Algorithms for Cloud Computing

Nokia Wrocław, Poland

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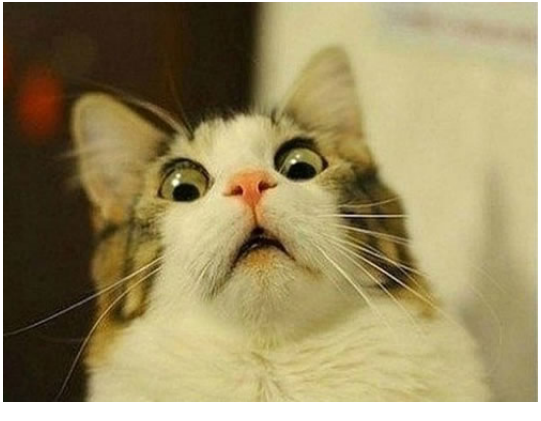
Miotacze Piorunów Team :-)

Miotacze Piorunów - the flag :-)

Roadmap

http://dailynewsdig.com/wp-content/uploads/2013/06/20-Funny-Shocked-Cat-Memes-3.jpg

Roadmap



http://dailynewsdig.com/wp-content/uploads/2013/06/20-Funny-Shocked-Cat-Memes-3.jpg

Cloud blitzkrieg! :-)

http://upload.wikimedia.org/wikipedia/commons/1/10/Bundesarchiv_Bild_101I-646-5188-17%2C_Flugzeuge_Junkers_Ju_87.jpg

Part 1

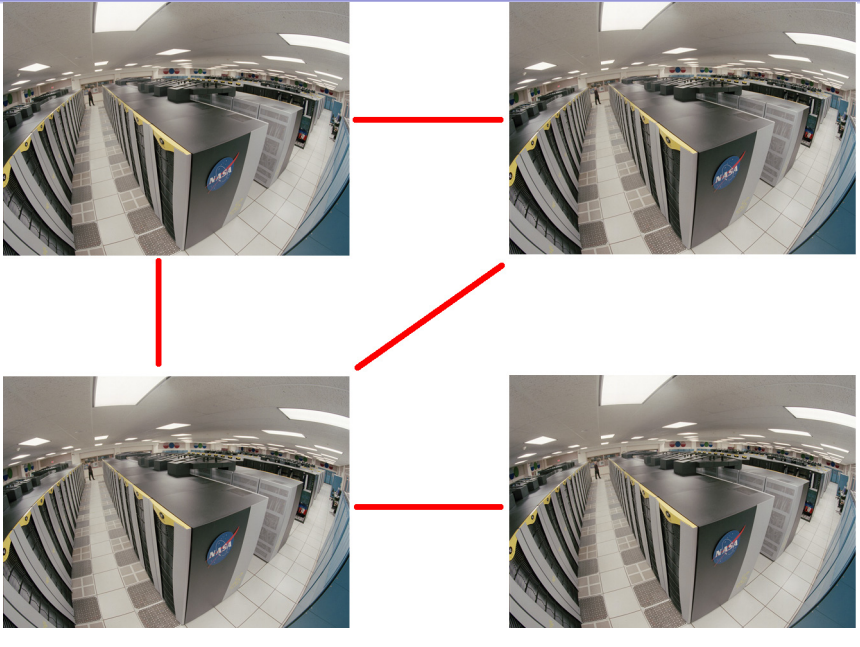
Supercomputers - ’60-’80

http://upload.wikimedia.org/wikipedia/commons/c/c4/CDC_6600.jc.jpg

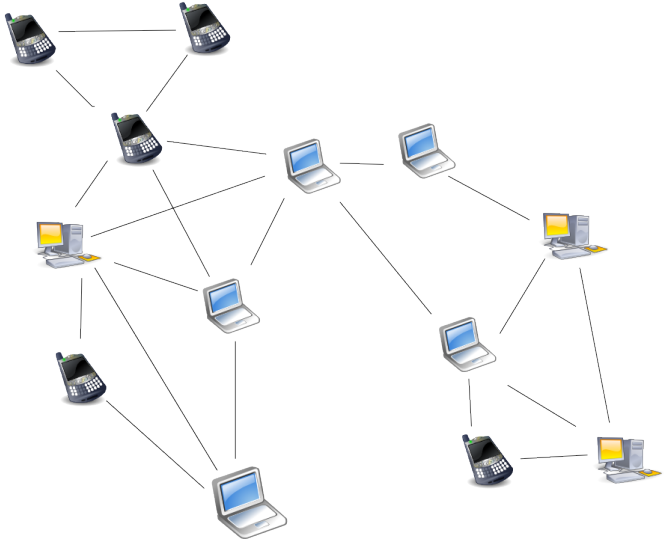
Clusters - since ’70

http://upload.wikimedia.org/wikipedia/commons/3/3d/Us-nasa-columbia.jpg

Grids - since ’90



P2P - since end of ’90



http://upload.wikimedia.org/wikipedia/en/f/fa/Unstructured_peer-to-peer_network_diagram.png

Clouds - since ’00

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- No single definition
  - A bit grid-like
  - With massive storage
  - CPUs + data put close

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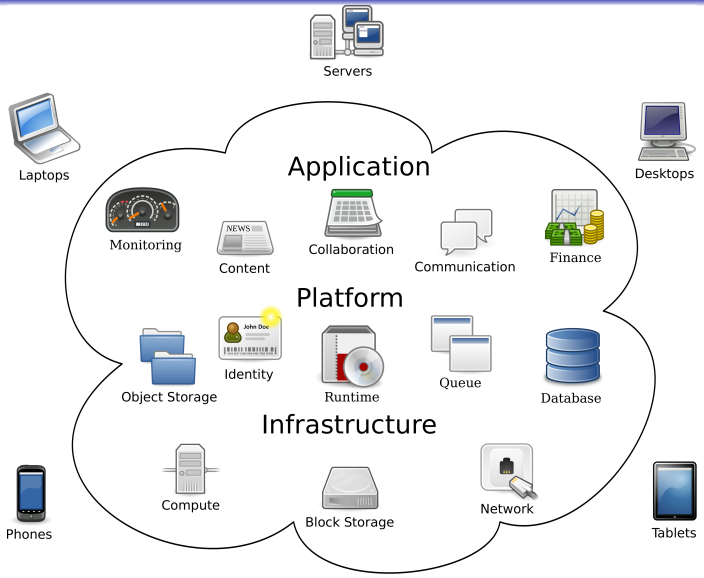
Cloud types



Cloud Computing

http://upload.wikimedia.org/wikipedia/commons/b/b5/Cloud_computing.svg

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- Mean Time Between Failures (MTBF):
  - Server: 6 years
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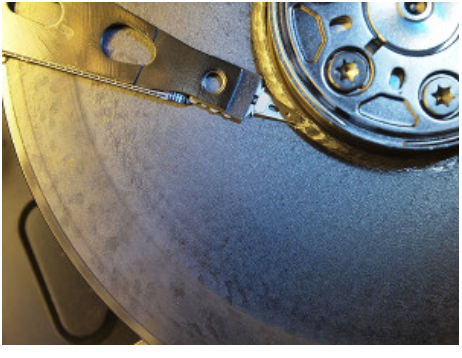

Lesson learned

At scale incredibly rare is a commonplace.

http://upload.wikimedia.org/wikipedia/commons/b/b9/Hard_disk_failure.jpeg

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  - Any time
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- Addressed by software
- Algorithms

http://upload.wikimedia.org/wikipedia/commons/1/19/Train_wreck_at_Montparnasse_1895.jpg

Part 2

The problem

- Massive scale system
- Node has new data
- How to inform others?

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- We can do better than that...

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1. Each node:
    1. Pick random node
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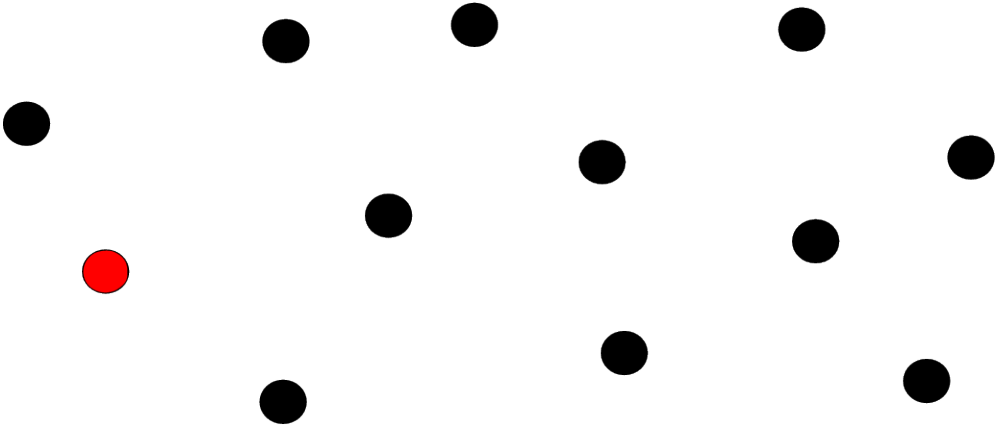
2. Run on all nodes

Example run



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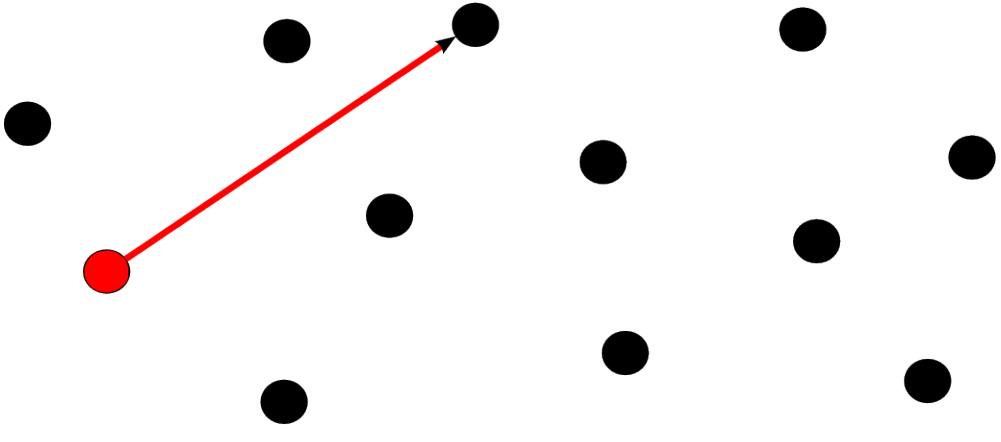

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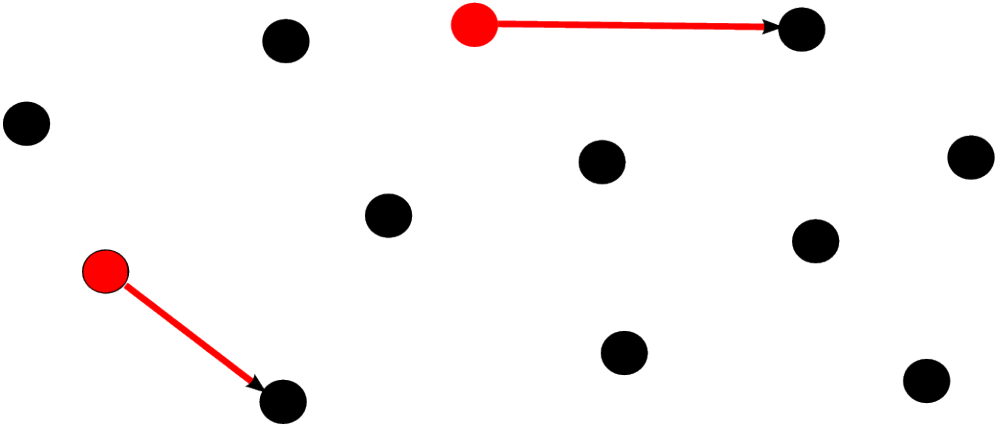

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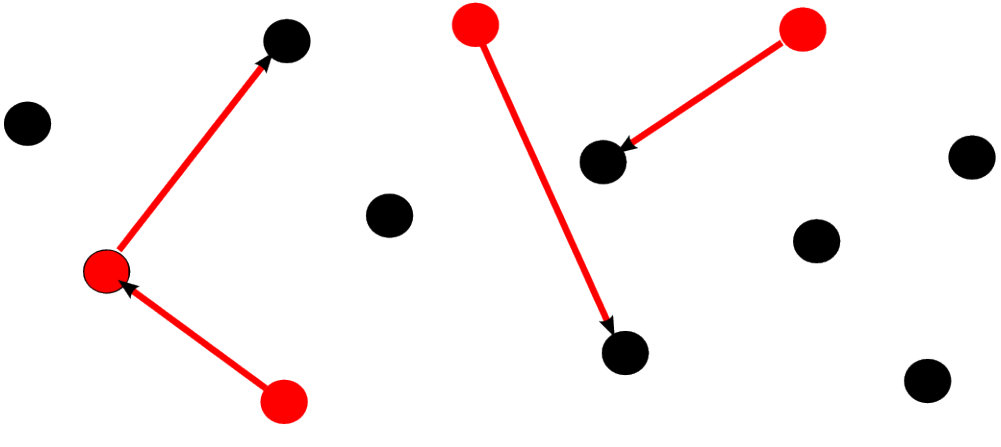

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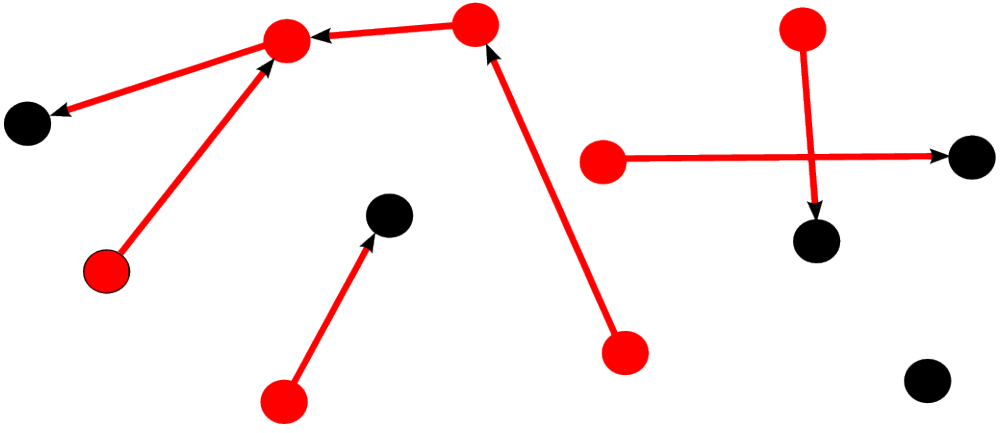
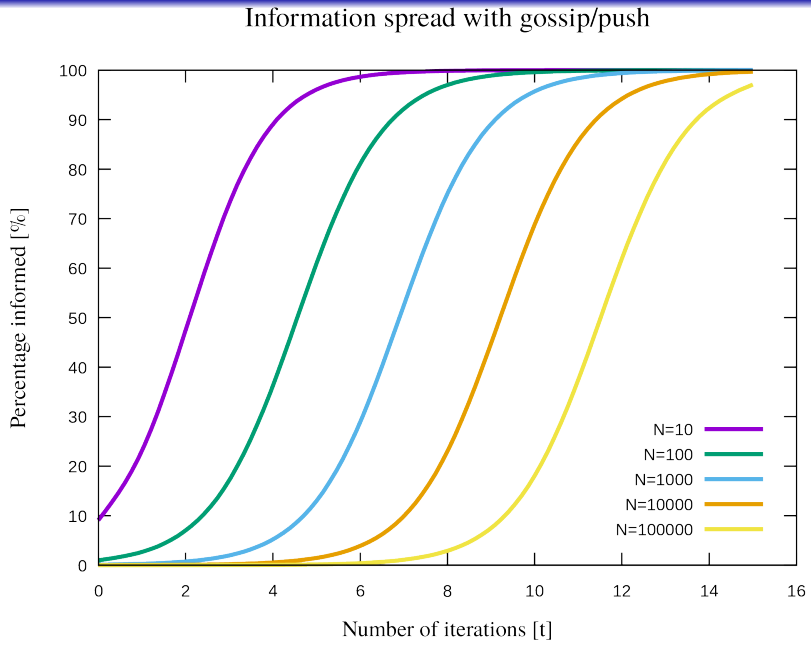


Spreads like a disease!



Gossip at Amazon S3

- Amazon S3:
  - **S**imple **S**torage **S**ervice
  - Online file storage
  - Part of *Amazon Web Services*
- Gossiping:
  - Spreading state info
  - Base component of storage
- Some numbers:
  - Over $2 * 10^{12}$ objects (2013)
  - 99.9% availability/month
  - 99.99% availability/year
  - 99.999999999% durability/year

https://upload.wikimedia.org/wikipedia/commons/e/ed/AWS_Simple_Icons_Storage_Amazon_S3_Bucket_with_Objects.svg
https://upload.wikimedia.org/wikipedia/commons/1/1d/AmazonWebservices_Logo.svg

Part 3

Basic concepts

- Aka. "failure detection"

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  - *Speed* == time to first detection
  - *Scale* == distributing load on nodes uniformly
- **Accuracy** vs. **completeness**
- Cannot have both (over unreliable networks)!

The idea

- Inform others:
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- Sounds familiar? :-)

Yup!

Local entries table

- Each node keeps table
- Table for node **A**:

1	2	3
A	5	
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  1. Node name
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  3. Entry timeout
- Timeout is local
- Timed out entries are dead
- Heartbeat incremented on send

Merging entries

A

A	5	
B	4	-41
C	5	-13

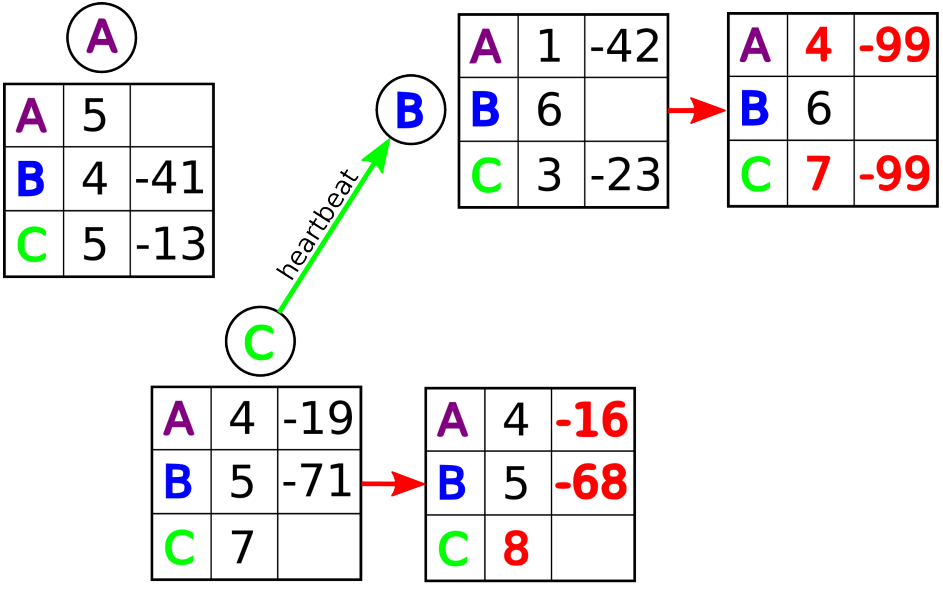
B

A	1	-42
B	6	
C	3	-23

C

A	4	-19
B	5	-71
C	7	

Merging entries



Amazon DynamoDB

- Amazon DynamoDB:
  - Database-like
  - Distributed Hash Table (DHT)
  - Powers Amazon Web Services
  - Used by Amazon S3
- Membership + failure detection
- No central register
- Excelent scaling

https://upload.wikimedia.org/wikipedia/commons/e/ed/AWS_Simple_Icons_Storage_Amazon_S3_Bucket_with_Objects.svg
https://upload.wikimedia.org/wikipedia/commons/1/1d/AmazonWebservices_Logo.svg

Part 4

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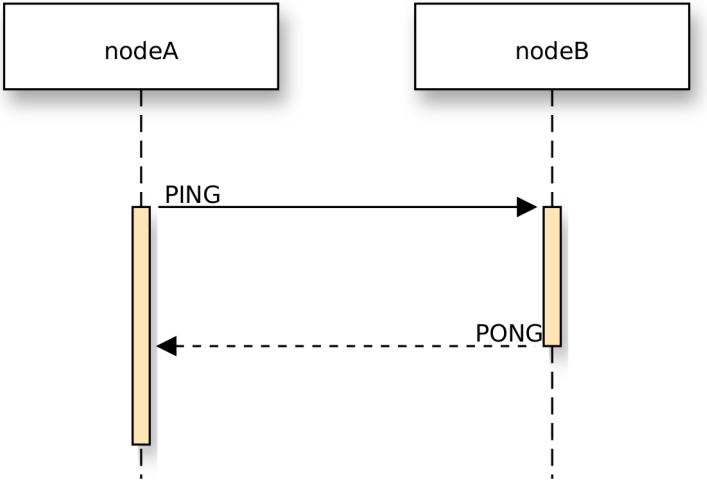
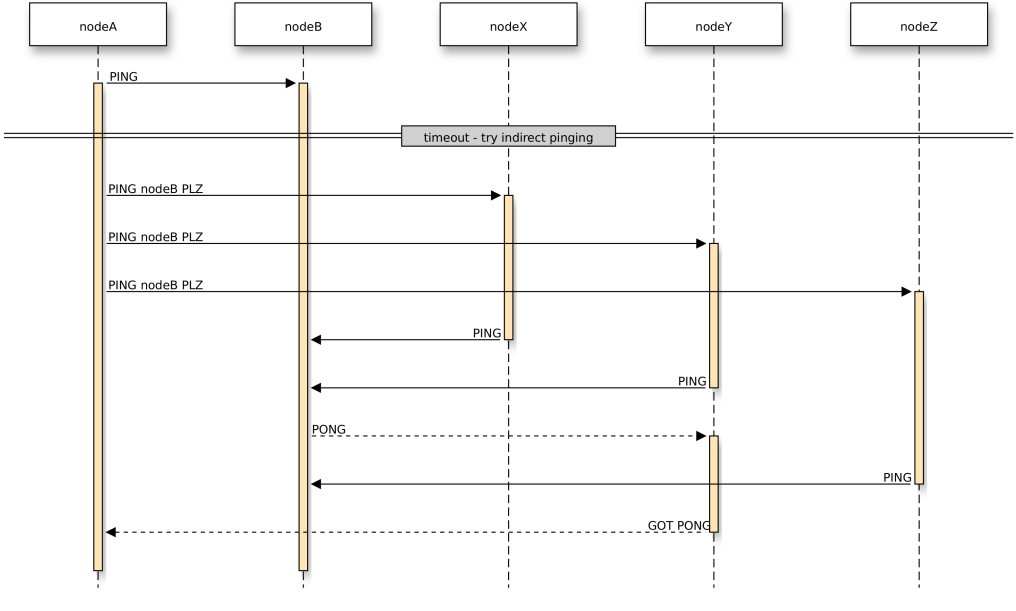
- Extra attempt to verify:
  - Special (more network paths)
  - Temporal (more time to response)

Example - direct ping succeeded

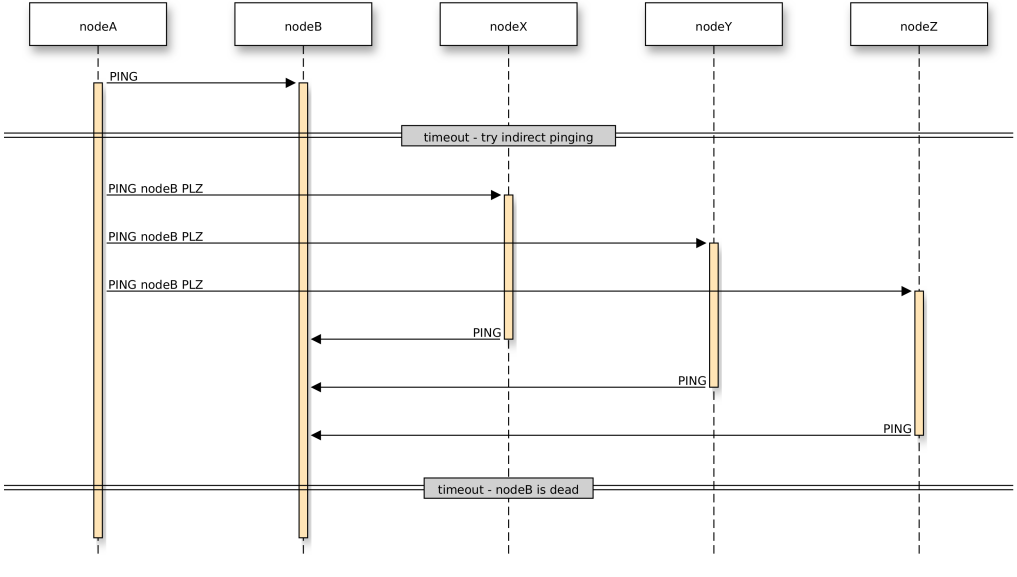
Example - direct ping succeeded



Example - direct ping failed



Example - all pings failed



Suspicion mechanism

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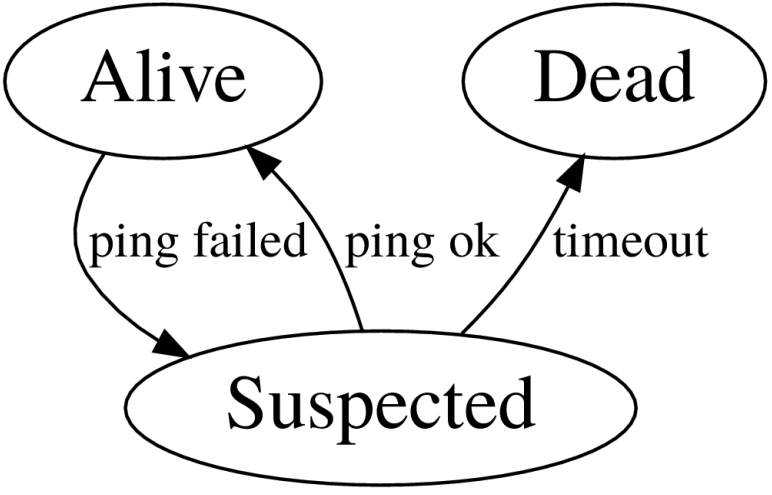

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  - Input: (key -> values[])
  - Output: (key -> merged-values)

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  - 1991:
    - Opel Vectra, ABS
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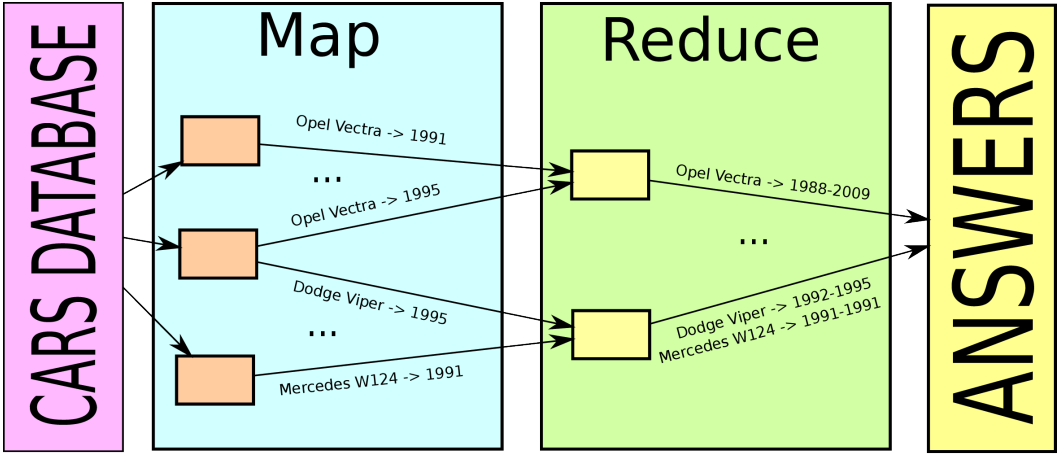
Computations



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- Algorithm:
  - Highly parallel
  - Widely adopted
  - Common solution for batch tasks

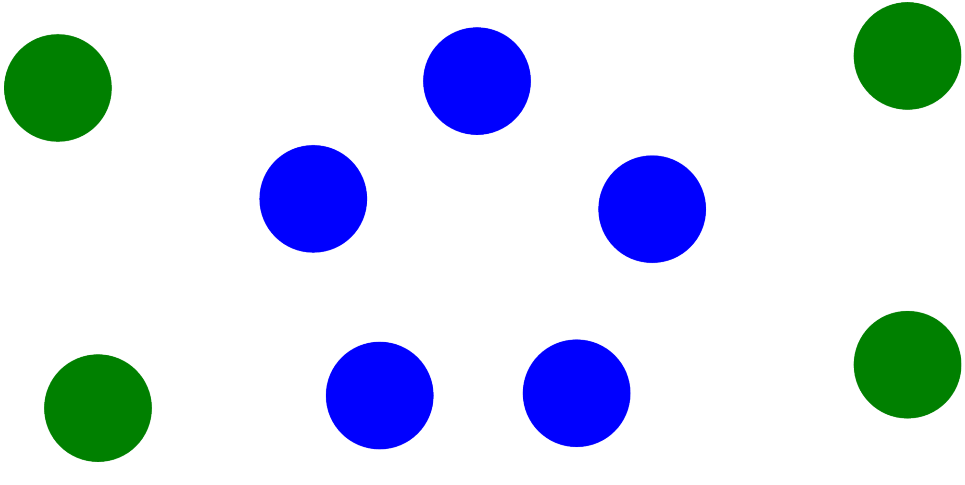
Practical applications

https://upload.wikimedia.org/wikipedia/commons/a/aa/Logo_Google_2013_Official.svg
https://upload.wikimedia.org/wikipedia/commons/0/0e/Hadoop_logo.svg
https://upload.wikimedia.org/wikipedia/en/f/f8/CouchDB.svg

https://upload.wikimedia.org/wikipedia/en/e/eb/MongoDB_Logo.png
https://upload.wikimedia.org/wikipedia/en/8/8e/Riak_distributed_NoSQL_key-value_data_store_logo.png

Part 6

Once upon a time...



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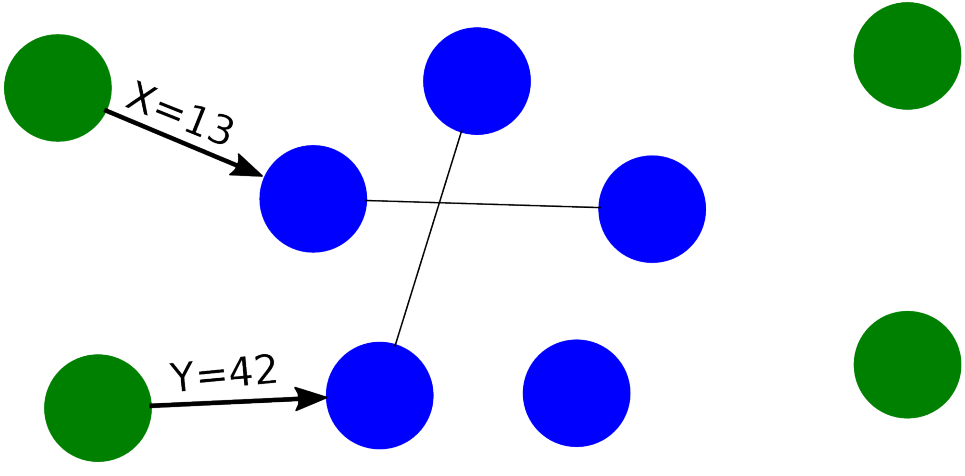

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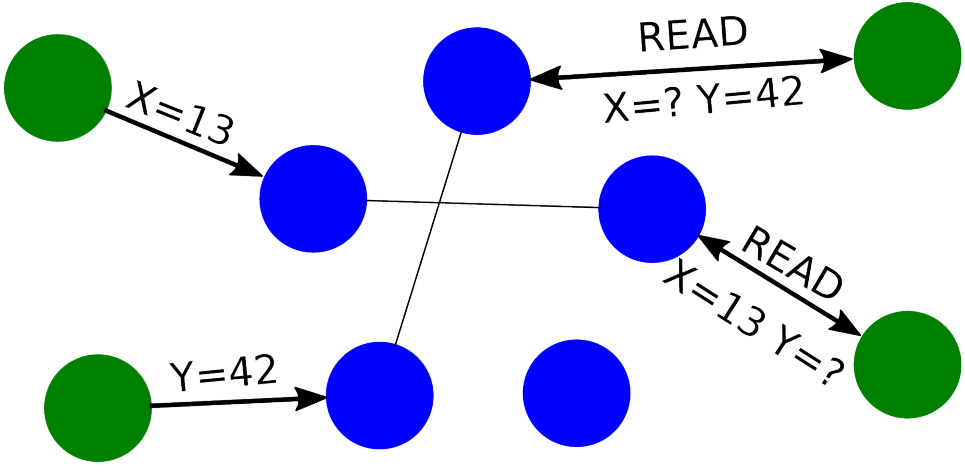

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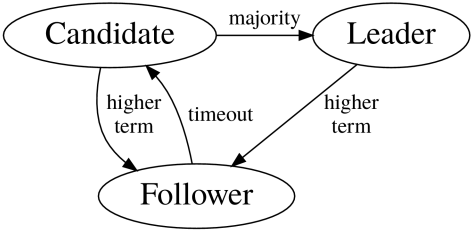
- Example algorithms:
  - Paxos
  - Raft

Raft's organization

- Node is in a given state



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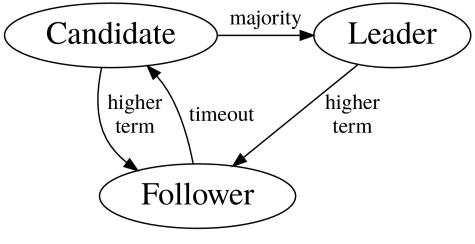

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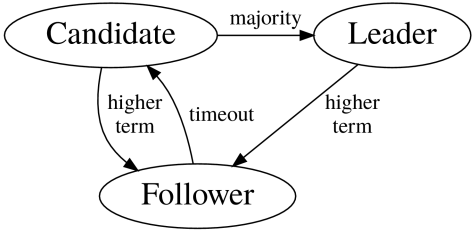

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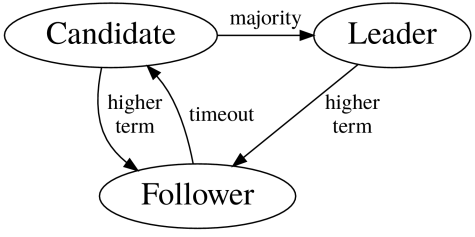
- Leader:
  - Send heartbeats
  - Synchronizes followers
- Clients talk with leader

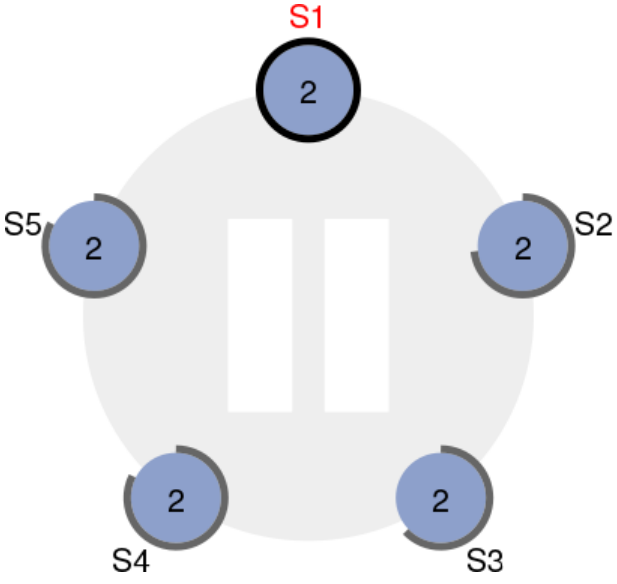


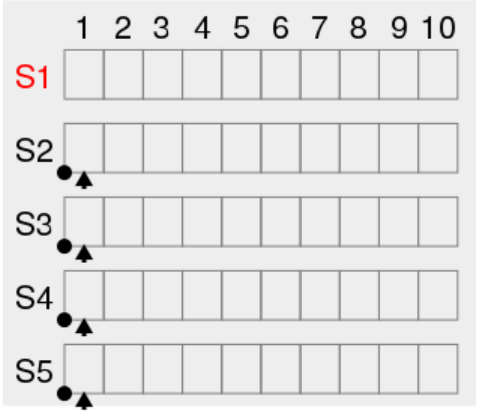
Log replication

https://fiftytwomedia.files.wordpress.com/2011/05/cloned-sheep.jpg

How log (state machine) is replicated?

Log replication





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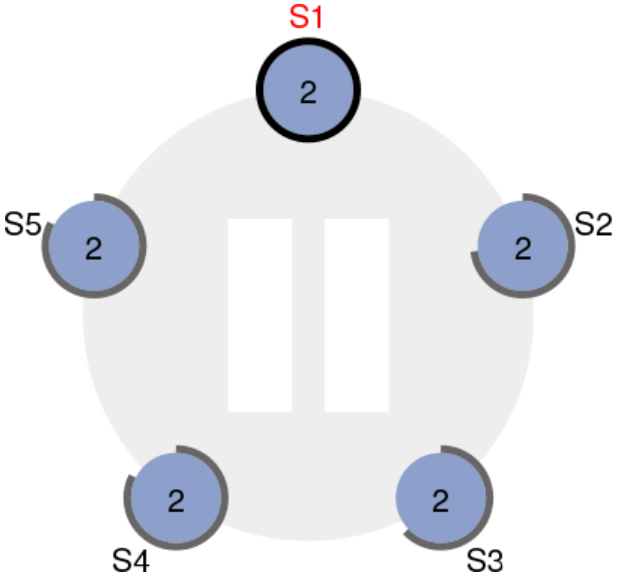

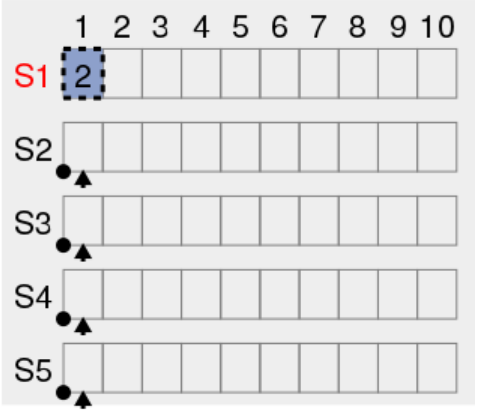

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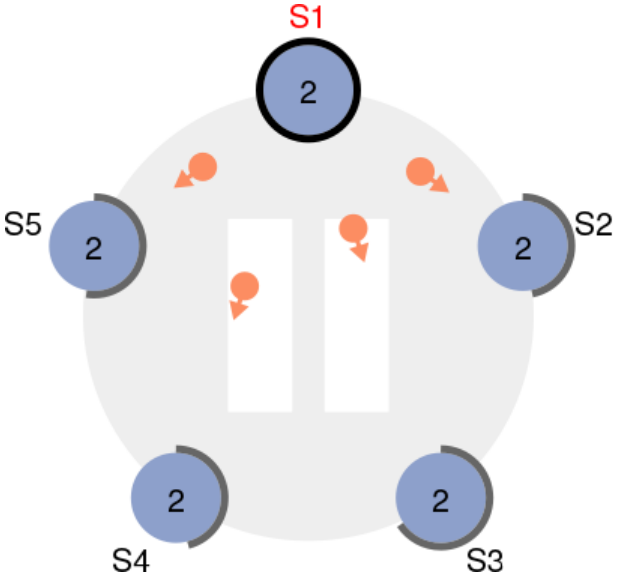

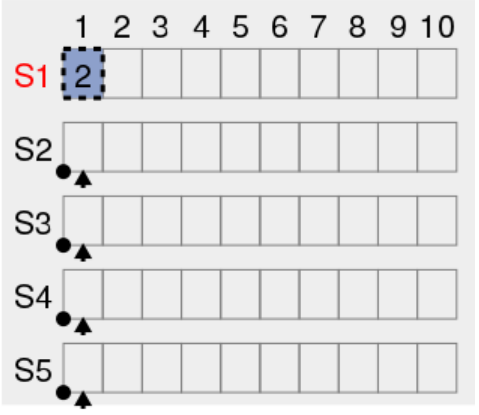

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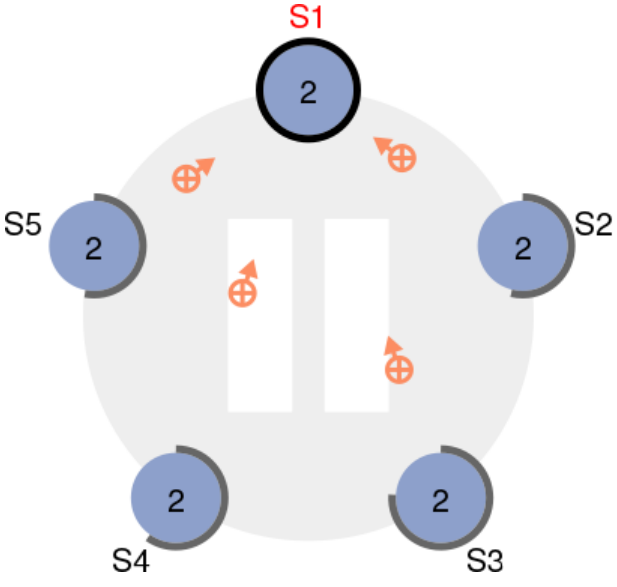

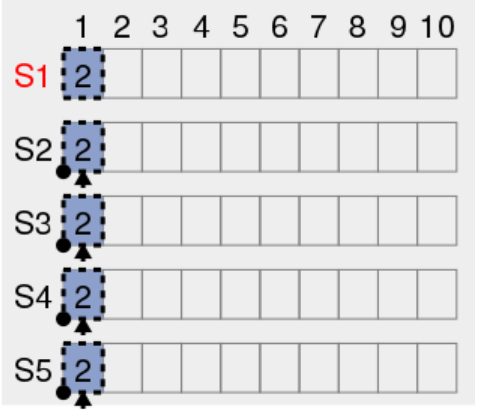

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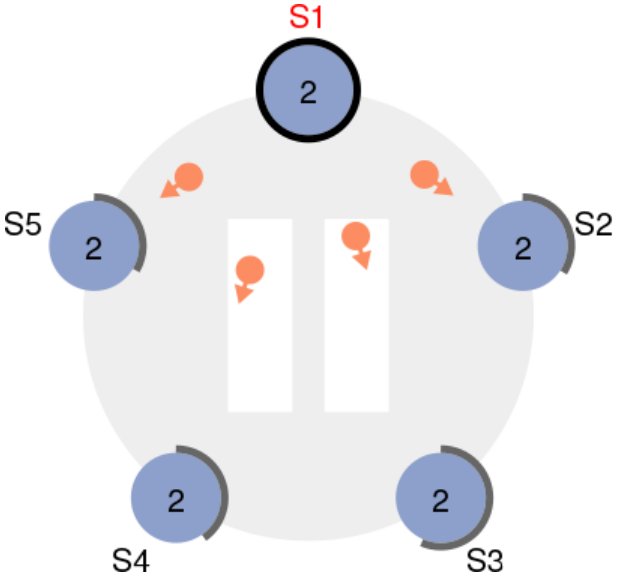
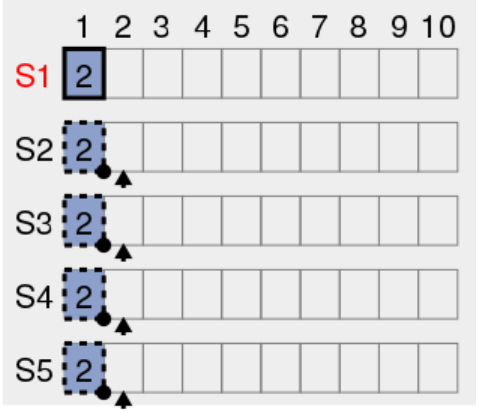
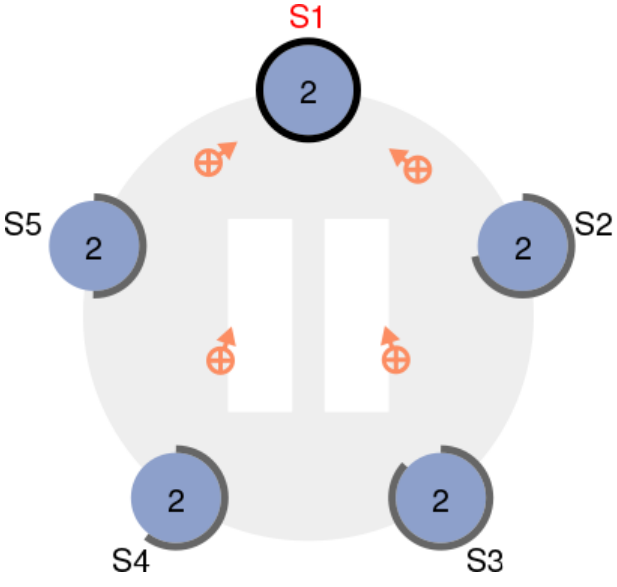
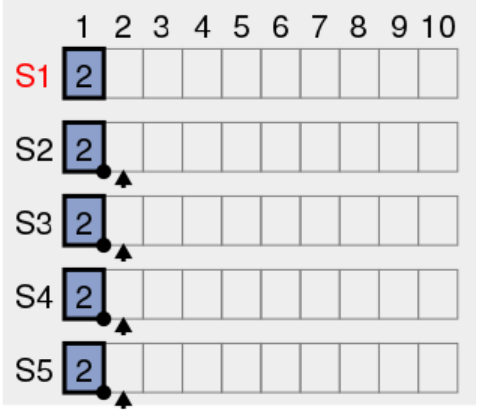




Log replication



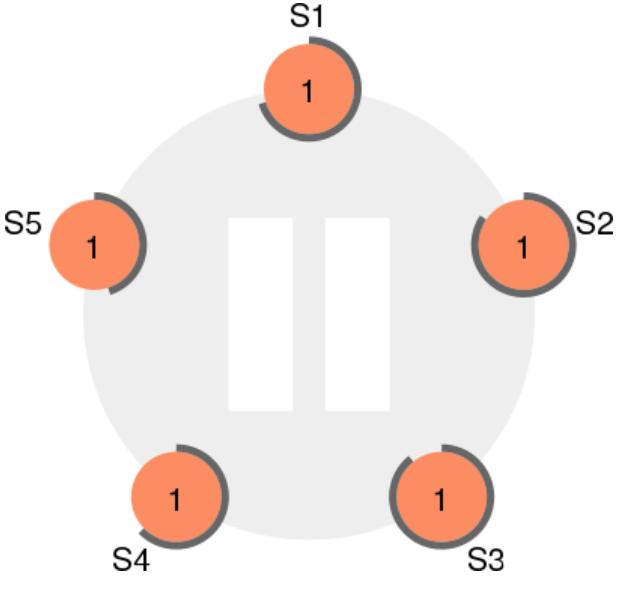


Leader election

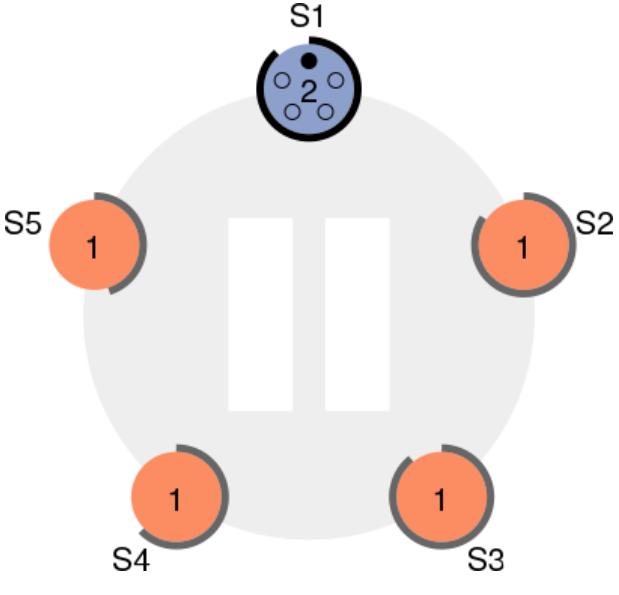
How leader election works?

http://i.huffpost.com/gen/1849024/thumbs/o-ELECTION-BALLOT-facebook.jpg

Leader election



Leader election



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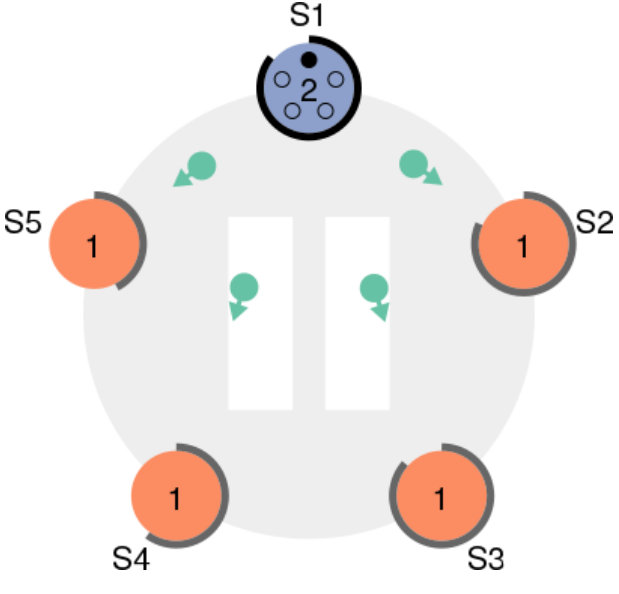
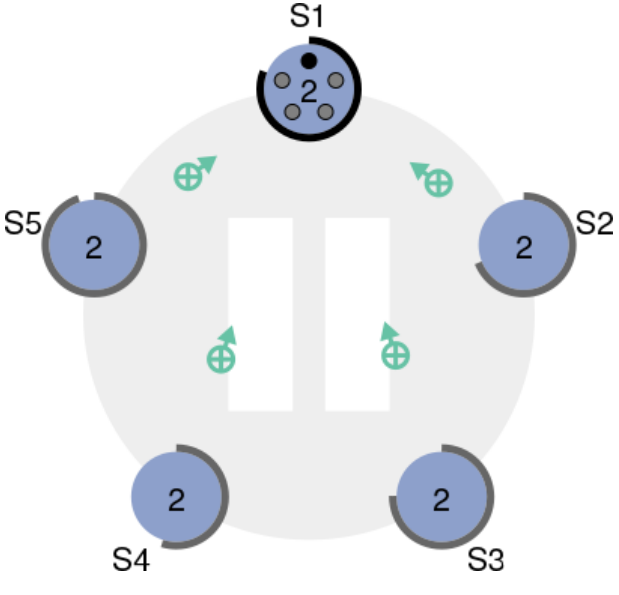


Leader election



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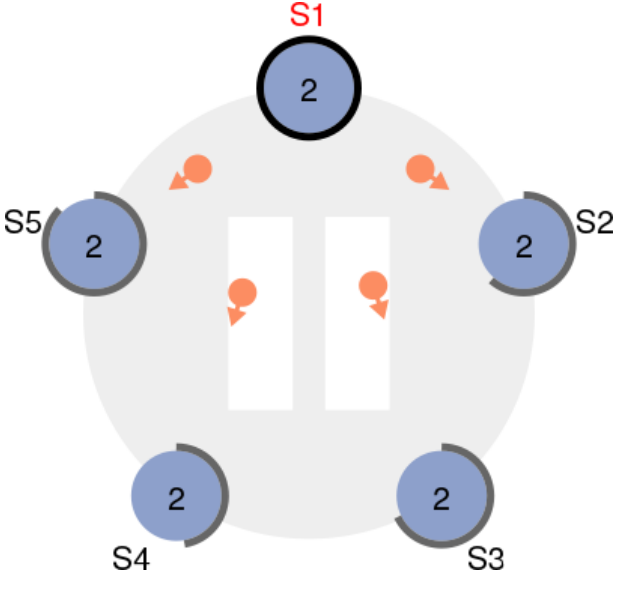
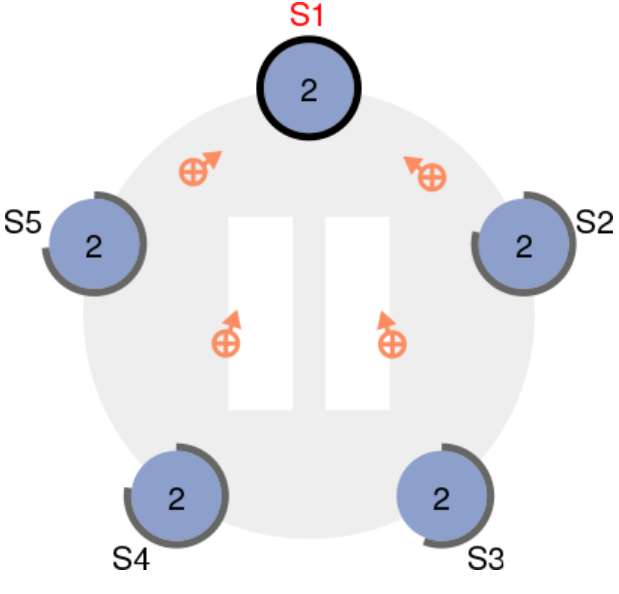


Leader election

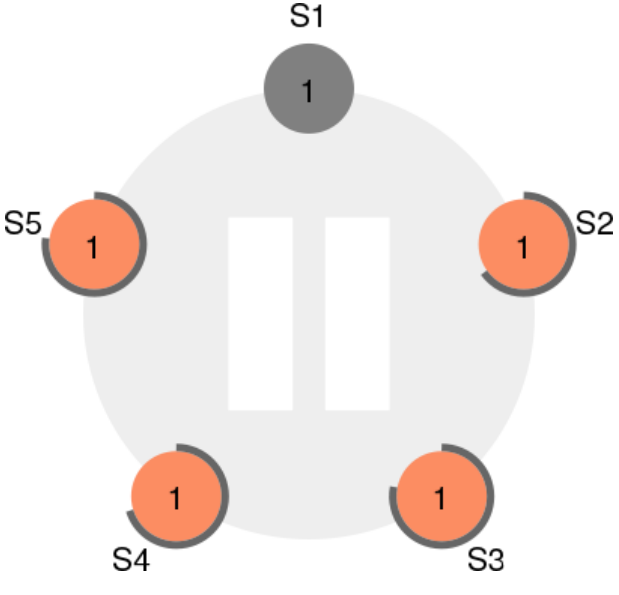


That simple?

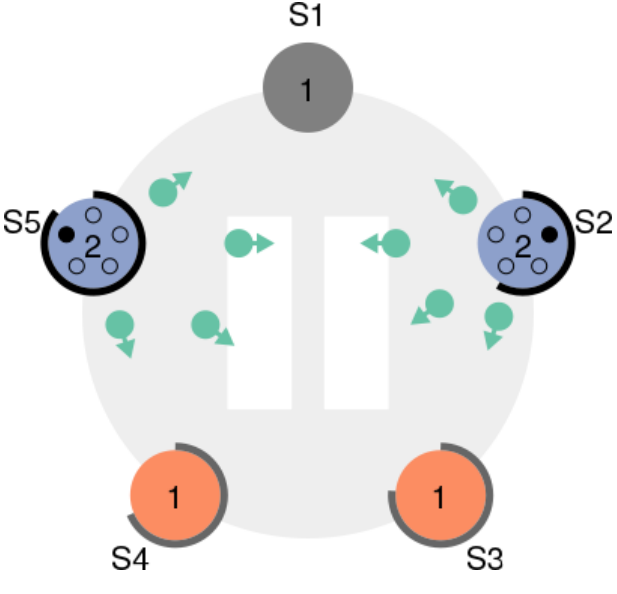
http://cache.gawkerassets.com/assets/images/4/2010/01/500x_hamshred.jpg

Does leader election always work?

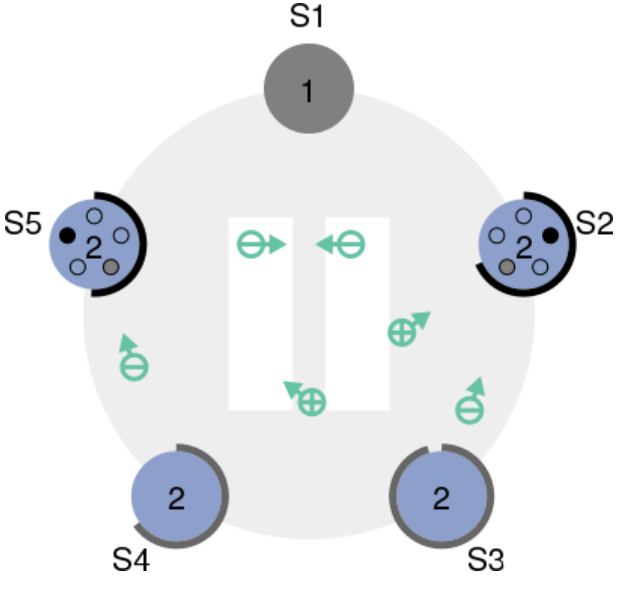
Split vote



Split vote



Split vote



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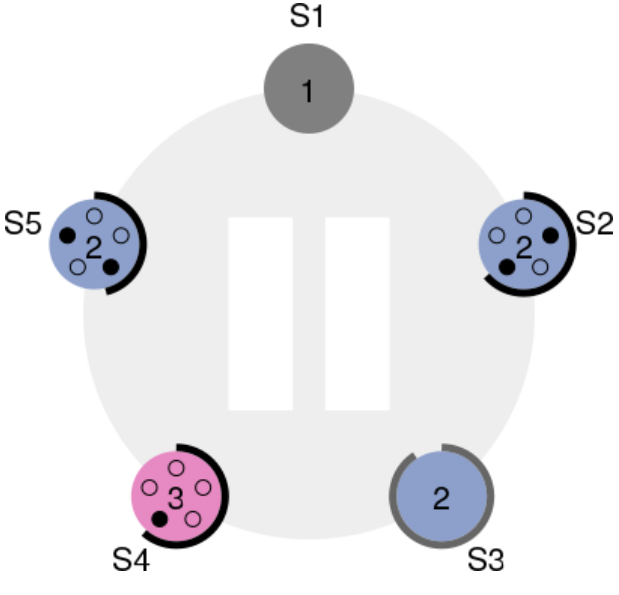

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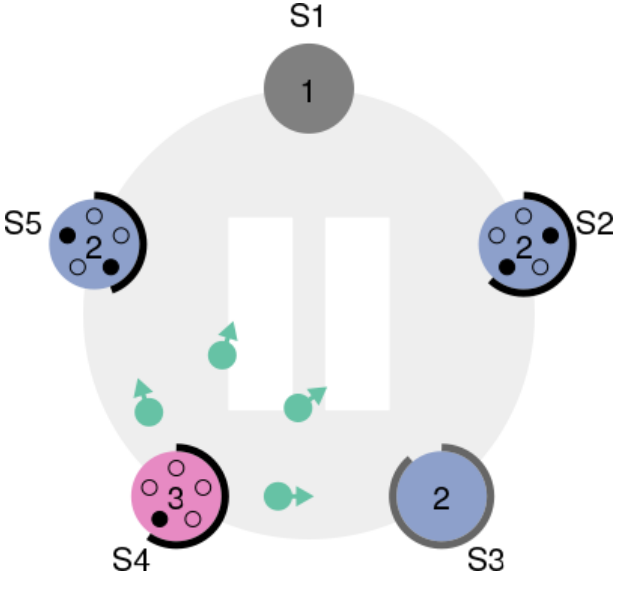

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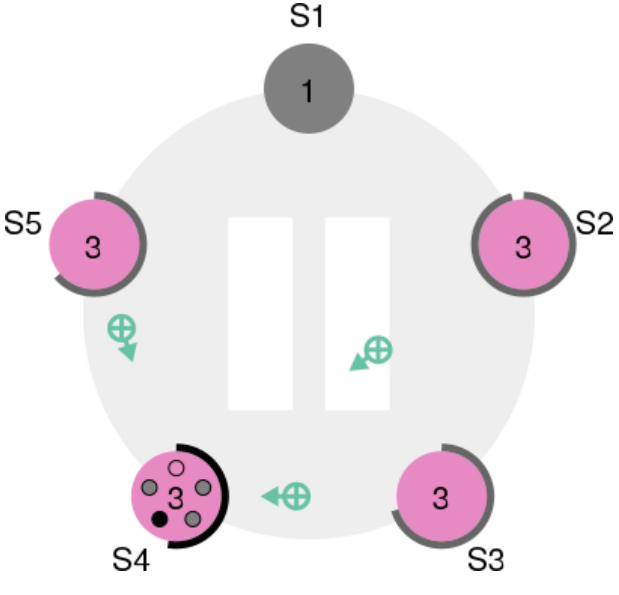

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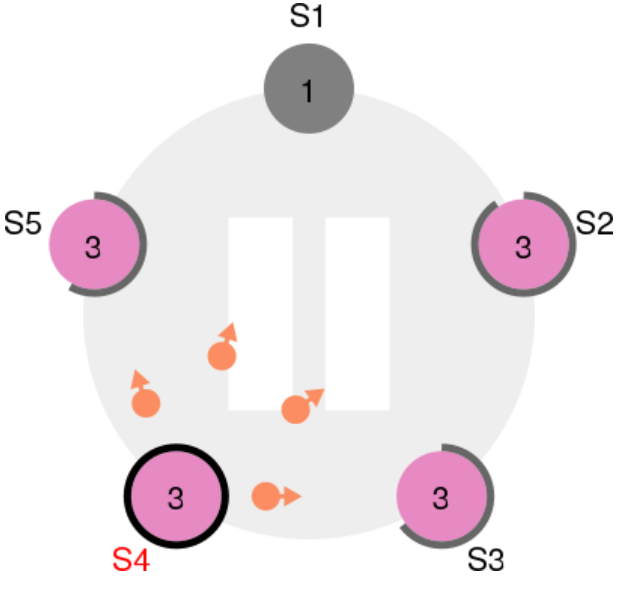

Raft's ecosystem

- Base of CockroachDB

- Widespread use
- "Paxos made simple"

Raft's ecosystem

- Base of CockroachDB

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Raft's implementations:

cppa-raft, LogCabin, bspolley/raft, noeleo/raft, whitewater, willemt/raft, NRaft, dupdob/RAFTiNG, dinghy, melee, raft-clj, rodriguezvalencia/rafting, draft, zraft_lib, eraft, huckleberry, rafter, rafterl, Flotten, graft, go-raft, etcd/raft, hashicorp/raft, jpathy/raft, peterbourgon/raft, pontoon, seaturtles, kontiki, allengeorge/libraft, barge, chicm/CmRaft, copycat, drpicox/uoc-raft-2013p, jalvaro/raft, jgroups-raft, RaftKVDatabase/JSimpleDB, OpenDaylight, pvilas/raft, Raft4WS, Raft-JVM, r4j, liferaft, benbjohnson/raft.js, dannycoates/raft-core, kanaka/raft.js, skiff, ocaml-raft, py-raft, simpleRaft, floss, giraft, harryw/raft, zodiac-prime, hoverbear/raft, akka-raft, archie/raft, cb372/raft, chelan, ckite, scalaraft, lite-raft, C5, yora, srned/Prez, fxsjy/Ins

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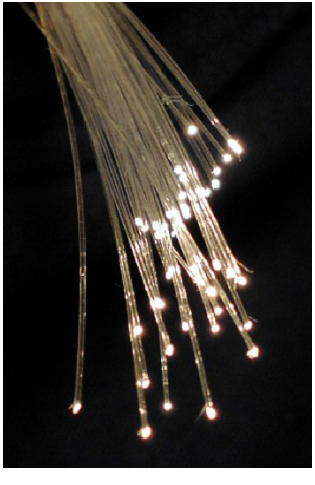
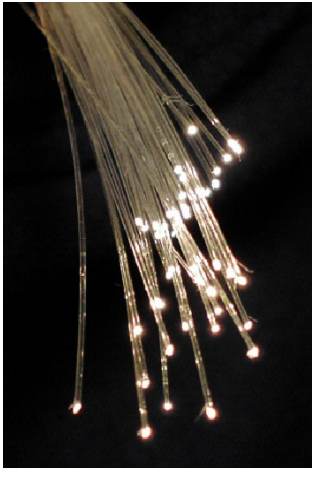
Part 7

Network partitioning



Network partitioning



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http://upload.wikimedia.org/wikipedia/commons/b/b9/Kitchen-Scissors.jpg
http://upload.wikimedia.org/wikipedia/commons/4/49/Fibreoptic.jpg

CAP theorem

- Systems' properties:
  1. **C**onsistency

CAP theorem

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CAP theorem

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CAP theorem

Having C/A/P – choose (at most) 2 of 3!

CAP theorem

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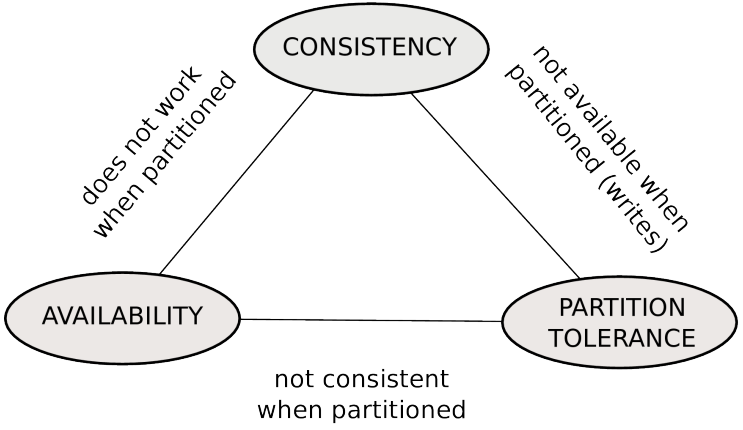

CAP theorem

Having C/A/P – choose (at most) 2 of 3!

Example systems' classification

- Having:
  - **C**onsistency
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  - **P**artition-tolerance

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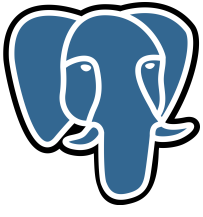

Example systems' classification

- Having:
  - **C**onsistency
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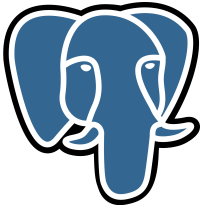
  - **P**artition-tolerance
- Examples:
  - PostgreSQL – **CA**P
  - MongoDB – **C**A**P**



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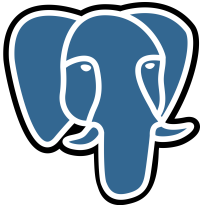
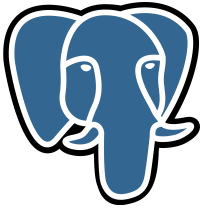


Example systems' classification

- Having:
  - **C**onsistency
  - **A**vailability
  - **P**artition-tolerance
- Examples:
  - PostgreSQL – **CA**P
  - MongoDB – **C**A**P**
  - Cassandra – C**AP**
- In reality:
  - Modulo bugs! :-)
  - Often configuration-dependent...
  - "*Call me maybe*" series



mongoDB

https://upload.wikimedia.org/wikipedia/commons/2/29/Postgresql_elephant.svg
https://upload.wikimedia.org/wikipedia/commons/5/5e/Cassandra_logo.svg
https://upload.wikimedia.org/wikipedia/en/e/eb/MongoDB_Logo.png

Part 8

Synchronizing time

- Given events:
  - **A** (at **nodeA**)
  - **B** (at **nodeB**)
- Did **A** happened before **B**?

Synchronizing time

- Given events:
  - **A** (at **nodeA**)
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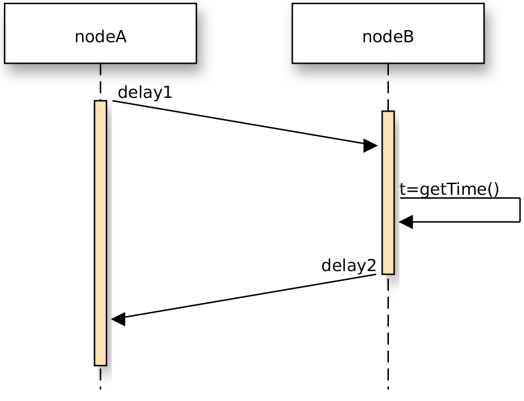
- Check their time!

Synchronizing time

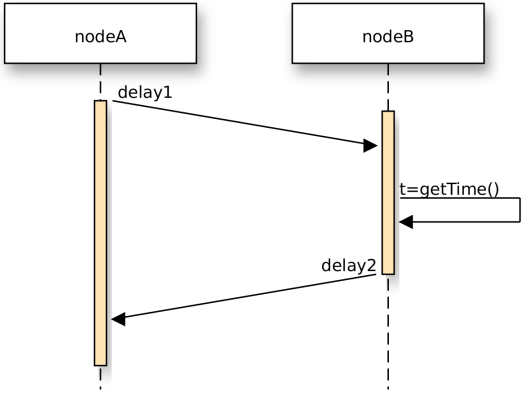
- Given events:
  - **A** (at **nodeA**)
  - **B** (at **nodeB**)
- Did **A** happened before **B**?
- Check their time!
  - Are clocks in sync? (*clock skew*)
    - How precise?
    - What about latencies?
  - Will clocks remain in sync? (*clock drift*)

http://1.bp.blogspot.com/-m4Wd15SQ3eY/T75YMmeYwrI/AAAAAAAAAaw/nrH2BxGSimw/s320/Clock+art-Salvador+Dali.jpg

Cristian's algorithm

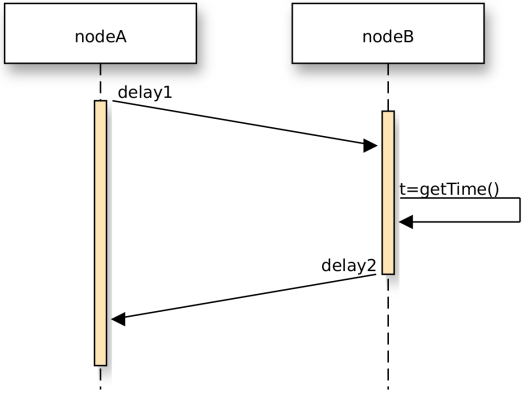


Cristian's algorithm



- Assuming $delay1 = delay2$
- New time: $t_1 = t + \frac{RTT}{2}$
- Where:
  - RTT – Round Trip Time
  - t_1 – new local time
  - t – time from remote party

Cristian's algorithm



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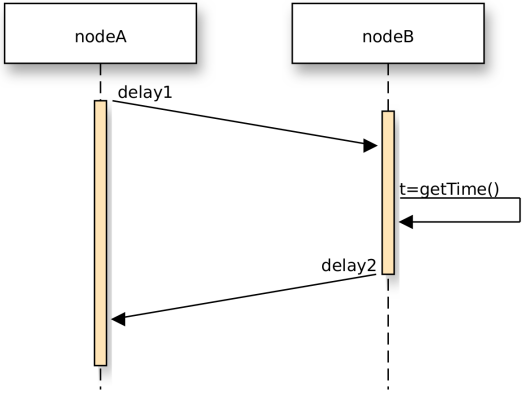
- Fairly Simple™;-)
- Often imprecise

Cristian's algorithm



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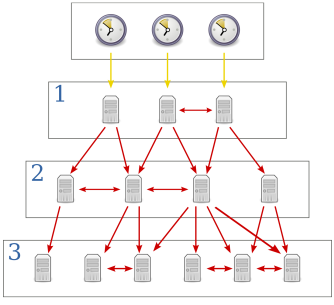
- Where:
  - RTT – Round Trip Time
  - t_1 – new local time
  - t – time from remote party
- Fairly Simple™;-)
- Often imprecise
- Single point of synchronization
- Does not scale

NTP's algorithm

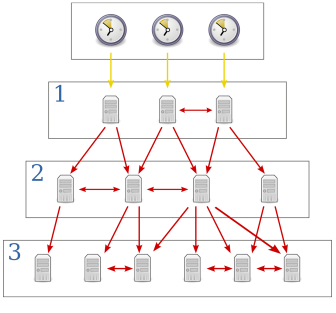
- **N**etwork **T**ime **P**rotocol

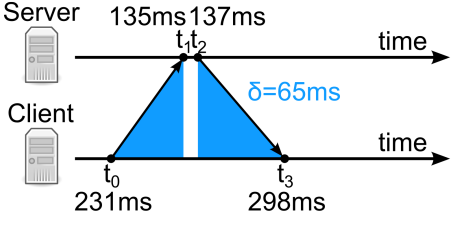


- More clock sources
- Better scalability

NTP's algorithm

- **N**etwork **T**ime **P**rotocol





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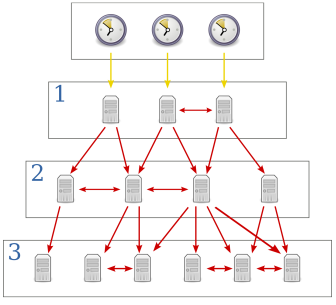

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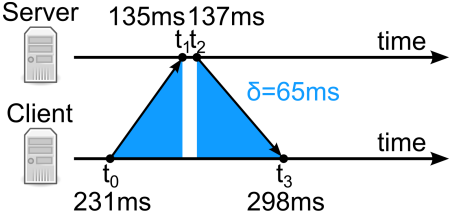
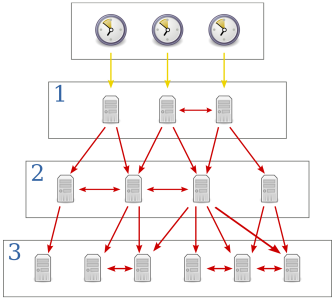


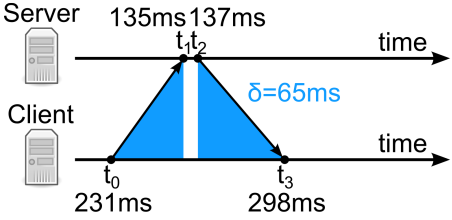
- Better *RTT* estimation
- Probabilistic analysis of data
- Continuous operation

NTP's algorithm

- **N**etwork **T**ime **P**rotocol



- More clock sources
- Better scalability



- Better *RTT* estimation
- Probabilistic analysis of data
- Continuous operation

- Commonly use in the Internet
- Still clocks skew and drift. . .

http://upload.wikimedia.org/wikipedia/commons/c/c9/Network_Time_Protocol_servers_and_clients.svg

http://upload.wikimedia.org/wikipedia/commons/8/8d/NTP-Algorithm.svg

Now what if...

- Cannot solve?

Now what if...

- Cannot solve?
  - Step back
  - Find a different path...

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- What is REALLY needed?

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  - Ordering knowledge
  - "What happened first?"

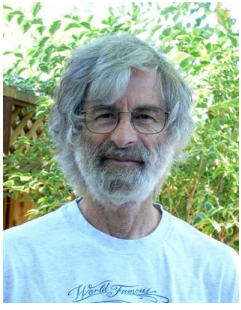
Now what if...

- Cannot solve?
  - Step back
  - Find a different path...
- What is REALLY needed?
  - Ordering knowledge
  - "What happened first?"
- Can be done without time...

Part 9

Logical ordering

- **L**amport's **T**ime **S**tamp
- Proposed by *Leslie Lamport*
- Establishes *happens-before* relation



Logical ordering

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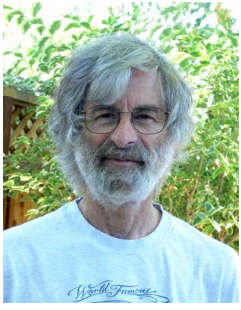
- Each process has counter *lts*
- Initially $lts = 0$



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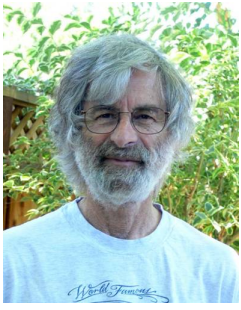
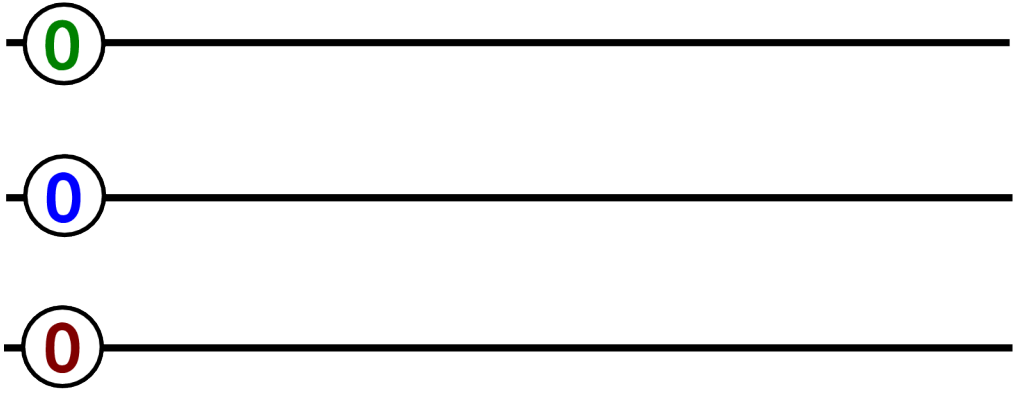


https://upload.wikimedia.org/wikipedia/commons/5/50/Leslie_Lamport.jpg

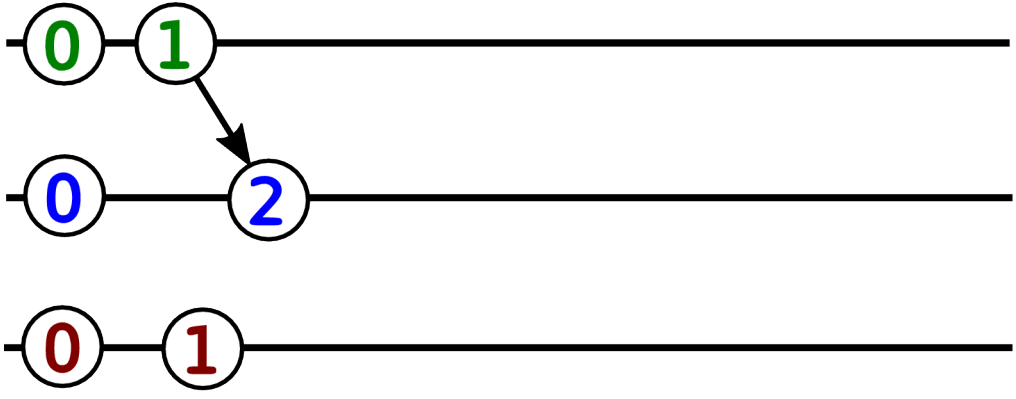
Come again?

http://lshss.pubs.asha.org/data/Journals/LSHSS/930529/LSHSS_45_3_220fig0.jpeg

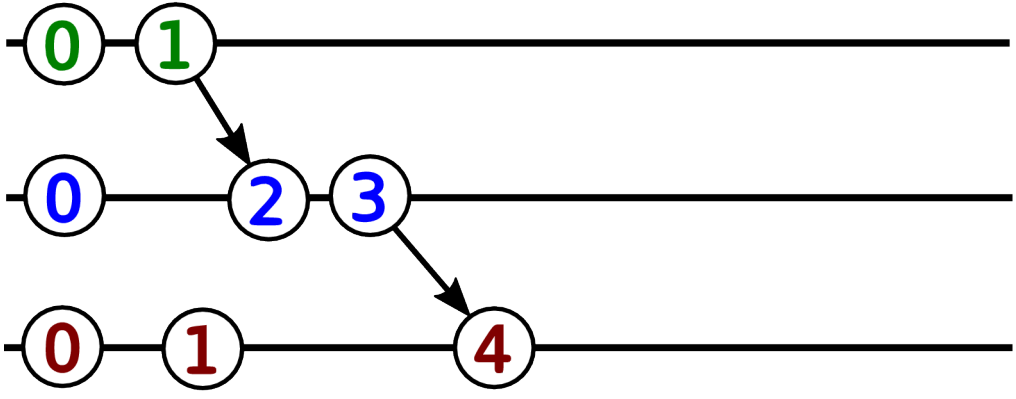
Example



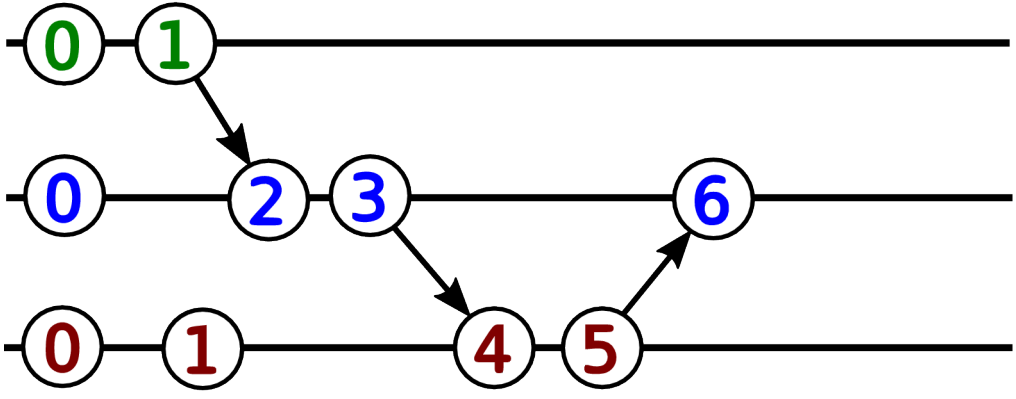
Example



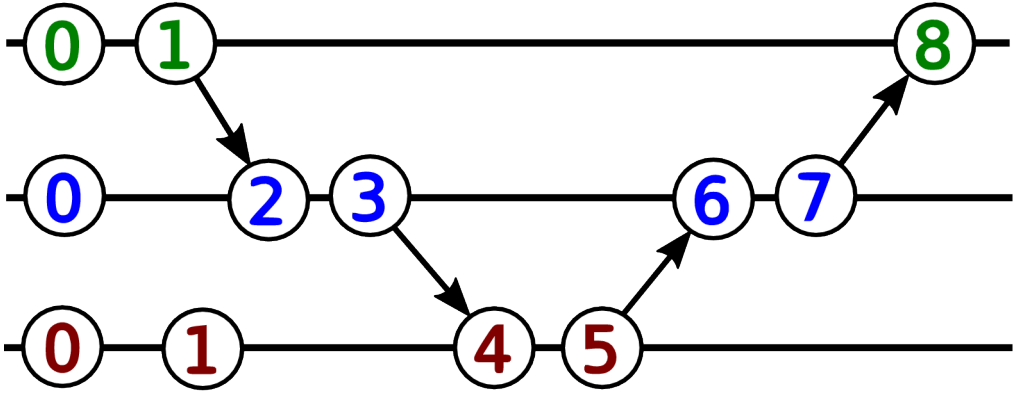
Example



Example



Example



Properties

- Events: A and B
- With timestamps: $C(A)$ and $C(B)$

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  - But **not** $B \rightarrow A$

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    - $A \rightarrow B$
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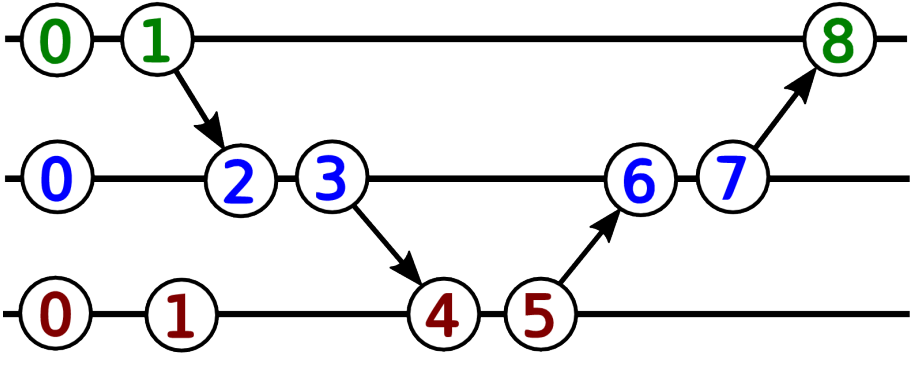
  - But **not** $B \rightarrow A$
- Cause-effect ordering!

Let's check!

$$C(A) < C(B) \Leftrightarrow A \rightarrow B \vee A \parallel B$$



Lamport's timestamps at . . .

- Pretty much everywhere. . . ;)
- Including. . .

Lamport's timestamps at . . .

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Lamport's timestamps at . . .

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- Including. . .

- Part of BTS software:
  - WCDMA OAM
  - SRAN OAM
  - Cloud OAM
- Distributed service registration
- Introduces logical ordering
- Registration updates' ordering

https://upload.wikimedia.org/wikipedia/commons/0/02/Nokia_wordmark.svg

Part 10

Enhanced logical ordering

- Similar to Lamport's timestamps
- Detects parallel events

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- Each process has vector of counters $vc = [c1, c2, ..., cN]$
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- Detects parallel events
- Each process has vector of counters $vc = [c1, c2, ..., cN]$
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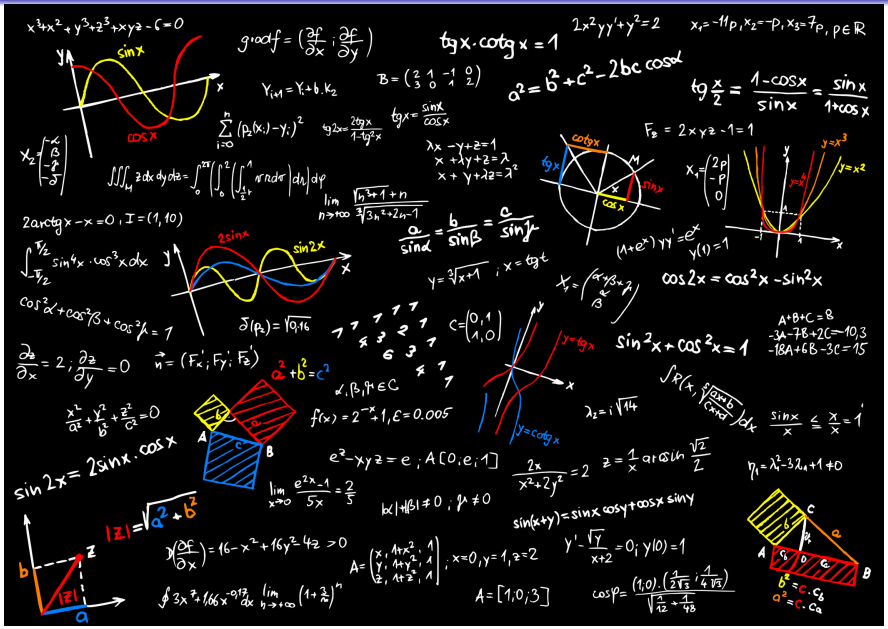
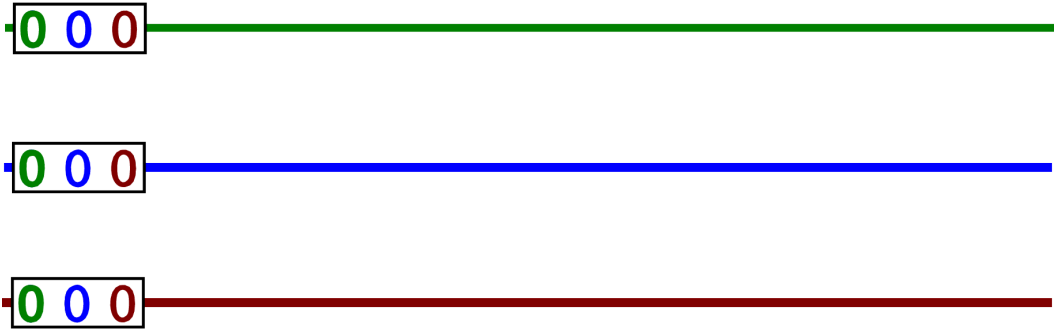
- Algorithm:
  - On i-th node
  - Before sending: $vc[i] = vc[i] + 1$
  - Include vector in the message
  - When receiving:
    - $\forall j \neq i : vc[j] = max(vc[j], msg\_vc[j])$
    - $vc[i] = vc[i] + 1$
- Also can increment local counter at will

You don’t say...

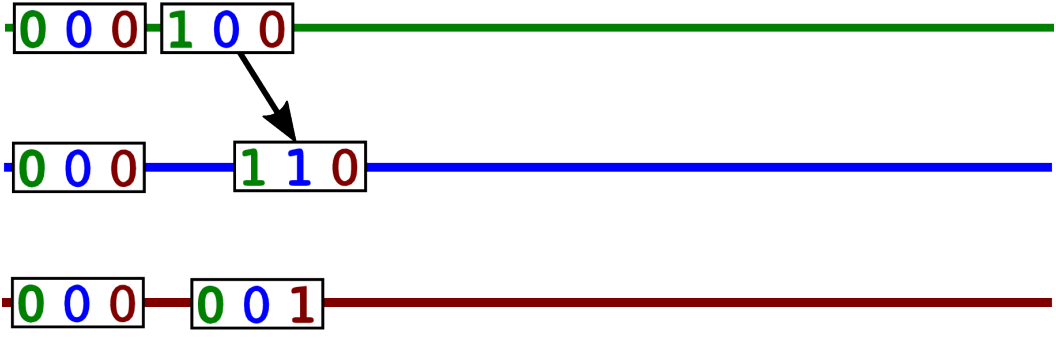


http://syosseths.com/z/acapics/mathslide.jpg

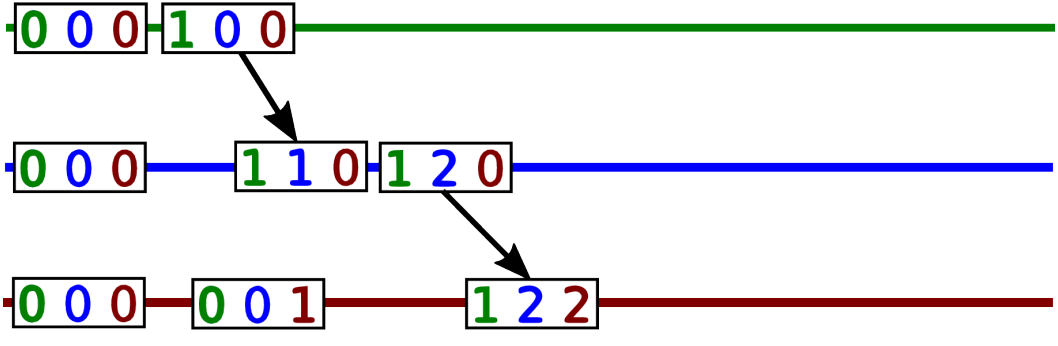
Example



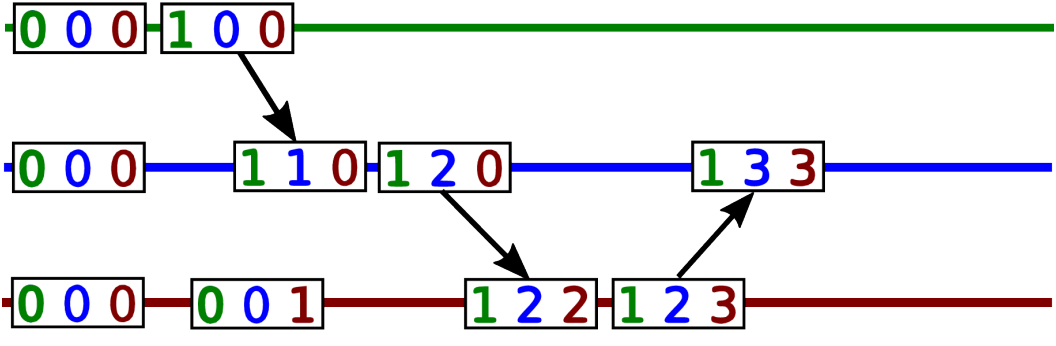
Example



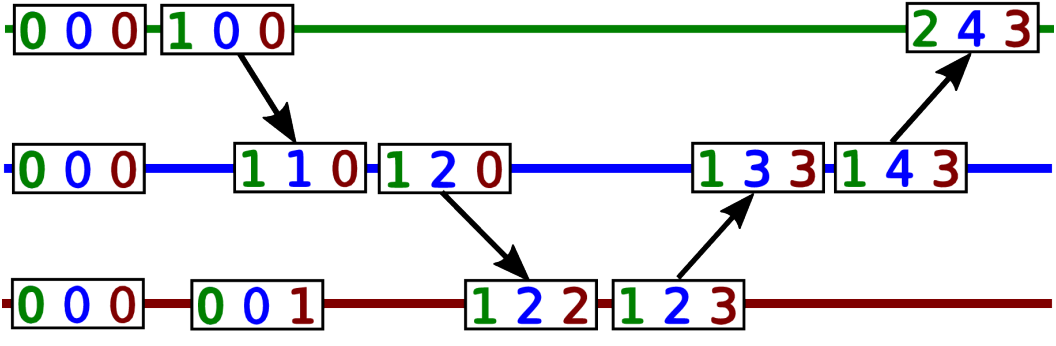
Example



Example



Example



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- Causality:
  - $A \rightarrow B \Leftrightarrow vc(A) < vc(B)$
  - $A \parallel B \Leftrightarrow \neg(vc(A) \leq vc(B)) \wedge \neg(vc(B) \leq vc(A))$

Let's check!

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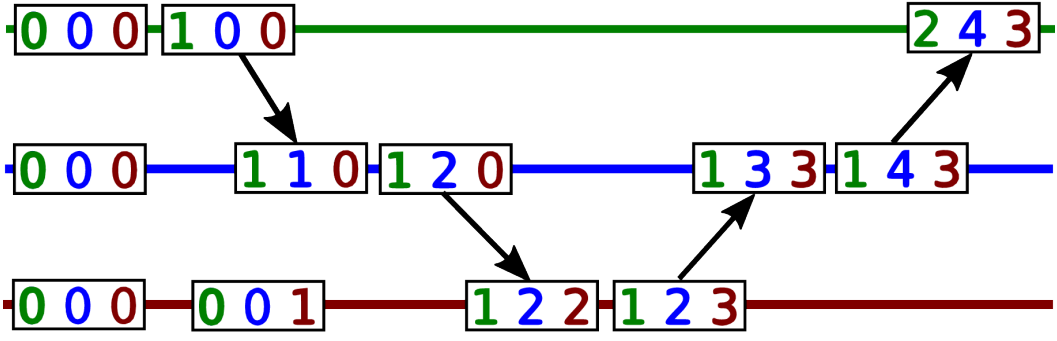


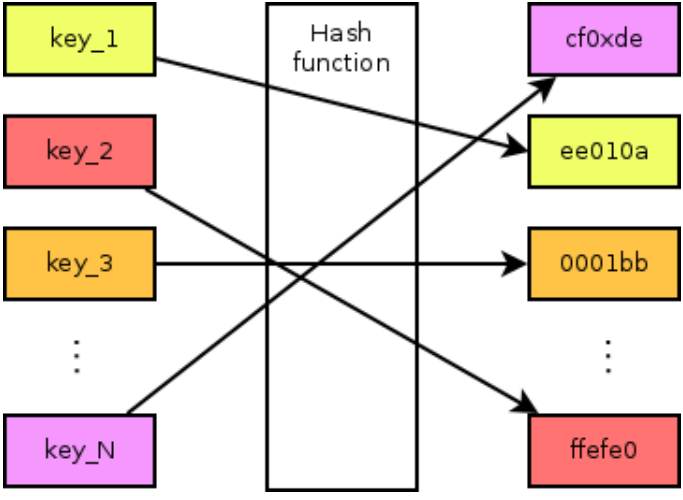
Vector clocks inside Riak

- Riak:
  - NoSQL data base
  - Based on "Dynamo" paper
- VC for eventual consistency
- Help solve conflicts:
  - Resolve duplicates
  - Detect latest version
  - Detect simultaneous updates

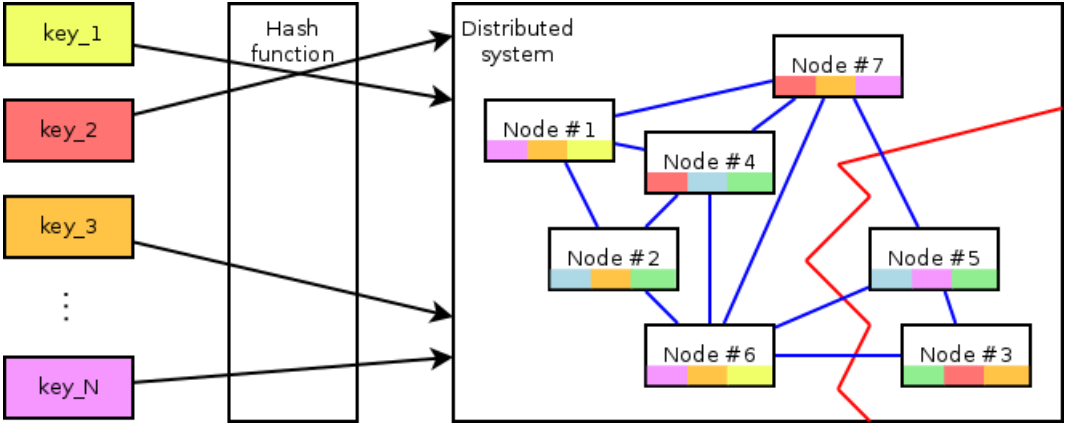
https://upload.wikimedia.org/wikipedia/en/8/8e/Riak_distributed_NoSQL_key-value_data_store_logo.png

Part 11

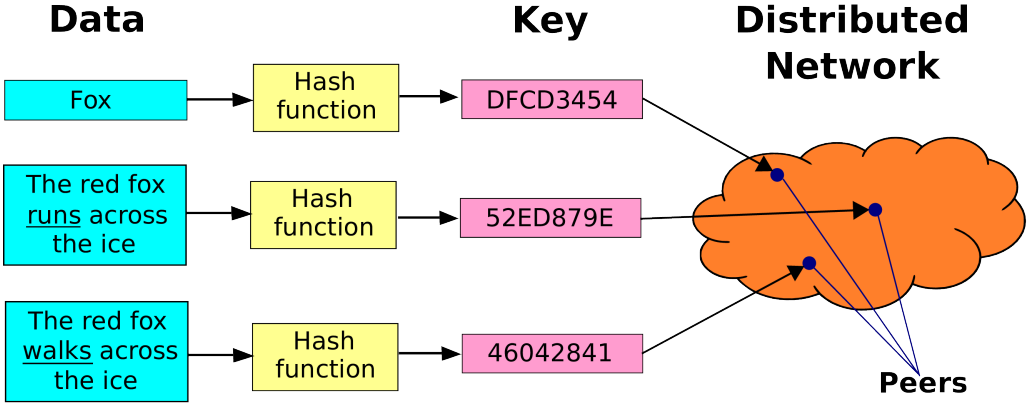
Hash table


key_1
key_2
key_3
key_N
Hash function
cf0xde
ee010a
0001bb
ffefe0

Distributed Hash Table (DHT)



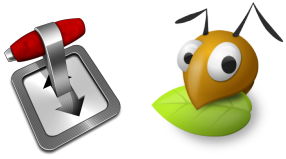
Keys distribution

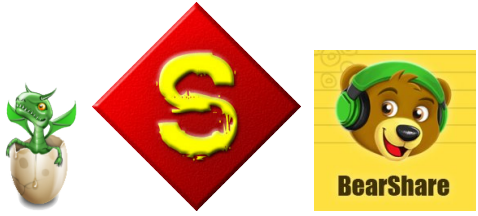


https://upload.wikimedia.org/wikipedia/commons/9/98/DHT_en.svg

DHTs everywhere

- Common since the end of ’90
- Base of most NoSQL DBs
- Advantages:
  - Massive storage
  - Decentralized
  - Fault tolerant
  - Scalable

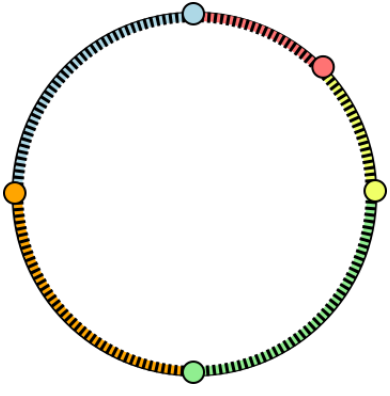




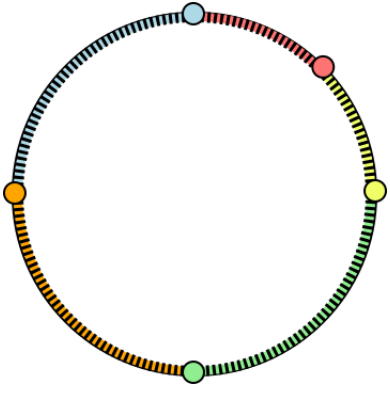
https://upload.wikimedia.org/wikipedia/commons/5/5e/Cassandra_logo.svg
http://www.gluster.org/images/antmascot.png?1432254431
https://upload.wikimedia.org/wikipedia/en/8/8e/Riak_distributed_NoSQL_key-value_data_store_logo.png
https://upload.wikimedia.org/wikipedia/commons/6/6d/Transmission_icon.png
https://upload.wikimedia.org/wikipedia/en/9/9f/UTorrent_%28logo%29.png
https://upload.wikimedia.org/wikipedia/commons/9/9e/Qbittorrent_logo.png
https://upload.wikimedia.org/wikipedia/commons/f/ff/Qbittorrent_mascot.png
https://upload.wikimedia.org/wikipedia/en/d/d5/BitComet_logo.svg
https://upload.wikimedia.org/wikipedia/commons/0/0a/Shareaza.png
https://upload.wikimedia.org/wikipedia/en/d/d6/Logo_of_BearShare_from_Website.jpg

Part 12

The ring

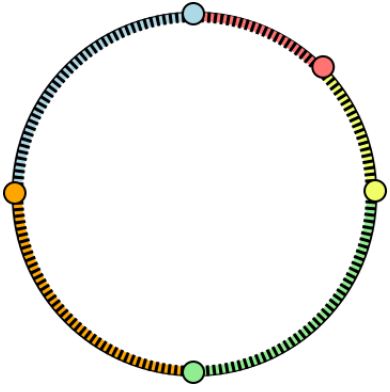


The ring



- Ring-organized
- m-bits (2^m possible entries)
- Ordered clock-wise
- Node keeps preceding keys

The ring



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- Nodes hashed by:
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  - Port

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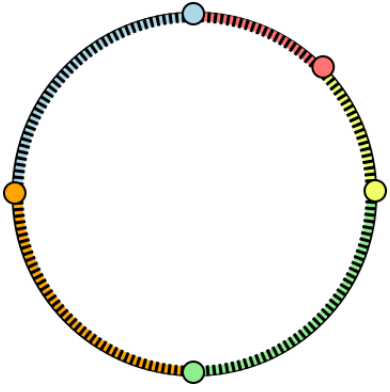

- Ring-organized
- m-bits (2^m possible entries)
- Ordered clock-wise
- Node keeps preceding keys
- Nodes hashed by:
  - Address (IP?)
  - Port
- Keys:
  - User's hash
  - Share key space with nodes
- *SHA-1* commonly used

Finger table

- Each node keeps own
- m-entries
- $(n + 2^i)\%2^m$
- Where:
  - i – entry number
  - n – node's number
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- Where:
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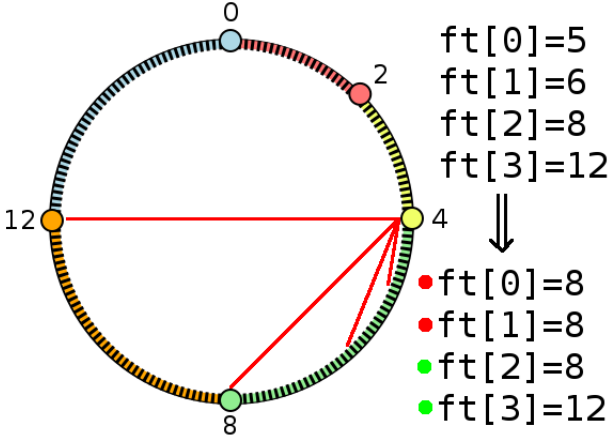
- Here: $n = 4$, $m = 4$
- i.e. $2^4 = 16$ entries



One ring to hash them all!

https://upload.wikimedia.org/wikipedia/commons/b/b7/Unico_Anello.png

Query algorithm

1. Having query for k
2. If has k – return it

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3. $next = \max(ft[i] : i \in \langle 0; m) \wedge ft[i] \leqslant k)$
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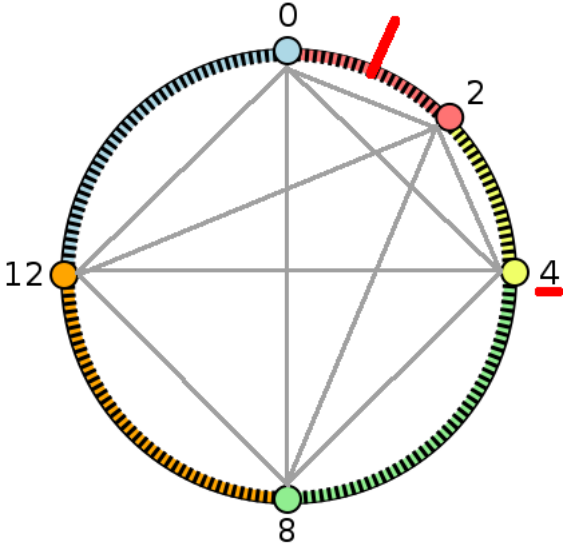
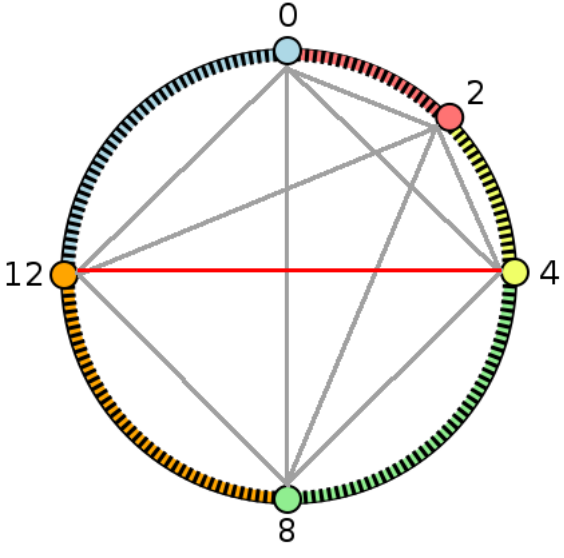
5. If has $next$ – return it
6. Else return first successor

Query example



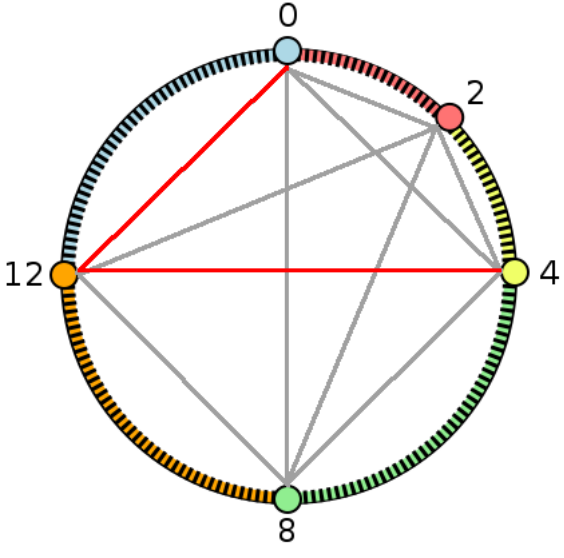
- Node 4 – query 1

Query example



- Node 4 – query 1
- Finger tables:
  1. $n = 4$
     - $ft[0] = 8$
     - $ft[1] = 8$
     - $ft[2] = 8$
     - $ft[3] = 12$

Query example



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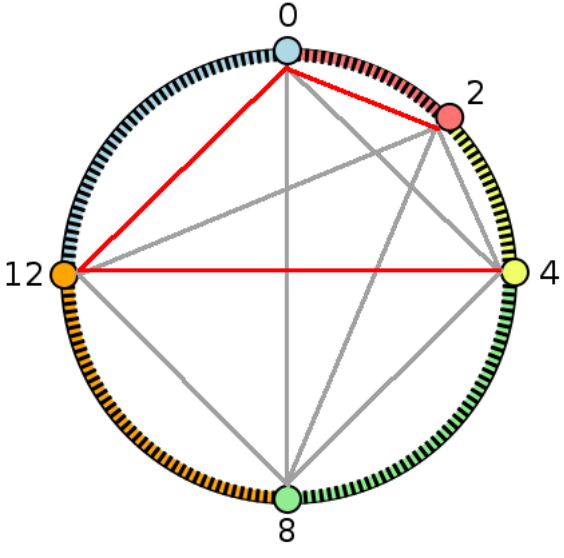
  1. $n = 4$
     - $ft[0] = 8$
     - $ft[1] = 8$
     - $ft[2] = 8$
     - $ft[3] = 12$
  2. $n = 12$
     - $ft[0] = 0$
     - $ft[1] = 0$
     - $ft[2] = 0$
     - $ft[3] = 4$

Query example



- Node 4 – query 1
- Finger tables:
  1. $n = 4$
     - $ft[0] = 8$
     - $ft[1] = 8$
     - $ft[2] = 8$
     - $ft[3] = 12$
  2. $n = 12$
     - $ft[0] = 0$
     - $ft[1] = 0$
     - $ft[2] = 0$
     - $ft[3] = 4$
  3. $n = 0$
     - $ft[0] = 2$
     - $ft[1] = 2$
     - $ft[2] = 4$
     - $ft[3] = 8$

Additional notes

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- (Amortized) $O(\log N)$ lookup
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- Failures handing:
  - Duplication of data
  - More entries per finger table
  - Keeping few predecessors
  - Monitoring neighborhood

Part 13

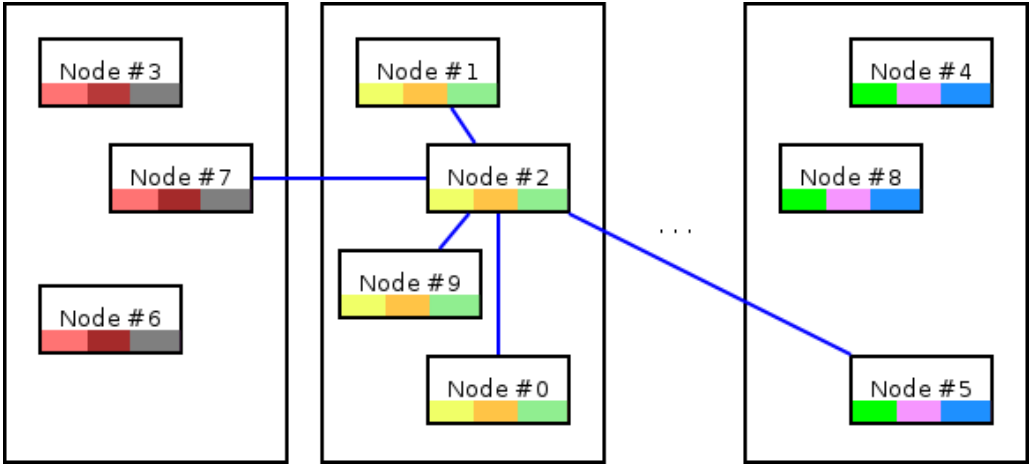
Idea

- Split space:
  - *k affinity groups*
  - $k \approx \sqrt{N}$

Idea

- Split space:
  - *k affinity groups*
  - $k \approx \sqrt{N}$
- Group based on node's hash
- Node in a group knows:
  - All members of its group
  - One node per other groups
  - All group's hashes

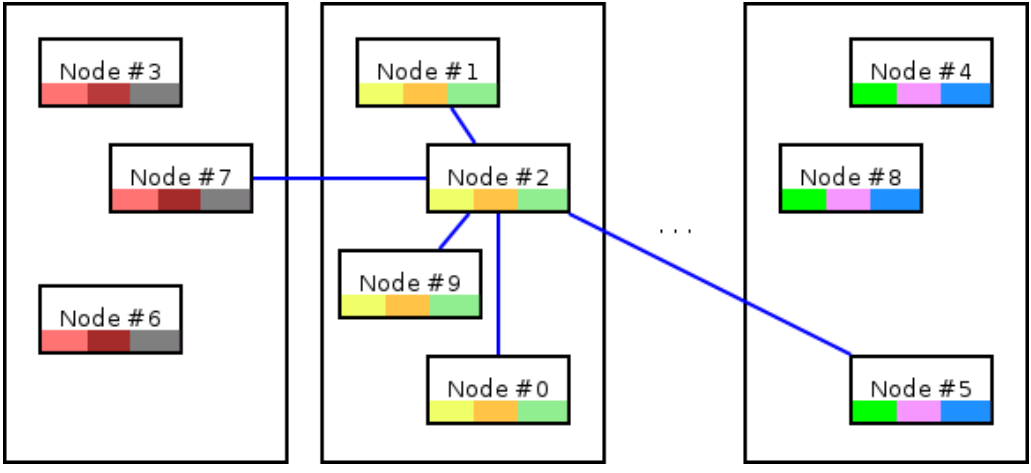
Example - node 2



Local query

Querying for key from the same affinity group

Node #2 querying "yellow" key



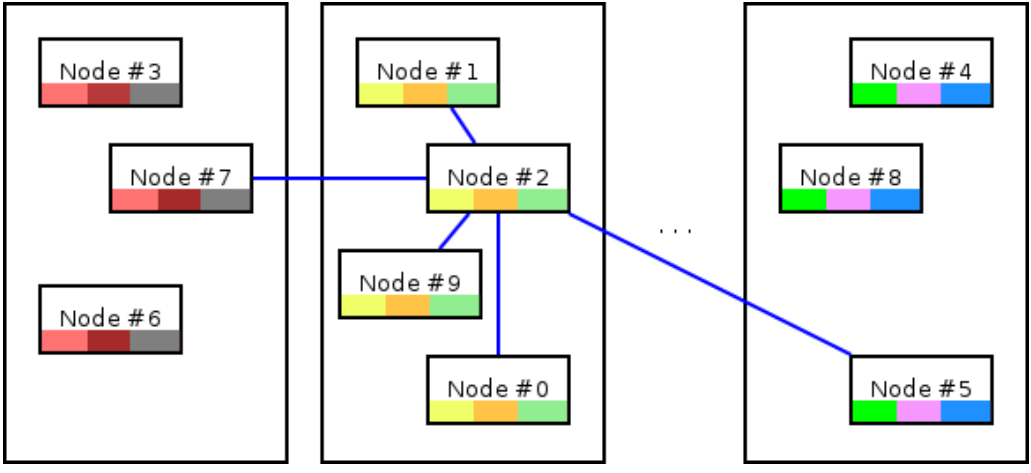
It’s here!

http://asalesguyrecruiting.com/wp-content/uploads/2014/03/Oh-Hell-Yeah-566x372.png

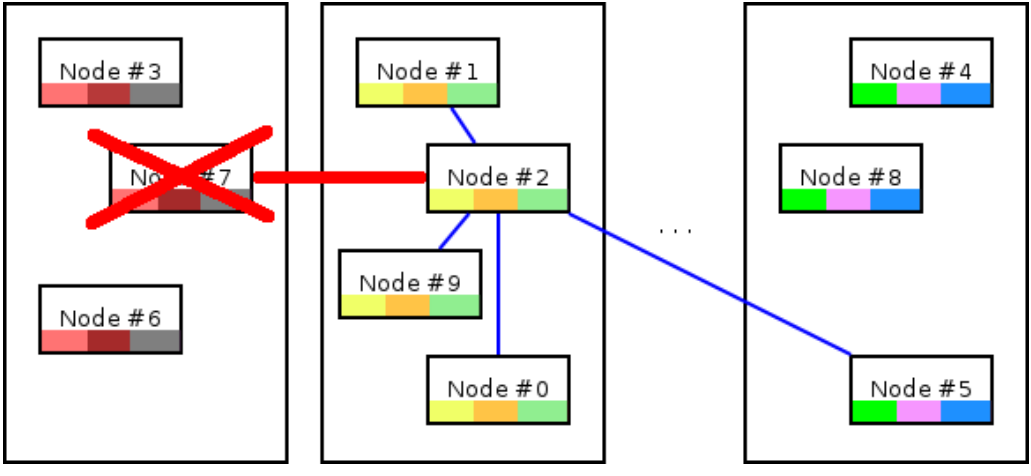
Remote query

Querying for key from different affinity group

Node #2 querying "red" key



Node #2 querying "red" key



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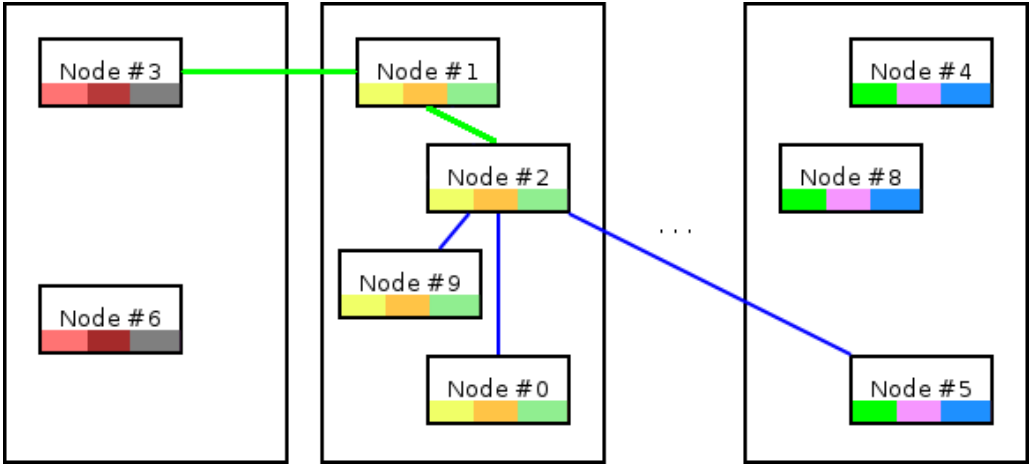
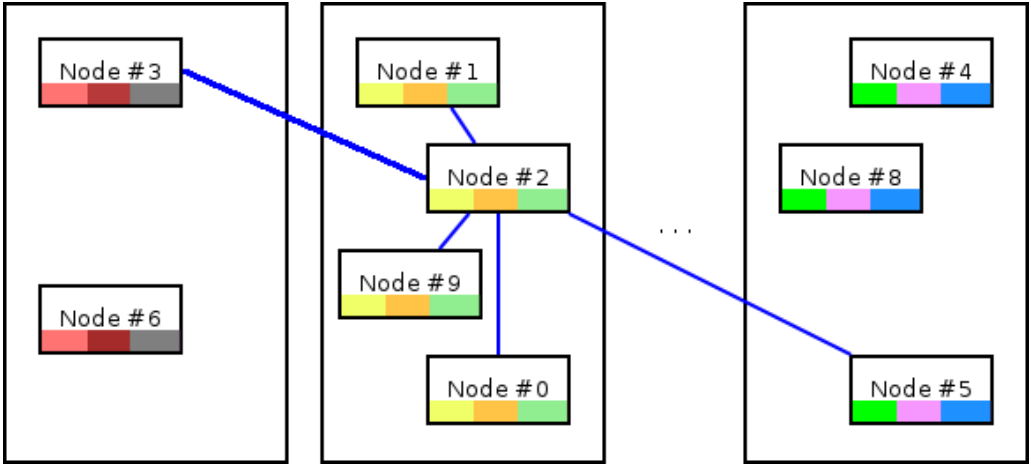


Node #2 querying "red" key



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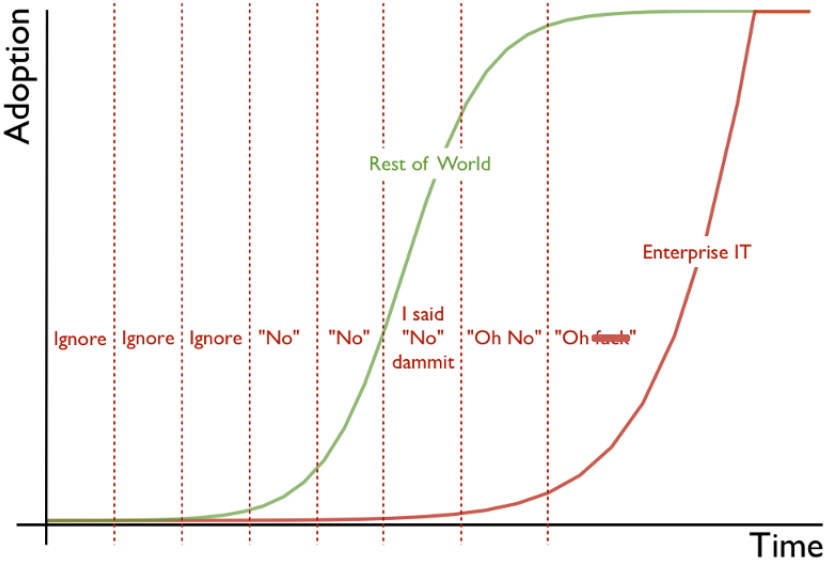
- Failures handing:
  - Monitoring own affinity group
  - Querying others for affinity neighbors

Part 14

Cloud @ enterprises



http://enterpriseitadoption.com/images/adoption_cycle.png

More to learn...

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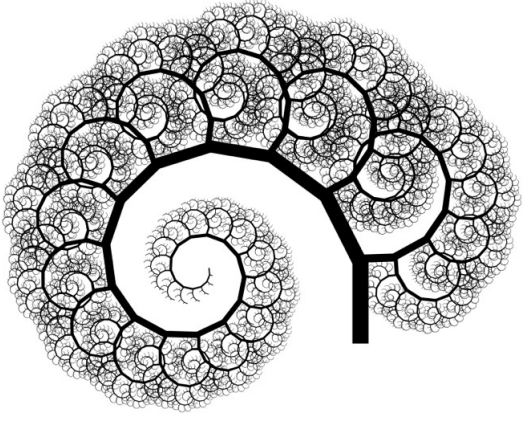
  - Cloud computing applications
  - Cloud networking



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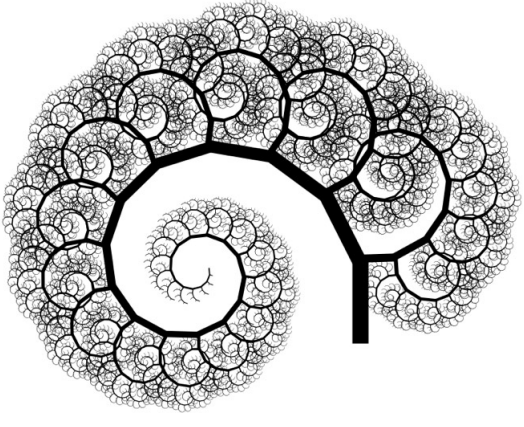

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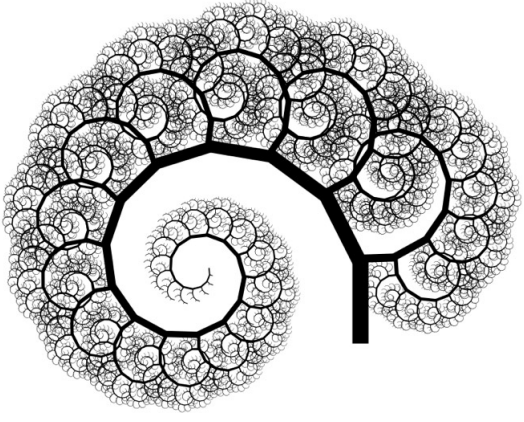

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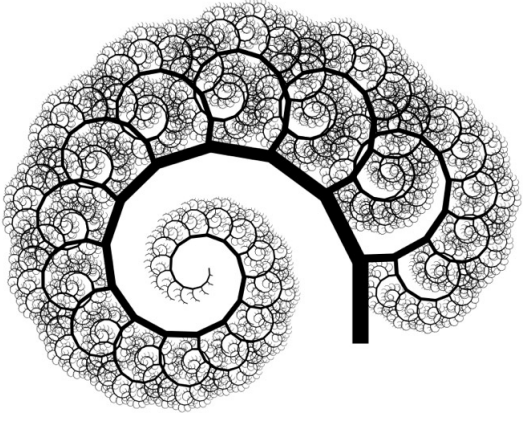
- Hot topics:
  - Docker
  - NewSQL
- . . .



http://matthewjamestaylor.com/img/recursive-drawing/pubic-hair.jpg

Keep learning

Johann Wolfgang von Goethe

What we do not understand we do not possess.

Keep learning

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- Knowledge is power
- Better understanding
- Control over environment

Questions?