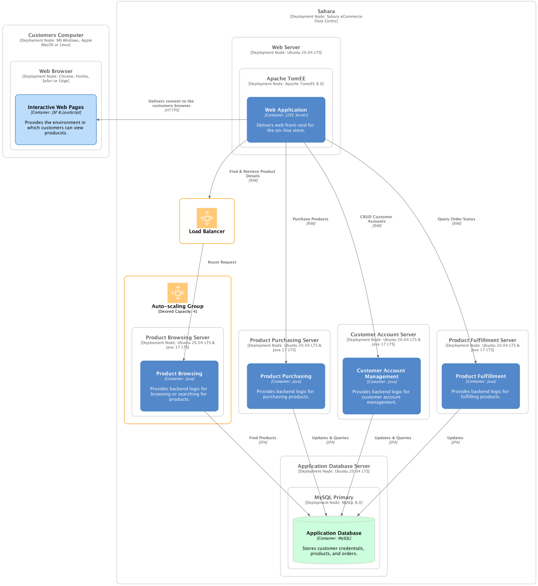
Distributed Computing II

CSSE6400

Brae Webb

April 4, 2022

Previously in CSSE6400...



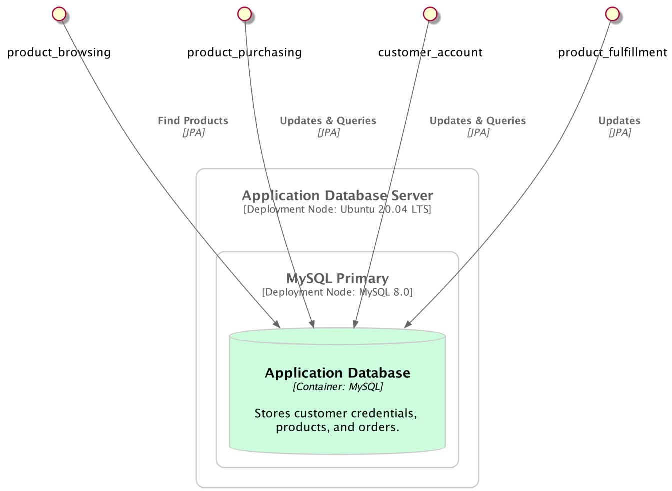
- We scaled a stateless service.
- It was stateless as it didn't require persistent data.
- This is normally easy to do.

Question

What is the *problem*?

The database

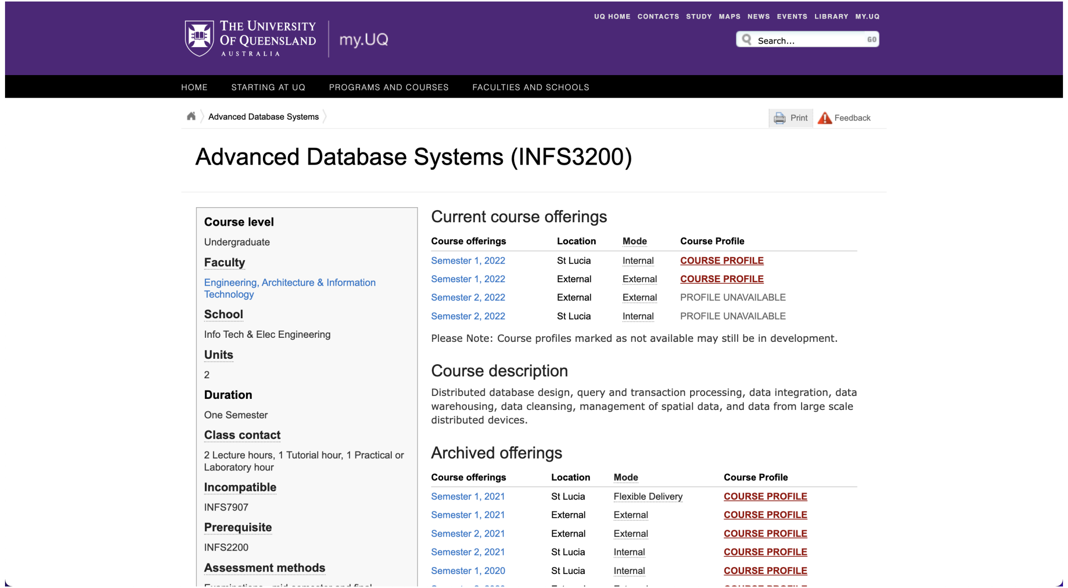
Database



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

Disclaimer

This is *not* a database course.



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Advanced Database Systems | Print | Feedback

Advanced Database Systems (INFS3200)

Course level
Undergraduate

Faculty
Engineering, Architecture & Information Technology

School
Info Tech & 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

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

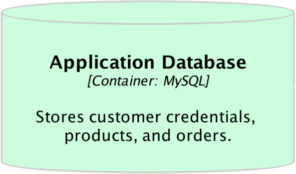
- *Replication*
- Partitioning
- Independent databases

Question

What is *replication*?

Definition 1. Replication

Data copied across multiple different machines.



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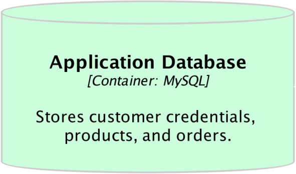
4321	Lifelike Elephant Inflatable	5	$50.00



product_id	name	stock	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

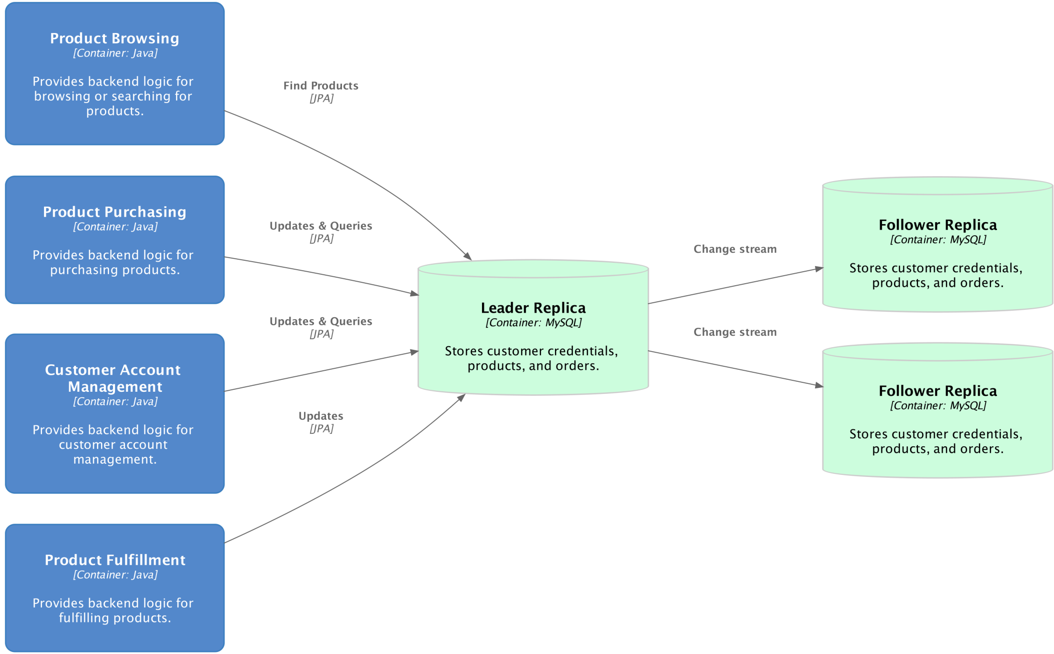
Question

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.

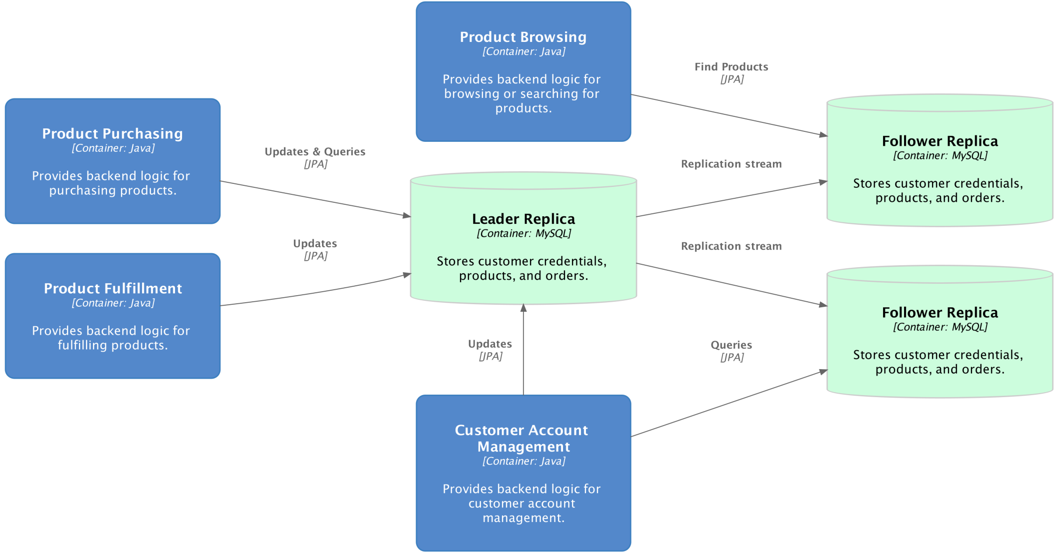
Leader-based Replication

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.

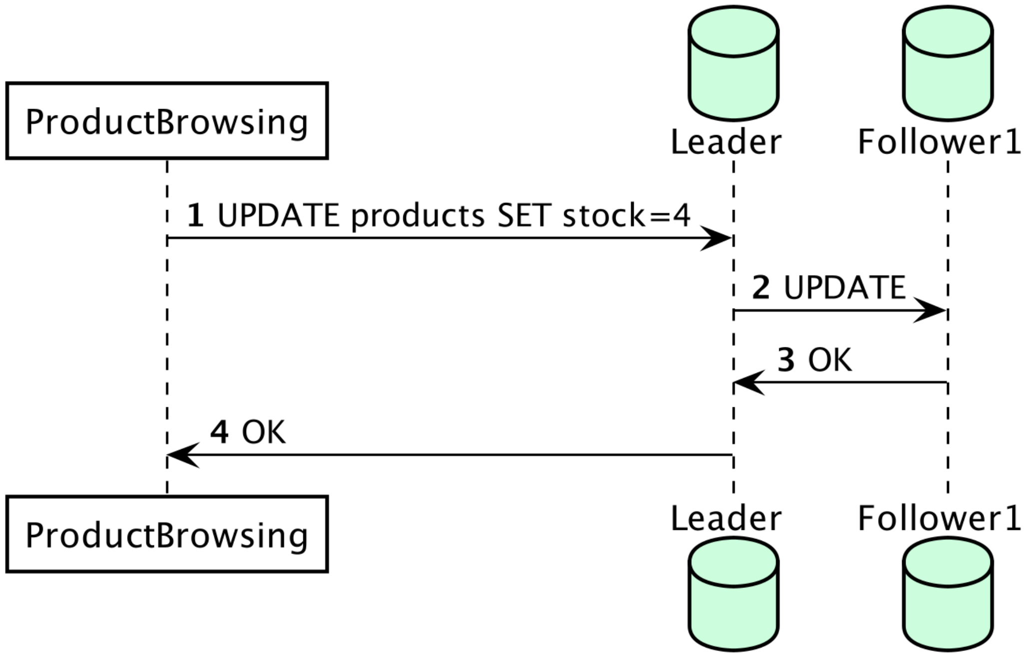
On read Any replica can be queried.

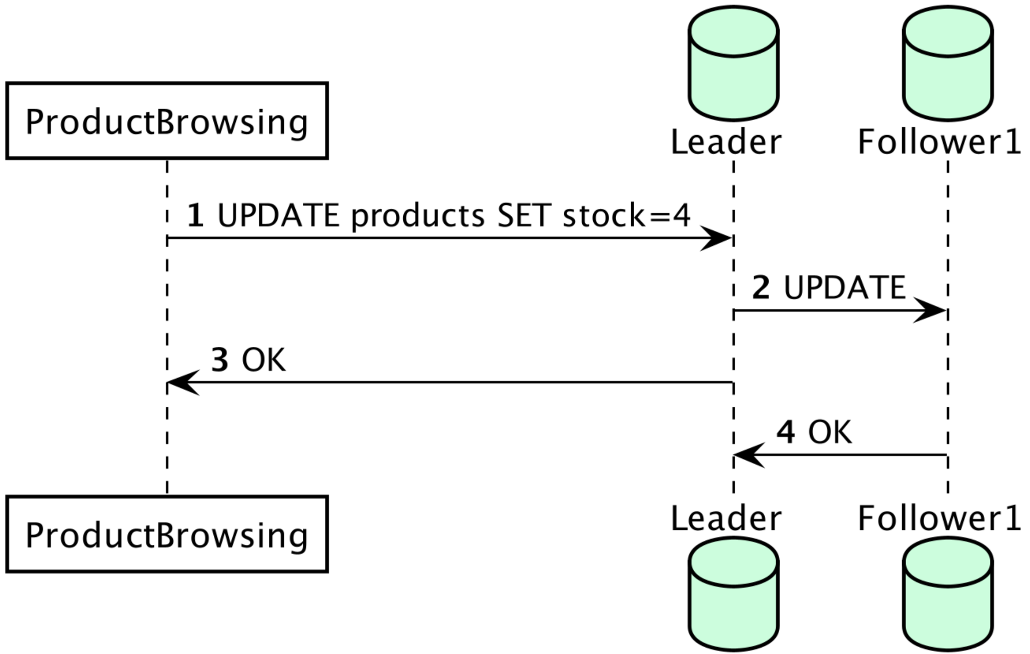


- Built-in to PostgreSQL, MySQL, MongoDB, RethinkDB, and Espresso.
- Can be added to Oracle and SQL Server.

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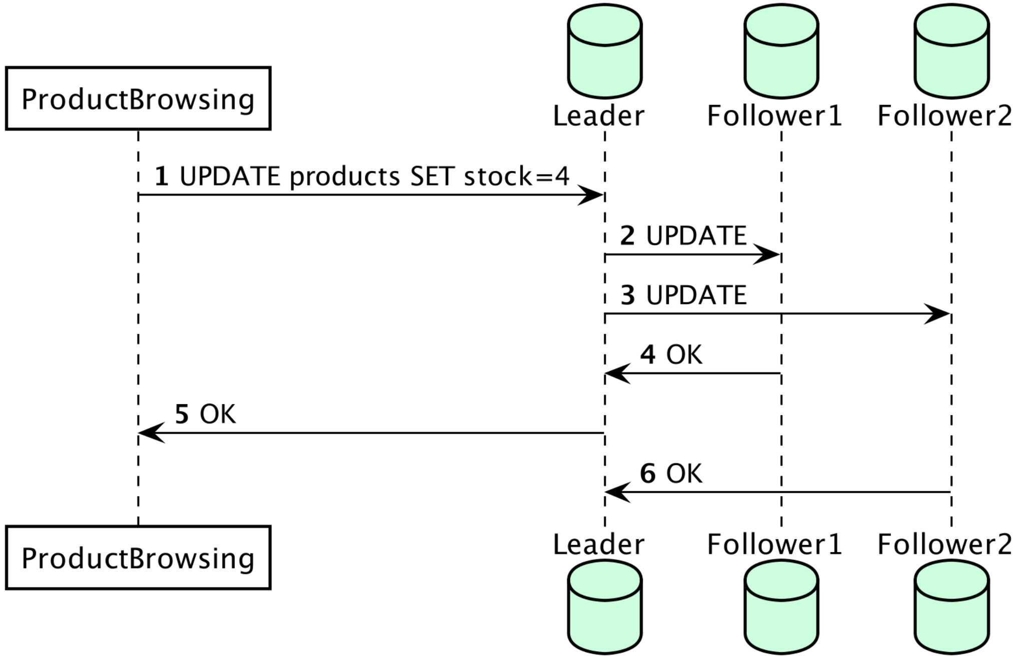
ProductBrowsing
Leader
Follower1
Follower2
1 UPDATE products SET stock=4
2 UPDATE
3 UPDATE
4 OK
5 OK
6 OK
ProductBrowsing
Leader
Follower1
Follower2

Synchronous propagation

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

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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.

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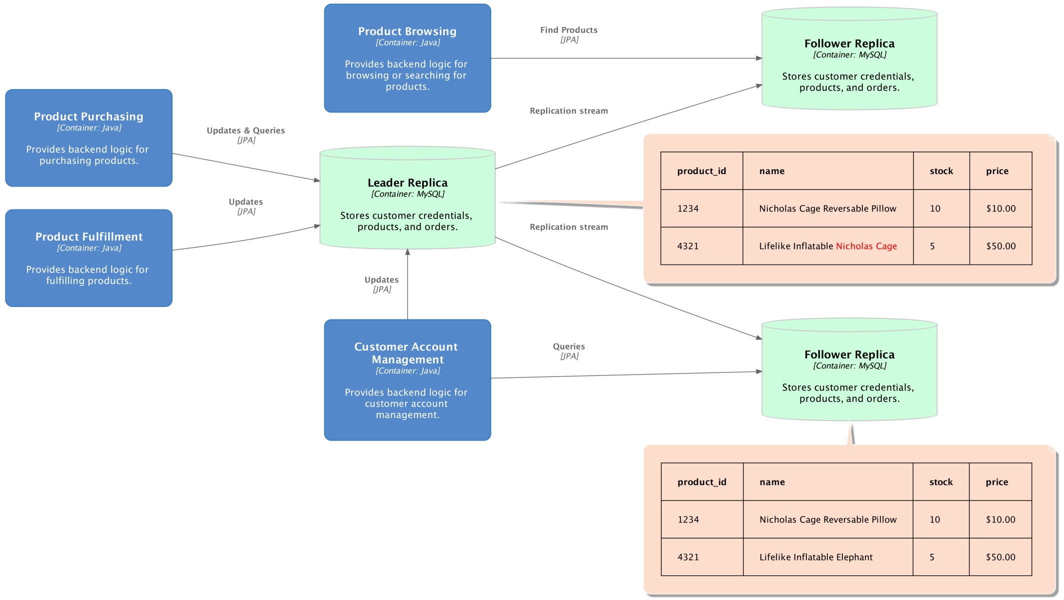
- If the leader goes down before propagating, the *write is lost*.

Asynchronous propagation

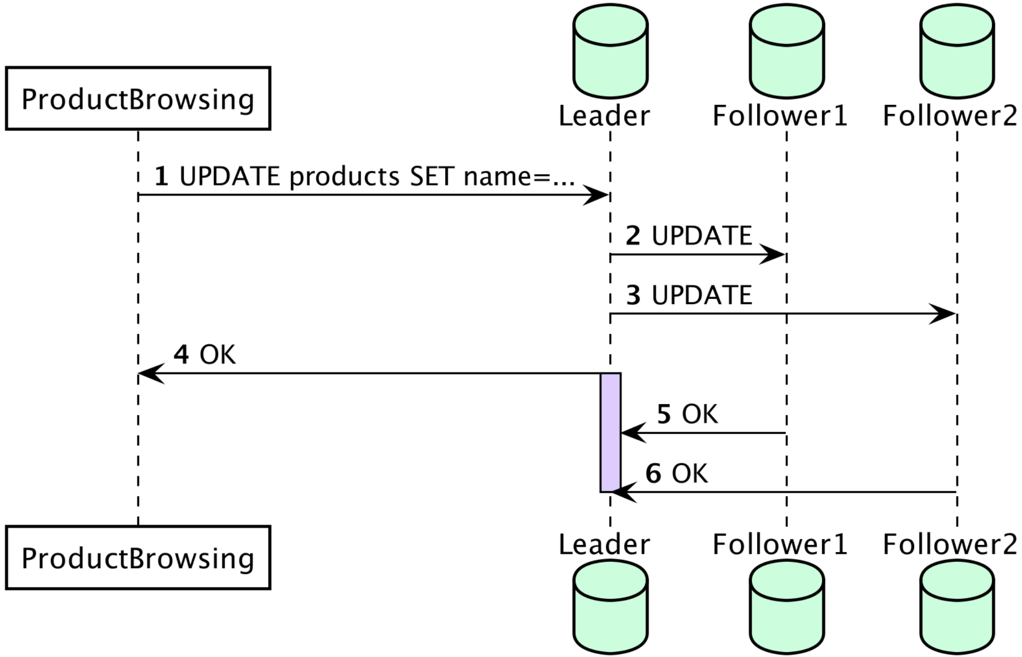
- Writes *don't* have to *wait* for propagation.
- If the leader goes down before propagating, the *write is lost*.
- Replicas can have out-dated or *stale* data.

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*

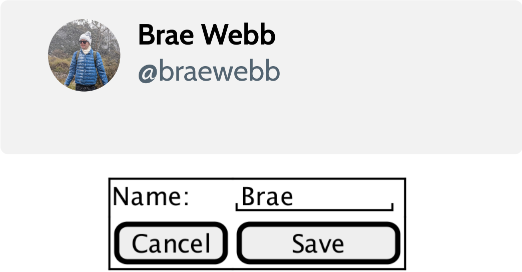
- If writes stop for long enough
- Eventually is intentionally ambiguous

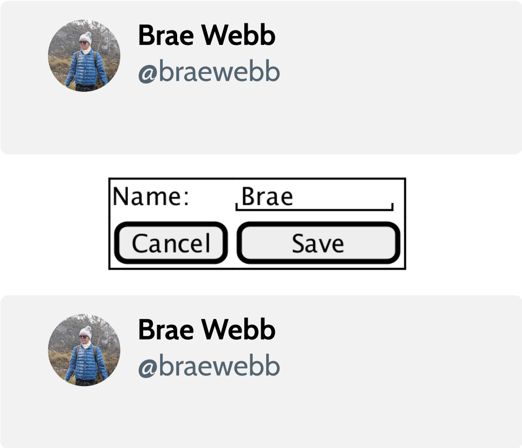
Eventual Consistency

Problems?

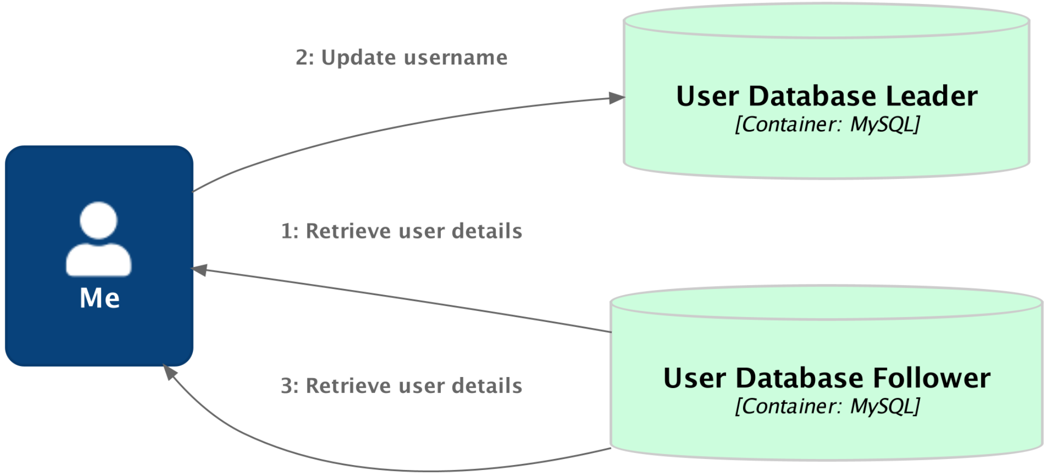
Brae Webb

@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
3: Retrieve user details
User Database Follower
[Container: MySQL]

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

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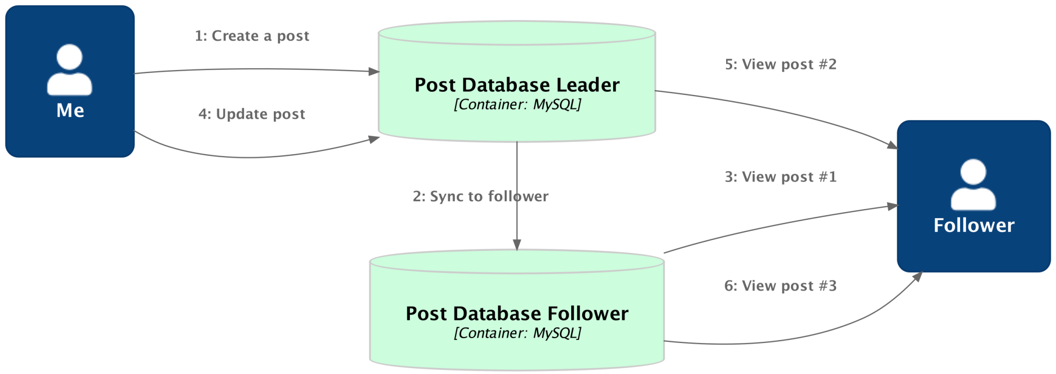
My fist post


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.

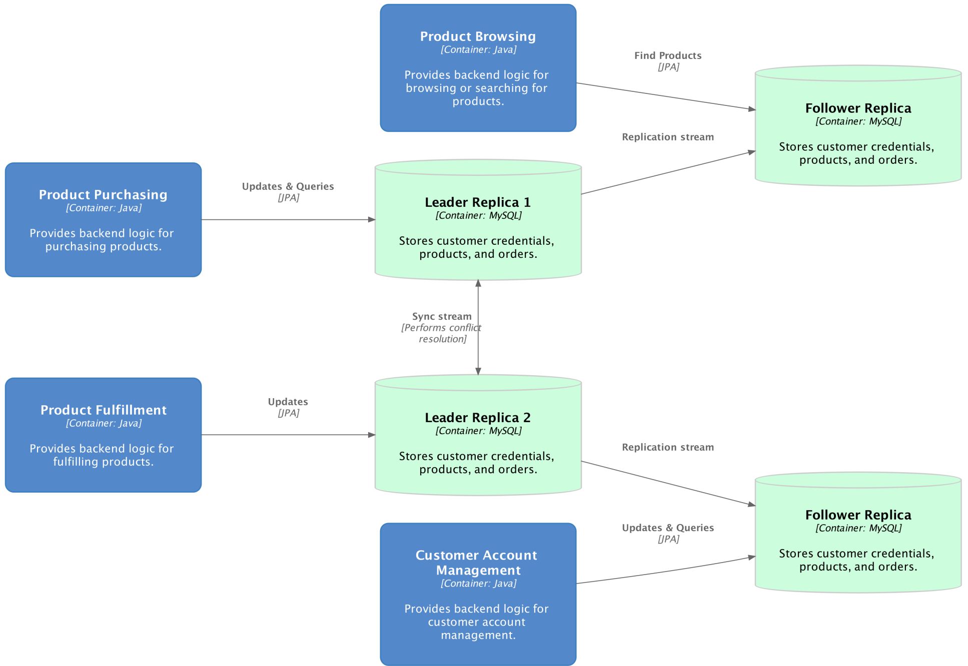
User doesn’t travel back in time

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.
Updates & Queries
[JPA]
Customer Account Management
[Container: Java]
Provides backend logic for customer account management.

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*.

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

Question

What might go wrong?

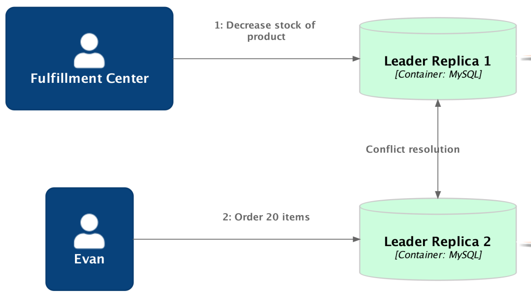
Question

What might go wrong?

Answer

Write conflicts

Write conflicts require the conflict to be resolved.



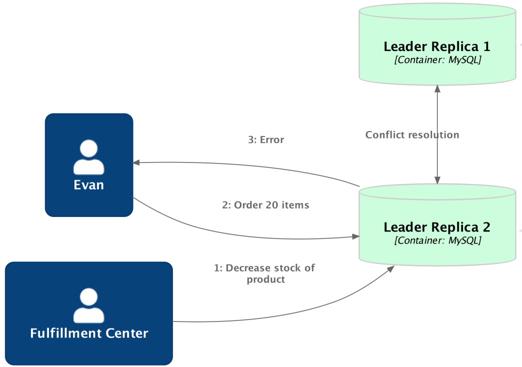
product_id	name	stock	price
1234	Nicholas Cage Reversable Pillow	19	$10.00
4321	Lifelike Inflatable Elephant	5	$50.00

product_id	name	stock	price
1234	Nicholas Cage Reversable Pillow	0	$10.00
4321	Lifelike Inflatable Elephant	5	$50.00

-1 Pillows? How do we resolve this?

Where possible

Avoid write conflicts



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Where impossible

Convergence

Convergence Strategies

- Assign each *write* a unique ID.

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- Assign each *leader replica* a unique ID.

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

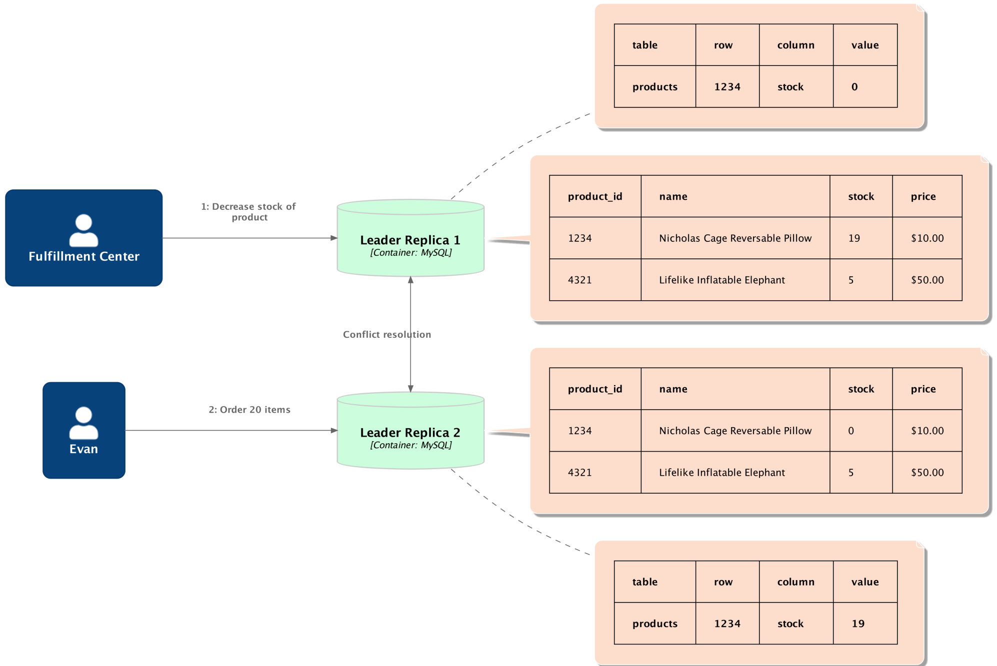


table	row	column	value
products	1234	stock	0

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.

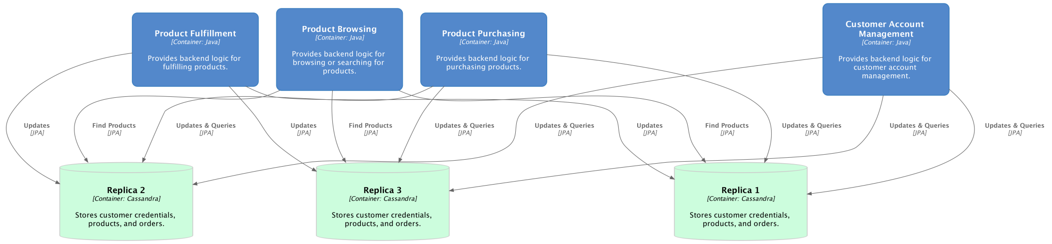
On Read When a conflict is next read, ask for a resolution.

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

Third Approach

Leaderless Replication

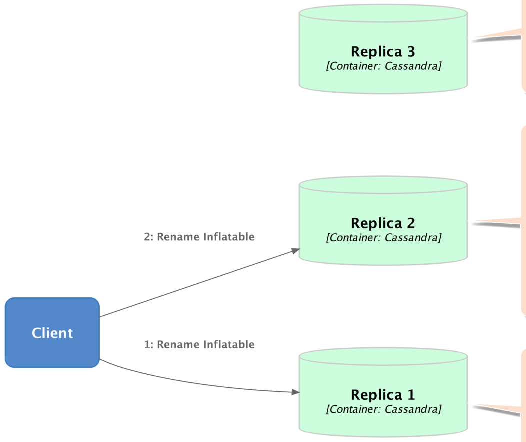
- Early distributed databases were leaderless.
- Resurgance after Amazon created Dynamo.
- Dynamo is an internal service and not DynamoDB.
- Riak, Cassandra, and Voldemort are leaderless databases.



Reads and writes can be written to any node.

How do they work?

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



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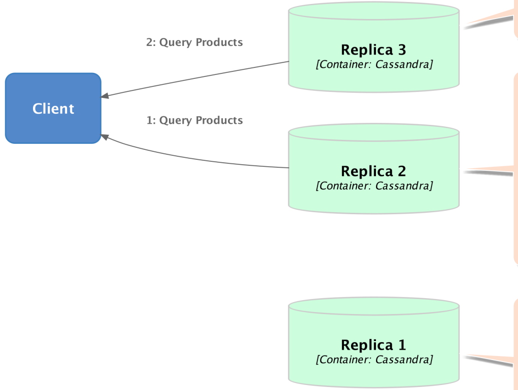

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product_id	name	stock	price
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At least one of the reads has the updated value

How are changes propagated?

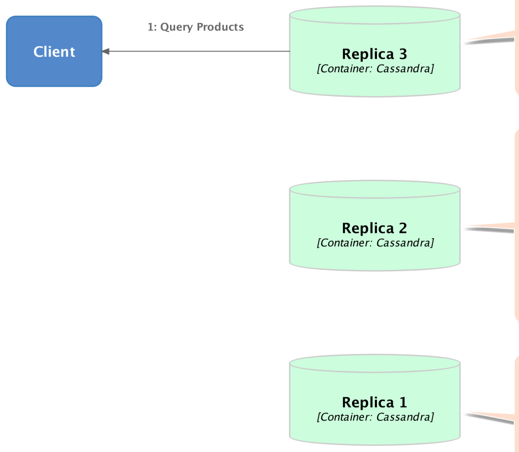
- Read Repair

How are changes propagated?

- Read Repair
- Anti-entropy Process

Question

How do we know it’s consistent?



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Answer

Quorum Reads and Writes

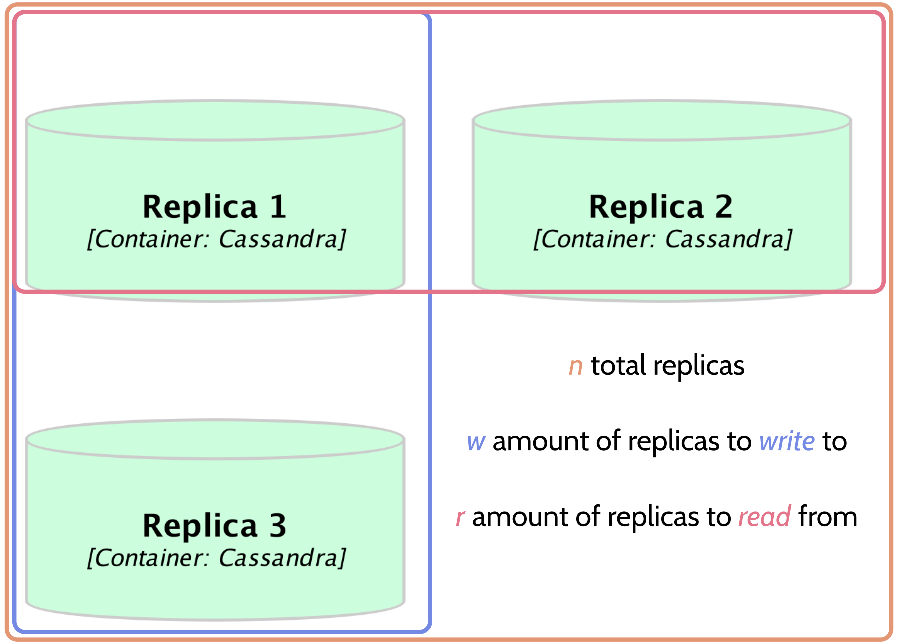
$$w + r > n$$

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: 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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- *Leader-based* replication is most common and simpliest.

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- *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?

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Answer

- *Replication*
- Partitioning
- Independent databases

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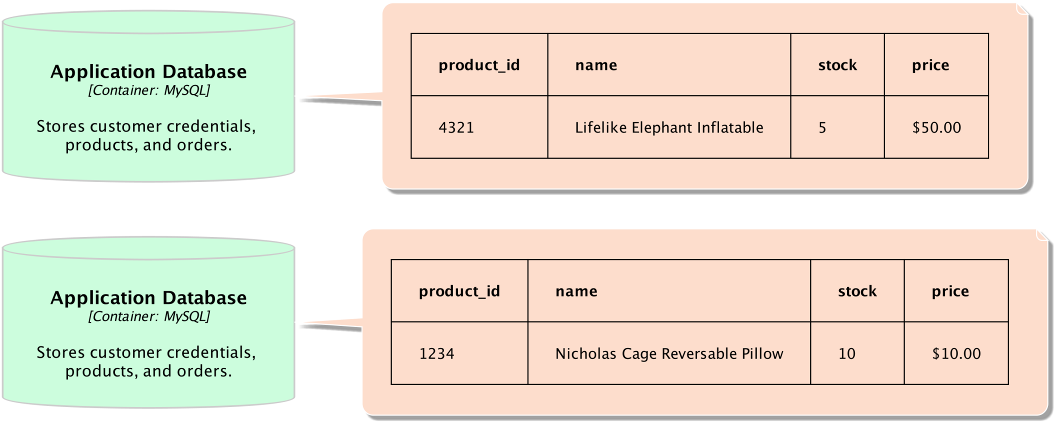
Answer

- Replication
- *Partitioning*
- Independent databases

Definition 6. Partitioning

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

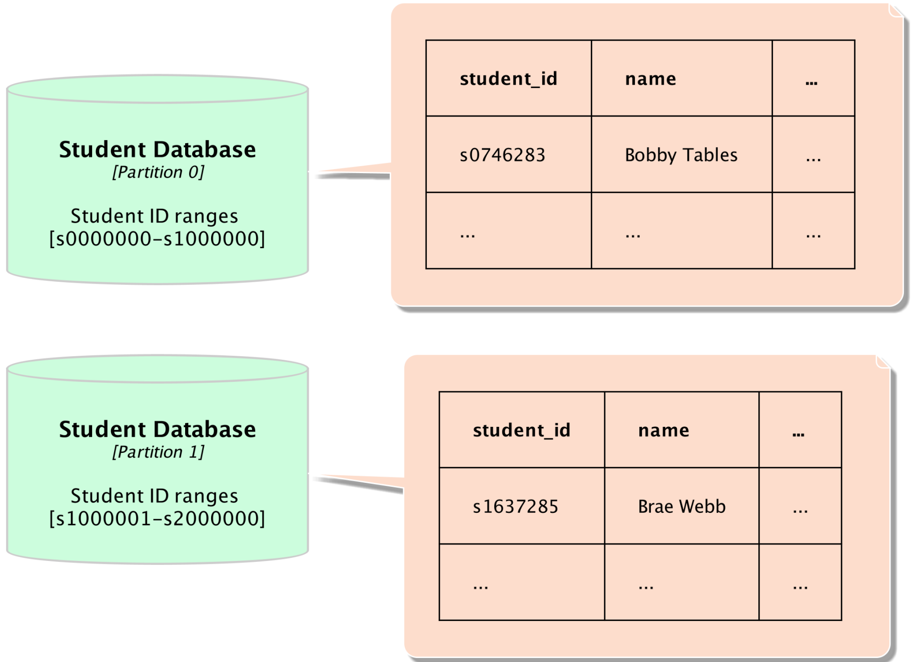
Also called shardes, regions, tablets, etc.



- 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

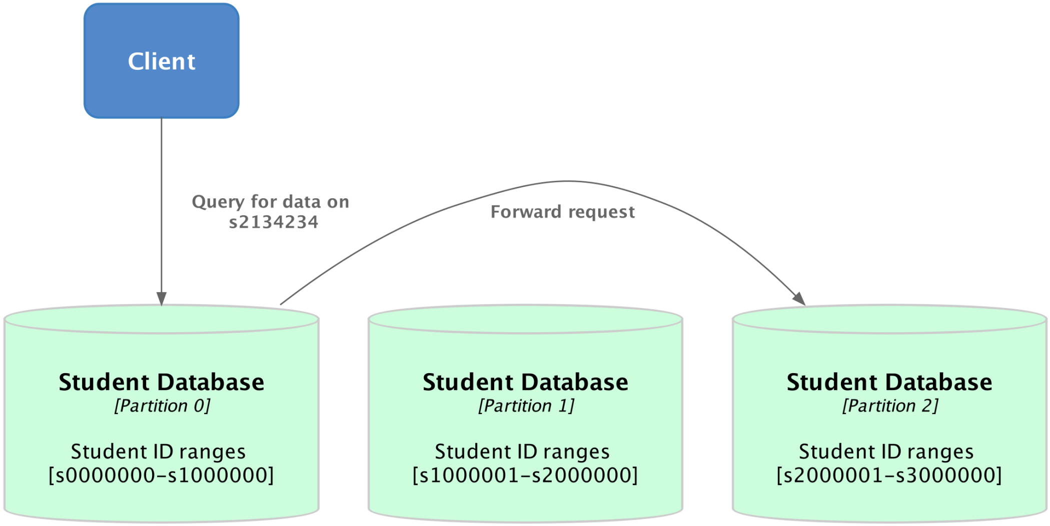
Question

How do we route queries?

Unlike stateless, only one node can process queries.

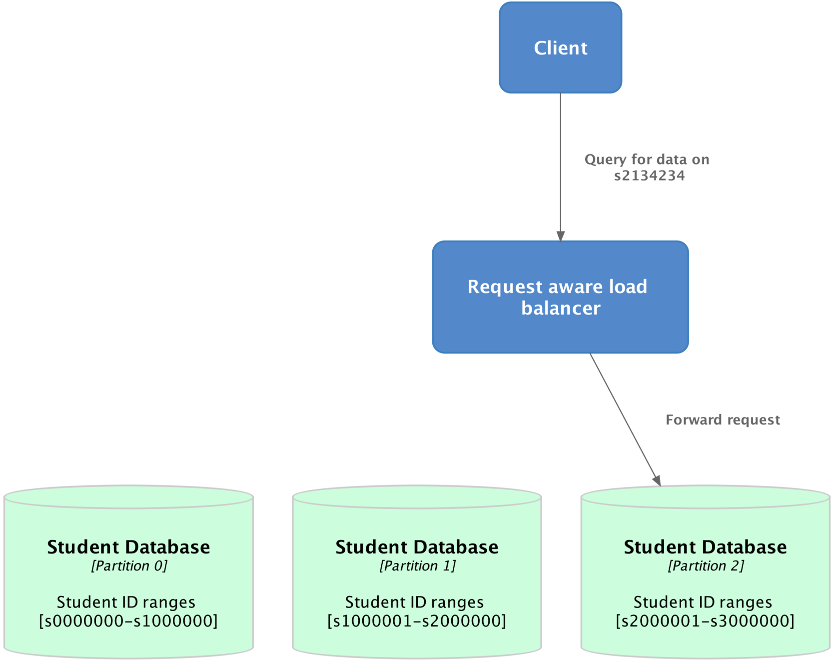
Query-insensitive Load Balancer

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]

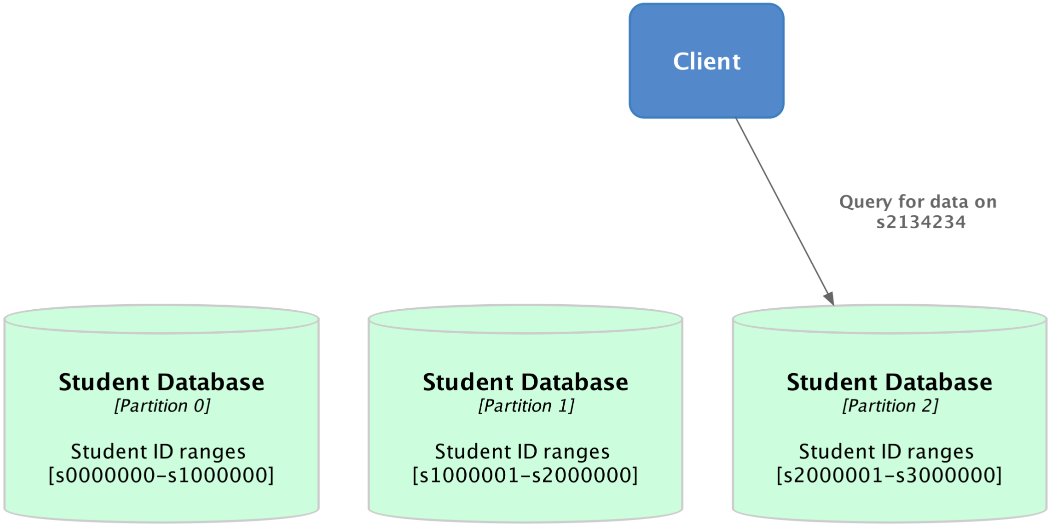
Query-sensitive Load Balancer

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]
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[Partition 1]
Student ID ranges
[s1000001–s2000000]
Student Database
[Partition 2]
Student ID ranges
[s2000001–s3000000]

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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.

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

How do we fix database scaling issues?

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Answer

- Replication
- *Partitioning*
- Independent databases

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How do we fix database scaling issues?

Answer

- Replication
- Partitioning
- *Independent databases*

Distributed state creates a lot of *complexity*

And when programmers have complexity, they create bugs

When programmers are faced with complexity

They create *abstractions*

One key database abstraction

Transactions

Introduced by IBM System R in 1975

Definition 7. Transaction

A group of operations performed as if they were one.

What does as if it were one mean?

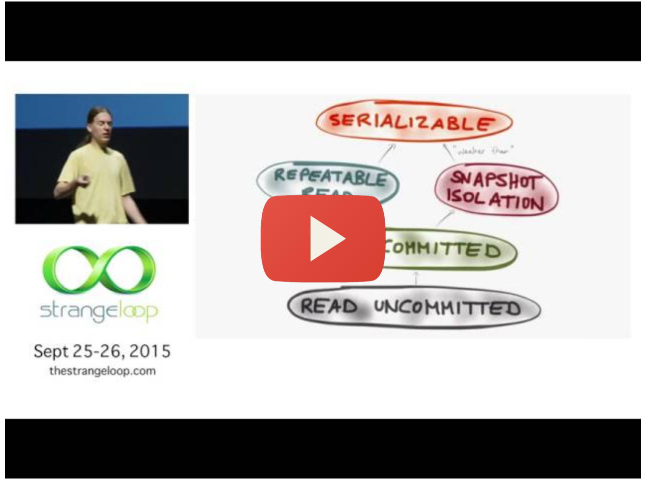
A tomic
C onsistent
I solated
D urable

The pushback

NoSQL and microservice architectures pushed back against transactions.

- Transactions were used fairly universally for a long time.
- Push back occurred when people decided they weren't scalable.

For more on transactions



https://www.youtube.com/watch?v=5ZjhNTM8XU8

Summary

- Replications

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  - Leader-based, multi-leader, and leaderless

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  - ACID properties
  - Pushback causing headaches