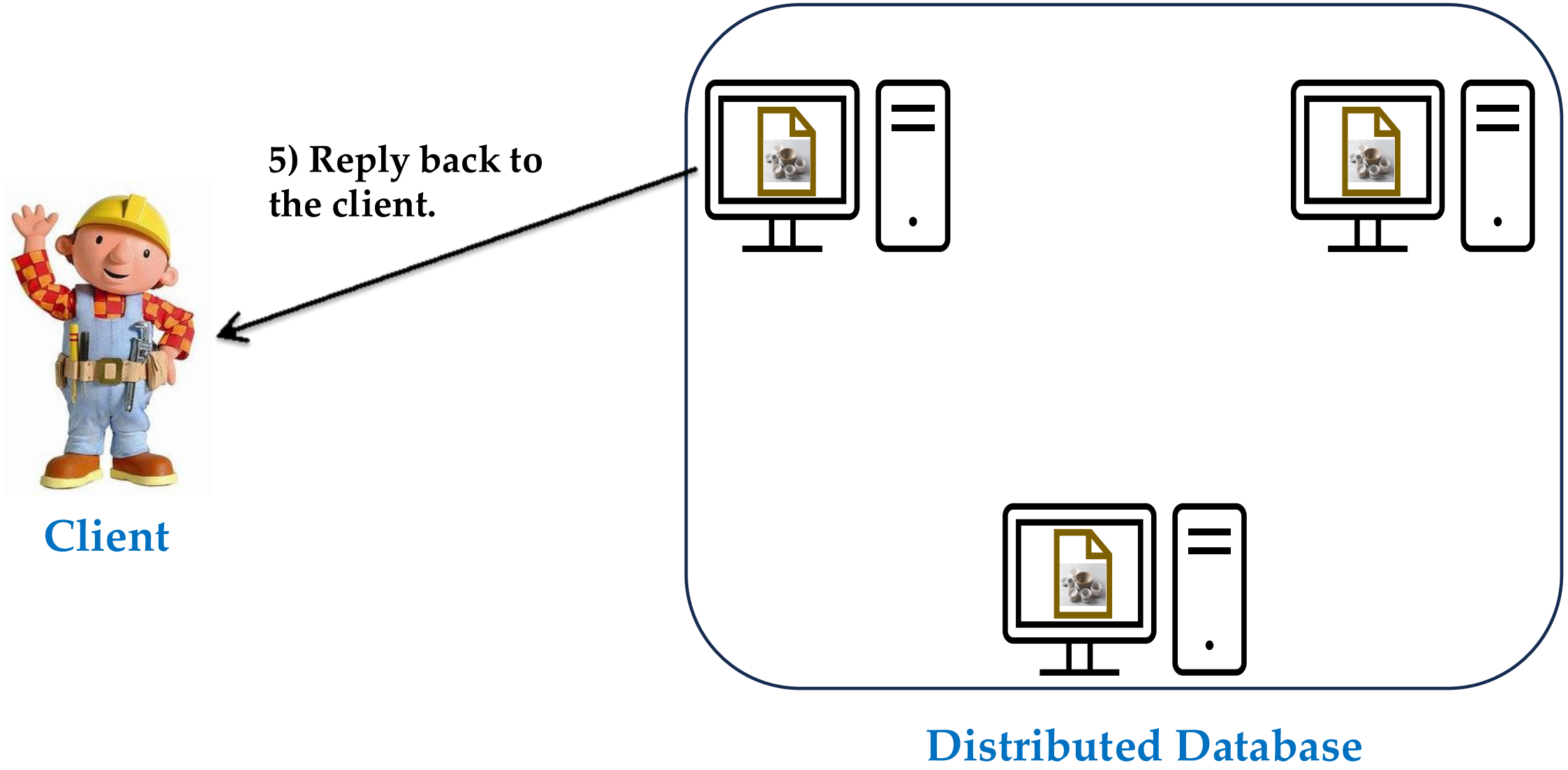

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- Imagine, your system uses **2PL** for concurrency control, which requires **holding locks until commit**.
- In the case of a distributed transaction, each involved partition needs to hold locks until the **end of 2PC** protocol.
- If some records are **popular** → highly accessed by a lot of distributed transactions.
  - Holding locks will prevent transactional concurrency.
  - Resulting in a **drop in throughput**!
  - Moreover, **high latency** due to communication among partitions.

Disadvantage of Commit Protocols

- Can we do anything more?

Deterministic Databases

- Determine the **plan** to execute the transactions ahead of time.

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Deterministic Databases

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- Every partition executes the distributed transaction in accordance with the plan.
- This allows **skipping** the use of 2PC protocol!

Intuition behind Deterministic Databases

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  - Two partitions may decide differently on the fate on a transaction.
  - But **why** do two partitions decide differently? **Why** wouldn't all partitions want to commit the transaction?
  - A partition would abort the transaction in two cases:
    - **Non-deterministic events**: failures.
    - **Deterministic events**: aborts forced by transaction logic .

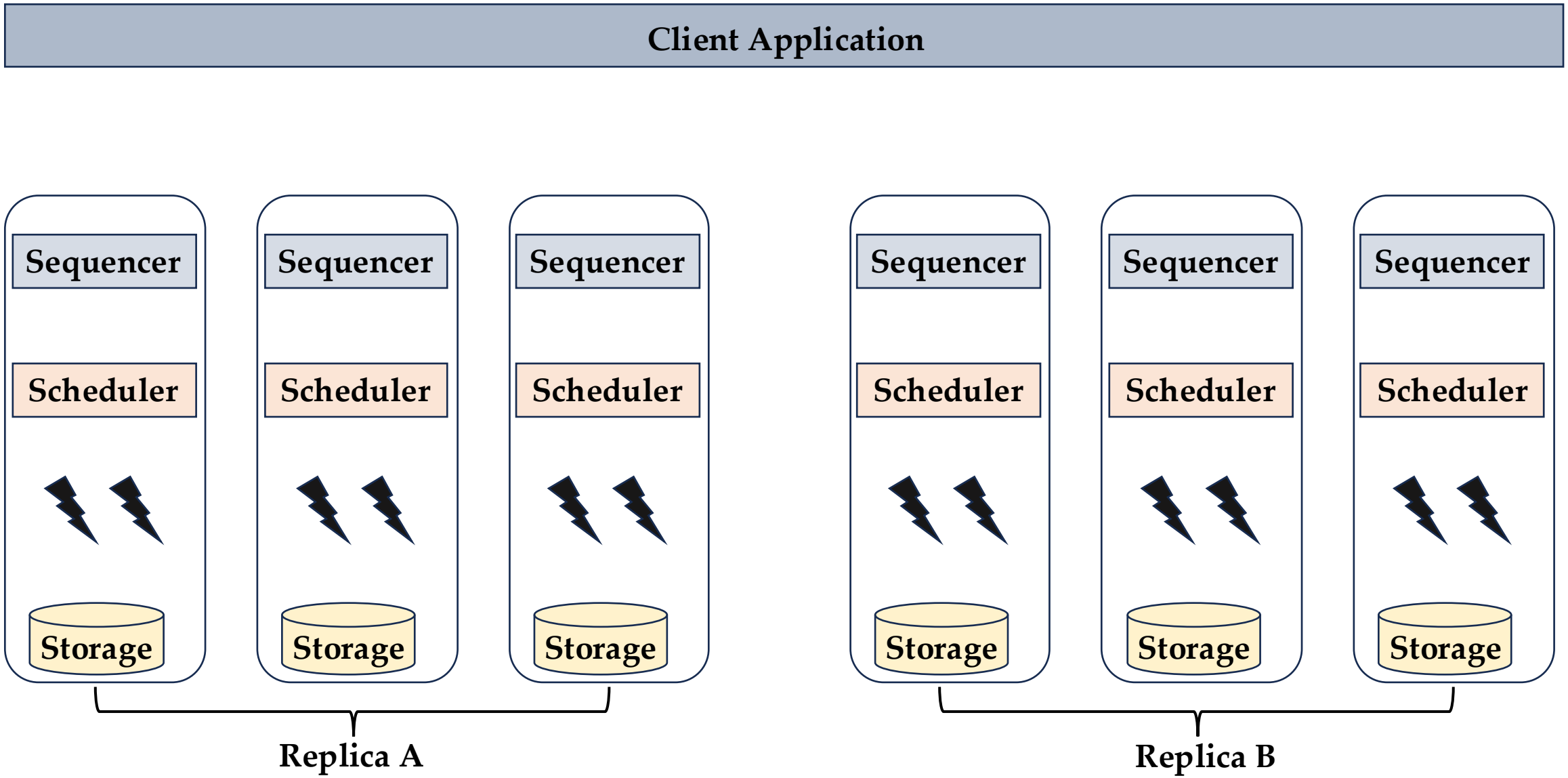
Calvin

Calvin

- A transactional architecture that supports the design of a deterministic database.

- Another key motivation: provide transactional support for applications that were moving away from the use of transactions.
  - NoSQL databases.

Calvin Architecture



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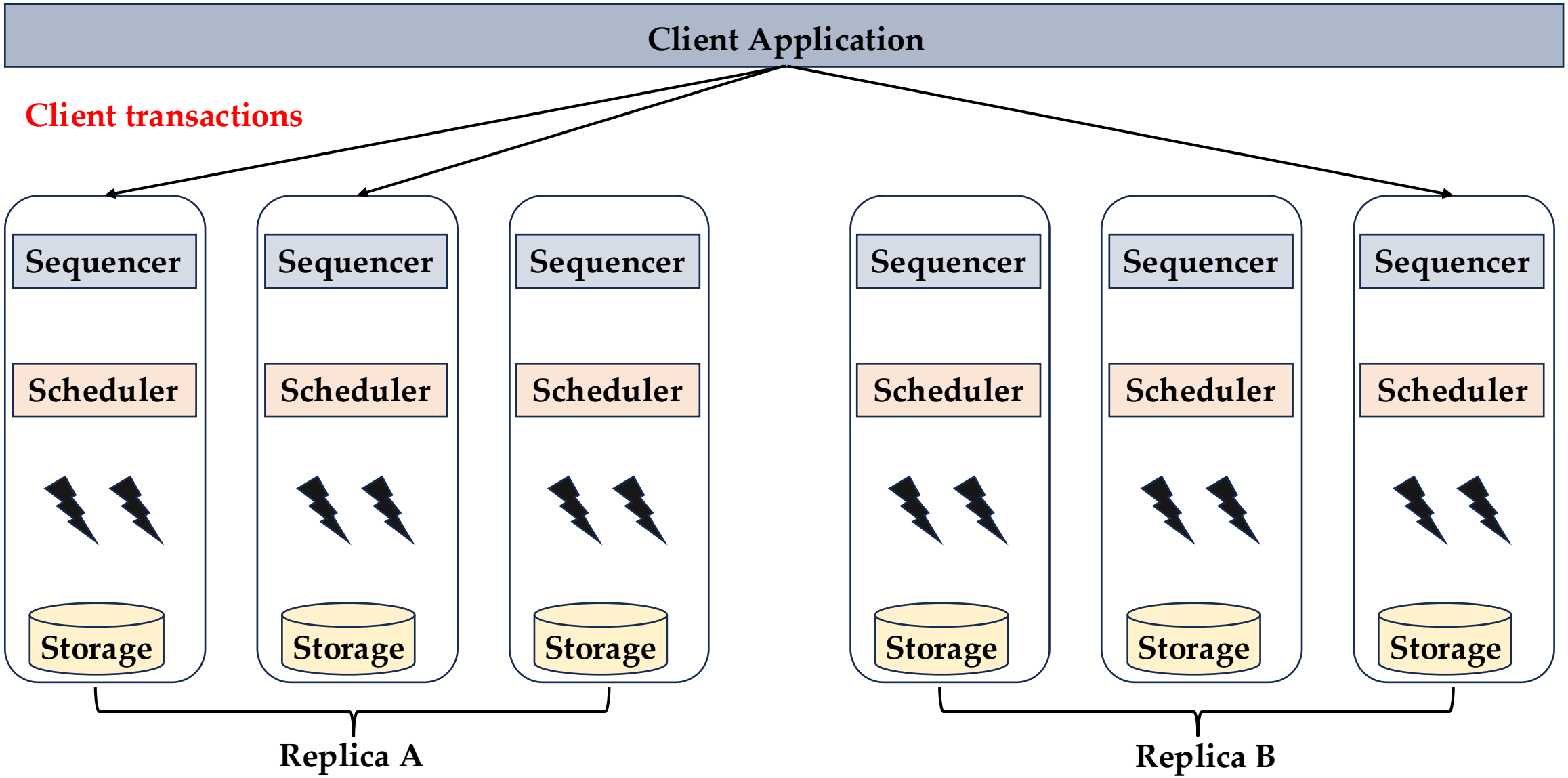

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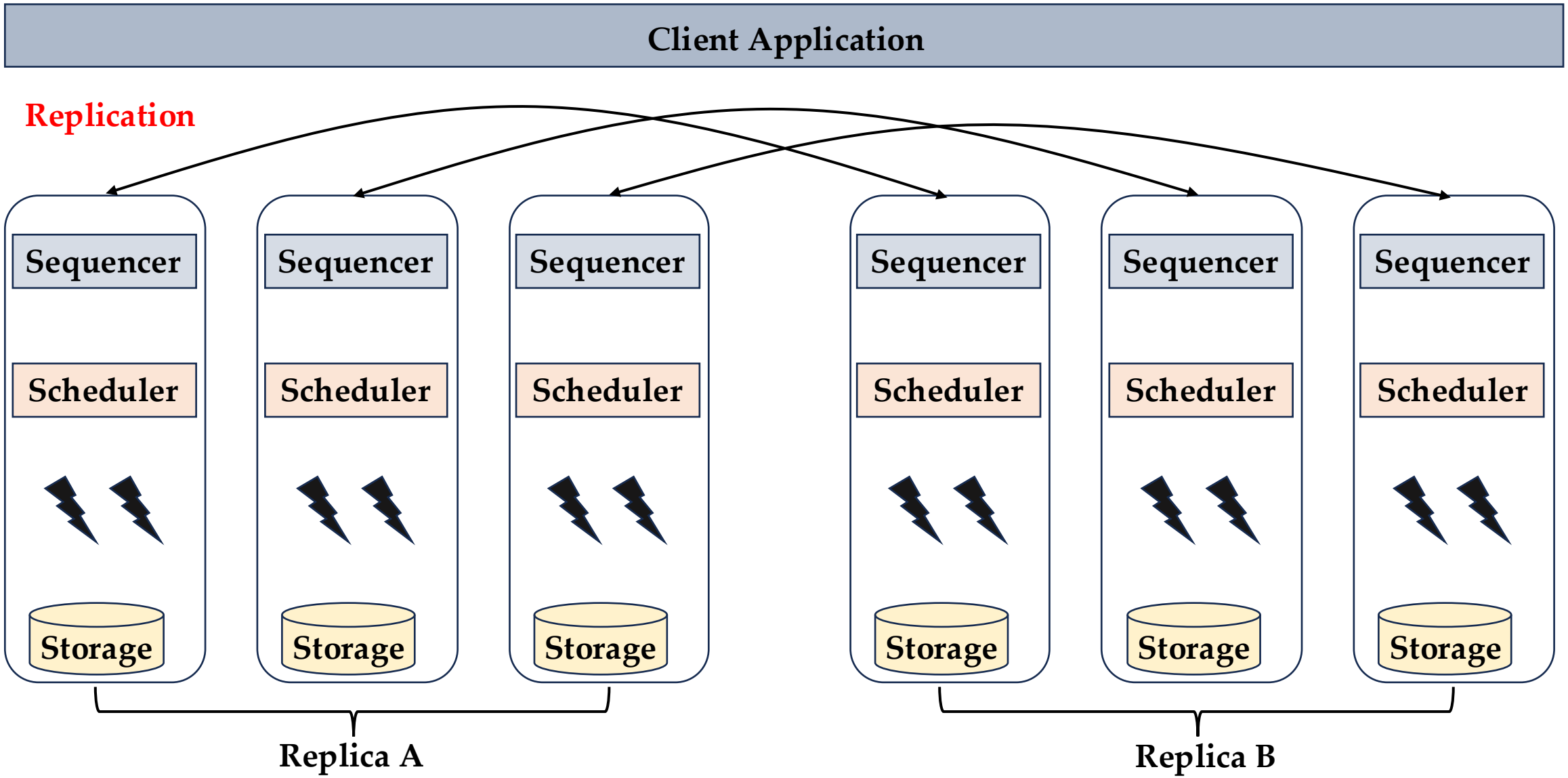

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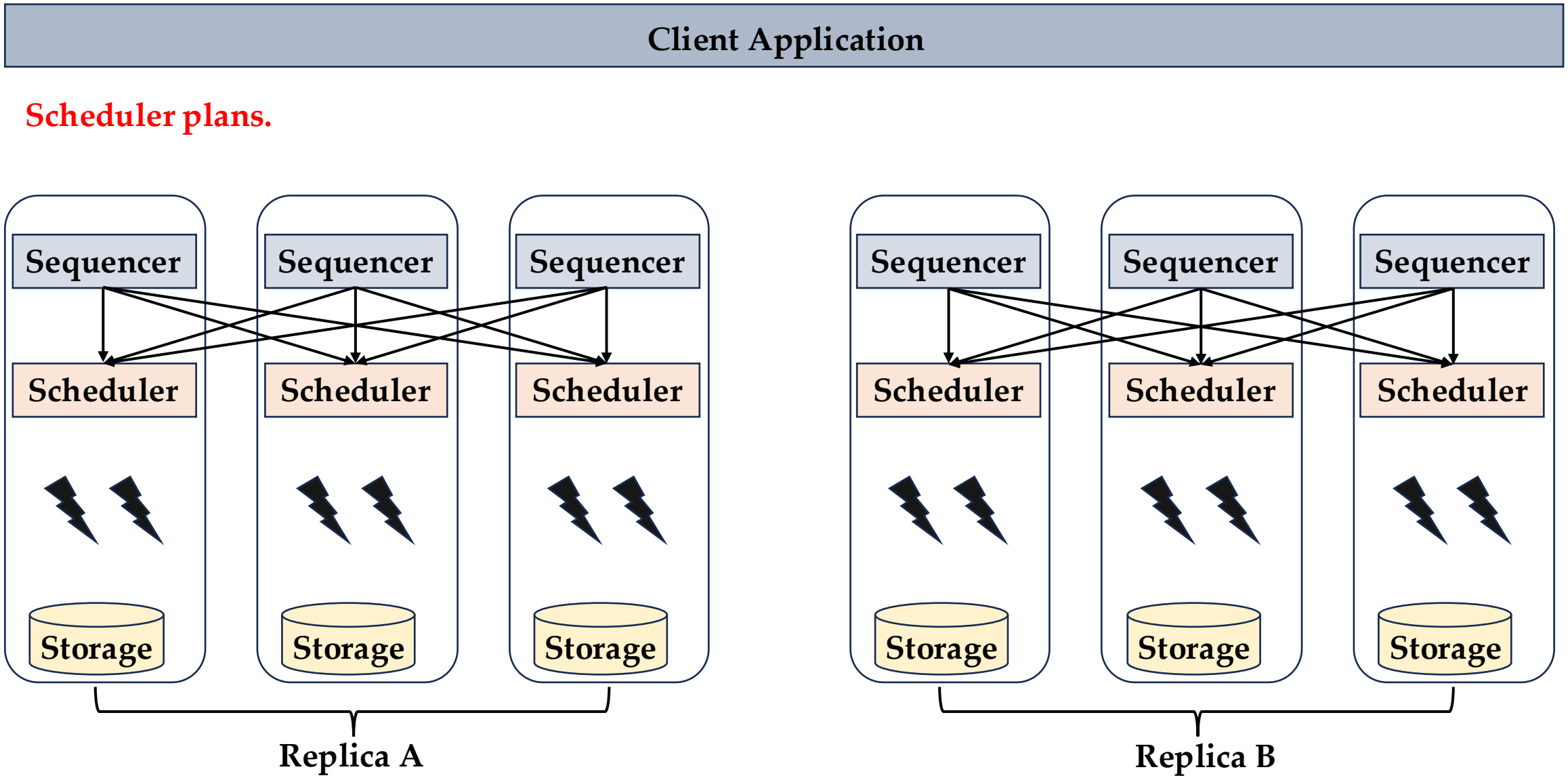

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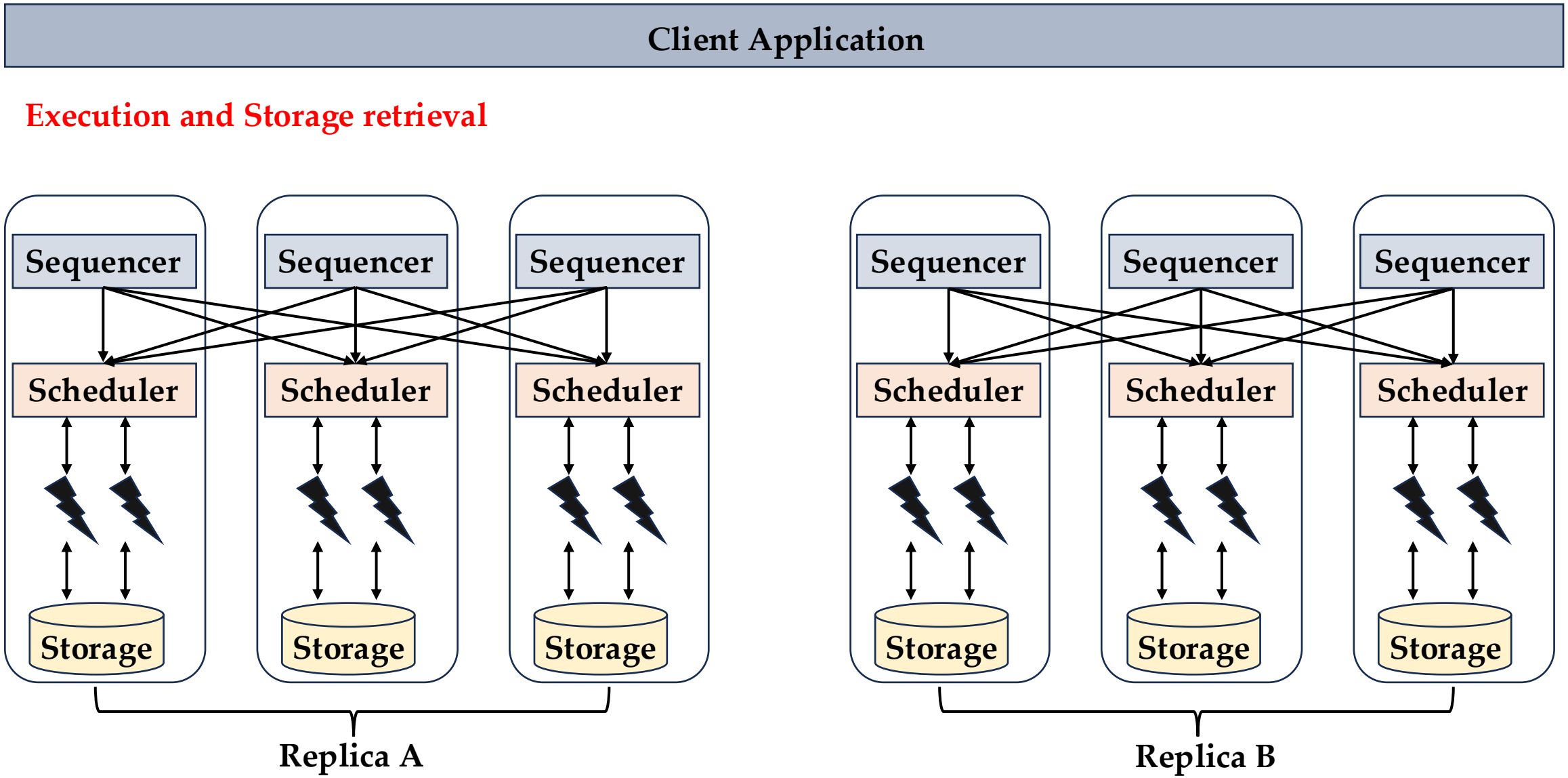

Calvin Architecture

- Three key components:
  - Sequencer
  - Scheduler
  - Execution and Storage

Sequencer

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  - Collects incoming client transactions.
  - Determines all the transaction inputs (read sets).
  - Replicates transactional inputs across all replicas.

- It is the task of the sequencer to **create an order** for all the transactions that it has received!

Sequencer

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- How does sequencer collect client transactions?
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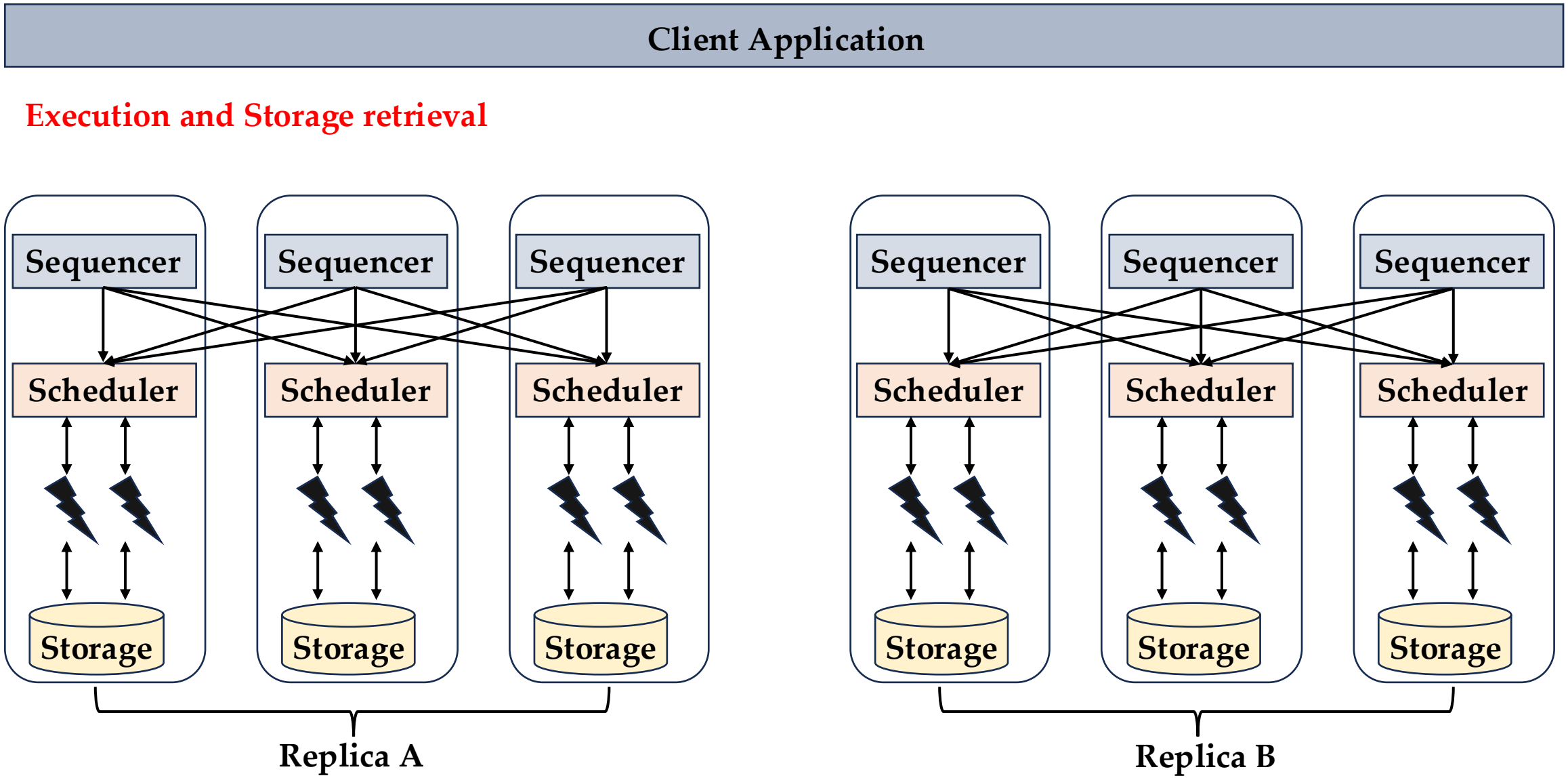
- Calvin follows an **epoch-based design**.
  - An epoch lasts a specific amount of time (say 10ms).
  - During an epoch each sequencer collects as many transactions as it can.
  - Once an epoch expires, it creates a batch of collected requests and initiates replication.
  - Post this it forwards the batch to a scheduler.
  - Each batch has **a pair of identifiers**: sequencer no and epoch no.

Scheduler


Client Application
Execution and Storage retrieval
Sequencer
Sequencer
Sequencer
Scheduler
Scheduler
Scheduler
Storage
Storage
Storage
Replica A
Sequencer
Sequencer
Sequencer
Scheduler
Scheduler
Scheduler
Storage
Storage
Storage
Replica B

Scheduler

- Scheduler receives transaction batches from the sequencer at each partition.
  - How does it **merge** them into one batch**?**

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- Scheduler receives transaction batches from the sequencer at each partition.
  - How does it **merge** them into one batch**?**

- Remember, each batch has a sequence number and an epoch number.
  - These numbers together can help in creating one batch.

  - For example, merging in the ascending order of sequencer identifiers (1,2,…)

Scheduler

- What else does the Scheduler do?

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- Initiate execution of the batch of transactions.
- What is the **first step** to execution?

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- What is the **first step** to execution?
- Run a concurrency control protocol → We will run strict 2PL.

Strict 2PL in Calvin Scheduler

- To run strict 2PL, a transaction needs to borrow all the locks in the beginning.
- As read sets are known, Calvin runs a thread to request locks for local reads.
- Two changes for strict 2PL in Calvin:

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- Two changes for strict 2PL in Calvin:
  - If transaction A occurs before B in the sequence order and they both need lock for the same variable x, then A must request lock on x before B.
  - Lock manager can only grant locks in the order transactions requested locks.

Execution

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  1. Read-Write Set Analysis
  2. Perform Local Reads
  3. Serve Remote Reads
  4. Collect Remote Read Results
  5. Execution and Applying Write.

Read-Write Set Analysis

- **Analyze** a transaction's read-write sets.
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  - Find out which of the reads and writes can be done locally.

- **Determine** active and passive participants.
  - Active participants → remote nodes that include write sets.
  - Passive participants → remote nodes that include read sets.

Perform Local Reads

- **Fetch** all the records that need to be read and are present locally at the node!

- Essentially, a copy of the record (or pointer) is placed in the buffer.

Serve Remote Reads

- **Send** all the locally read records to all the active participants.

Collect Remote Reads

- Prior to executing the transaction, a node needs **access** to all the records (read sets).

- Need to collect all the remote records from all the participants.

Transaction Execution

- **Execute** the transaction logic.

- **Apply** local writes.

Challenges for Calvin and Deterministic Databases

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- Often, it is not possible to determine all the records a transaction needs to read prior to its execution.
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- Often, it is not possible to determine all the records a transaction needs to read prior to its execution.
  - For example, due to complex code logic
- Calvin needs to run a **reconnaissance phase** to handle such cases.
- Reconnaissance tries to execute the transactions to discover all the read-write sets.

Can we do something better?