Gossip and Epidemic Approaches

CS 6410: Advanced Systems

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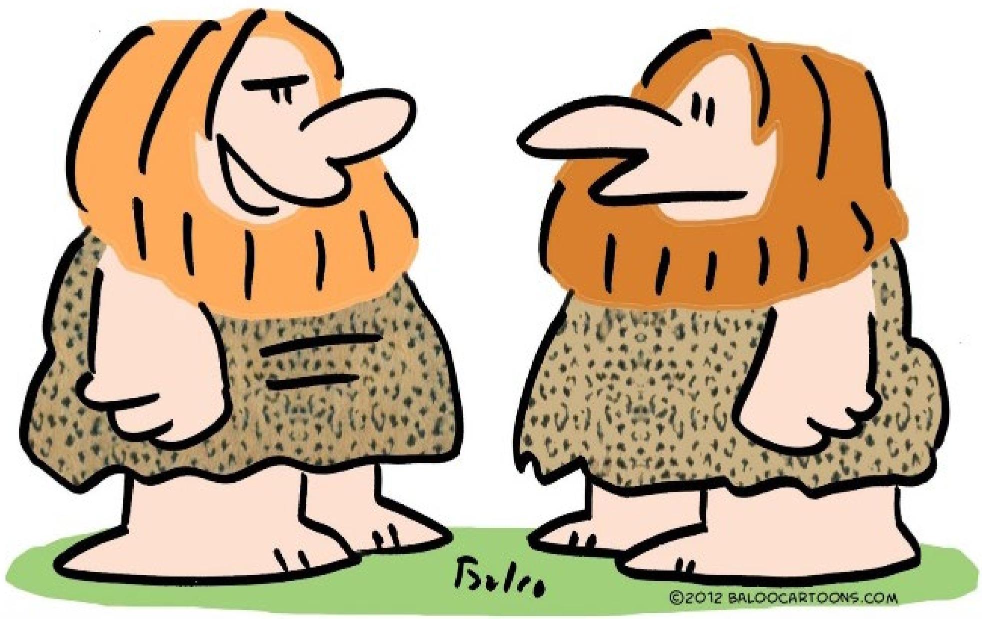
[Slides borrowed liberally from Ki Suh Lee and Eugene Bagdasaryan]



"Now that we've learned to talk,
let's start some *rumors!*"

What is the big idea?

What are these ideas aimed for?

What is the difference with other approaches?

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What are these ideas aimed for?

- Data consistency, fault-tolerance

What is the difference with other approaches?

- “Eventual” consistency, scalability, fault-tolerance

CAP theorem

CAP = Consistency, Availability, Partition tolerance

- Other approaches focus on Consistency and Partition Tolerance
  E.g. Paxos sometimes is unavailable for writes, but would remain consistent

- This paper wants to provide Availability, Partition Tolerance, and “relaxed” form of consistency; i.e. eventual consistency
  i.e. all replicas have all updates *eventually*

EPIDEMIC ALGORITHM FOR REPLICATED DATABASE MAINTENANCE

Xerox Palo Alto Research Center 1987

Authors

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Timeline

1978	**Lamport**	Time, Clocks, and the Ordering of Events in a Distributed System
1982	**Lamport**	The Byzantine Generals Problem
1985	**FLP**	Impossibility of Distributed Consensus with One Faulty Process
1987	**Demers**	Epidemic algorithms for replicated database maintenance
1990	**Schneider**	Implementing fault-tolerant services using the state machine approach: A tutorial
1995	**Terry**	Managing update conflicts in Bayou, a weakly connected replicated storage system
1998	**Lamport**	The part-time parliament

Real applications

- Amazon Web Services (AWS), Microsoft Azure blobstore, Google
- Uber
- Apache Cassandra
- Docker’s multi-host networking
- Cloud providers multi node networking (Heroku)

Context

- Xerox wanted to replicated a database on to hundreds to thousand sites
- Each update is injected at a single site and must be propagated to all other sites
- Xerox Corporate Internet (CIN): A packet from a machine in Japan to one in Europe may traverse as many as 14 gateways and *7 phone lines*
- CIN predates the Internet

Problem

- High network traffic to send update over the large set of nodes
- Time to propagate update to all nodes is significant

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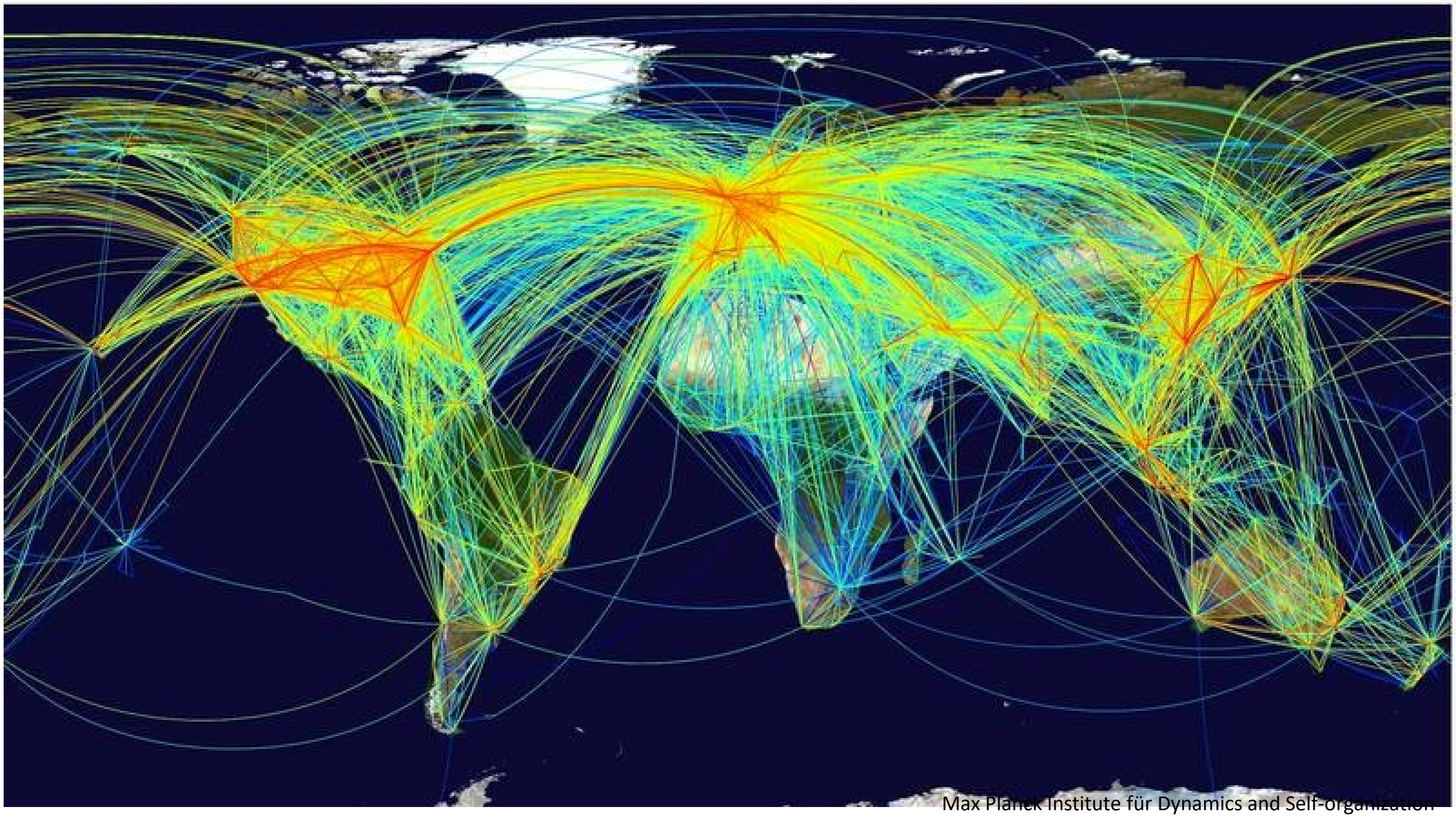
” For a domain stored at 300 sites, 90,000 mail messages might he introduced each night”.

Basic idea



Max Planck Institute für Dynamics and Self-organization

Objective

- Design algorithms that scale gracefully
- Every replica receives every update ***eventually***

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“Replace complex deterministic algorithms for replicated database consistency with simple randomized algorithms that require few guarantees from the underlying communication system.“

Why epidemic? Why gossip?

- Highly available
- Fault-tolerant
- Overhead is tunable
- Fast
- Scalable
- Epidemic spreads eventually to everyone

Types of nodes

- **infective** – node that holds an update it is willing to share
- **susceptible** – node that has not yet received an update
- **removed** – node that has received an update but is no longer willing to share

$$s + i + r = 1$$

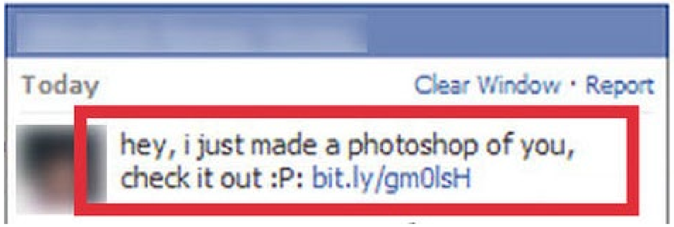
Types of communication

- Direct mail
- Anti-entropy
- Rumor mongering

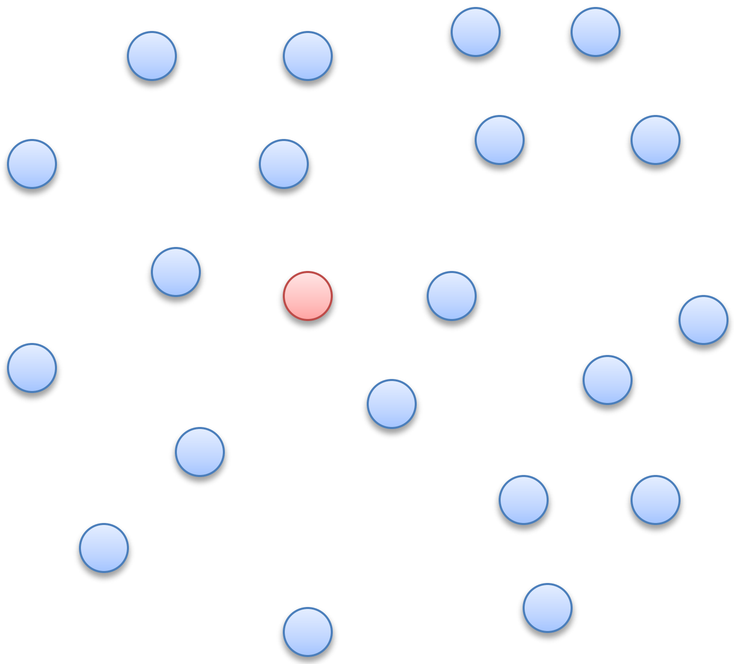
DIRECT MAIL

- attempts to notify all other sites of an update soon after it occurs.

- **Social network case** – infected accounts sends private message to his whole contact list with malicious link



DIRECT MAIL



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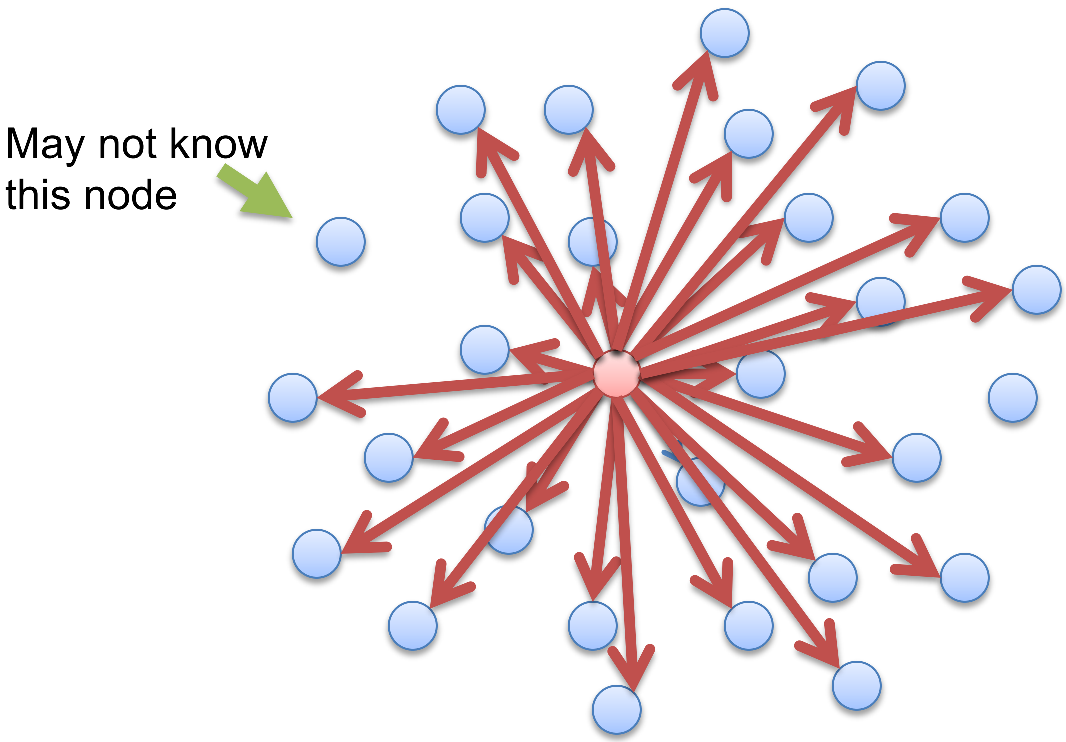

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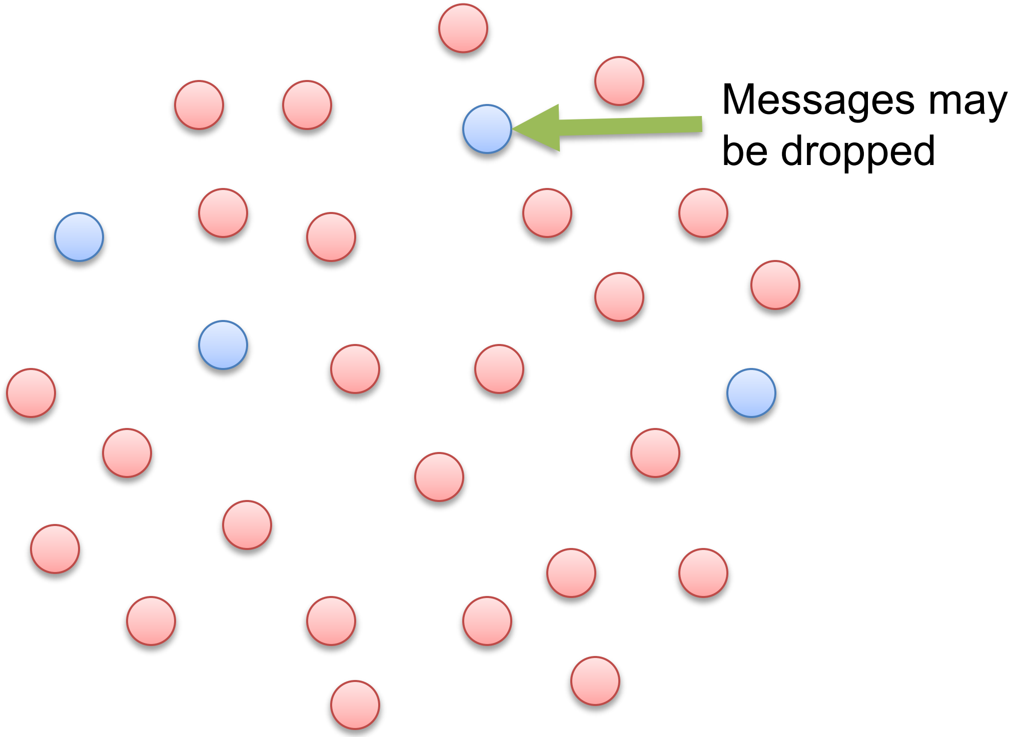


DIRECT MAIL

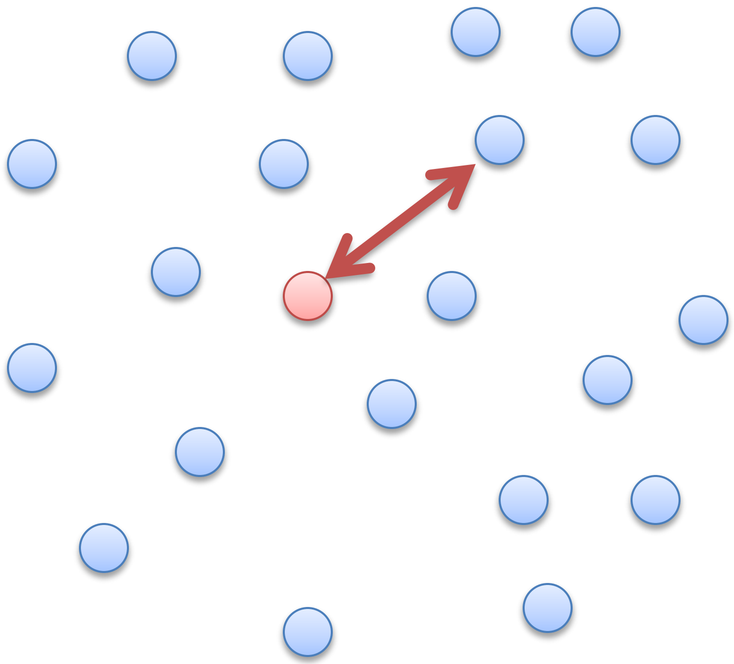
- Pros:
  - Fast
- Cons:
  - not reliable
  - heavy load on network

ANTI-ENTROPY

- Every site regularly chooses another site at random and by exchanging database contents with it resolves any differences between the two

- **Real life case** – meet sometimes with old friends and tell all the fun stories about you and your friends.

ANTI-ENTROPY



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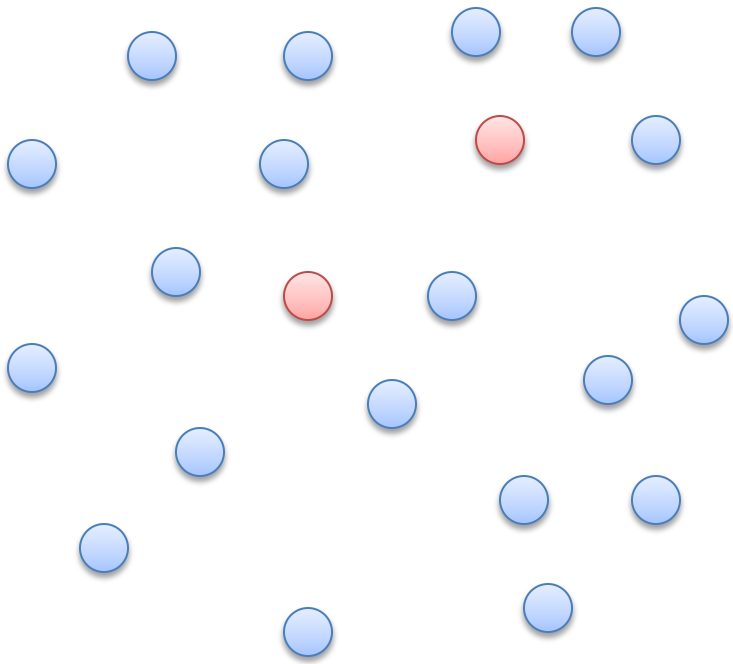

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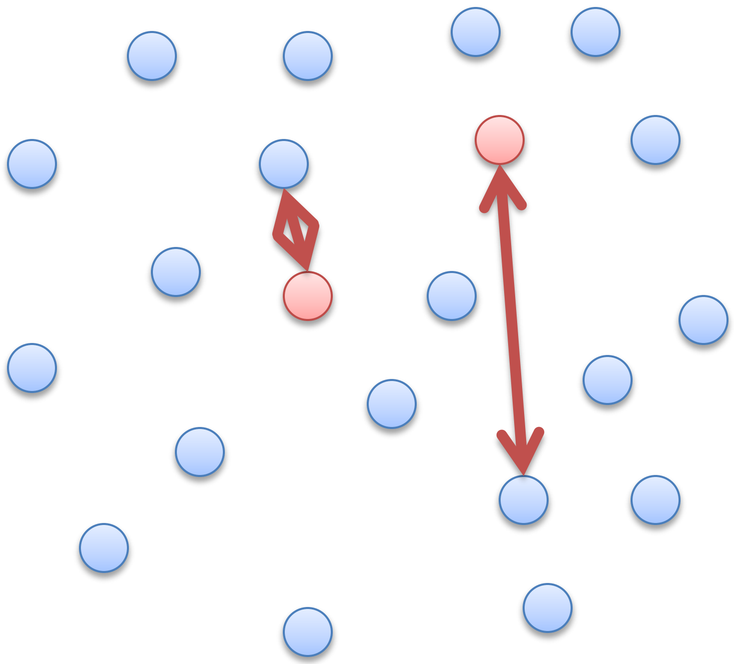

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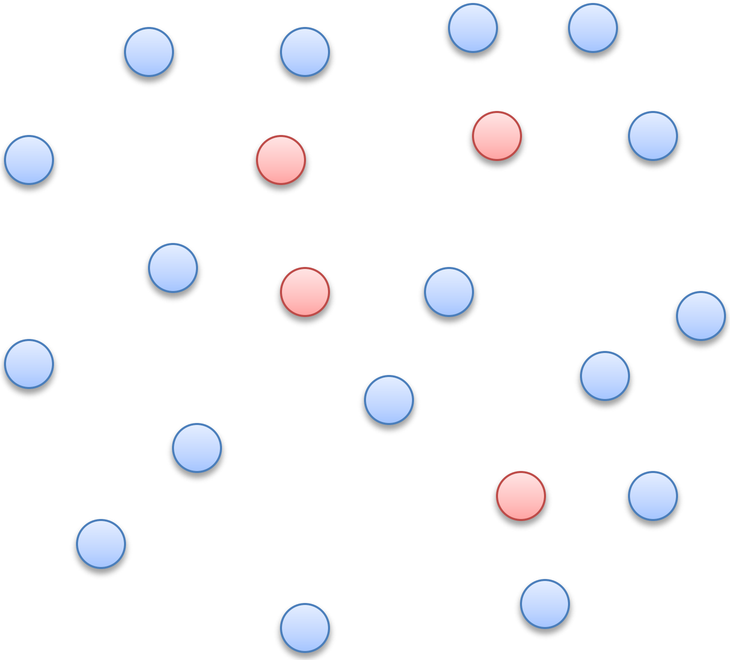

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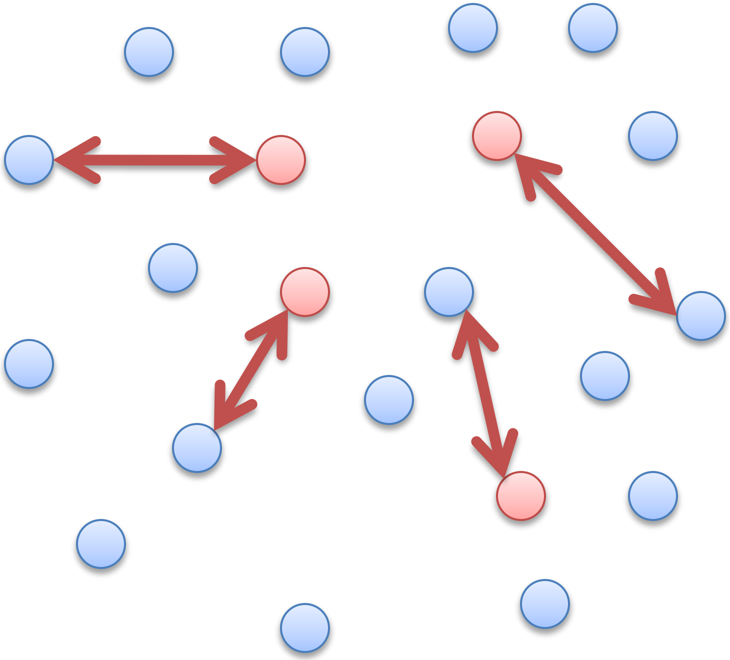

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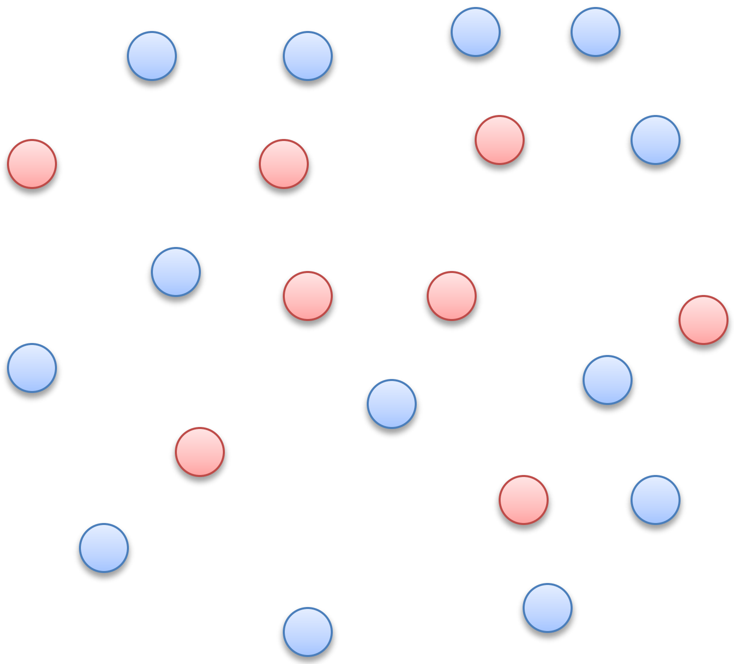

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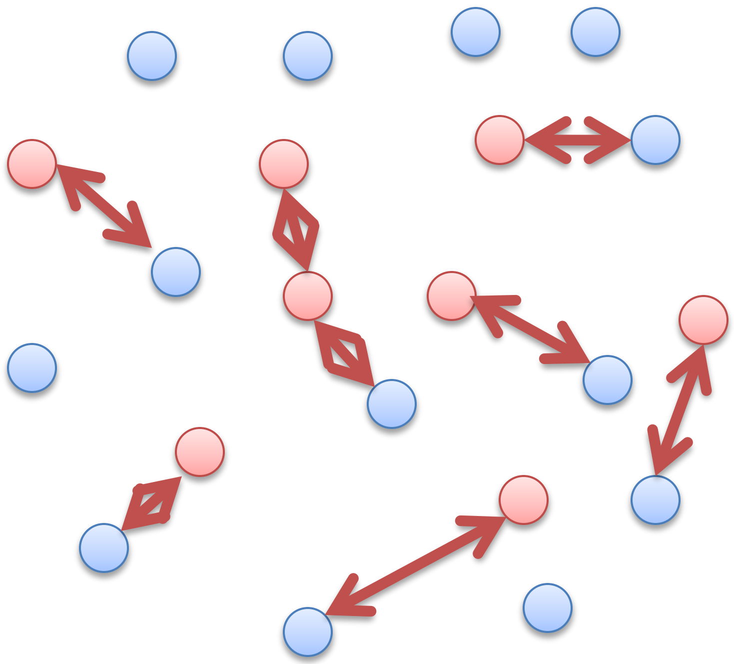

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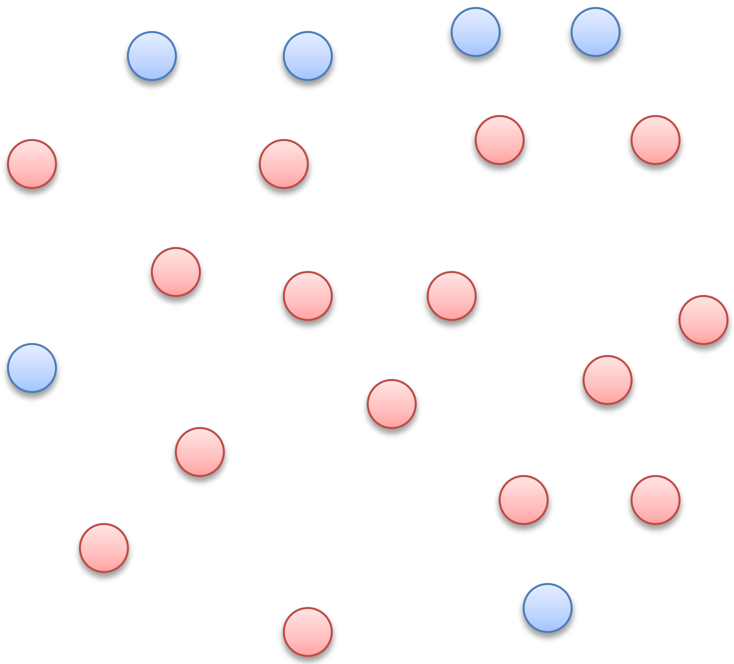

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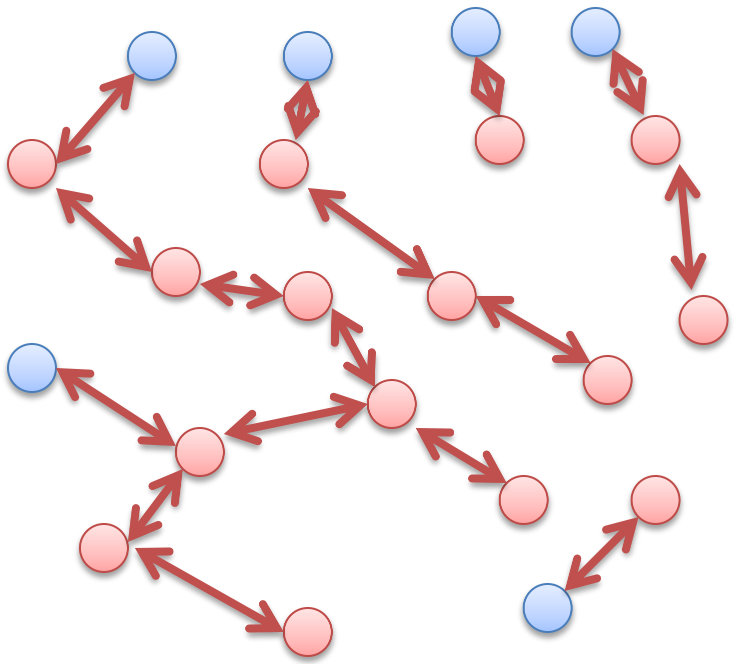

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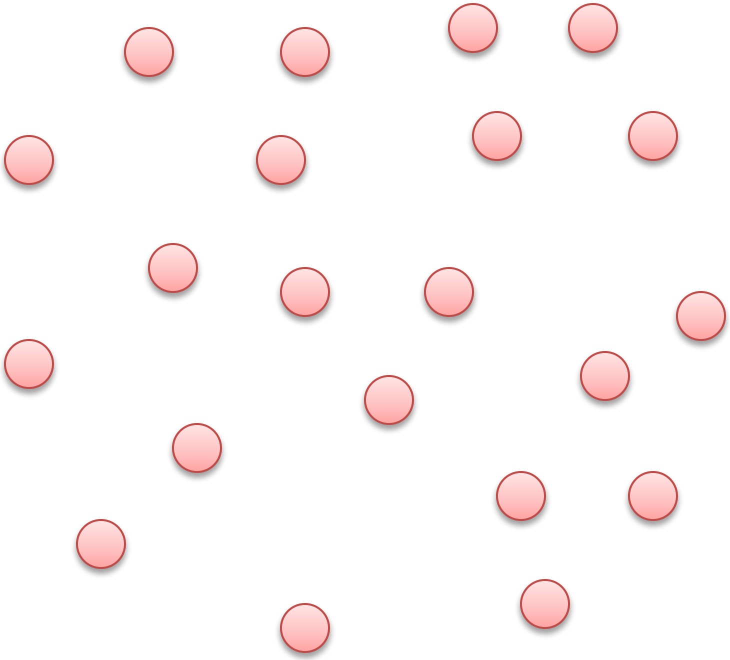


Anti-entropy

Pros

- Complete sync of all info

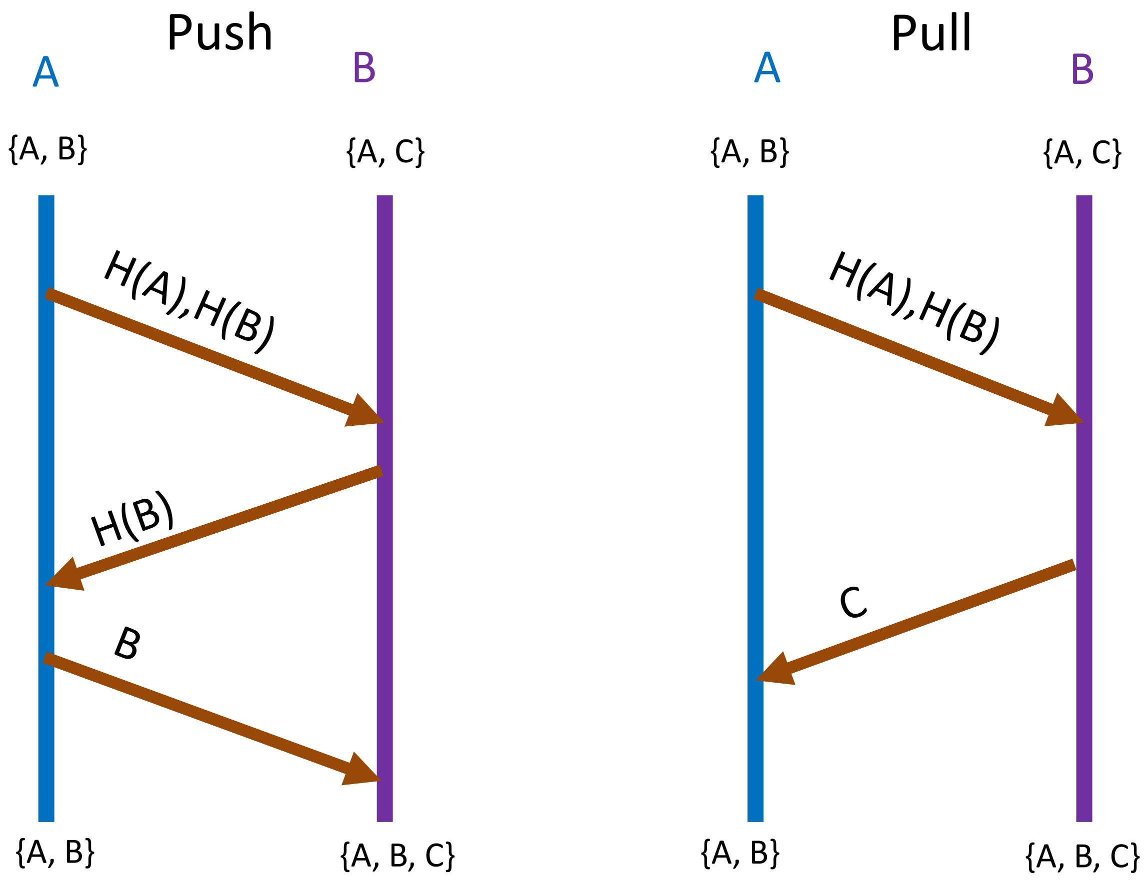
Cons

- Very expensive to run

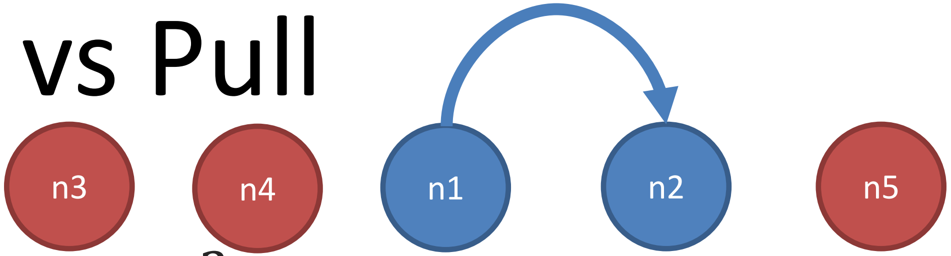
Optimizations:

- Checksums
- Recent Update Lists
- Inverted Index by timestamp

Push vs Pull



Push vs Pull



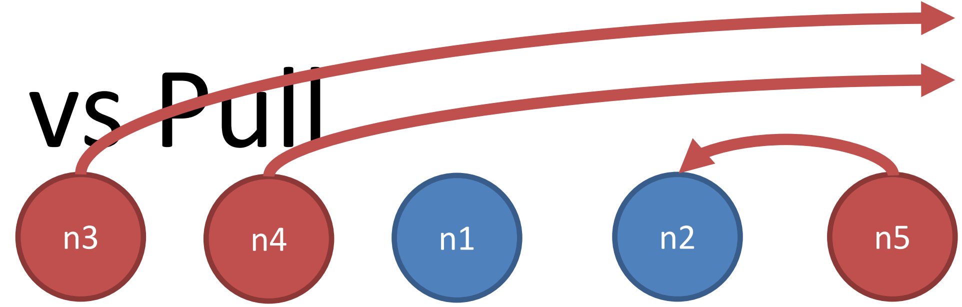
- Pull or Push-pull

$$p_{i+1} = (p_i)^2$$

p_i - probability of a site remaining susceptible after i-th round

To remain susceptible **n1** needs to contact another node **n2** on round **i+1**, which is also susceptible (with probability p_i)

Push vs Pull



- Push

$$p_{i+1} = p_i(1 - \frac{1}{n})^{n(1-p_i)}$$

p_i - probability of a site remaining susceptible after i-th round

$(1 - \frac{1}{n})$ – prob an infected node choose everything except the selected node **n1**

$n(1 - p_i)$ – amount of infected nodes

Push vs Pull

- Pull or Push-pull

$$p_{i+1} = (p_i)^2$$

- Push

$$p_{i+1} = p_i(1 - \frac{1}{n})^{n(1-p_i)} \approx p_i e^{-1}$$

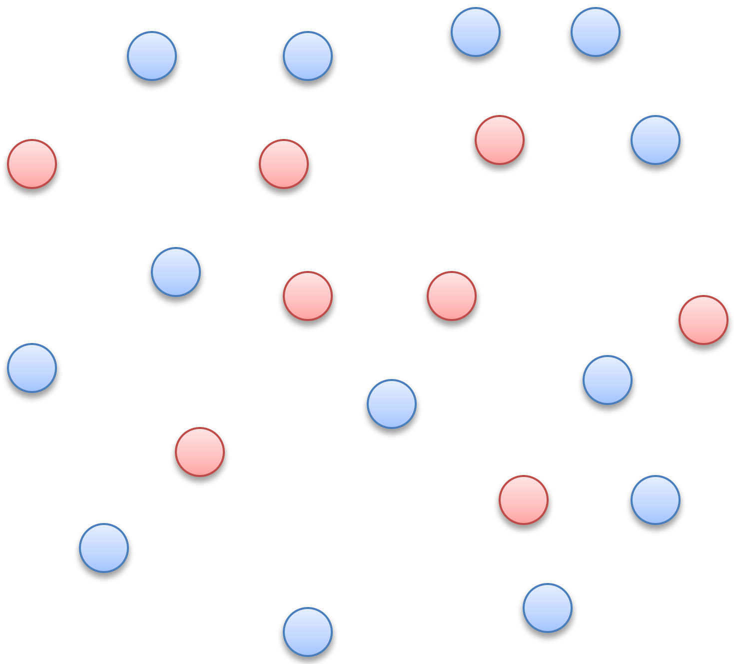
Pull converges to 0 much faster

Rumor mongering

- Share an update, while it is hot. When everyone knows about it stop spreading.

- **News case** – newspapers write more articles on trending topics spreading information.

RUMOR MONGERING



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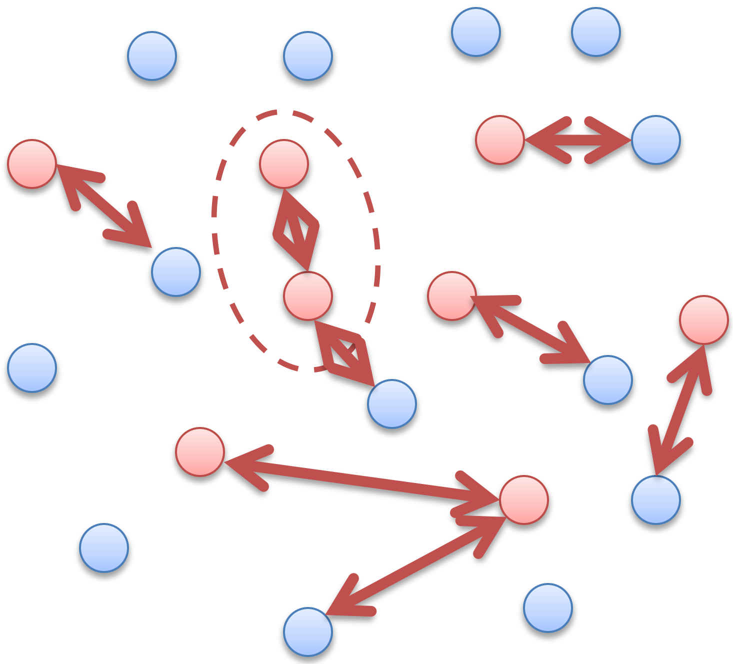

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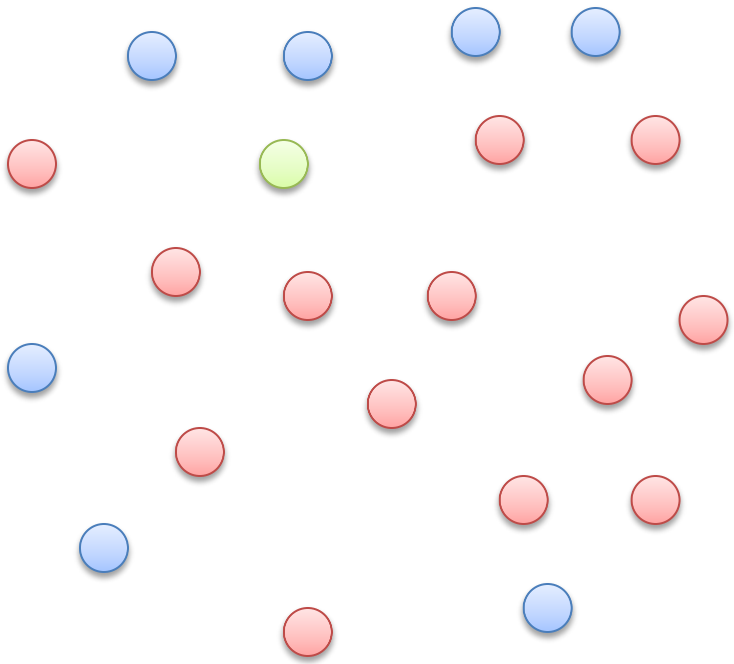

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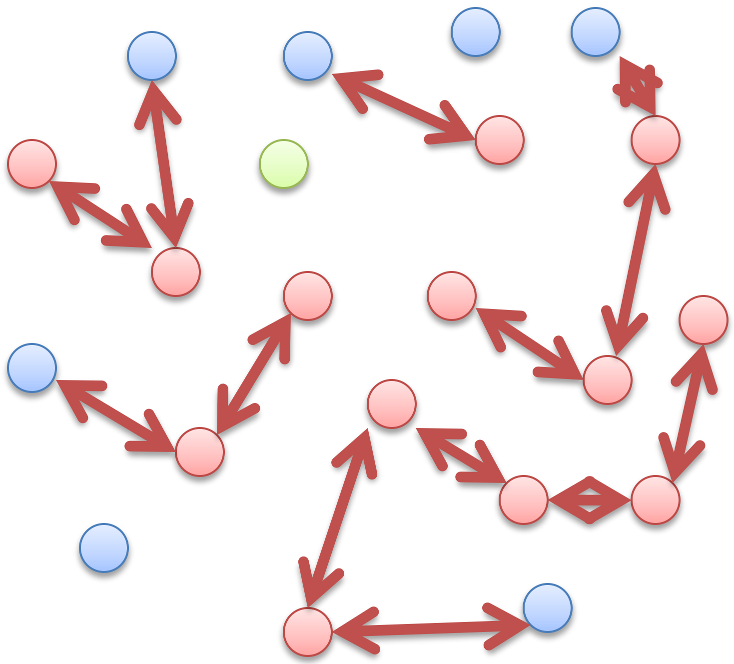


RUMOR MONGERING

Pros

- Less traffic, than Direct mail
- Fast

Cons

- Some sites could miss the information

Can be improved by Complex Epidemics

Complex epidemics

- Hot rumors analogy
- Based on epidemiology literature

  $s + i + r = 1,$ s- susceptible, i - infective, r – removed
- If node contacted already infected node, it loses interest and stops talking with probability $\mathbf{1/k}$
- If k=1, 20% will miss the rumor for k=2 only 6%

$$s = e^{-(k+1)(1-s)}$$

Complex epidemics

Criteria:

- Residue

  Amount of untouched nodes (s) after epidemics ended ($i = 0$) in $s + i + r = 1$

- Traffic

$$m = \frac{Total\ update\ traffic}{Number\ of\ sites}$$

- Delay

  Introduced t_{avg} and t_{last}

Variations

- Blind vs. Feedback
- Counter vs. Coin
- Push vs. Pull
- Minimization
- Connection Limit
- Hunting

Table 1. Push, Feedback & Counters

Counter	Residue	Trafic	Convergence	
k	s	m	t_{avg}	t_{last}
1	0.176	1.74	11.0	16.8
2	0.037	3.30	12.1	16.9
3	0.011	4.53	12.5	17.4
4	0.0036	5.64	12.7	17.5
5	0.0012	6.68	12.8	17.7

Table 2. Push, Blind & Coin

1	0.960	0.04	19	38
2	0.205	1.59	17	33
3	0.060	2.82	15	32
4	0.021	3.91	14.1	32
5	0.008	4.95	13.8	32

Table 3. Pull, Feedback & Counters

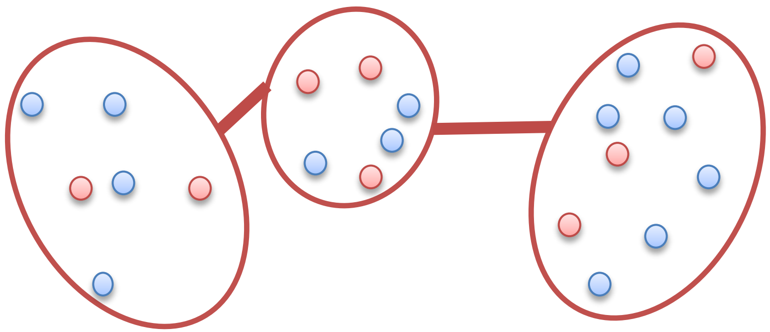
1	0.031	2.7	9.97	17.63
2	0.00058	4.49	10.07	15.39
3	0.000004	6.09	10.08	14.00

Deletion

- Death Certificates
  - Dormant DC
    - Too long to distribute
    - Can be lost
  - Anti-entropy with Dormant DC
    - Activate DC on sync with another node, if this node doesn’t have it
  - Rumor mongering with Dormant DC
    - Parallel to normal data distribution through rumor mongering

Spatial Distributions

- Different weights on connections between nodes
- Can reduce traffic on critical links
- Favor nearby neighbors
- Trade off between convergence time and average traffic per link



Perspective/Questions?

Perspective

- Fast, eventually consistent protocol
- Low traffic in the system

Potential problems:

- Weird topology can decrease performance
- Byzantine Failures

Before Next Time

- Read papers below and write review
  - ***End-to-end arguments in system design,*** J.H. Saltzer, D.P. Reed, D.D. Clark. *ACM Transactions on Computer Systems (TOCS)*, Volume 2, Issue 4 (November 1984), pages 277-288 http://portal.acm.org/citation.cfm?id=357402
  - ***Hints for computer system design***, B. Lampson. *ACM Symposium on Operating Systems Principles (SOSP)*, 1983, pages 33-48 https://dl.acm.org/doi/10.1145/800217.806614
- Check website for updated schedule