CS 188/219

Scalable Internet Services

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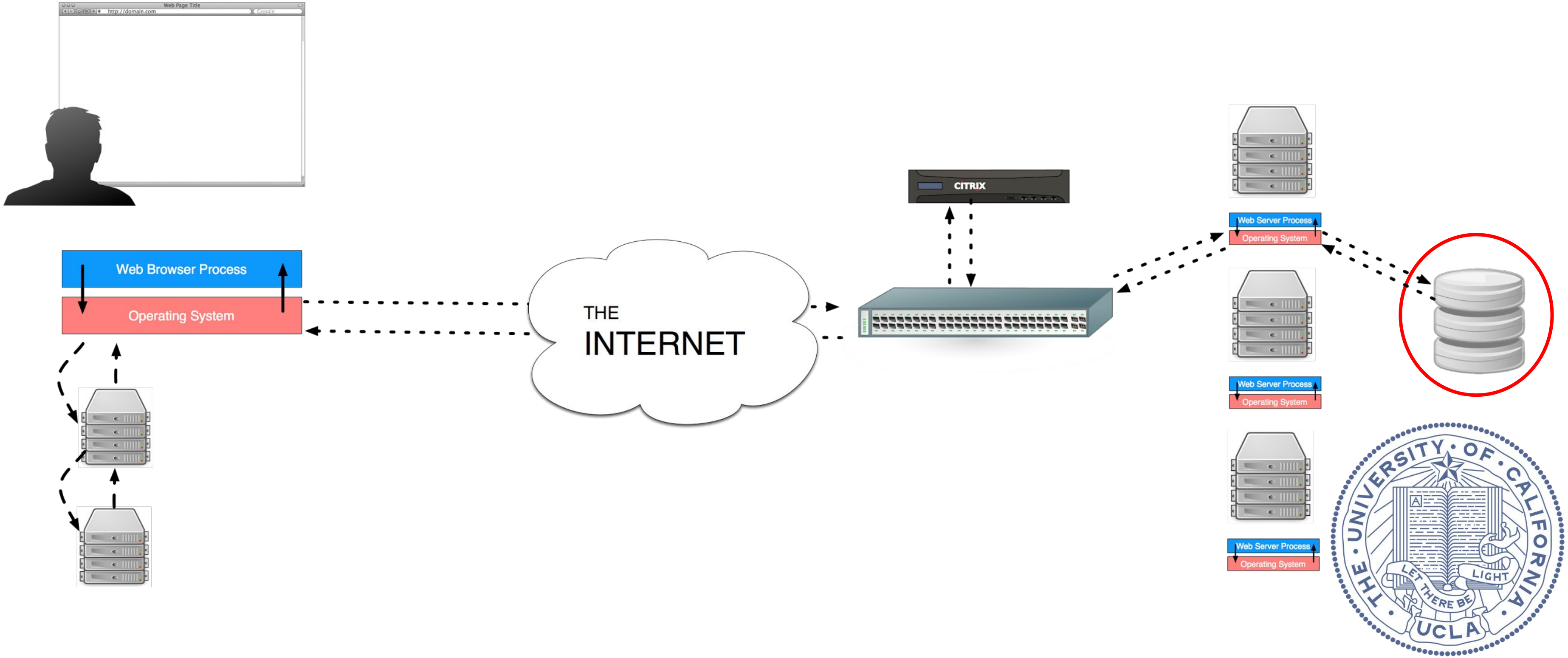
May 6, 2015

For Today


Web Page Title
http://domain.com
Google
Web Browser Process
Operating System
THE
INTERNET
CITRIX
Web Server Process
Operating System
Web Server Process
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Web Server Process
Operating System
THE UNIVERSITY OF CALIFORNIA
LET THERE BE LIGHT
UCLA

Motivation

After today's lecture you will understand how NoSQL can be used to build scalable internet services.

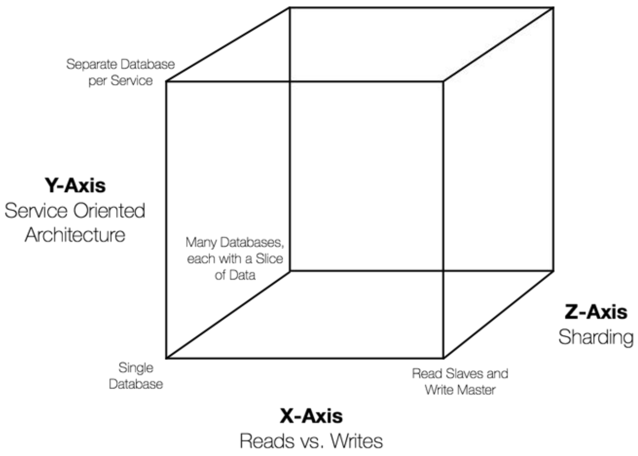
NoSQL data stores won't likely be part of your project, but after this lecture you should understand when you could look to them in practice.

Motivation

As our application has experienced greater and greater popularity, the data layer has proven difficult to scale horizontally.

Without a scaling path for our data layer, it will be a bottleneck limiting our application.

Motivation



Separate Database per Service

Y-Axis
Service Oriented Architecture

Many Databases, each with a Slice of Data

Z-Axis
Sharding

Single Database

Read Slaves and Write Master

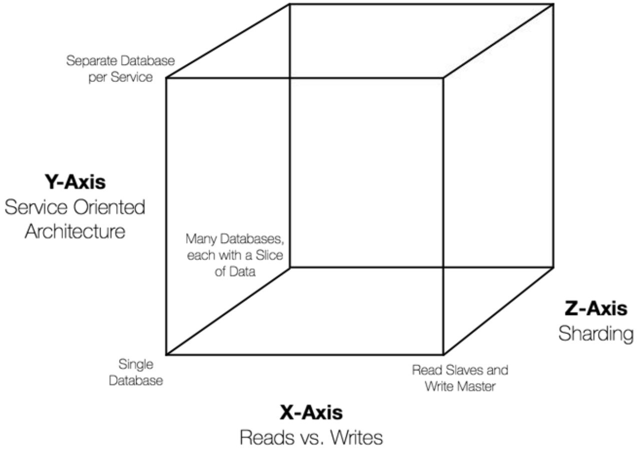
X-Axis
Reads vs. Writes

Relational Databases are great tools for our data layer, but we can’t simply spread load across multiple RDBMSes.

We’ve looked at a few techniques for scaling RDBMSes:

- Sharding
- Service Oriented Architectures
- Distinguishing Reads from Writes

Motivation


Separate Database per Service
Y-Axis
Service Oriented Architecture
Many Databases, each with a Slice of Data
Z-Axis
Sharding
Single Database
Read Slaves and Write Master
X-Axis
Reads vs. Writes

What if these techniques aren't sufficient for our target application?

- There's no good way to shard our application?
- We've already broken our application out via SOA and still have load hotspots?
- We're already using read-slaves and it's not enough?

When relational databases fail to scale to our needs, we need to turn to non-relational solutions.

NoSQL

Non-relational databases are sometimes called NoSQL databases.

This is an umbrella term for many types of databases

- Key-value stores
- Column-oriented data stores
- Document-oriented stores
- Graph databases

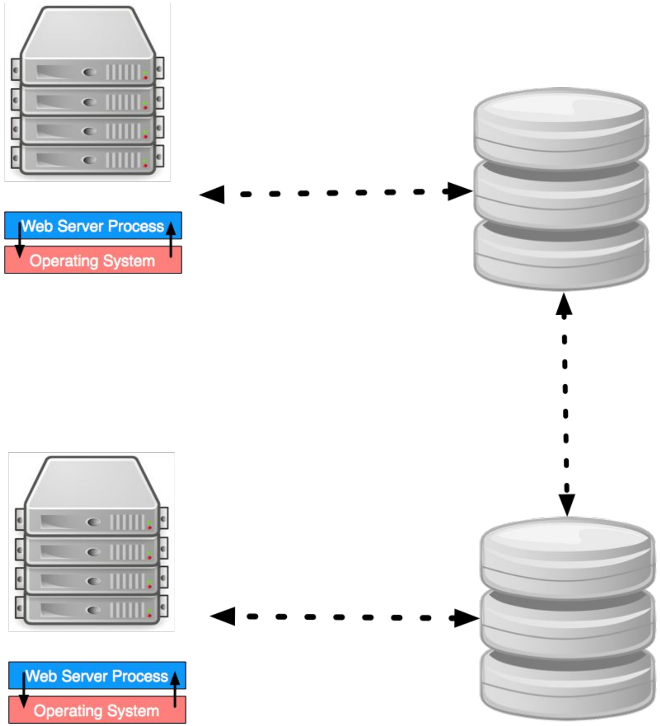
NoSQL

Most NoSQL solutions are good at horizontal scaling.

- You can easily add hardware to the database to increase throughput.

In exchange for better horizontal scaling, these databases provide the application layer fewer guarantees

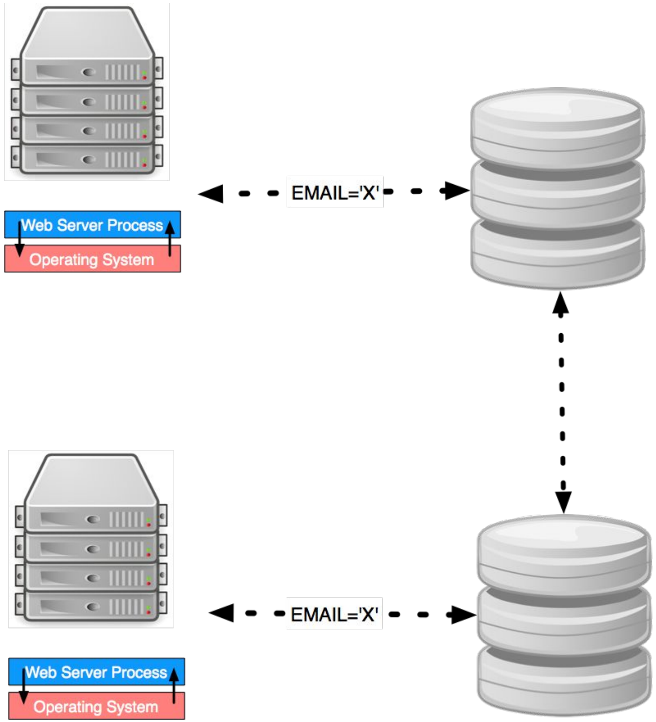
NoSQL



Let’s say we want a database to span multiple machines.

We can update on both nodes, and the databases keep each other in synch.

NoSQL



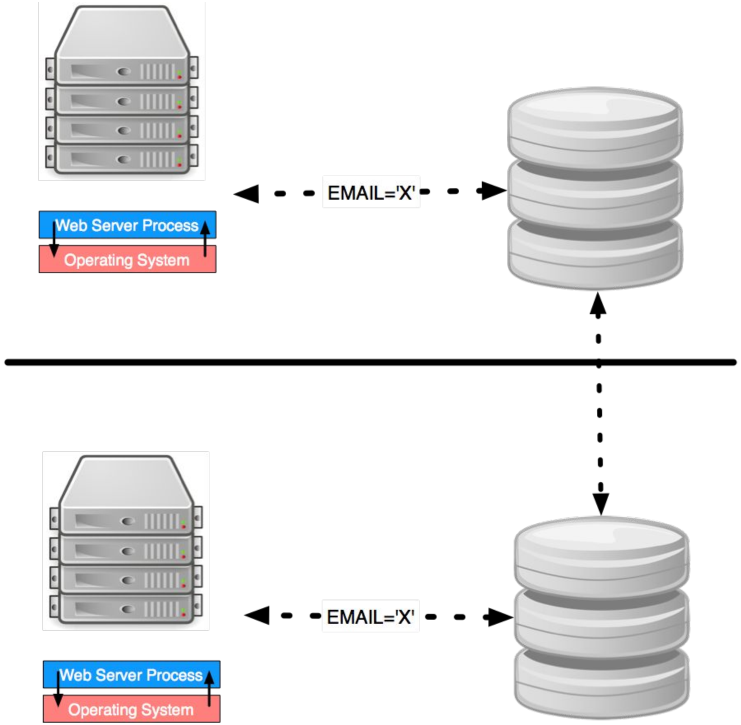
Lets say:

- We have two clients sending writes.
- There's a uniqueness constraint on email.

If both try to write the same email address to different rows, and the databases can communicate, they can resolve this in some manner.

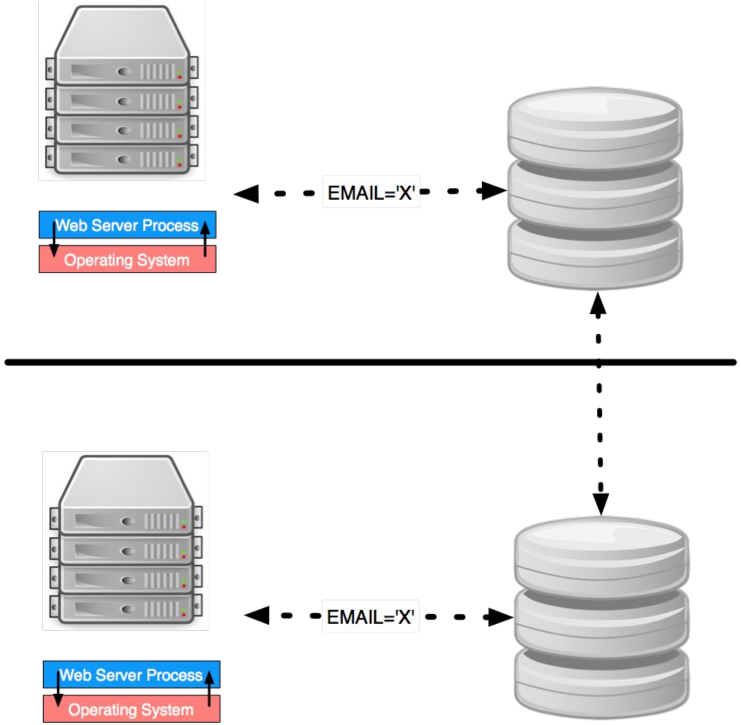
- Ex: Allow one, fail the other.

NoSQL



How do we handle a network partition?

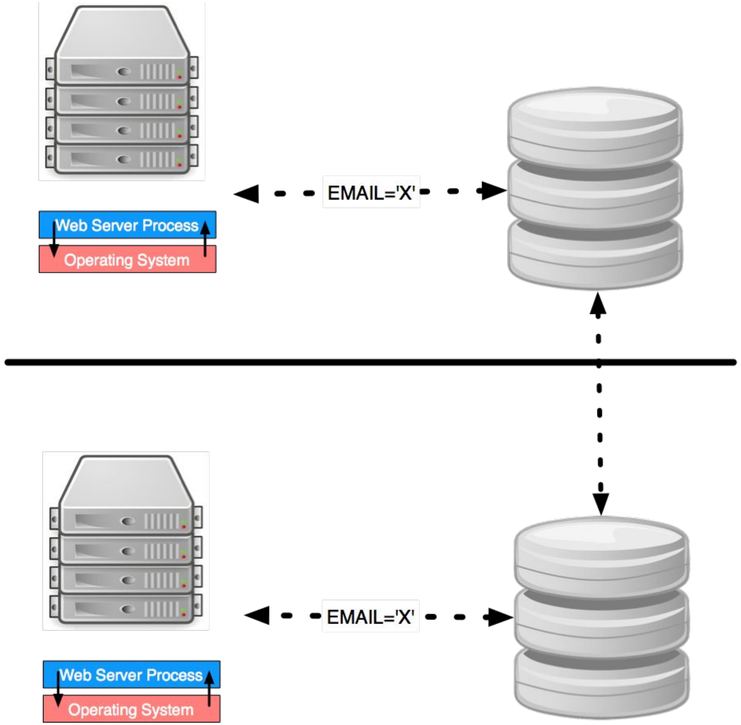
NoSQL



How do we handle a network partition?

- If the databases can't communicate, they don't know if this update violates database consistency.
- Allow the write and hope for the best?
  - And fix it later if needed?
- Not accept such writes during a partition?

NoSQL

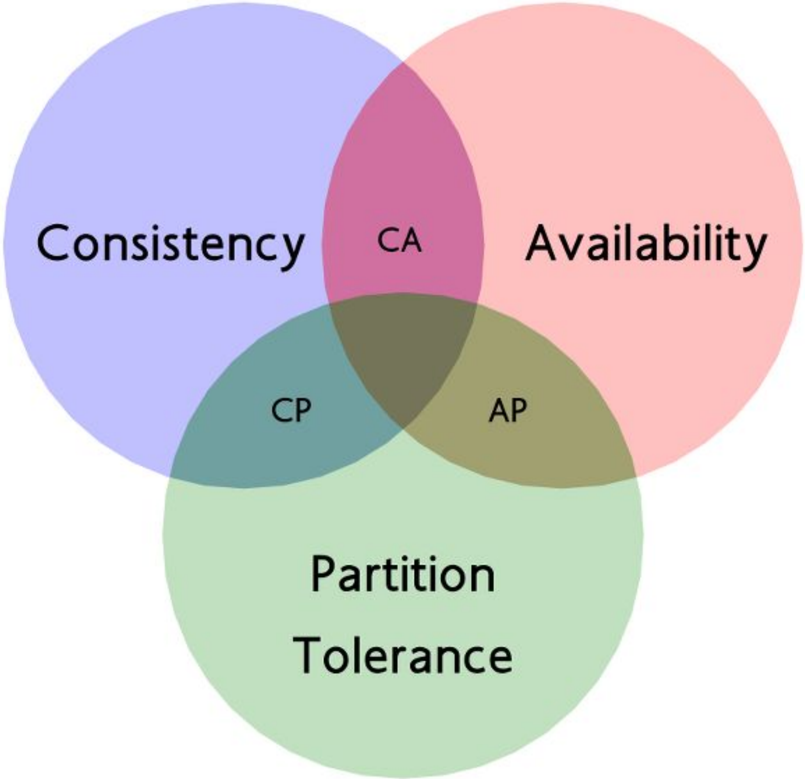


If we allow the write, our database is not consistent.

If we don’t allow the write, our database is unavailable.

If we ignore this scenario, we can’t tolerate network partitions.

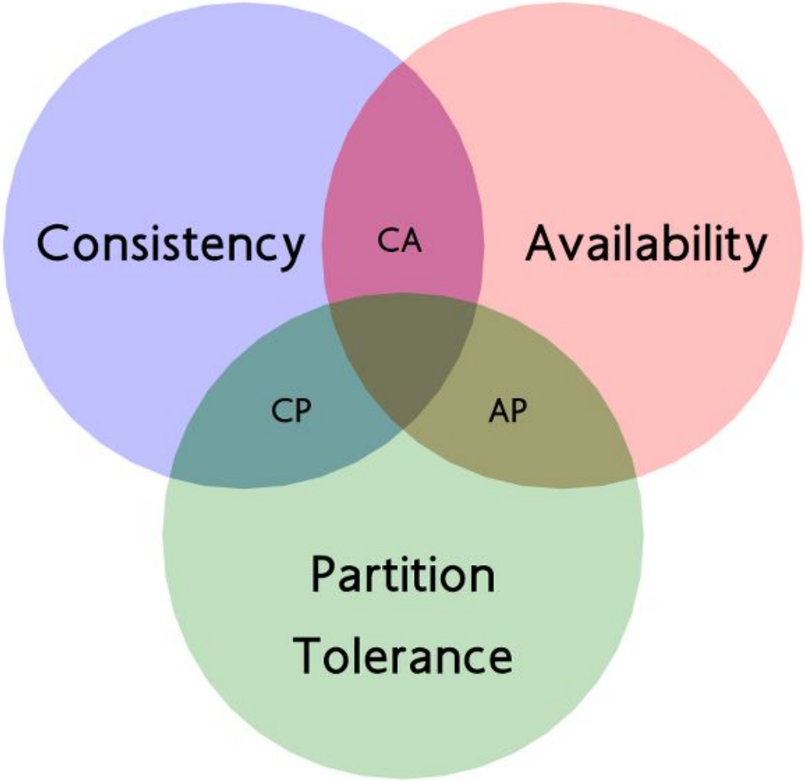
NoSQL



It is situations like these that motivated the CAP theorem.

- Eric Brewer, late 90s.
- “Consistency, Availability, Partition Tolerance: choose any two.”

NoSQL

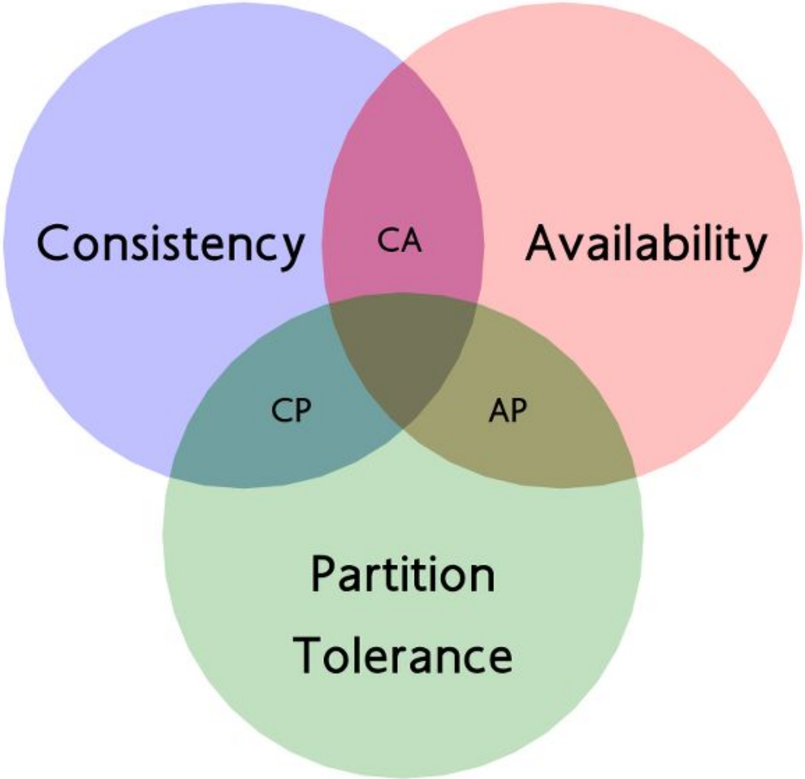


AP systems:

- Always up
- Can handle network partitions
- Not always consistent.

In the earlier example, an AP solution would accept the writes.

NoSQL

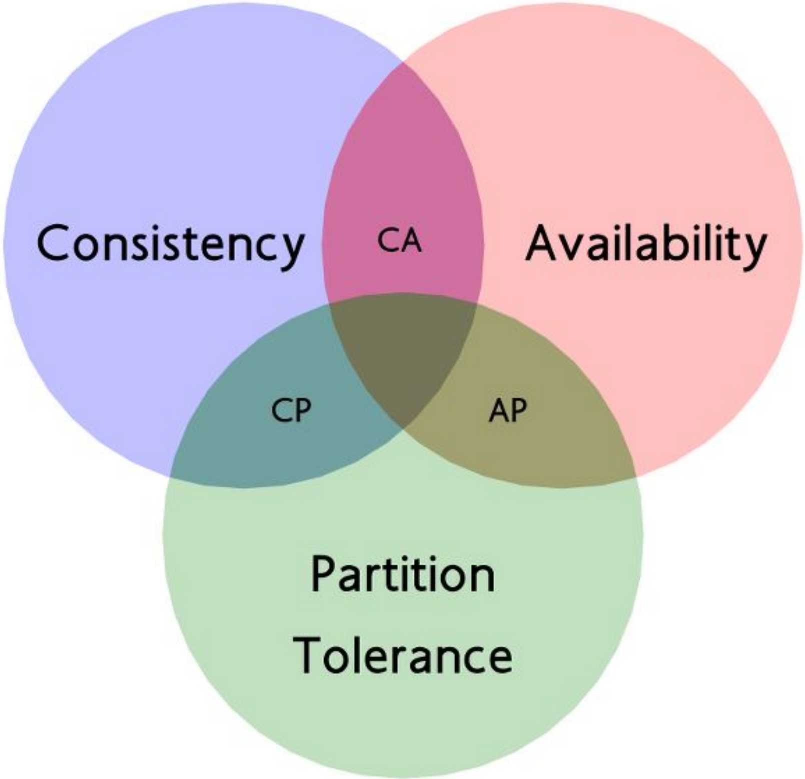


CP systems:

- Always consistent.
- Handle network partitions.
- Sometimes will be unavailable to clients

In the earlier example, a CP solution would not allow any writes

NoSQL

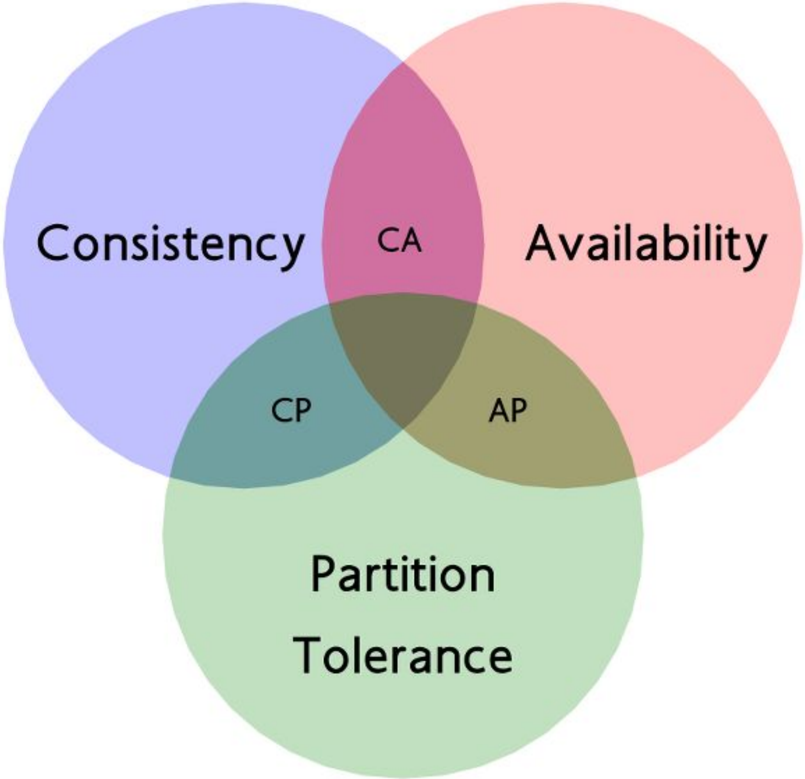


CA systems:

- Always up.
- Always consistent.
- Assume no network partitions.

A CA solution would never get into the earlier scenario because it wouldn’t be deployed where partitions could happen.

NoSQL



Assuming no partitions is very limiting

- For HA and latency reasons, we'd like to have multi-site
- Even within a datacenter, we could have a partition

As a result, tradeoffs tend to be more C vs A

ACID vs. BASE

The **BASE** acronym was created to describe these NoSQL solutions that make tradeoffs between Availability and Consistency

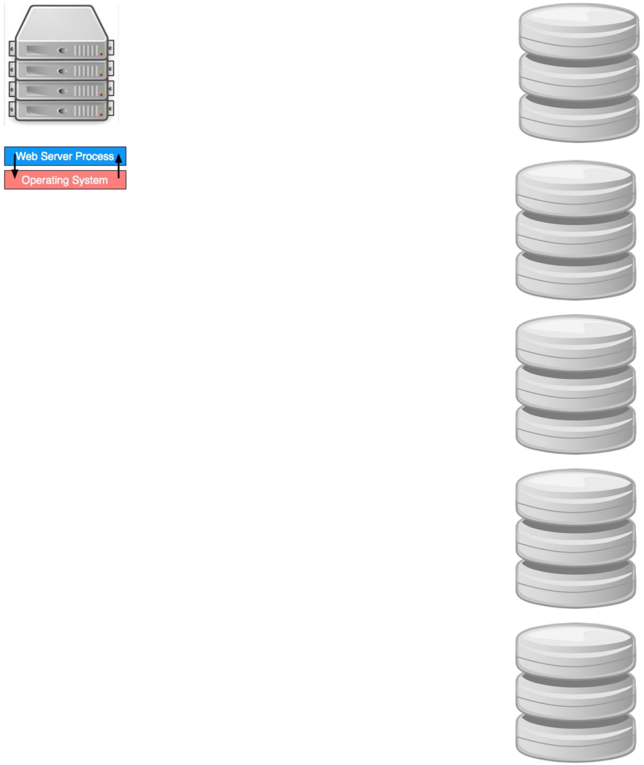
ACID	**BASE**
Atomicity	**B**asically
Consistency	**A**vailable
Isolation	**S**oft State
Durability	**E**ventually Consistent

Consistency

Consistency comes in many forms:

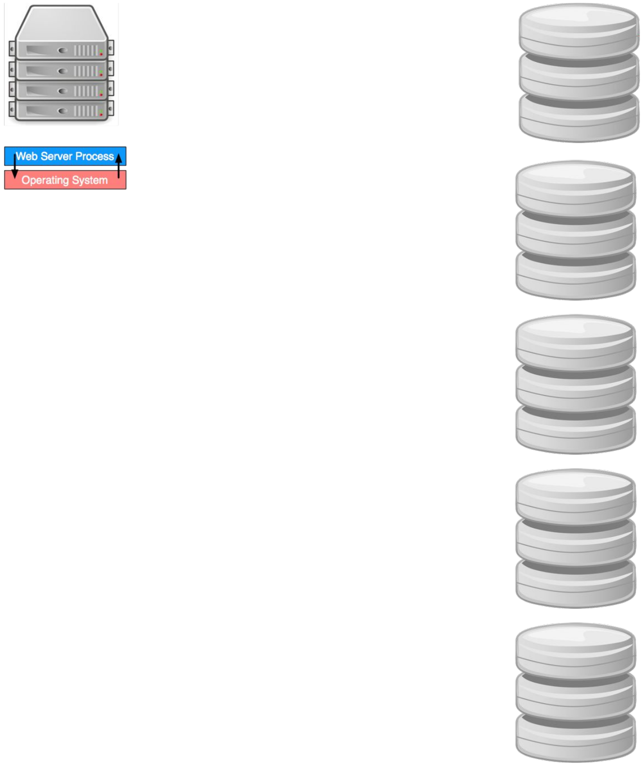
- Strong Consistency
  - After update, everyone sees new value
- Eventual Consistency
  - Eventually the system will converge on the new value
  - Read-your-writes Consistency
    - You immediately see any data you have written
  - Causal Consistency
    - You see your own writes, and anyone you communicate with sees your writes
  - Session Consistency
    - Within a session, you see your own writes.

NWR



N, W & R are a useful shorthand for describing the read/write strategy of a data store.

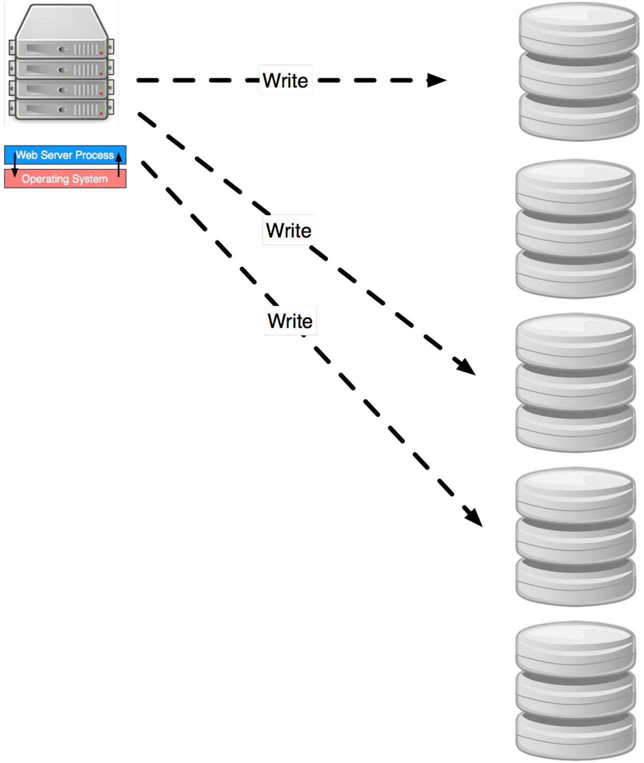
NWR



N refers to the number of separate nodes that each retain a copy of the data.

In this example, N is 5.

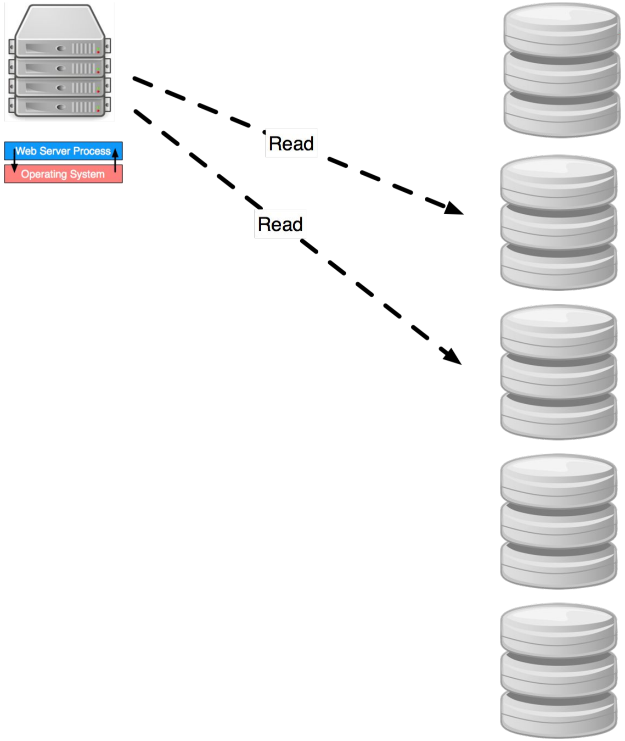
NWR



W refers to the number of nodes that we persist to before considering a write written.

In this example,
W is 3.

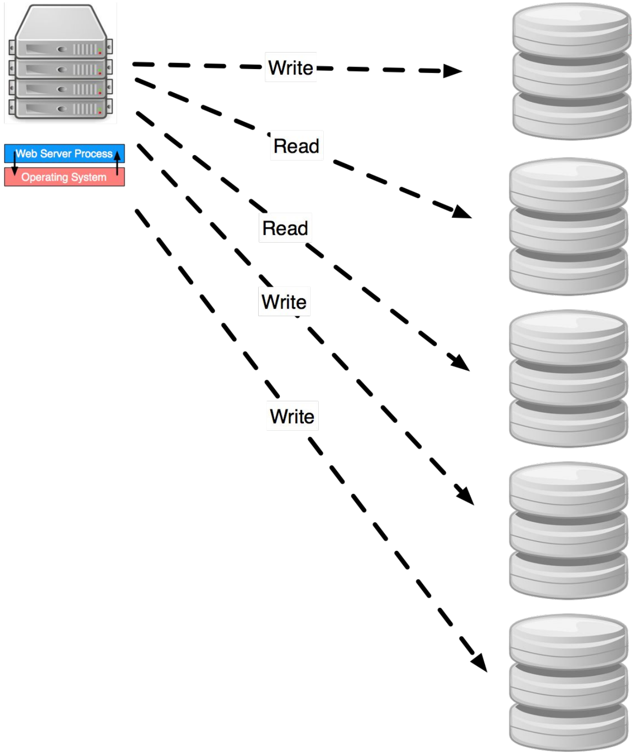
NWR



R refers to the number of nodes that we consult when reading.

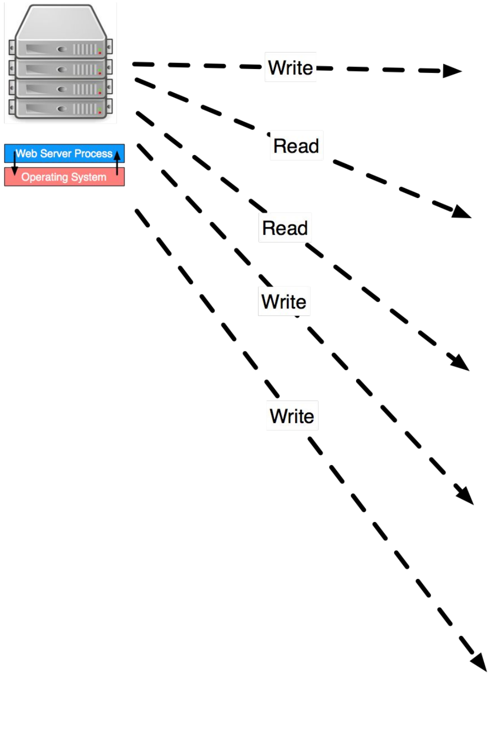
In this example, R is 2.

NWR



If W + R <= N, then you can’t be sure that a read has seen all previous writes

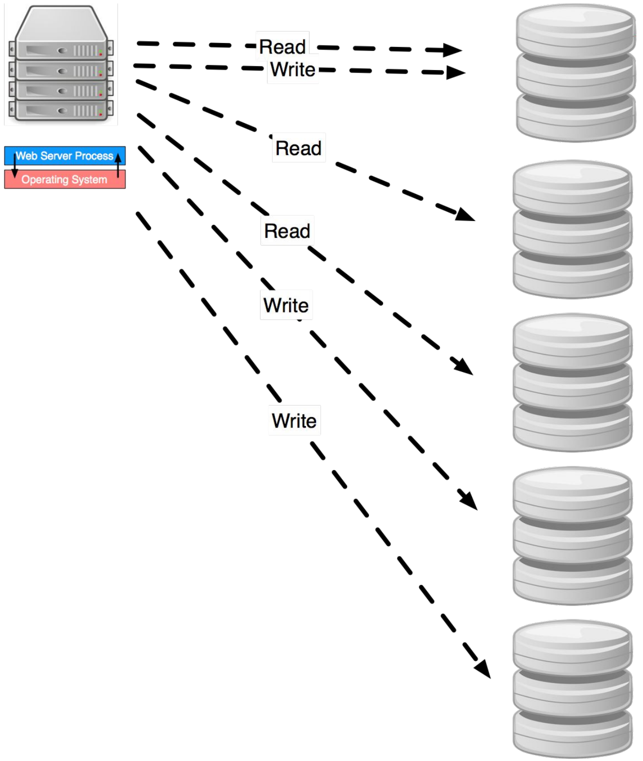
NWR



If W + R <= N, then you can’t be sure that a read has seen all previous writes.

3 + 2 <= 5.

NWR



If W + R > N, then you can be sure that a read has seen all previous writes.

Any two size-3 subsets of 5 servers must have overlap

3 + 3 > 5.

NWR

For strong consistency, many combinations can work.

- $R=N$, $W=1$: Write to any one server, consult all server on reads. Use the newest value.
- $R=1$, $W=N$: Write to all servers, consult any server on reads.
- $R = N/2 + 1$, $W = N/2 + 1$: Write to a quorum, read from a quorum.

NWR

For weaker notions of consistency, we choose W + R <= N.

Exactly which type of consistency we see will depend on “session stickiness”

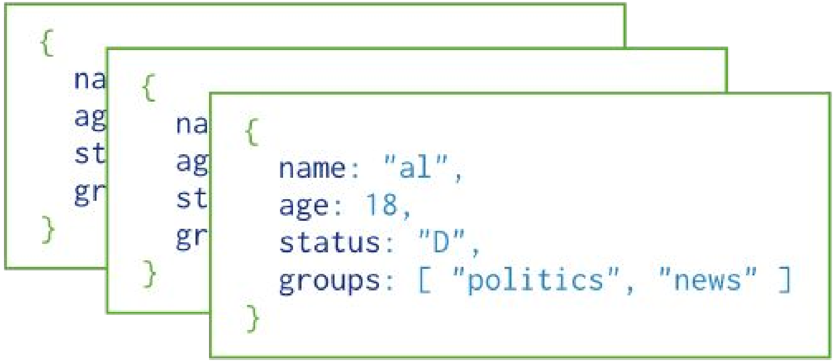
- I can write to multiple nodes, but if User A’s reads and writes to the same node, we can more easily implement “see your own writes” consistency.
- Similar use of stickiness to achieve Session Consistency.

NoSQL

There are different types of NoSQL stores

- Document-oriented stores
    - We will look at MongoDB
- Key-value stores
    - We will look at Redis
- Column-oriented data stores
    - We will look at Cassandra
- Graph databases
    - We won’t be looking at these today
    - Specialized data stores, not always horizontally scalable.

MongoDB



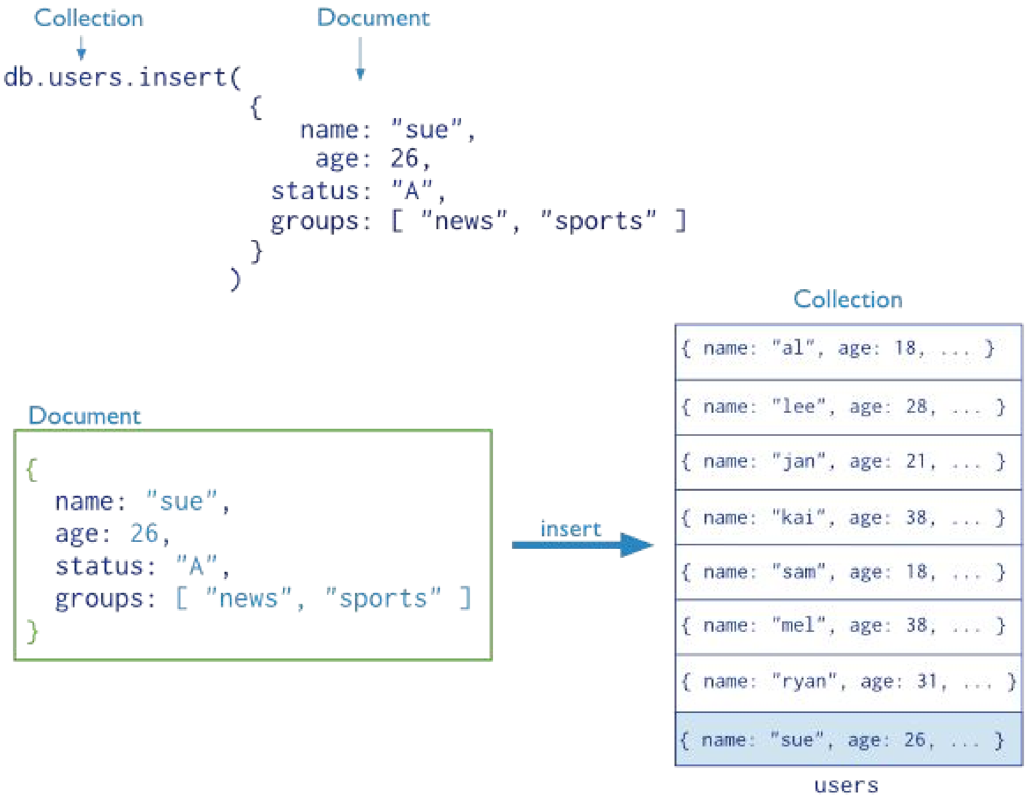
```
{
   name: "al",
   age: 18,
   status: "D",
   groups: [ "politics", "news" ]
}
```

Collection

MongoDB is a Document-oriented data store.

- Stores “Documents” that are nested hash-like structures.
- These Documents are stored in “Collections” (similar to a table in RDBMS).
- Has no fixed Schema.
- Docs can have references to other docs

MongoDB



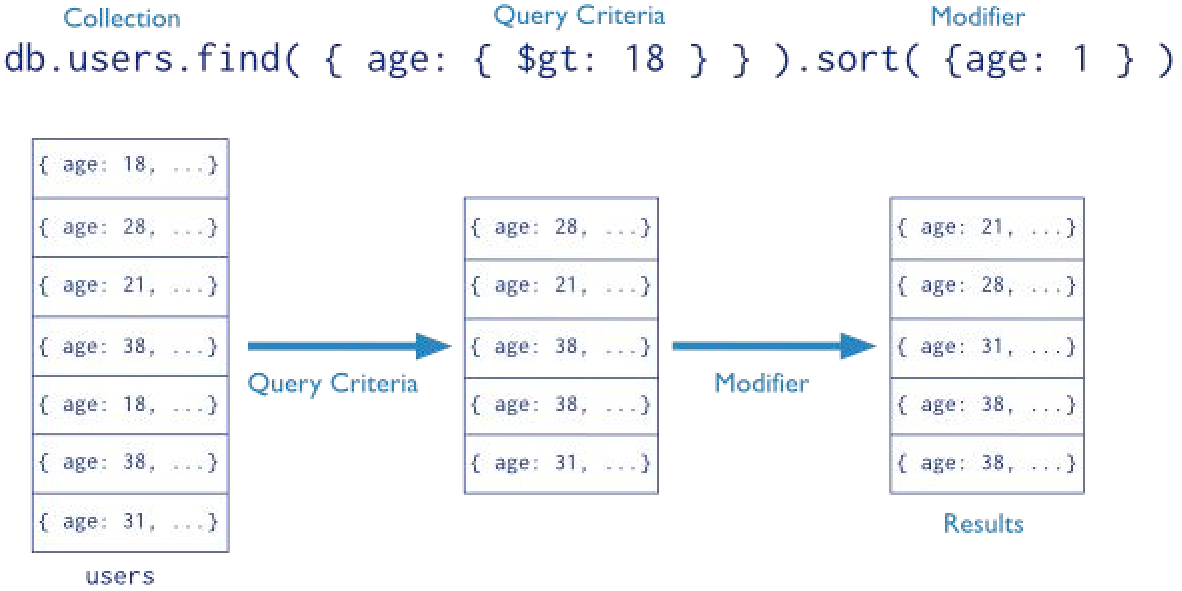
```
db.users.insert(
                 {
                   name: "sue",
                    age: 26,
                 status: "A",
                 groups: [ "news", "sports" ]
                 }
               )
```

```
{
  name: "sue",
  age: 26,
  status: "A",
  groups: [ "news", "sports" ]
}
```

```
{ name: "al", age: 18, ... }
{ name: "lee", age: 28, ... }
{ name: "jan", age: 21, ... }
{ name: "kai", age: 38, ... }
{ name: "sam", age: 18, ... }
{ name: "mel", age: 38, ... }
{ name: "ryan", age: 31, ... }
{ name: "sue", age: 26, ... }
```

Query language is not SQL

MongoDB



```
db.users.find( { age: { $gt: 18 } } ).sort( {age: 1 } )
```

```
{ age: 18, ...}
{ age: 28, ...}
{ age: 21, ...}
{ age: 38, ...}
{ age: 18, ...}
{ age: 38, ...}
{ age: 31, ...}
```

```
{ age: 28, ...}
{ age: 21, ...}
{ age: 38, ...}
{ age: 38, ...}
{ age: 31, ...}
```

```
{ age: 21, ...}
{ age: 28, ...}
{ age: 31, ...}
{ age: 38, ...}
{ age: 38, ...}
```

Query language is not SQL

MongoDB

Documents are stored in JSONB

- Binary version of JSON
- Can nest other JSON documents

No notion of transactions

- Unit of atomicity is the Document.
- Inserting multiple documents can fail individually

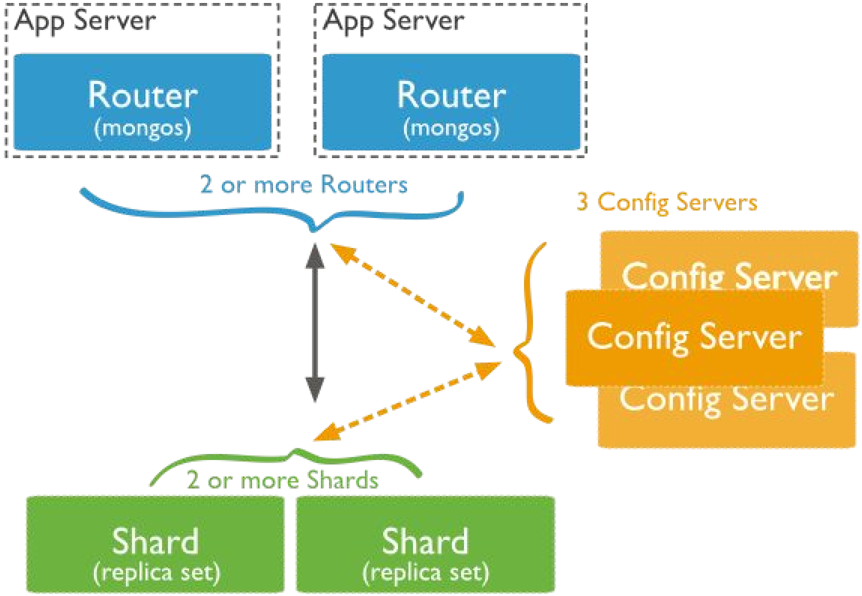
MongoDB

No notion of Joins.

- If you want to do computation based on relations between documents, read them into memory and do them at the application layer.

Can have secondary indexes based on document values

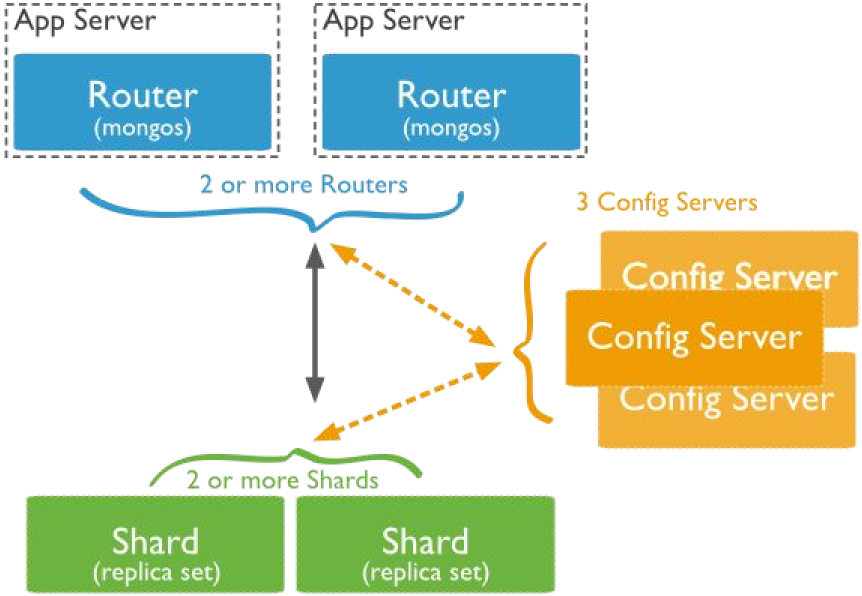
MongoDB



Collections can be sharded

- Each shard can have a replica set
- Config Servers manage the mapping between shards and data.
- Mongos routes queries to the appropriate shard

MongoDB



Replica sets use asynchronous replication

You can configure your driver to read from the primary only, or to read from read-replicas

- Reading from Primary: (R=1, W=1, N=1)
- Reading from replicas: (R=1, W=1, N=3)

Redis

Redis is a key-value data store.

- Also called a data structure store
- Supports many data structures
    - ○ Lists
    - ○ Sorted Sets
    - ○ Hashes
    - ○ Bitmaps

Primarily keeps data structures in memory

- Persistence to disk is optional

Redis

Redis interface

- Each data type allows similar mechanisms to what you would do in memory
- Access hashes by key
- Access lists by index
- Sorted sets can return top-K
- Push/pop on lists

Redis

Redis sort of has transactions

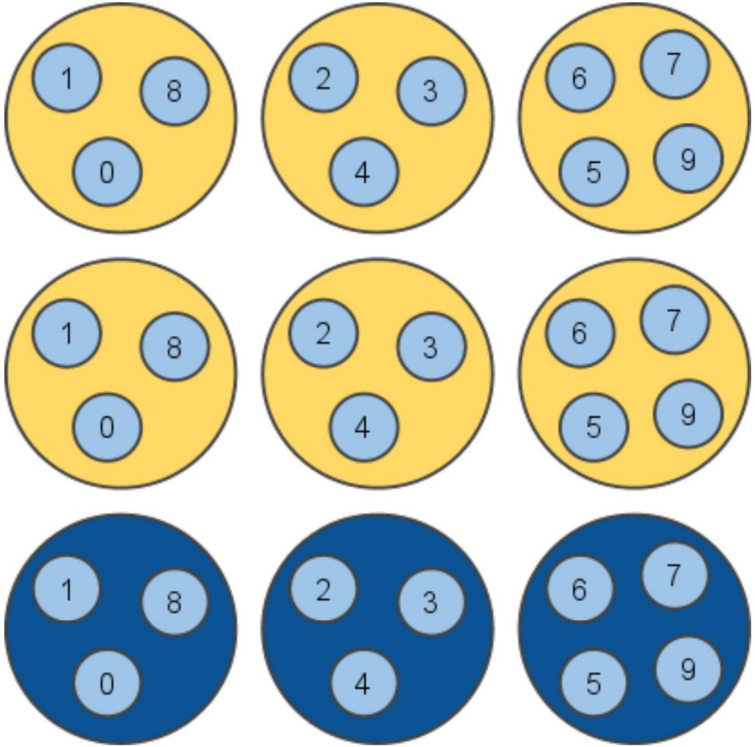
- Redis operations are simple
- You can batch up a series of commands into a transaction
- When a command fails, the previous do not roll back

Redis

Two options for disk persistence

- RDF: Redis Database File
  - Forks process and saves a dump
- AOF: Append Only File
  - Saves updates to a log
  - Log is replayed upon start

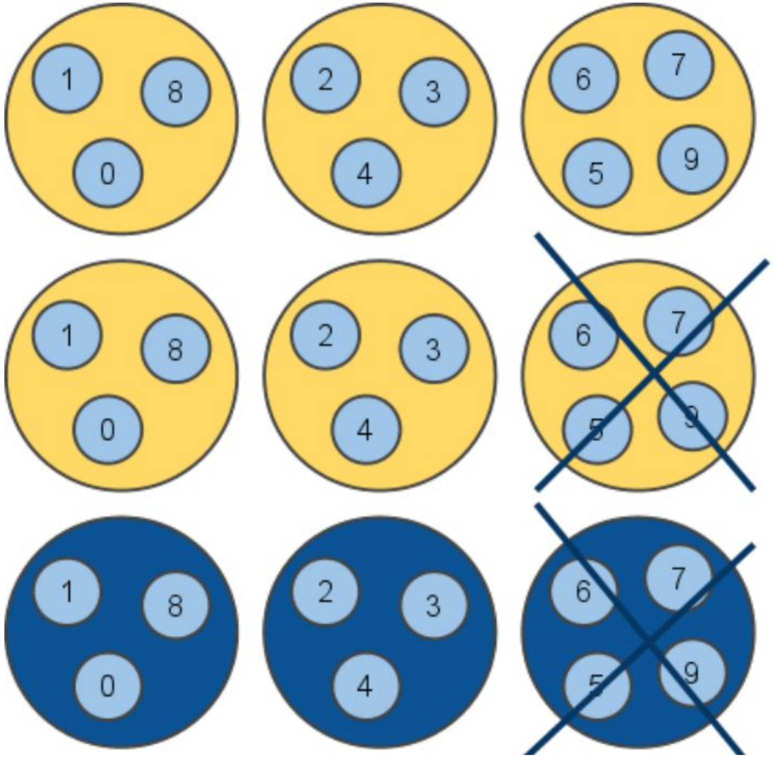
Redis



Redis cluster supports sharding

Single master for writes, replicas for failover.

Redis

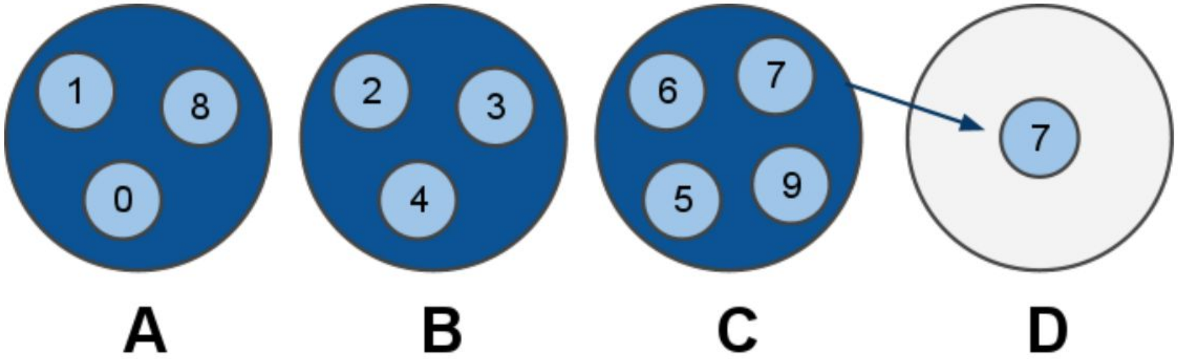


Cluster can handle all reads if up to two nodes are down.

It’s possible to read from slaves, but default sends all read and write operations to master.

Redis

Cluster can also dynamically rebalance after adding hardware.



Cassandra

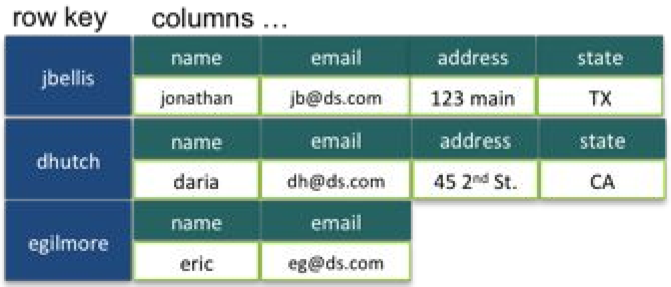
Most similar to a RDBMS

Cassandra has table-like structures called ColumnFamilies

- ColumnFamilies have many rows
- Rows are like a big hash, with many keys and values
- Rows are heterogeneous and can be schemaless
- Rows can be very long
    - Have many keys and values

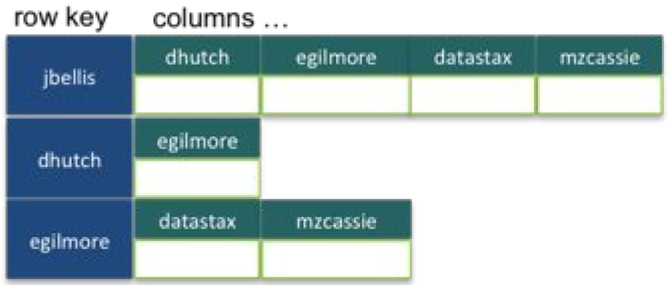
Cassandra

Static Column Family:

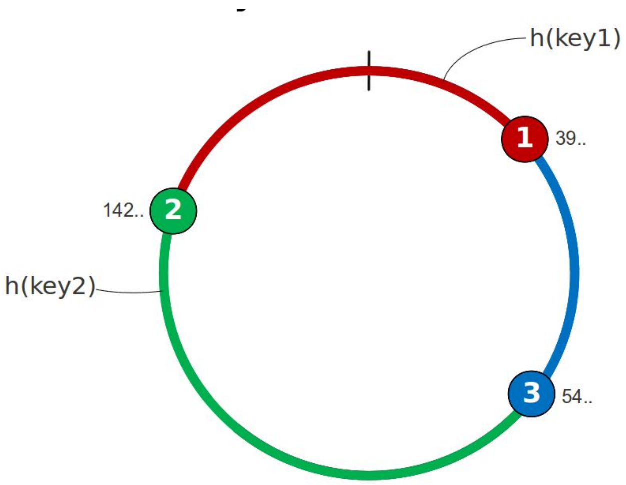


row key	columns ...			
jbellis	name	email	address	state
	jonathan	jb@ds.com	123 main	TX
dhutch	name	email	address	state
	daria	dh@ds.com	45 2nd St.	CA
egilmore	name	email		
	eric	eg@ds.com		

Dynamic Column Family



row key	columns ...			
jbellis	dhutch	egilmore	datastax	mzcassie
dhutch	egilmore			
egilmore	datastax	mzcassie		



Cassandra

Interface is called CQL, similar to SQL

```
    SELECT * WHERE KEY = 11194251 AND
startdate = '2011-10-08-0500';
```

Features are very limited

- Most queries are key-value
- Secondary indices are allowed
- Sorting is very limited

Cassandra

No transactions

- Atomic batches exist
- No isolation from other batches

No Joins.

- Do this at the application layer

Cassandra

- Cassandra is a masterless system
- Distributed and highly available
- Data is automatically split across nodes
- Reads are eventually consistent
    - But can be made strictly consistent (per statement)

Cassandra

- Consistency per statement

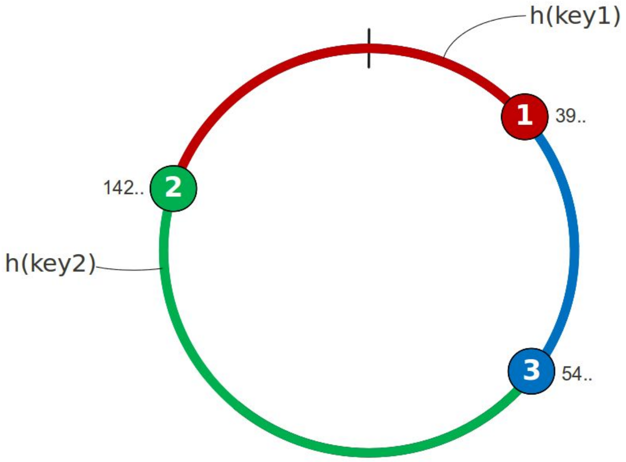
```
SELECT * WHERE KEY = 11194251...
  CONSISTENCY LEVEL ONE       (R=1)
  CONSISTENCY LEVEL ALL       (R=N)
  CONSISTENCY LEVEL QUORUM    (R=N/2+1)

UPDATE ... WHERE KEY = 11194251...
  CONSISTENCY LEVEL ONE       (W=1)
  CONSISTENCY LEVEL ALL       (W=N)
  CONSISTENCY LEVEL QUORUM    (W=N/2+1)
```

Cassandra

Cassandra distributes keyspace across a virtual ring of nodes.

- This ring can be randomized or ordered
- Ordered allows faster range queries
- Randomized avoids hotspots



Motivation

After today’s lecture you will understand how NoSQL can be used to build into scalable internet services.

NoSQL data stores won’t likely be part of your project, but after this lecture you should understand when you could look to them in practice.

For Next Time...

This Friday in lab we will do full-group demos.

- 5-10 minutes, describe your application and demo it to the whole group

Start writing simple tsung tests for your app.

For Thursday, read Chapter 4 in HPBN.