# CS 188

## Scalable Internet Services

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October 22, 2018

# Today's Agenda

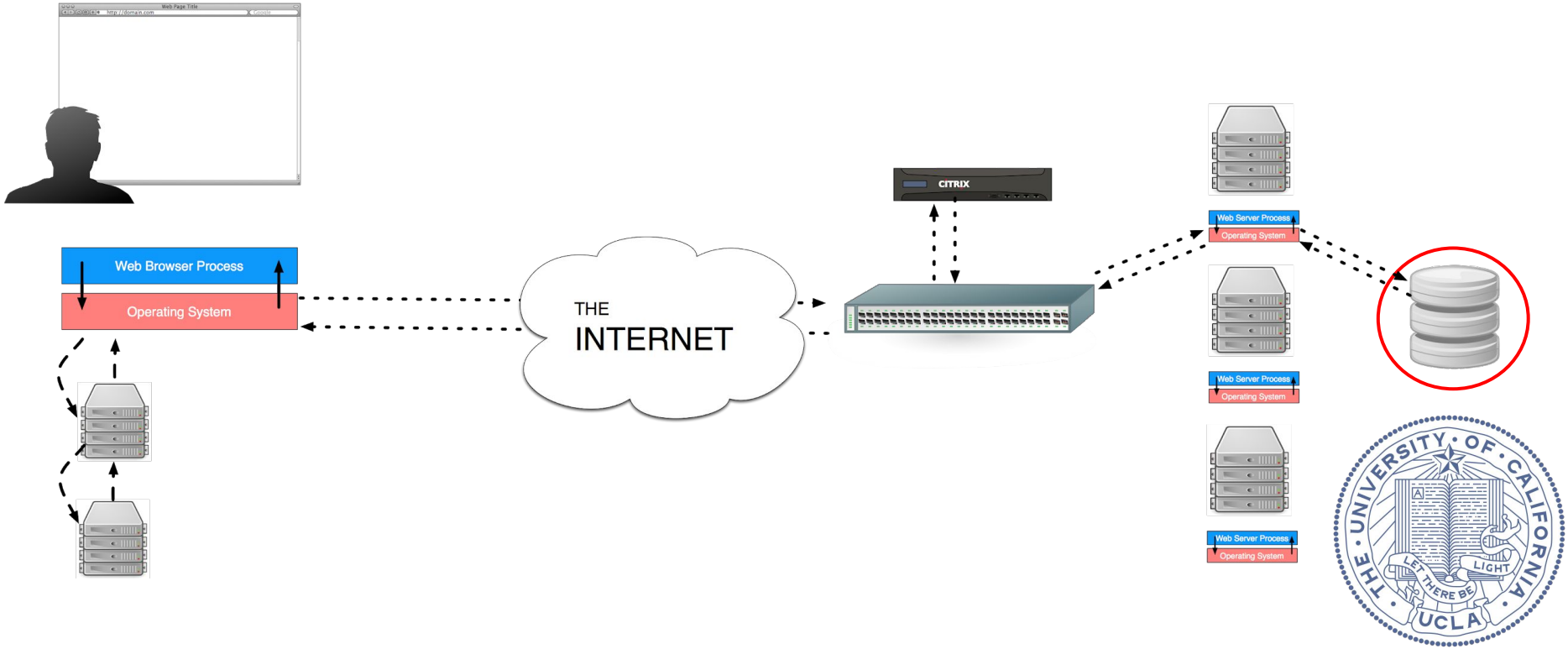
Motivation

A Stable Data Layer

Database Concurrency Control

Query Analysis

# Motivation


Web Browser Process
Operating System
THE
INTERNET
CITRIX
Web Server Process
Operating System
Web Server Process
Operating System
Web Server Process
Operating System
THE UNIVERSITY OF CALIFORNIA
LET THERE BE LIGHT
UCLA

# Motivation

After today you should…

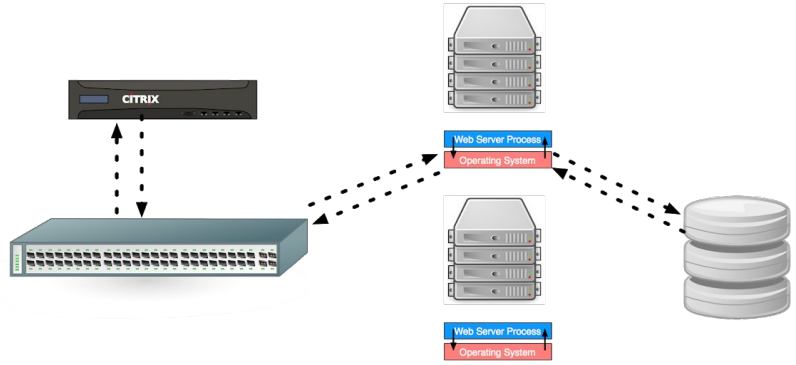
- Understand the importance of relational databases in architecting scalable internet systems.
- Understand how to design with concurrency in mind.
- Have a basic idea how to speed up your data layer
  - Where to start
  - Rails-specific techniques
  - Identify the source of slowness in a query

# Motivation

Prior to this lecture we haven't focused much on the data layer.

We've assumed many stateless application servers.

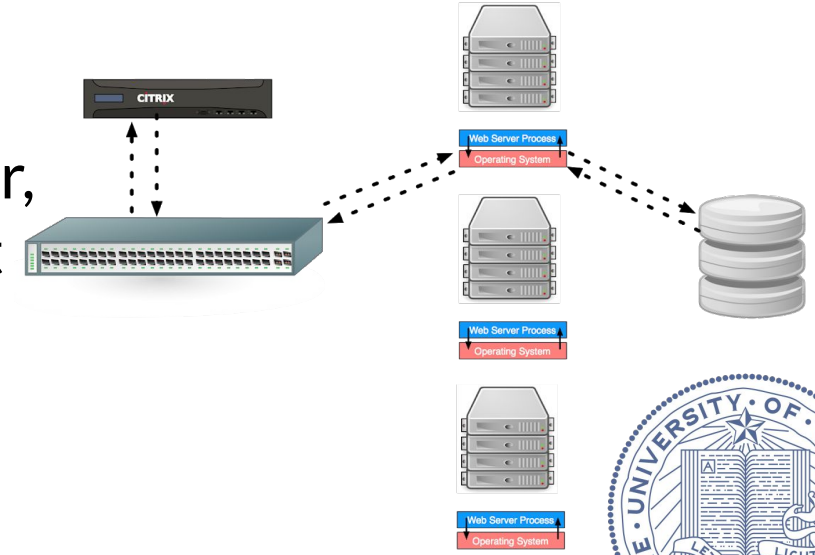
Why do we separate the concerns of managing state and running our application?



# Motivation

**Managing state is hard**: durable writes aren't easy.

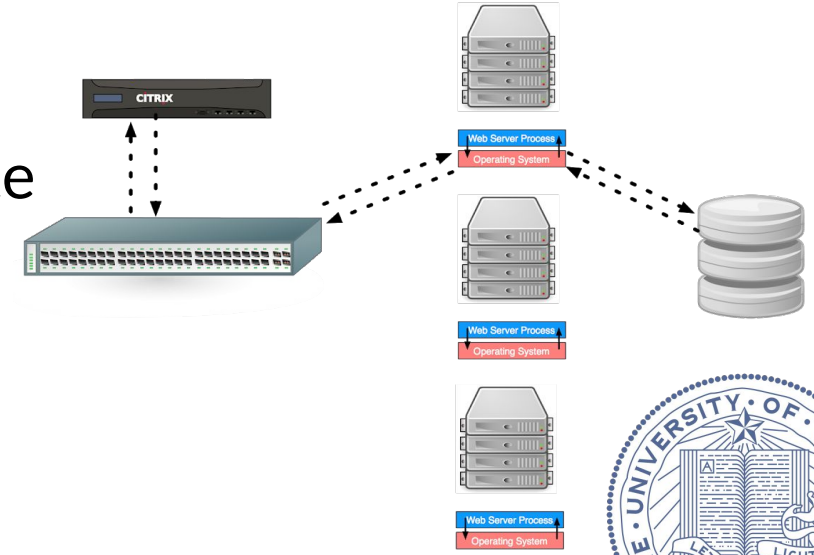
- If a request writes data and we return success to the user, we never want a subsequent machine failure to lose that data



# Motivation

**Managing state is hard**: requests are being handled concurrently.

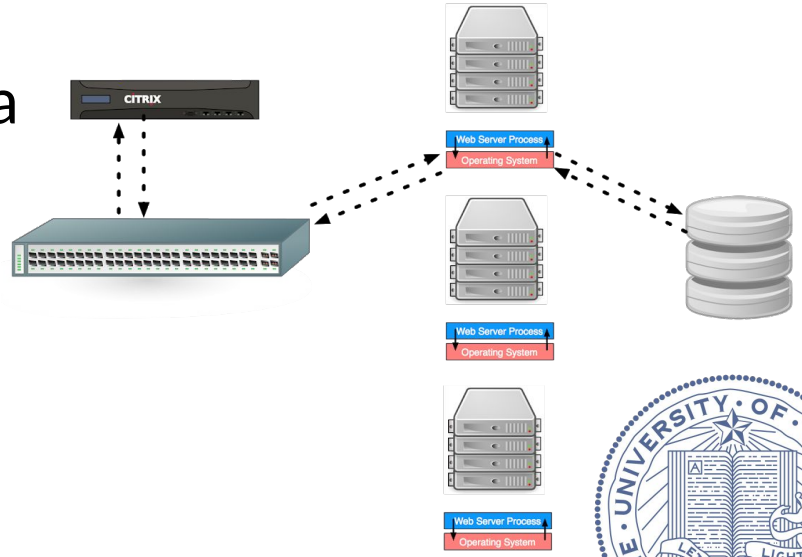
- If requests A and B want to read and write the same state at the same time, how do we handle this?



# Motivation

**Managing state is hard**: scaling stateful systems is not easy.

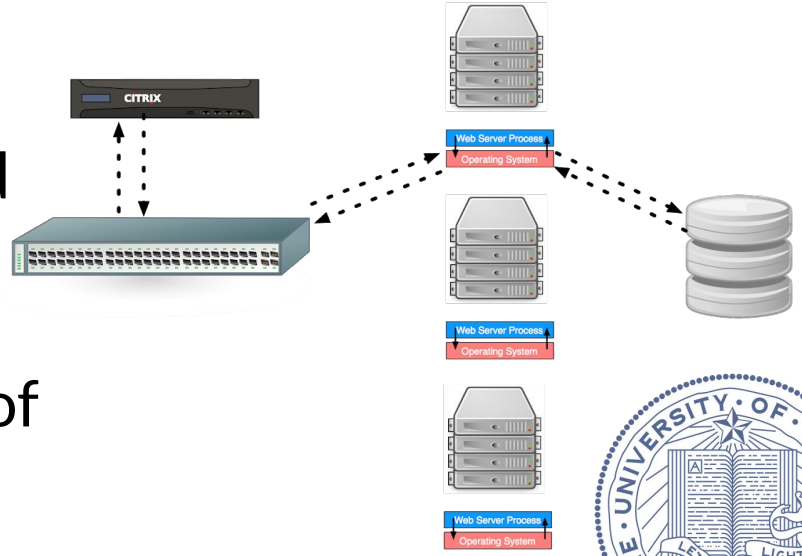
- If we don't break out our data layer from our application layer, we need to scale our data layer when we scale our application layer.
- Scaling stateless servers is much easier



# Motivation

**Managing state is hard**: we don't want developers to have to deal with this.

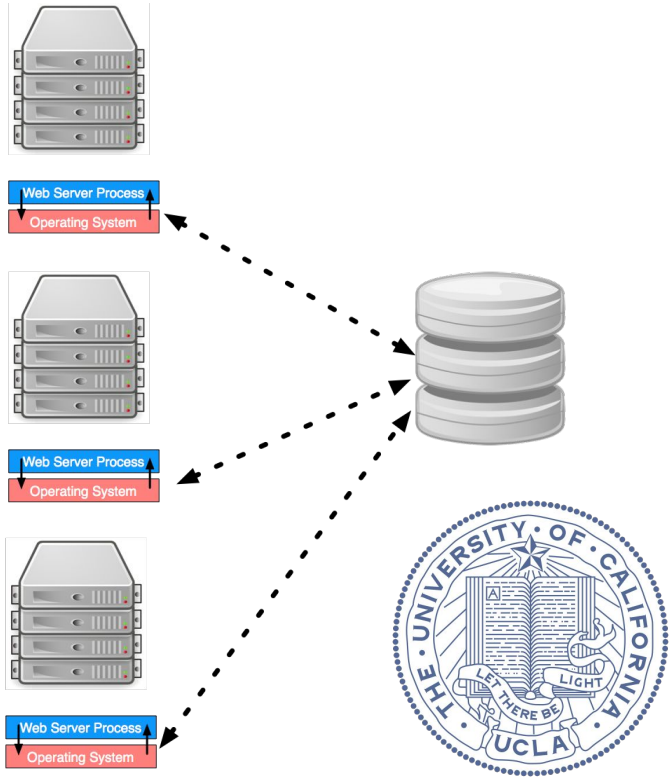
- Our business logic is updated regularly. We don't want to have to manage this complexity as a regular part of application development.



# Motivation

Thus, we separate our architecture into many stateless application servers responding to requests, and a database to store state.

- Separates scaling concerns of data layer
- Separates correctness concerns of data layer

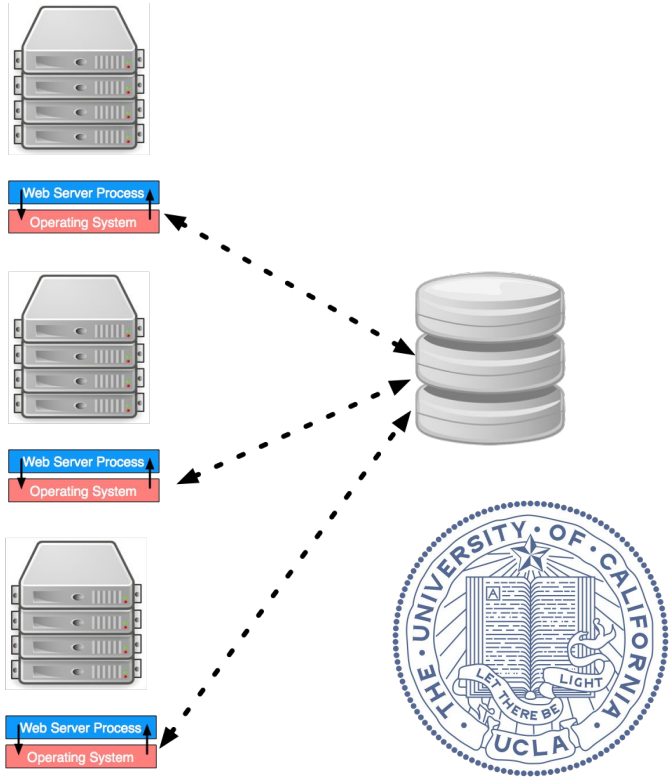


# A Stable Data Layer - Transactions

These application servers have needs

- Data needs to be seen by other requests/servers
- Access shouldn't be slow
- High Availability
- Data layer should make sense:

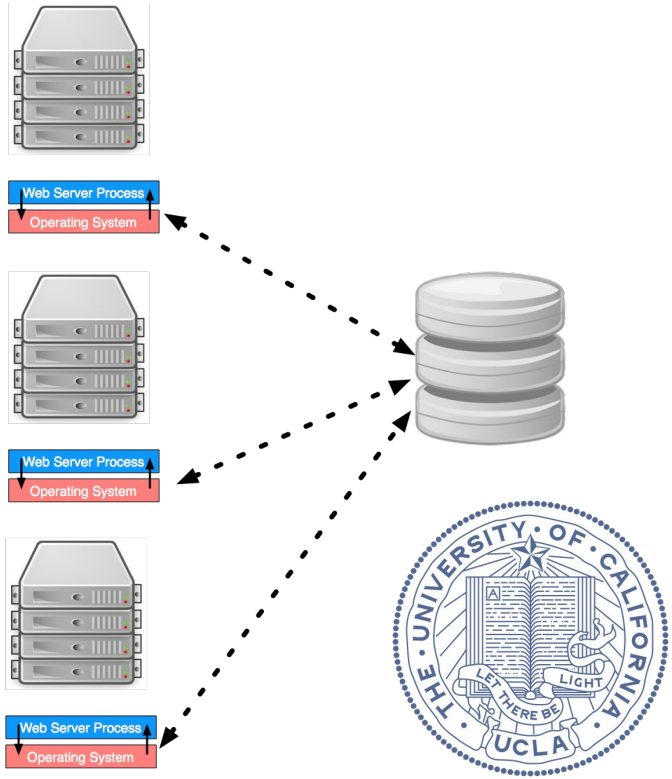
```
if david.balance > 100
  david.withdrawal(100)
  mary.deposit(100)
end
```



# Motivation

There are many options for a stable data layer.

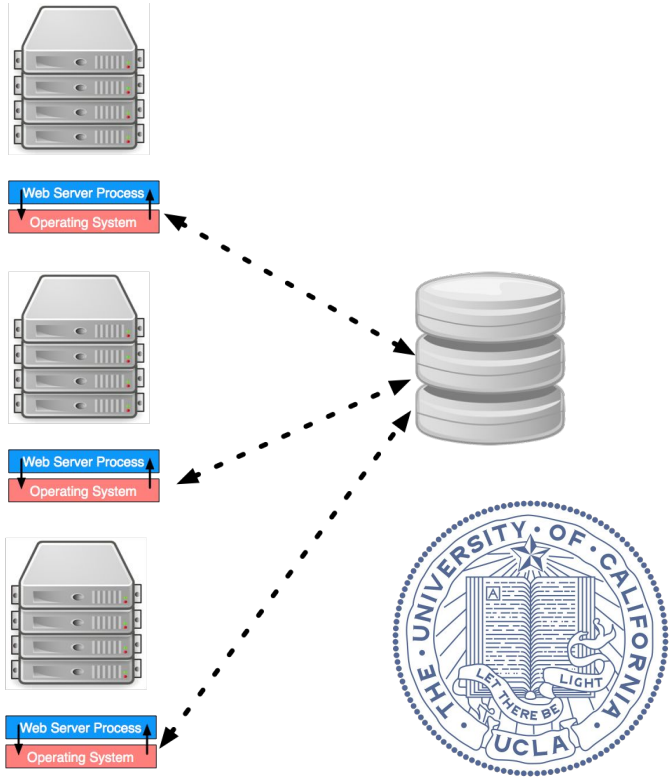
- Relational (SQL):
  - MySQL
  - Postgresql
  - Oracle
  - MS SQL
- Non-relational (NoSQL):
  - Cassandra
  - MongoDB
  - Redis



# Motivation

- Relational Databases...
  - Are a general-purpose persistence layer
  - Have more features
  - Limited ability to scale horizontally
- Non-relational Databases...
  - Tend to be more specialized
  - Require more from the application layer
  - Are better at scaling horizontally

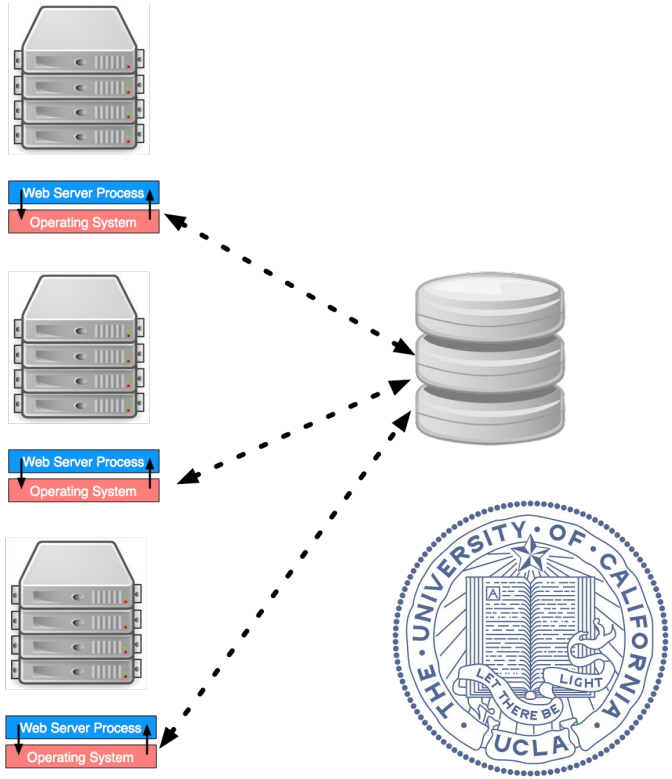
If your needs fit within a RDBMS ability to scale, they tend to be best. If your scaling needs exceed RDBMS, go non-relational.



# Motivation

How we will approach these topics:

- All about relational databases
- Concurrency control
- SQL query analysis
- Scaling options for relational databases:
  - Sharding
  - Service Oriented Architectures
  - Distinguishing Reads from Writes
- A survey of NoSQL options



# A Stable Data Layer

## Database Transactions

- Background
  - Concept that allows a system to guarantee certain semantic properties.  Gives control over concurrency.
  - Rigorously defined guarantees mean we can build correct systems on top of them.
  - T: R(X), R(Y), W(X), Commit

# A Stable Data Layer - Transactions

## ACID properties in a database:

- Atomicity
  - All or nothing.
  - No partial application of a transaction.

- Consistency
  - At the beginning and at the end of the transaction, the database should be consistent.
  - Consistency is defined by the integrity constraints
    - Foreign keys, NOT NULL, etc.

# A Stable Data Layer - Transactions

ACID properties in a database:

- Isolation
  - A transaction should not see the effects of other uncommitted transactions.

- Durability
  - Once committed, the transaction's effects should not disappear. (being overwritten by later transactions is fine)

# A Stable Data Layer - Transactions

## These have overlapping concerns

- Atomicity and Durability are related and are generally provided by journaling
- Consistency and Isolation are provided by concurrency control (usually implemented via locking)

## No help with side-effects

- Actions that are visible outside of the system
- Transfer money, communicate with web service, etc.

# A Stable Data Layer - Transactions

Schedule (or “history”):

- Abstract model used to describe execution of transactions running in the system.

| | | | |
|---|---|---|---|
| T1 | R(X), W(X), Com. | | |
| T2 | | R(Y), W(Y), Com. | |
| T3 | | | R(Z), W(Z), Com. |

# A Stable Data Layer - Transactions

Conflicting Actions:

- Two actions are said to be in conflict if
  - The actions belong to different transactions
  - At least one of the actions is a write operation
  - The actions access the same object (read or write)
- Example of conflicting actions:
  - `T1: R(X), T2: W(X), T3: W(X)`
- And these are not conflicting:
  - `T1: R(X), T2: R(X), T3: R(X)`
  - `T1: R(X), T2: W(Y), T3: R(X)`

**Conflict** => we can't blindly execute them in parallel.

# A Stable Data Layer - Transactions

Why can't we blindly execute them in parallel? Example:

| | | | |
|---|---|---|---|
| T1 | | R(X) | W(Y), Com. |
| T2 | W(X) | | Abort |

# A Stable Data Layer - Transactions

Why can't we blindly execute them in parallel? Example:

**Dirty Read Problem**

Transactions read a value written by a transaction that is later aborted and removed from the database. Reading transactions will have incorrect results.

| | | | |
|---|---|---|---|
| T1 | | R(X) | W(Y), Com. |
| T2 | W(X) | | Abort |

# A Stable Data Layer - Transactions

Why can't we blindly execute them in parallel? Example:

| | | | |
|---|---|---|---|
| T1 | R(All X), AVG | W(Y) | Com. |
| T2 | W(Some X), Com. | | |

# A Stable Data Layer - Transactions

Why can't we blindly execute them in parallel? Example:

**Incorrect Summary Problem**

1st transaction takes a summary over the values of all the instances of a repeated data item. While a 2nd transaction updates some instances of the data item. Resulting summary will not reflect a correct result for any deterministic order of the transactions. Result will be random depending on the timing of the updates.

| | | | |
|---|---|---|---|
| T1 | R(All X), AVG | W(Y) | Com. |
| T2 | W(Some X), Com. | | |

# A Stable Data Layer - Transactions

A schedule is **serial** if

- The transactions are executed non-interleaved

Two schedules are **conflict equivalent** if

- They involve the same actions of the same transactions
- Every pair of conflicting actions is ordered in the same way

Schedule S is **conflict serializable** if

- S is **conflict equivalent** to some serial schedule

A schedule is **recoverable** if

- Transactions commit only after all transactions whose changes they read, commit.

# A Stable Data Layer - Transactions

Example of a schedule that is not **conflict serializable**:

| | | | |
|---|---|---|---|
| T1 | R(A), W(A) | | R(B), W(B) |
| T2 | | R(A), W(A), R(B), W(B) | |

Because it is not **conflict equivalent** to this:

| | | |
|---|---|---|
| T1 | R(A), W(A), R(B), W(B) | |
| T2 | | R(A), W(A), R(B), W(B) |

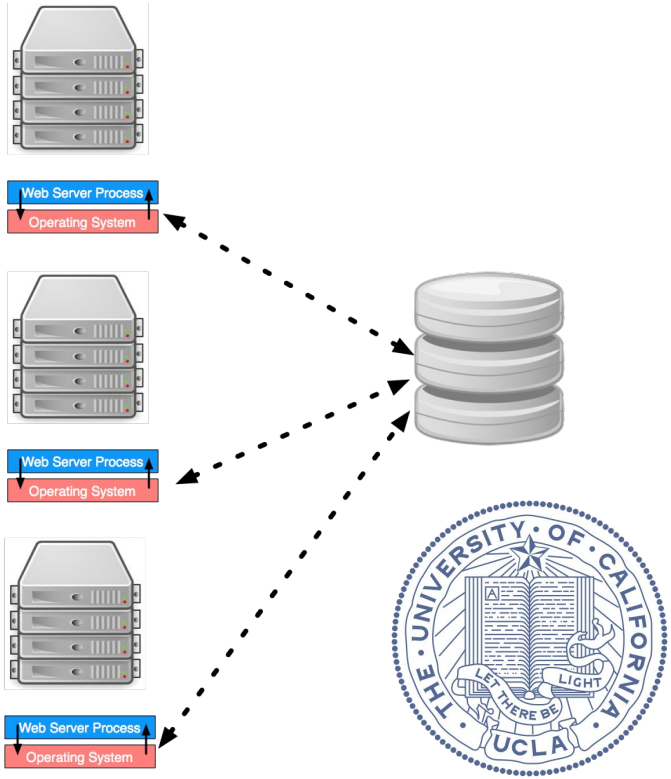
or this:

| | | |
|---|---|---|
| T1 | | R(A), W(A), R(B), W(B) |
| T2 | R(A), W(A), R(B), W(B) | |

# A Stable Data Layer - Transactions

Why is it important that we get a serializable schedule?

Why not just execute serially?



# A Stable Data Layer - Transactions

A serial schedule is important for consistent results - good when you are keeping track of your bank balance in the database

A serial execution of transactions is safe but slow

Most general purpose relational databases default to employing conflict-serializable and recoverable schedules

If you don't want to do a serial execution, what else can you do?

# A Stable Data Layer - Transactions

How do we implement a database with schedules that are conflict serializable and recoverable?

## Locks

- A lock is a system object associated with a shared resource such as a data item, a row, or a page in memory
- Prevent undesired, incorrect, or inconsistent operations on shared resources by concurrent transactions
- A database lock may need to be acquired by a transaction before accessing the object

# A Stable Data Layer - Transactions

Two types of database locks:

- Write-lock
  - Blocks writes and reads
  - Also called “exclusive lock”
- Read-lock
  - Blocks writes
  - Also called “shared lock”

# A Stable Data Layer - Transactions

## Two-Phase Locking

- 2PL is a concurrency control method that guarantees serializability
- Two-Phase Locking Protocol
  - Each Transaction must obtain a S (shared) lock on object before reading, and an X (exclusive) lock on object before writing
    - If a Transaction holds an X lock on an object, no other Transaction can get a lock (S or X) on that object
  - A transaction cannot request additional locks once it releases any locks
  - Two phases: acquire locks, release locks
- Issue: can result in “cascading aborts”

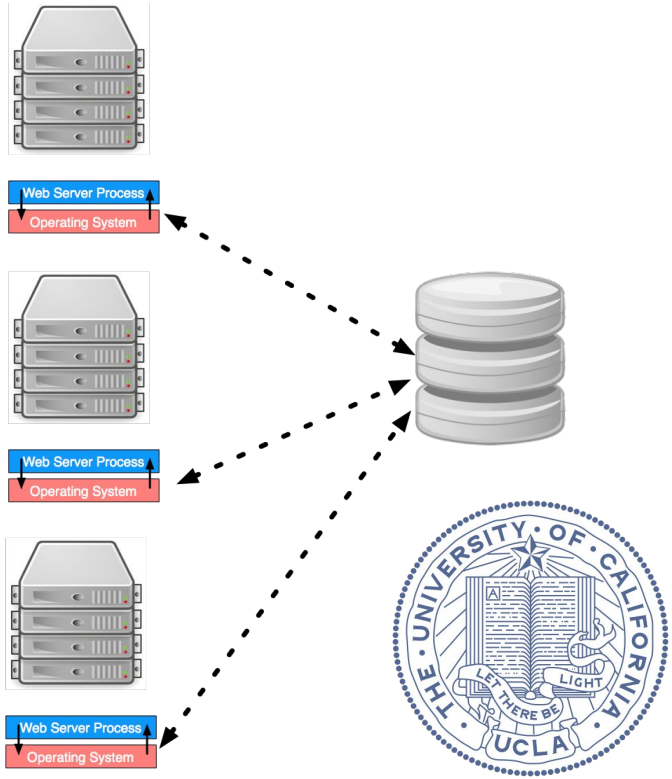
```
T1: R(A) W(A) unlock(A) ......... abort
T2:                          R(A) .......... abort
```

# Concurrency Control in Rails

We've got many application servers running our application.

We are using a relational database to ensure that each request sees a consistent view of the database.

What does this look like in practice?



# Concurrency Control in Rails

Rails uses two types of concurrency control:

- Optimistic
  - Let's not prevent concurrency problems, but instead detect them.  And blow up when we detect them.
- Pessimistic
  - Let's prevent concurrency problems before they start.

# Concurrency Control in Rails

## Optimistic locking in Rails

- Easy to setup: just add an integer `lock_version` column to the table in question.
- Whenever an ActiveRecord object is read from the database, the `lock_version` is remembered.
- When the programmer tries to persist this object back to the database, it compares the `lock_version` it saw with the current lock version.
  - If they are different, it throws a `StaleObjectException`
  - If they are the same, it writes to the database and increments the `lock_version`
- This locking is an application level construct, the database knows nothing about it

# Concurrency Control in Rails

Optimistic Locking Example:

```
p1 = Product.find(5)
p1.name = “Daipers”

p2 = Product.find(5)
p2.name = “Sheets”

p1.save!  # works fine
p2.save!  # throws StaleObjectException
```

# Concurrency Control in Rails

Optimistic locking

Strengths:

- Predictable performance
- Lightweight

Weaknesses:

- Sometimes your users will see errors
  - Or you will engineer re-tries

# Concurrency Control in Rails

## Pessimistic locking in Rails

- Easy to use: just add a `lock : true` option to ActiveRecord find.
- Whenever an ActiveRecord object is read from the database with that option, an exclusive lock is acquired.
- While this lock is held, others are prevented from acquiring the lock or reading/writing the value.
  - Others block until lock is released.
- This locking is database-level locking.
  - Implemented using `SELECT FOR UPDATE`

# Concurrency Control in Rails

Pessimistic locking example:

```
transaction do
  p1 = Product.find(5).lock(true)
  p1.name = “Daipers”

  p1.save!  # works fine
end
```

```
transaction do
  p2 = Product.find(5).lock(true)
  p2.name = “Sheets”

  p2.save!  # works fine
end
```

This works great, yet it’s not commonly used.

- **What could go wrong?**

# Concurrency Control in Rails

## What could possibly go wrong?

```
transaction do

  p1 = Product.find(5).lock(true)
  p1.name = “Daipers”
  …
  my_long_procedure()
  …
  p1.save!

end
```

```
transaction do


  p1 = Product.find(5).lock(true)
  p1.name = “Daipers”
  p1.save!

end
```

# Concurrency Control in Rails

## What could possibly go wrong?

```
transaction do
  o1 = Order.find(7).lock(true)
  ...
  p1 = Product.find(5).lock(true)
  p1.name = “Daipers”
  p1.save!
  …
  o1.amount = 4
  o1.save!
end
```

```
transaction do
  p1 = Product.find(5).lock(true)
  p1.name = “Daipers”
  p1.save!
  ...
  o1 = Order.find(7).lock(true)
  …
  o1.amount = 4
  o1.save!
end
```

# Concurrency Control in Rails

Pessimistic locking

Strengths:

- Failed transactions are more rare

Weaknesses:

- Need to deal with deadlocks
- Performance is less predictable

# Concurrency Control in Rails

**Which mode would you choose?**

```
transaction do
  determine_auction_winner()
  send_email_to_winner()
  save_auction_outcome()  # db write
end
```

# Concurrency Control in Rails

**Which mode would you choose?**

```
transaction do
  record_facebook_like()
  update_global_counter_of_all_likes_ever() # db write
end
```

# Query Analysis

Ok, so you've hooked up MySQL to your Rails app and it's slower than you'd like.

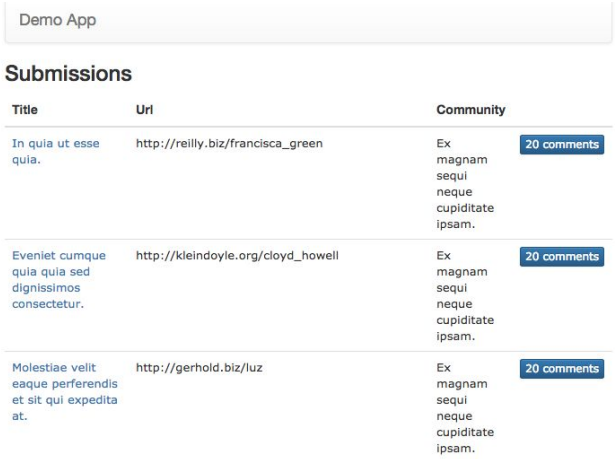
You think it might be the database.  How do we find out?

# Query Analysis

Let's use an example from the Demo app!

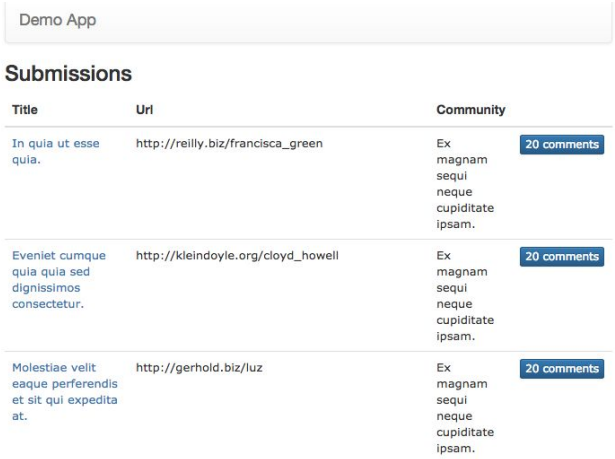
By changing the way you interact with the Rails ORM (ActiveRecord), you can significantly improve performance.

Example from the Demo app.  You can see these in the "`database_optimizations`" branch on github.




# Query Analysis

I deployed this on a m3.medium instance and requested “/”.




There were:

- 20 Communities
- 400 Submissions
- 8000 Comments

**`Completed 200 OK`**

**`ActiveRecord: 220.6ms.`**

- Why so slow?

# Query Analysis

First step: find out what Rails is doing.

In development mode, Rails will put the SQL it's generating in the log.

To (temporarily) enable this in production, change:

```
config.log_level = :debug
```

in `config/environments/production.rb`

# Query Analysis

```
class SubmissionsController < ApplicationController
  def index
    @submissions = Submission.all
  end
end
```

```
<h3>Submissions</h3>
<table class="table">
 <thead><tr><th>Title</th><th>Url</th><th>Community</th><th colspan="3"></th></tr></thead>
 <tbody>
   <% @submissions.each do |submission| %>
     <tr>
       <td><%= link_to(submission.title, submission.url) %></td>
       <td><%= submission.url %></td>
       <td><%= submission.community.name %></td>
       <td><%= link_to "#{submission.comments.size} comments", submission, class: 'btn btn-primary btn-xs'%></td>
     </tr>
   <% end %>
 </tbody>
</table>
```

# Query Analysis

```
Processing by SubmissionsController#index as HTML
Submission Load (0.5ms)  SELECT `submissions`.* FROM `submissions`
Community Load (0.3ms)  SELECT  `communities`.* FROM `communities` WHERE `communities`.`id` = 1 LIMIT 1
SELECT COUNT(*) FROM `comments` WHERE `comments`.`submission_id` = 1
SELECT  `communities`.* FROM `communities` WHERE `communities`.`id` = 1 LIMIT 1  [["id", 1]]
SELECT COUNT(*) FROM `comments` WHERE `comments`.`submission_id` = 2
SELECT  `communities`.* FROM `communities` WHERE `communities`.`id` = 1 LIMIT 1  [["id", 1]]
SELECT COUNT(*) FROM `comments` WHERE `comments`.`submission_id` = 3
SELECT  `communities`.* FROM `communities` WHERE `communities`.`id` = 1 LIMIT 1  [["id", 1]]
....
SELECT  `communities`.* FROM `communities` WHERE `communities`.`id` = 20 LIMIT 1  [["id", 20]]
SELECT COUNT(*) FROM `comments` WHERE `comments`.`submission_id` = 400
```

# Query Analysis

Because we are issuing so many queries, the overhead associated with each SQL statement is expensive.

**How should we fix this?**

# Query Analysis

Because we are issuing so many queries, the overhead associated with each SQL statement is expensive.

**How should we fix this?**

**Issue fewer queries.**

- Don’t ask for  the community each time (esp. repeats)
- Don’t ask for the number of comments each time.

# Query Analysis

## Change from this:

```
class SubmissionsController < ApplicationController
  def index
    @submissions = Submission.all
  end
end
```

## To this:

```
class SubmissionsController < ApplicationController
  def index
    @submissions = Submission.includes(:comments).includes(:community).all
  end
end
```

# Query Analysis

**Result: ActiveRecord 39.6ms**

```
Submission Load (0.9ms)  SELECT `submissions`.* FROM `submissions`

Comment Load (38.3ms)  SELECT `comments`.* FROM `comments` WHERE `comments`.`submission_id` IN (1, 2,...
399, 400)

Community Load (0.4ms)  SELECT `communities`.* FROM `communities` WHERE `communities`.`id` IN (1, 2, ...19,
20)
```

# Query Analysis

With MySQL you can use EXPLAIN to analyze queries

- Won't actually execute the query.
- Helps us understand how and when MySQL will use indices.
- Returns a table of data from which you identify potential improvements

# Query Analysis

```
mysql> EXPLAIN SELECT COUNT(DISTINCT `submissions`.`id`) FROM
`submissions`  JOIN `comments` WHERE `comments`.`submission_id` =
`submissions`.`id` AND `comments`.`message` = 'This is not a
test!'\G
*************************** 1. row ***************************
           id: 1
  select_type: SIMPLE
        table: comments
         type: ALL
possible_keys: NULL
          key: NULL
      key_len: NULL
          ref: NULL
         rows: 19188
        Extra: Using where
*************************** 2. row ***************************
           id: 1
  select_type: SIMPLE
        table: submissions
         type: eq_ref
possible_keys: PRIMARY
          key: PRIMARY
      key_len: 4
          ref: default_db_name.comments.submission_id
         rows: 1
        Extra: Using index
2 rows in set (0.00 sec)
```

# Query Analysis

How to read EXPLAIN output:

These results are the most important for performance analysis

| | |
|---|---|
| `select_type` | The SELECT type |
| `type` | The join type |
| `possible_keys` | The indices available to be chosen |
| `key` | The index actually chosen |
| `rows` | Estimate of rows to be examined |

# Query Analysis

`select_type`

The type of select statement being performed.

- Most are fine, but two indicate potential performance problems
  - Dependent Subquery: reevaluated for every different value of the outer query
  - Uncacheable Subquery: reevaluated for every value of the outer query

# Query Analysis

`type`

The type of JOIN being used.  From best to worst:

- system - The table only has one row
- const - From uniqueness, we know only one row can match
- eq_ref, ref - Only one row at most can match from the previous table
- fulltext - mysql fulltext index
- ref_or_null - like ref, but also null values
- index_merge
- unique_subquery
- index_subquery
- range - Only rows in a given range are retrieved, but can use index
- index - Full table scan, but can scan index instead of actual table
- ALL - Full table scan

# Query Analysis

`possible_keys & key`

`Possible_keys` lists the indices that could possibly be used. `Key` indicates which was actually chosen.

- If you don't like the index that MySQL is using, you can tell it to ignore indices using the IGNORE INDEX
- If possible_keys is null, you have no indices that MySQL can use and should consider adding some.

# Query Analysis

`rows`

MySQL's estimate of how many rows need to be read.  If this number is really big, that can indicate a problem.

# Query Analysis

Optimizations take three main forms:

- Add or modify indices
- Query optimizations
- Modify table structure
  - Denormalization, for example

# Query Analysis - Indices

## What is an index?

- Fast, compact structure for identifying row locations
- Chop down your result set as quickly as possible
- MySQL will only use one index per table per query
  - It cannot combine two separate indexes to make one more useful index.

# Query Analysis - Indices

Adding indices in Rails:

```
class AddNameIndexProducts < ActiveRecord::Migration
  def change
    add_index :products, :name
  end
end
```

# Query Analysis - Indices

Adding foreign keys in Rails:

- The “Rails way” is to enforce these things at the application layer
- You may disagree, in which case you can use the “Foreigner” gem like so:

```
class AddForeignKeyToOrders < ActiveRecord::Migration
  def change
    add_foreign_key :orders, :products
  end
end
```

# Query Analysis - Indices

Indices work best when they can be kept in memory.  Some ways to trim the fat:

- Can I reduce the characters in that VARCHAR index?
- Can I use a TINYINT instead of a BIGINT?
- Can I use an integer to describe a status instead of a text-based value?

# Query Analysis - Query Optimization

Modify your query.

Example at the SQL level:

```
mysql> explain select count(*) from txns where parent_id - 1600 = 16340
  select_type: SIMPLE
  table: txns
  type: index
  key: index_txns_on_reverse_txn_id
  rows: 439186
  Extra: Using where; Using index
```

# Query Analysis - Query Optimization

Modify your query.

Example at the SQL level:

```
mysql> explain select count(*) from txns where parent_id = 16340 + 1600
  select_type: SIMPLE
  table: txns
  type: const
  key: index_txns_on_reverse_txn_id
  rows: 1
  Extra: Using index
```

# Motivation

After today you should…

- Understand the importance of relational databases in architecting scalable internet systems.
- Understand how to design with concurrency in mind.
- Have a basic idea how to speed up your data layer
  - Where to start
  - Rails-specific techniques
  - Identify the source of slowness in a query

# For Next Time...

Keep pushing forward on your project

- This week's demo will be on AWS
- The sooner you get application features up and deployed, the sooner we can load test and scale your application!