Epidemic Algorithms For Replicated Database Maintenance

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Presented by Bo Teng
April 26th 2016

Background and Motivation

- Originated from study of Clearinghouse Servers on the Xerox Corporate Internet (CIN)
- World wide CIN consists of several hundred Ethernets connected by gateways and phone lines of different capacity
- Some domains stored in all Clearinghouse servers (HIGHLY REPLICATED)
- Need to achieve and maintain mutual consistency in replicas
    - Efficient, robust and scalable algorithm

Outline

1. **Problem statement**
2. Direct Mail
3. Anti-entropy
4. Rumor mongering
5. Deletion & death certificate
6. Spacial distribution

Problem statement

- Database **replicated** at many sites
- **Large**, **heterogeneous**, slightly **unreliable**, slowly **changing** Network
- Assume **synchronized** clocks in different sites
- Examine methods that achieves and maintains consistency in replicas
  - Direct mail
  - Anti-entropy
  - Rumor mongering

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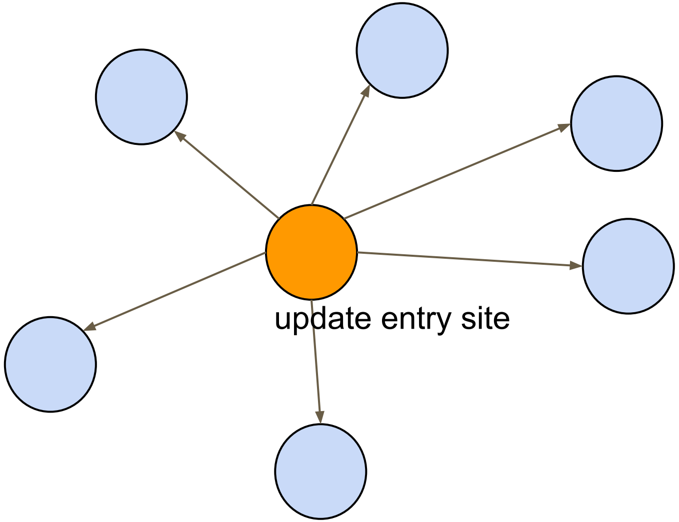
Direct Mail



- Timely, reasonably efficient, but not reliable
- Problems?
  - Message discarded when message queue overflows
  - Message lost due to bad network
  - Inaccurate member list at sender

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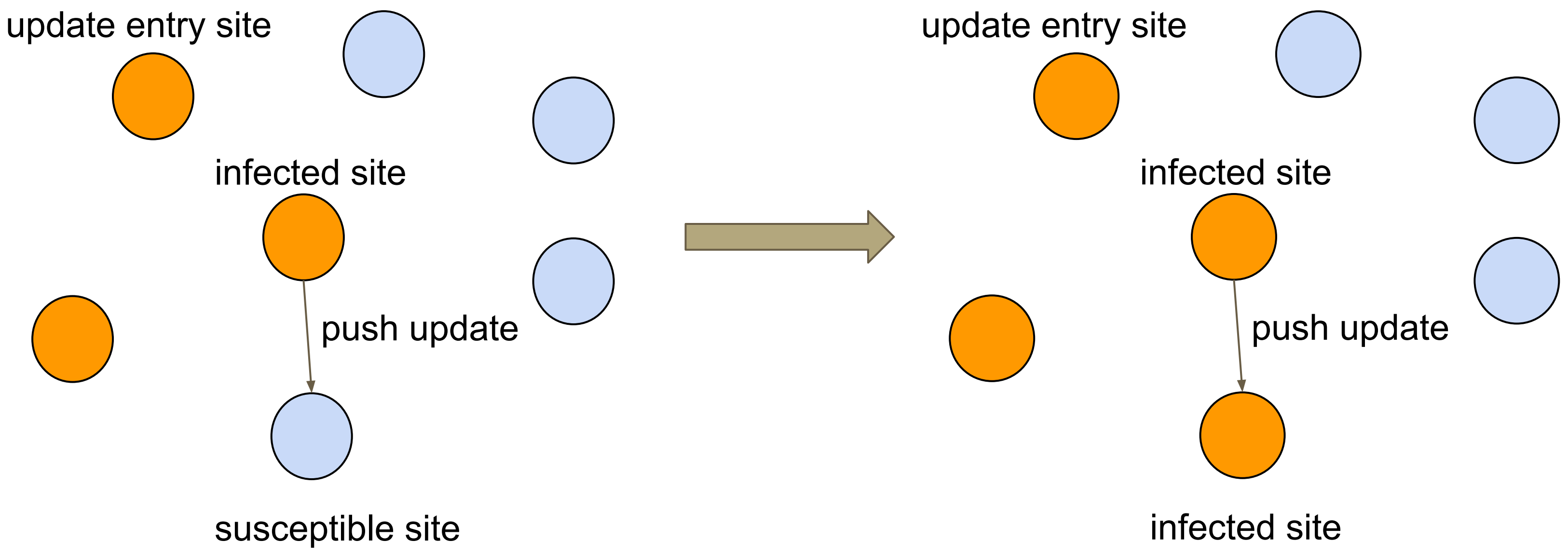
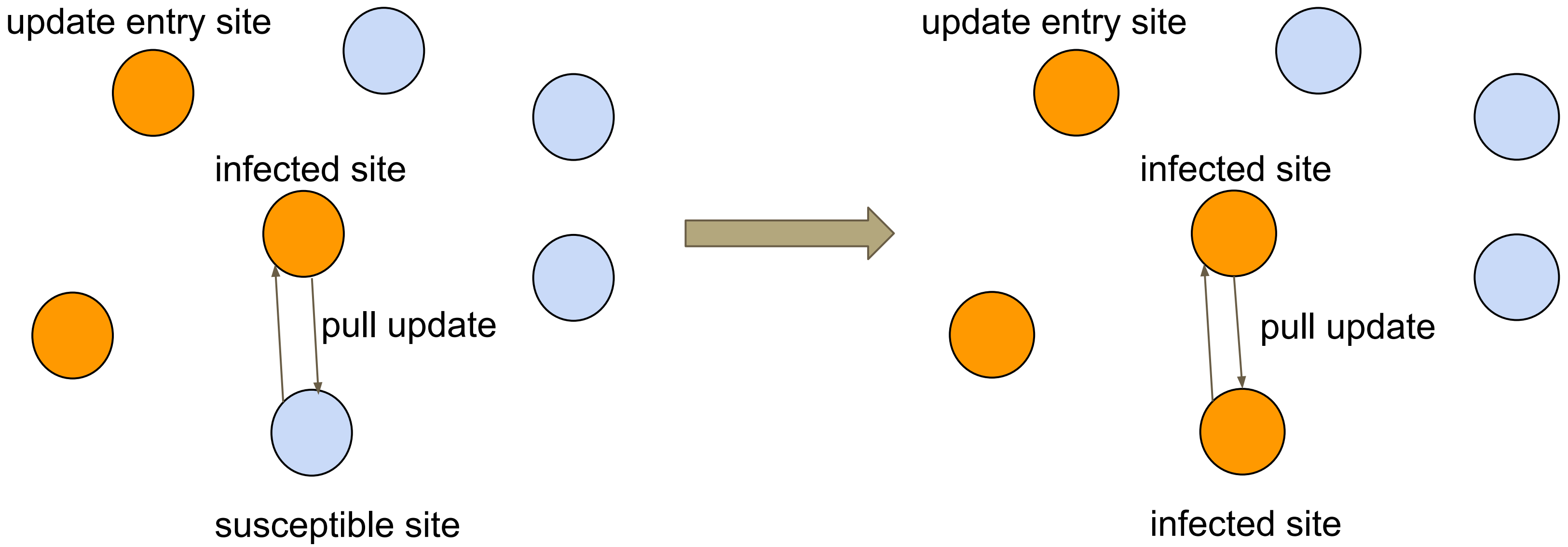
Anti-entropy: push



Anti-entropy: pull



Anti-entropy: Pull vs. Push

- Probability a site **s** is susceptible after (i+1)th round:
  - Pull: **s** is susceptible at round i & **s** contacts a susceptible site at round i+1
    $p_{i+1} = p_i^2$
  - Push: **s** is susceptible at round i & no infected node contacts **s** at round i+1
    $p_{i+1} = p_i(1 - 1/n)^{n(1-pi)} = p_i(1/e)$
- Convergence rate: Pull > Push
- Hybrid push-pull variation available

Anti-entropy

- Reliable, but propagates slower than direct mail and is expensive
- Could be run as back-up algorithm for direct mail
- Problem:
  - Compare two complete copies of database.
  - Most data are in complete agreement, most work is wasted
  - A copy of database is sent through network

Anti-entropy: Optimization

- Maintain checksum of database
  - Compare DB only when checksum differs
  - BUT checksum likely to disagree before updates reach all replicas
- Maintain checksum and *recent update list*
  - Exchange *recent update list* with updates within time window τ first
  - Update DB and checksum using *recent update list*, then compare checksum
- Maintain *inverted index* of DB by timestamp
  - Exchange information in reverse timestamp order
  - Incrementally recompute checksums

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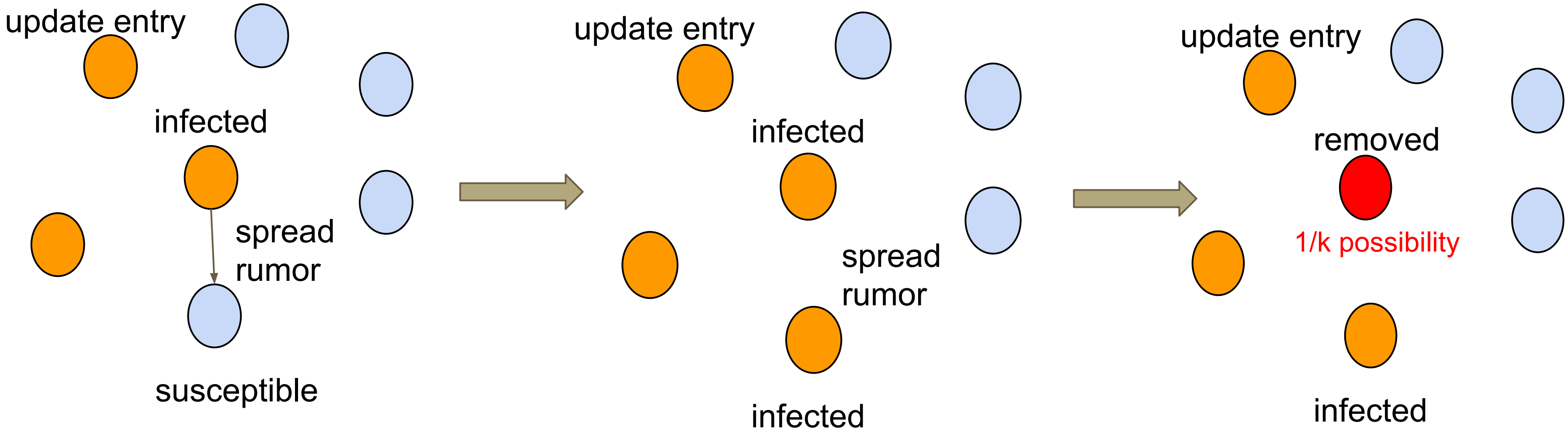
Rumor Mongering: Algorithm



Rumor Mongering: Probability of failure

- System becomes quiescent when all infected sites become removed
- There exists an explicit probability of failure. Fortunately, this probability could be make arbitrarily small

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

- k = 1: 20% sites miss the rumor
  k = 2:   6% sites miss the rumor
  k = 6: only 0.1% sites miss the rumor

Rumor Mongering: Variations

- Blind vs. Feedback
  - Feedback: site loses interest depending on recipient feedback
  - Blind: site loses interest regardless of the recipient
- Counter vs. Coin
  - Coin: sender loses interest with probability of 1/k
  - Counter: sender loses interest after k unnecessary contacts
- Pull vs. Push
  - $s = e^{-\lambda m}$ push: $\lambda = 1/(1-1/e)$; pull: $\lambda = -\ln\delta$

Rumor Mongering: Performance Metrics

- Residue
  - Percent susceptibles when epidemic finishes
- Traffic
  - m = (Total update traffic) / (Number of sites)
- Delay
  - Average/maximum time for receiving update

Rumor Mongering: Results

- Counter/feedback improves *Convergence time*

Table 1. Performance of an epidemic on 1000 sites using feedback and counters.

Counter k	Residue s	Traffic m	Convergence t_{ave}	t_{last}
1	0.18	1.7	11.0	16.8
2	0.037	3.3	12.1	16.9
3	0.011	4.5	12.5	17.4
4	0.0036	5.6	12.7	17.5
5	0.0012	6.7	12.8	17.7

Table 2. Performance of an epidemic on 1000 sites using blind and coin.

Coin k	Residue s	Traffic m	Convergence t_{ave}	t_{last}
1	0.96	0.04	19	38
2	0.20	1.6	17	33
3	0.060	2.8	15	32
4	0.021	3.9	14.1	32
5	0.008	4.9	13.8	32

Rumor Mongering: Results

- Pull improves *Residue* and *Convergence time* over Push

Table 1. Performance of an epidemic on 1000 sites using feedback and counters. push

Counter k	Residue s	Traffic m	Convergence t_{ave}	t_{last}
1	0.18	1.7	11.0	16.8
2	0.037	3.3	12.1	16.9
3	0.011	4.5	12.5	17.4
4	0.0036	5.6	12.7	17.5
5	0.0012	6.7	12.8	17.7

Table 3. Performance of a pull epidemic on 1000 sites using feedback and counters†.

Counter k	Residue s	Traffic m	Convergence t_{ave}	t_{last}
1	3.1×10^{-2}	2.7	9.97	17.6
2	5.8×10^{-4}	4.5	10.07	15.4
3	4.0×10^{-6}	6.1	10.08	14.0

WHAT ABOUT DELETION?

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Resurrection if not deleted all at once!

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6. Spacial distribution

Death certificate

- Replace deleted item with death certificate
- Death certificate carries timestamp and propagate as ordinary data
- Eventually all old copies are replaced with death certificates

This does not completely solve the problem...

When to delete death certificate?

- Delete *death certificate* if timestamp older by a time threshold τ
- Deciding τ: tradeoff between space usage and risk of resurrection
  - Increasing time threshold reduces resurrection risk but increases the amount of space consumed by death certificate
- Lower both resurrection risk and space usage: **Dormand Death Certificate !**
  - After time threshold, delete most death certificate
  - Retain “dormant” copies only at few sites
  - Dormant death certificates “awaken” when encounter obsolete items (unlikely)

When to delete dormant death certificate?

Dormant Death Certificate

- Two time thresholds : ʊ1and ʊ2
  - Retain death certificates till ʊ1
  - Retain dormant death certificates at several sites till ʊ1+ʊ2
- If “awakened” before before ʊ1+ʊ2 is reached?
  - Use a activation timestamp (originally the same as ordinary timestamp)
  - Upon “awakening”, set activation timestamp to current time

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Spacial Distribution

- Communication cost not uniform
- Favors closer sites in selection

  $p(d) \approx (Q(d-1)^{-a+1} - Q(d)^{-a+1}) / (Q(d) - Q(d-1))$

- Creates less network traffic compared to random uniform selection

Spatial Distribution: Results

- Traffic is greatly reduced with reasonable increase of delay

Table 5. Simulation results for anti-entropy, connection limit 1.

Spatial Distribution	t_{last}	t_{ave}	Compare Traffic		Update Traffic	
			Average	Bushey	Average	Bushey
uniform	11.0	7.0	3.7	47.5	5.8	75.2
$a = 1.2$	16.9	9.9	1.1	6.4	2.7	18.0
$a = 1.4$	17.3	10.1	1.1	4.7	2.5	13.7
$a = 1.6$	19.1	11.1	0.9	2.9	2.3	10.2
$a = 1.8$	21.5	12.4	0.8	1.7	2.1	7.0
$a = 2.0$	24.6	14.1	0.7	0.9	1.9	4.8

Thank You!