

# Distributed Systems II

*Software Architecture*

Brae Webb

March 25, 2024

*Distributed Systems Series*

Distributed I *Reliability* and *scalability* of  
*stateless* systems.

Distributed II *Complexities* of *stateful*  
systems.

Distributed III *Hard problems* in distributed  
systems.

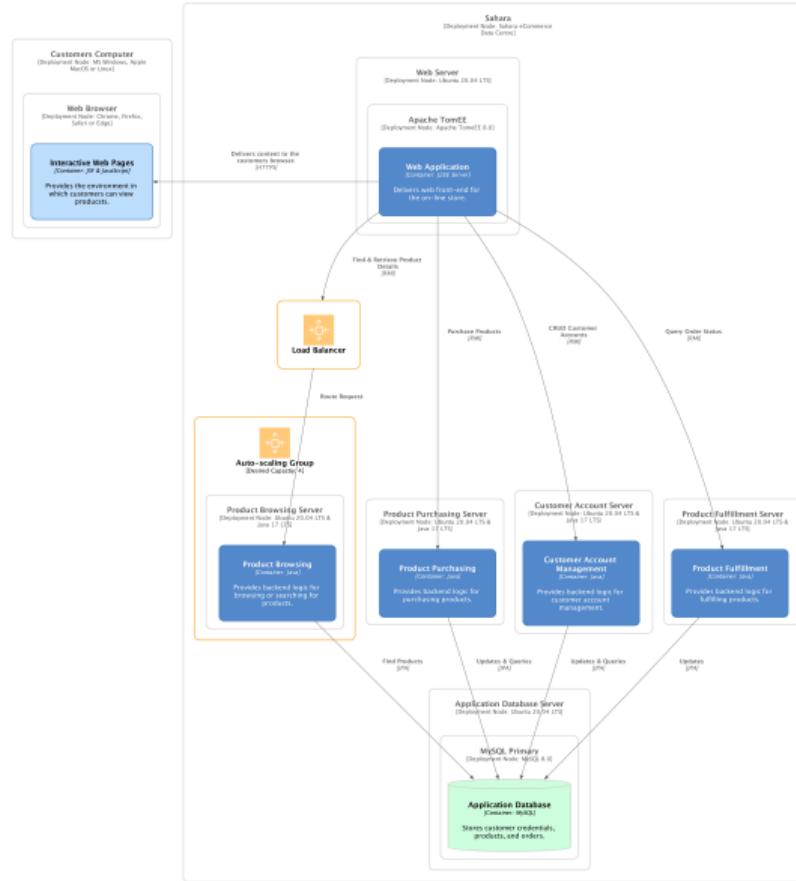
*Distributed Systems Series*

Distributed I Reliability and scalability of stateless systems.

Distributed II *Complexities* of *stateful* systems.

Distributed III Hard problems in distributed systems.

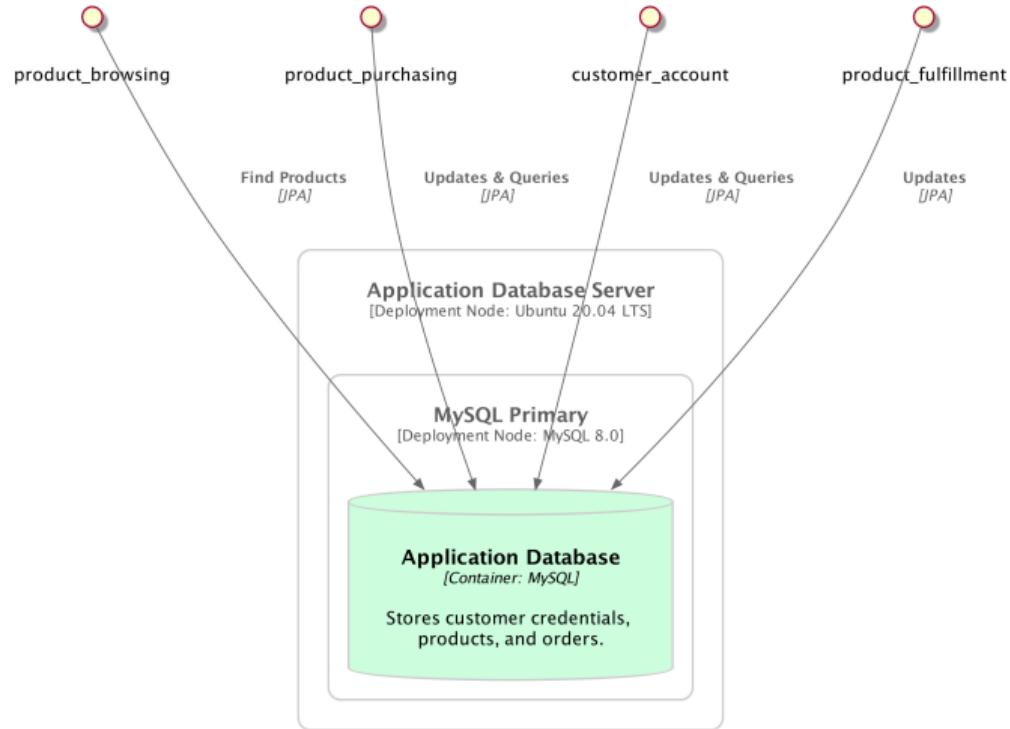
# Previously in CSSE6400...



*Question*

What is the *problem*?

## Database



*Disclaimer*

This is *not* a database course.



# Advanced Database Systems (INFS3200)

**Course level**

Undergraduate

**Faculty**

Engineering, Architecture &amp; Information Technology

**School**

Info Tech &amp; Elec Engineering

**Units**

2

**Duration**

One Semester

**Class contact**

2 Lecture hours, 1 Tutorial hour, 1 Practical or Laboratory hour

**Incompatible**

INFS7907

**Prerequisite**

INFS2200

**Assessment methods**

## Current course offerings

**Course offerings****Location****Mode****Course Profile**

Semester 1, 2022

St Lucia

Internal

[COURSE PROFILE](#)

Semester 1, 2022

External

External

[COURSE PROFILE](#)

Semester 2, 2022

External

External

PROFILE UNAVAILABLE

Semester 2, 2022

St Lucia

Internal

PROFILE UNAVAILABLE

Please Note: Course profiles marked as not available may still be in development.

## Course description

Distributed database design, query and transaction processing, data integration, data warehousing, data cleansing, management of spatial data, and data from large scale distributed devices.

## Archived offerings

**Course offerings****Location****Mode****Course Profile**

Semester 1, 2021

St Lucia

Flexible Delivery

[COURSE PROFILE](#)

Semester 1, 2021

External

External

[COURSE PROFILE](#)

Semester 2, 2021

External

External

[COURSE PROFILE](#)

Semester 2, 2021

St Lucia

Internal

[COURSE PROFILE](#)

Semester 1, 2020

St Lucia

Internal

[COURSE PROFILE](#)

*Question*

How do we fix database scaling issues?

*Question*

How do we fix database scaling issues?

*Answer*

- Replication

*Question*

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*Answer*

- Replication
- Partitioning

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- Replication
- Partitioning
- Independent databases

*Question*

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*Question*

What is *replication*?

*Definition 1.* Replication

Data copied across multiple different machines.



product_id	name	stock	price
1234	Nicholas Cage Reversible Pillow	10	\$10.00
4321	Lifelike Elephant Inflatable	5	\$50.00



product_id	name	stock	price
1234	Nicholas Cage Reversible Pillow	10	\$10.00
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*Definition 2.* Replica

Database node which stores a copy of the data.

*Question*

What are the advantages of *replication*?

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*Answer*

- *Scale* out our to cope with higher loads.

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- Provide *fault tolerance* from a single instance failure.

*Question*

What are the advantages of *replication*?

*Answer*

- *Scale* out our to cope with higher loads.
- Provide *fault tolerance* from a single instance failure.
- Locate instances *closer to end-users*.

*Question*

How do we replicate our data?

*First approach*

Leader-follower Replication



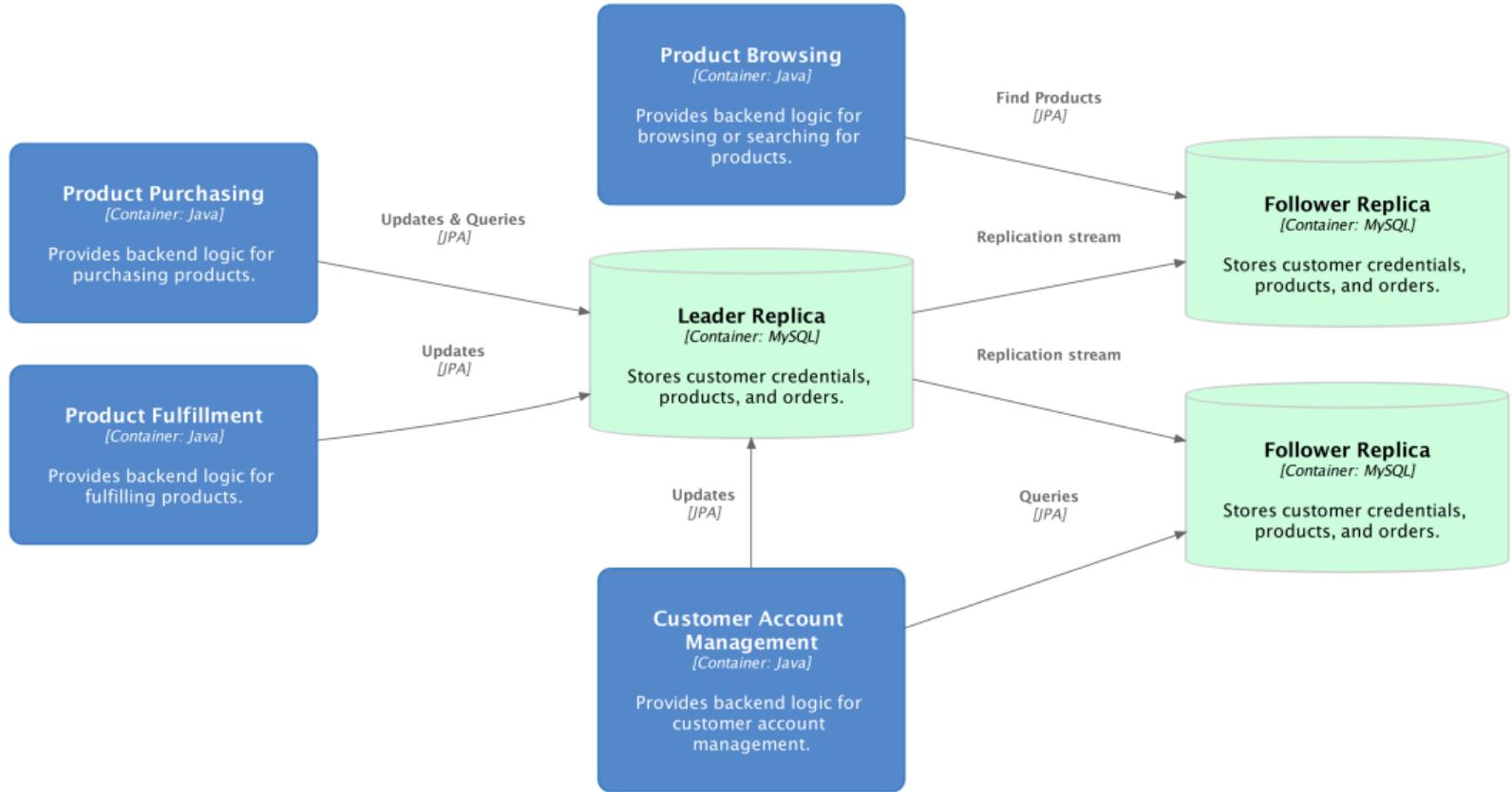
### *Leader-based Replication*

On write Writes sent to leader, change is propagated via change stream.

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On write Writes sent to leader, change is propagated via change stream.

On read Any replica can be queried.



*Propogating changes*

*Synchronous vs. Asynchronous*

ProductBrowsing

Leader

Follower1

1 UPDATE products SET stock=4

2 UPDATE

3 OK

4 OK

ProductBrowsing

Leader

Follower1

ProductBrowsing

Leader

Follower1

1 UPDATE products SET stock=4

2 UPDATE

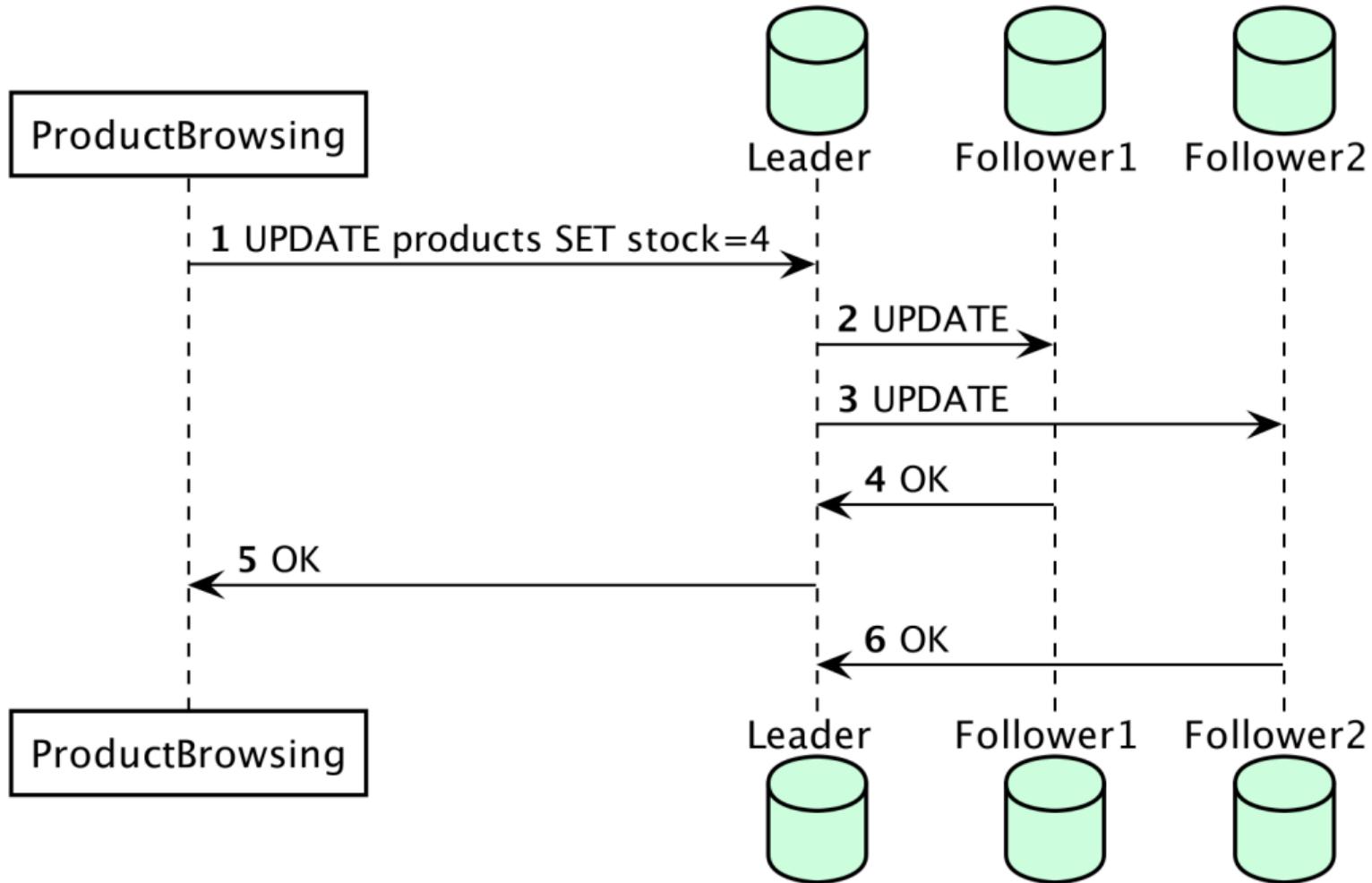
3 OK

4 OK

ProductBrowsing

Leader

Follower1



### *Synchronous propagation*

- Writes must propagate to *all followers* before being successful.

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- Writes must propagate to *all followers* before being successful.
- *Any* replica goes down, *all* replicas are un-writable.
- Writes must *wait* for propagation to all replicas.

### *Asynchronous propagation*

- Writes *don't* have to *wait* for propagation.

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- If the leader goes down before propagating, the *write is lost*.

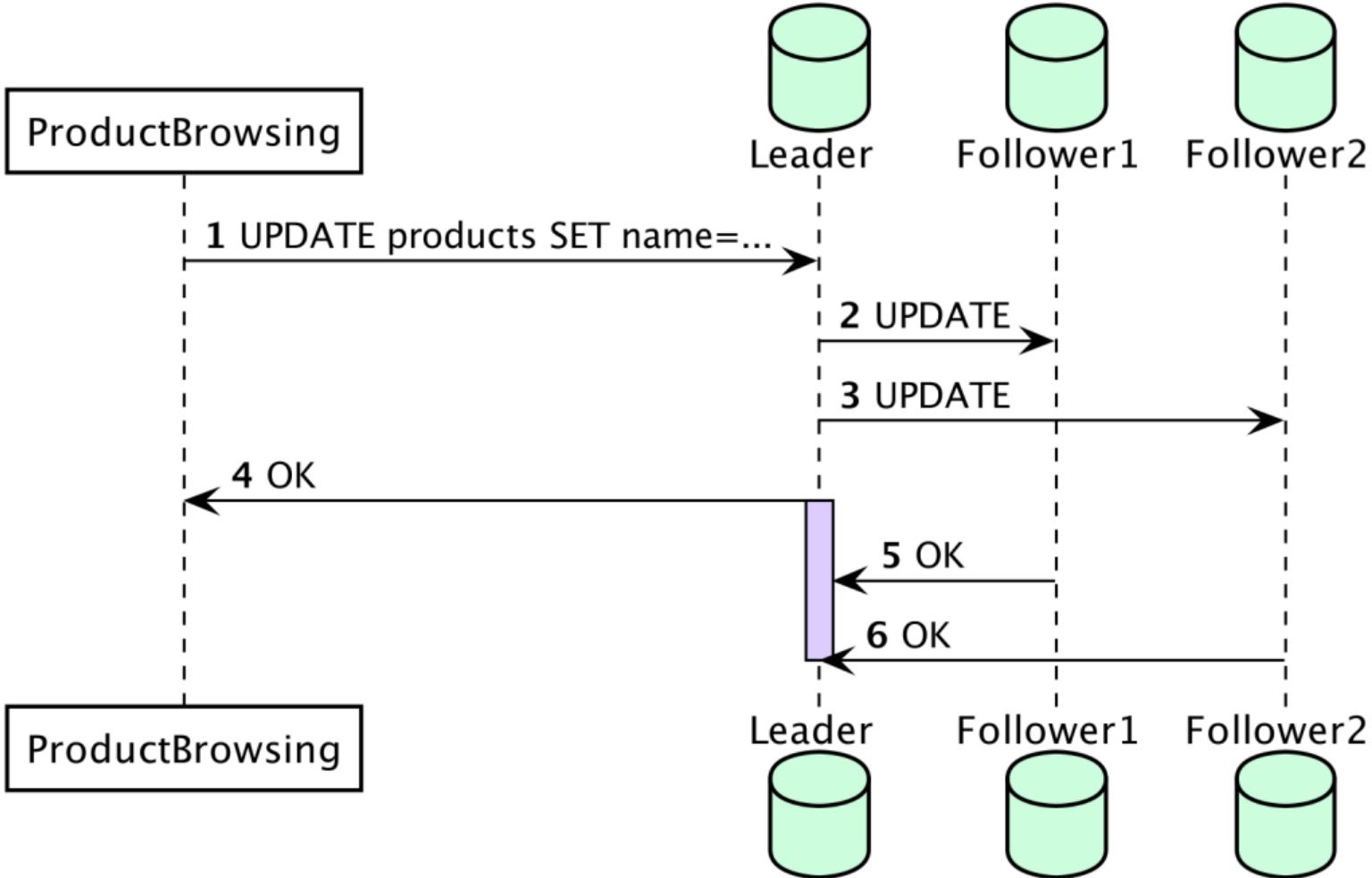
## *Asynchronous propagation*

- Writes *don't* have to *wait* for propagation.
- If the leader goes down before propagating, the *write is lost*.
- Replicas can have out-dated or *stale* data.

*Definition 3.* Replication Lag

The time taken for replicas to update *stale* data.





*Eventually, all replicas must become consistent*

The system is *eventually consistent*

*Eventual Consistency*

Problems?



**Brae Webb**  
@braewebb



**Brae Webb**  
@braewebb

Name: Brae

Cancel

Save



**Brae Webb**  
@braewebb

Name:

Cancel

Save



**Brae Webb**  
@braewebb



*Definition 4.* Read-your-writes Consistency

Users always see the updates that *they have made*.



**Brae Webb**  
@braewebb

My fist post



**Brae Webb**

@braewebb

My fist post



**Brae Webb**

@braewebb

My first post



**Brae Webb**

@braewebb

My fist post



**Brae Webb**

@braewebb

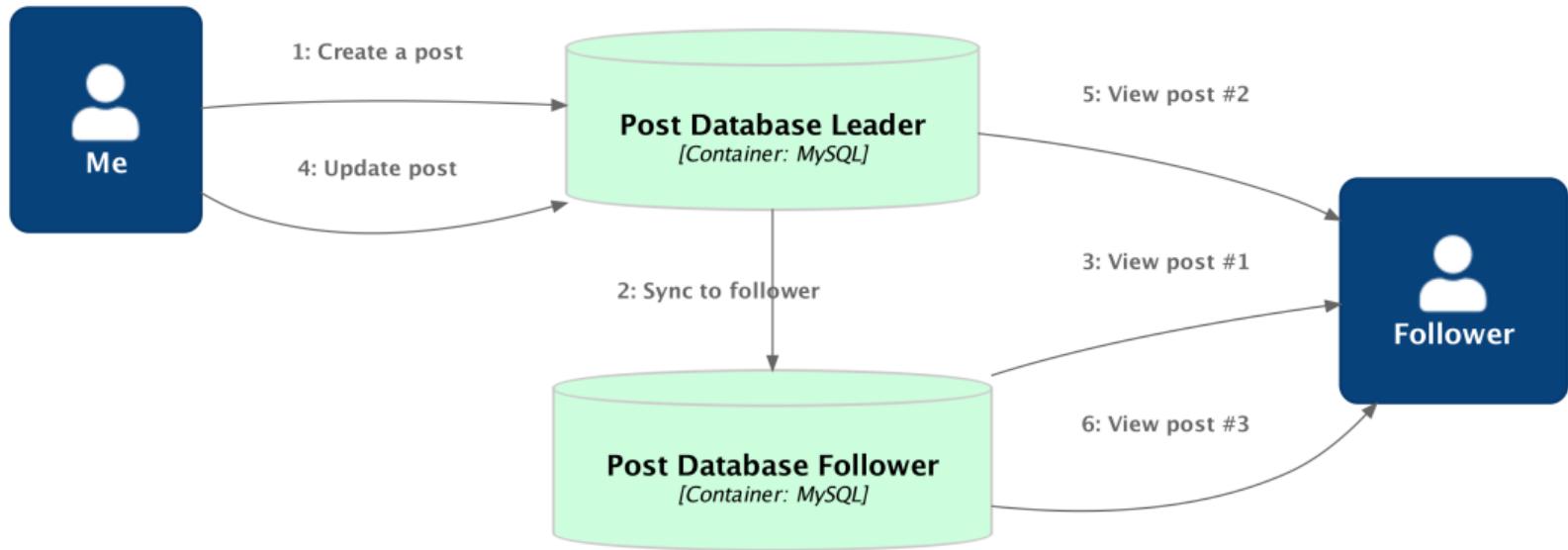
My first post



**Brae Webb**

@braewebb

My fist post



### *Definition 5.* Monotonic Reads

Once a user reads an updated value, they don't later see the old value.

## *Summary*

- Leader-follower databases allow *reads to scale* more effectively.
- Asynchronous propagation weakens consistency to *eventually consistent*.
- Leader-follower databases still have a *leader write bottle-neck*.

*Second approach*

Multi-leader Replication



*Why multi-leader?*

- If you have multiple leaders, you can write to any, allowing *writes to scale*.

### *Why multi-leader?*

- If you have multiple leaders, you can write to any, allowing *writes to scale*.
- A leader going down doesn't prevent writes, giving *better fault-tolerance*.

*Question*

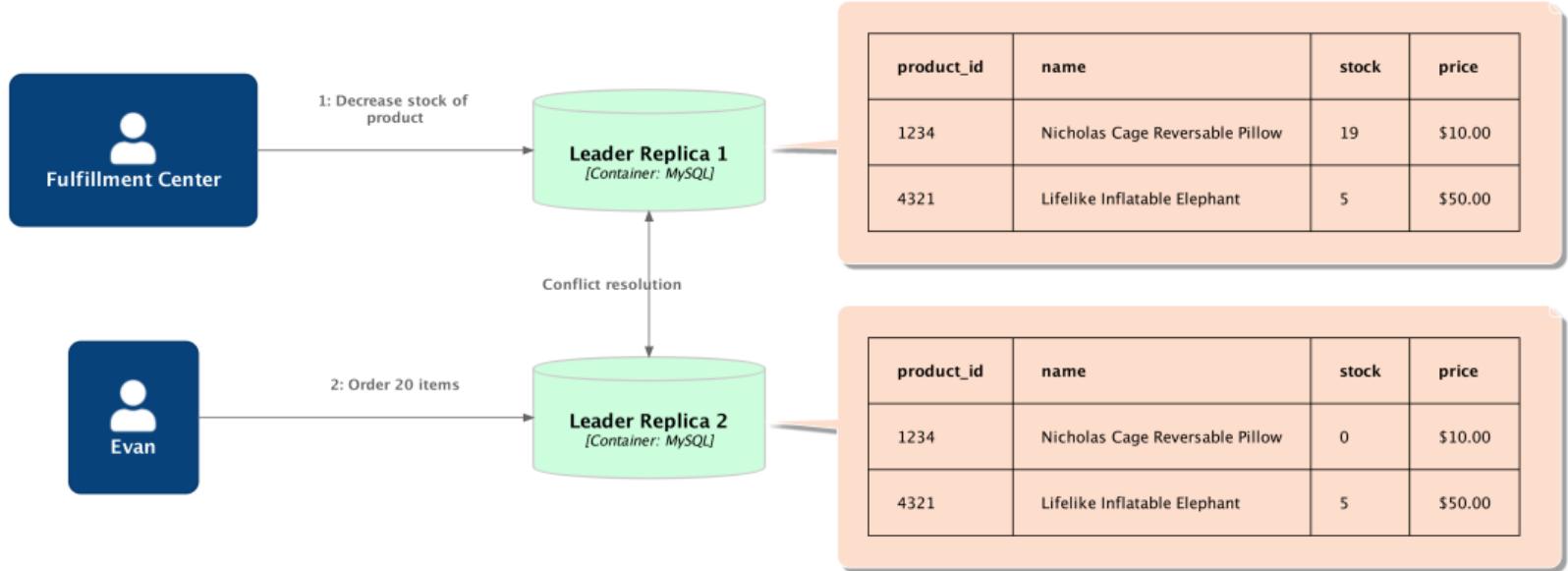
What might go wrong?

*Question*

What might go wrong?

*Answer*

Write conflicts



*Where possible*

Avoid write conflicts



*Where impossible*

Convergence

## *Convergence Strategies*

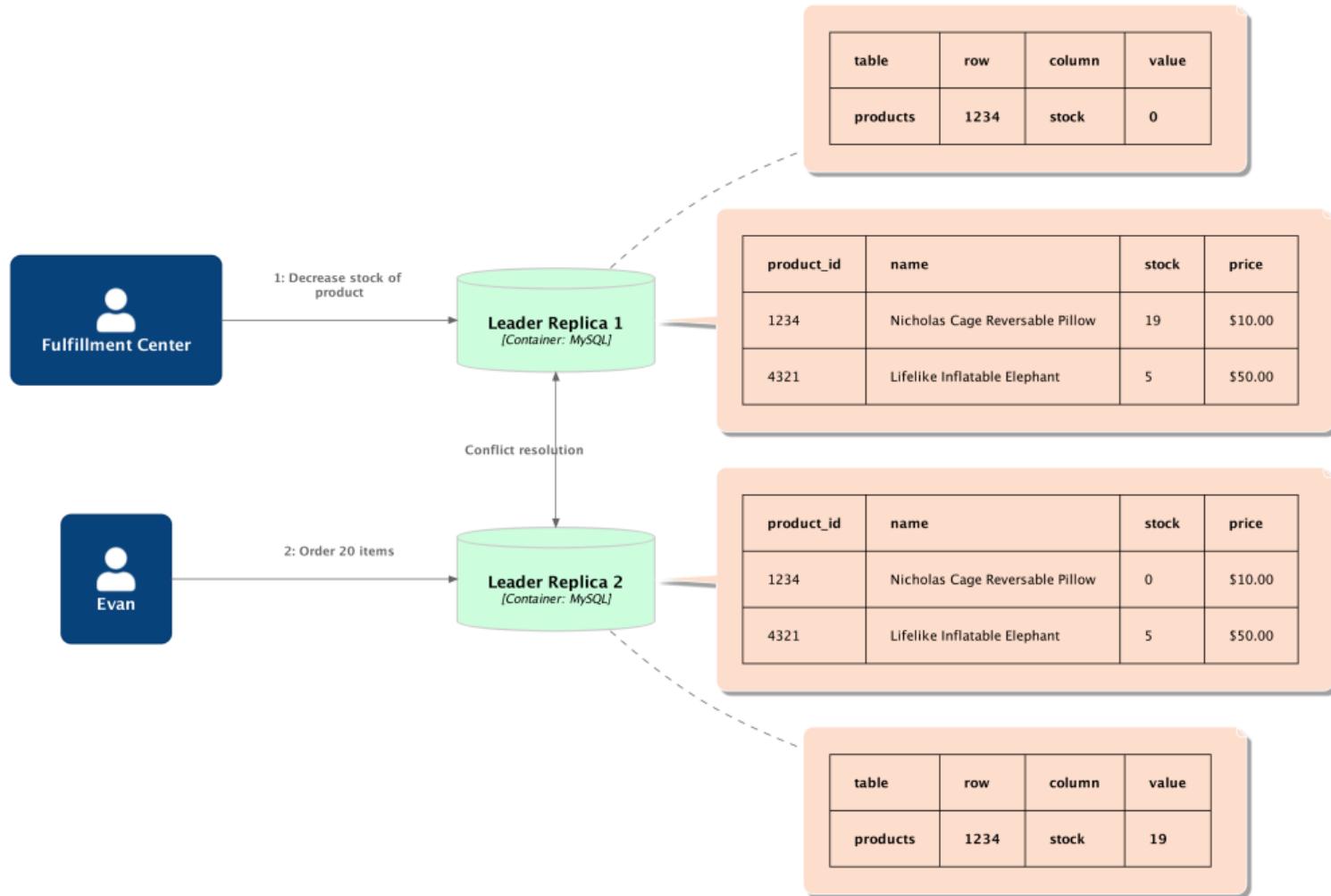
- Assign each *write* a unique ID.

### *Convergence Strategies*

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- Assign each *leader replica* a unique ID.

## *Convergence Strategies*

- Assign each *write* a unique ID.
- Assign each *leader replica* a unique ID.
- Custom resolution logic.



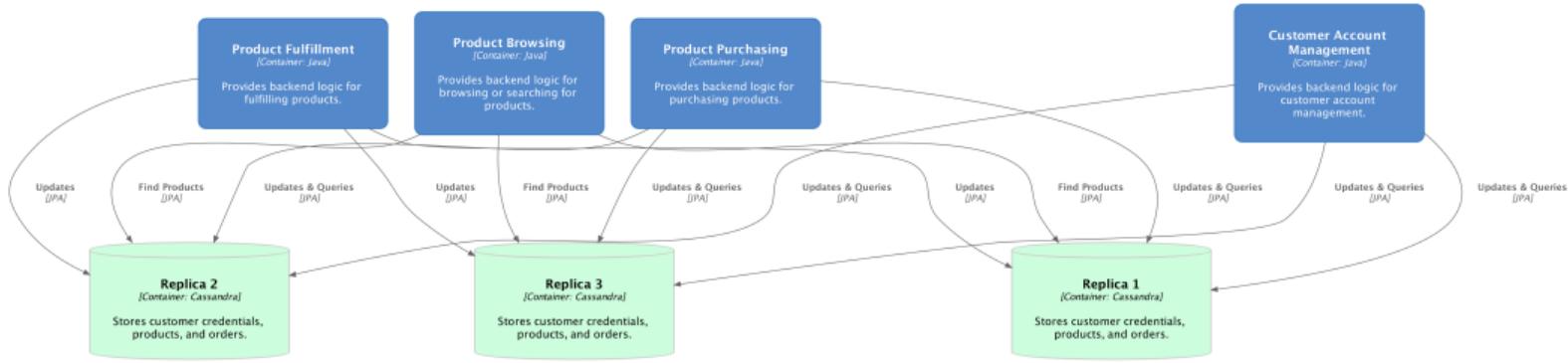
### *Resolving Conflicts*

**On Write** When a conflict is first noticed, take proactive resolution action.

**On Read** When a conflict is next read, ask for a resolution.

*Third Approach*

## Leaderless Replication



*How do they work?*

Each read/write is sent to *multiple* replicas.





*How are changes propagated?*

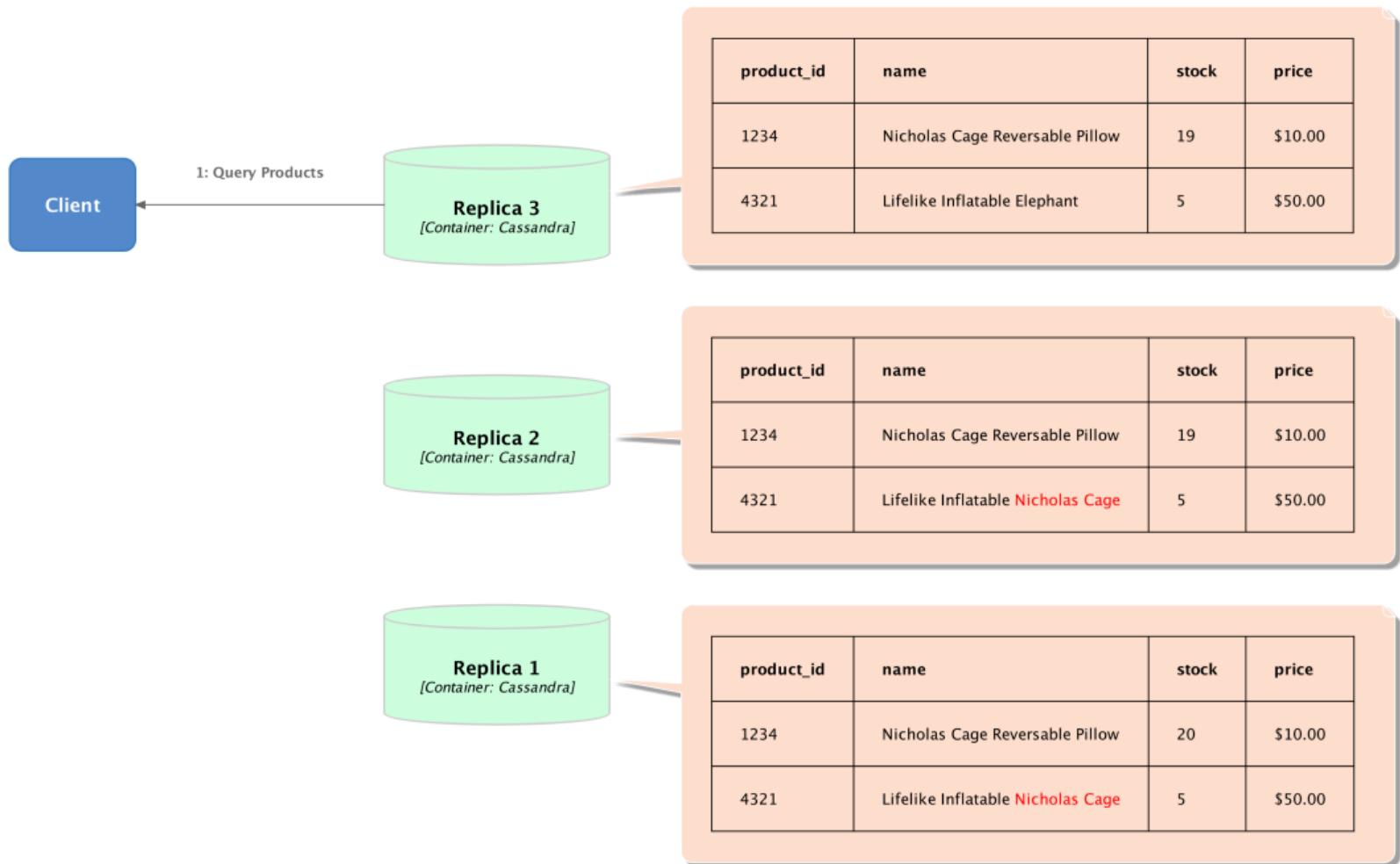
- Read Repair

*How are changes propagated?*

- Read Repair
- Anti-entropy Process

*Question*

How do we know it's consistent?



*Question*

How do we know it's consistent?

*Question*

How do we know it's consistent?

*Answer*

Quorum Reads and Writes

## *Quorum Consistency*

$$w + r > n$$

*n* total replicas

*w* amount of replicas to *write* to

*r* amount of replicas to *read* from

## *Quorum Consistency*

$$2 + 2 > 3$$

*n* total replicas

*w* amount of replicas to *write* to

*r* amount of replicas to *read* from

## *Quorum Consistency*

$$1 + 3 > 3$$

*n* total replicas

*w* amount of replicas to *write* to

*r* amount of replicas to *read* from



**Replica 1**  
[Container: Cassandra]



**Replica 2**  
[Container: Cassandra]



**Replica 3**  
[Container: Cassandra]

$n$  total replicas

$w$  amount of replicas to *write* to

$r$  amount of replicas to *read* from

## *Summary*

- *Replication* copies data to multiple replicas.

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- *Replication* copies data to multiple replicas.
- *Leader-based* replication is most common and simplest.
- Replication introduces *eventual consistency*.
- *Multi-leader* replication scales writes as well as reads but introduces *write conflicts*.
- *Leaderless* replication is another approach which keeps the problems of multi-leader.

*Question*

How do we fix database scaling issues?

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*Answer*

- *Replication*
- Partitioning
- Independent databases

*Question*

How do we fix database scaling issues?

*Answer*

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### *Definition 6.* Partitioning

Split the data of a system onto multiple nodes, these nodes are *partitions*.



product_id	name	stock	price
4321	Lifelike Elephant Inflatable	5	\$50.00



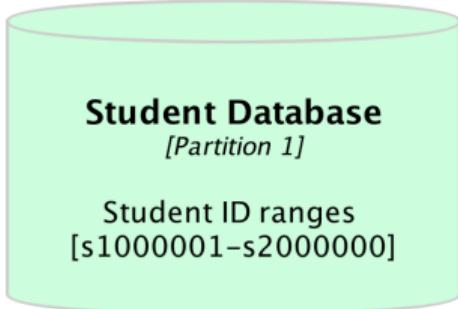
product_id	name	stock	price
1234	Nicholas Cage Reversible Pillow	10	\$10.00

*Question*

How should we decide which data is stored where?



student_id	name	...
s0746283	Bobby Tables	...
...	...	...



student_id	name	...
s1637285	Brae Webb	...
...	...	...

*Question*

What is the problem with this?

*Question*

What is the problem with this?

*Answer*

Over time some partitions become inactive, while others receive almost all load.

*Question*

How should we decide which data is stored where?

*Question*

How should we decide which data is stored where?

*Answer*

Maximize spread of requests, avoiding *skewing*.

*Question*

Have we seen this before?

*Question*

Have we seen this before?

*Answer*

Hashing?

*Question*

What is the problem with this?

*Question*

What is the problem with this?

*Answer*

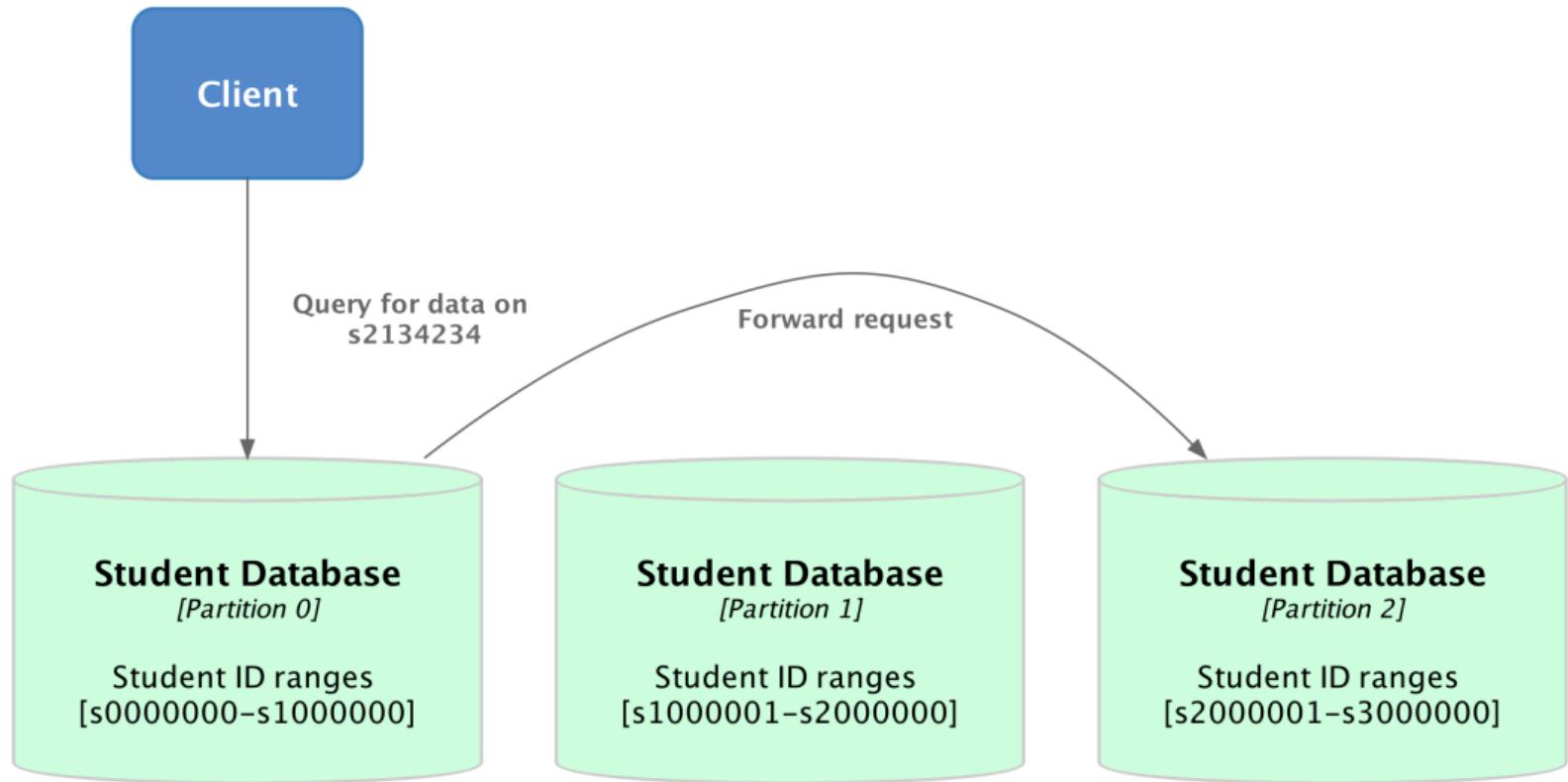
Range queries are inefficient, i.e. get all students between s4444444 and s4565656

*Question*

How do we route queries?

### *Query-insensitive Load Balancer*

Randomly route to any node, responsibility of the node to re-route to the correct node.



### *Query-sensitive Load Balancer*

A load balancer which understands which queries should be forwarded to which node.



### *Client-aware Queries*

Place the responsibility on clients to choose the correct node.



## *Summary*

- *Partitioning* splits data across multiple nodes.

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## Summary

- *Partitioning* splits data across multiple nodes.
- A *consistent method* to chose which node is required.
- Partitioning by *primary key* can create *skewing*.
- Partitioning by *hash* makes range queries less efficient.
- Three approaches to *routing requests*.

*Disclaimer*

We have ignored the hard parts of replication.

*Question*

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*Answer*

- Replication
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*Summary*

- Replications

## *Summary*

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  - Leader-based, multi-leader, and leaderless

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- Leader-based, multi-leader, and leaderless
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## *Summary*

- Replications
  - Leader-based, multi-leader, and leaderless
  - Eventual consistency
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  - Consistent method to pick nodes for data

## *Summary*

- Replications
  - Leader-based, multi-leader, and leaderless
  - Eventual consistency
  - Write conflicts
- Partitioning
  - Consistent method to pick nodes for data
  - Avoiding skewing