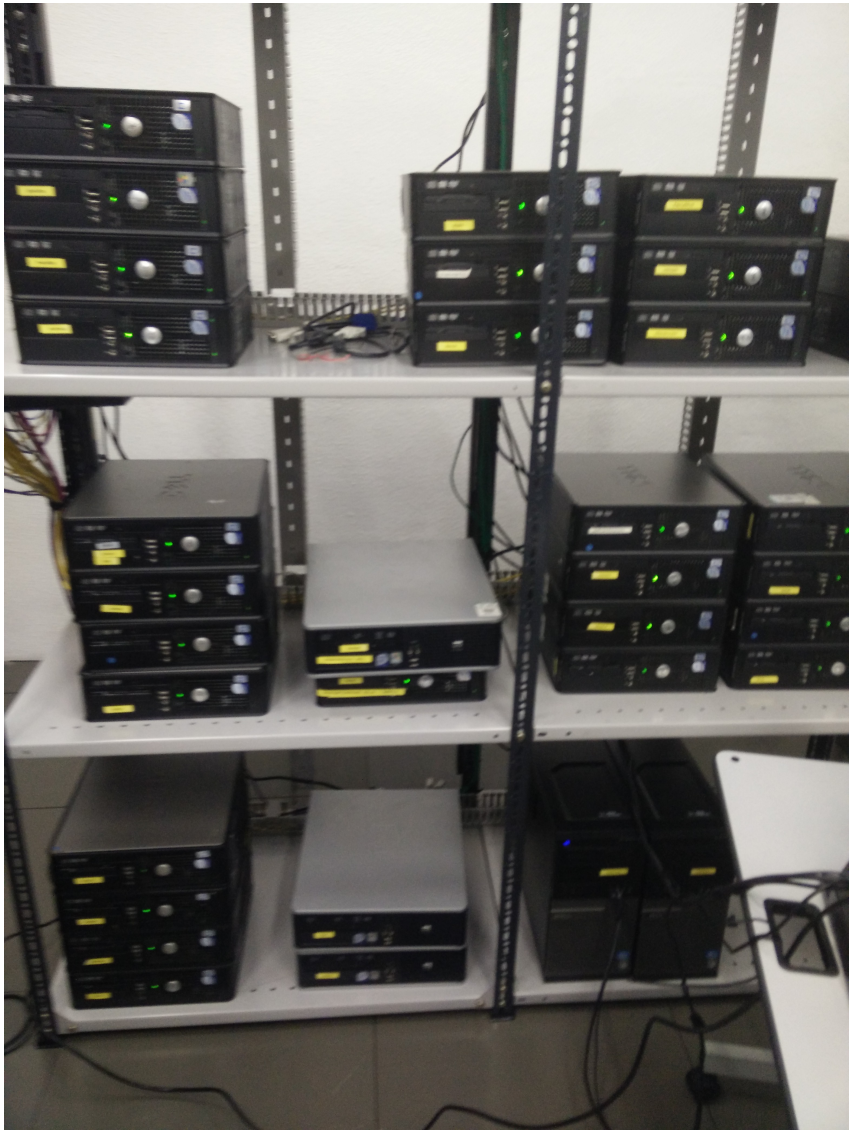
Fault Tolerance, Replication, and Consistency

Motivation: Hadoop Cluster



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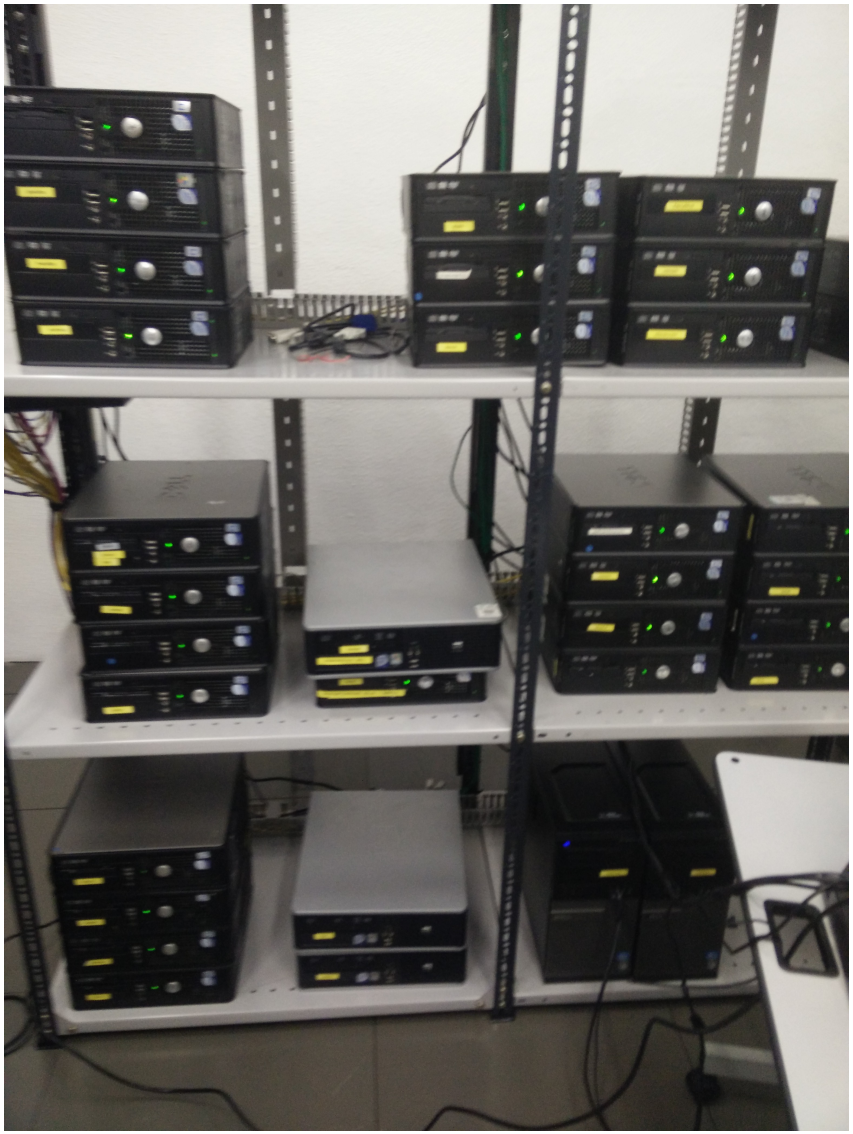

Mostly retired desktops

Intel Core 2: launched in 2008

Support is gathering old servers

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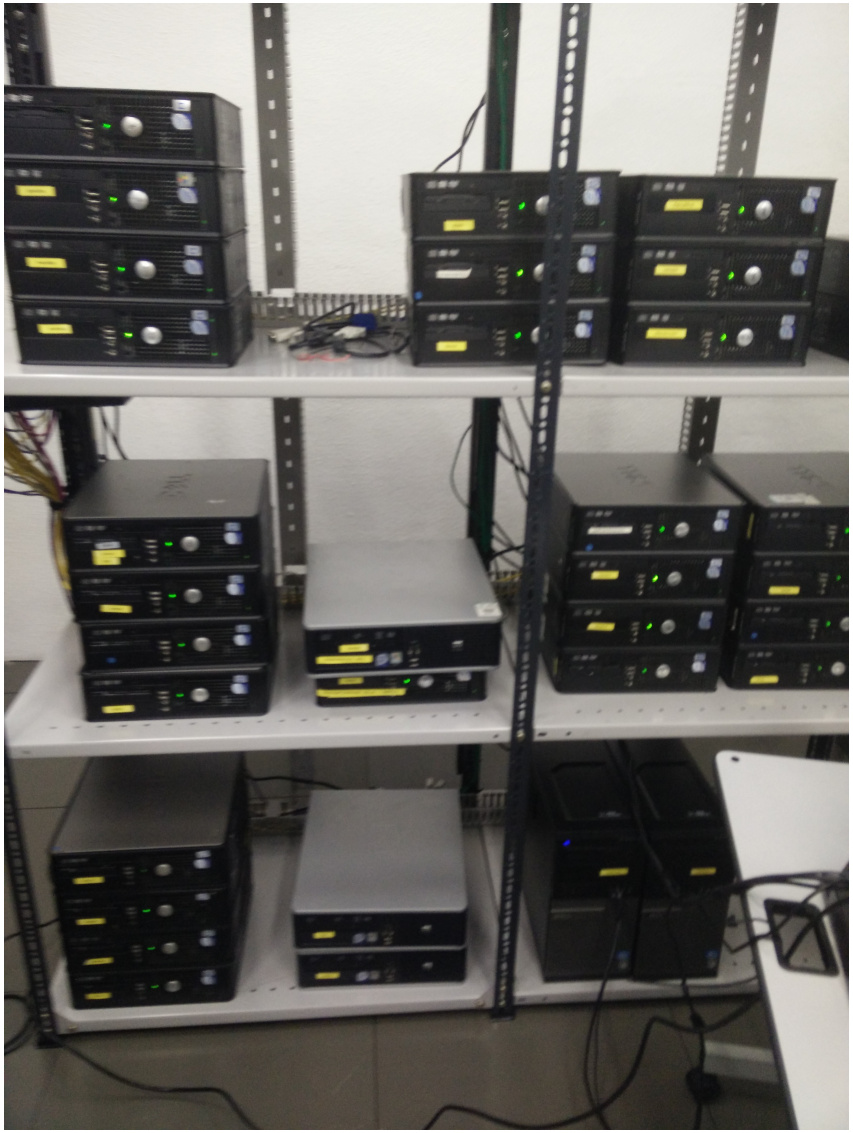

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Test case for fault tolerance!

Fault Tolerance

In any sufficiently large cluster, machines will fail.
In any sufficiently large job, machines will fail.

Defining Failure

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Defective RAM
Undetected disk errors
Wrong software version

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Byzantine: Many untrustworthy nodes, worst-case behavior
Hacked
Volunteer nodes (Tor, BitTorrent, Bitcoin)

Failure: An Outline

1. Timeouts
2. Replication
3. Consistency
4. Consensus
5. Recovery

Timeouts and Health Reports

Node HTTP Address	Last health-update
faulks.inf.ed.ac.uk:8042	Thu Oct 08 09:27:09 +0100 2015
tessarini.inf.ed.ac.uk:8042	Thu Oct 08 09:27:13 +0100 2015
blundell.inf.ed.ac.uk:8042	Thu Oct 08 09:27:08 +0100 2015
dancla.inf.ed.ac.uk:8042	Thu Oct 08 09:27:09 +0100 2015
bw1425n01.inf.ed.ac.uk:8042	Thu Oct 08 09:26:17 +0100 2015
glendora.inf.ed.ac.uk:8042	Thu Oct 08 09:27:09 +0100 2015
strathisla.inf.ed.ac.uk:8042	Thu Oct 08 09:27:12 +0100 2015

Detects crashed and possibly slow nodes.
A node might omit specific requests, but pass health.

So A Node Times Out

Mark the node offline, ask another?

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Service is loaded

$\rightarrow$

Timeouts

$\rightarrow$

Nodes marked offline

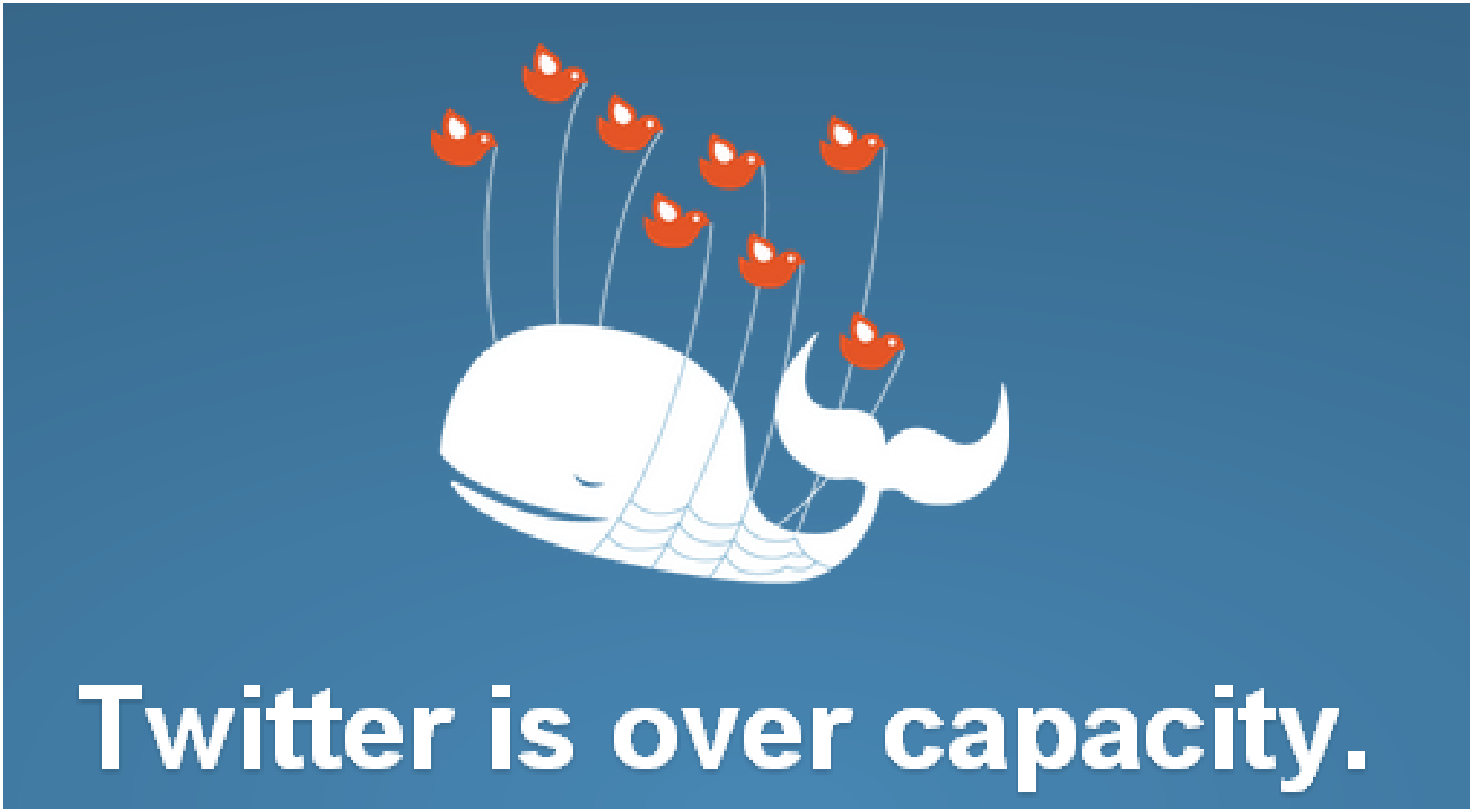
$\rightarrow$

More load on remaining servers

$\rightarrow$

Repeat.

Avoid cascading failure: drop incoming requests.



Avoid cascading failure:

- Capacity planning!
- Rate-limit machine failure
- Heuristics for small failures can backfire in larger failures

Replication

Store several copies of the same data!
In HDFS: 3 copies by default.

Read from any copy $\Longrightarrow$ better read performance.

Replicas for Fault Tolerance

Crashed, slow, or omission: read from another replica

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Fine for read-only. What if the data changes?

Consistency?

Web Pages

Stale pages might be fine, but don't mix old and new in one page.
If somebody shares a link, it should work.

Domain Names

Caching with a time limit. Inconsistent answers are ok with time limit.

Banking

Reorder transactions to charge customers the most fees.
A transaction succeeds or fails.

E-Commerce

Don't assign the same seat on a plane (or do. . .)

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Consistency needs depend on the application!

Models for Consistency

Strict: Absolute ordering of all accesses by time

Linearisability: There exists some linear story (like a bank statement)

Sequential: Nodes read in a consistent order

Example

	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6
Alice	Writes A					
Bob		Writes B				
Carol			Reads B	Reads A		
Dan					Reads B	Reads A

✗ Strict

✓ Linearisabile

✓ Sequential: Carol and Dan saw the same order.

Example

	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6
Alice	Writes A					
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Carol			Reads B	Reads A		
Dan					Reads B	Reads A
Eve				Reads A	Reads B	

- ✗ Strict
- ✗ Linearisabile
- ✗ Sequential: Eve saw a different order.

Models for Consistency

Strict: Absolute ordering of all accesses by time

Linearisability: There exists some linear story (like a bank statement)

Sequential: Nodes read in a consistent order

Causal: Causually related events are ordered correctly

FIFO: Writes from same node are ordered consistently
But writes from different nodes can be inconsistently ordered

Explicit Consistency Options (`sync`)

Weak: Only when programmer says so
Entry: When a lock is acquired
Release: When a lock is released

Eventual Consistency

Update one replica, let the others update lazily.

Some algorithms guarantee consistency eventually, depsite *some* failures.

Consistency: Two Generals Problem

Two generals leading armies on opposite sides of a city.
Need to both attack or both retreat.
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Theorem: no protocol ensures consensus.

Byzantine Generals Problem

Multiple generals, majority vote: message exchange has to be 3x number of lost messages.

Byzantine Fault Tolerance: need $3m + 1$ nodes to agree on a bit if m nodes are faulty.

Want more/proof? Take distributed systems!

CAP Theorem: Consistency, Availability, Partition tolerance

Consistency: Nodes see same data at the same time
Availability: Node failures do not prevent system operation
Partition Tolerance: Network failures do not prevent system operation

Conjecture: pick two of the above.
Related theorem for a special case.

Recovery

Something failed, now what?

Backward Recovery

Checkpointing: return to previous. Can be expensive to store.

Packet retransmission (when client does not ACK).

Forward recovery

Plan for some loss e.g. error correcting codes

Backward recovery is more common.

Fail! Summary

Ways to fail

Ways to be consistent

Redundancy by replicas or recomputing