Supporting Network Coordinates on PlanetLab

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Hourglass Project at Harvard
http://www.eecs.harvard.edu/~syrah/hourglass
Outline

1. Review Network Coordinates
2. Discuss Two Implementation Problems and our Solutions
3. Conclude with plug for our NC service
Coordinates Simplify Distributed Systems Problems

Pick server with lowest mean latency

Use Centroid Of NCs to pick Game Server

Players

Game servers

(-40,22) (-15,20) (20,20)

(-50,4) (0,8) (25,-2)

(-42,-10) (-25,-17) (20,-15)

(18,-25)
Coordinates are a Powerful Abstraction

Apply well-understood geometric algorithms to problems in distributed systems

<table>
<thead>
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<th>Dist. Sys. Problem</th>
<th>Geometric Algorithm</th>
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<td>Content distribution</td>
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<td>Cluster analysis</td>
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<td>Network analysis</td>
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<td>Principal Component Analysis</td>
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<td>Unknown Problem</td>
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<td>Minimum length matching</td>
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How Network Coordinates Work (I)

Goal: Minimize global latency prediction error

1. A starts measurement to B.
How Network Coordinates Work (II)

Goal: Minimize global latency prediction error

1. A starts measurement to B.
2. B replies with its coord. A deduces RTT.

RTT = 60ms
How Network Coordinates Work (III)

Goal: Minimize global latency prediction error

1. A starts measurement to B.
2. B replies with its coord. A deduces RTT.
3. A computes estimate and error.

\[
\text{Estimate} = |(100,80)-(70,40)| = 50\text{ms}
\]
\[
\text{Error} = (60 - \text{Estimate}) = 10\text{ms}
\]
Goal: Minimize global latency prediction error

1. \( A \) starts measurement to \( B \).
2. \( B \) replies with its coord. \( A \) deduces RTT.
3. \( A \) computes estimate and error.
4. \( A \) moves toward ideal coord, relative to \( B \).

Estimate = \(|(100,80)-(70-40)|=50\text{ms} \)
Error = \((60 - \text{Estimate}) = 10\text{ms}\)
How Network Coordinates Work (V)

Goal: Minimize global latency prediction error

1. A starts measurement to B.
2. B replies with its coord. A deduces RTT.
3. A computes estimate and error.
4. A moves toward ideal coord, relative to B.
5. Repeat with C, D, E.
How Network Coordinates Work (VI)

Goal: Minimize global latency prediction error

1. A starts measurement to B.
2. B replies with its coord. A deduces RTT.
3. A computes estimate and error.
4. A moves toward ideal coord, relative to B.
5. Repeat with C, D, E.
6. Predict to X
Outline

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2. Discuss Two Implementation Problems and our Solutions
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Problem #1: Latencies are not Static

Latencies measurements have errors and change

RTT = 60ms, 61ms, 59ms, 1000ms, 70ms, 60ms, ...

RTT = 5ms, 5ms, 6ms, 40ms, 41ms, 40ms, ...

A

B

D
Problem #1(a): Errors are Unpredictable

Three hours of measurements from berkeley to uvic.ca

82% of measurements within 1ms of median
Problem #1(b): Latencies can change

Three days of measurements from ntu.edu.tw to 6planetlab.edu.cn

Need to remove noise, but remain adaptive
Solution #1: Moving Minimum as Latency Filter

- Remove outliers and respond to latency change
- Minimum of previous four samples worked best

<table>
<thead>
<tr>
<th>Time</th>
<th>Age</th>
<th>Newest</th>
<th>Oldest</th>
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</thead>
<tbody>
<tr>
<td>$t_0$</td>
<td>ms</td>
<td>60</td>
<td>61</td>
</tr>
<tr>
<td>$t_1$</td>
<td>Receive 1000ms RTT</td>
<td>1000</td>
<td>60</td>
</tr>
<tr>
<td>$t_2$</td>
<td>Receive 70ms RTT</td>
<td>70</td>
<td>1000</td>
</tr>
</tbody>
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Other simple techniques did not work.
Network Coordinates on PlanetLab

- Points represent locations of PL nodes in 3-d relative coordinate space
- We used Vivaldi, but both problems inherent in any NC implementation
Latency Filters in Practice: Video Comparison

- Raw Vivaldi Coordinates vs. Latency Filter
- Latency Filters eliminate outliers that cause distortion of many coords all at once (e.g. minute 38 of the video)
Latency Filters: Accuracy

270 PlanetLab nodes; last two of four hour trial. Graph shows relative error experienced by each node.

Relative Error = |RTT-prediction|/RTT
Problem #2: Changing a Coordinate is Expensive

• Even with latency filter, frequent coordinate change
• App-specific cost for coord update
  – Cause operator migration in streaming DB
  – Routing table change

• Short-term variations in RTT should not cause coordinate changes.
  - However, still need to track longer-term changes
    in network topology, e.g., BGP updates.
• Is it possible to tell apps less frequently and
  retain high accuracy?
Solution #2: Coordinate Windows as Update Filters

1. Keep history of recent coordinates
2. Divide history into two windows (sets): current (newest) and start (oldest)
3. When current and start diverge (by some metric), update application with new coordinate

- Two metrics:
  - Local Relative Distance
  - Energy
Update Filters: *Local Relative Distance* Heuristic (1)

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

![Diagram showing points A and B with distance d between them]
Update Filters: *Local Relative Distance Heuristic* (2)

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

\[
\begin{align*}
\text{Start } W_s & \\
C_0 & \\
\text{Current } W_c & 
\end{align*}
\]
Update Filters: *Local Relative Distance* Heuristic (3)

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

Start $W_s$

Current $W_c$
Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

\[
\text{Start } W_s \quad \text{Current } W_c
\]
Update Filters: Local Relative Distance Heuristic (5)

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

Start $W_s$

| $C_0$ | $C_1$ | $C_2$ | $C_3$ |

Current $W_c$
Update Filters: *Local Relative Distance* Heuristic (6)

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

Start $W_s$, Current $W_c$
Update Filters: *Local Relative Distance* Heuristic (7)

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

3. Compare centroids of windows

\[
\text{If } \text{Centroid}(W_s) - \text{Centroid}(W_c) > d \times \epsilon
\]
**Update Filters: Local Relative Distance Heuristic (8)**

Base update on distance moved relative to nearest neighbor

1. Remember nearest known neighbor

2. Add coordinates to start and current windows

3. Compare centroids of windows

4. Update app-level coordinate

If \( \text{Centroid}(W_s) - \text{Centroid}(W_c) > d \times \epsilon \)

\[ \text{App coord} = \text{Centroid}(W_c) \]
Video Comparison

• Both Filters Combine for a much more stable set of coordinates.
• Same 10 minute segment as before.
Update Filters: Greater Stability, Same Accuracy

270 PlanetLab nodes; last two of four hour trial. Graph shows relative error experienced by each node.
Other Results

• Application-oriented metrics: Relative Rank Loss (Lua et al.), two new metrics
• Effect of neighbor set size
• Impact of triangle inequality violations on stability

• Using Network Coordinates for Distributed Query Operator Placement (IPTPS ‘05, NetDB ‘05, ICDE ‘06)
Conclusion: They work, go use them

NCs work in the “real world” with the addition of two techniques:

1. Latency filters - Summarize current link latency
2. Update filters - Tell app only when necessary

NC service available on January 1, 2006
  • Proxy coords for non-PL nodes soon after

Go use ‘em!

Questions?

Hourglass Project at Harvard
http://www.eecs.harvard.edu/~syrah/hourglass
Relative Error on PlanetLab

Second half of four hour run; June 24, 2005;
270 nodes; Medians: 8% and 12%
Network Coordinate Service

- **API:**
  - double estimateLatency (double[] remoteNC)
  - double[] getNC ()
  - double getConfidence ()
  - double getRelativeError ()
  - double forceUpdate (IP remoteNode)

- **Available January 1, 2006**
- **XML/RPC interface**
Future Work: Triangle Violations and Instability

- Do these filters matter on a larger network? -- Azureus
- Strong correlation between extent of triangle violations and stability

![Graph showing the correlation between average triangle violation and average change per update.](Image)
Application-Oriented Metrics

Example of Incorrect Ranking: RTT (X,A) = 50, RTT(X,B) = 60

RRL:
- incorrect: add 1
- divide by number of pairs
- percent of incorrect rankings

WRRL:
- incorrect: add diff(RTT)/diff(RTT)
- divide by sum of (diff(RTT)/diff(RTT))
- magnitude of incorrect rankings

RALP:
- incorrect: add pct loss e.g (RTT(X,B)-RTT(X,A))/RTT(X,A)
- I.e. percentage slow-down for incorrect coordinates
- reflects app-perceived penalty for using coordinates
Application-Oriented Metric: RALP

- Relative Application Latency Penalty

Percentage of the actual latency that you are penalized by having a mis-ordering, for all pairs of links.
Application-Oriented Metric: RRL

- Relative Rank Loss: probability of incorrect ranking

Percent of incorrect orderings of pairs of nodes.
Four hour PL trace, 226 nodes.
Application-Oriented Metric: WRRL

- Weighted Relative Rank Loss: magnitude of incorrect rankings

For each node, sum of magnitude of incorrect rankings, over sum of all rankings.
Latency Filter Applied to Error-Prone Link

Same three hours of measurements from berkeley to uvic.ca

98% of output now within 1ms of median
Latency Filter Applied to Periodic Link

Three days of measurements from ntu.edu.tw to 6planetlab.edu.cn

Short filters adapt to new latency plateaus and drop outliers
Coordinate Update (II)

\( \text{VIVALDI}(\bar{x}_j, w_j, l_{ij}) \)

1. \( w_s = \frac{w_i}{w_i + w_j} \)
2. \( \varepsilon = \frac{||\bar{x}_i - \bar{x}_j|| - l_{ij}}{l_{ij}} \)
3. \( \alpha = c_e \times w_s \)
4. \( w_i = (\alpha \times \varepsilon) + ((1 - \alpha) \times w_i) \)
5. \( \delta = c_c \times w_s \)
6. \( \bar{x}_i = \bar{x}_i + \delta \times (||\bar{x}_i - \bar{x}_j|| - l_{ij}) \times u(\bar{x}_i - \bar{x}_j) \)
Update Filters: Increase Stability

- **Stability**: coord change per time (ms/sec)