Epidemic Algorithms For Replicated Database Maintenance

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Presented by Bo Teng
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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
Outline

1. Problem statement
2. Direct Mail
3. Anti-entropy
4. Rumor mongering
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6. Spacial distribution
Anti-entropy: push

update entry site  
infected site  
push update  
susceptible site

update entry site  
infected site  
push update  
infected site

8
Anti-entropy: pull

update entry site
infected site
pull update
susceptible site

update entry site
infected site
pull update
infected site
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 $i+1$
    \[ p_{i+1} = p_i(1 - 1/n)^{n(1-p_i)} = p_i(1/e) \]

- 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 $\tau$ 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

update entry
infected
spread rumor
susceptible

update entry
infected
spread rumor

update entry
removed
1/k possibility
infected
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 made 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: \( \mu = 1/(1-1/e); \) pull: \( \mu = -\ln \delta \)
Rumor Mongering: Performance Metrics

- Residue
  - Percent susceptibles when epidemic finishes

- Traffic
  - \( m = \frac{\text{Total update traffic}}{\text{Number of sites}} \)

- 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.

<table>
<thead>
<tr>
<th>Counter $k$</th>
<th>Residue $s$</th>
<th>Traffic $m$</th>
<th>$t_{ave}$</th>
<th>$t_{last}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>1.7</td>
<td>11.0</td>
<td>16.8</td>
</tr>
<tr>
<td>2</td>
<td>0.037</td>
<td>3.3</td>
<td>12.1</td>
<td>16.9</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><strong>0.011</strong></td>
<td><strong>4.5</strong></td>
<td><strong>12.5</strong></td>
<td><strong>17.4</strong></td>
</tr>
<tr>
<td>4</td>
<td>0.0036</td>
<td>5.6</td>
<td>12.7</td>
<td>17.5</td>
</tr>
<tr>
<td>5</td>
<td>0.0012</td>
<td>6.7</td>
<td>12.8</td>
<td>17.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Coin $k$</th>
<th>Residue $s$</th>
<th>Traffic $m$</th>
<th>$t_{ave}$</th>
<th>$t_{last}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.96</td>
<td>0.04</td>
<td>19</td>
<td>38</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>1.6</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>0.060</td>
<td>2.8</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td><strong>0.021</strong></td>
<td><strong>3.9</strong></td>
<td><strong>14.1</strong></td>
<td><strong>32</strong></td>
</tr>
<tr>
<td>5</td>
<td>0.008</td>
<td>4.9</td>
<td>13.8</td>
<td>32</td>
</tr>
</tbody>
</table>
Rumor Mongering: Results

- Pull improves Residue and Convergence time over Push

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

<table>
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<tr>
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<tr>
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</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Counter</th>
<th>Residue $s$</th>
<th>Traffic $m$</th>
<th>$t_{ave}$</th>
<th>$t_{last}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$3.1 \times 10^{-2}$</td>
<td>2.7</td>
<td>9.97</td>
<td>17.6</td>
</tr>
<tr>
<td>2</td>
<td>$5.8 \times 10^{-4}$</td>
<td>4.5</td>
<td>10.07</td>
<td>15.4</td>
</tr>
<tr>
<td>3</td>
<td>$4.0 \times 10^{-6}$</td>
<td>6.1</td>
<td>10.08</td>
<td>14.0</td>
</tr>
</tbody>
</table>
WHAT ABOUT DELETION?
WHAT ABOUT DELETION?

Resurrection if not deleted all at once!
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5. **Deletion & death certificate**
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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 $\tau$
- Deciding $\tau$: 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: $\tau_1$ and $\tau_2$
  - Retain death certificates till $\tau_1$
  - Retain dormant death certificates at several sites till $\tau_1 + \tau_2$

- If “awakened” before before $\tau_1 + \tau_2$ 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.**

<table>
<thead>
<tr>
<th>Spatial Distribution</th>
<th>$t_{last}$</th>
<th>$t_{ave}$</th>
<th>Compare Traffic</th>
<th>Update Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>Bushey</td>
</tr>
<tr>
<td>uniform</td>
<td>11.0</td>
<td>7.0</td>
<td>3.7</td>
<td>47.5</td>
</tr>
<tr>
<td>$a = 1.2$</td>
<td>16.9</td>
<td>9.9</td>
<td>1.1</td>
<td>6.4</td>
</tr>
<tr>
<td>$a = 1.4$</td>
<td>17.3</td>
<td>10.1</td>
<td>1.1</td>
<td>4.7</td>
</tr>
<tr>
<td>$a = 1.6$</td>
<td>19.1</td>
<td>11.1</td>
<td>0.9</td>
<td>2.9</td>
</tr>
<tr>
<td>$a = 1.8$</td>
<td>21.5</td>
<td>12.4</td>
<td>0.8</td>
<td>1.7</td>
</tr>
<tr>
<td>$a = 2.0$</td>
<td>24.6</td>
<td>14.1</td>
<td>0.7</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Thank You!