Data-Intensive Distributed Computing

CS 451/651 431/631 (Winter 2018)

Part 7: Mutable State (2/2)

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These slides are available at http://lintool.github.io/bigdata-2018w/

The Fundamental Problem

We want to keep track of *mutable* state in a *scalable* manner

Assumptions:

State organized in terms of logical records

State unlikely to fit on single machine, must be distributed

MapReduce won't do!

Motivating Scenarios

Money shouldn't be created or destroyed:

Alice transfers $100 to Bob and $50 to Carol

The total amount of money after the transfer should be the same

Phantom shopping cart:

Bob removes an item from his shopping cart…

Item still remains in the shopping cart

Bob refreshes the page a couple of times… item finally gone

Motivating Scenarios

People you don't want seeing your pictures:

Alice removes mom from list of people who can view photos
Alice posts embarrassing pictures from Spring Break
Can mom see Alice's photo?

Why am I still getting messages?

Bob unsubscribes from mailing list and receives confirmation
Message sent to mailing list right after unsubscribe
Does Bob receive the message?

Three Core Ideas

Why do these scenarios happen?

Partitioning (sharding)

To increase scalability and to decrease latency

Need distributed transactions!

Replication

To increase robustness (availability) and to increase throughput

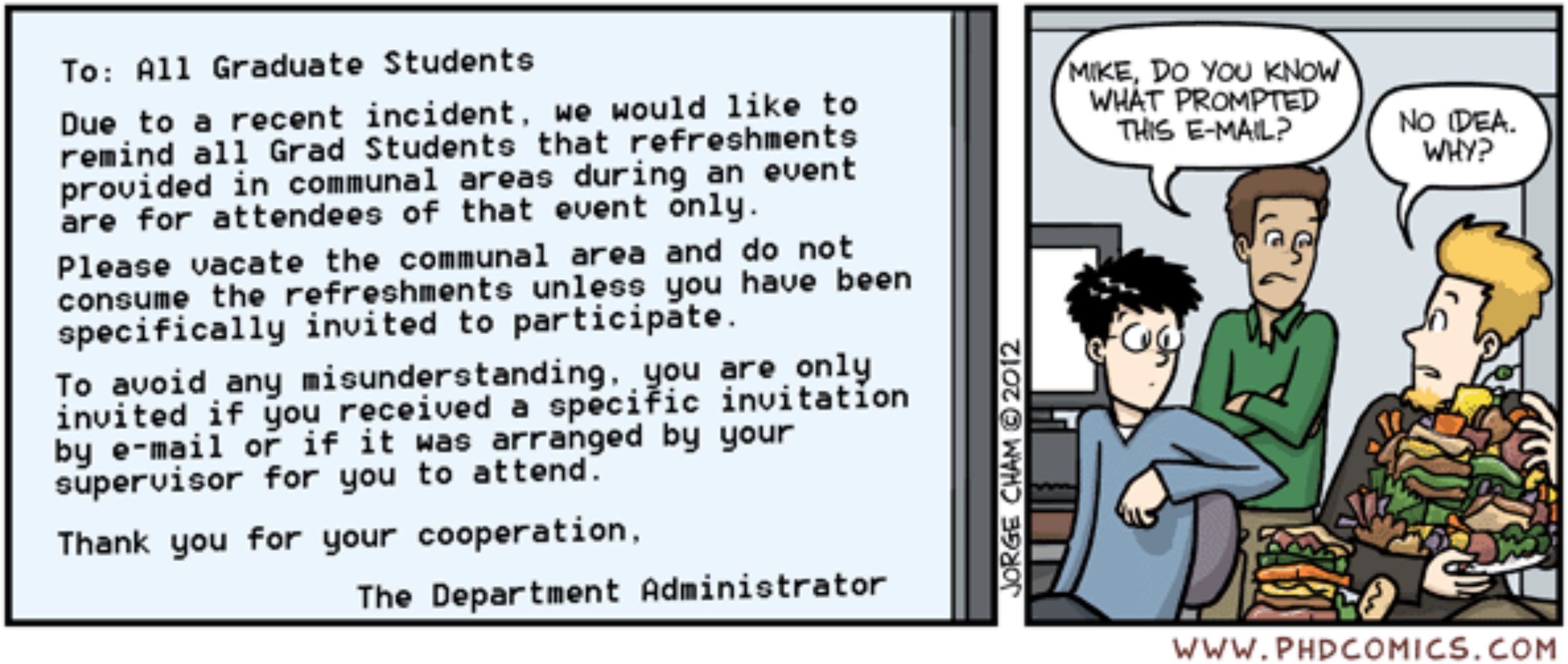
Need replica coherence protocol!

Caching

To reduce latency

Need cache coherence protocol!

Source: Wikipedia (Cake)



Morale of the story: there's no free lunch!

(Everything is a tradeoff)

Source: www.phdcomics.com/comics/archive.php?comicid=1475

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Relational Databases

… to the rescue!

Source: images.wikia.com/batman/images/b/b1/Bat_Signal.jpg

How do RDBMSes do it?

Transactions on a single machine: (relatively) easy!

Partition tables to keep transactions on a single machine

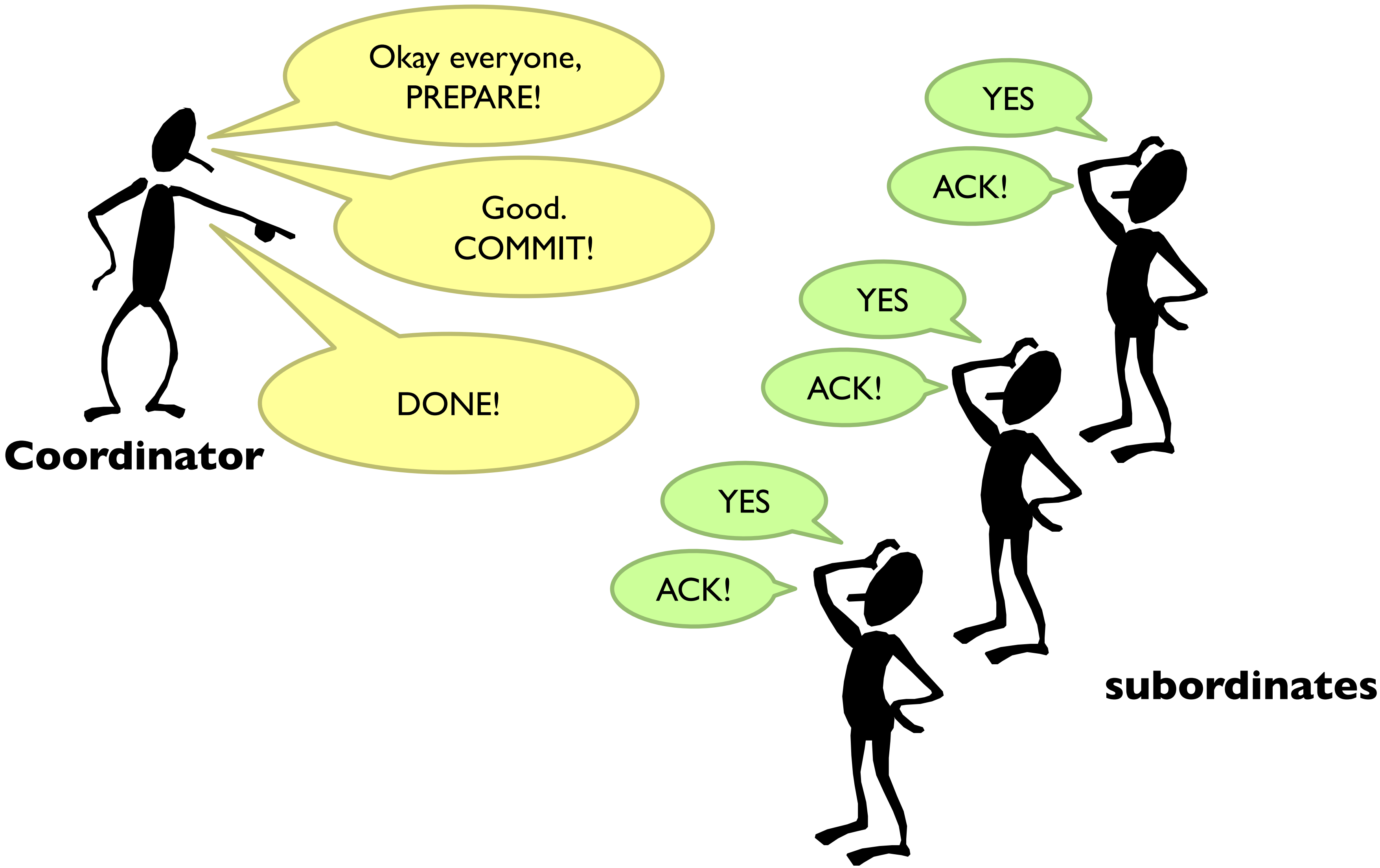
Example: partition by user

What about transactions that require multiple machines?

Example: transactions involving multiple users

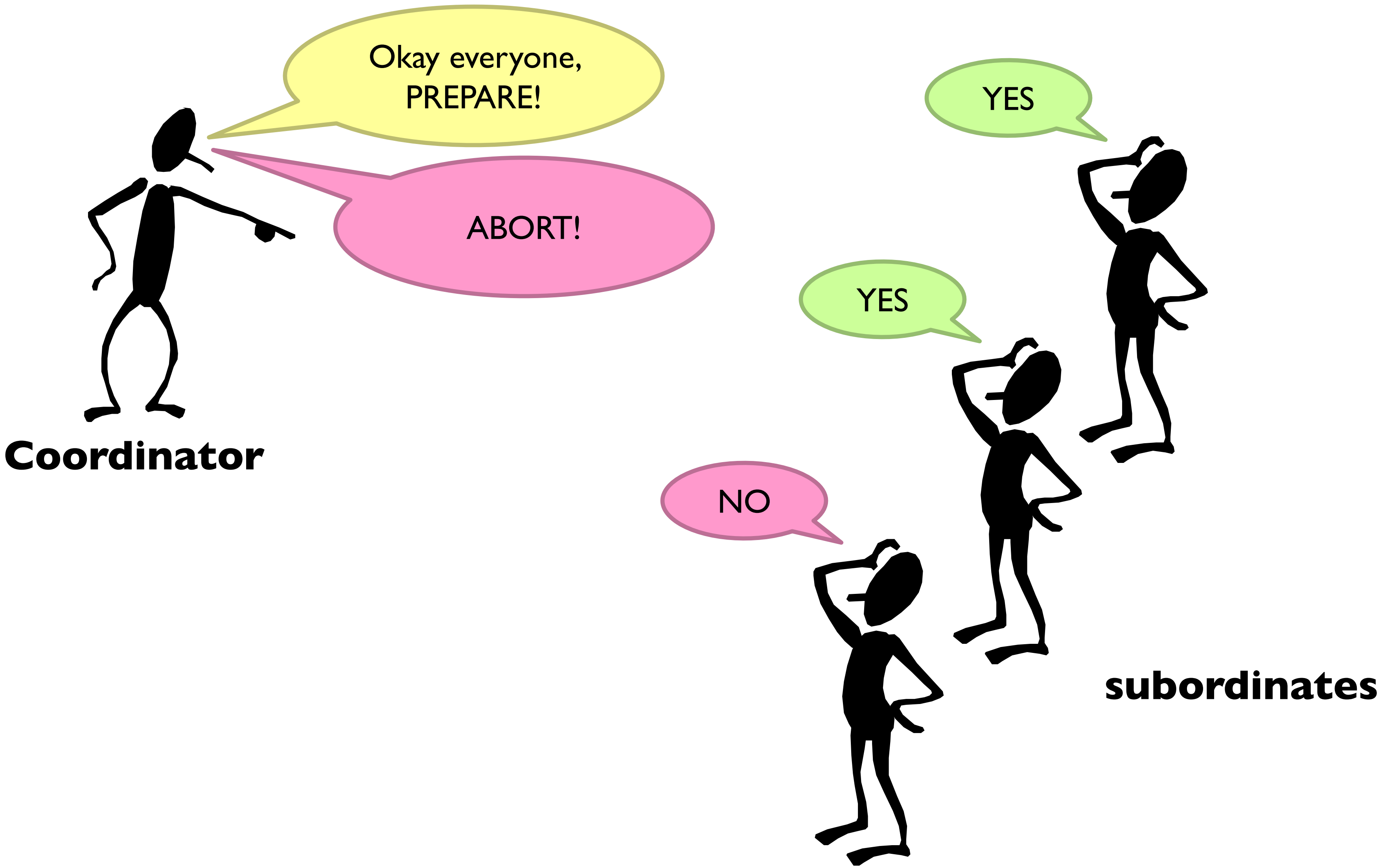
Solution: Two-Phase Commit

2PC: Sketch

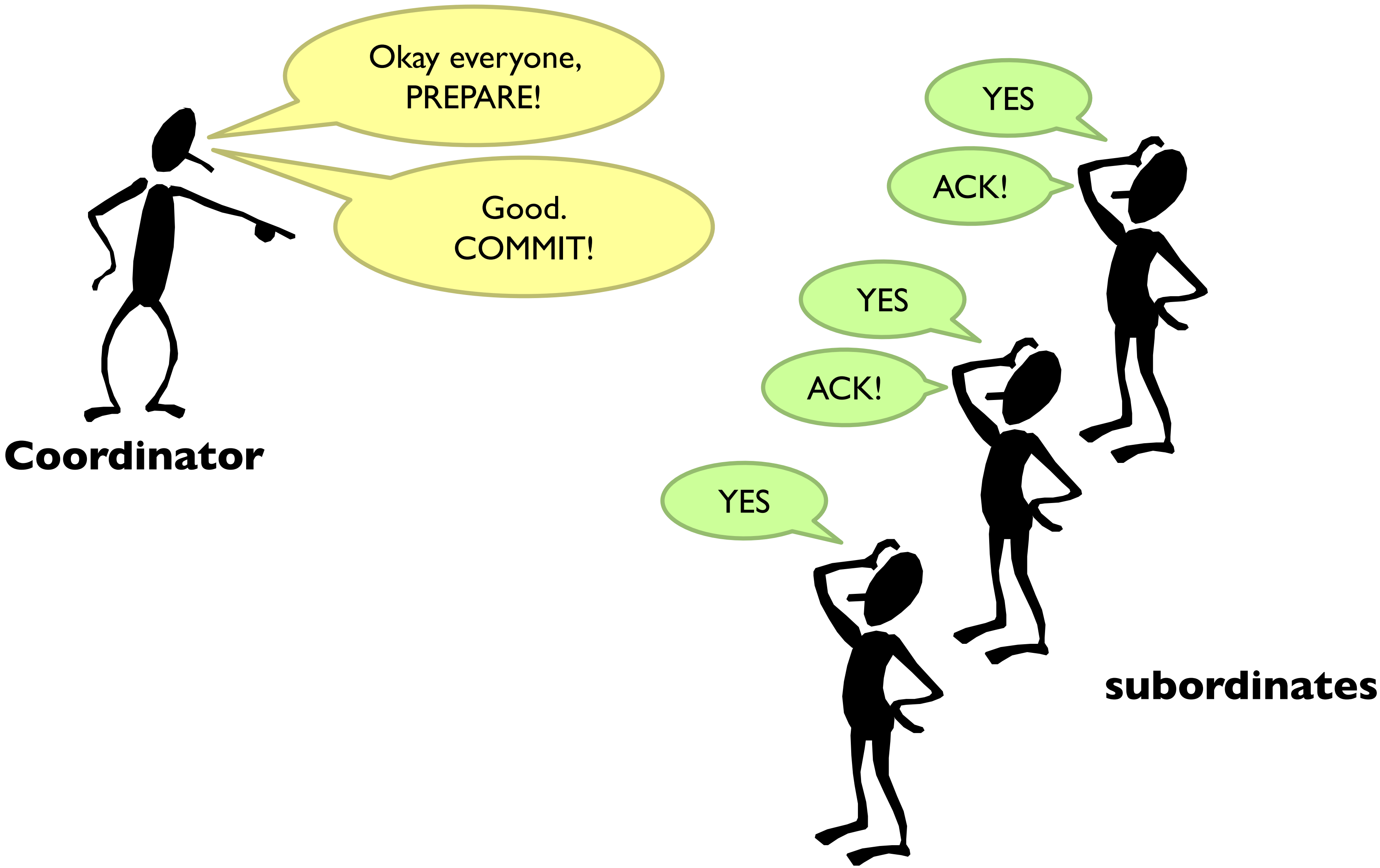


Okay everyone,
PREPARE!
Good.
COMMIT!
DONE!
Coordinator
YES
ACK!
YES
ACK!
YES
ACK!
subordinates

2PC: Sketch


Okay everyone, PREPARE!
ABORT!
YES
YES
NO
Coordinator
subordinates

2PC: Sketch



Okay everyone, PREPARE!
Good. COMMIT!
YES
ACK!
YES
ACK!
YES
Coordinator
subordinates

2PC: Assumptions and Limitations

Assumptions:

Persistent storage and write-ahead log at every node

WAL is never permanently lost

Limitations:

It's blocking and slow

What if the coordinator dies?

Beyond 2PC: Paxos!

(details beyond scope of this course)

“Unit of Consistency”

Single record transactions:

Relatively straightforward

Complex application logic to handle multi-record transactions

Arbitrary transactions:

Requires 2PC or Paxos

Middle ground: entity groups

Groups of entities that share affinity

Co-locate entity groups

Provide transaction support within entity groups

Example: user + user’s photos + user’s posts etc.

Where have we learned this trick before?

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CAP "Theorem"

(Brewer, 2000)

Consistency

Availability

Partition tolerance

… pick two

CAP Tradeoffs

CA = consistency + availability

E.g., parallel databases that use 2PC

AP = availability + tolerance to partitions

E.g., DNS, web caching

Is this helpful?

CAP not really even a "theorem" because vague definitions

More precise formulation came a few years later

Source: Abadi (2012) Consistency Tradeoffs in Modern Distributed Database System Design. IEEE Computer, 45(2):37-42

Abadi Says…

CP makes no sense!

CAP says, in the presence of P, choose A or C

But you'd want to make this tradeoff even when there is no P

Fundamental tradeoff is between consistency and latency

Not available = (very) long latency

Replication possibilities

Update sent to all replicas at the same time

To guarantee consistency you need something like Paxos

Update sent to a master

Replication is synchronous

Replication is asynchronous

Combination of both

Okay, but if the master fails?

Update sent to an arbitrary replica

Okay, now what?

All these possibilities involve tradeoffs!

"eventual consistency"

Move over, CAP

PACELC ("pass-elk")

PAC

If there's a partition, do we choose A or C?

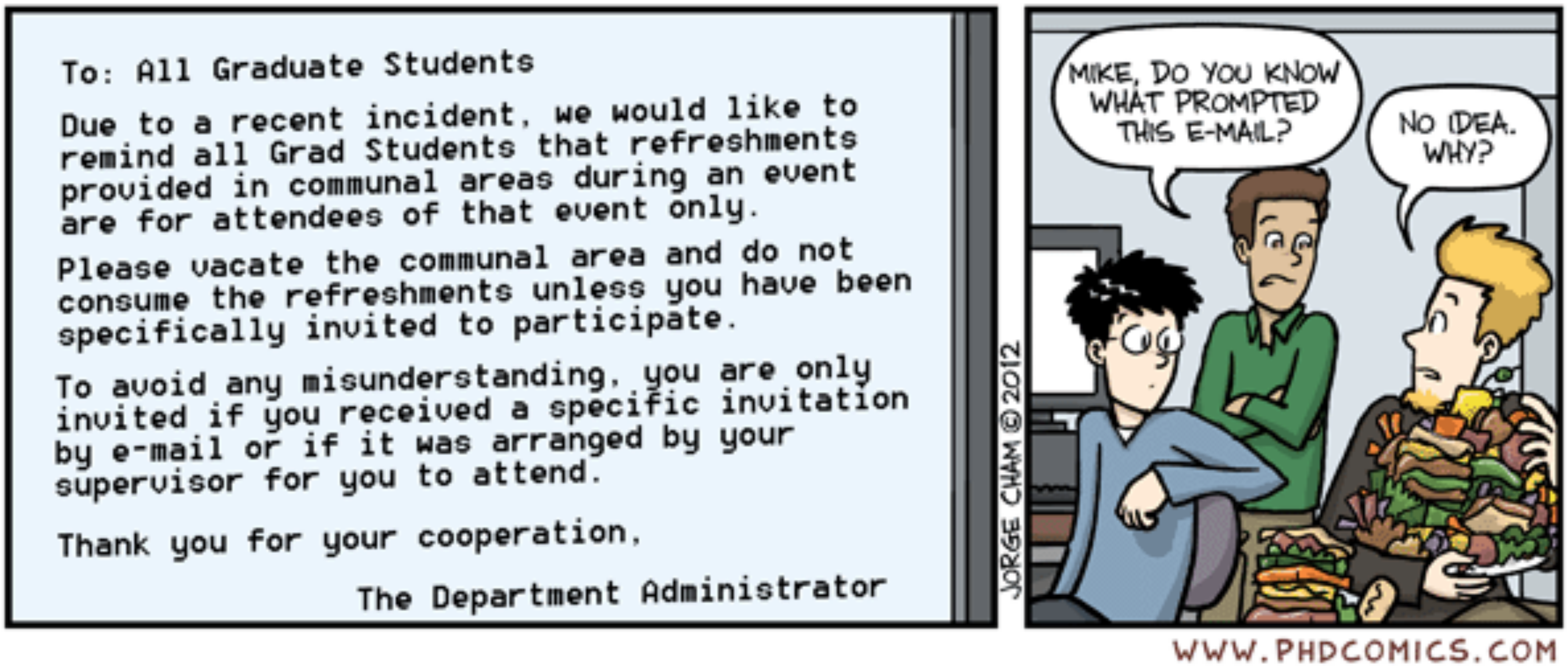
ELC

Otherwise, do we choose **L**atency or **C**onsistency?

Eventual Consistency

Sounds reasonable in theory…
What about in practice?

It really depends on the application!



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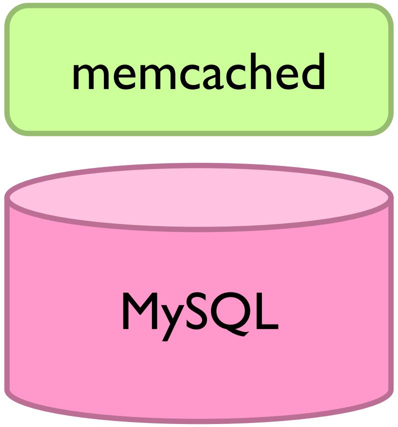
Facebook Architecture



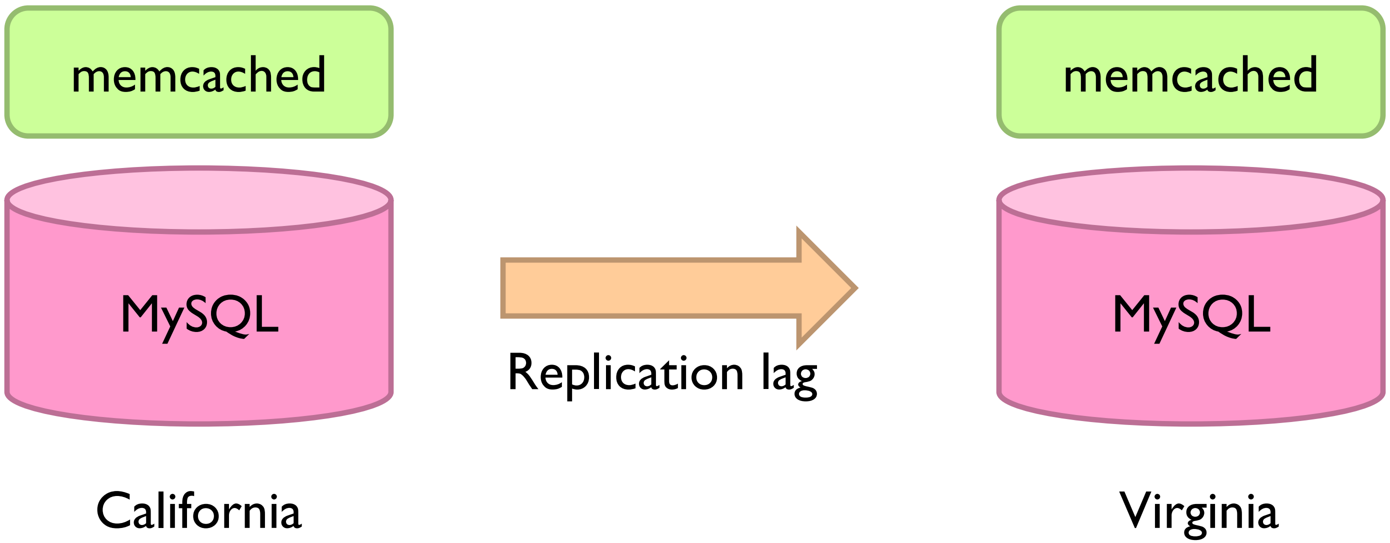
Read path:
Look in memcached
Look in MySQL
Populate in memcached

Write path:
Write in MySQL
Remove in memcached

Subsequent read:
Look in MySQL
Populate in memcached

Source: www.facebook.com/note.php?note_id=23844338919

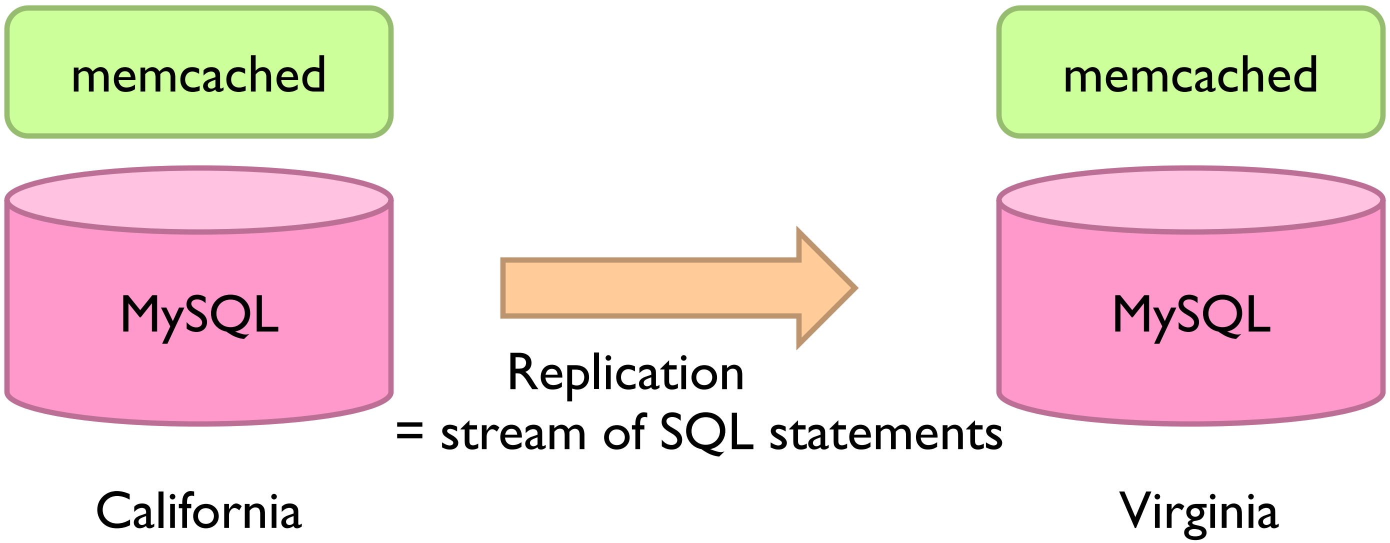
Facebook Architecture: Multi-DC



1. User updates first name from “Jason” to “Monkey”.
2. Write “Monkey” in master DB in CA, delete memcached entry in CA and VA.
3. Someone goes to profile in Virginia, read VA replica DB, get “Jason”.
4. Update VA memcache with first name as “Jason”.
5. Replication catches up. “Jason” stuck in memcached until another write!

Source: www.facebook.com/note.php?note_id=23844338919

Facebook Architecture: Multi-DC



Solution: Piggyback on replication stream, tweak SQL

```
REPLACE INTO profile (`first_name`) VALUES ('Monkey’)
WHERE `user_id`='jsobel' MEMCACHE_DIRTY 'jsobel:first_name'
```

Source: www.facebook.com/note.php?note_id=23844338919

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Now imagine multiple datacenters…

What’s different?

Source: Google

Yahoo's PNUTS

Yahoo's globally distributed/replicated key-value store

Provides *per-record* timeline consistency

Guarantees that all replicas provide all updates in same order

Different classes of reads:

Read-any: may time travel!

Read-critical(required version): monotonic reads

Read-latest

PNUTS: Implementation Principles

Each record has a single master

Asynchronous replication across datacenters

Allow for synchronous replication within datacenters

All updates routed to master first, updates applied, then propagated

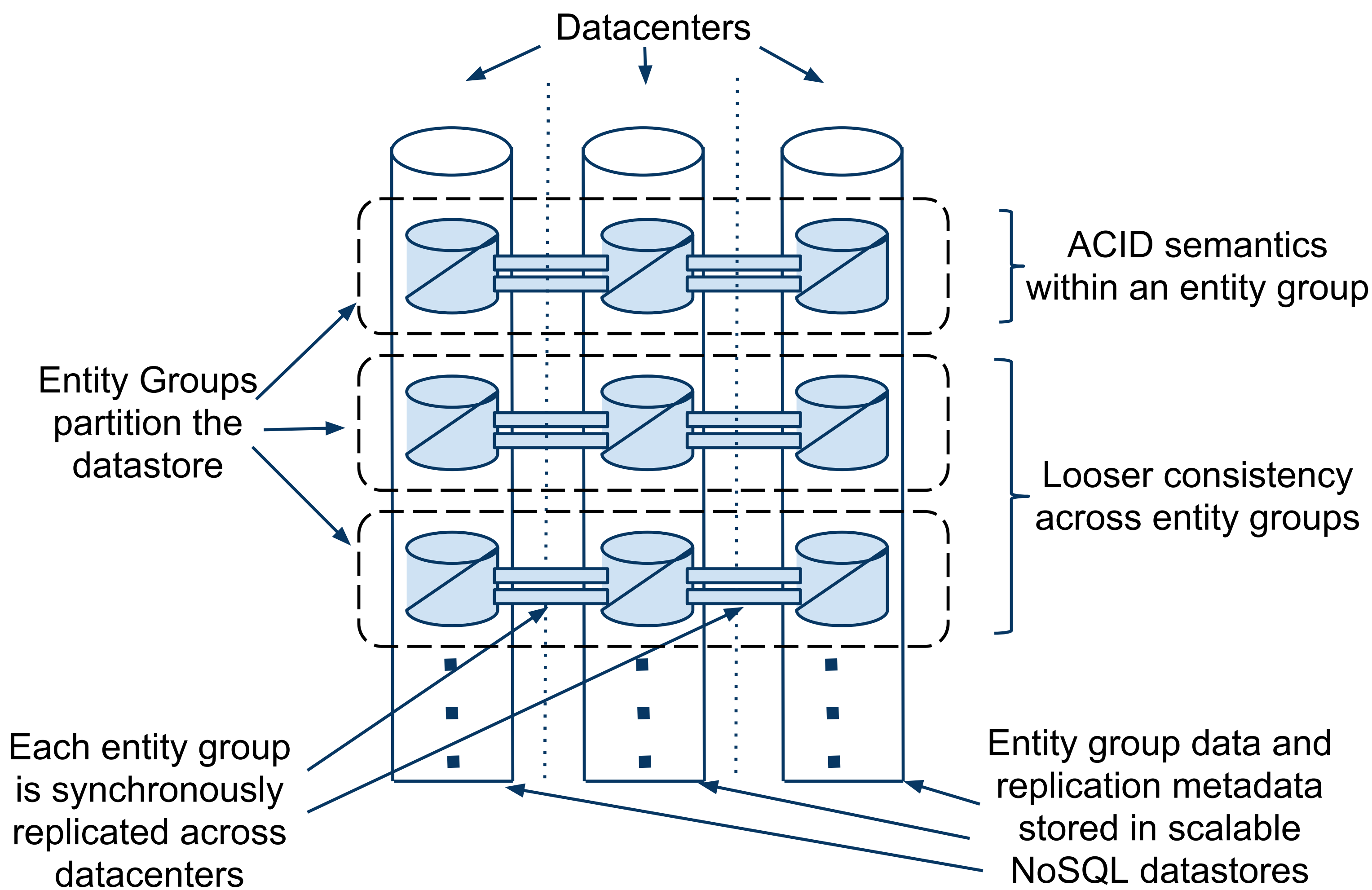
Protocols for recognizing master failure and load balancing

Tradeoffs:

Different types of reads have different latencies

Availability compromised during simultaneous master and partition failure

Google's Megastore



Source: Baker et al., CIDR 2011

Google's Spanner

Features:

Full ACID translations across multiple datacenters, across continents!

External consistency (= linearizability):

system preserves *happens-before* relationship among transactions

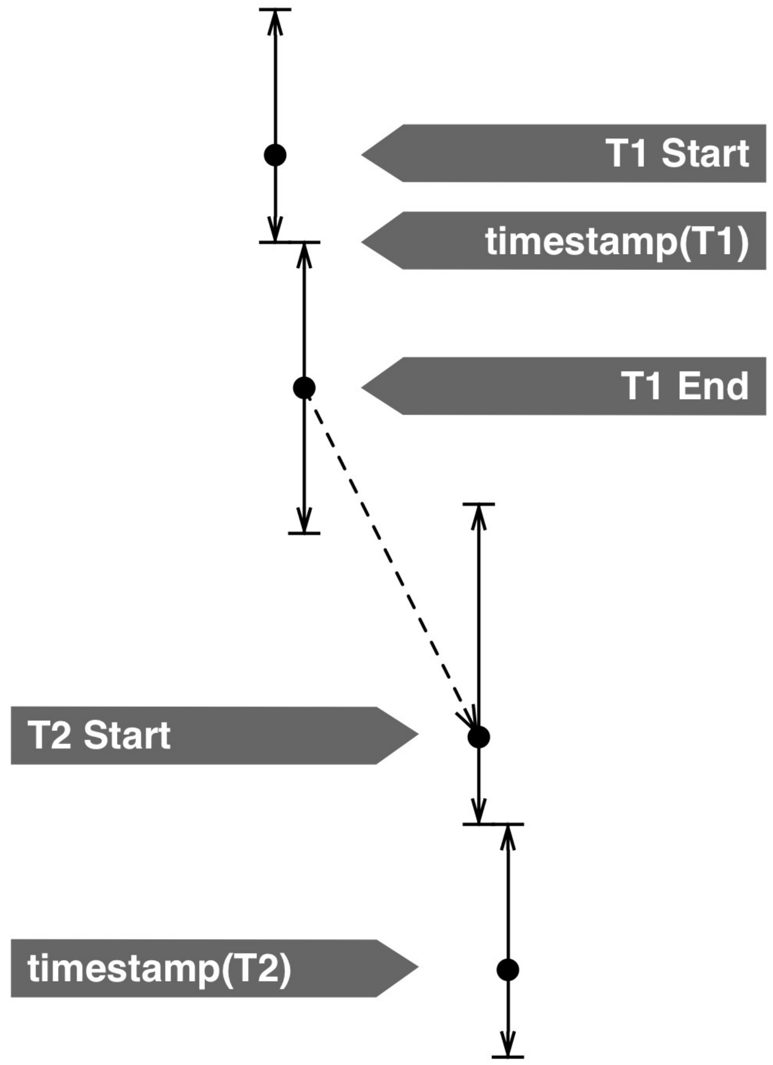
How?

Given write transactions A and B, if A *happens-before* B, then

timestamp(A) < timestamp(B)

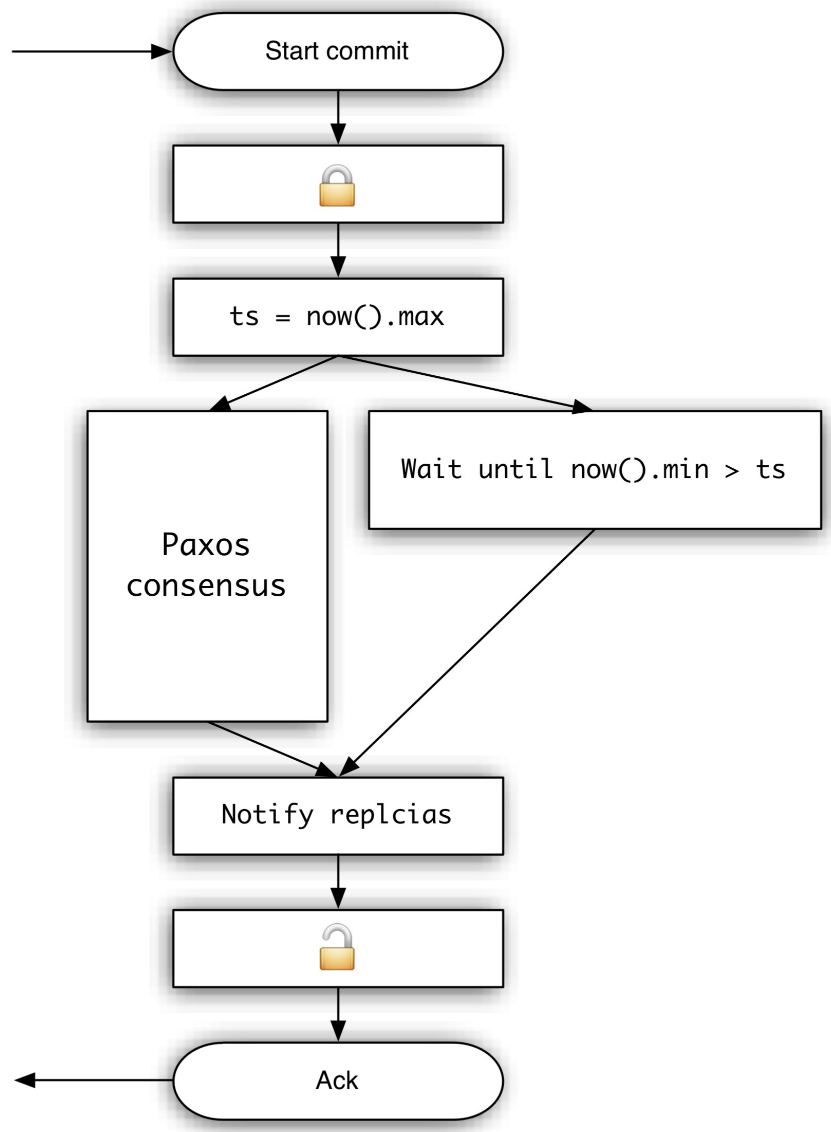
Source: Llyod, 2012

Why this works



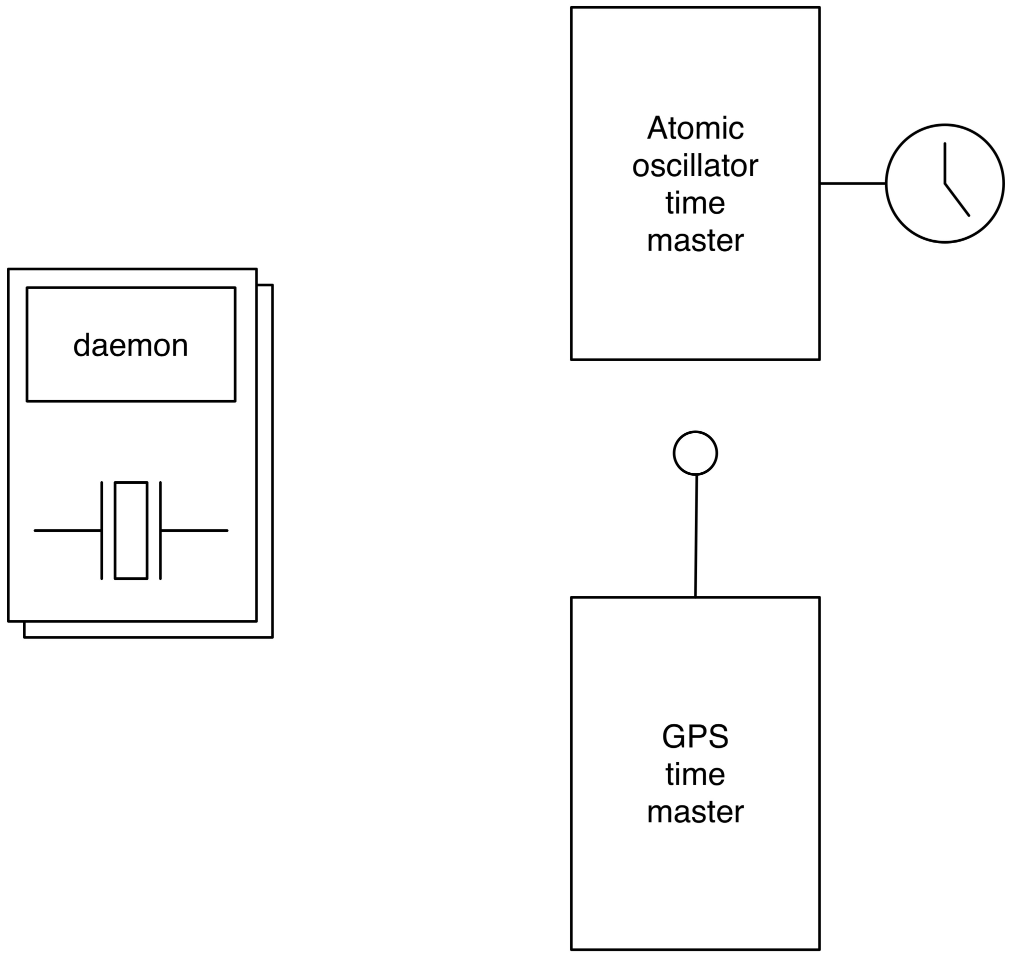
Source: Llyod, 2012

TrueTime → write timestamps



Source: Llyod, 2012

TrueTime



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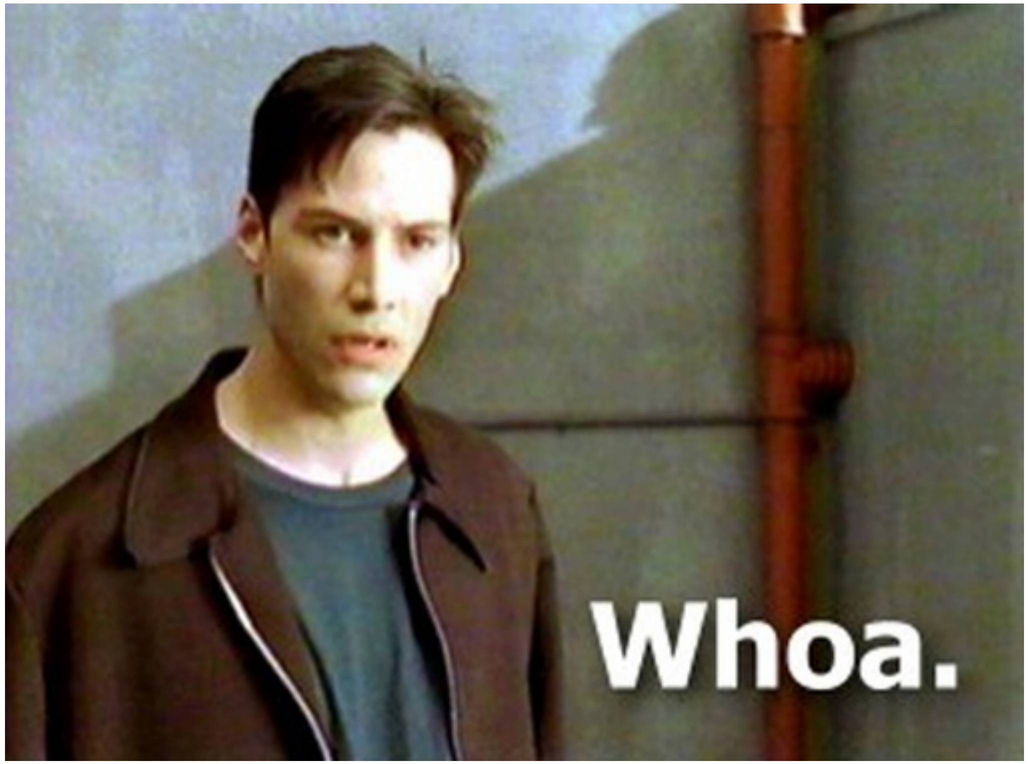

What's the catch?

Source: The Matrix

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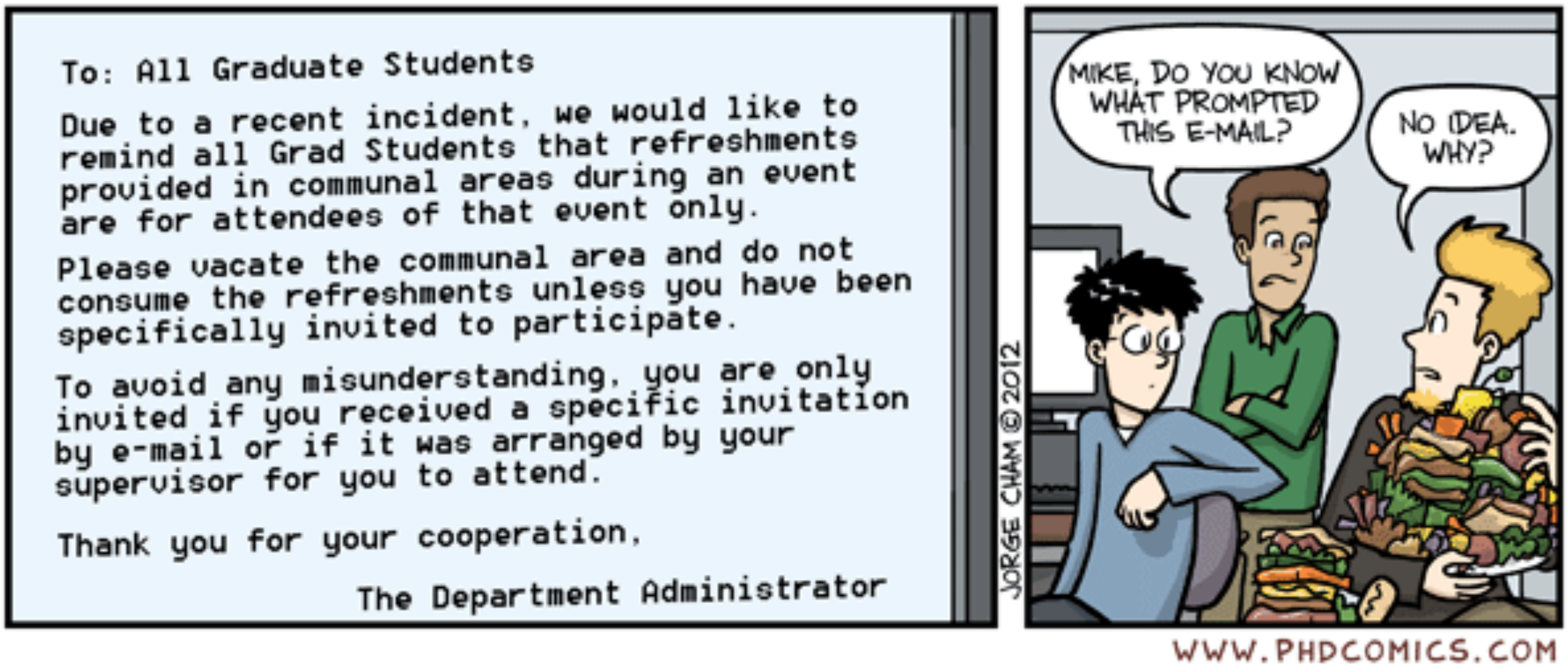

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Source: Wikipedia (Japanese rock garden)