WEBARCH 253: Storage Systems

Peter Bailis
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Who am I?

Peter Bailis
Getting Ph.D. in Computer Science @ Cal
Study distributed systems and databases

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[complicated games of Telephone]

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Appreciate interruptions and questions!

Who are you?

Who are you?

Engineering?

Who are you?

Engineering?

Product?

Who are you?

Engineering?

Product?

Management?

Who are you?

Engineering?

Product?

Management?

Legal?

Who are you?

Engineering?

Product?

Management?

Legal?

Entrepreneur?

Who are you?

Engineering?

Product?

Management?

Legal?

Entrepreneur?

Thought leader?

Who are you?

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Other?

Why data storage?
Classic Data Mgmt
IRL Data Mgmt
Break
Web Arch
Scaling
NoSQL

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Why data storage?

Why data storage?

- When we make a web request, where do we get the data from?
- When we create data, where do we put it?
- Where do “resources” live?

bit.ly clone

bit.ly clone

- Lots of data to store
  - shortcut to url mapping
  - statistics about links
  - information about users

bit.ly clone

long url	http://news.google.com
short url	http://bit.ly/awekl
hit count	482240

long url	http://facebook.com/user/profile/
short url	http://bit.ly/czasw
hit count	11023

long url	http://msnbc.com/news/article/
short url	http://bit.ly/olkjpl
hit count	1232

Data Storage Design

Data Storage Design

- What is the storage format?
- How do we lay out data?
- How do we access data?

Why use a file?

Why use a file?

```
http://news.google.com, http://bit.ly/awekl, 482240

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Pros?

Why use a file?

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...
```

Pros?

Cons?

Problems with Files

- What if we want to add another field?
- What if we want to query different parts of data? How efficient is this?
- What if we have concurrent accesses?
- What data structures should we use?

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Data Independence

- Databases: apps shouldn't have to worry about these problems!
- Underlying storage format independent of application-level logic

Relational Data Stores

- RDBMS

Relational Data Stores

- **RDBMS:** Relational Database Management System
- Invented in the 1970s
- e.g., Oracle, MySQL, Postgres, IBM DB2, Microsoft SQL Server

Relational Model

- Reason about sets of facts, or "tables"
  - Each fact is a "row"
- Attributes are "columns" of row

long_url	short_url	hit_count
http://news.google.com	awekl	482240
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relation

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row

relation

column

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SQL Query Language

- High-level query language over tables
- Declarative: say "what" you want computed, not "how"

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- High-level query language over tables
- Declarative: say "what" you want computed, not "how"

Why is this good?

SELECT example

SELECT example

```
mysql> SELECT * from links;
+--------------------------+-----------------------+-----------+------------+
| long_url                 | short_url             | hit_count | created    |
+--------------------------+-----------------------+-----------+------------+
| http://www.google.com    | qwelmw                | 2         | 2012-10-19 |
| http://www.facebook.com  | adfer                 | 45        | 2012-10-22 |
+--------------------------+-----------------------+-----------+------------+
```

SELECT example

SELECT example

```
mysql> SELECT * from links WHERE hit_count < 20;
+----------------------+----------------------+-----------+------------+
| long_url             | short_url            | hit_count | created    |
+----------------------+----------------------+-----------+------------+
| http://www.google.com | qwelmw               | 2         | 2012-10-19 |
+----------------------+----------------------+-----------+------------+
1 row in set (0.00 sec)
```

INSERT example

INSERT example

```
mysql> insert into links VALUES ("http://www.twitter.com", "eovle", 0,
CURDATE());
Query OK, 1 row affected (0.00 sec)
```

UPDATE example

UPDATE example

```
mysql> UPDATE links SET hit_count = '0' WHERE created > '2012-10-22';Query OK,
23 rows affected (0.00 sec)

Rows matched: 23  Changed: 23  Warnings: 0
```

Useful Properties

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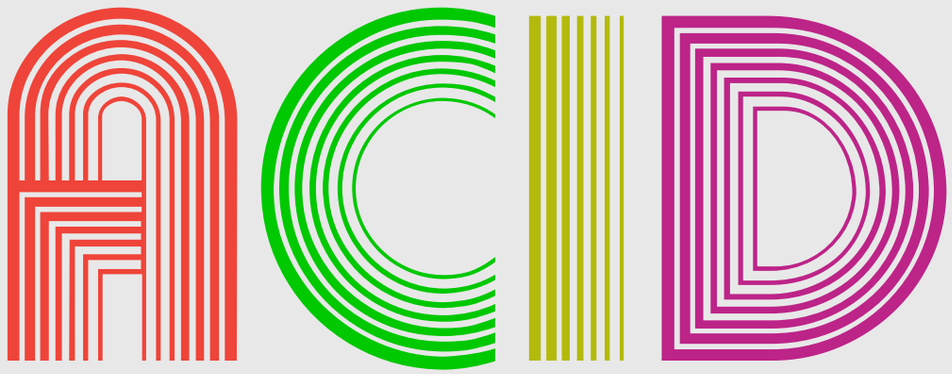
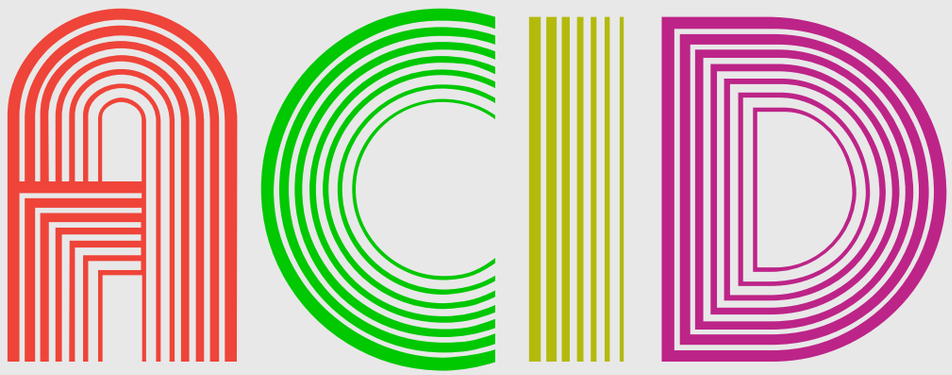


Useful Properties

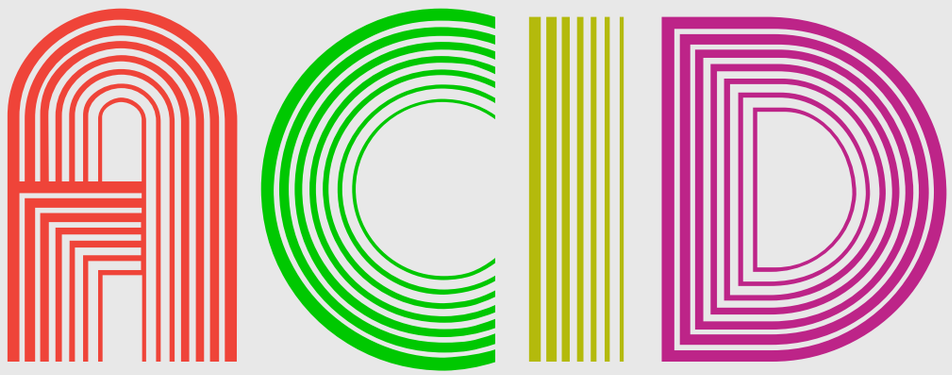
Atomicity: all updates happen or none do



Useful Properties

Atomicity: all updates happen or none do

Consistency: easy to reason about database



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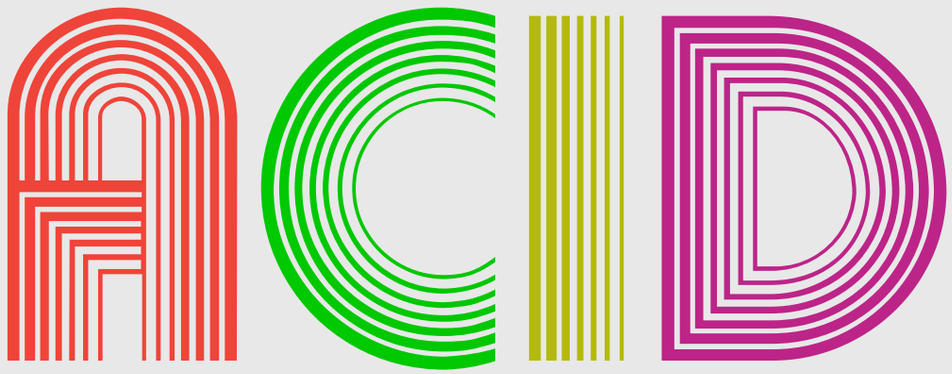
Isolation: operations are separated from each other



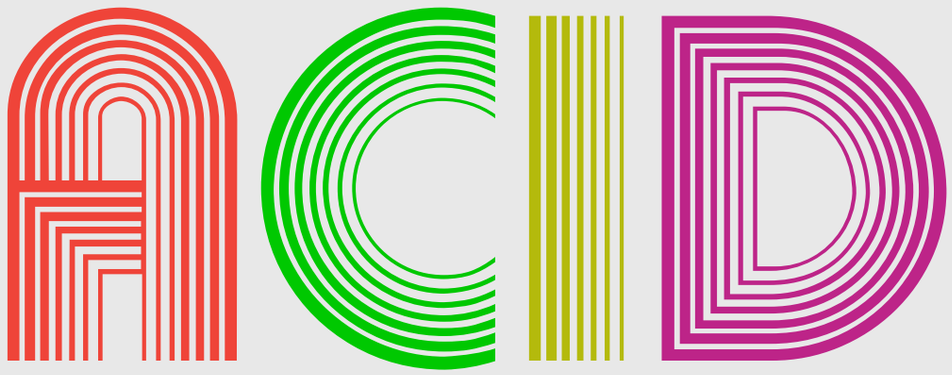
Useful Properties

Atomicity: all updates happen or none do

Consistency: easy to reason about database

Isolation: operations are separated from each other

Durability: updates won't disappear



RDBMS Pros and Cons

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PROs

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- High-level query language
- Data independence
- Isolation of users

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CONs

RDBMS Pros and Cons

PROs

- High-level query language
- Data independence
- Isolation of users

CONs

- Have to define schema at start
- Few open source multi-server implementations
- Often require complex tuning

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IRL Data Management

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Organizational roles often dedicated
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data is "safe"

protect institutional interests

sharing of data is controlled

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PROs

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protect institutional interests

sharing of data is controlled

CONs

slow changes (e.g., schemas)

more overhead

"feral databases"

Let's Pretend...

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you run a supermarket:

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1. you store your data in a database
   what do you put in it?

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2. you lose all of your data
   what breaks?

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you run a supermarket:

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   ~~what breaks?~~ what **doesn't** break?

3. how costly is it to restore your data?

Let's Pretend...

you run a supermarket:

1. you store your data in a database
   what do you put in it?

2. you lose all of your data
   ~~what breaks?~~ what **doesn't** break?

3. how costly is it to restore your data?
   what can('t) be restored?

Reliability

Companies pay for databases
not just for the database

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Pay because data has
immense business value

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not just for the database

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$$$ buys

insurance + someone to yell at on the phone

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Typical Web Architecture

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Client Browser

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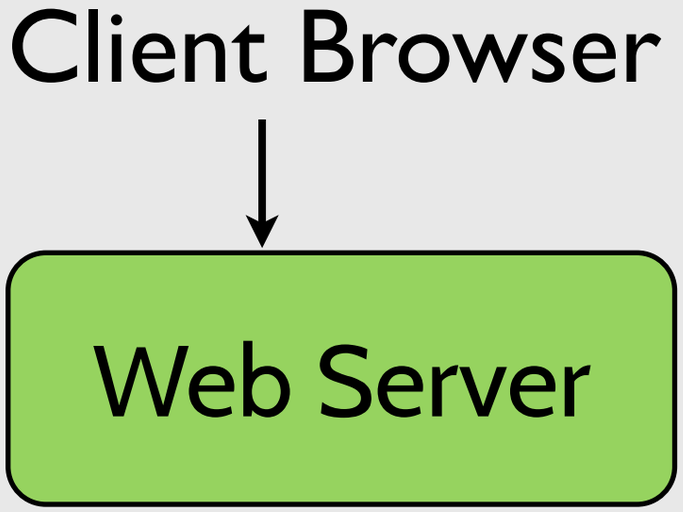
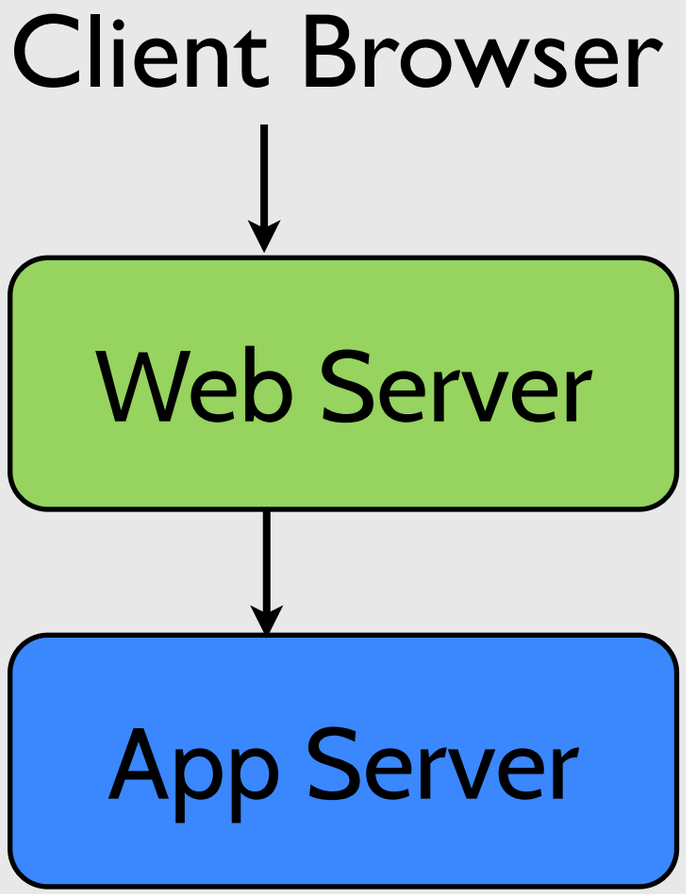


Accepts request from client

Typical Web Architecture



Accepts request from client

Decides what to fetch and how to present it

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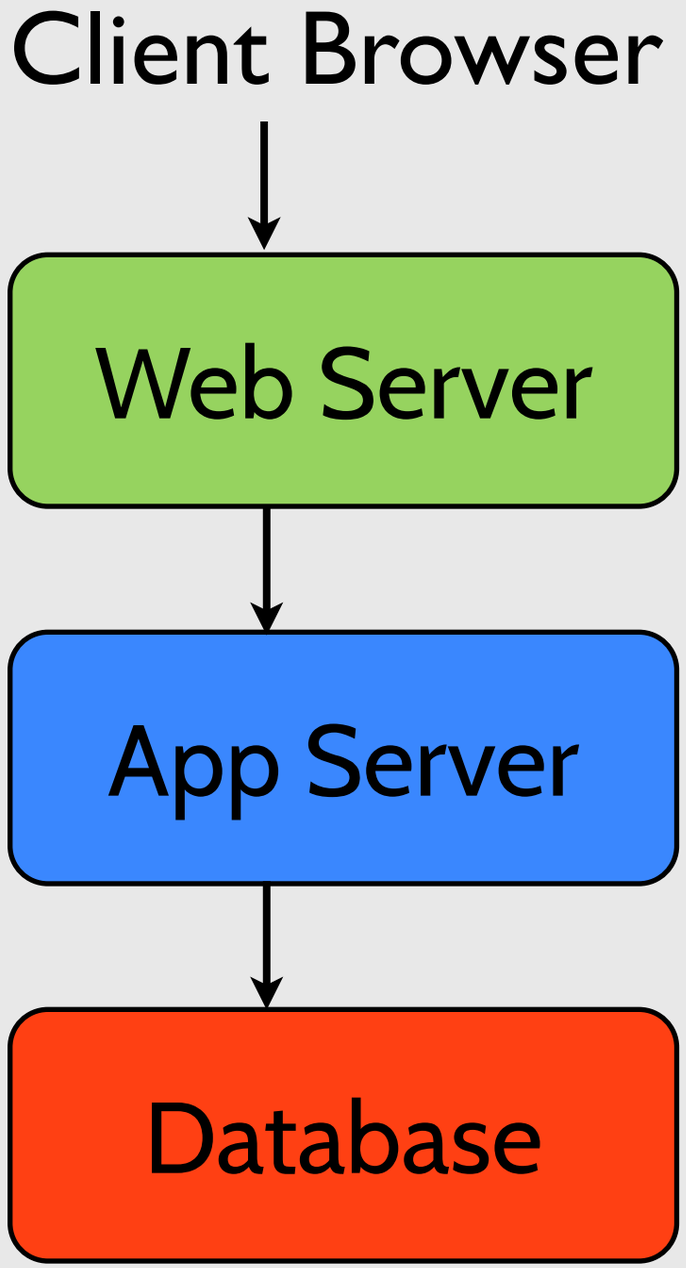

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Fetches data from storage

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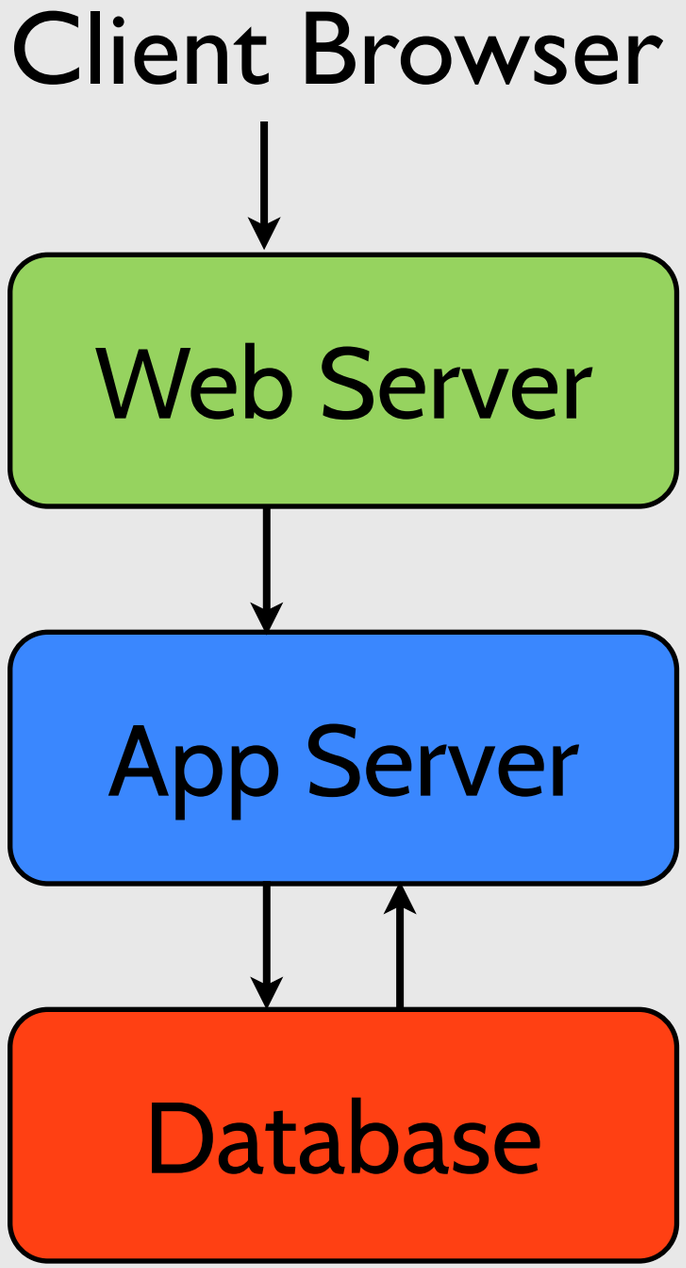

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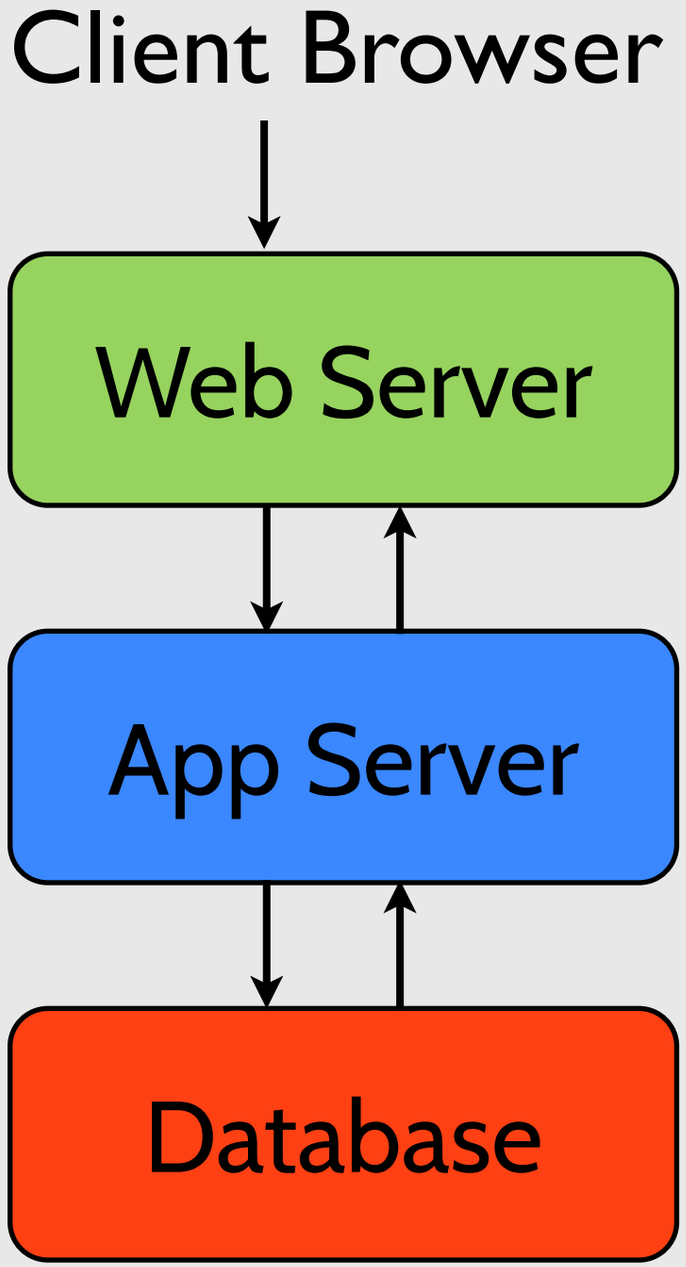

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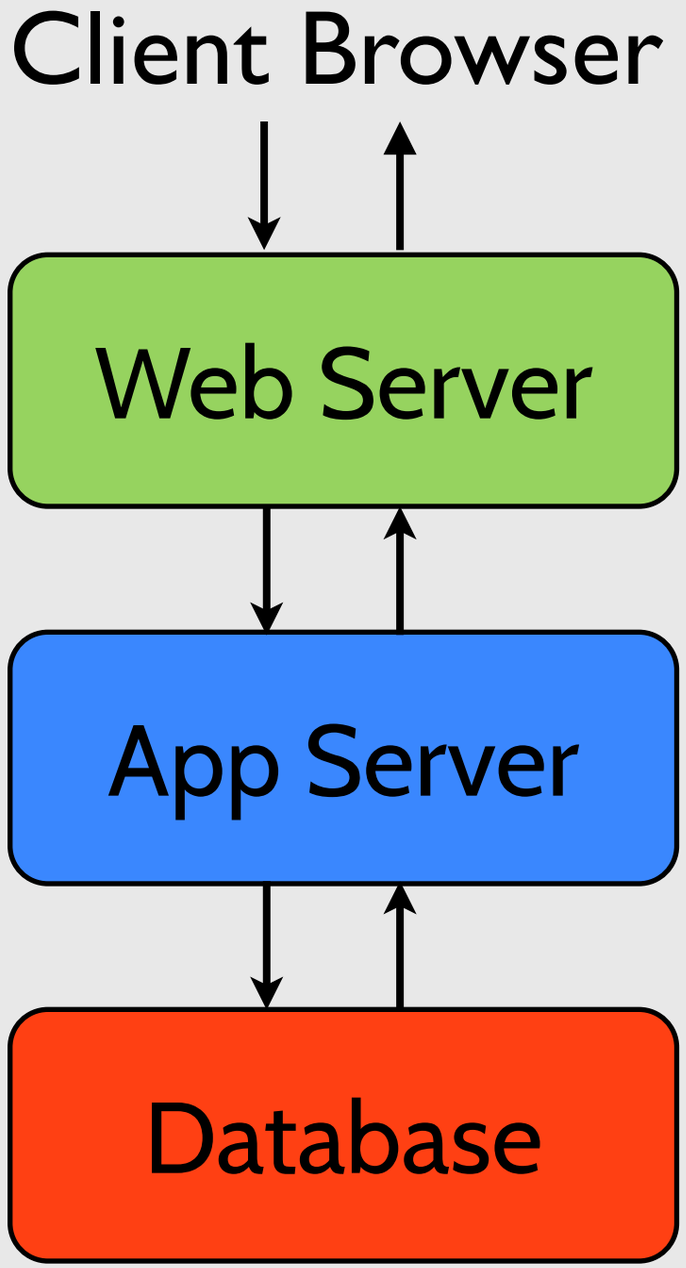

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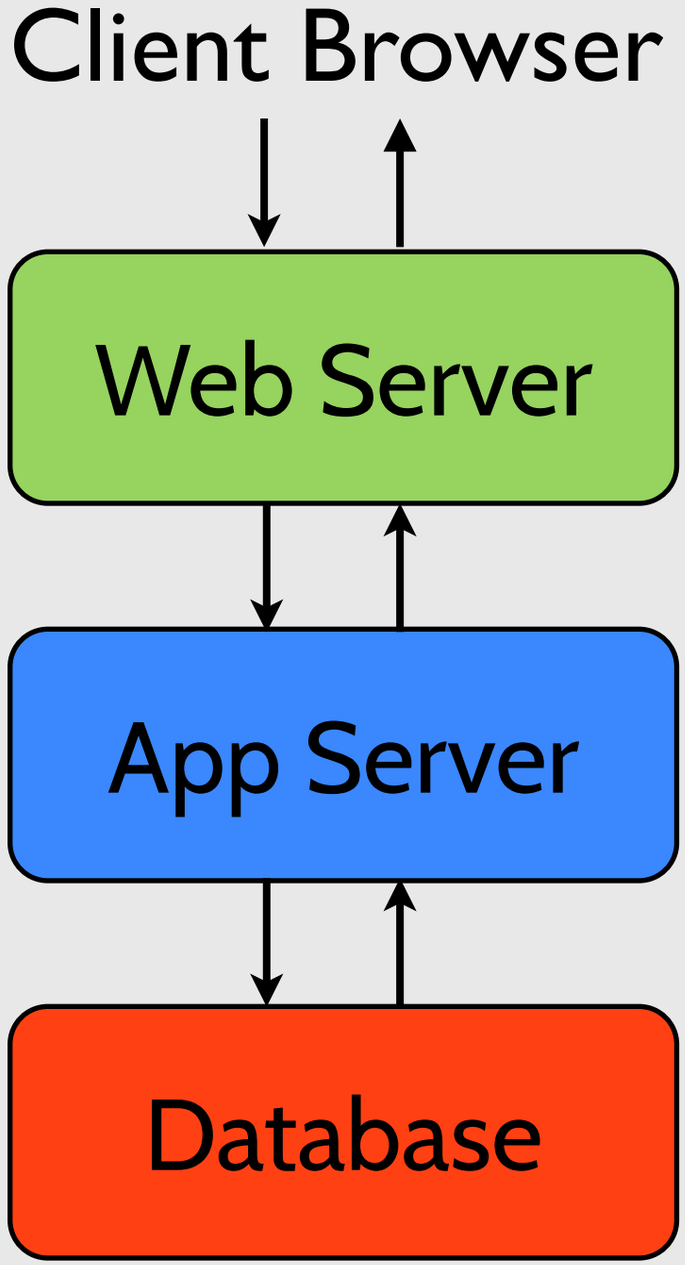
HTTP



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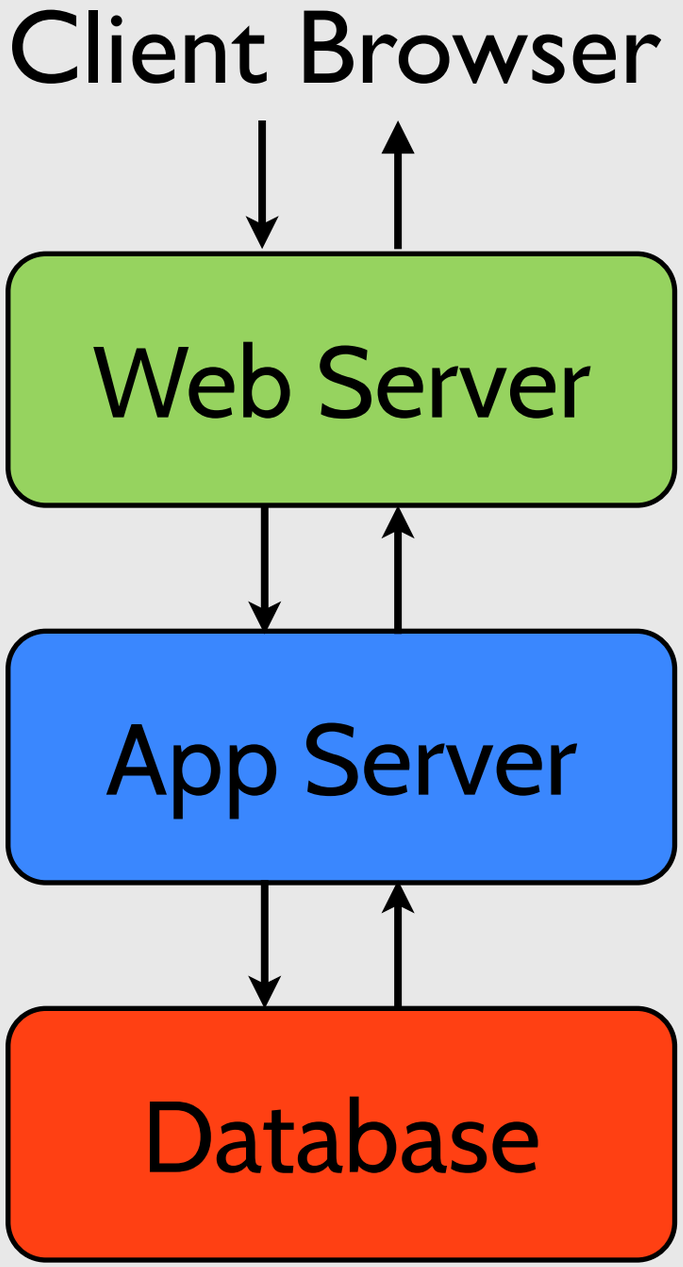

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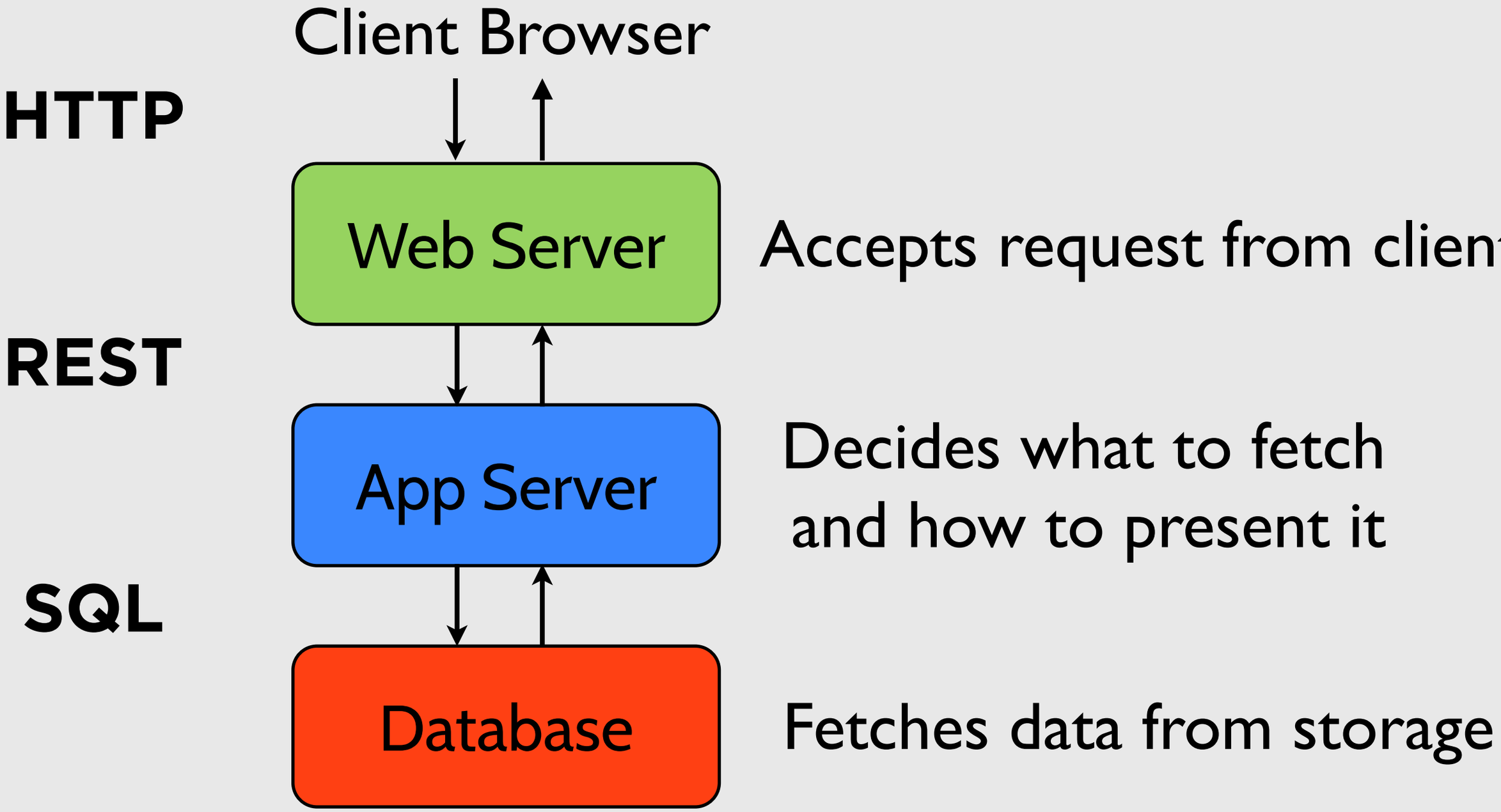
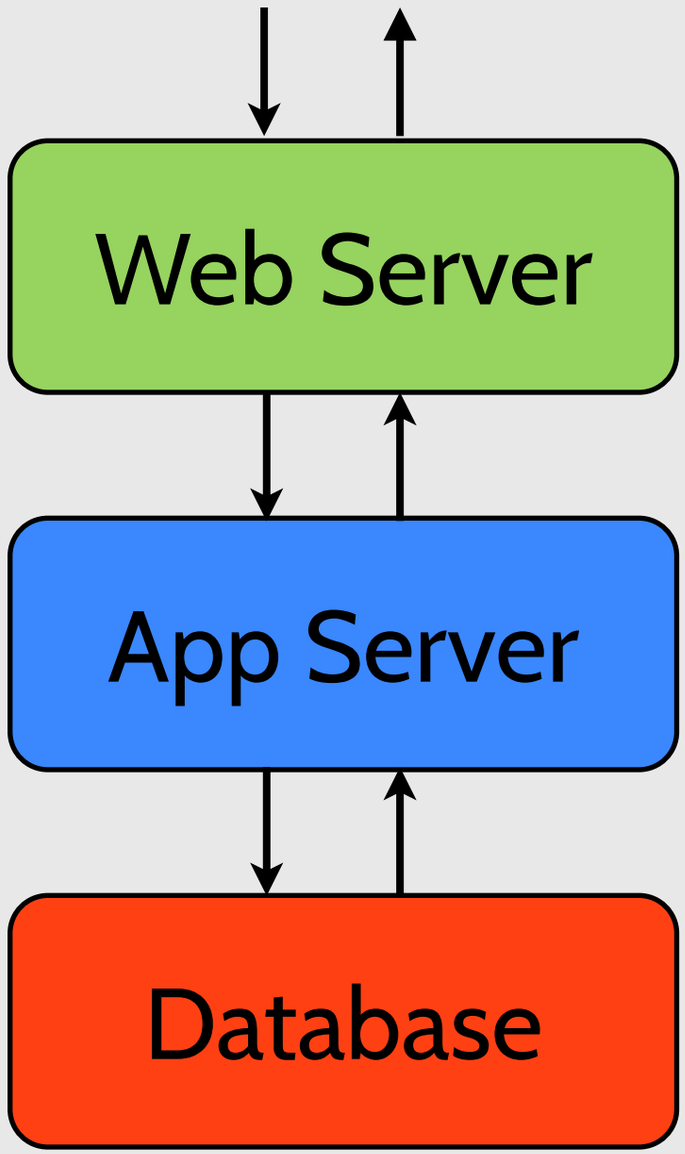


Caching



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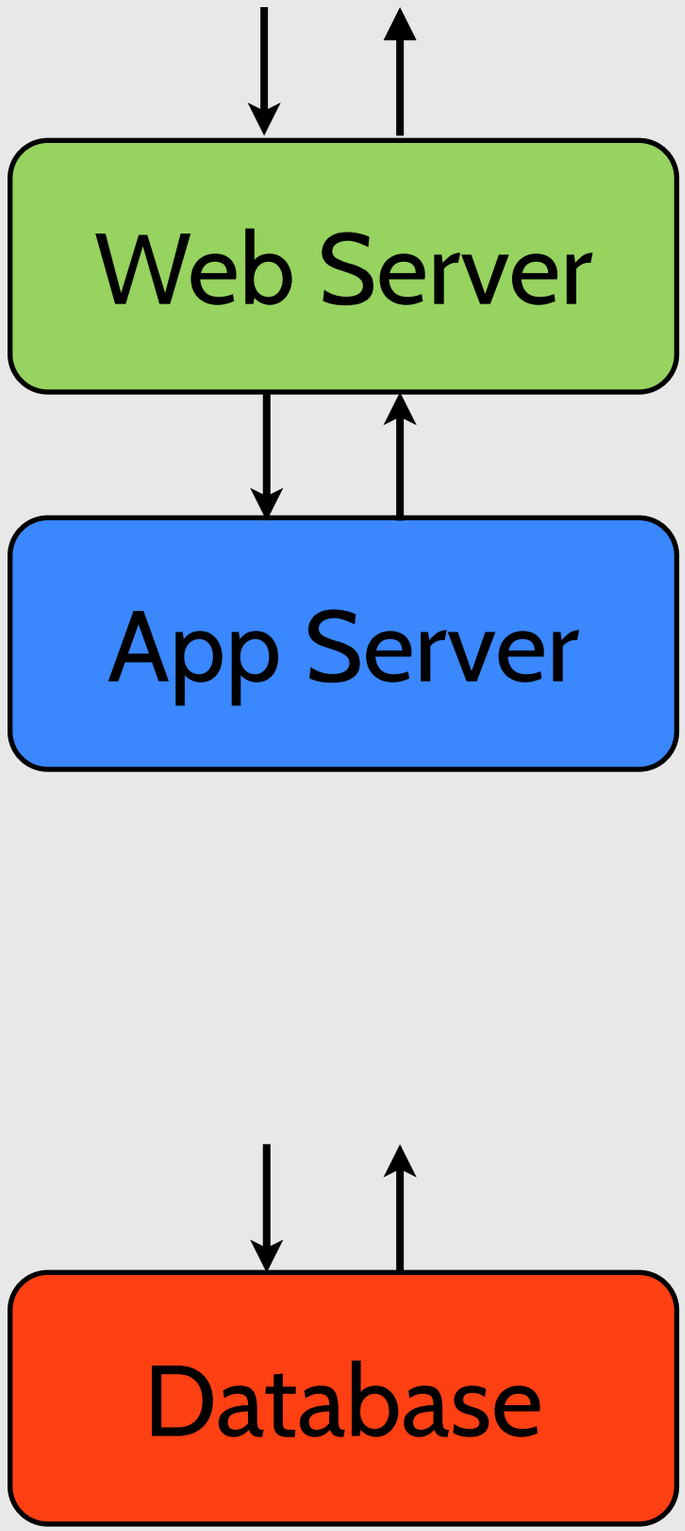

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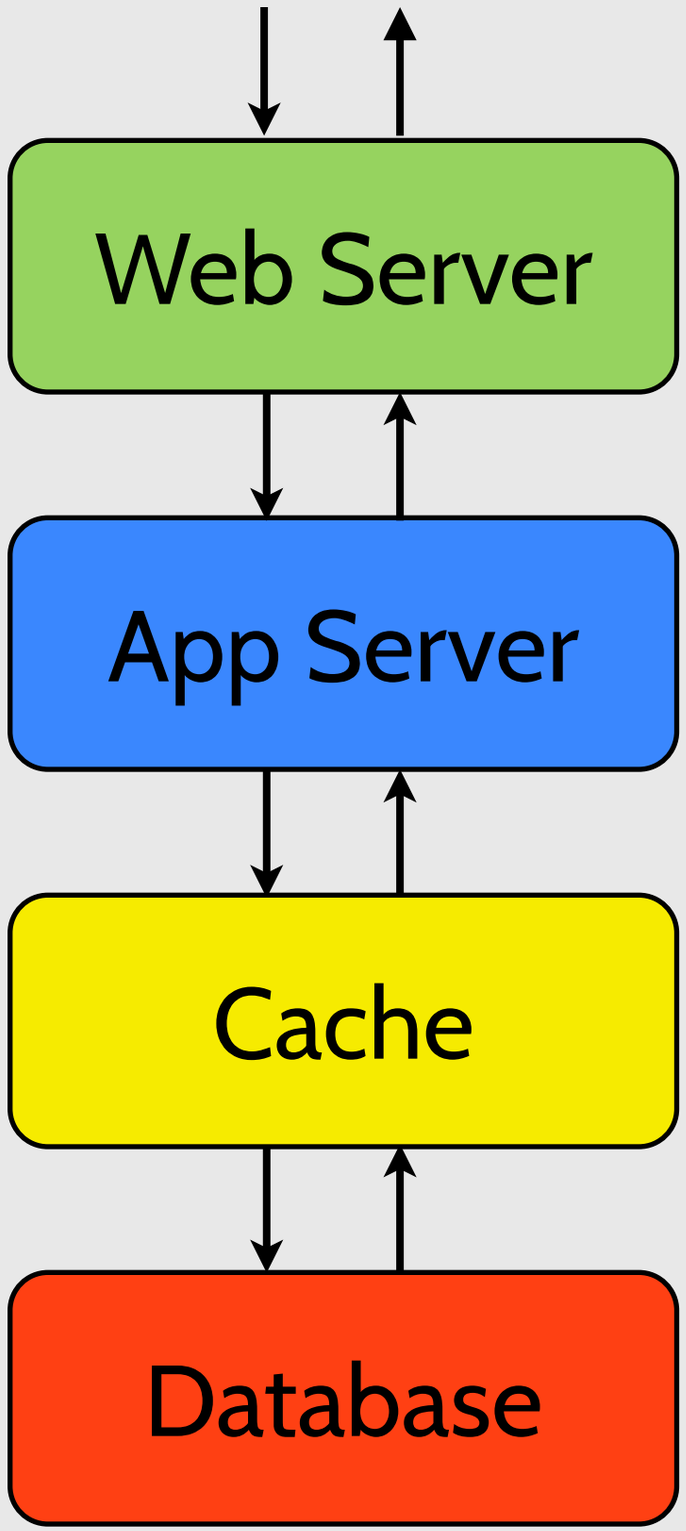

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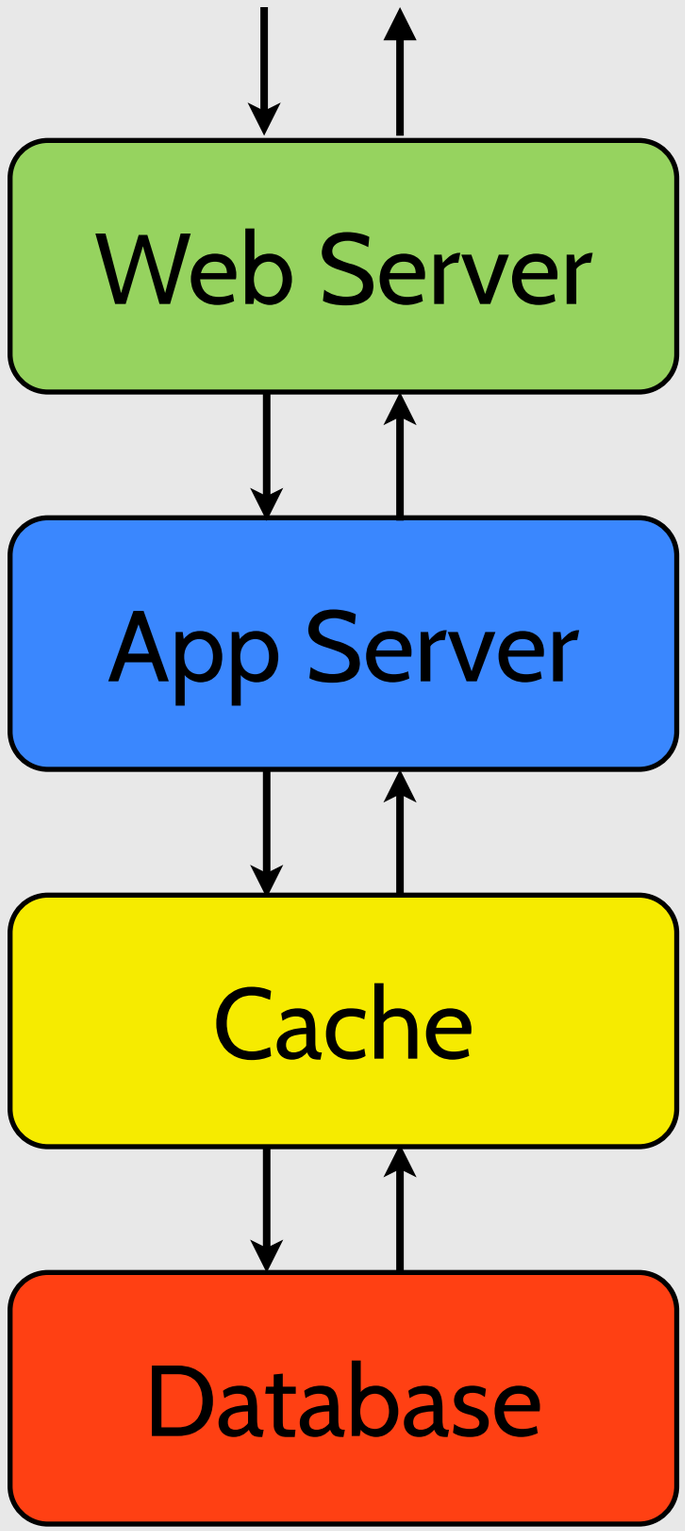
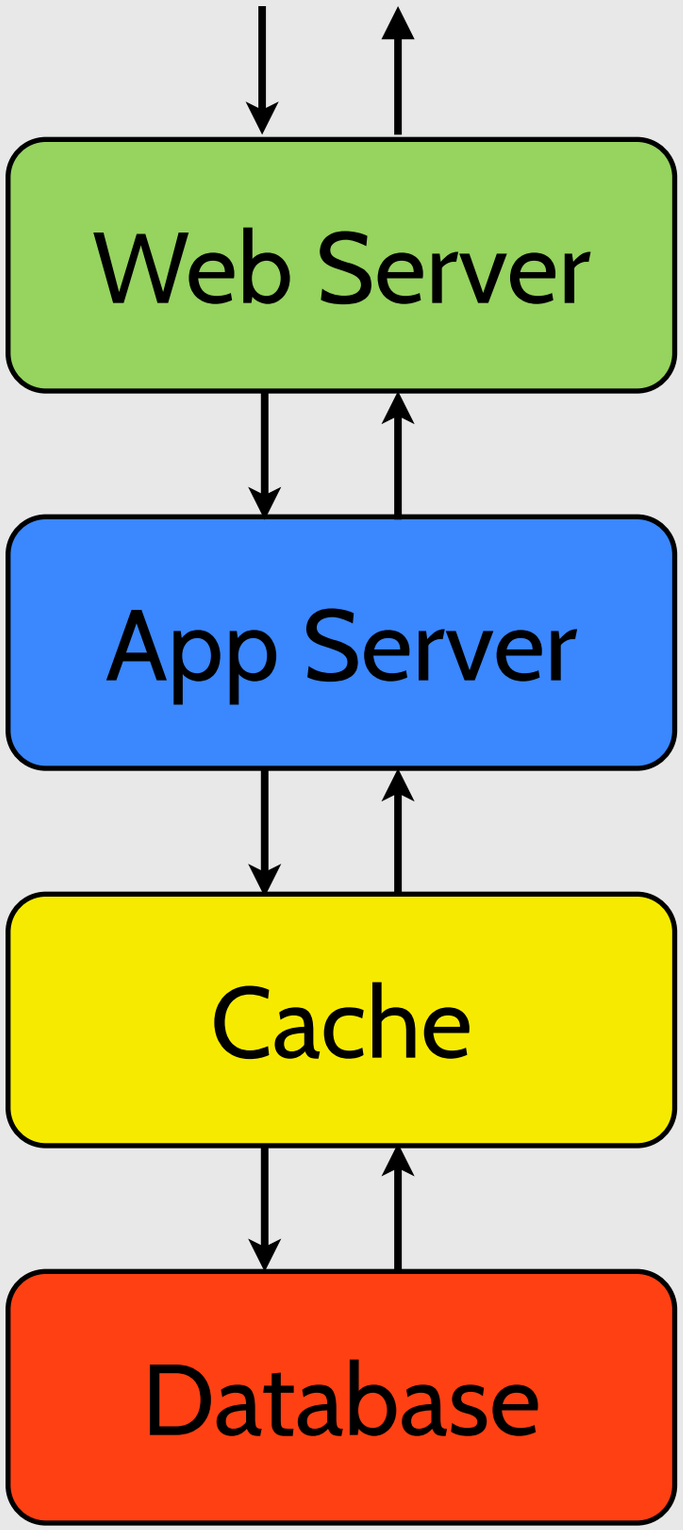


REST

Caching

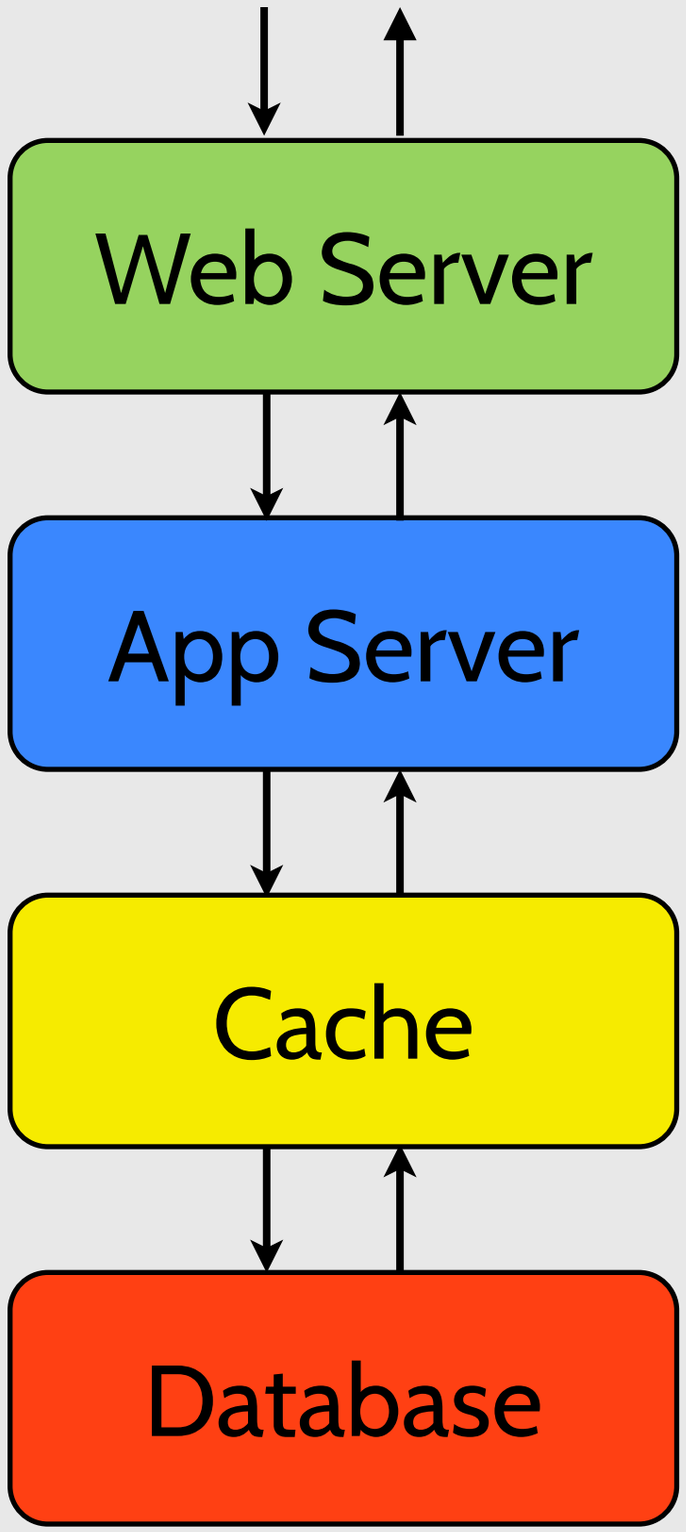


REST

SQL

Caching

reduce load on database
by placing cheap copies
in front of DB



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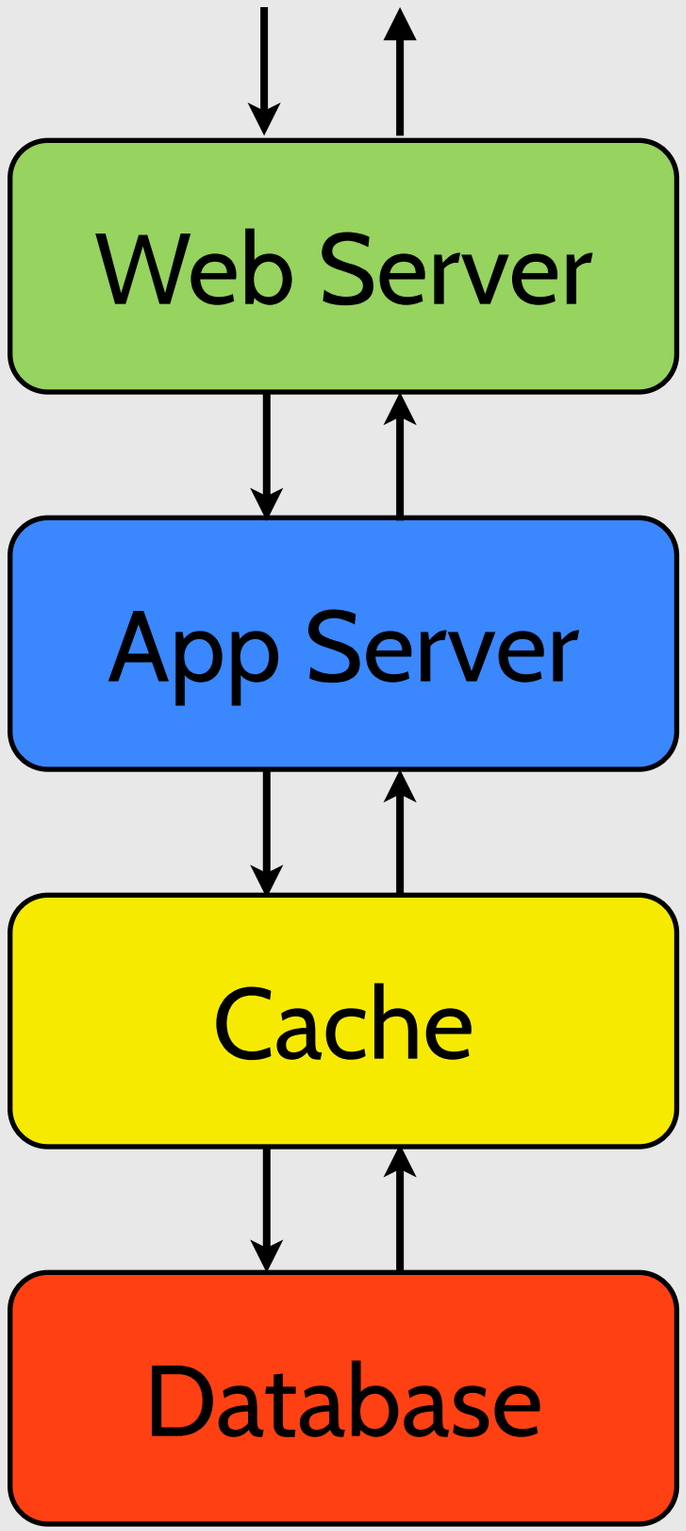

REST

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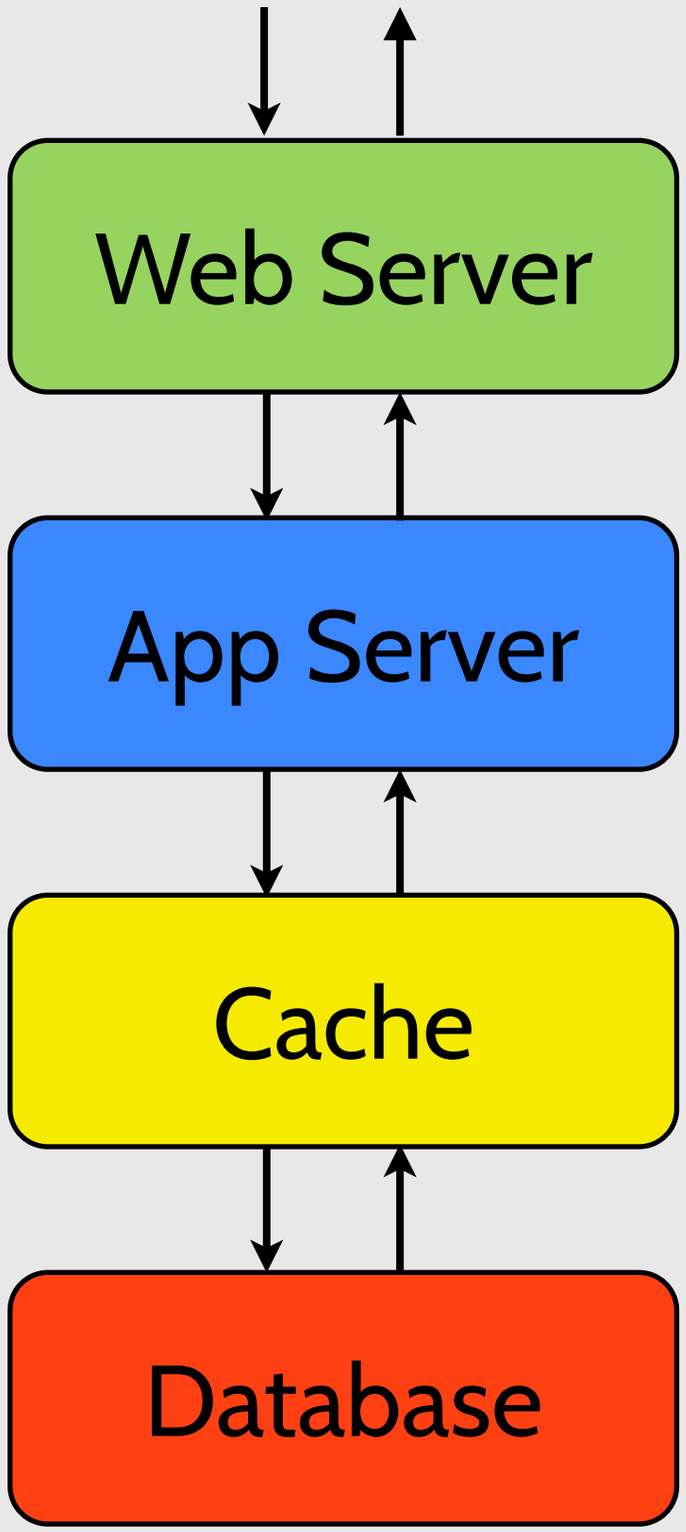
problem?

Caching



REST

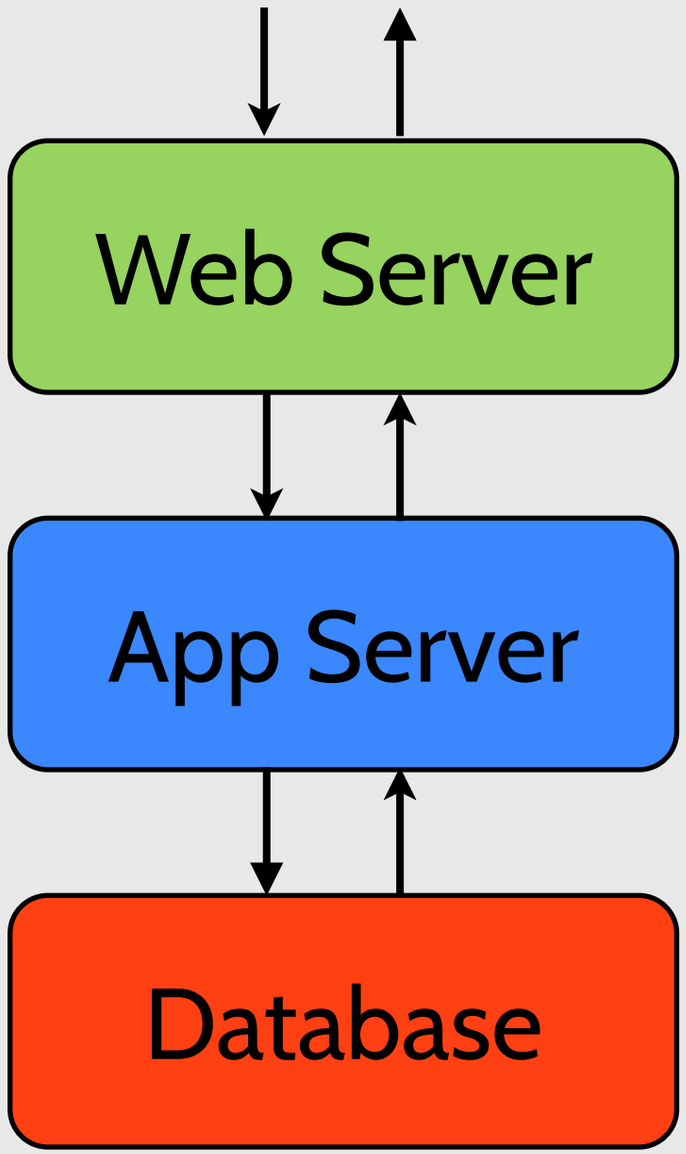
SQL

reduce load on database by placing cheap copies in front of DB

problem?

have to keep cache(s) up to date...

Horizontal Scale-out



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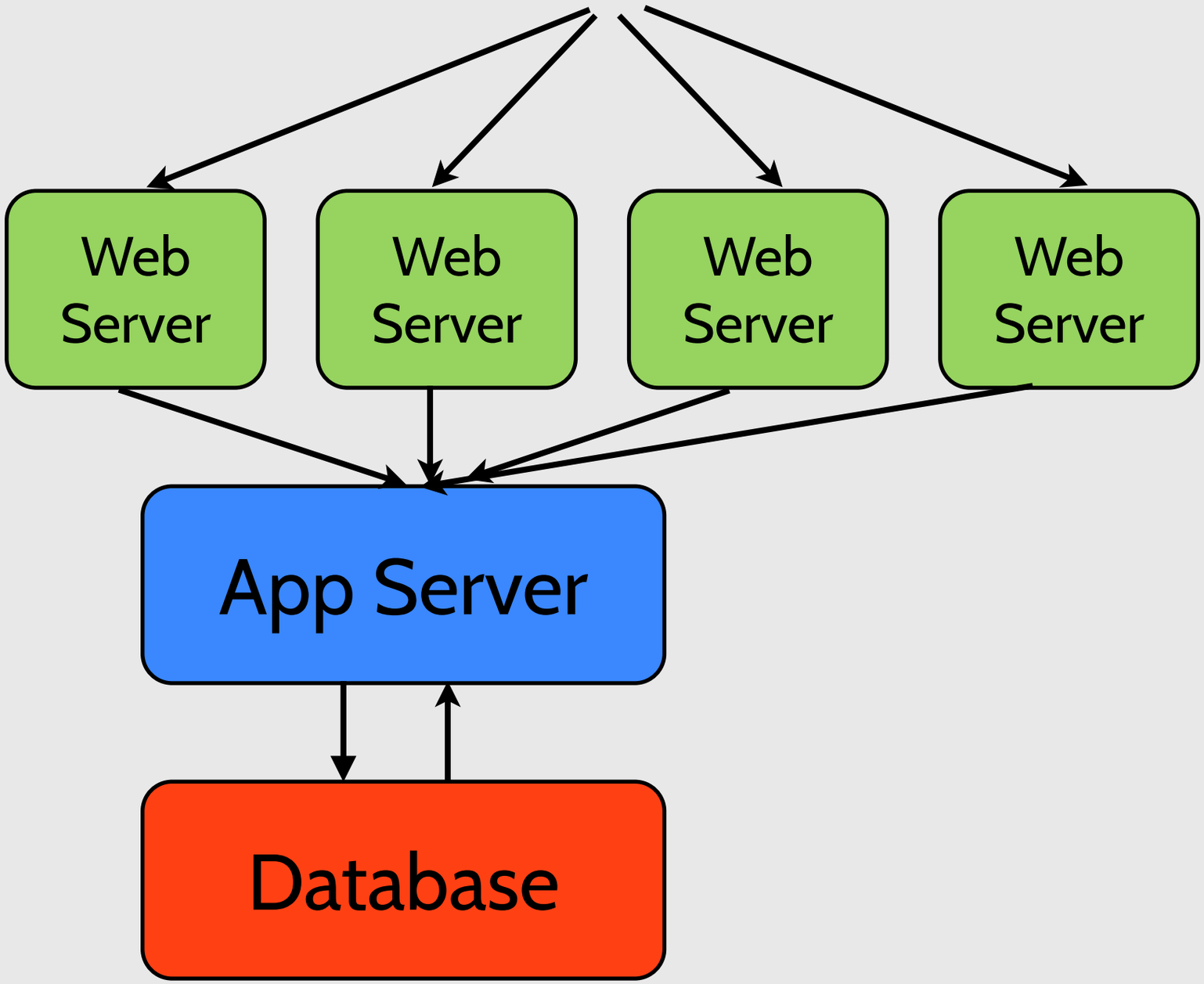

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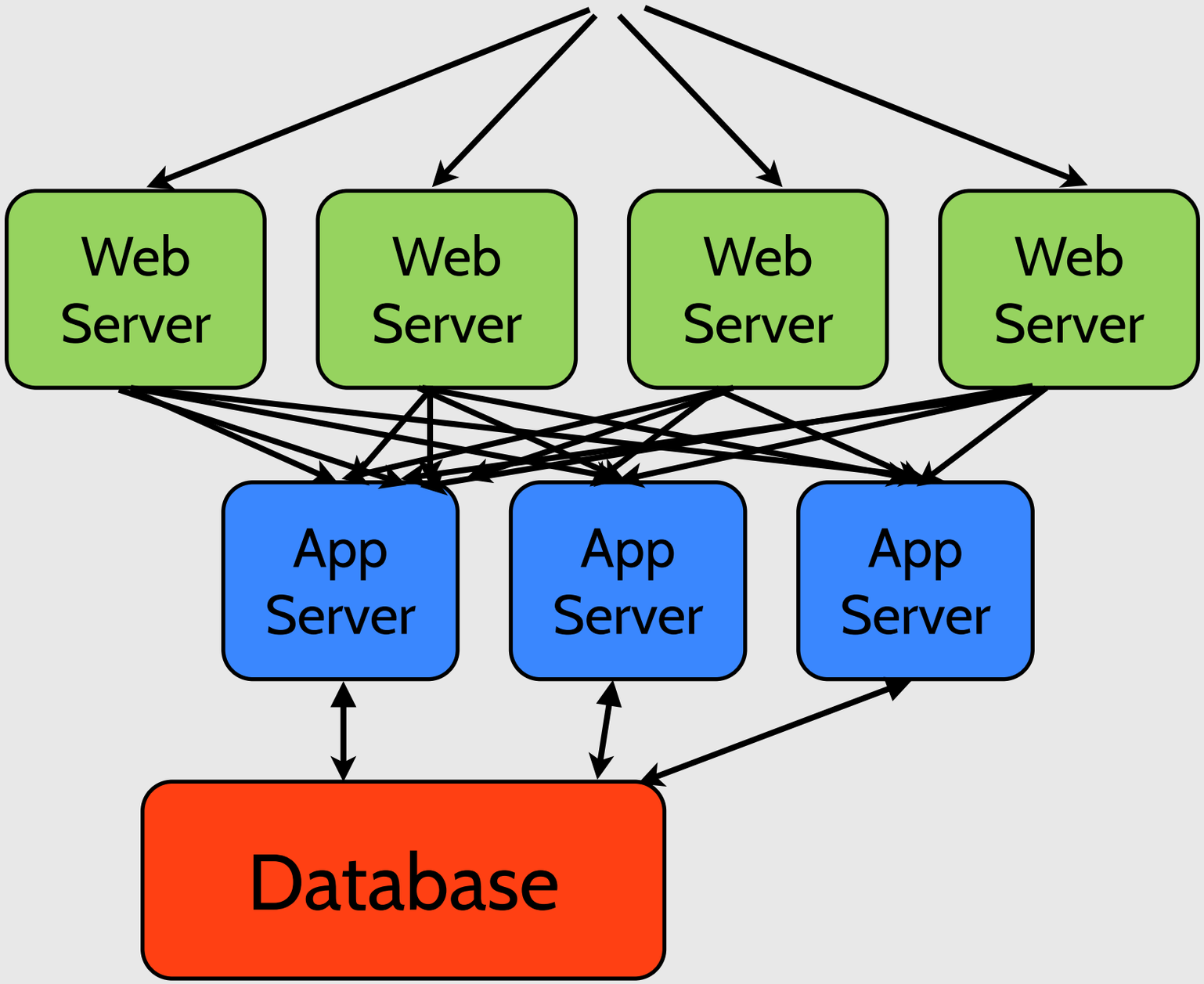

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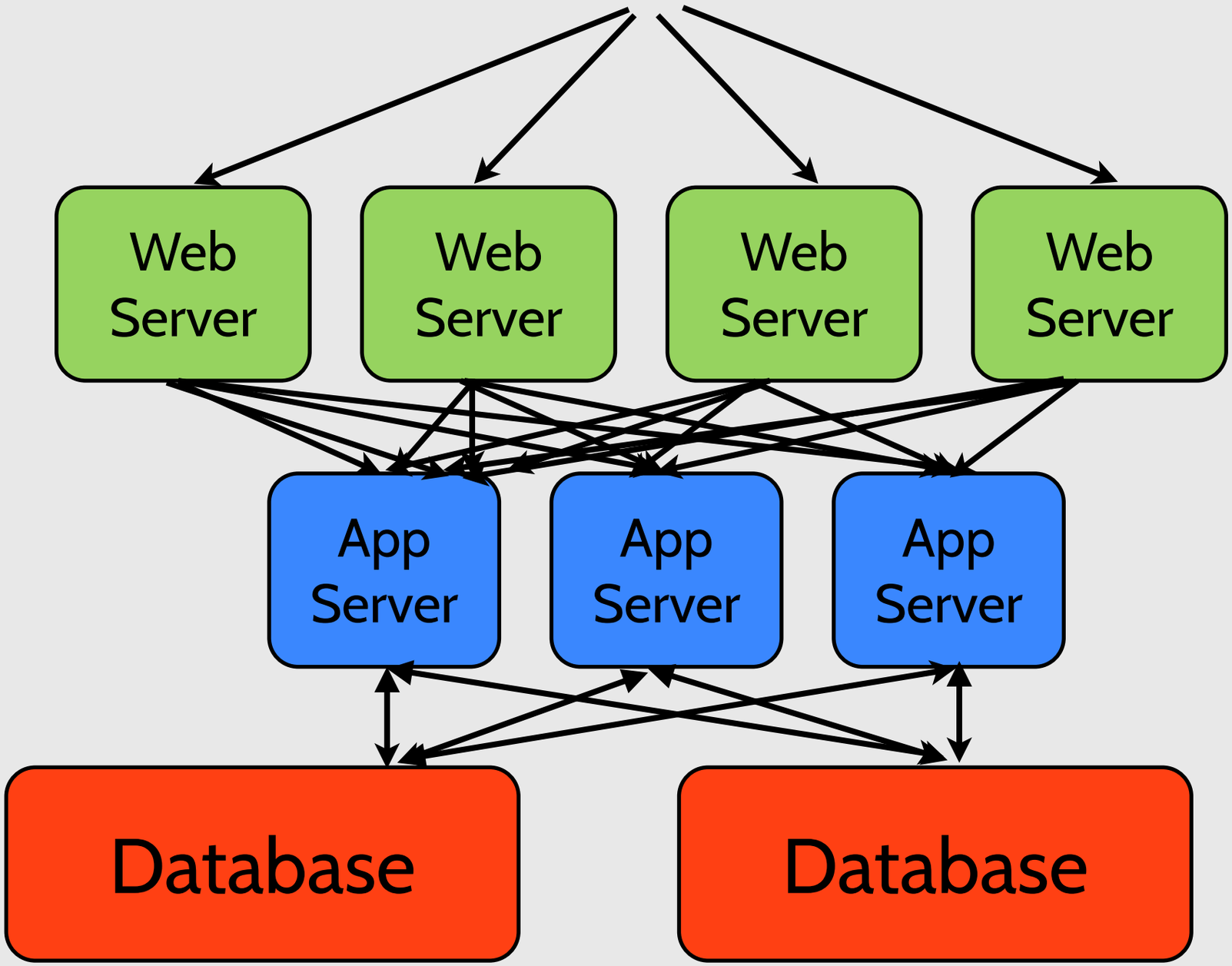

Statelessness

Front-end, mid-tier are often stateless--why?

Statelessness

Front-end, mid-tier are often stateless--why?

Simplifies programming, reasoning about services

DBs can manage complexity of state management; promote reuse of complex code

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Scaling

- What if data can't fit on a single server?
- What if a server goes down?
- What if a machine fails completely?

Fun: "Why is it hard to scale a database in layman's terms?" http://qr.ae/8jOUH

Scaling

- What if data can't fit on a single server?
- What if a server goes down?
- What if a machine fails completely?

A good problem to have, but not easy!

Fun: "Why is it hard to scale a database in layman's terms?" http://qr.ae/8jOUH

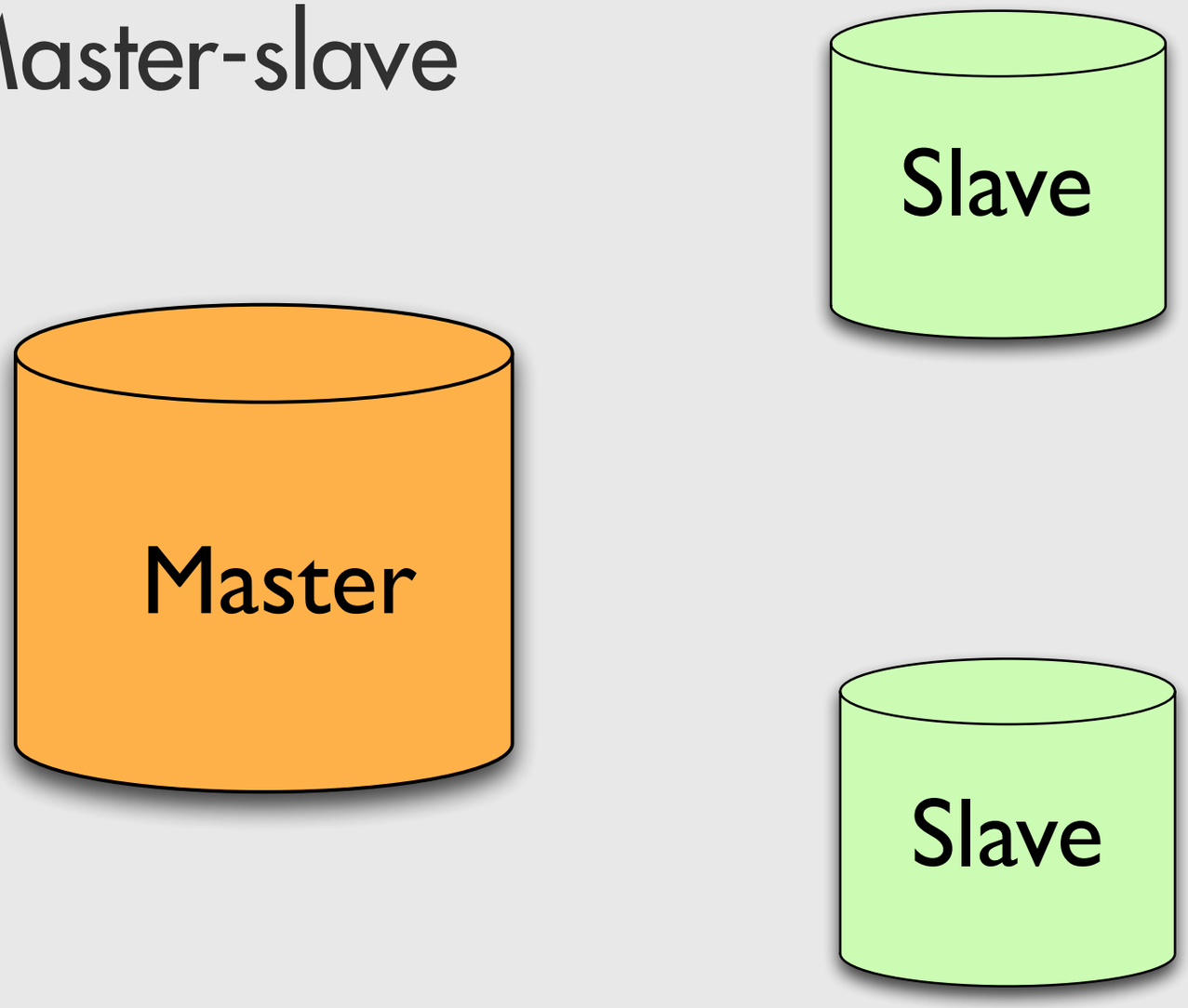
Replication

Replication

- Provides durability: don't lose data
- Provides capacity: multiple servers
- Leads to many interesting challenges

Typical Replication

- 3-way
- Master-slave



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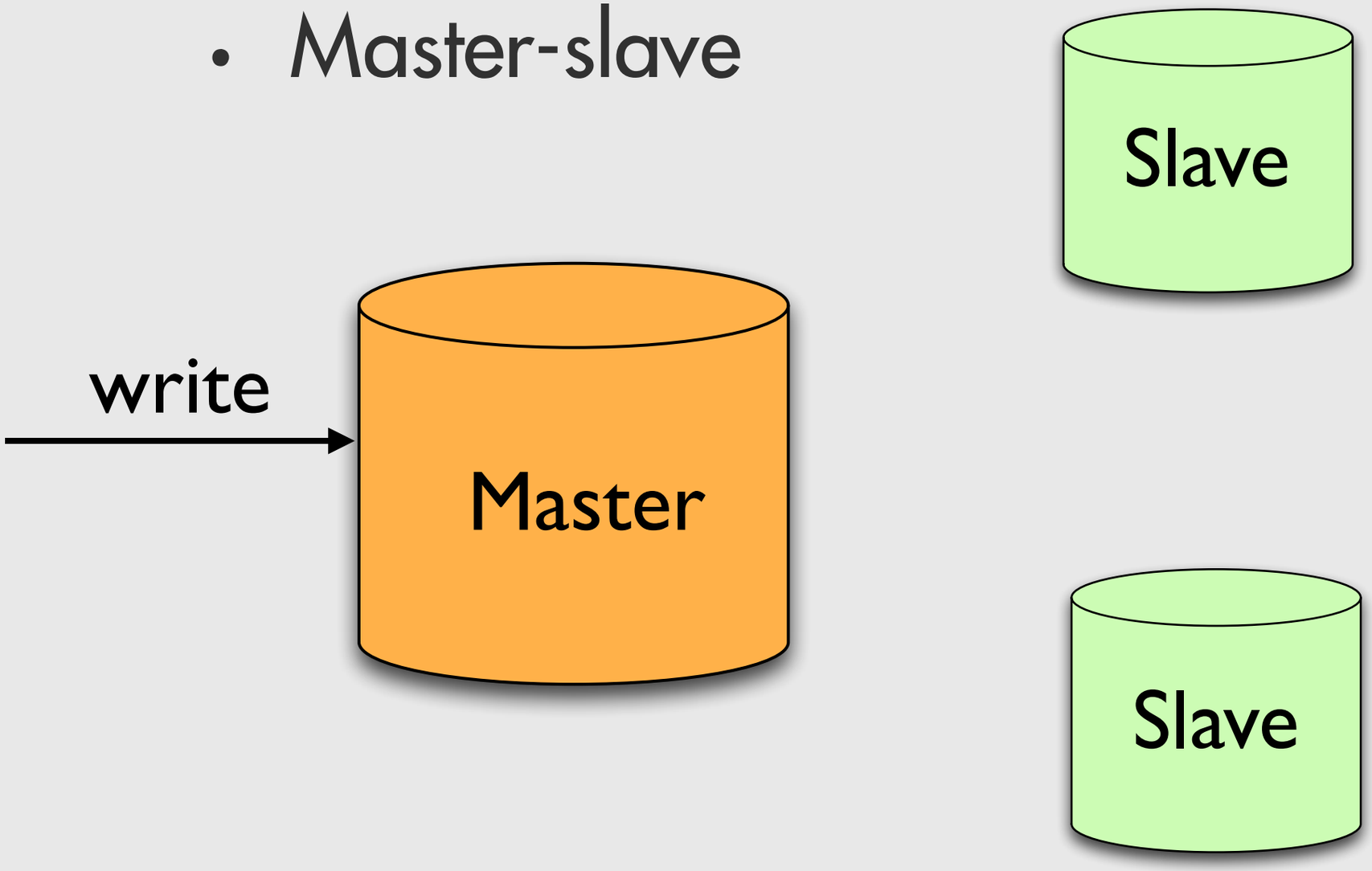

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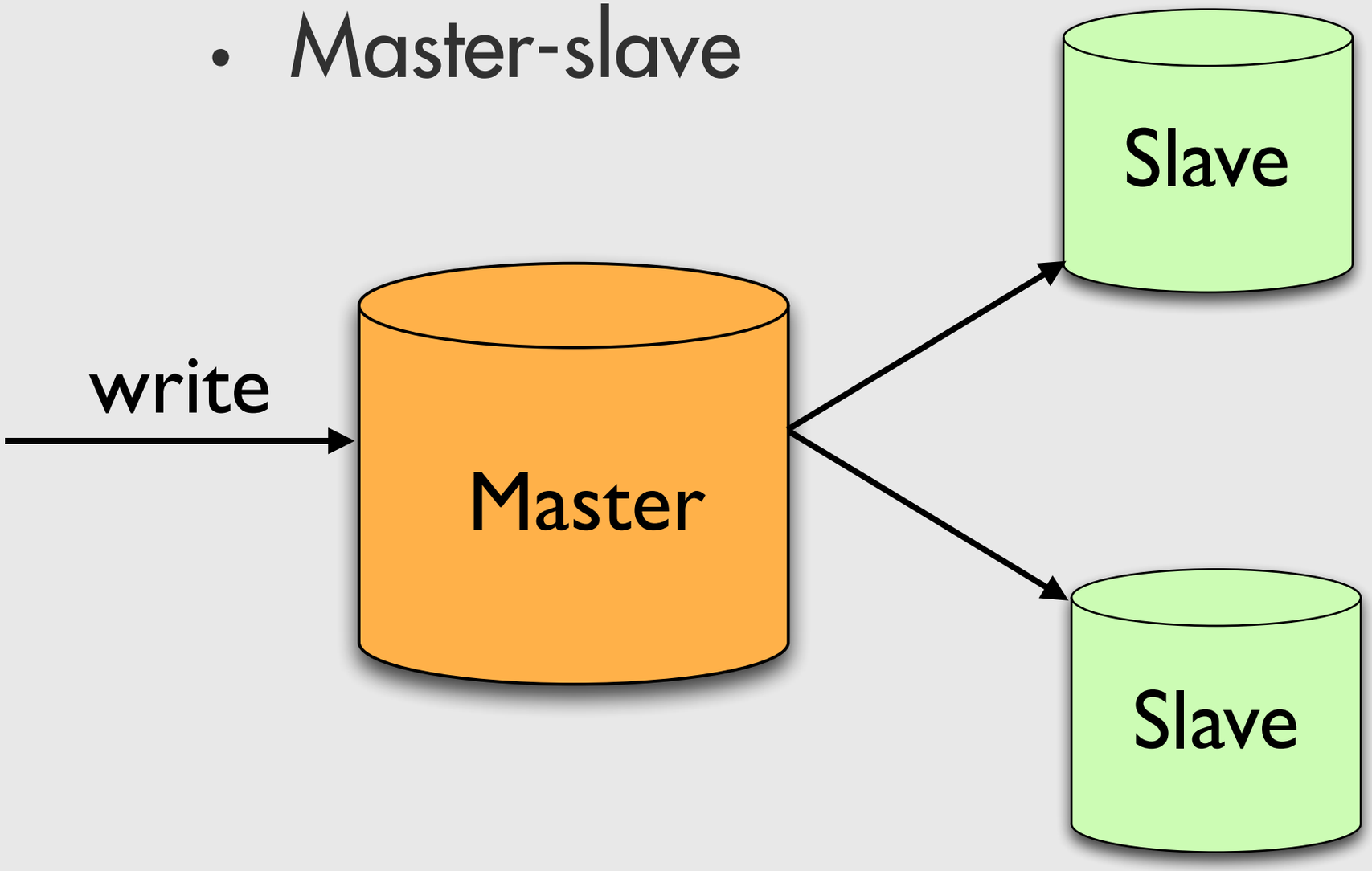

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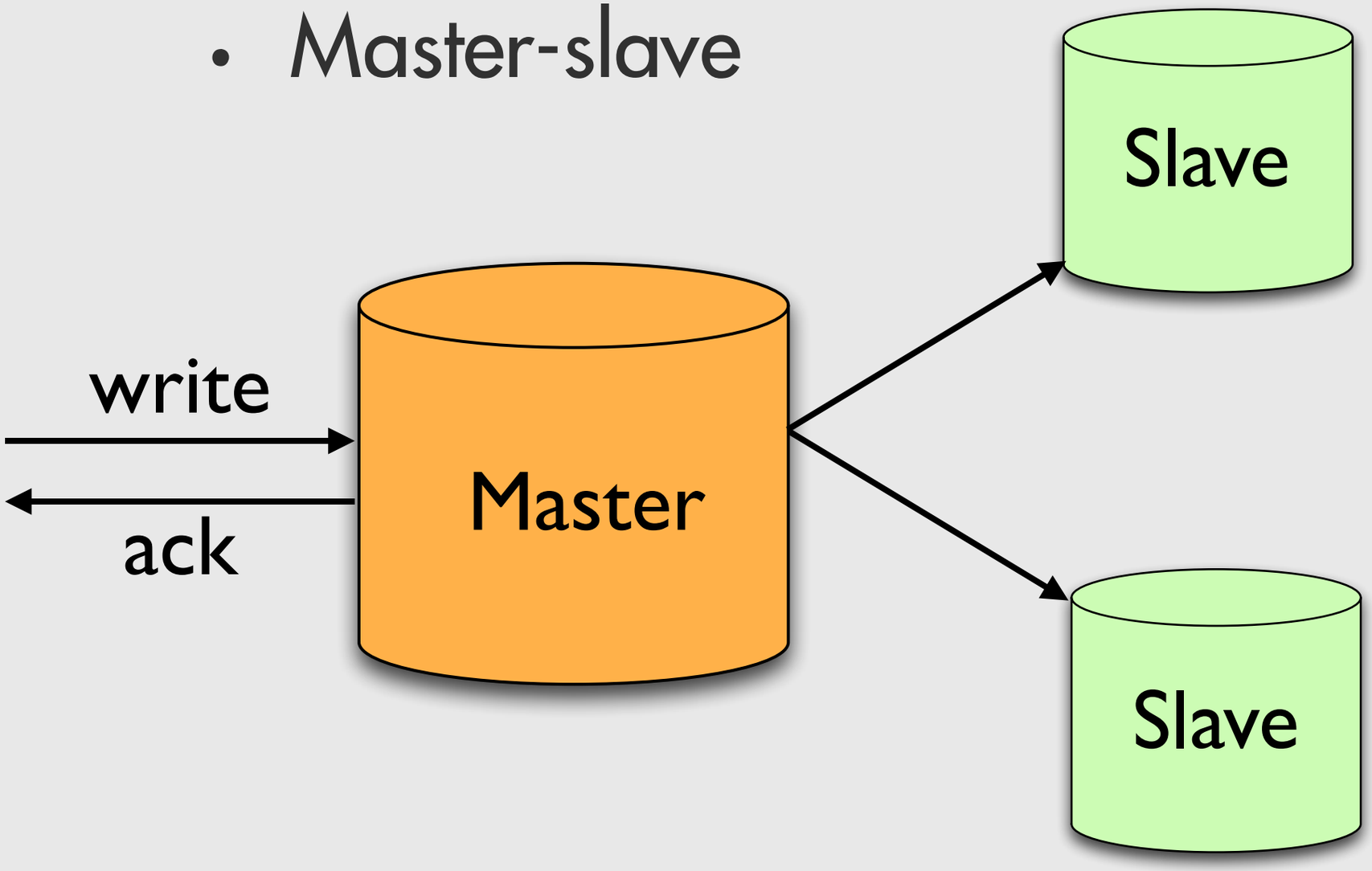

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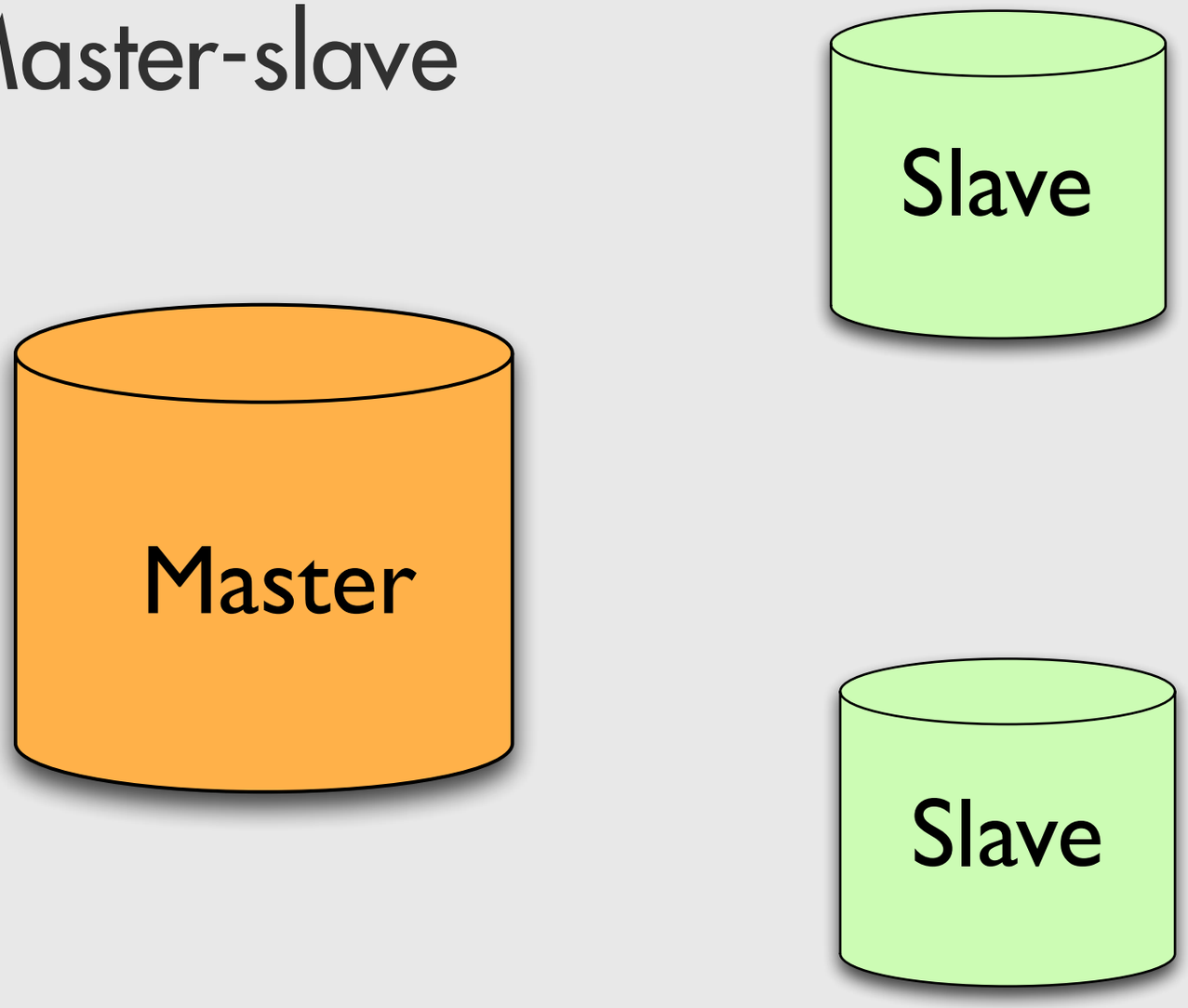

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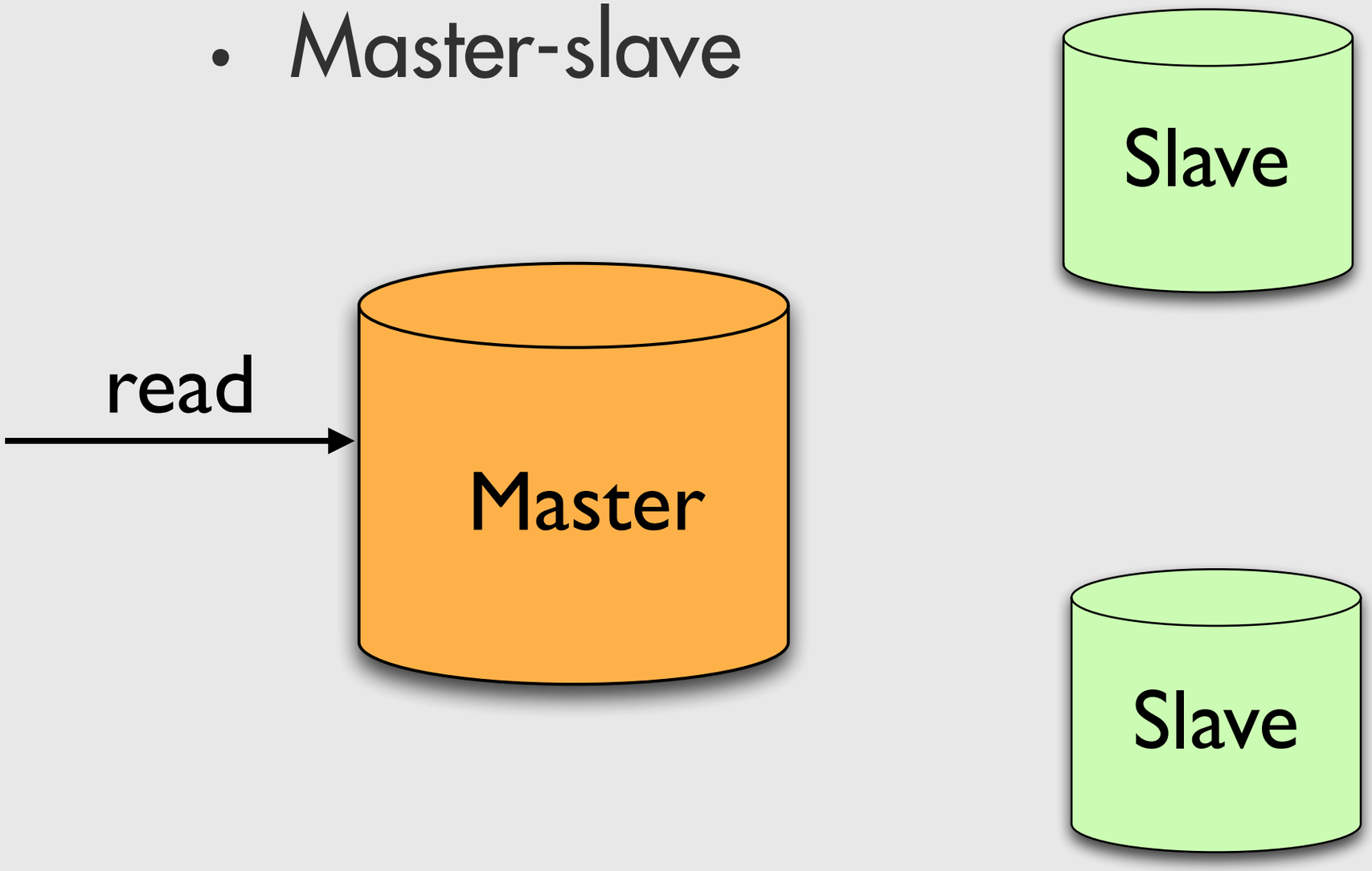

Typical Replication

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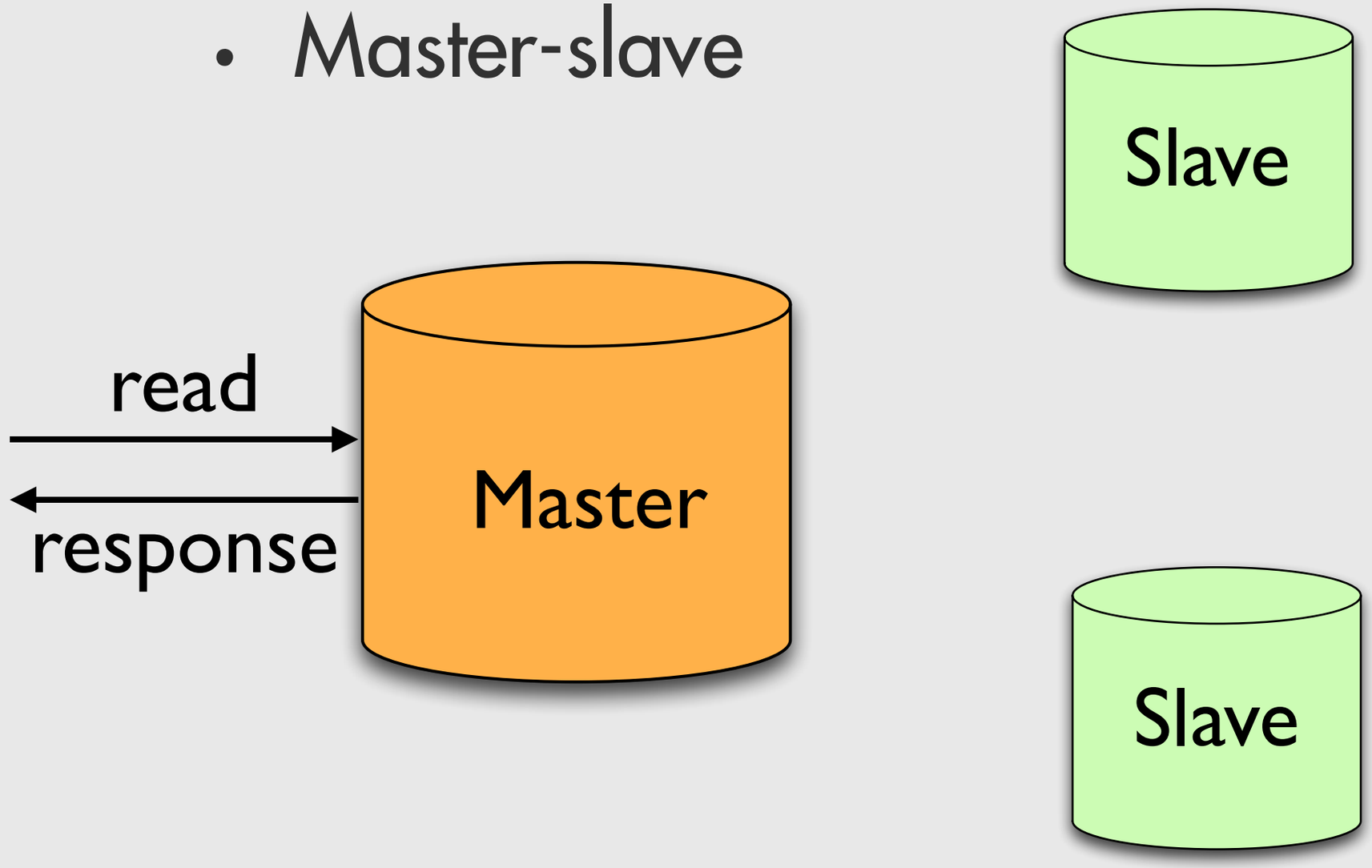

Data Placement

- Which servers get what data?
- How many copies of the data?

Data Placement

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Data Placement

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assign students to servers based on age:

Data Placement

- Which servers get what data?

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don't stress, this is just to show a taste of what's required...

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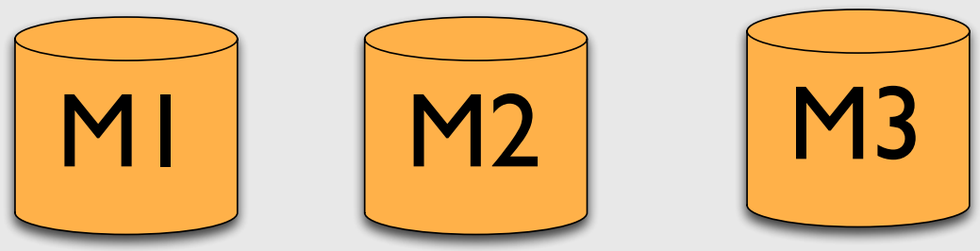

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assign students to servers based on age:

[1-33]

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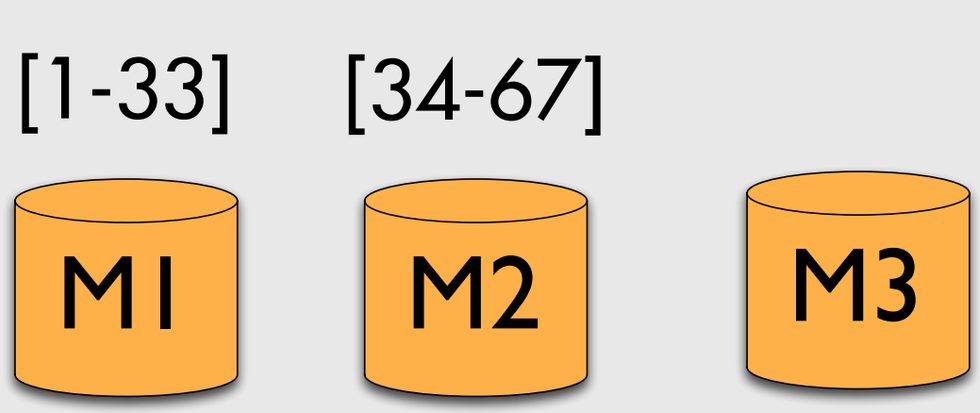

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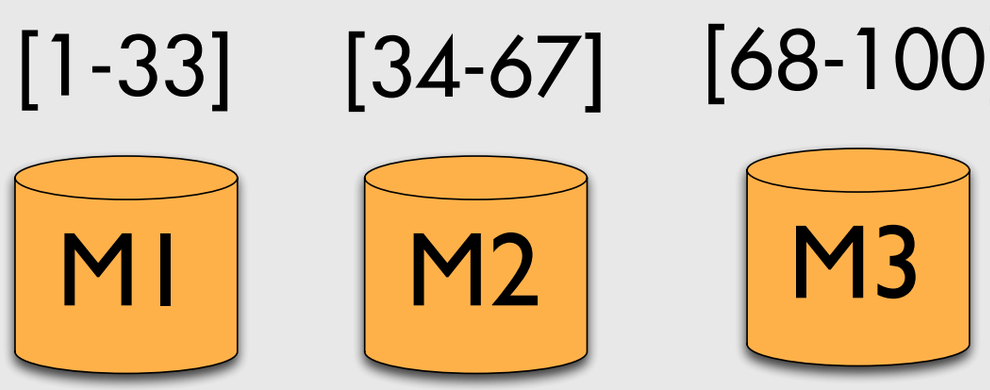

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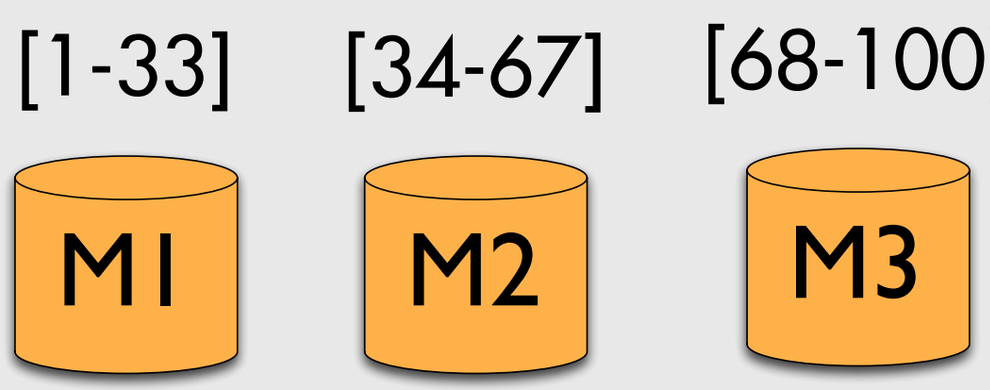

RANGE partitioning

Data Placement

- Which servers get what data?

assign students to servers based on age:

RANGE partitioning

server = hash(age) % 3

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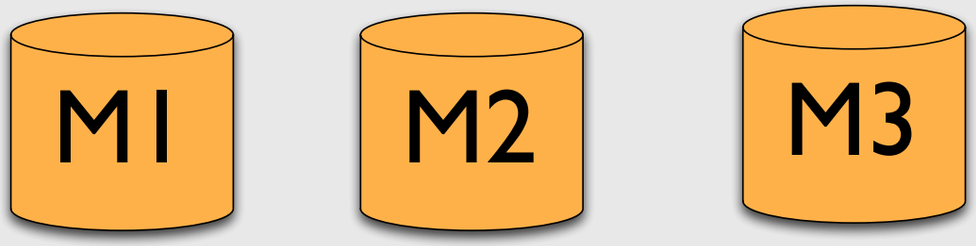

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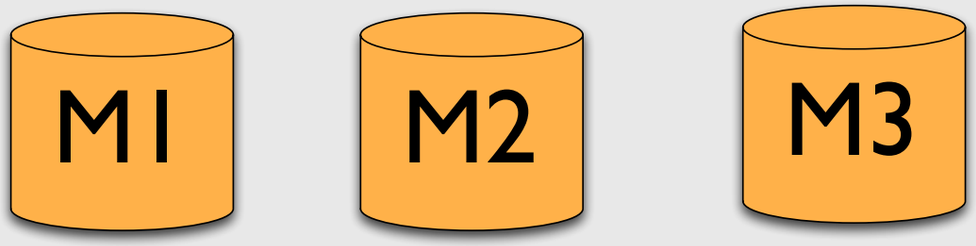

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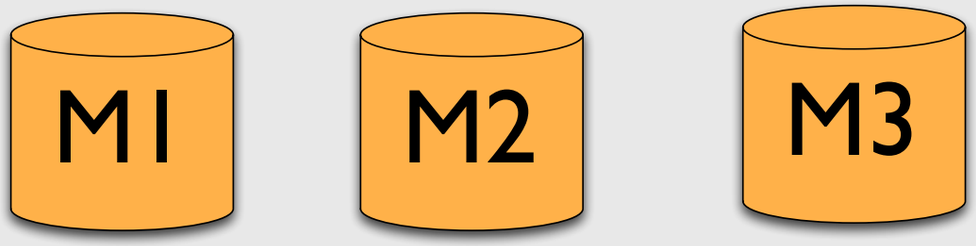

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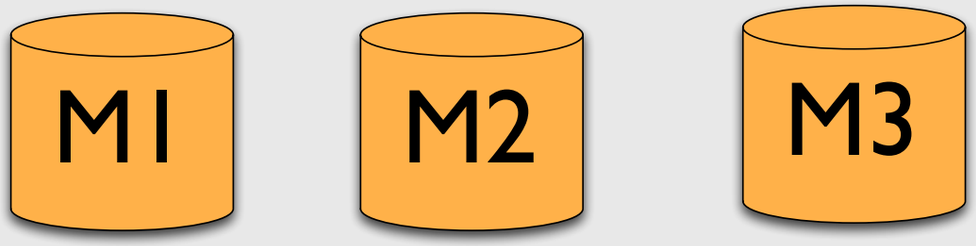

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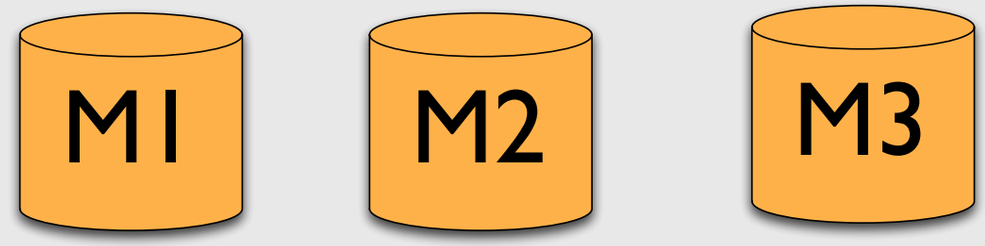

HASH partitioning

Data Placement

- Which servers get what data?
  - range vs. hash vs. ?

- How many copies of the data?
  - Durability: how many failures?
  - Capacity: how many requests?

Typical Replication

- 3-way
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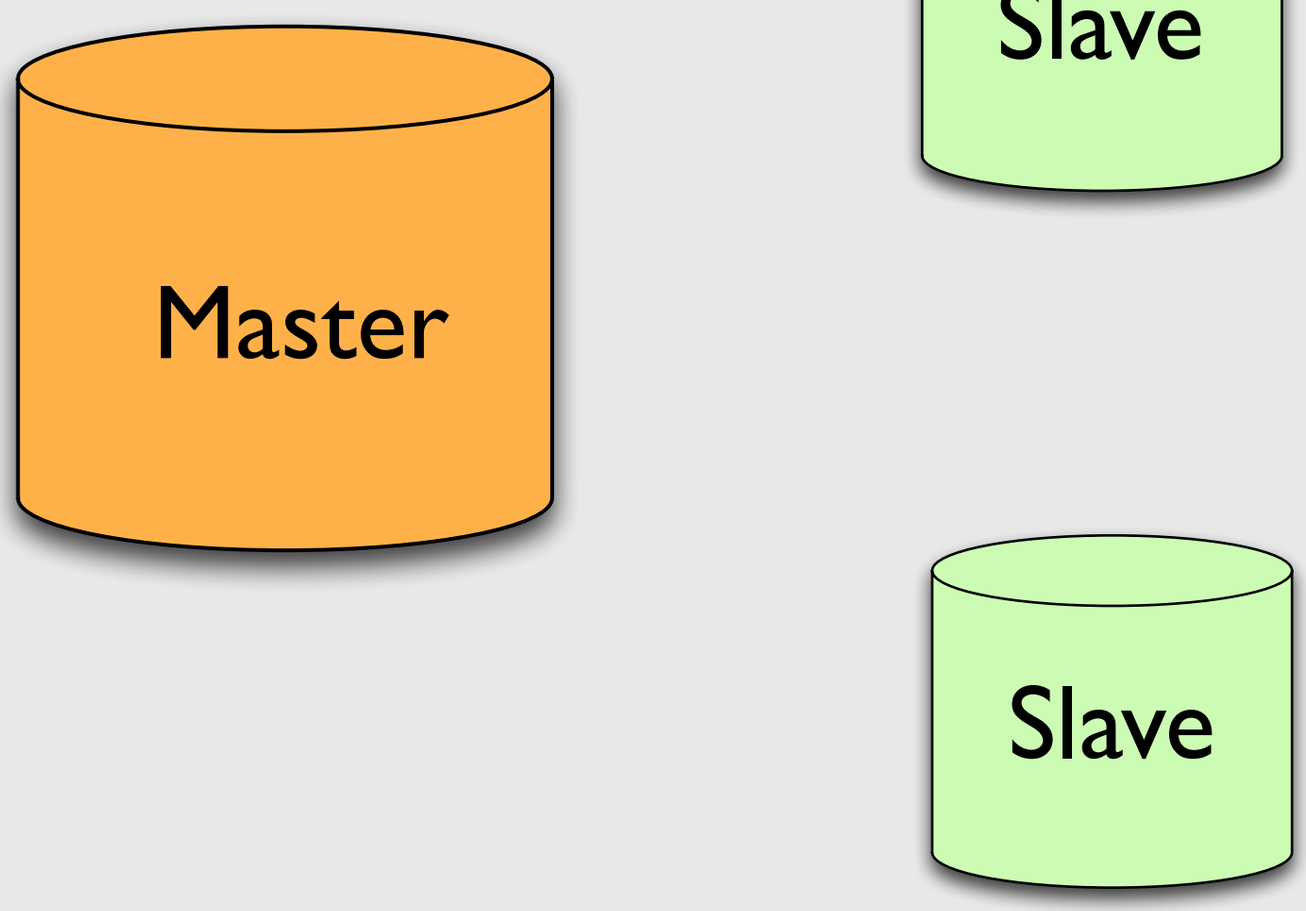

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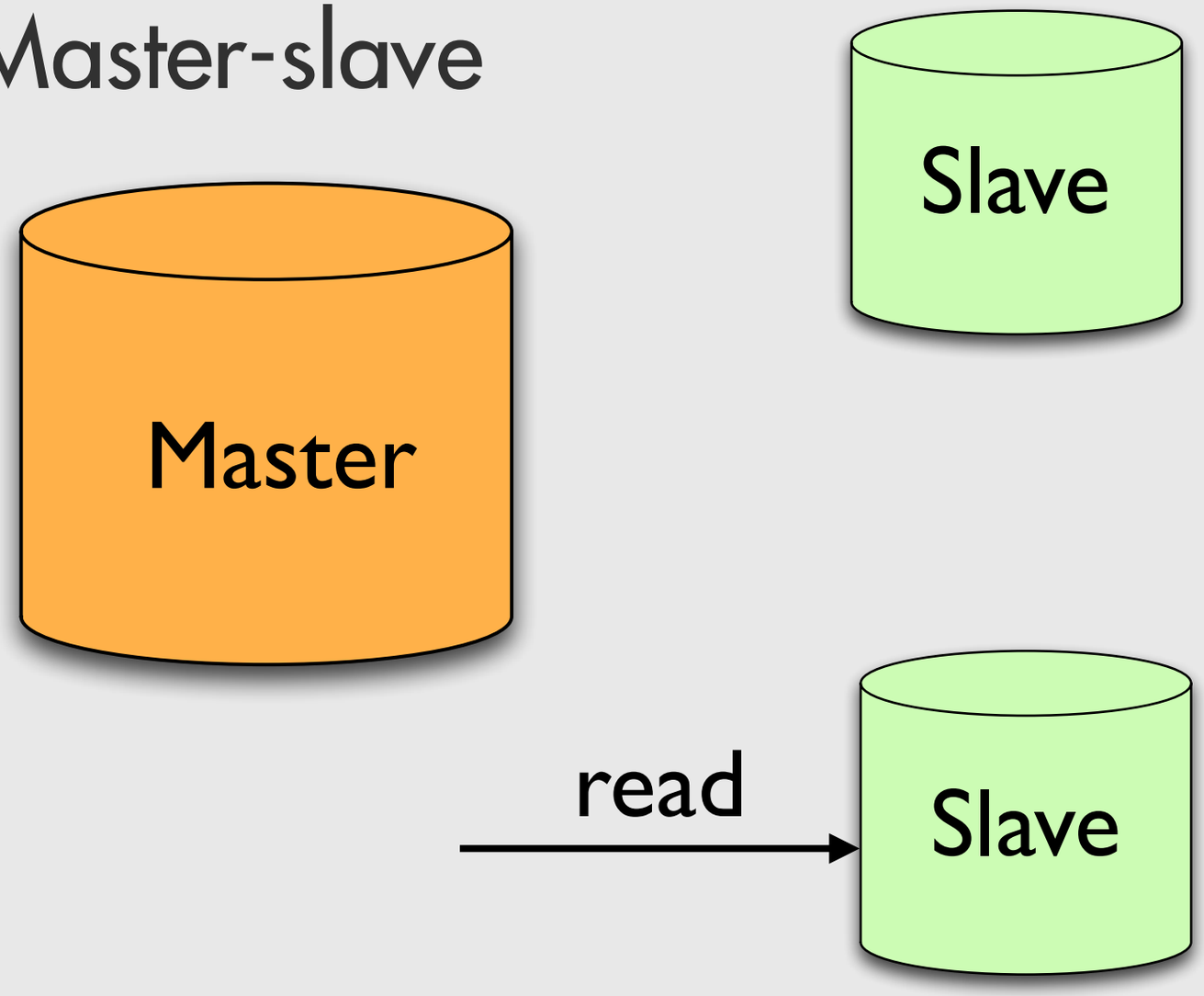

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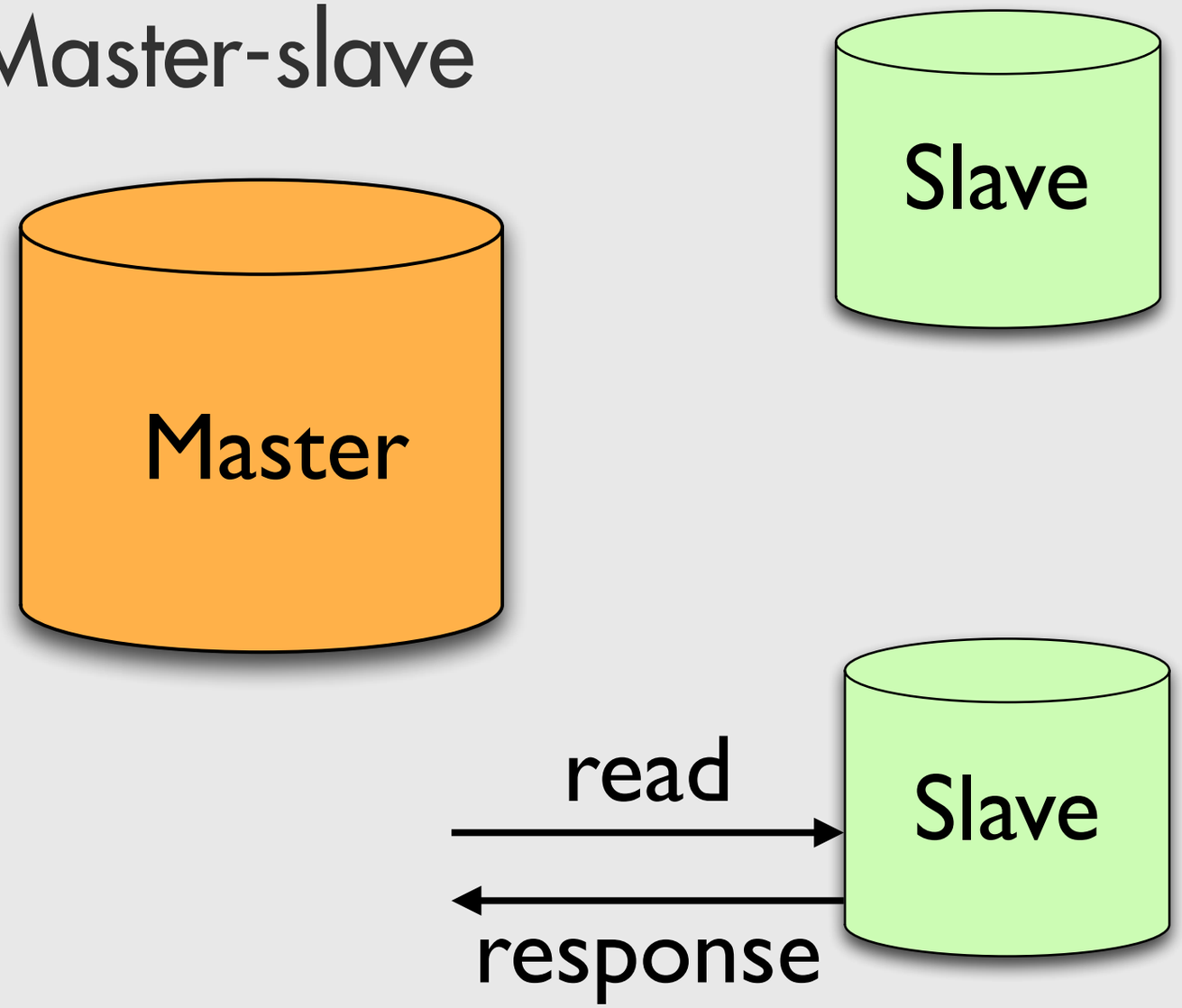

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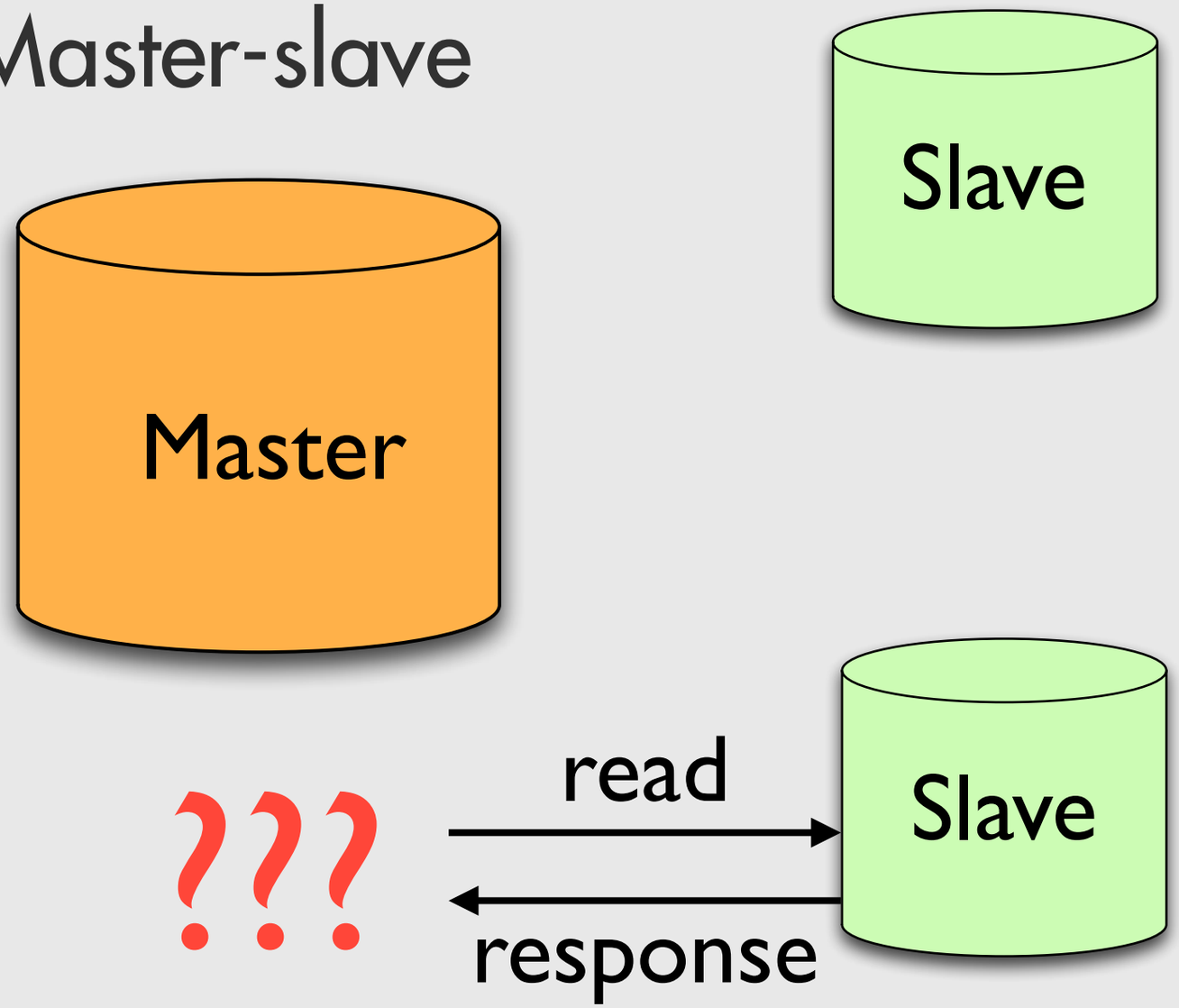

Consistency

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  - Very expensive if servers are located around the world!

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Compromise:
latency versus staleness
latency vs consistency
(CAP lecture)

Why data storage?
Classic Data Mgmt
IRL Data Mgmt
Break
Web Arch
Scaling
NoSQL

Database Usage

- Different storage systems are optimized for different tasks
  - Random access
  - Sequential access
- Different kinds of data
- Different load & query volume

What do we put in a DB?

- URL mappings?
- View counts?
- Email addresses?
- Pictures?
- Server logs?

What is NoSQL?

- "New" approach to data storage
- Simple but predictable data models
- Often have to build own features
- Designed for massive scale-out

When it comes to NoSQL, there's lots of hype and some merit
A reasonable, short answer to "What is NoSQL": http://stackoverflow.com/a/1164798
A longer answer: http://static.usenix.org/publications/login/2011-10/openpdfs/Burd.pdf

Key-Value Store

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```
put(key,value)
```

Key-Value Store

`put(key,value)`

`get(key)`

Key-Value Store

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PROs

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PROs

- Simple API
- Easy to understand perf
- Easy to scale, implement

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- Handle own schema management, complex features (e.g., WHERE)

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CONs

- Simple API
- Handle own schema management, complex features (e.g., WHERE)

e.g., Riak, Voldemort, Memcached

Document Store

```
{“long_url” : “http://
   news.google.com”,
 “short_url” : “http://
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no pre-defined schema,
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no pre-defined schema,
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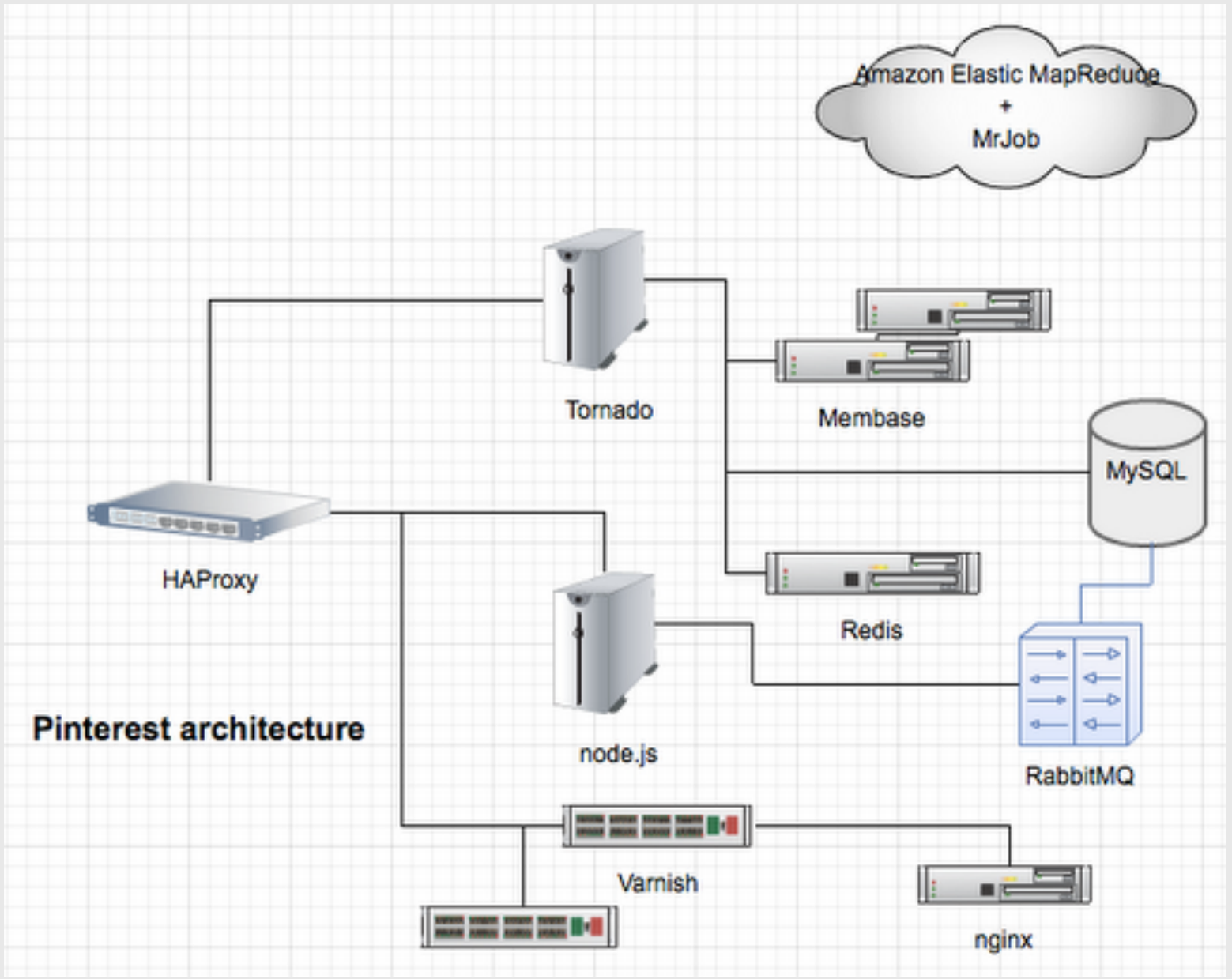
e.g., MongoDB, CouchDB, Cassandra, Redis,
Amazon DynamoDB

Blob Store

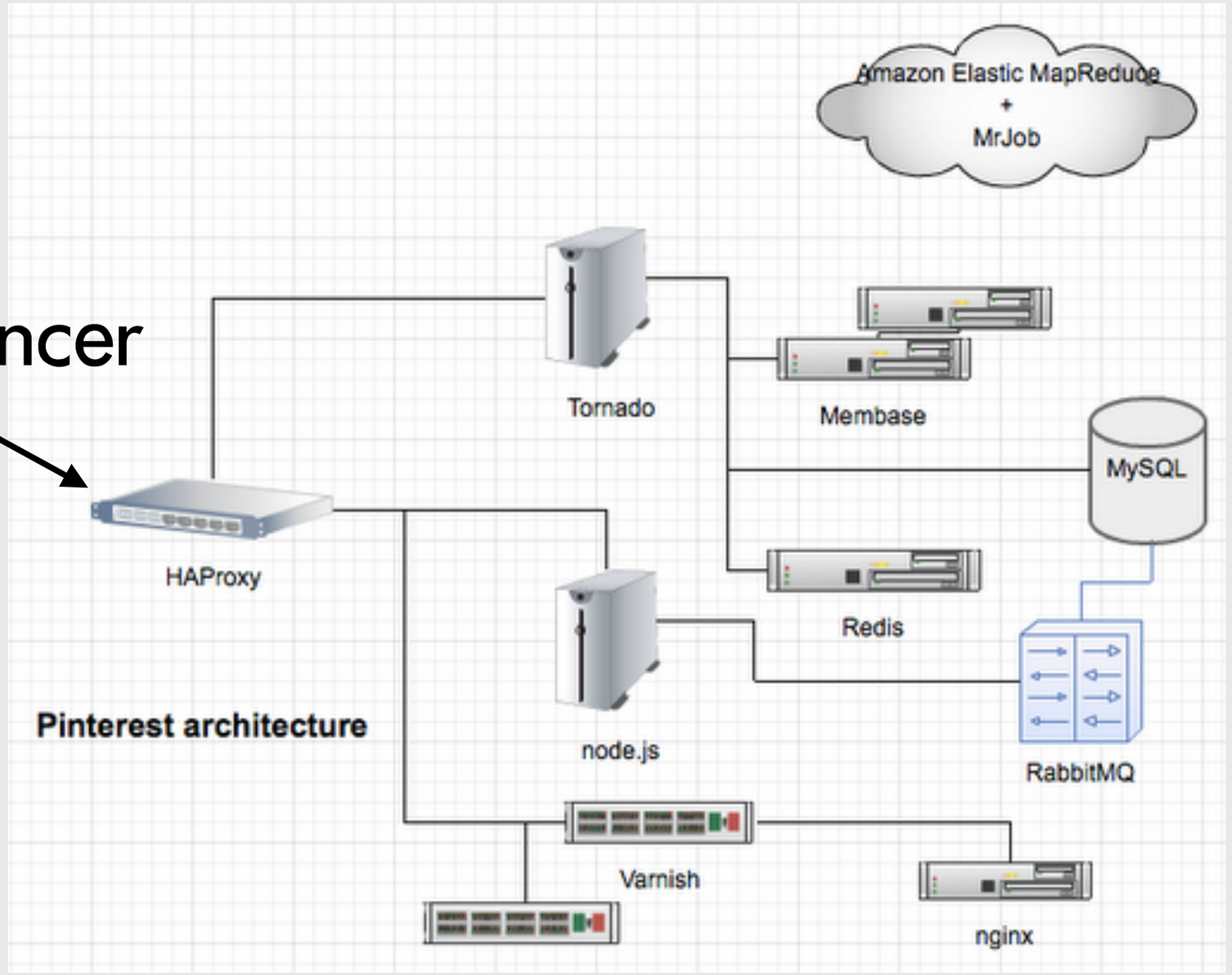
optimized for larger files

e.g., Hadoop File System,
Amazon S3 (Dropbox, Netflix),
Riak CS,
MS Azure Blob Storage



http://nosql.mypopescu.com/post/1765841584 7/polyglot-persistence-at-pinterest-redis-membase

load balancer



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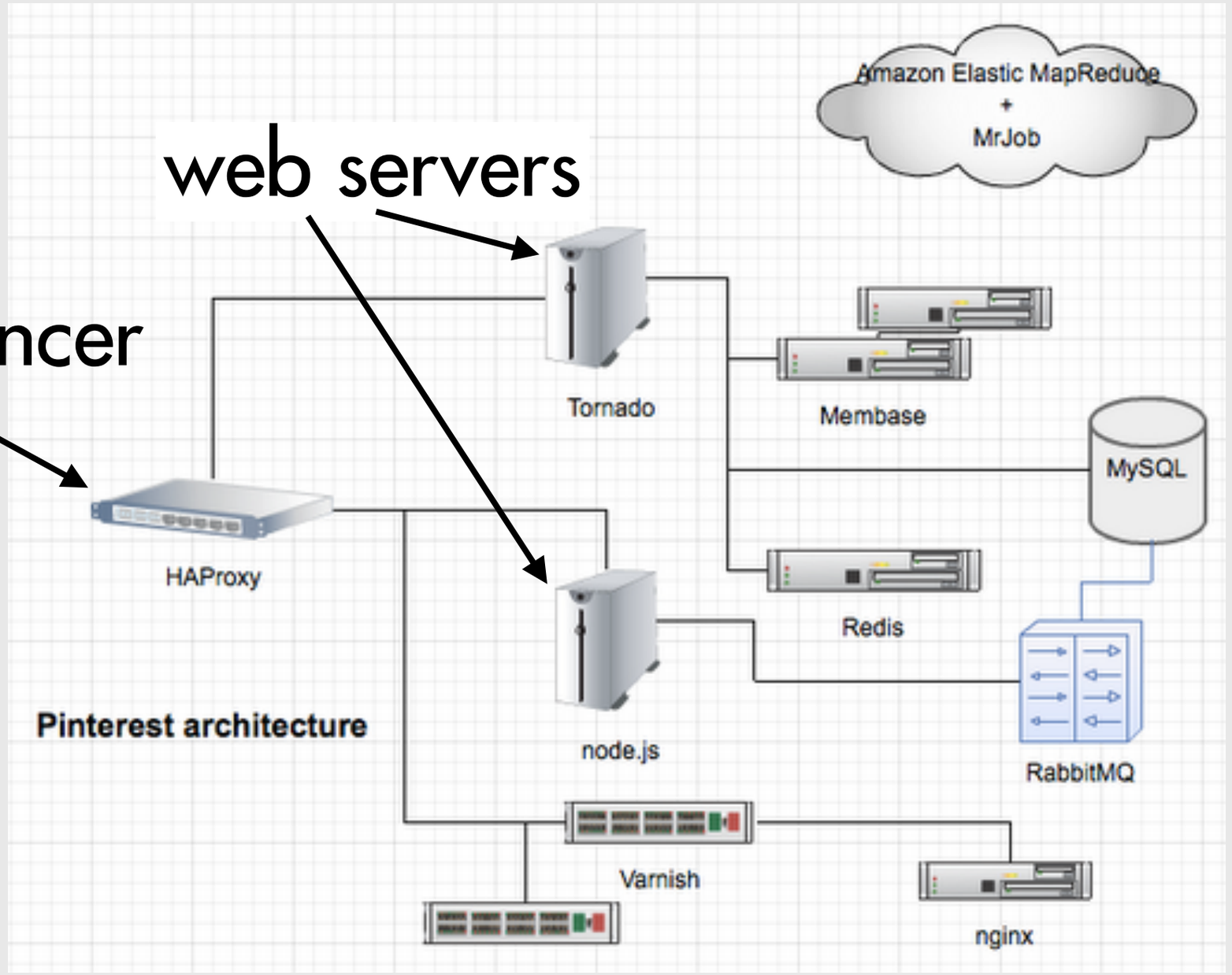
load balancer

web servers



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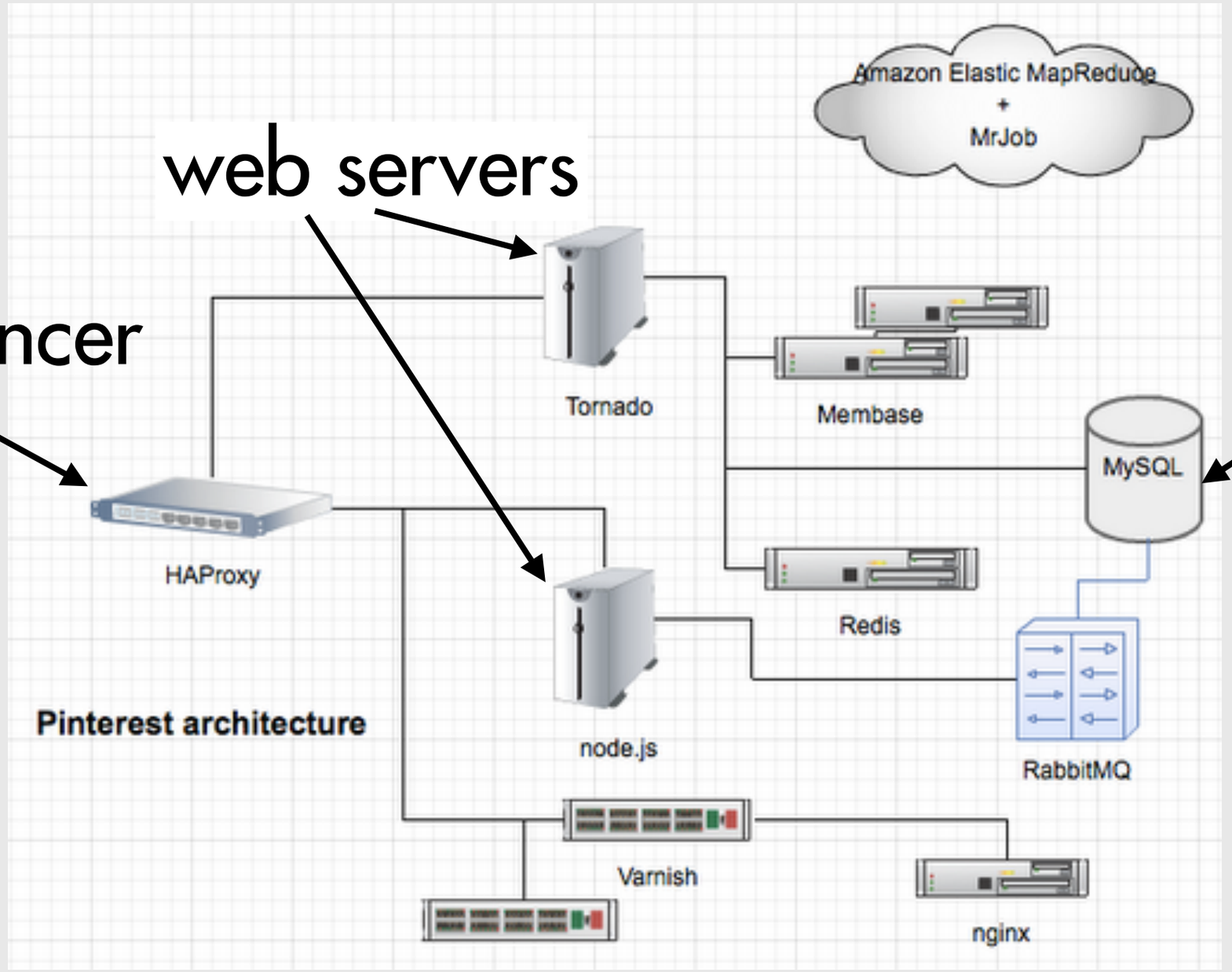
web servers

database



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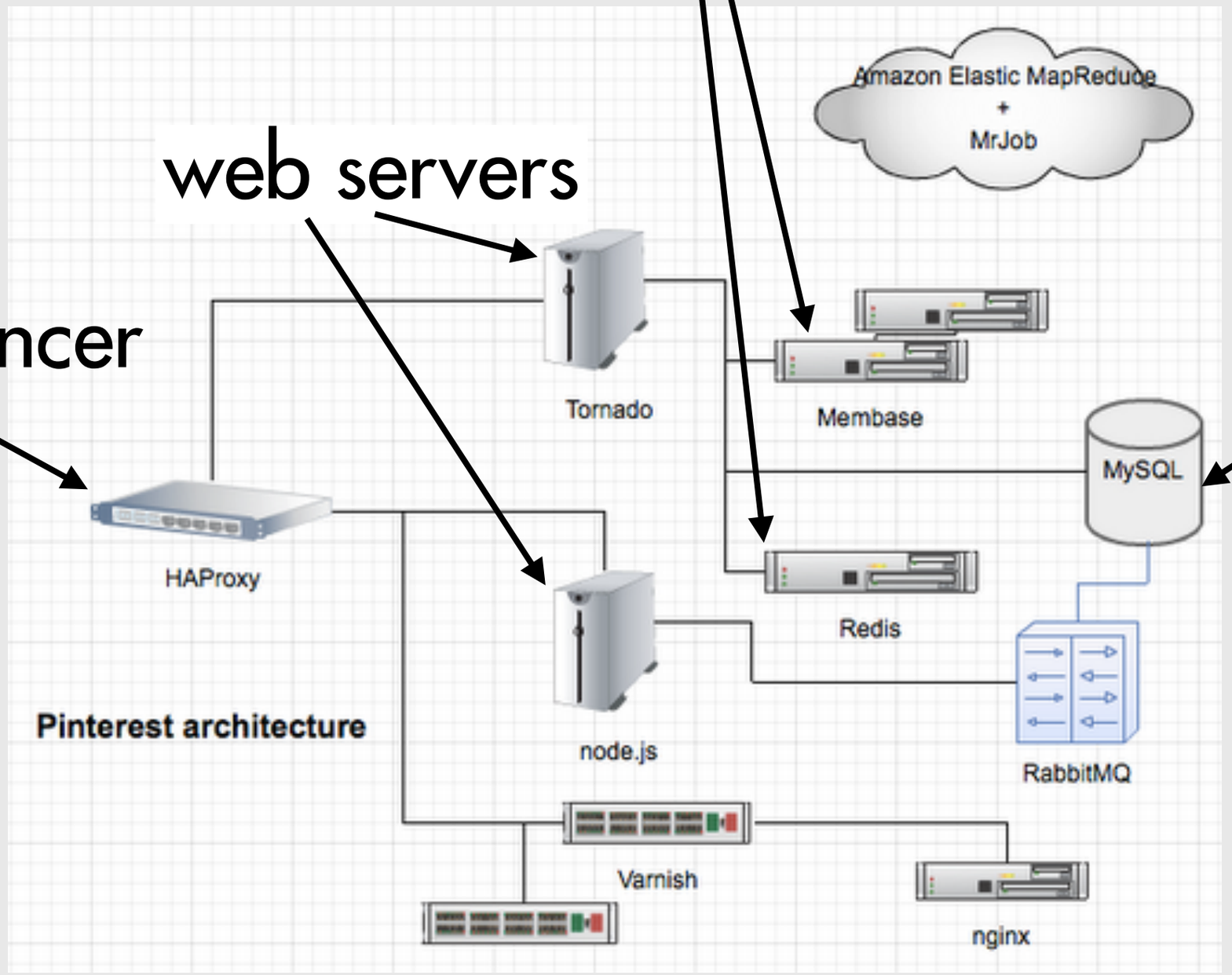
DB caches

web servers

load balancer

database



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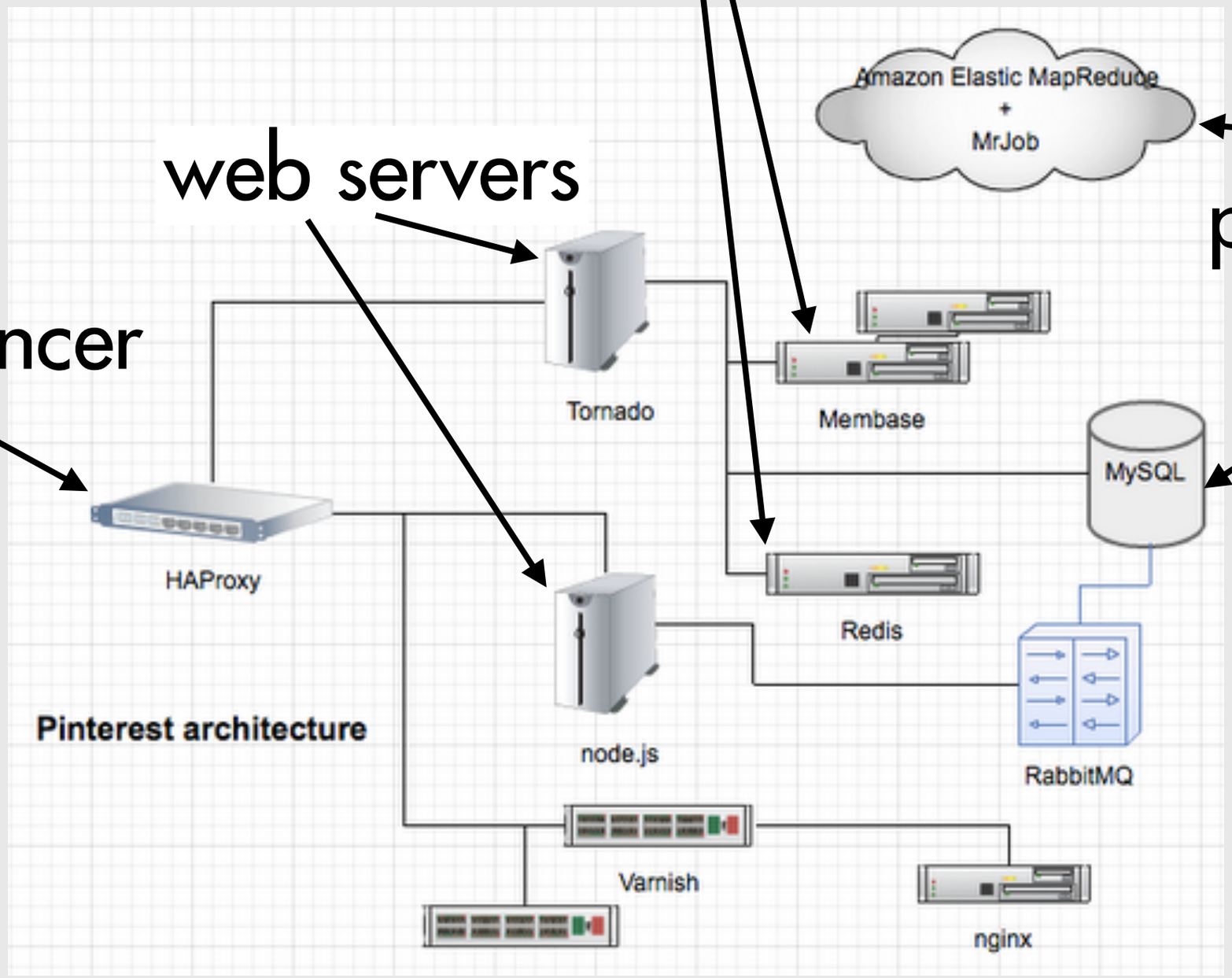

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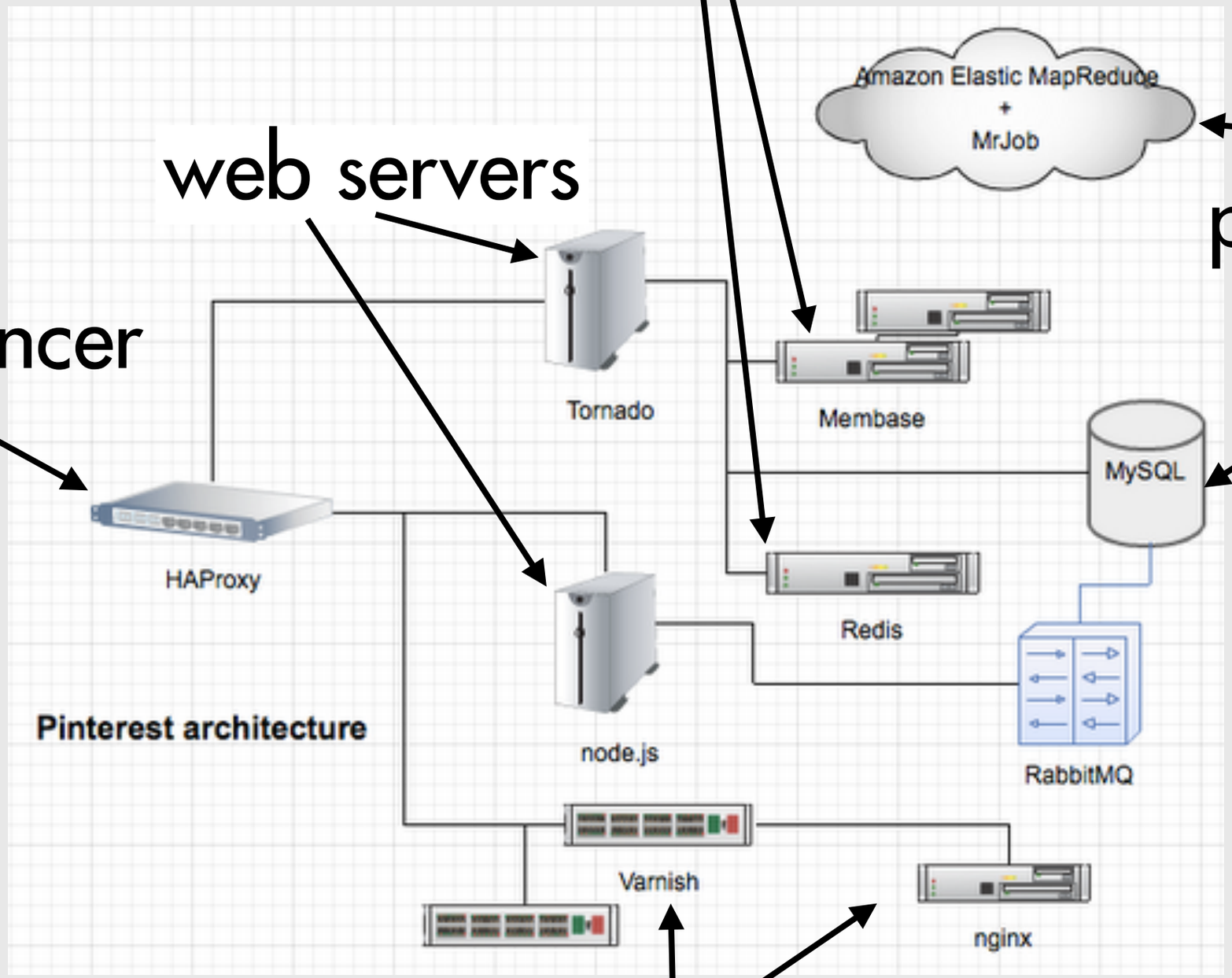

data processing

load balancer

database

HTTP caching

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Facebook

- MySQL
- Memcached
- HBase
- Custom blob store (Haystack)

well-documented, e.g.,
http://www.quora.com/Facebook-Engineering/What-is-Facebooks-architecture

What's a database, anyway?

Summary

- Databases designed to solve many common data storage problems
- Storage comes in many flavors; right choice is often specific to use case
- When in doubt, start simple!

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pbailis@cs.berkeley.edu