Performance Debugging for Distributed Systems of Black Boxes

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Summarized by Kyung-Min Kim and Kyoung-Woon On
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Introduction & Related work
Introduction

- Complex distributed systems are built from black box components
- These systems may have performance problems
- Distributed systems with black box component are hard to debug
- We need to design tools that isolate performance bottlenecks in black-box distributed systems
Related work

- Systems that trace end-to-end causality via modified middleware
  - Magpie (Microsoft Research)
  - Pinpoint (Stanford/Berkeley)
  - Products such as AppAssure, PerformaSure, OptiBench

- Systems that make inferences from traces
  - Intrusion detection (Zhang & Paxson, LBL)
  - They use traces + statistics to find compromised systems
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Problem Settings
Problem Settings

- **Situation**: an external request to the system causes activities in the graph along a causal path.
- **Assumption**: all latencies can be ascribed to the node traversals.
Goals

- **Isolating performance bottlenecks**
  - Find *high-impact* causal path patterns
    - Causal path
    - High-impact
  - Identify *high-latency* nodes on high-impact patterns
    - Add significant latency to these patterns

- **Without modifications or semantic knowledge**
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Approach
Approach

- Obtain traces of messages between components
- Analyze traces using our algorithms
  - Nesting: faster, more accurate, limited to RPC-style systems
  - Convolution: works for all message-based systems
- Visualize results and highlight high-impact paths
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Algorithms
The nesting algorithm

- RPC-style communication
- Infers causality from “nesting” relationships
  - Suppose A calls B and B calls C before returning to A
  - Then the B↔C call is “nested” in the A↔B call
- Uses statistical correlation

![Diagram showing the nesting algorithm](image-url)
Nesting: an example causal path in detail
Details of the nesting algorithm

1. Find call pairs in the trace
   - (A⇒B, B⇒A), (B⇒D, D⇒B), (B⇒C, C⇒B)
2. Find and score all nesting relationships
   - B⇒C nested in A⇒B
   - B⇒D also nested in A⇒B
3. Pick best parents
4. Derive call paths
   - A⇒B⇒[C ; D]
Pseudo-code for the nesting algorithm (1/3)

- Detects call pairs and find all possible nestings of one call pair in another

```plaintext
procedure FindCallPairs
for each trace entry (t1, CALL/RET, sender A, receiver B, callid id)
  case CALL:
    store (t1,CALL,A,B,id) in Topencalls
  case RETURN:
    find matching entry (t2, CALL, B, A, id) in Topencalls
    if match is found then
      remove entry from Topencalls
      update entry with return message timestamp t2
      add entry to Tcallpairs
      entry.parents := {all callpairs (t3, CALL, X, A, id2) in Topencalls with t3 < t2}
```

Pseudo-code for the nesting algorithm (2/3)

- Pick the most likely candidate for the causing call for each call pair

```plaintext
procedure ScoreNestings
for each child (B, C, t2, t3) in Tcallpairs
  for each parent (A, B, t1, t4) in child.parents
    scoreboard[A, B, C, t2-t1] += (1/|child.parents|)

procedure FindNestedPairs
for each child (B; C; t2; t3) in call pairs
  maxscore := 0
  for each p (A, B, t1, t4) in child.parents
    score[p] := scoreboard[A, B, C, t2-t1]*penalty
    if (score[p] > maxscore) then
      maxscore := score[p]
      parent := p
  parent.children := parent.children U {child}
```
Pseudo-code for the nesting algorithm (3/3)

- Derive call paths from the causal relationships

```plaintext
procedure FindCallPaths
initialize hash table Tpaths
for each callpair (A, B, t1, t2)
   if callpair.parents = null then
      root := { CreatePathNode(callpair, t1) }
   if root is in Tpaths then update its latencies
   else add root to Tpaths
function CreatePathNode(callpair (A, B, t1, t4), tp)
   node := new node with name B
   node.latency := t4 - t1
   node.call_delay := t1 - tp
   for each child in callpair.children
      node.edges := node.edges U { CreatePathNode(child, t1)}
return node
```
The “convolution algorithm”

- Finds causal relationships
  - Considering the aggregation of multiple messages.
  - Separates a whole system trace into a set of per-edge traces.

- Convert traces into time signals (per-edge traces)
  - Use signal processing techniques to find the cross correlations between signals
  - Can be used on traces of free-form message-based communications

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The “convolution algorithm”

- Look for time-shifted similarities
  - Compute cross correlation by convolution
    \[ C(t) = S_1 \otimes S_2(t) = \int_{-\infty}^{\infty} S_1(u)S_2(t - u)du \]
  - Find peaks in \( C(t) \)
  - Time shift of peak indicate delay
  - Considering the aggregation of multiple messages.
  - Separates a whole system trace into a set of per-edge traces.
The “convolution algorithm”

$s1(t): A \rightarrow B$

$s2(t): B \rightarrow C$

Peaks suggest causality between $A \rightarrow B$ and $B \rightarrow C$

delay
The “convolution algorithm”

- **Detect the spikes**
  - Compute mean and standard deviations of C
  - Spike if it is a local maximum N (e.g., 4) standard deviations above the mean
  - Require at least one point that is less than S (e.g., 3) standard deviations above the mean between spikes, where $S < N$
  - Choose largest to represent the spike

**Figure 7:** Example of convolution output, showing two spikes with bold lines. The x-axis represents the time shift; the y-axis roughly estimates the number of messages matching a given shift.
The “convolution algorithm”

- Time complexity: $O(em + eS\log S)$
  - $m = \# \text{ message}$
  - $e = \# \text{ edge in output graph}$
  - $s = \# \text{ time steps in trace}$

- Need to choose time step size
  - Must be shorter than delays of interest
  - Too coarse: poor accuracy
  - Too fine: long running time

- Robust to noise in trace

- Run-time is dependent on the trace duration and time quantum, not the trace length
Comparison of the two algorithms

<table>
<thead>
<tr>
<th></th>
<th>Nesting Algorithm</th>
<th>Convolution Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication style</td>
<td>RPC only</td>
<td>RPC or free-form messages</td>
</tr>
<tr>
<td>Rare events</td>
<td>Yes, but hard</td>
<td>No</td>
</tr>
<tr>
<td>Level of Trace detail</td>
<td>&lt;timestamp, sender, receiver&gt; + call/return tag</td>
<td>&lt;timestamp, sender, receiver&gt;</td>
</tr>
<tr>
<td>Time and space complexity</td>
<td>Linear space Linear time</td>
<td>Linear space Polynomial time</td>
</tr>
<tr>
<td>Visualization</td>
<td>RPC call and return combine</td>
<td>Less compact</td>
</tr>
</tbody>
</table>
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Experiments and Results
Maketrace

- Synthetic trace generator
- Needed for testing
  - Validate output for known input
  - Check corner cases
- Uses set of causal path templates (tracelet)
  - All call and return messages, with latencies
  - Gaussian delay between messages

- Recipe to combine paths
  - Parallelism, start/stop times for each path
  - Duration of trace
Desired results for one trace

- **Causal paths**
  - How often
  - How much time spent

- **Nodes**
  - Host/component mane
  - Time spent in node and all of the nodes it calls

- **Edges**
  - Time parent waits before calling child
Measuring Added Delay

- Added 200msec delay in WS2
- The nesting alg. detects the added delay, and so does the convolution algorithm
Results: Petstore

- Sample EJB application
- J2EE middleware for Java
  - Instrumentation from Stanford’s PinPoint project
- 50msec delay added in mylist.jsp

Figure 14: PetStore results, normal configuration (nesting algorithm)

Figure 15: PetStore results, constant-delay config. (nesting algorithm)
Validation of accuracy

- False negative rate for top N pattern
  - Is bounded in most cases by 1/N

**Figure 17:** False negative path pattern rate vs. pattern pruning
accuracy

- Trace parallelism
- Delay variation
- Message drop rate
Conclusions
Conclusions

- Looking for bottlenecks in black box systems
- Finding causal paths is enough to find bottlenecks
- Algorithms to find paths in traces really work
  - We find correct latency distribution
  - Two very different algorithms get similar results
  - Passively collected traces have sufficient information
Thank you