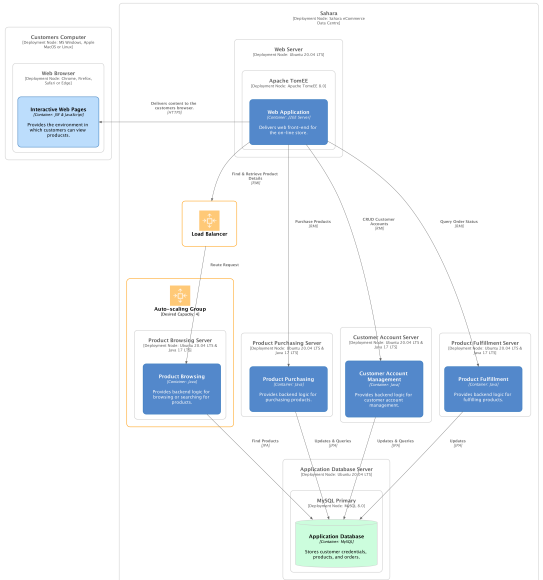
Distributed Computing II

CSSE6400

Brae Webb

April 4, 2022

Previously in CSSE6400…



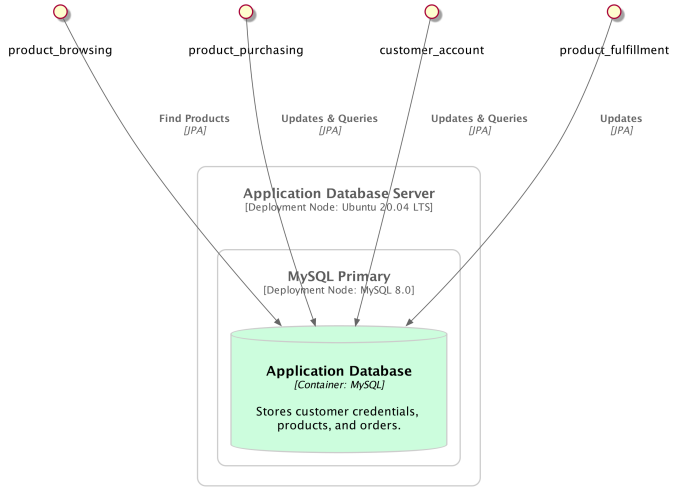
- We scaled a stateless service.
- It was stateless as it didn't require persistent data.
- This is normally easy to do.

Question

What is the *problem*?

The database

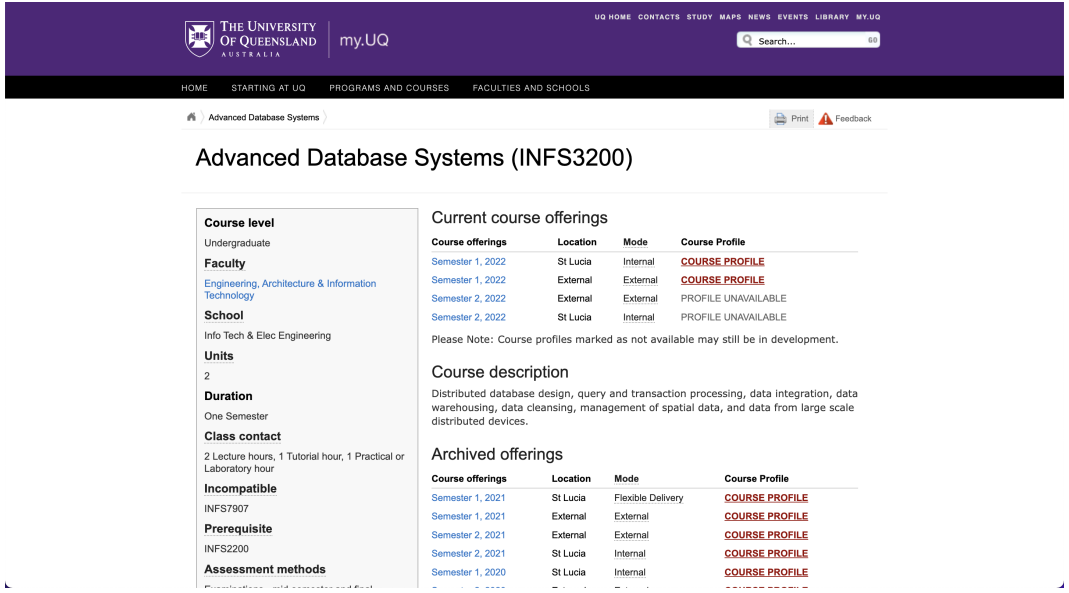
Database



- The database has state, persistent data.
- This is much harder to scale.

Disclaimer

This is *not* a database course.



This is a database course.

Question

How do we fix database scaling issues?

Question

How do we fix database scaling issues?

Answer

- Replication

Question

How do we fix database scaling issues?

Answer

- Replication
- Partitioning

Question

How do we fix database scaling issues?

Answer

- Replication
- Partitioning
- Independent databases

Question

How do we fix database scaling issues?

Answer

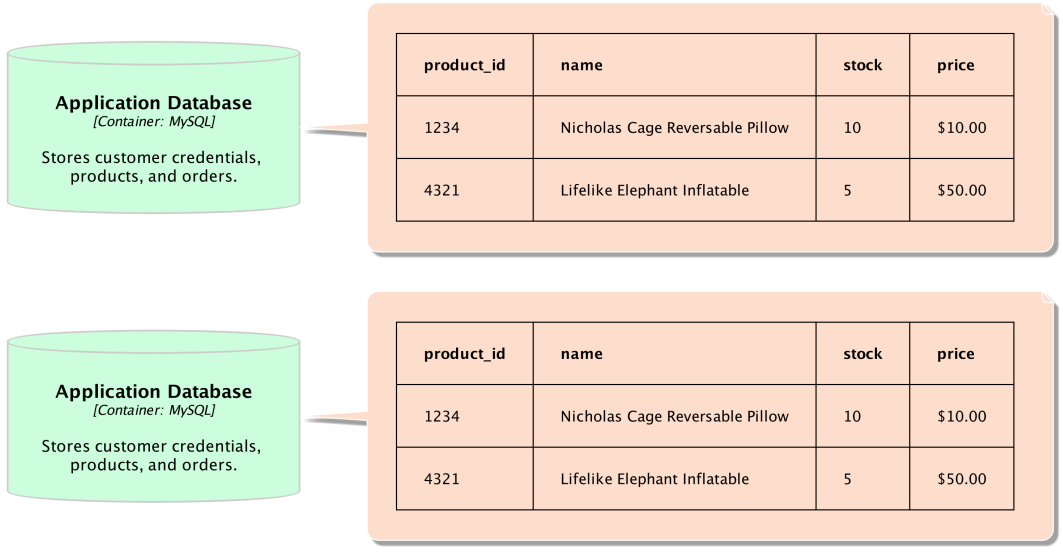
- *Replication*
- Partitioning
- Independent databases

Question

What is *replication*?

Definition 1. Replication

Data copied across multiple different machines.


Application Database
[Container: MySQL]
Stores customer credentials, products, and orders.
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
10
$10.00
4321
Lifelike Elephant Inflatable
5
$50.00
Application Database
[Container: MySQL]
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product_id
name
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price
1234
Nicholas Cage Reversable Pillow
10
$10.00
4321
Lifelike Elephant Inflatable
5
$50.00

Definition 2. Replica

Database node which stores a copy of the data.

Question

What are the advantages of *replication*?

Question

What are the advantages of *replication*?

Answer

- Scale out our database to cope with *load*.

Question

What are the advantages of *replication*?

Answer

- Scale out our database to cope with *load*.
- Provide *fault tolerance* from a single database instance failure.

Question

What are the advantages of *replication*?

Answer

- Scale out our database to cope with *load*.
- Provide *fault tolerance* from a single database instance failure.
- Locate databases *closer to end-users*.

- Scalability
- Reliability
- Performance

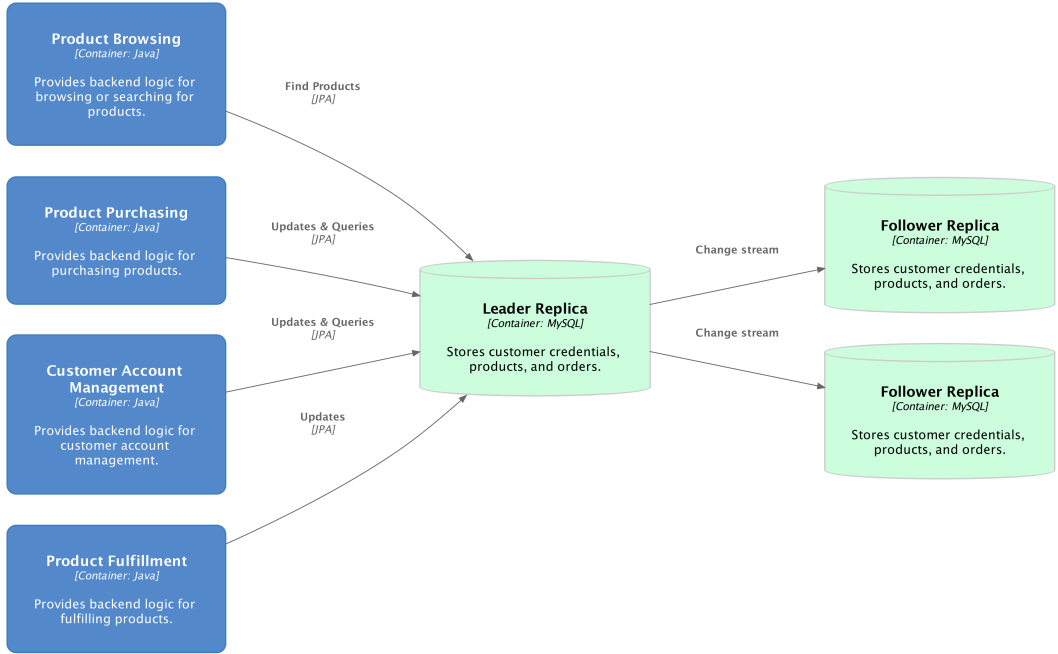
Question

How do we replicate our data?

- Easy without updates, just copy it.
- Updates, or writes, must propagate changes.

First approach

Leader-follower Replication



- Leader-follower is the most common implementation.
- Multiple followers, only one leader.

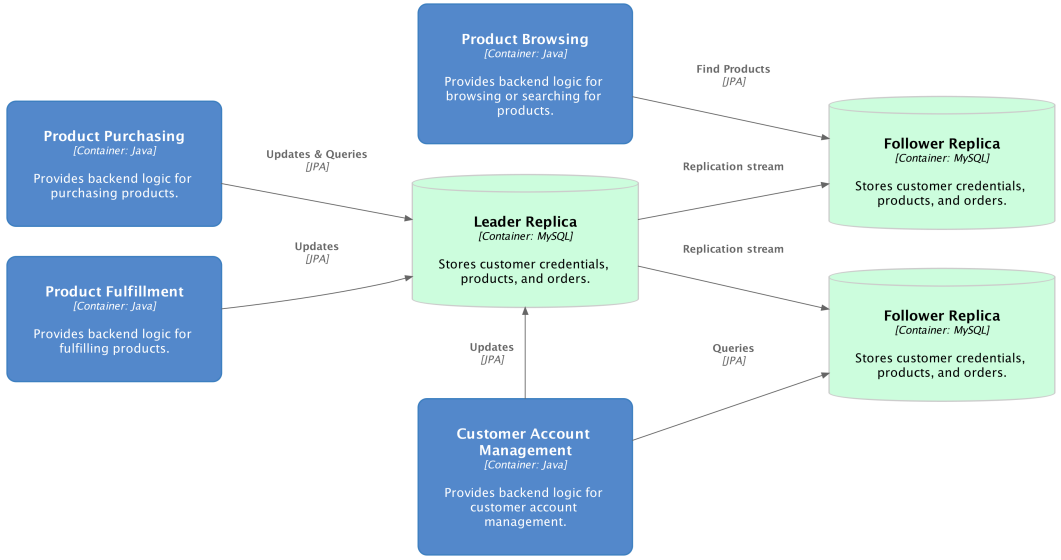
Leader-based Replication

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

Leader-based Replication

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

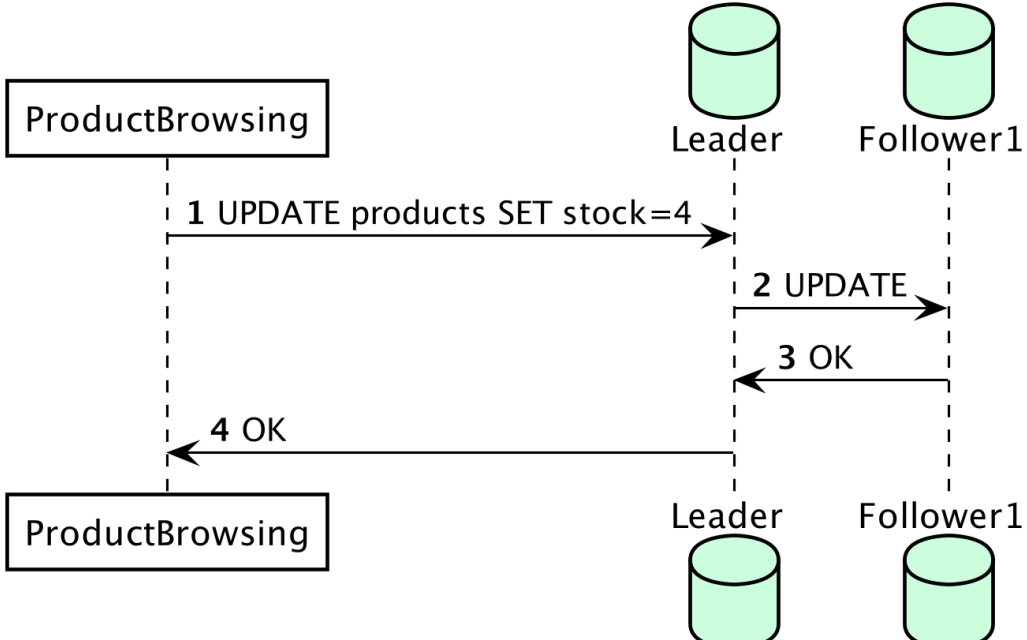
On read Any replica can be queried.

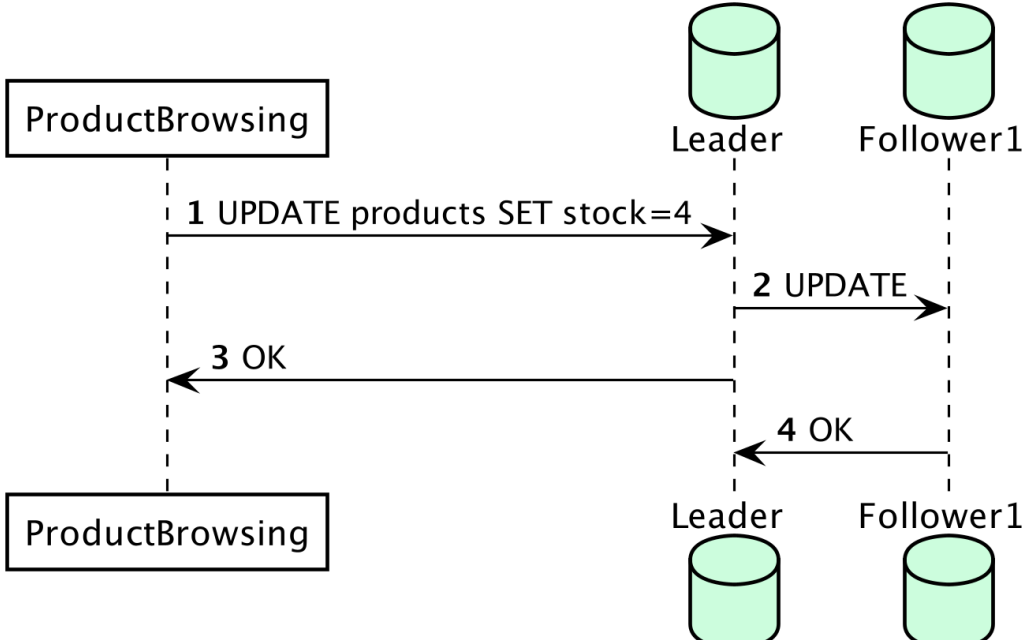


- Built-in to PostgreSQL, MySQL, MongoDB, RethinkDB, and Espresso.
- Can be added to Oracle and SQL Server.

Propogating changes

Synchronous vs. *Asynchronous*


ProductBrowsing
Leader
Follower1
1 UPDATE products SET stock=4
2 UPDATE
3 OK
4 OK
ProductBrowsing
Leader
Follower1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Leader
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1 UPDATE products SET stock=4
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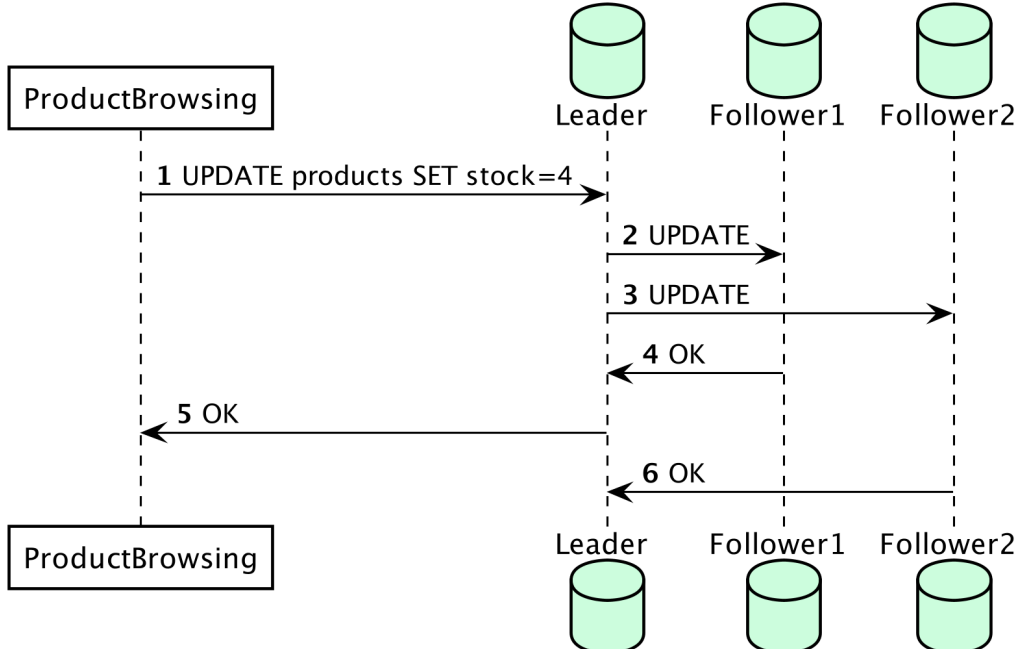
Leader
Follower1


ProductBrowsing
Leader
Follower1
Follower2
1 UPDATE products SET stock=4
2 UPDATE
3 UPDATE
4 OK
5 OK
6 OK
ProductBrowsing
Leader
Follower1
Follower2

Synchronous propagation

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

Synchronous propagation

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- *Any* replica goes down, *all* replicas are un-writable.

Synchronous propagation

- 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.

Asynchronous propagation

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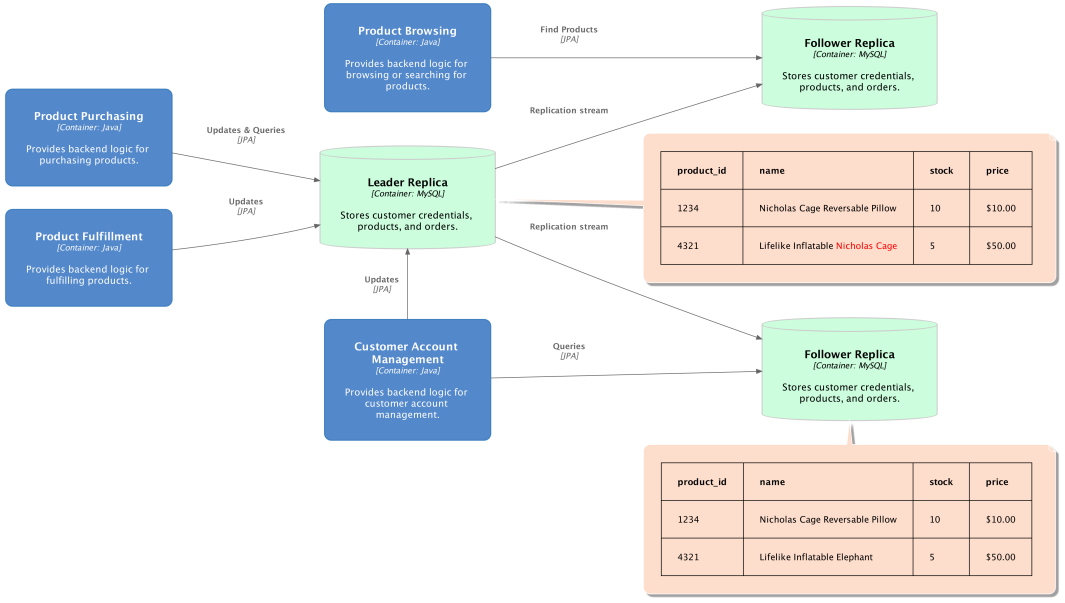
- If the leader goes down before propagating, the *write is lost*.

Asynchronous propagation

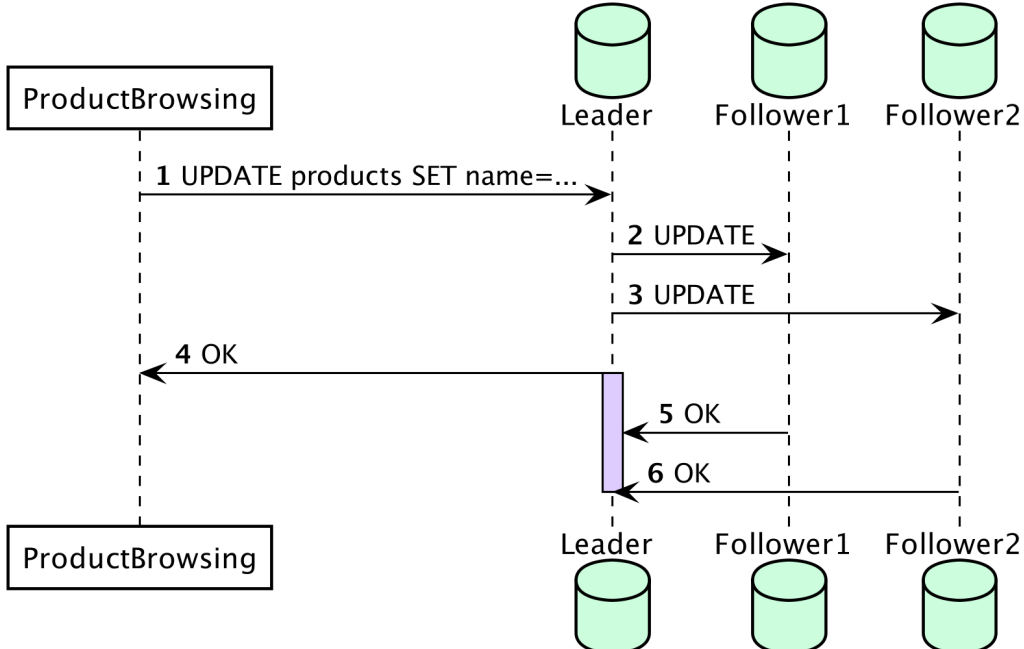
- Writes *don't* have to *wait* for propagation.
- If the leader goes down before propagating, the *write is lost*.
- Replicas can have out-dated or *stale* data.

Definition 3. Replication Lag

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



The time it takes for the change to the name of the product to update across all followers



The purple part is replication lag

Eventually, all replicas must become consistent

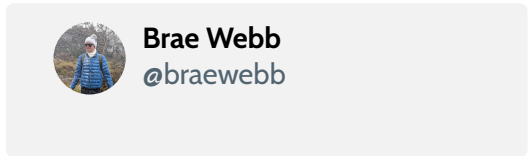
The system is *eventually consistent*

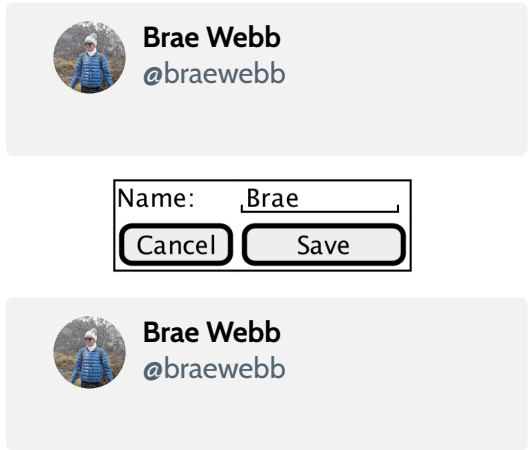
- If writes stop for long enough
- Eventually is intentionally ambiguous

Eventual Consistency

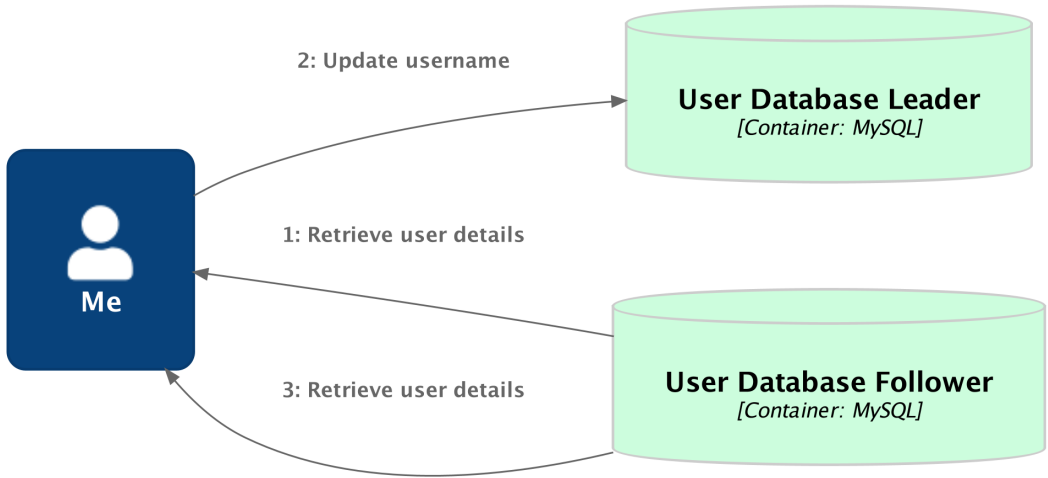
Problems?

Brae Webb
@braewebb


Brae Webb
@braewebb
Name:
Brae
Cancel
Save



- Read user details
- Decide I don't like by name
- Update name
- Read user details


2: Update username
User Database Leader
[Container: MySQL]
Me
1: Retrieve user details
User Database Follower
[Container: MySQL]
3: Retrieve user details

Definition 4. Read-your-writes Consistency

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

Doesn't care what other users see

Brae Webb
@braewebb

My fist post

Brae Webb
@braewebb

My fist post

Brae Webb
@braewebb

My first post

Brae Webb
@braewebb

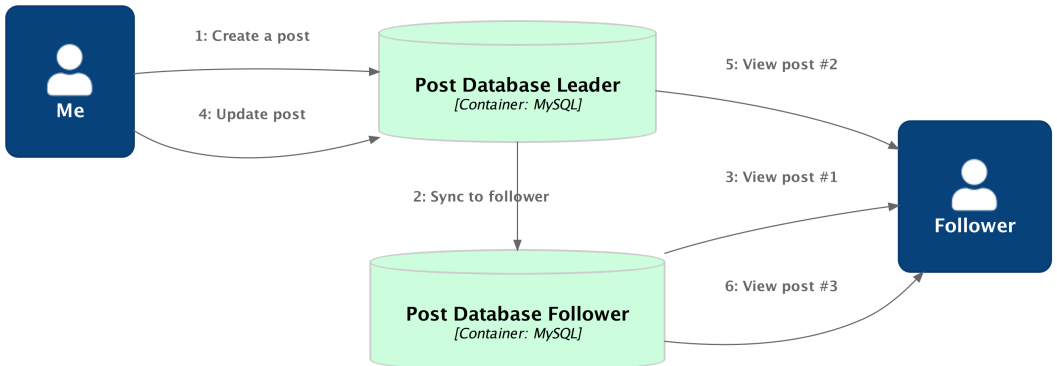
My fist post

Brae Webb
@braewebb

My first post

Brae Webb
@braewebb

My fist post


Me
1: Create a post
4: Update post
Post Database Leader
[Container: MySQL]
2: Sync to follower
Post Database Follower
[Container: MySQL]
5: View post #2
3: View post #1
6: View post #3
Follower

Definition 5. Monotonic Reads

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

User doesn't travel back in time

Consistent Prefix Reads

Oi!

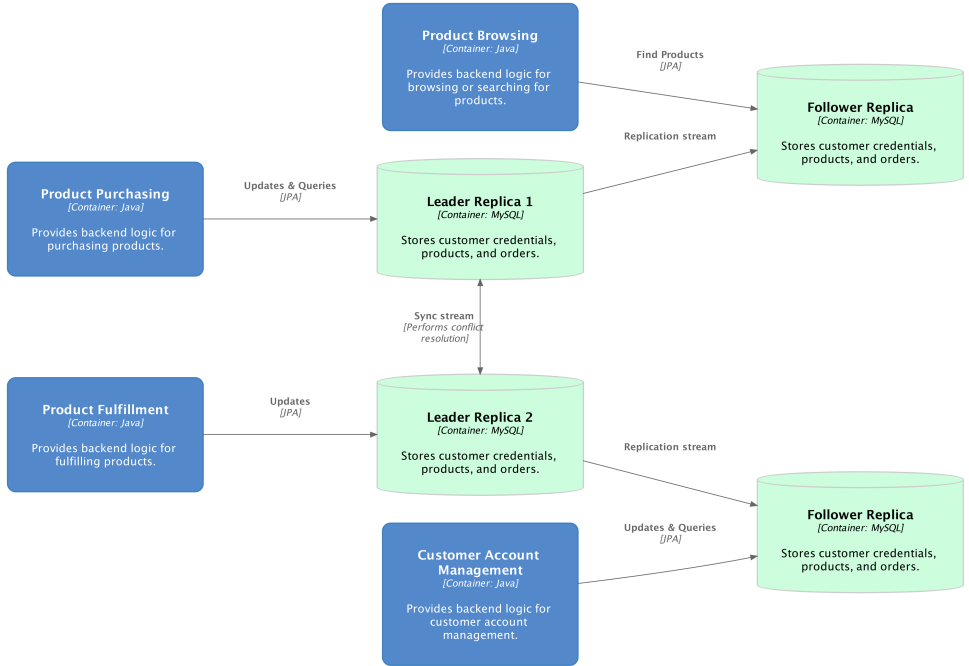
Consistent Precix Example

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


Product Browsing
[Container: Java]
Provides backend logic for browsing or searching for products.
Find Products
[JPA]
Follower Replica
[Container: MySQL]
Stores customer credentials, products, and orders.
Replication stream
Product Purchasing
[Container: Java]
Provides backend logic for purchasing products.
Updates & Queries
[JPA]
Leader Replica 1
[Container: MySQL]
Stores customer credentials, products, and orders.
Sync stream
[Performs conflict resolution]
Product Fulfillment
[Container: Java]
Provides backend logic for fulfilling products.
Updates
[JPA]
Leader Replica 2
[Container: MySQL]
Stores customer credentials, products, and orders.
Replication stream
Follower Replica
[Container: MySQL]
Stores customer credentials, products, and orders.
Customer Account Management
[Container: Java]
Provides backend logic for customer account management.
Updates & Queries
[JPA]

Why multi-leader?

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

Why multi-leader?

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

- Available via extensions in most databases, often not natively supported.
- Best to avoid where possible.

Question

What might go wrong?

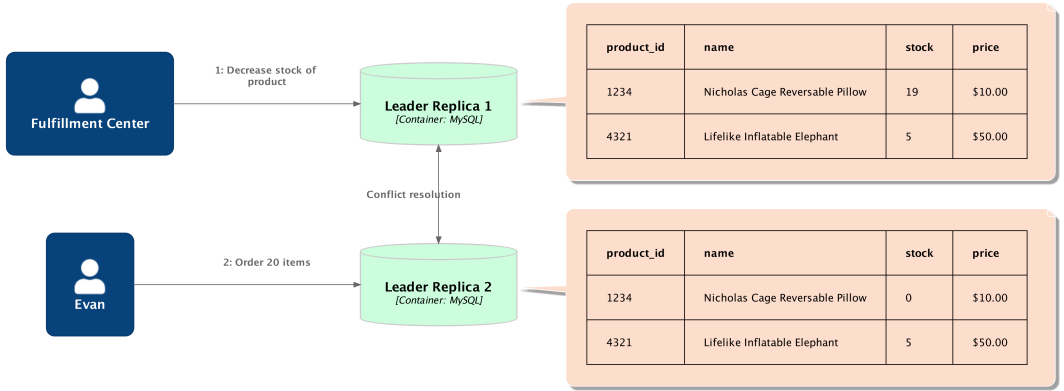
Question

What might go wrong?

Answer

Write conflicts

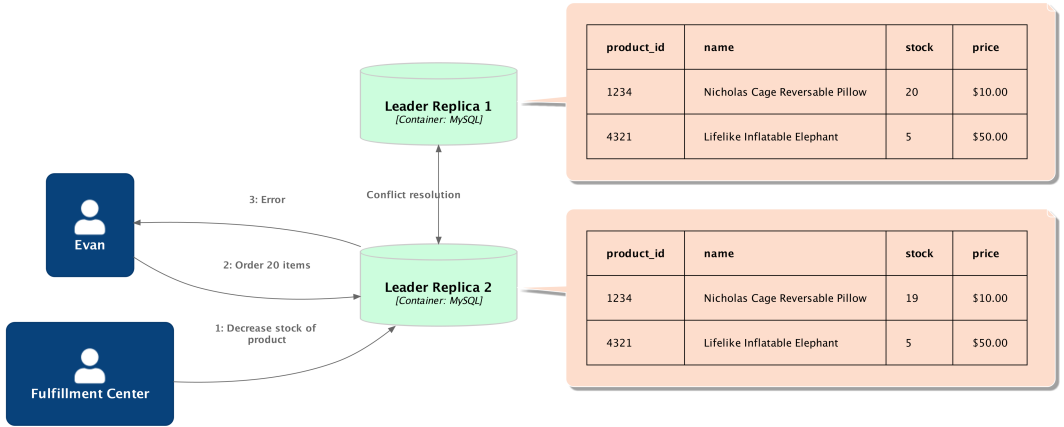
Write conflicts require the conflict to be resolved.



-1 Pillows? How do we resolve this?

Where possible

Avoid write conflicts



product_id	name	stock	price
1234	Nicholas Cage Reversable Pillow	20	$10.00
4321	Lifelike Inflatable Elephant	5	$50.00

product_id	name	stock	price
1234	Nicholas Cage Reversable Pillow	19	$10.00
4321	Lifelike Inflatable Elephant	5	$50.00

Where impossible

Convergence

Convergence Strategies

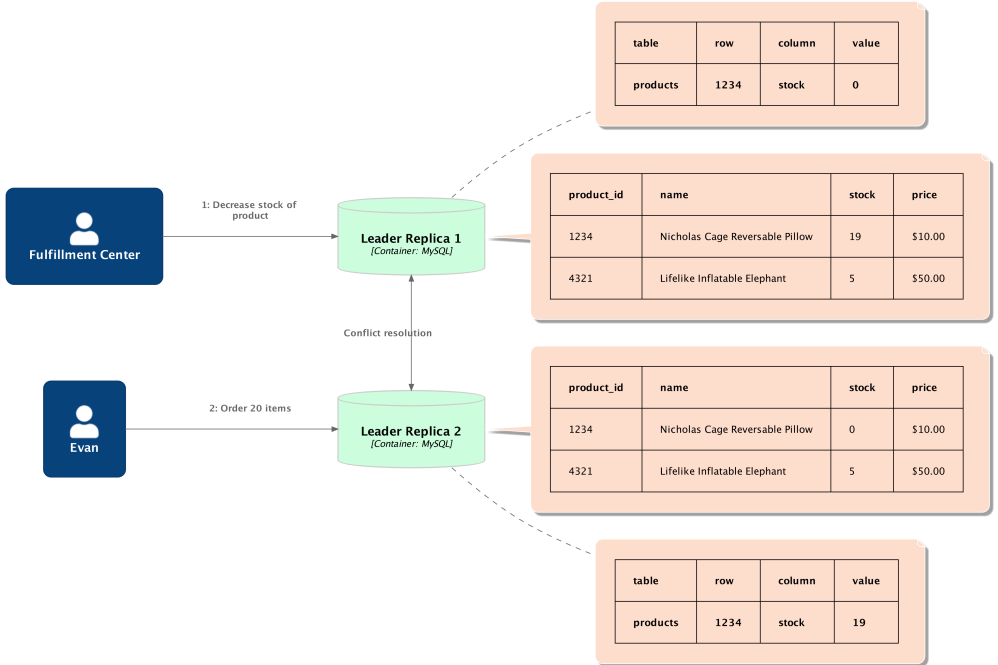
- Assign each *write* a unique ID.

Convergence Strategies

- Assign each *write* a unique ID.
- 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.


Fulfillment Center
1: Decrease stock of product
Leader Replica 1
[Container: MySQL]
Conflict resolution
Evan
2: Order 20 items
Leader Replica 2
[Container: MySQL]
table
row
column
value
products
1234
stock
0
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
19
$10.00
4321
Lifelike Inflatable Elephant
5
$50.00
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
0
$10.00
4321
Lifelike Inflatable Elephant
5
$50.00
table
row
column
value
products
1234
stock
19

Resolving Conflicts

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

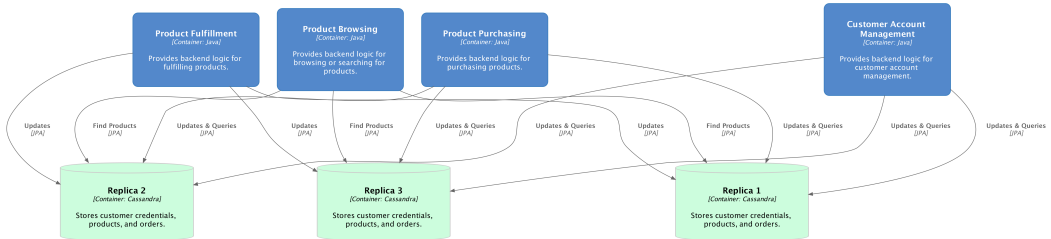
On Read When a conflict is next read, ask for a resolution.

- Bucardo allows a perl script for on write resolution.
- CouchDB prompts reads to resolve the conflict.

Third Approach

Leaderless Replication

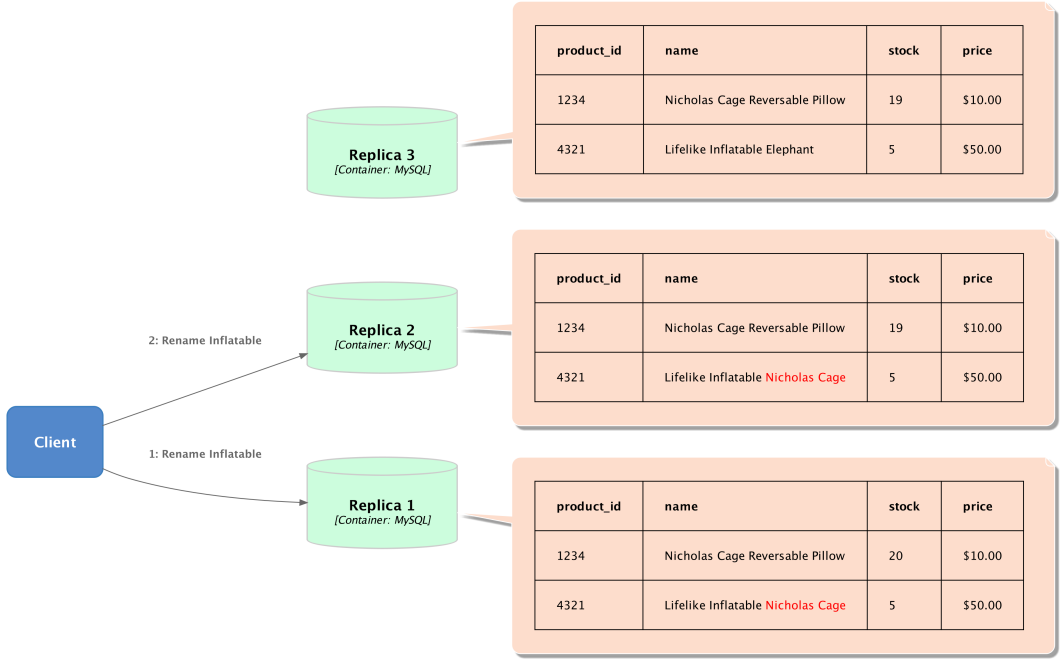
- Early distributed databases were leaderless.
- Resurgance after Amazon created Dynamo.
- Dynamo is an internal service and not DynamoDB.
- Riak, Cassandra, and Voldemort are leaderless databases.



Reads and writes can be written to any node.

How do they work?

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


Client
1: Rename Inflatable
2: Rename Inflatable
Replica 1
[Container: MySQL]
Replica 2
[Container: MySQL]
Replica 3
[Container: MySQL]
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
20
$10.00
4321
Lifelike Inflatable Nicholas Cage
5
$50.00
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
19
$10.00
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5
$50.00
product_id
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stock
price
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19
$10.00
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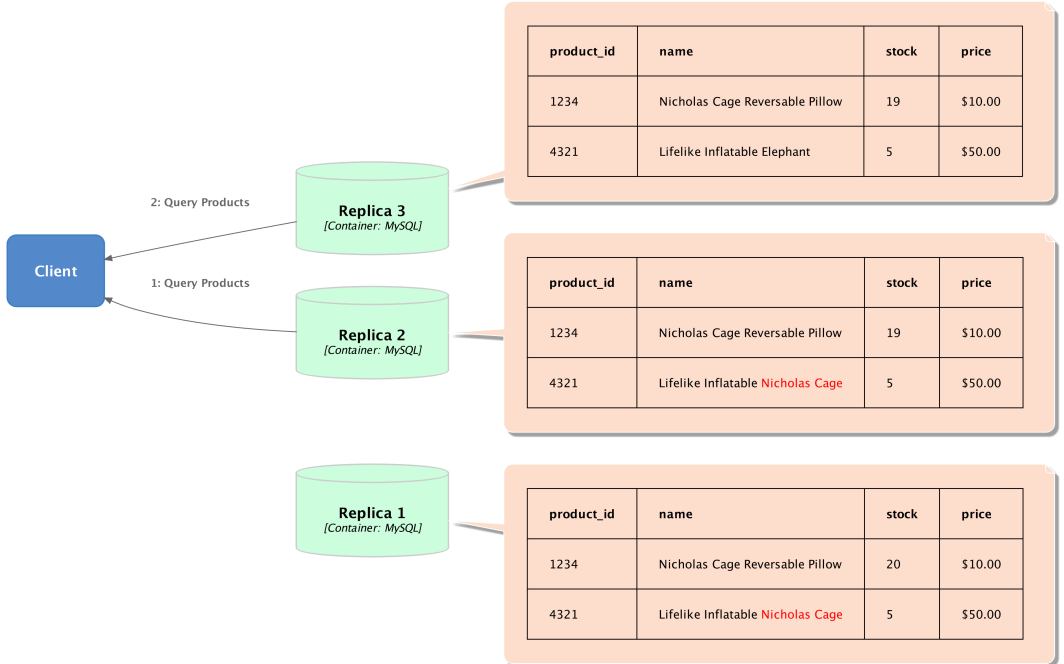
Lifelike Inflatable
5
$50.00



At least one of the reads has the updated value

How are changes propagated?

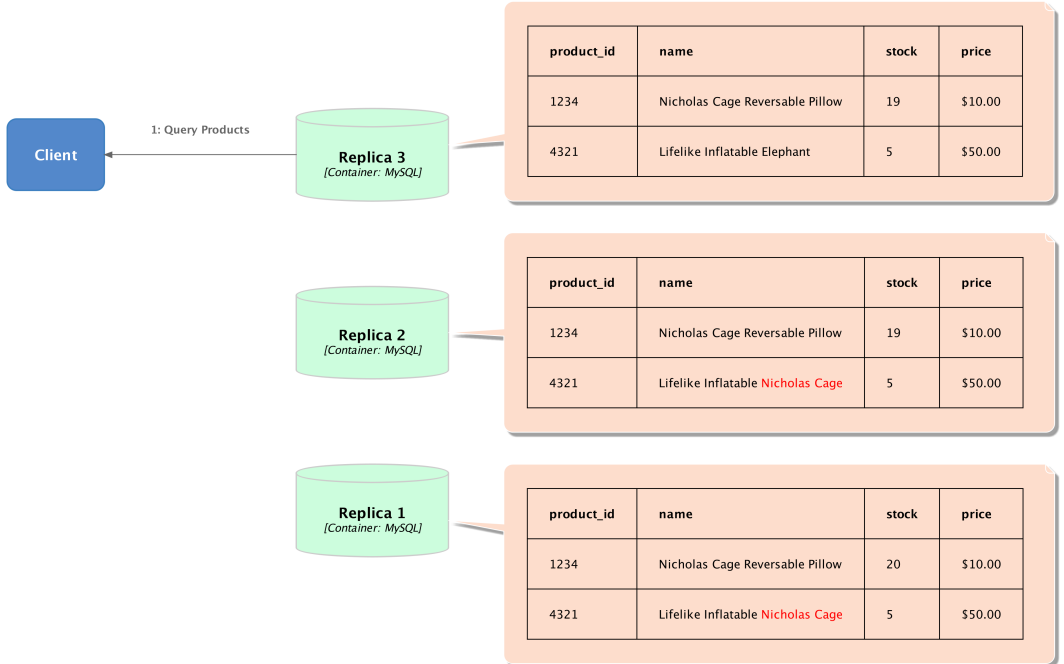
- Read Repair

How are changes propagated?

- Read Repair
- Anti-entropy Process

Question

How do we know it's consistent?


Client
1: Query Products
Replica 3
[Container: MySQL]
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
19
$10.00
4321
Lifelike Inflatable Elephant
5
$50.00
Replica 2
[Container: MySQL]
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
19
$10.00
4321
Lifelike Inflatable Nicholas Cage
5
$50.00
Replica 1
[Container: MySQL]
product_id
name
stock
price
1234
Nicholas Cage Reversable Pillow
20
$10.00
4321
Lifelike Inflatable Nicholas Cage
5
$50.00

Question

How do we know it's consistent?

Question

How do we know it's consistent?

Answer

Quorum Reads and Writes

Quorum Consistency

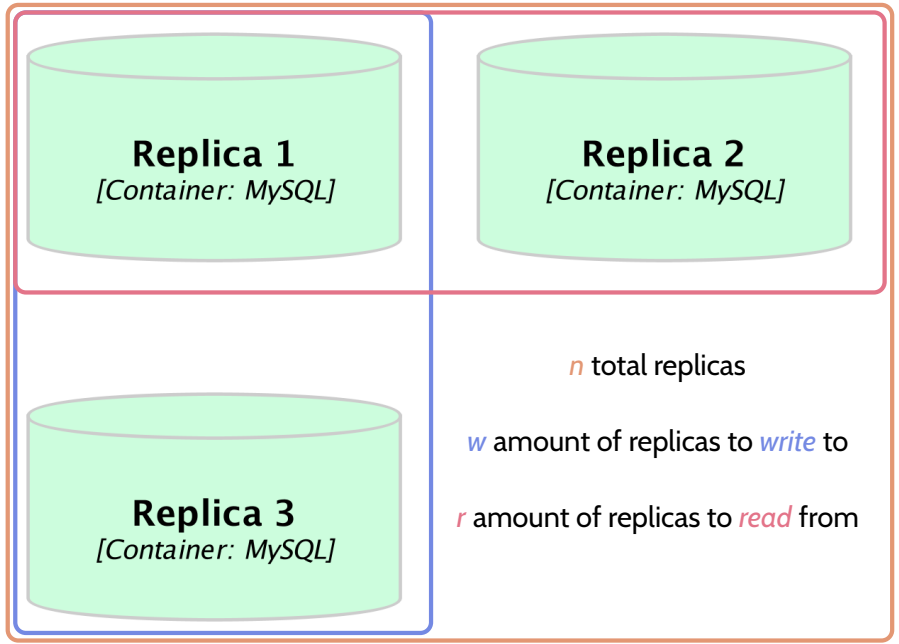
$$w + r > n$$

n total replicas

w amount of replicas to *write* to

r amount of replicas to *read* from

The nodes read from must overlap with the nodes written to


Replica 1
[Container: MySQL]
Replica 2
[Container: MySQL]
Replica 3
[Container: MySQL]
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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- *Leader-based* replication is most common and simpliest.

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- Replication introduces *eventual consistency*.
- *Multi-leader* replication scales writes as well as reads but introduces *write conflicts*.

Summary

- *Replication* copies data to multiple replicas.
- *Leader-based* replication is most common and simpliest.
- 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?

Question

How do we fix database scaling issues?

Answer

- *Replication*
- Partitioning
- Independent databases

Question

How do we fix database scaling issues?

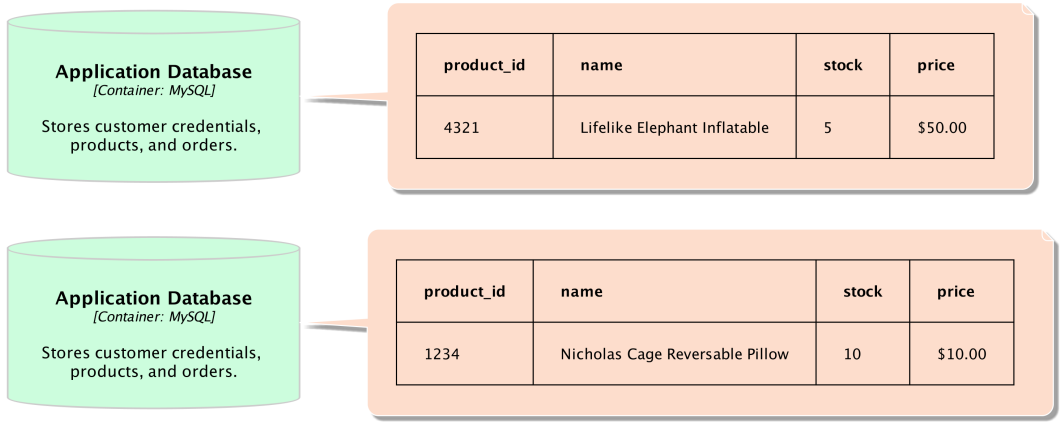
Answer

- Replication
- *Partitioning*
- Independent databases

Definition 6. Partitioning

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

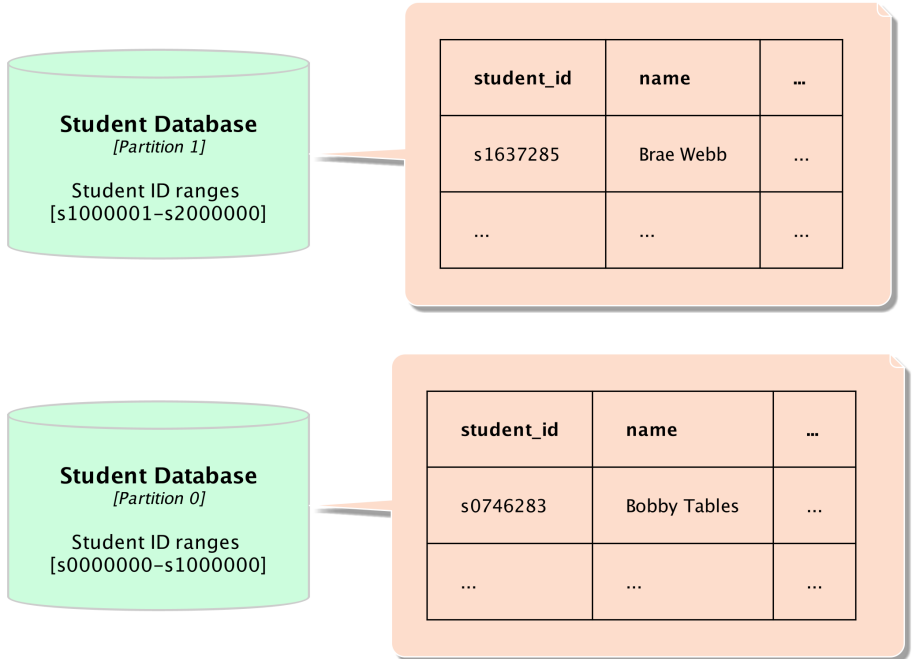
Also called shardes, regions, tablets, etc.



- Pioneered in the 1980s
- Allow scalability of large data, not just large load.
- Partitioning is normally combined with replication.

Question

How should we decide which data is stored where?



An example partitioning based on primary key, student ID

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?

Hash tables hash entries to maximize the spread between buckets.

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

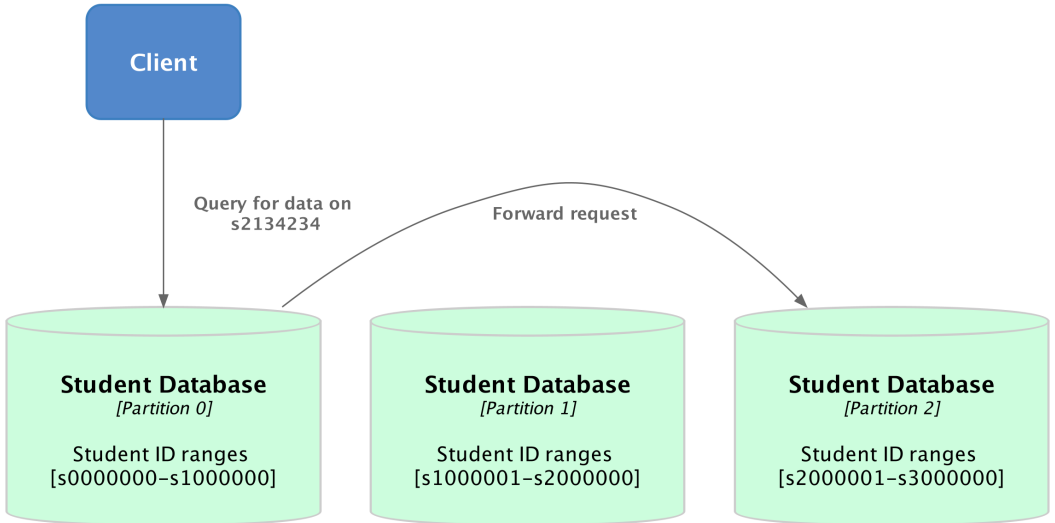
Question

How do we route queries?

Unlike stateless, only one node can process queries.

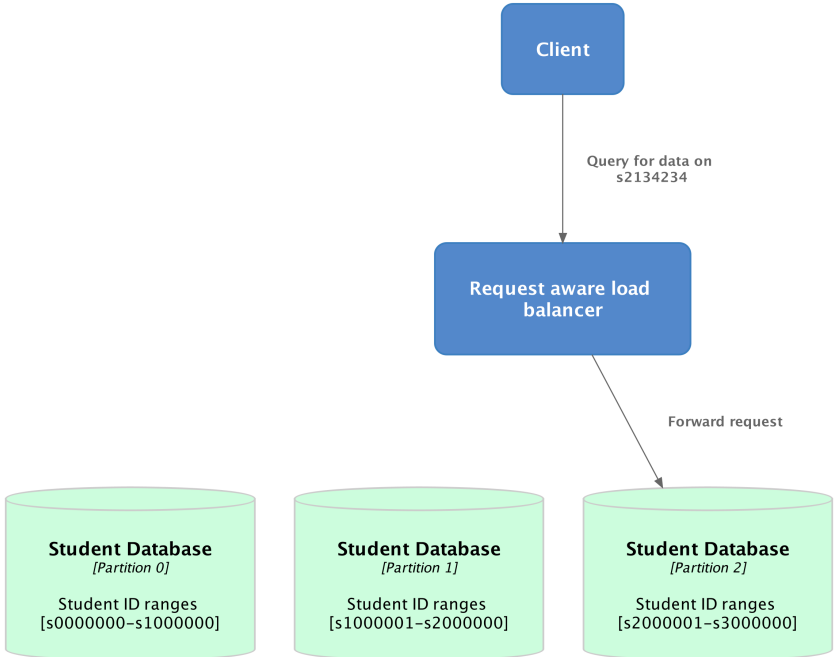
Query-insensitive Load Balancer

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


Client
Query for data on
s2134234
Forward request
Student Database
[Partition 0]
Student ID ranges
[s0000000-s1000000]
Student Database
[Partition 1]
Student ID ranges
[s1000001-s2000000]
Student Database
[Partition 2]
Student ID ranges
[s2000001-s3000000]

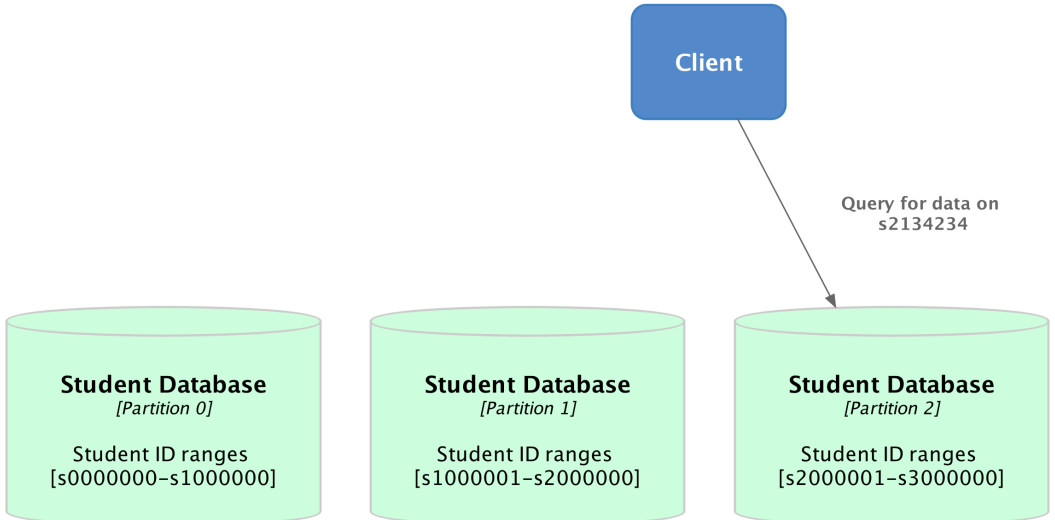
Query-sensitive Load Balancer

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


Client
Query for data on s2134234
Request aware load balancer
Forward request
Student Database
[Partition 0]
Student ID ranges
[s0000000-s1000000]
Student Database
[Partition 1]
Student ID ranges
[s1000001-s2000000]
Student Database
[Partition 2]
Student ID ranges
[s2000001-s3000000]

Client-aware Queries

Place the responsibility on clients to choose the correct node.


Client
Query for data on
s2134234
Student Database
[Partition 0]
Student ID ranges
[s0000000-s1000000]
Student Database
[Partition 1]
Student ID ranges
[s1000001-s2000000]
Student Database
[Partition 2]
Student ID ranges
[s2000001-s3000000]

Summary

- *Partitioning* splits data across multiple nodes.

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- *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

How do we fix database scaling issues?

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Answer

- Replication
- *Partitioning*
- Independent databases

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