Gossip Protocols

CS 6410

Eugene Bagdasaryan

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What was covered before?

- Paxos
- Byzantine Generals
- Impossibility consensus

What are these ideas aimed for?

What is the difference with the current paper?

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- Paxos
- Byzantine Generals
- Impossibility consensus

What are these ideas aimed for?

Data consistency, fault-tolerance

What is the difference with the current paper?

"Eventual" consistency, scalability, fault-tolerance

CAP theorem

CAP = Consistency, Availability, Partition tolerance

- Previous papers focused on Consistency and Partition Tolerance

  Paxos sometimes is unavailable for writes, but would remain consistent

- This paper wants to provide Availability, Partition Tolerance, and "relaxed" form of consistency

EPIDEMIC ALGORITHM FOR REPLICATED DATABASE MAINTENANCE

Xerox Palo Alto Research Center 1987

Authors

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John Larson
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Real applications

- Uber uses SWIM for real-time platform
- Apache Cassandra internode communication
- Docker's multi-host networking
- Cloud providers multi node networking (Heroku)
- Serf by Hashicorp

Context

- Xerox wanted to run replicated database on hundred or thousand sites
- Each update is injected at a single site and must be propagated to all other sites
- A packet from a machine in Japan to one in Europe may traverse as many as 14 gateways and 7 phone lines

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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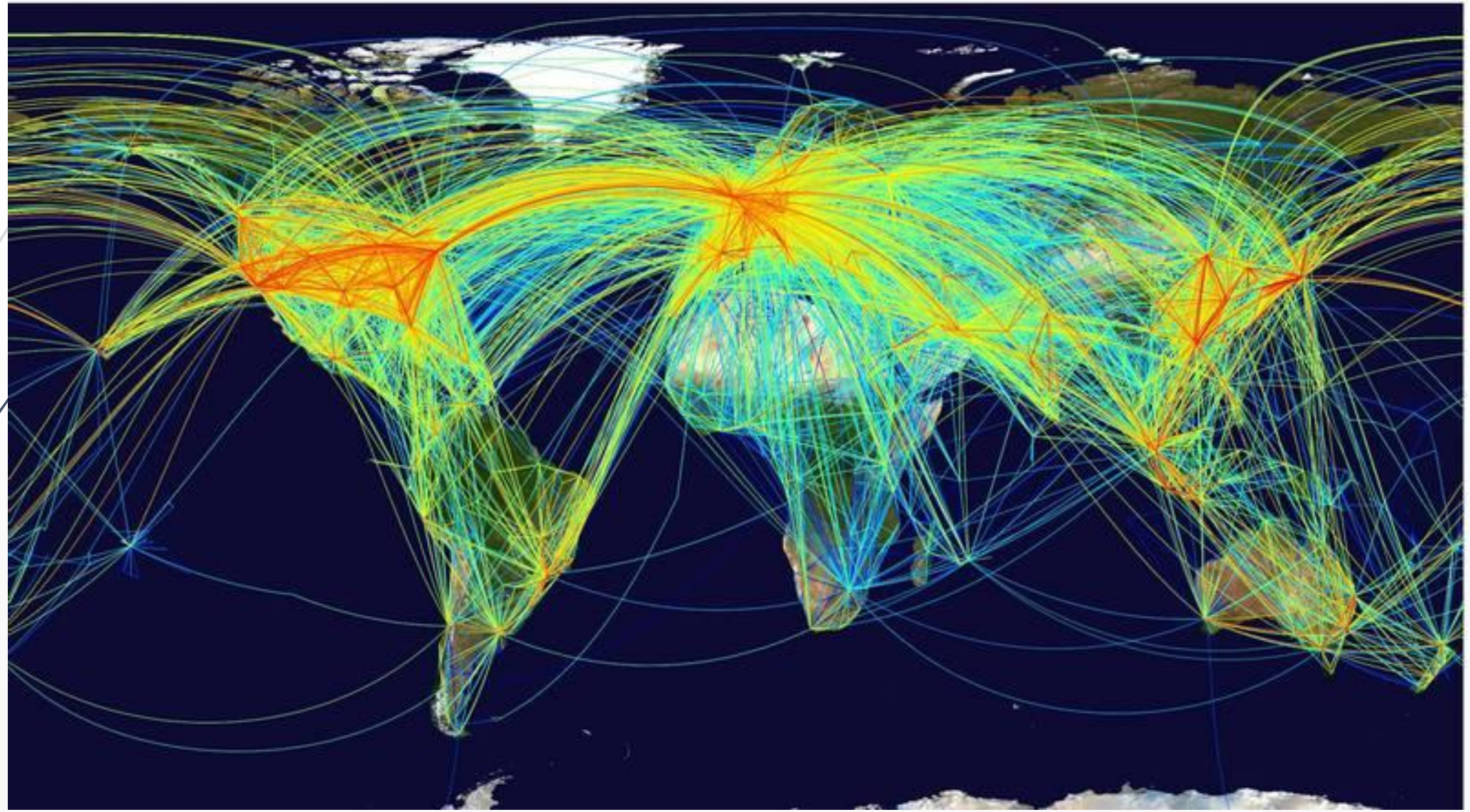
- Time to propagate update to all nodes is significant

" 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

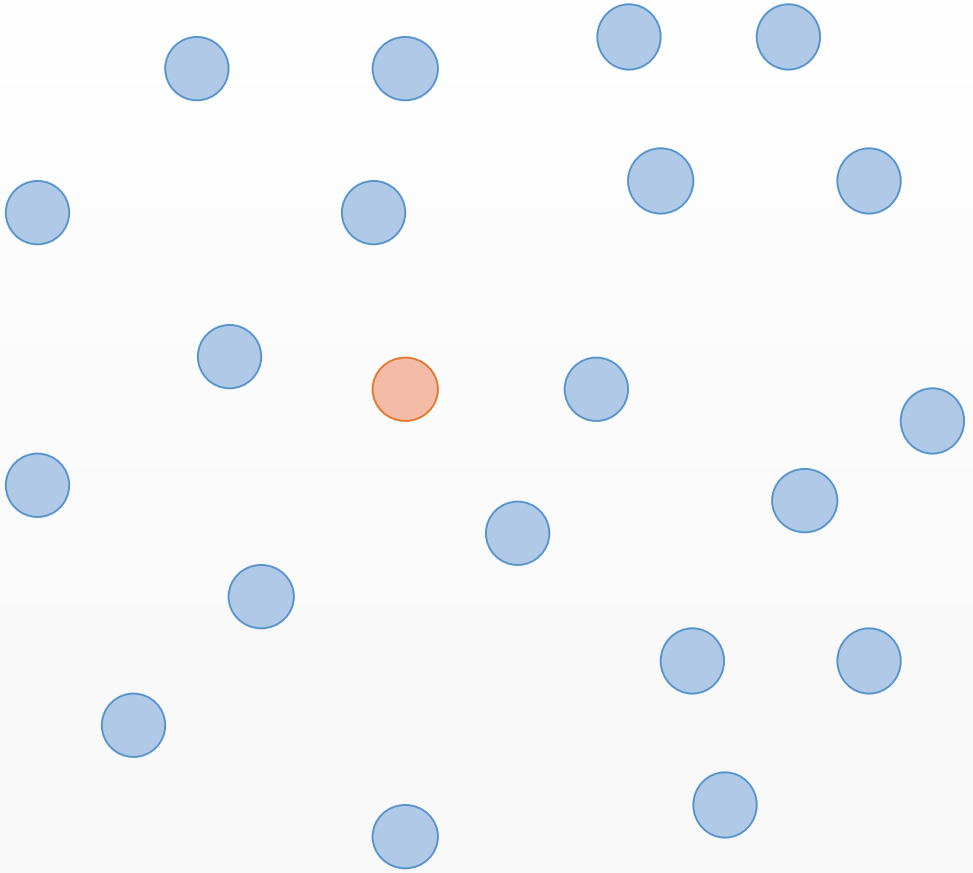
- Direct mail
- Anti-entropy
- Rumor mongering

DIRECT MAIL

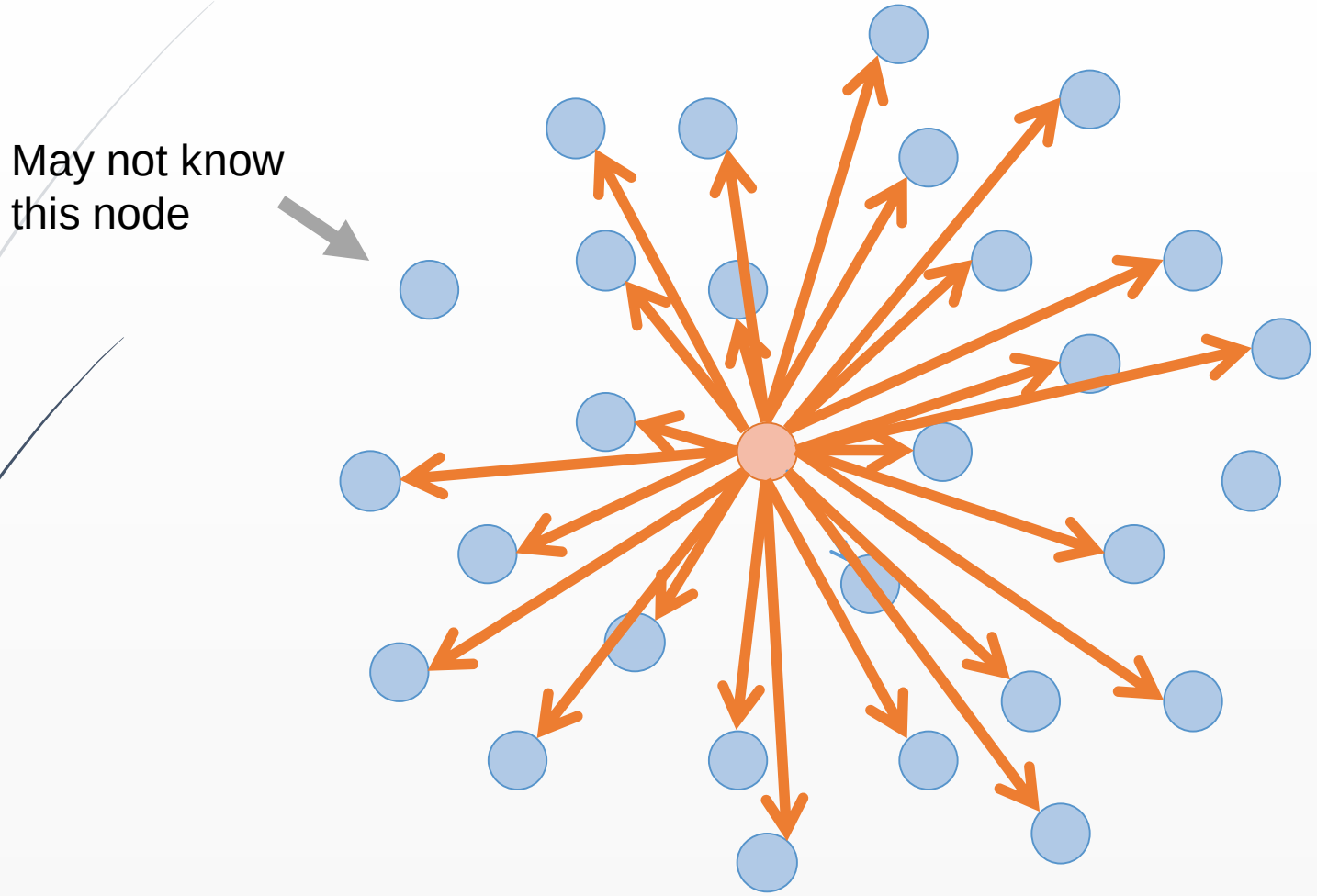
- attempts to notify all other sites of an update soon after it occurs.

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

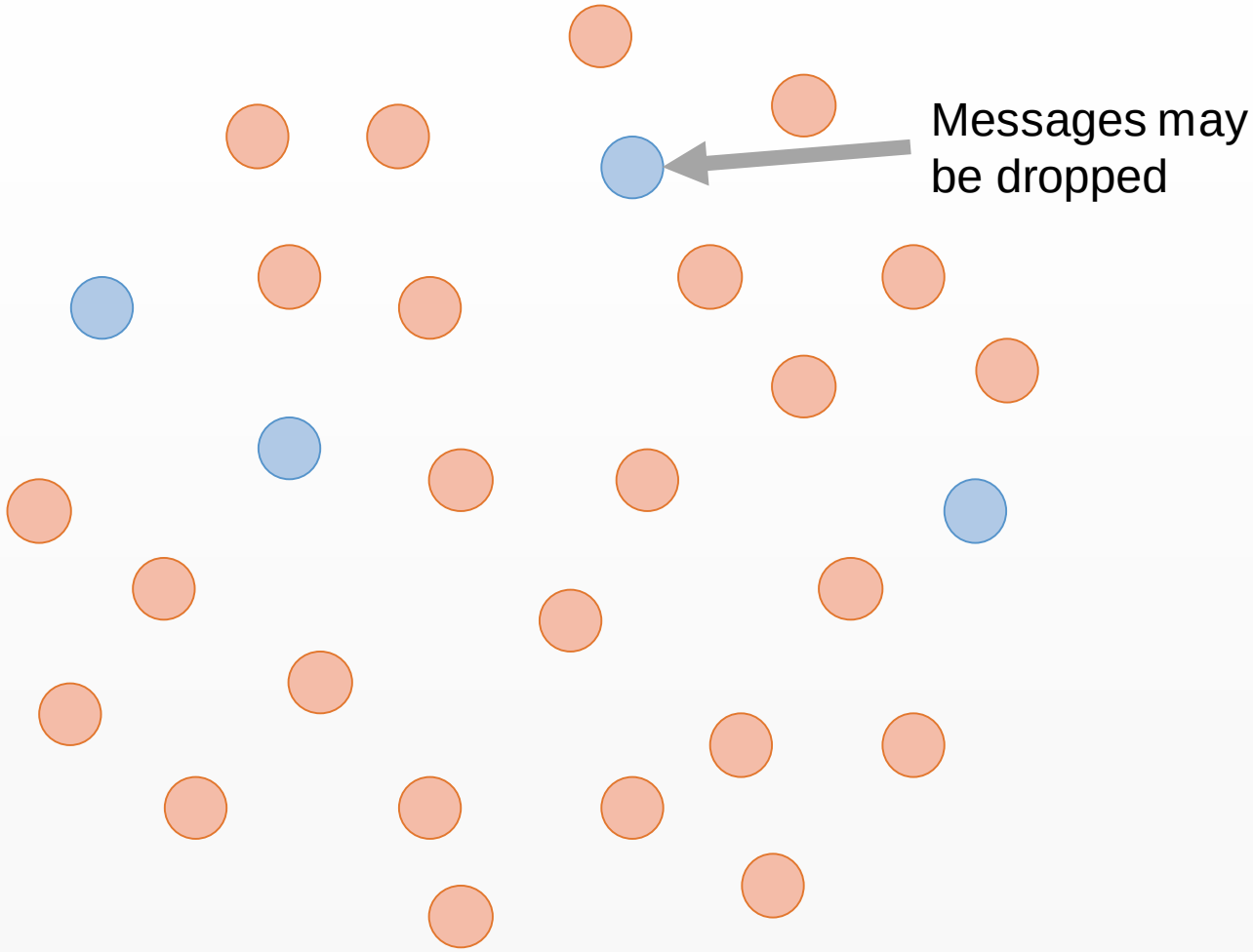
DIRECT MAIL



DIRECT MAIL



DIRECT MAIL



DIRECT MAIL

- Pros:

  Fast

- Cons:

  not reliable

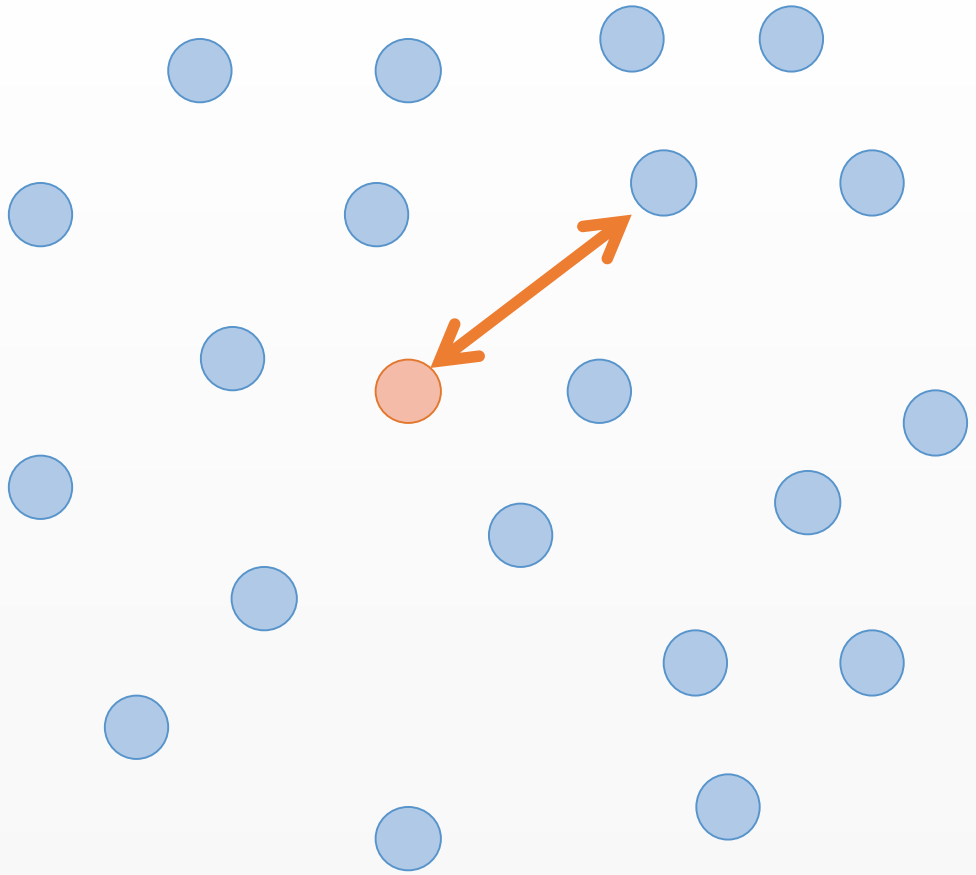
  heavy load on network

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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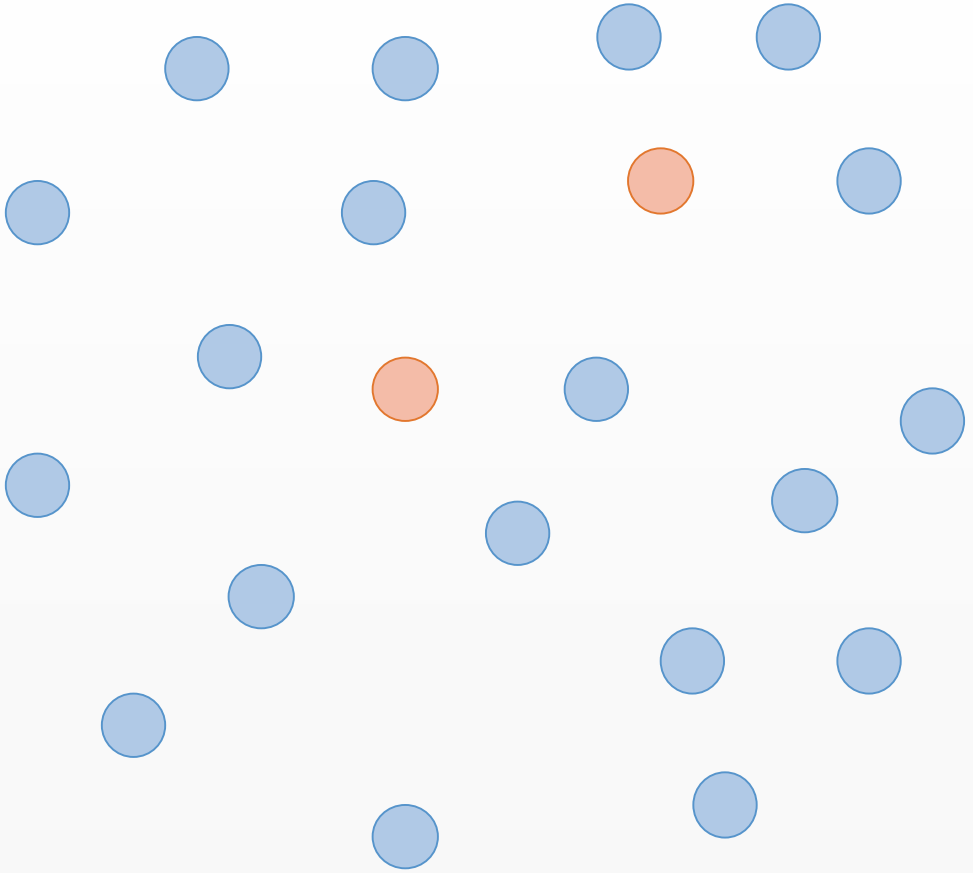

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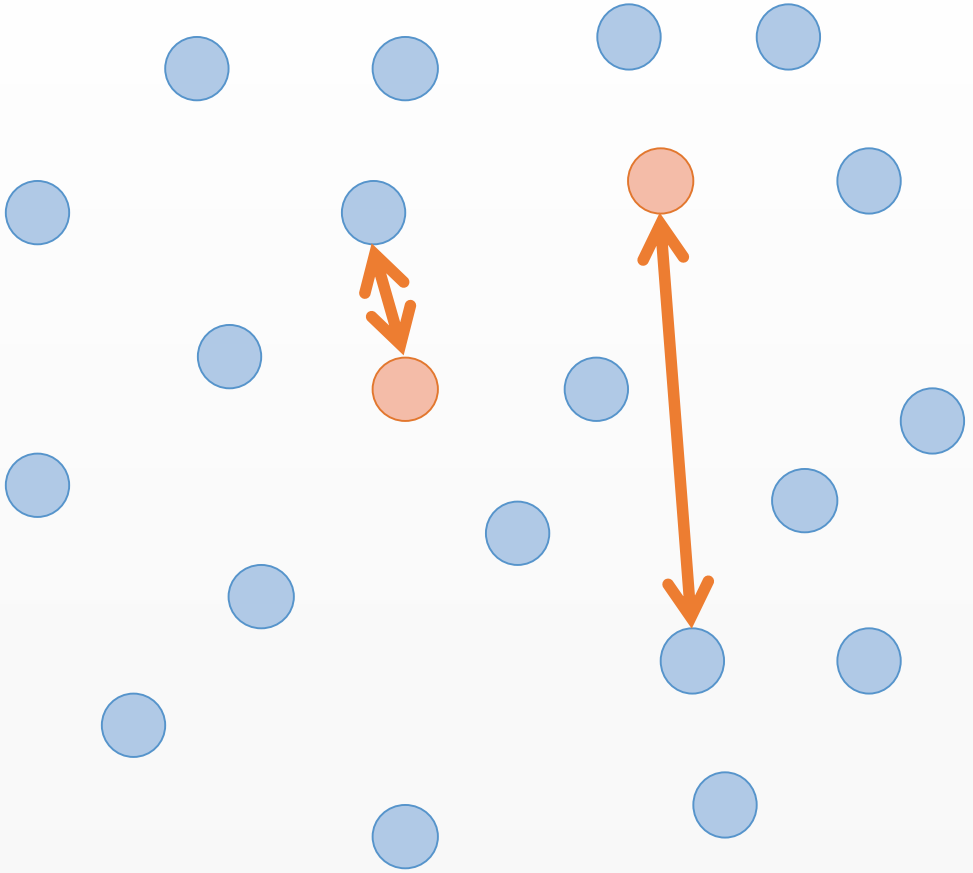

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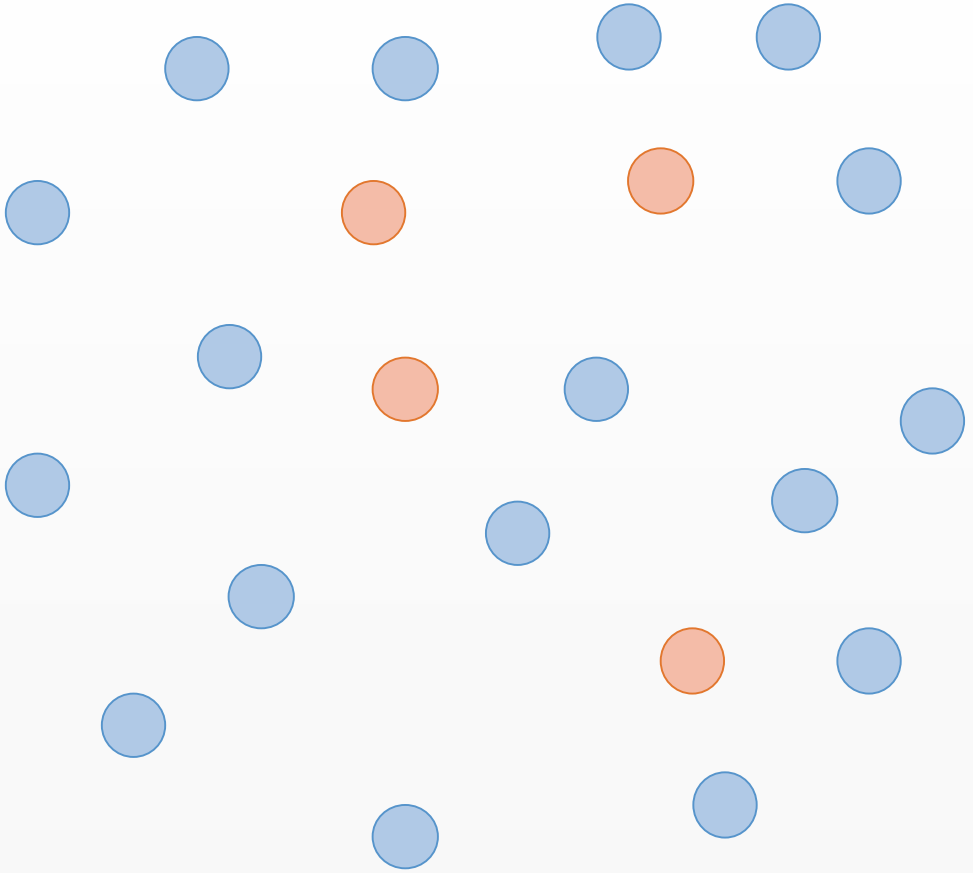

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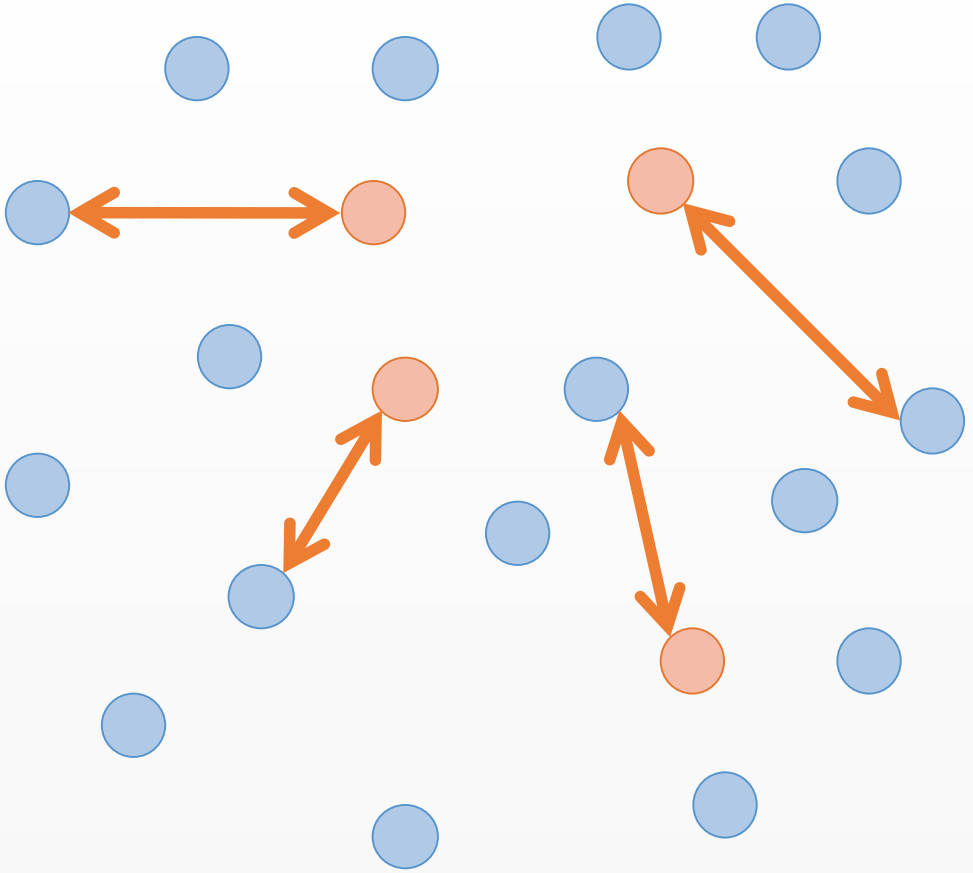

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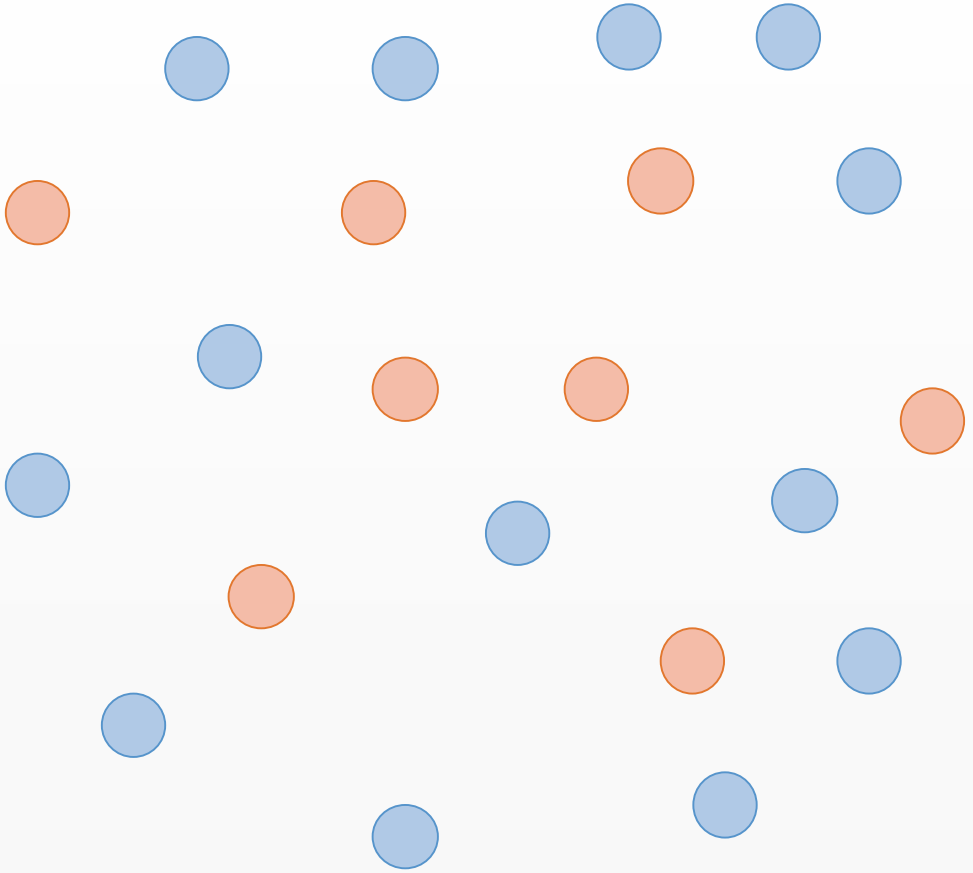

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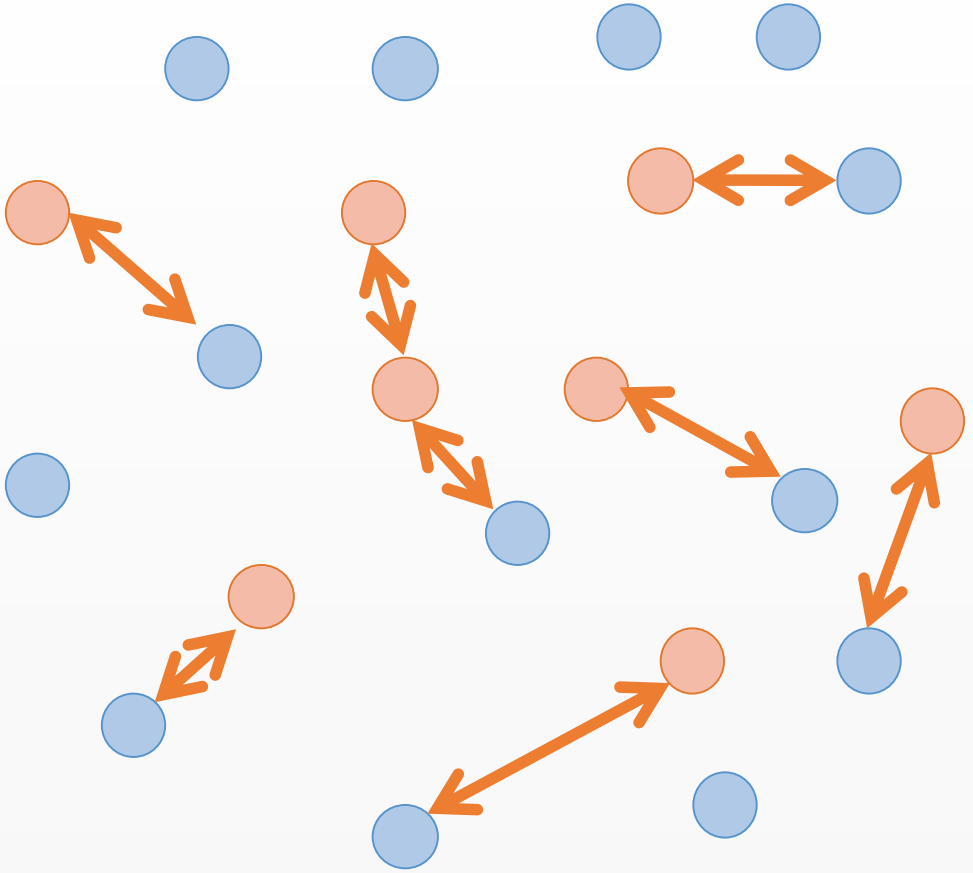

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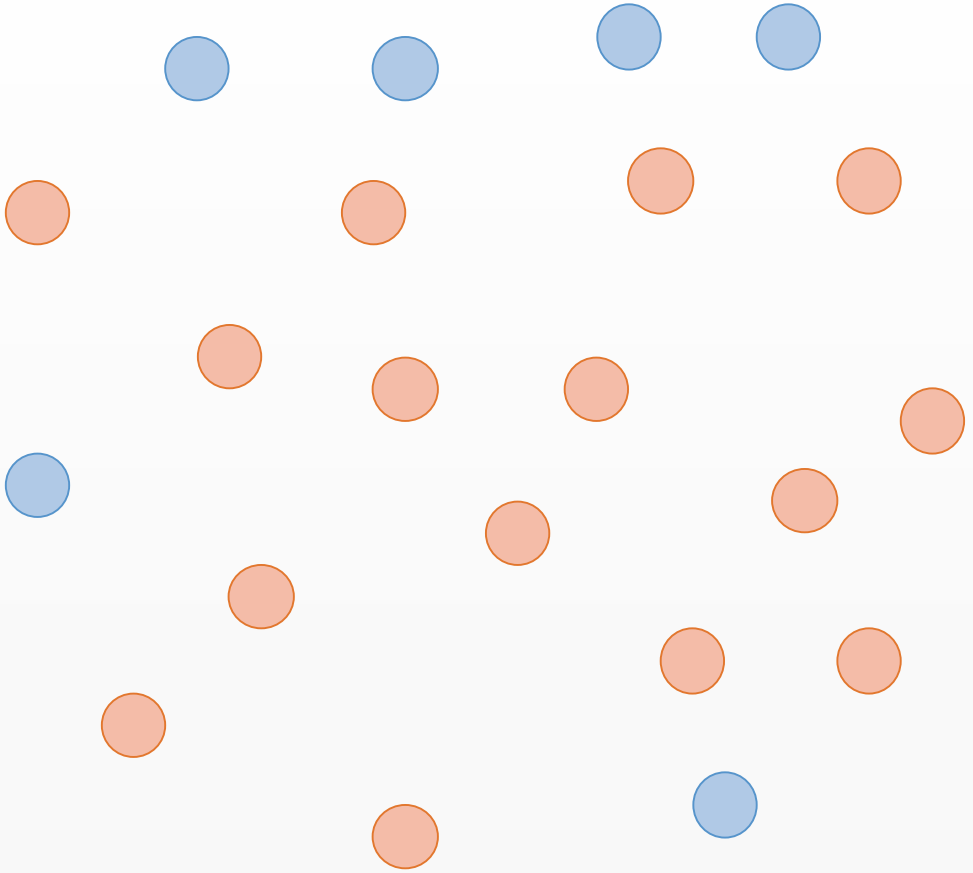

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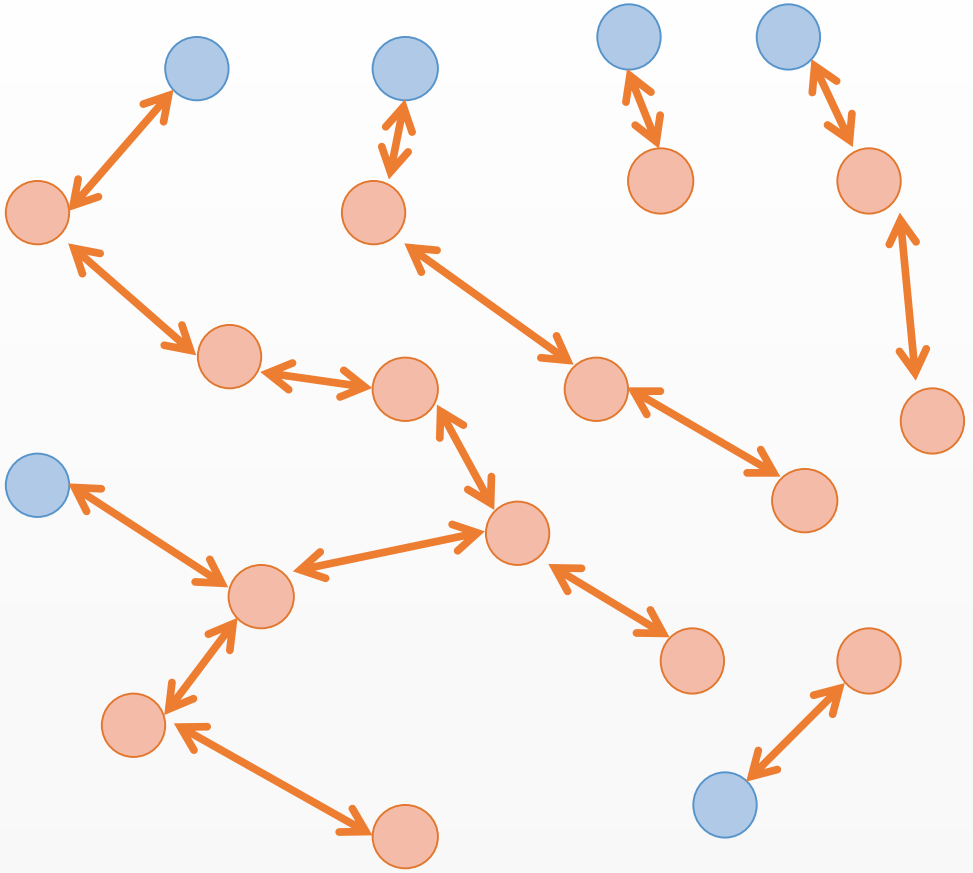
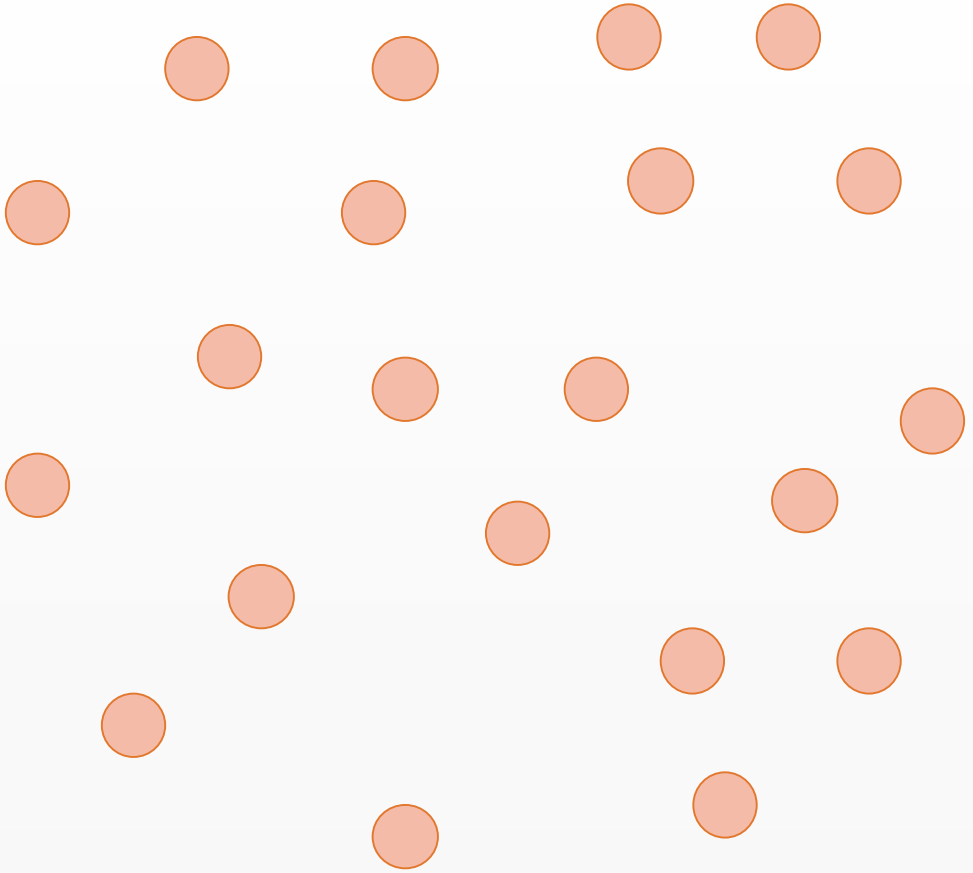


ANTI-ENTROPY



Anti-entropy

Pros

- Complete sync of all info

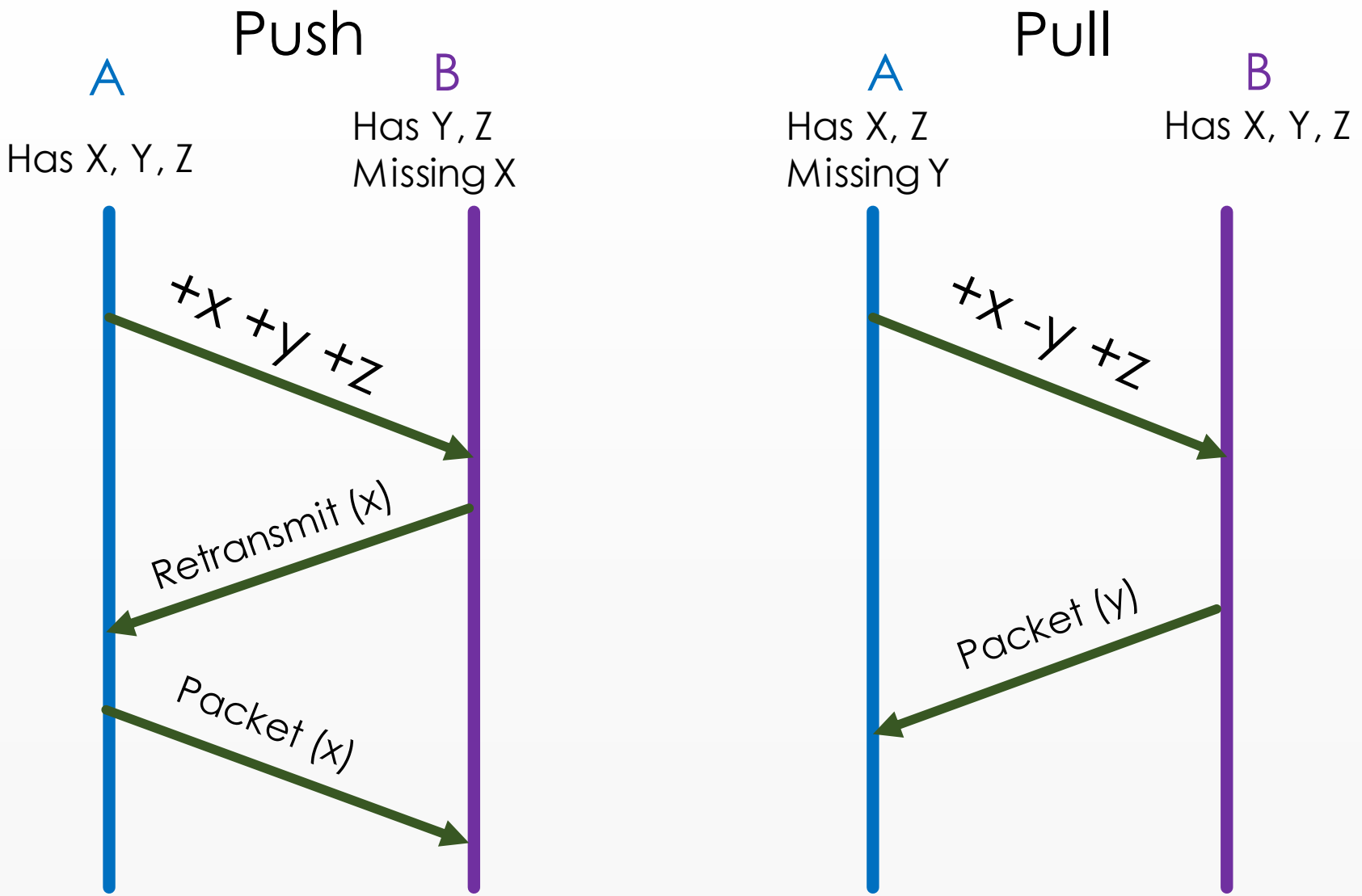
Cons

- Very expensive to run

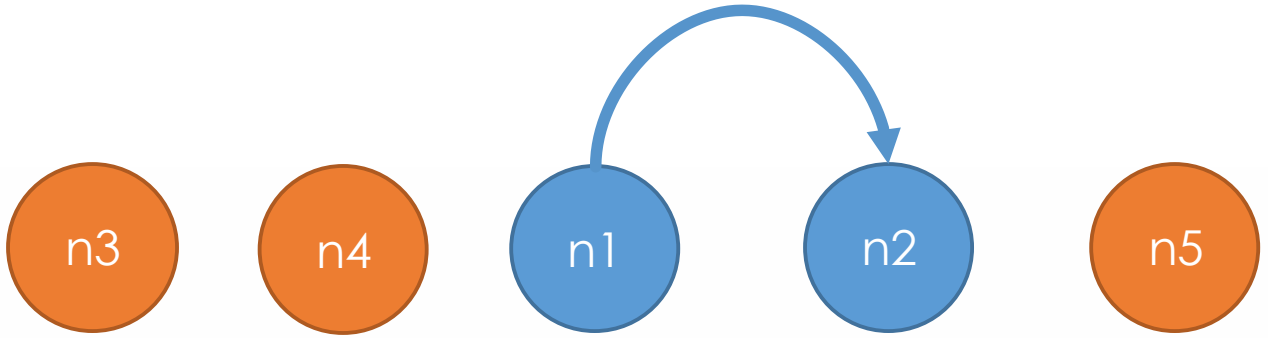
Optimizations:

- Checksums
- Recent Update Lists
- Inverted Index by timestamp

Push vs Pull


Push
A
Has X, Y, Z
B
Has Y, Z
Missing X
+X +Y +Z
Retransmit (x)
Packet (x)
Pull
A
Has X, Z
Missing Y
B
Has X, Y, Z
+X -Y +Z
Packet (y)

Push vs Pull



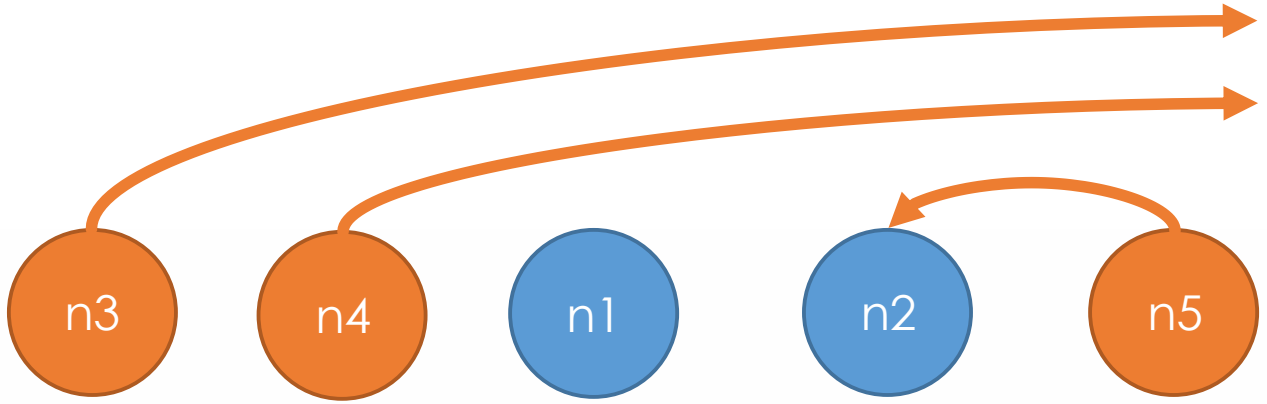
- Pull or Push-pull

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

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

$(1 - \frac{1}{n})$ – probability 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

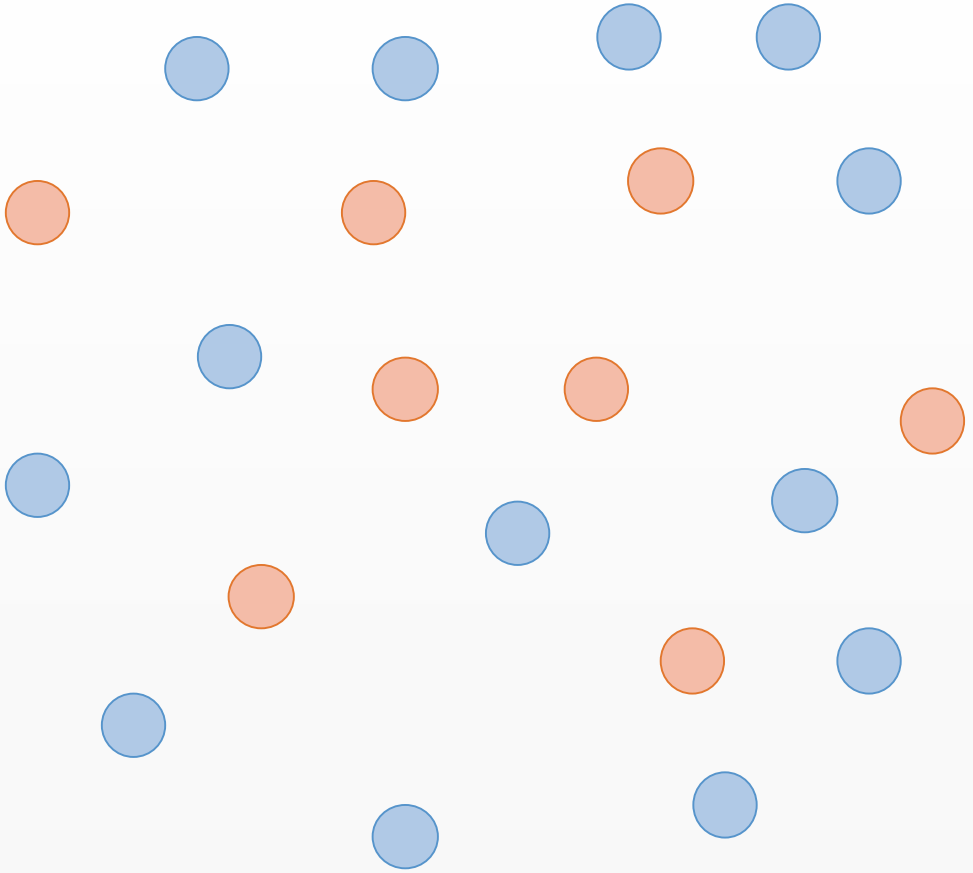
$$p_{i+1} = p_i(1 - \frac{1}{n})^{n(1-p_i)} \approx p_i e^{-1}$$

Pull converges to 0 much faster.

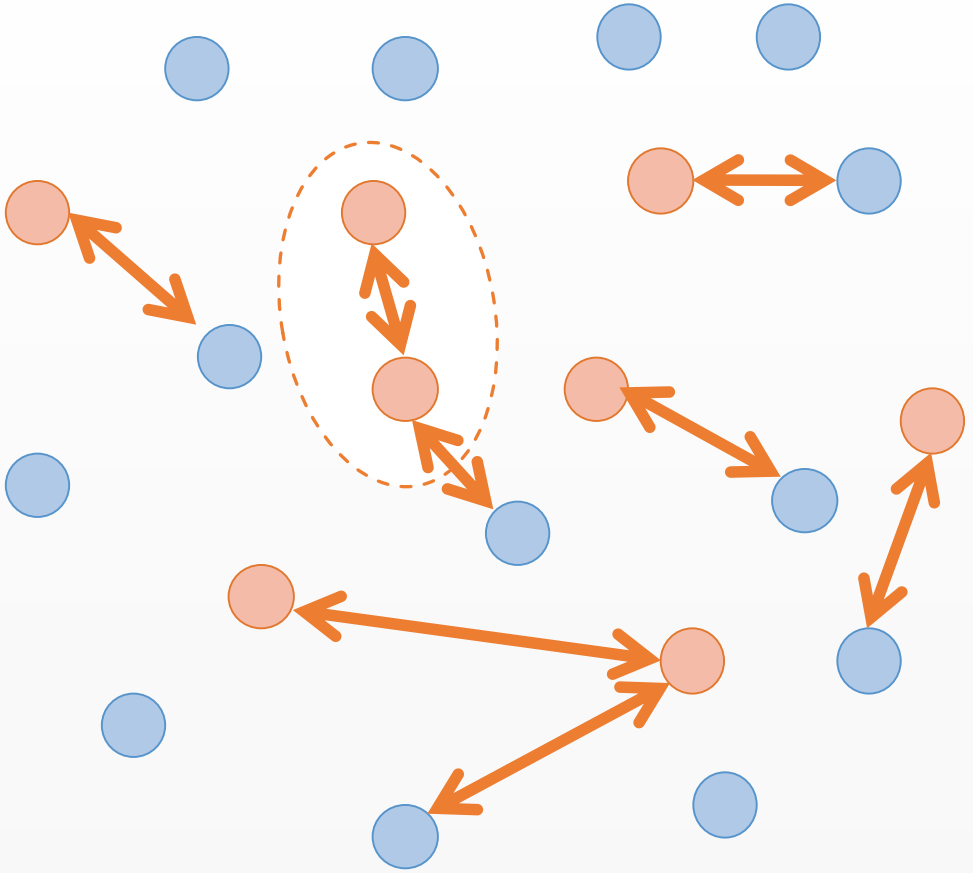
Rumor mongering

- 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.

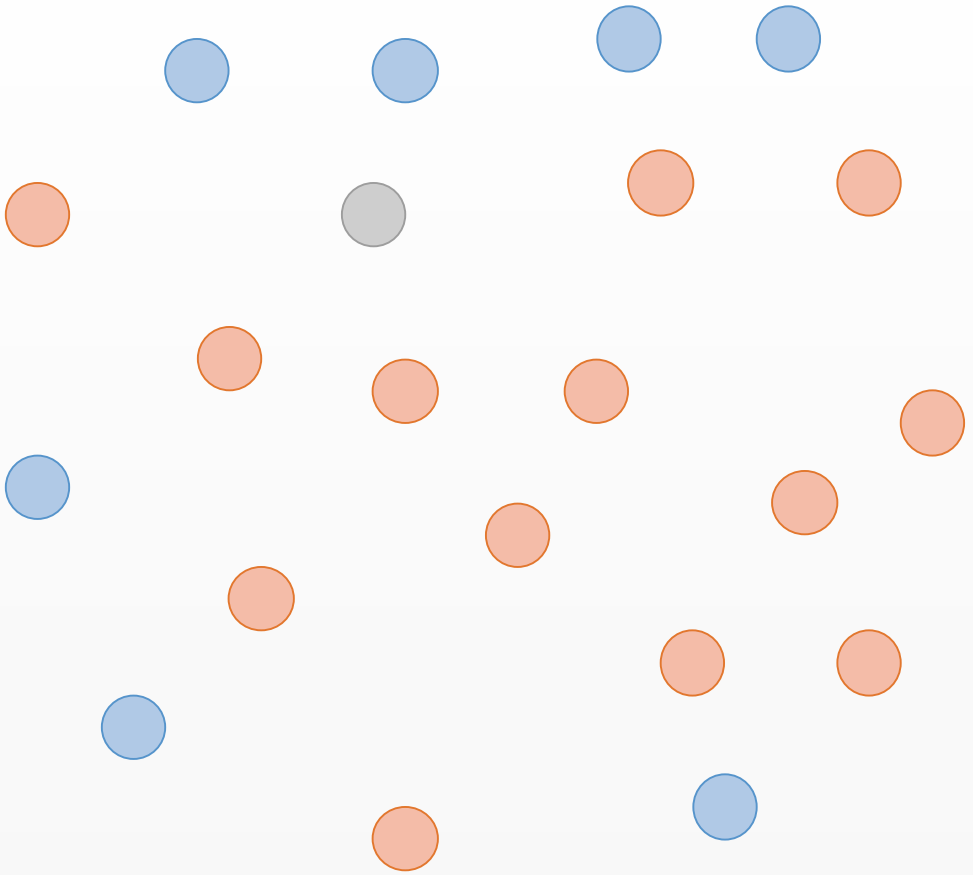
RUMOR MONGERING



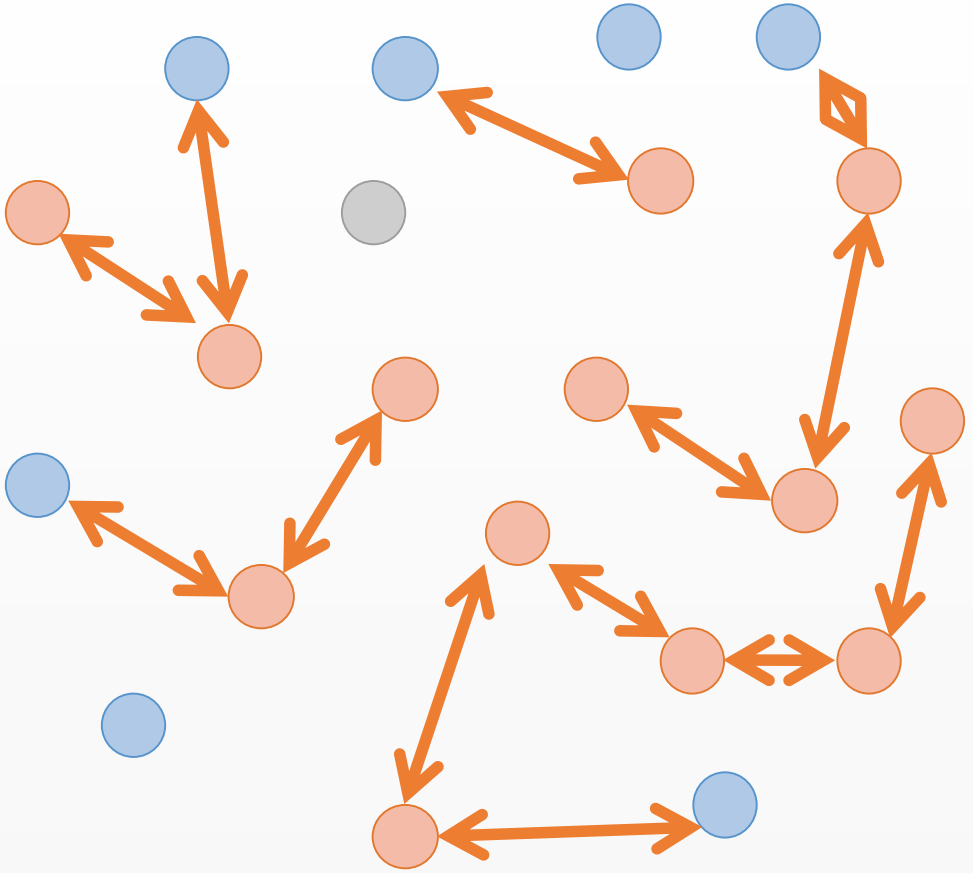
RUMOR MONGERING



RUMOR MONGERING



RUMOR MONGERING



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

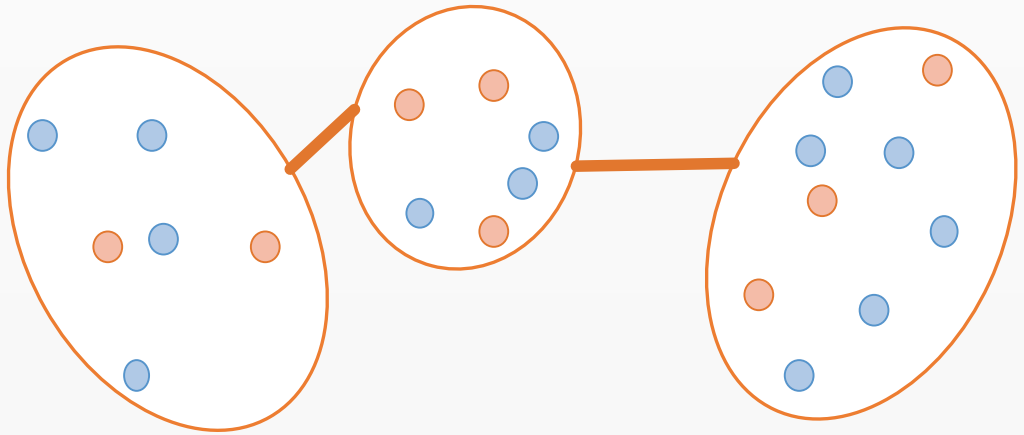
1	0.031	2.7	9.97	17.63
2	0.00058	4.49	10.07	15.39
3	0.000004	6.09	10.08	14.00

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

Astrolabe: a robust and scalable technology for distributed system monitoring, management, and data mining

Robbert van Renesse, Kenneth P. Birman, and Werner Vogels

Authors

Ken Birman
Cornell Univ.

Robbert van Renesse
Cornell Univ.

Werner Vogels
Amazon.com CTO

Context

- Rise of Web Services and computer-to-computer systems in 2000-s
- Availability and scalability of the system matters more than consistency
- Applications require fast data mining

Objective

Build a system that

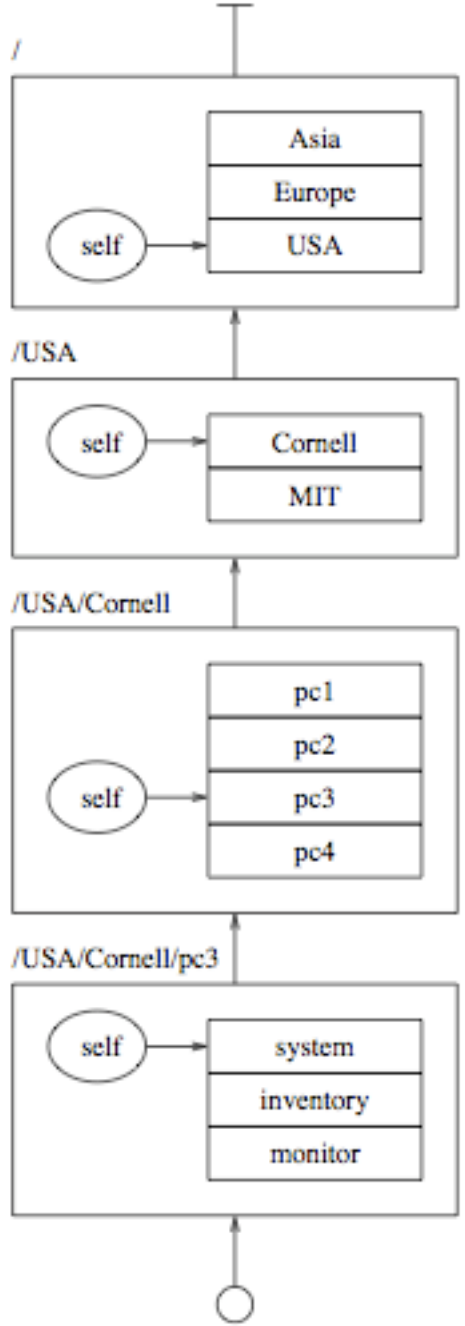
- Supports scaling
- Fault-tolerant
- Has an eventual consistency
- Guarantees security
- Can be controlled through SQL syntax

Overview

- Design principles
  - Scalability through hierarchy
  - Flexibility through mobile code
  - Robustness through a randomized p2p protocol
  - Security through certificates
- Now used in Amazon.com

ZONE AND MIB

- Zone name: path of zone identifiers from the root
- Management Information Base(MIB): attribute list containing the information associated with the zone
  - Each agent has a local copy of the root MIB, the MIBs of each child of the root
  - Each agent maintains MIB list of child zones



GOSSIP PROTOCOL

- Epidemic p2p protocol to propagate information
- Each zone elects a set of representative agents to gossip on behalf of that zone.
  - An agent may represent more than one zone
- Each agent periodically gossips
  - Picks one of the child zones at random,
  - Picks a random agent from child's list
  - Sends attributes of all the child zones up to root level.
- Gossip spreads quickly, O(log n)
- For scalability, robustness, and rapid dissemination of updates, eventual consistency is adopted.

EVENTUAL CONSISTENCY

- Probabilistic consistency
- Given an aggregate attribute *X* that depends on some other attribute *Y*
  - When an update *u* is made to *Y*, either *u* itself, or an update to *Y* made after *u*, is eventually reflected in *X*
  - With probability 1

ASTROLABE IS A FLEXIBLE MONITORING OVERLAY

swift.cs.cornell.edu

Name	Time	Load	Weblogic?	SMTP?	Word Version
swift	2271	1.8	0	1	6.2
falcon	1971	1.5	1	0	4.1
cardinal	2004	4.5	1	0	6.0

Periodically, pull data from monitored systems

cardinal.cs.cornell.edu

Name	Time	Load	Weblogic ?	SMTP?	Word Version
swift	2003	.67	0	1	6.2
falcon	1976	2.7	1	0	4.1
cardinal	2231	1.7	1	1	6.0

From Ken's slide http://www.cs.cornell.edu/courses/cs614/2006fa/Slides/Epidemics.ppt

STATE MERGE: CORE OF ASTROLABE EPIDEMIC

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cardinal	2201	3.5	1	1	6.0

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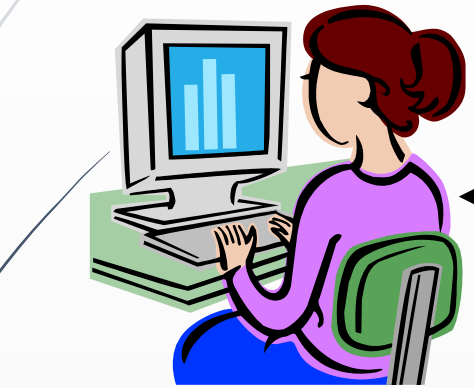

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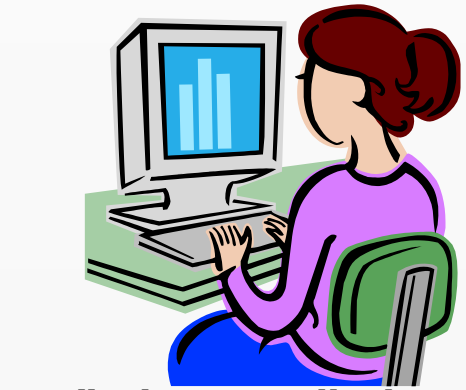

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swift	2011	2.0
cardinal	2201	3.5

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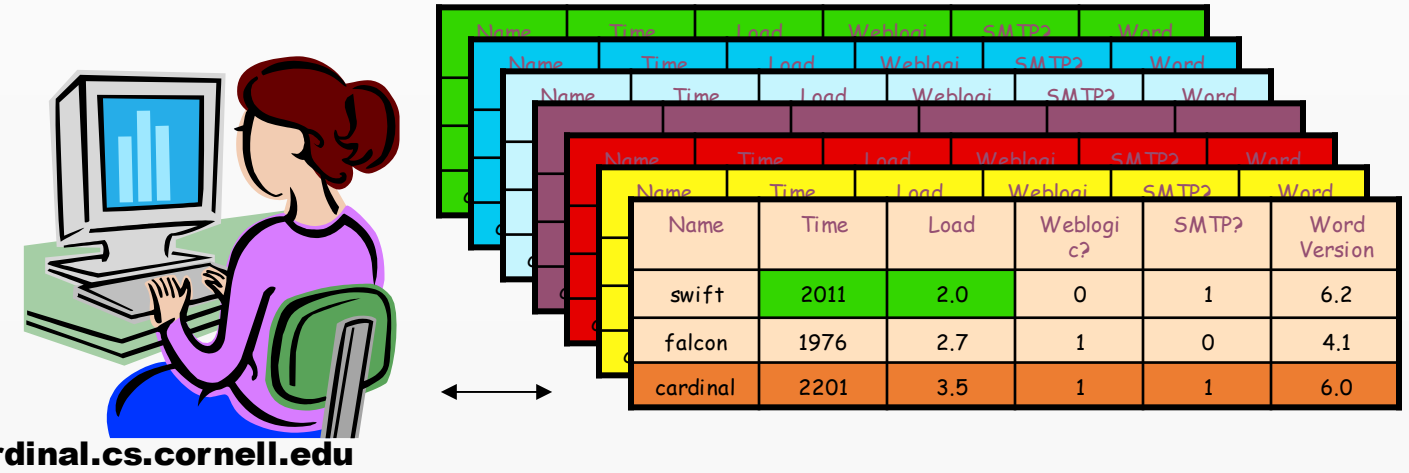
SCALING UP… AND UP…

- We don't want every system to "see" all others (cost would be huge)
- Instead, structure into "zones". You only see data from your neighbors…



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A FORM OF DATA MINING CONTINUOUSLY SUMMARIZES REMOTE INFORMATION

Dynamically changing query output is visible system-wide

SQL query "summarizes" data

Name	Avg Load	WL contact	SMTP contact
SF	2.6	123.45.61.3	123.45.61.17
NJ	1.8	127.16.77.6	127.16.77.11
Paris	3.1	14.66.71.8	14.66.71.12

Name	Load	Weblogic?	SMTP?	Word Version	...
swift	2.0	0	1	6.2	
falcon	1.5	1	0	4.1	
cardinal	4.5	1	0	6.0	

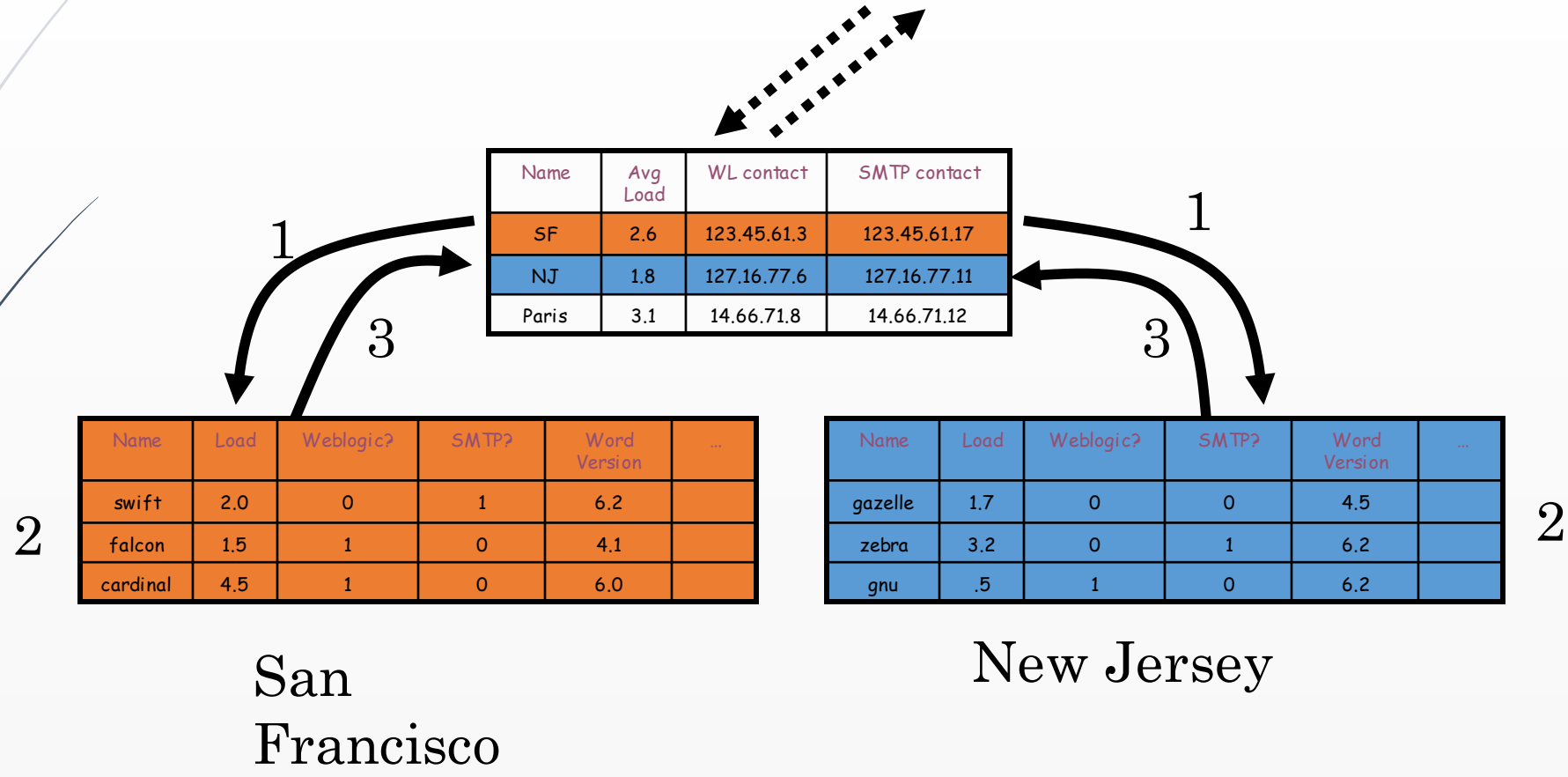
San Francisco

Name	Load	Weblogic?	SMTP?	Word Version	...
gazelle	1.7	0	0	4.5	
zebra	3.2	0	1	6.2	
gnu	.5	1	0	6.2	

New Jersey

From Ken's slide http://www.cs.cornell.edu/courses/cs614/2006fa/Slides/Epidemics.ppt

(1) QUERY GOES OUT… (2) COMPUTE LOCALLY… (3) RESULTS FLOW TO TOP LEVEL OF THE HIERARCHY



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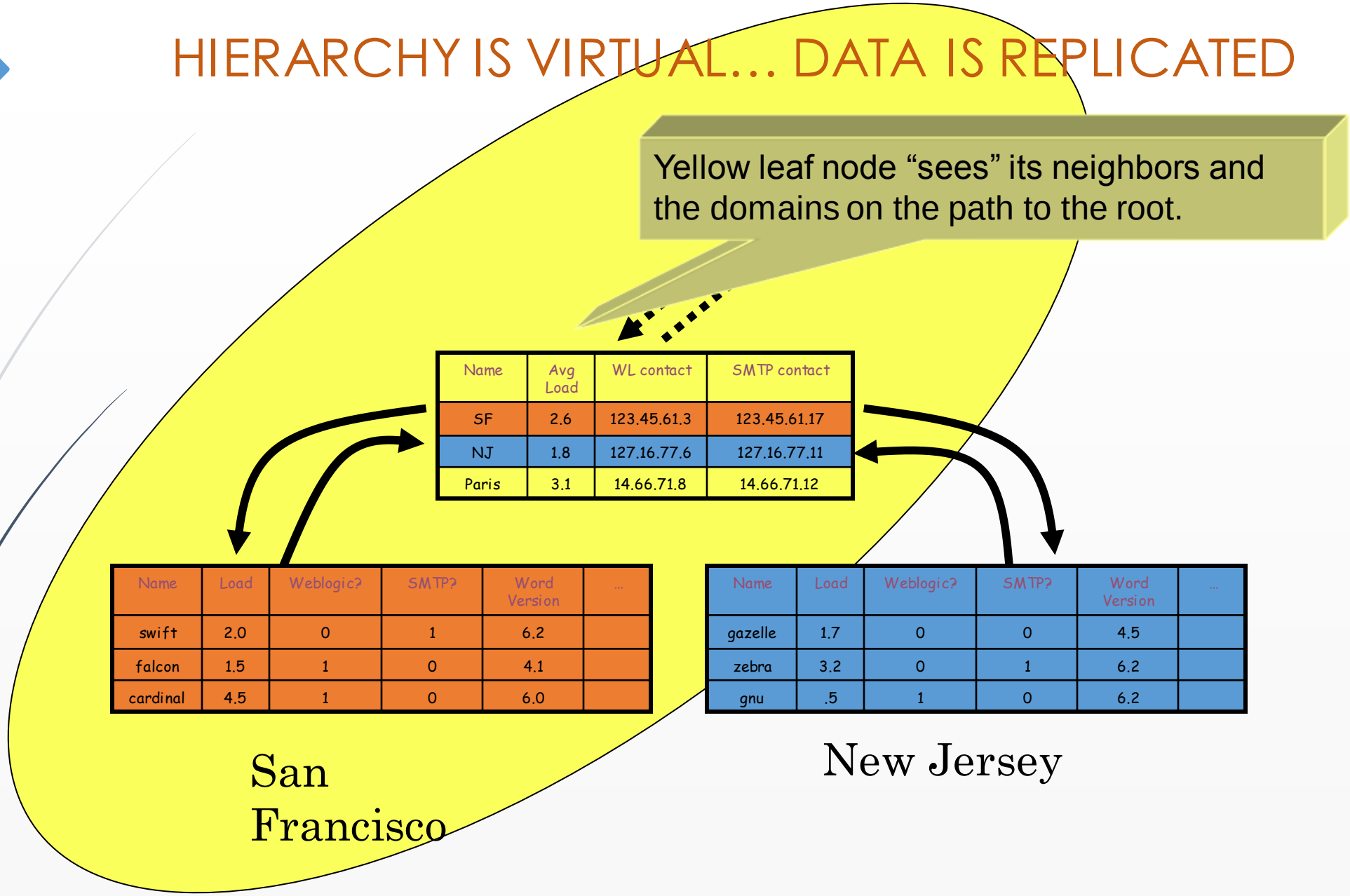
HIERARCHY IS VIRTUAL… DATA IS REPLICATED



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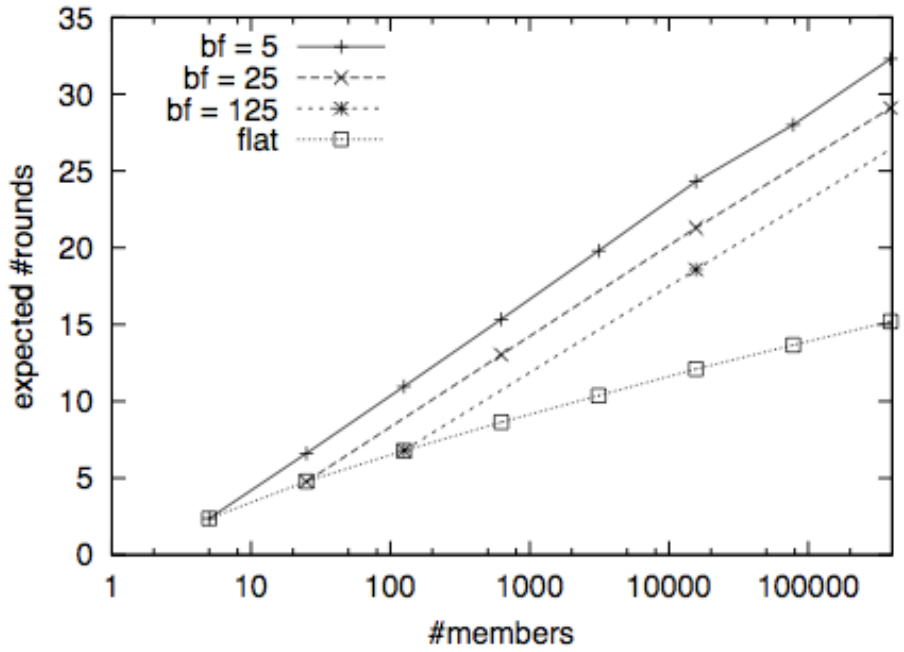

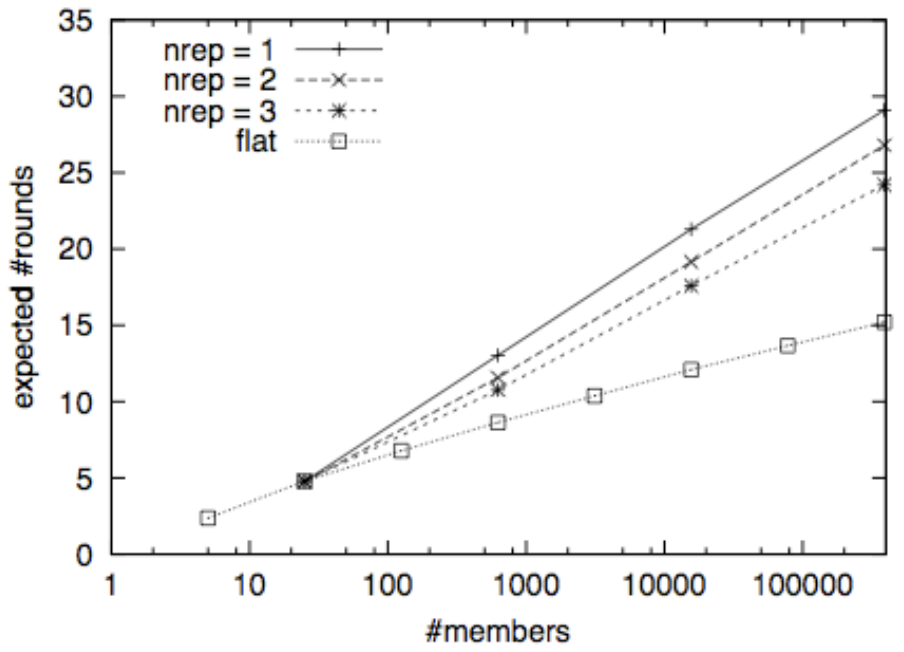

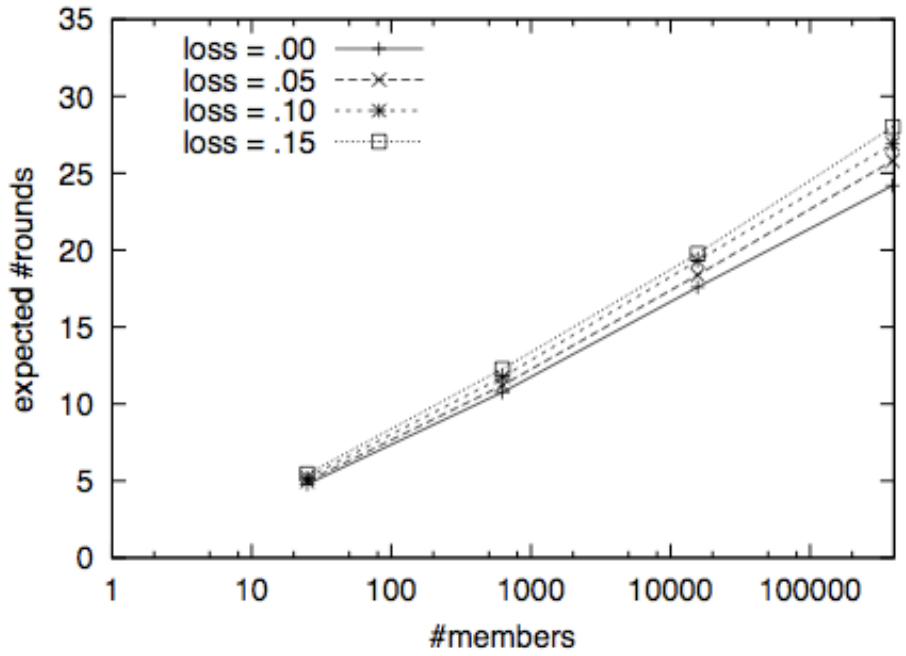

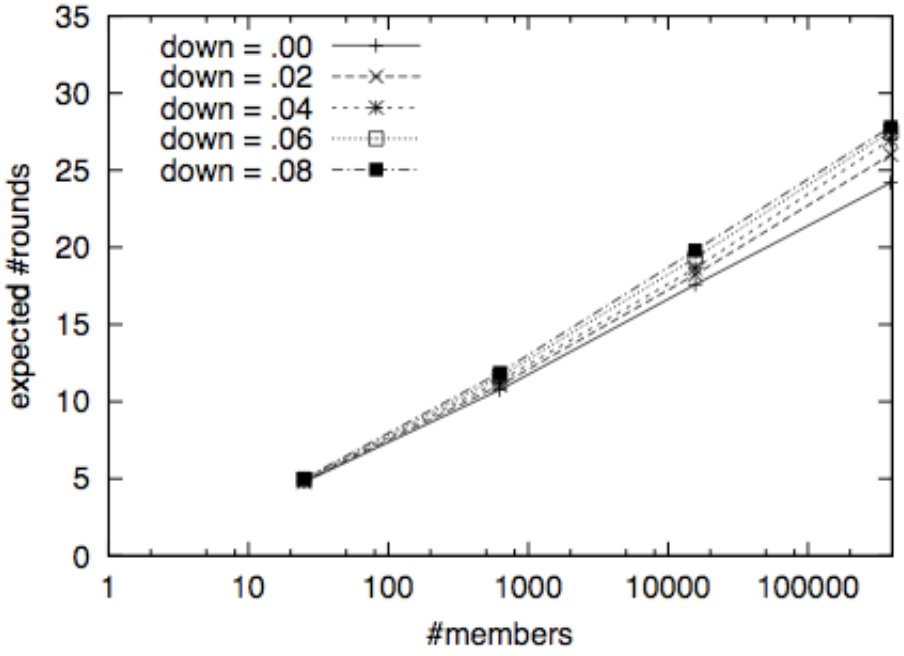

Average # of rounds necessary to infect all nodes

CONCLUSION

- Tree-based gossip protocol
- Robust and scalable
- Eventual Consistency

Thank you