Performance Debugging for Distributed Systems of Black Boxes

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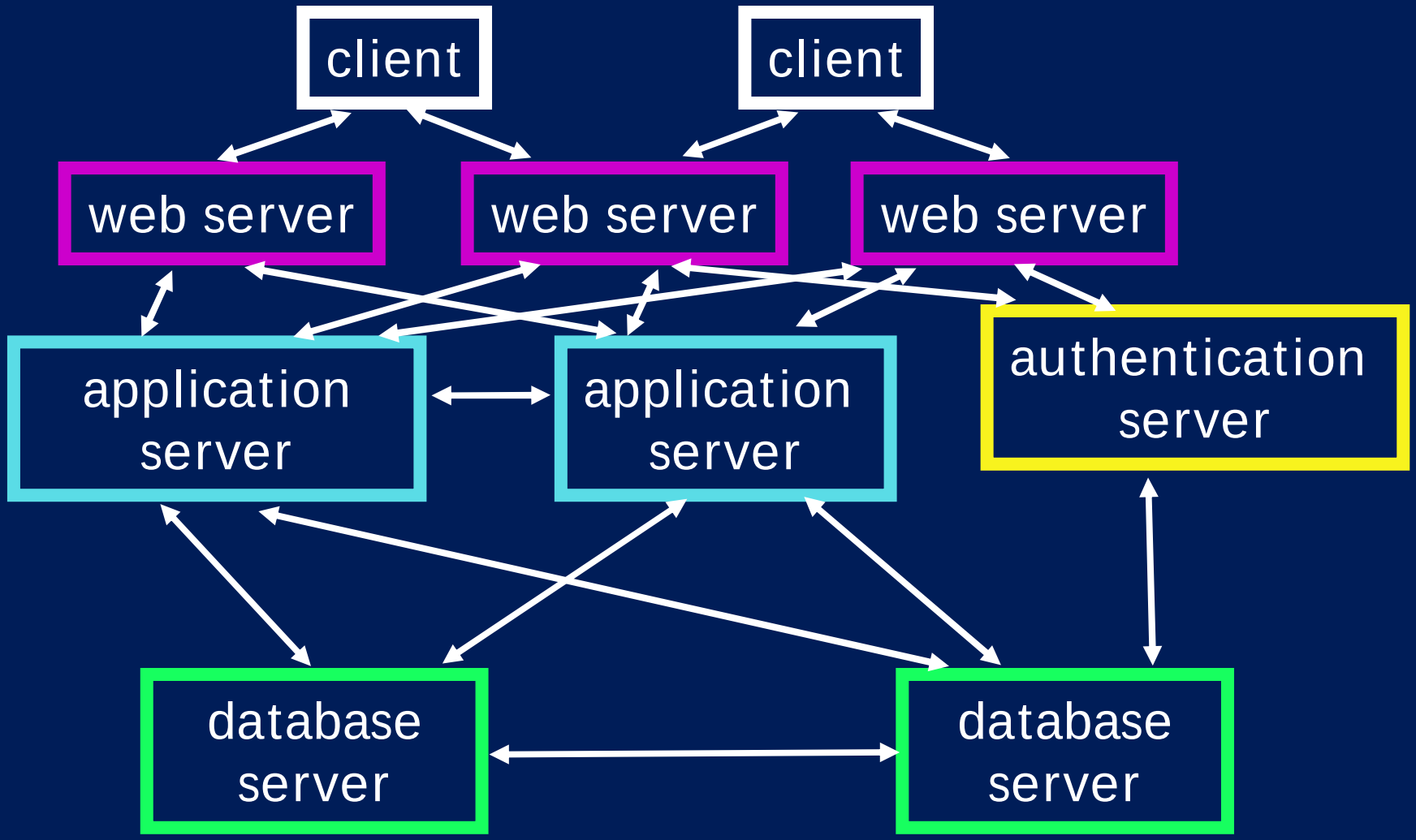
Example multi-tier system



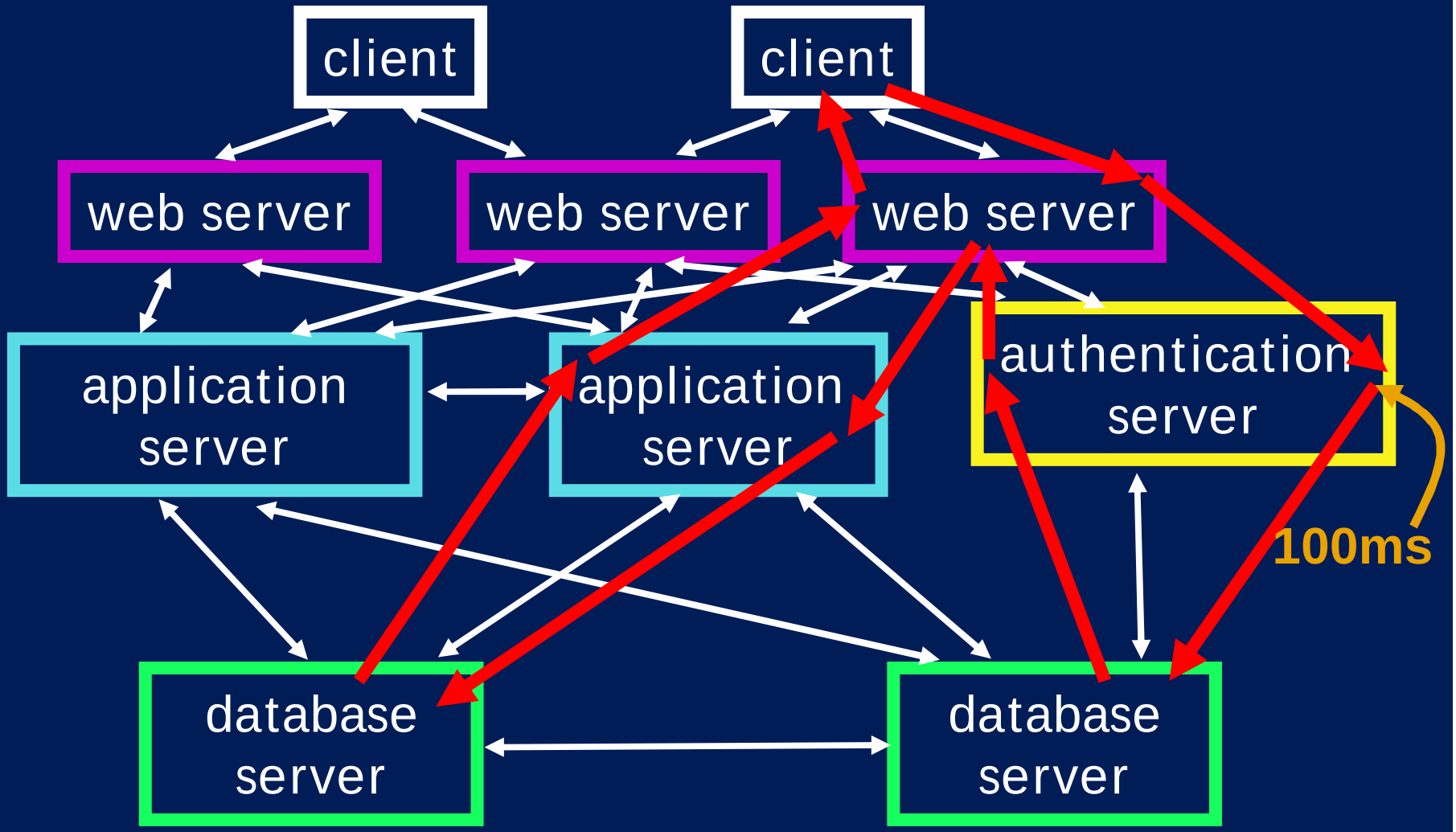
Motivation

- Complex distributed systems are built from black box components
- These systems may have performance problems
  - High or erratic latency
- Locating the causes of these problems is hard
  - We can’t always examine or modify system components
- We need tools to infer where bottlenecks are
  - Choose which black boxes to open

Contributions of our work

- Tools to highlight which black boxes to open
  - Require only passive information, such as packet traces
  - Infer where most of time is spent from traces
- Person can then use more invasive tools to instrument those boxes
- Reduce time and cost to debug complex systems
- Improve quality of delivered systems

Example causal path



Goals of our tools

- Find high-impact causal paths through a distributed system

  Causal path: series of nodes that sent/received messages
  - Each message is caused by receipt of previous message
  - Some causal paths occur many times

  High impact:
  - Occurs frequently
  - Contributes significantly to overall latency

- Without modifications or semantic knowledge
- Report per-node latencies on causal paths

Overview of our approach

- Obtain traces of messages between components
  - Ethernet packets, middleware messages, etc.
  - Collect traces as non-invasively as possible
- 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
- Require very little information:

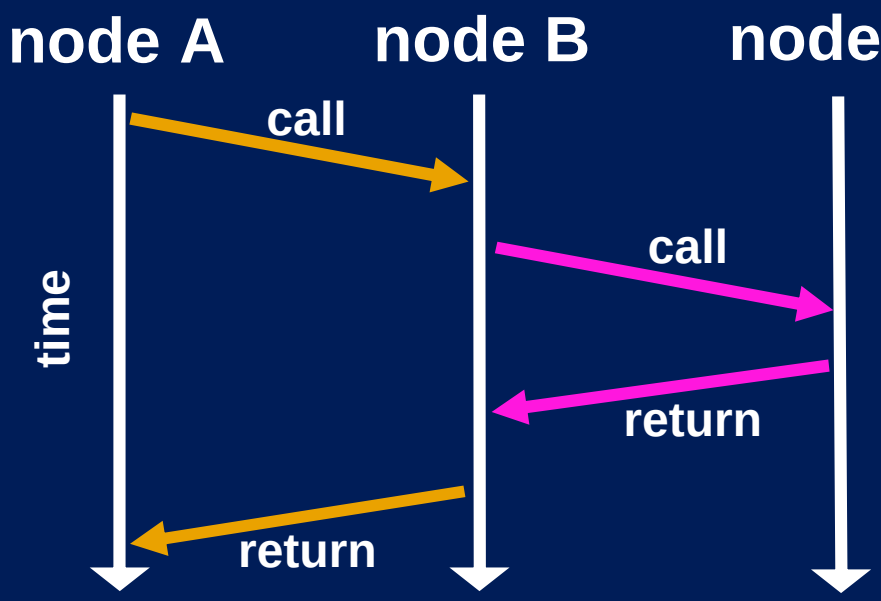
  [timestamp, source, destination, *call/return*, *call-id*]

Outline

- Problem statement & goals
- Overview of our approach
- Algorithms
  - The nesting algorithm
  - The convolution algorithm
- Experimental results
- Visualization GUI
- Related work
- Conclusions

The nesting algorithm

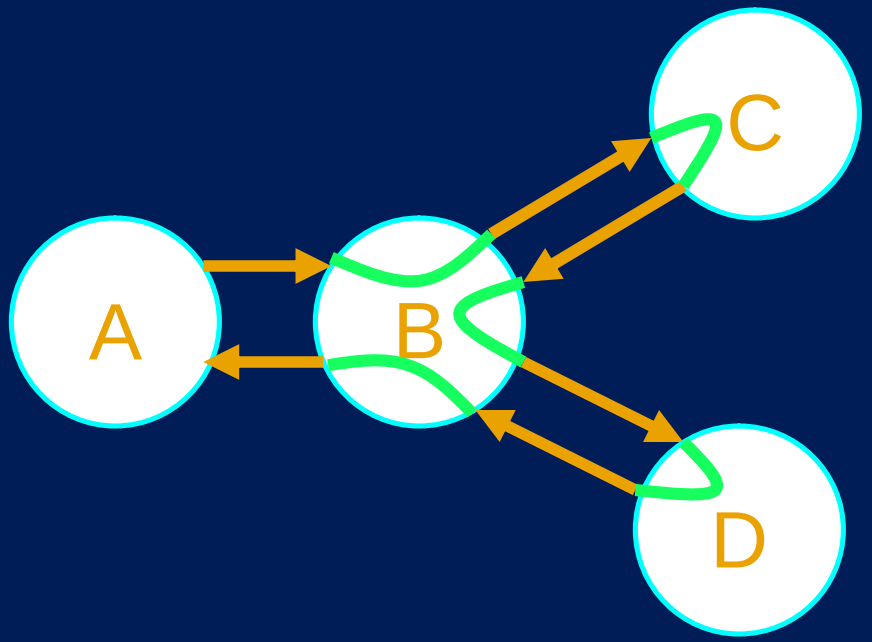
- Uses traces with call-return semantics
- Infers causality from “nesting” relationships
  - Suppose A calls B and B calls C before returning to A
  - Then the B↔C call is “nested” in the A↔B call

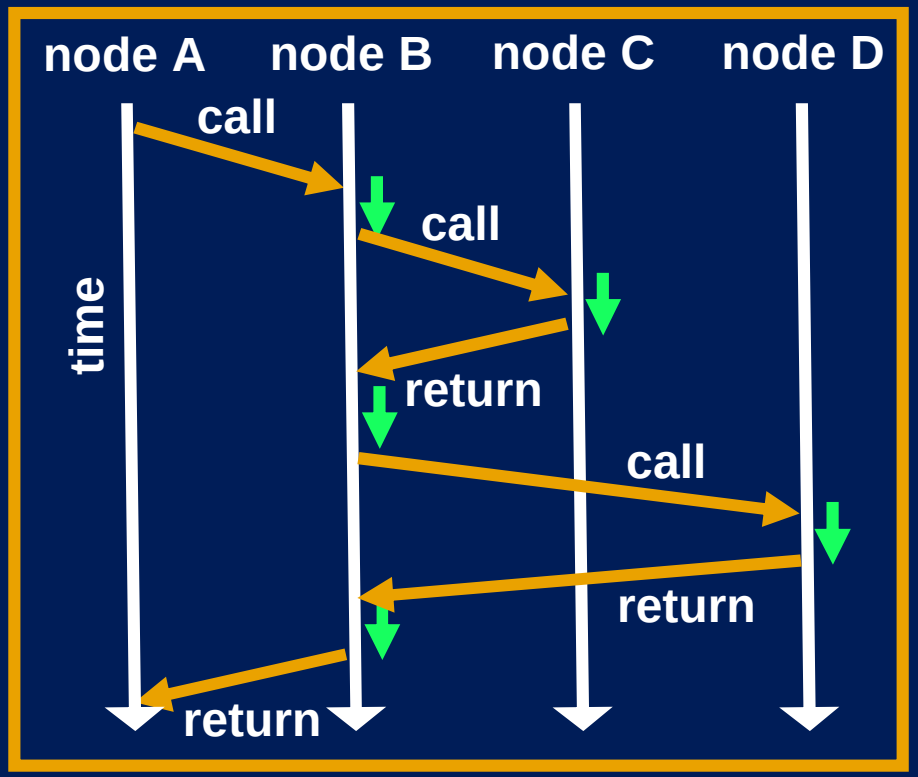


Nesting: an example causal path

Consider this system of 4 nodes

Looking for internal delays at each node



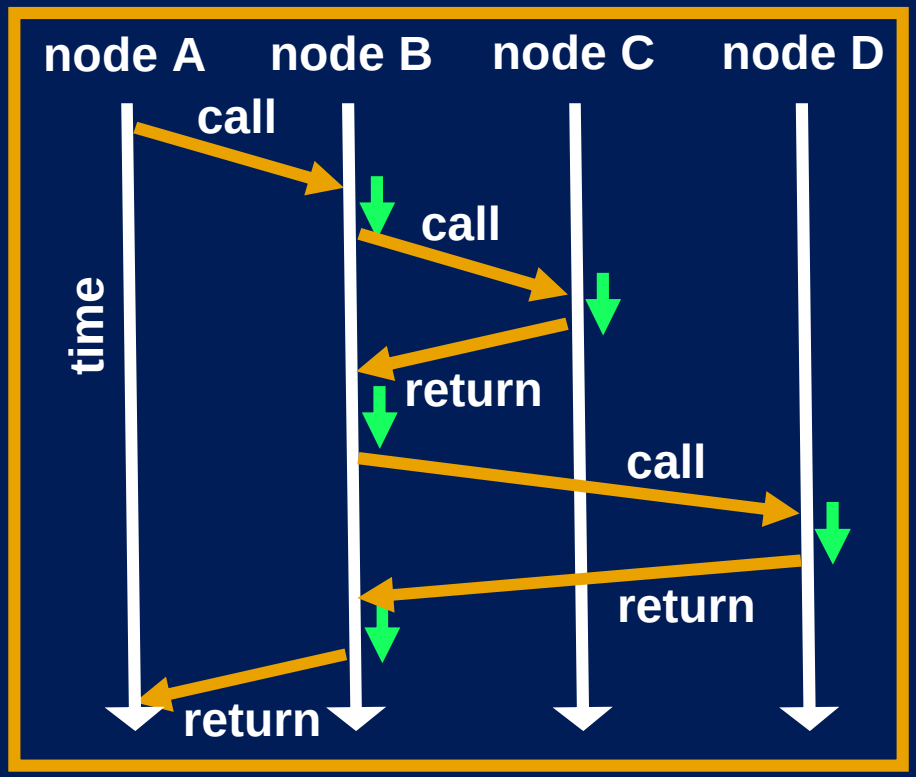


Steps of the nesting algorithm

1. Pair call and return messages
   - (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
   - Here: unambiguous
4. Reconstruct call paths
   - A→B→[C ; D]

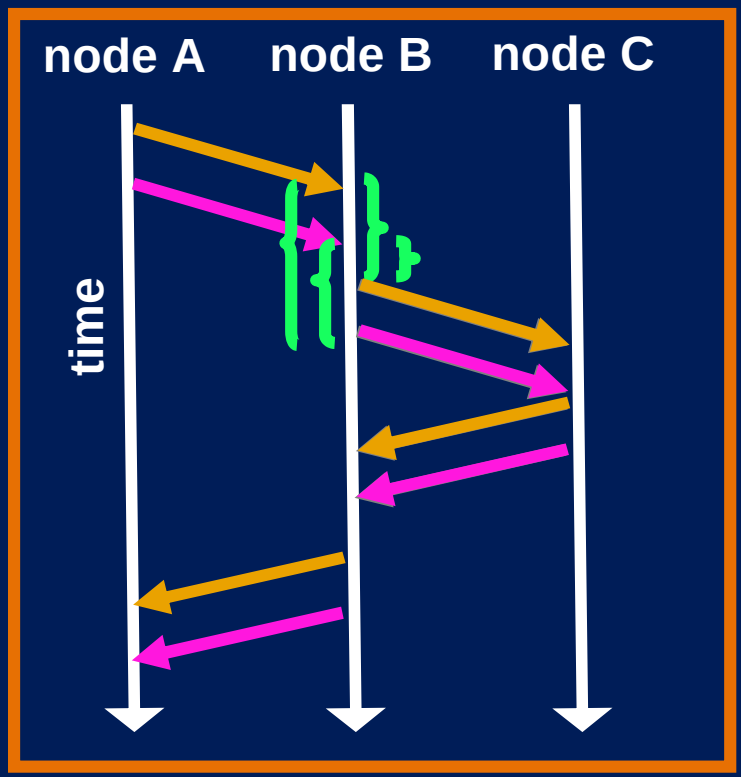
O(m) run time

m = number of messages



Inferring nesting

- Parallel calls are tricky
  - Local info not enough
  - Use aggregate info
  - Histograms keep track of possible latencies
    - One histogram per node triplet <A, B, C>
  - Two passes over trace
    - Build histograms
    - Assign nesting
  - Other heuristics in paper



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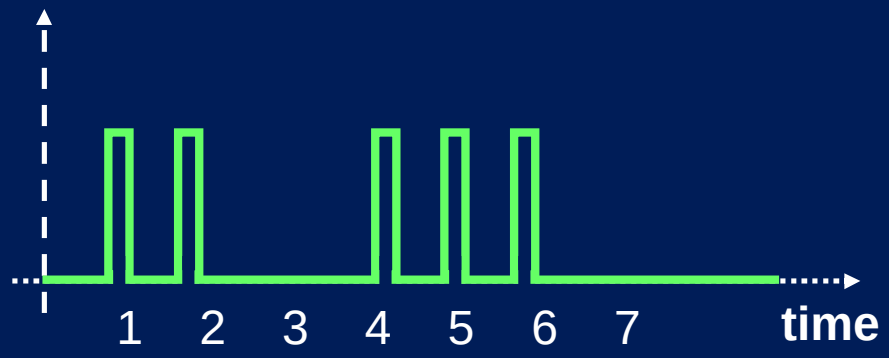
The convolution algorithm

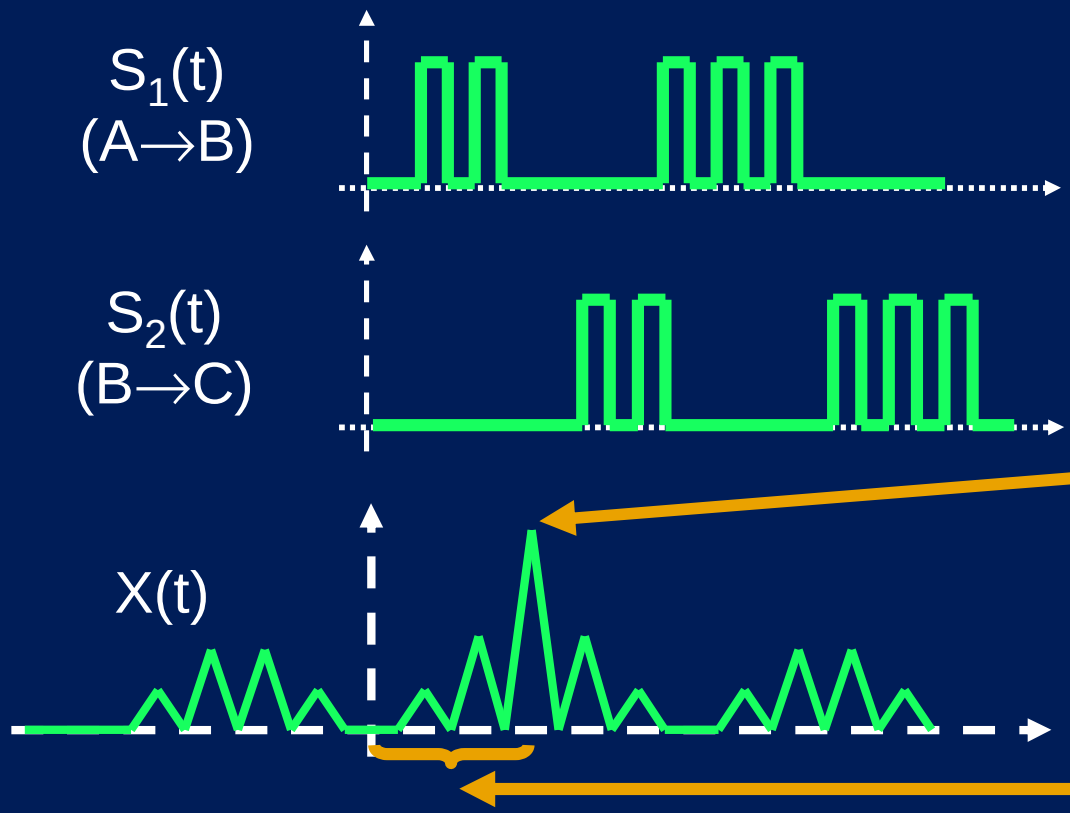
- "Time signal" of messages for each <source node, destination node>
  - A sent message to B at times 1,2,5,6,7



S1(t)= A→B messages

The convolution algorithm

- Look for time-shifted similarities
  - Compute **convolution** $X(t) = S_2(t) \otimes S_1(-t)$
  - Use Fast Fourier Transforms



Peaks in X(t) suggest causality between A→B and B→C

Time shift of a peak indicates delay

Convolution details

- Time complexity: O(em+eVlogV)
  - m = messages
  - e = output edges
  - V = number of 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

Algorithm comparison

- Nesting
  - Looks at individual paths and then aggregates
  - Finds rare paths
  - Requires *call/return* style communication
  - Fast enough for real-time analysis
- Convolution
  - Applicable to a broader class of systems
  - Slower: more work with less information
  - May need to try different time steps to get good results
  - Reasonable for off-line analysis
- More details in paper

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- Experimental results
  - Maketrace: a trace generator
  - Maketrace web server simulation
  - Pet Store EJB traces
  - Execution costs
- Visualization GUI
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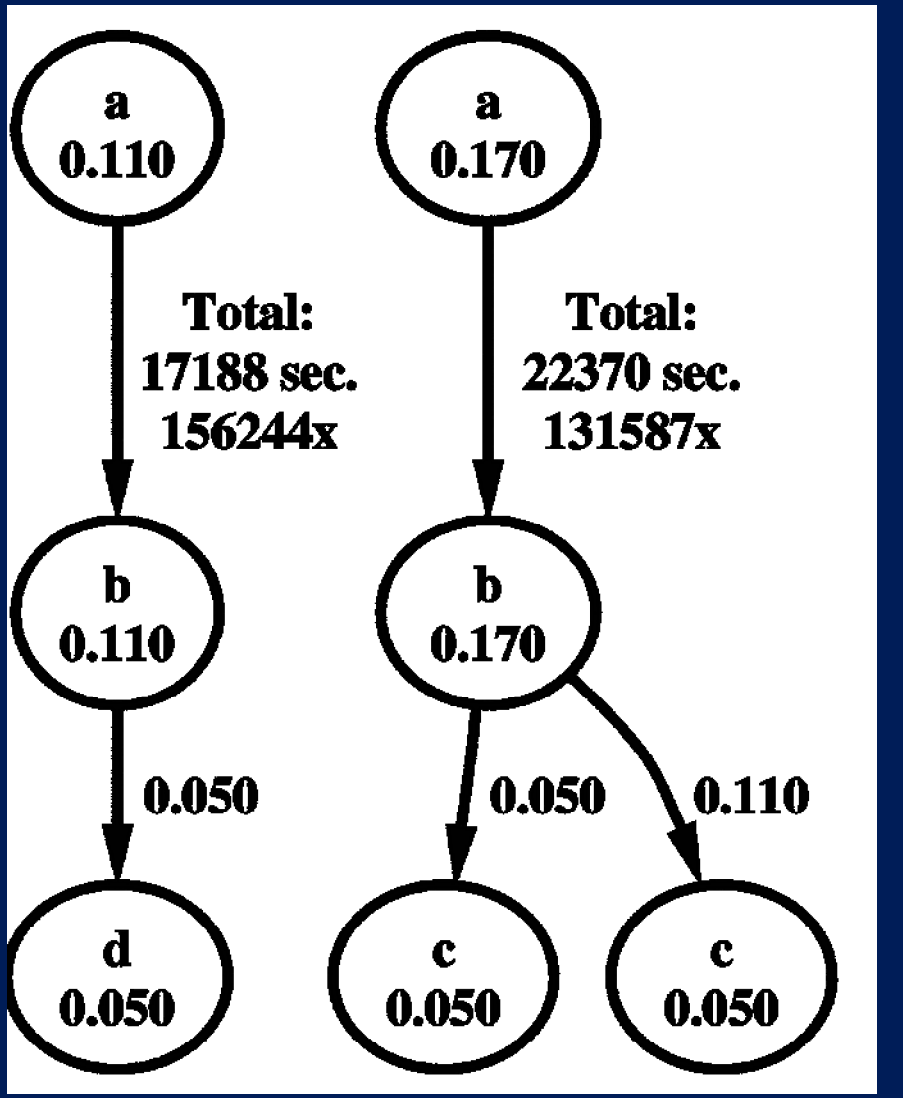
Maketrace

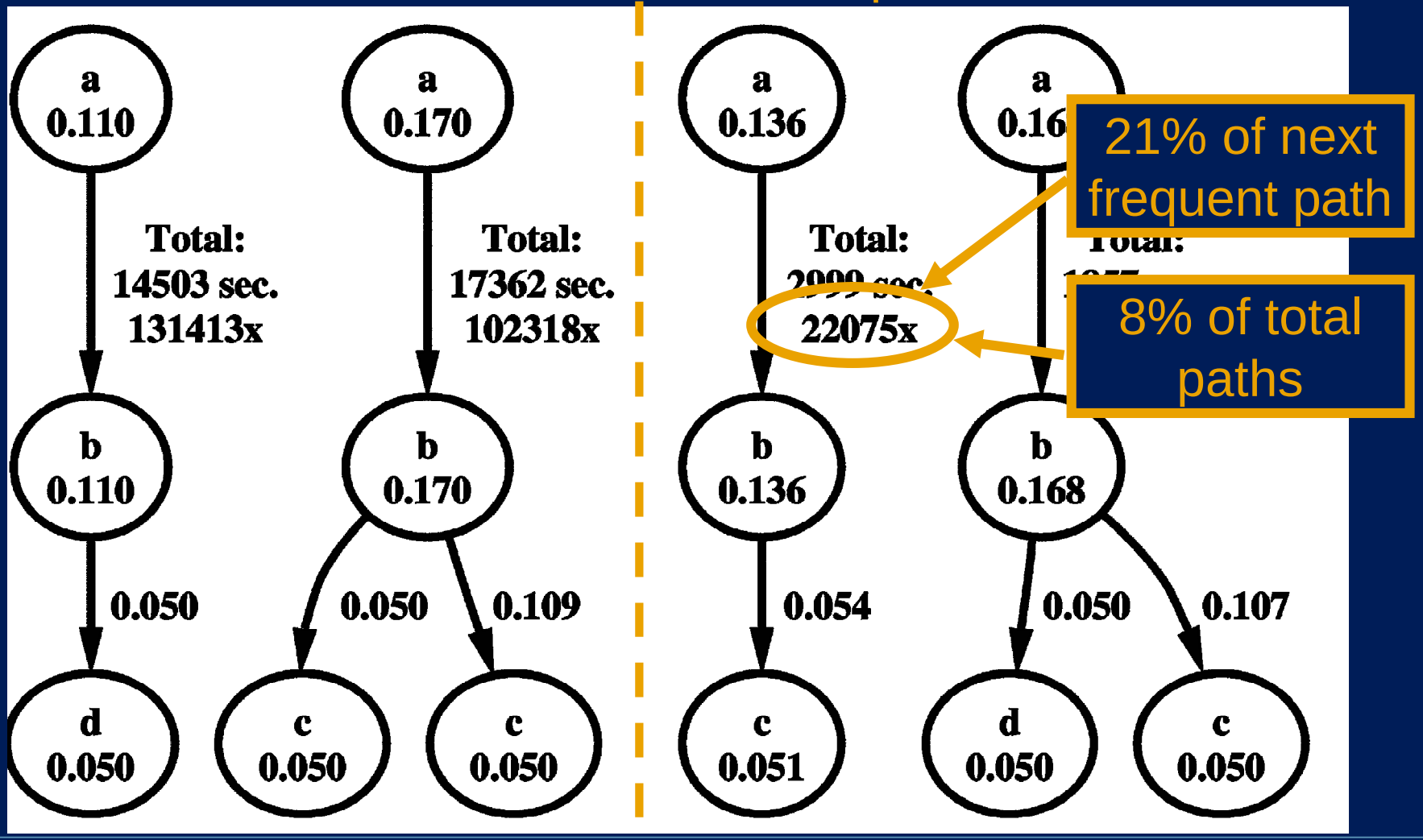
- Synthetic trace generator
- Needed for testing
  - Validate output for known input
  - Check corner cases
- Uses set of causal path templates
  - All call and return messages, with latencies
  - Delays are x ± y seconds, Gaussian normal distribution
- Recipe to combine paths
  - Parallelism, start/stop times for each path
  - Duration of trace

Desired results for one trace

- Causal paths
  - How often
  - How much time spent
- Nodes
  - Host/component name
  - Time spent in node and all of the nodes it calls
- Edges
  - Time parent waits before calling child

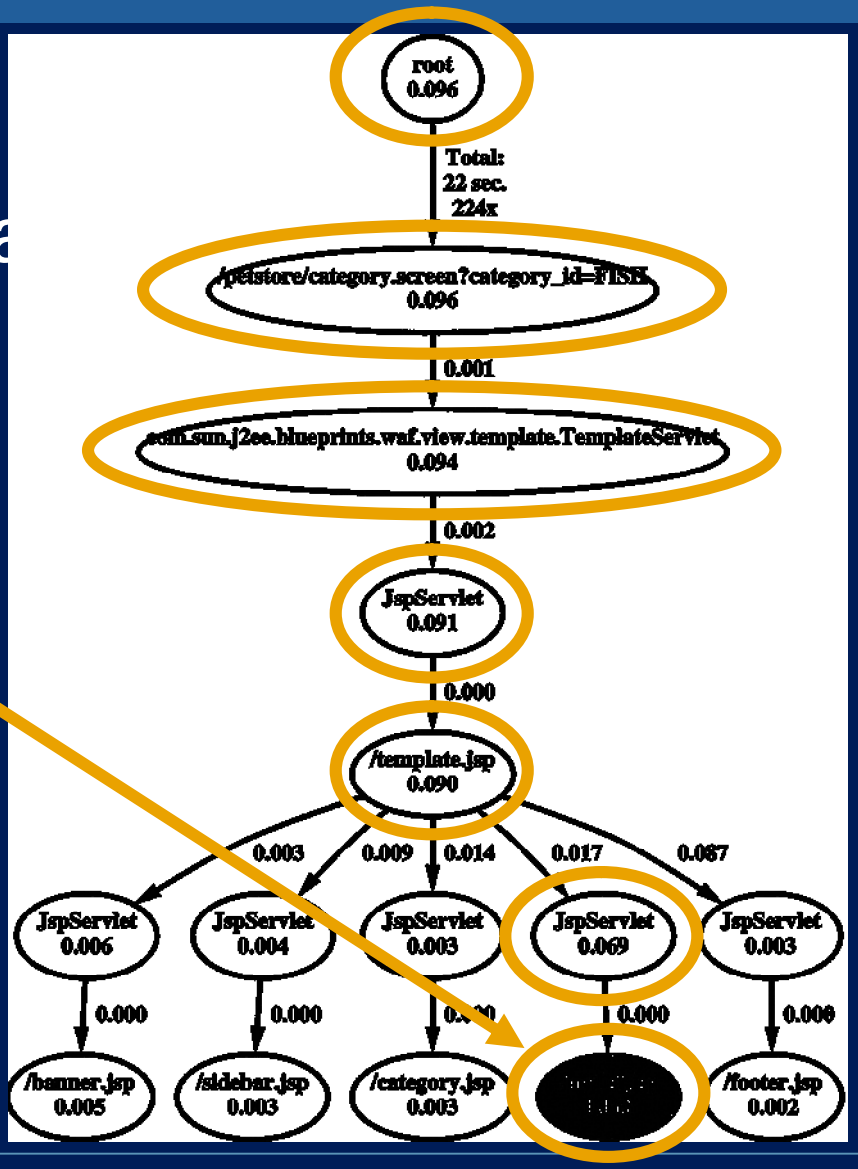


Experimental results for same trace



Results: Petstore

- Sample EJB application
- J2EE middleware for Java
  - Instrumentation from Stanford's PinPoint project
- Delay added in mylist.jsp



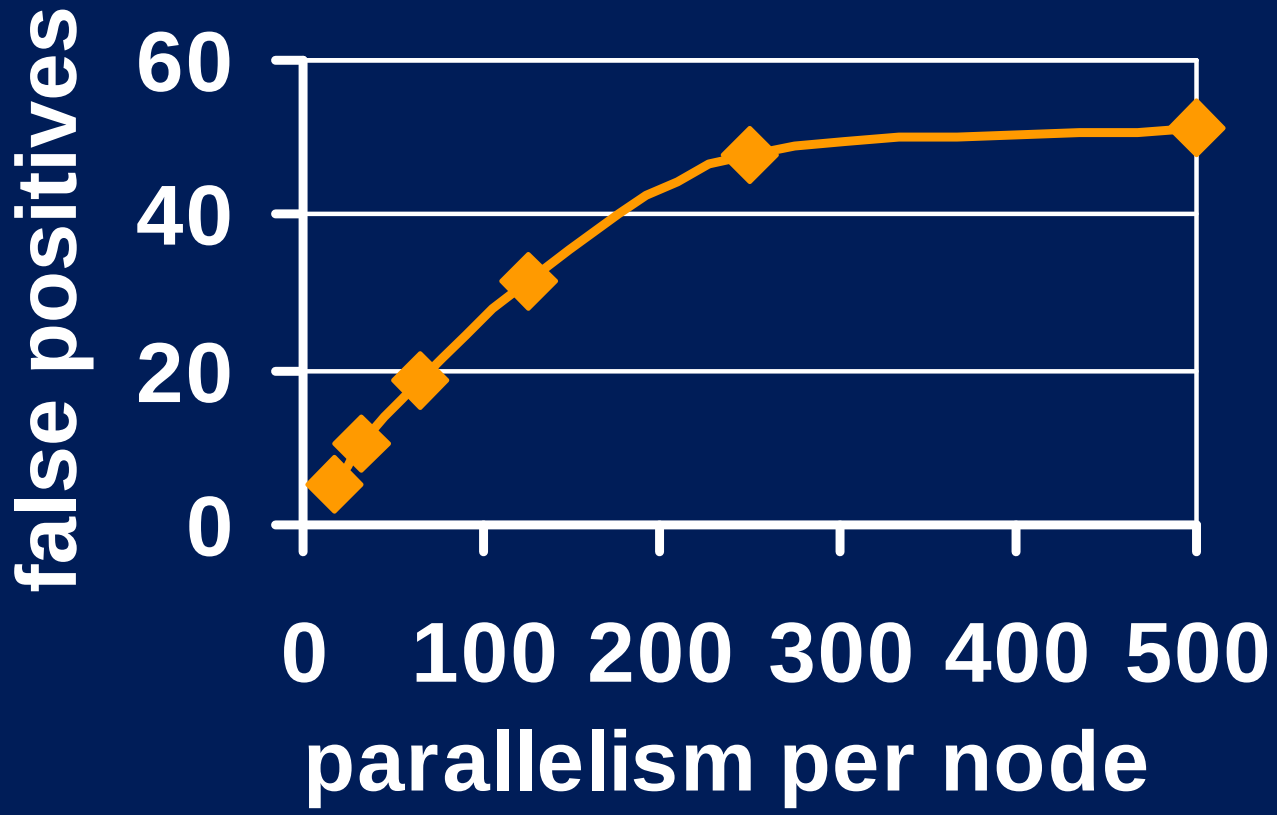
Results: running time

Trace	Length (messages)	Duration (sec)	Memory (MB)	CPU time (sec)
Nesting				
Multi-tier (short)	20,164	50	1.5	0.23
Multi-tier	202,520	500	13.8	2.27
Multi-tier (long)	2,026,658	5,000	136.8	23.97
PetStore	234,036	2,000	18.4	2.92
Convolution (20 ms time step)				
PetStore	234,036	2,000	25.0	6,301.00

More details and results in paper

Accuracy vs. parallelism

- Increased parallelism degrades accuracy slightly
- Parallelism is number of paths active at same time

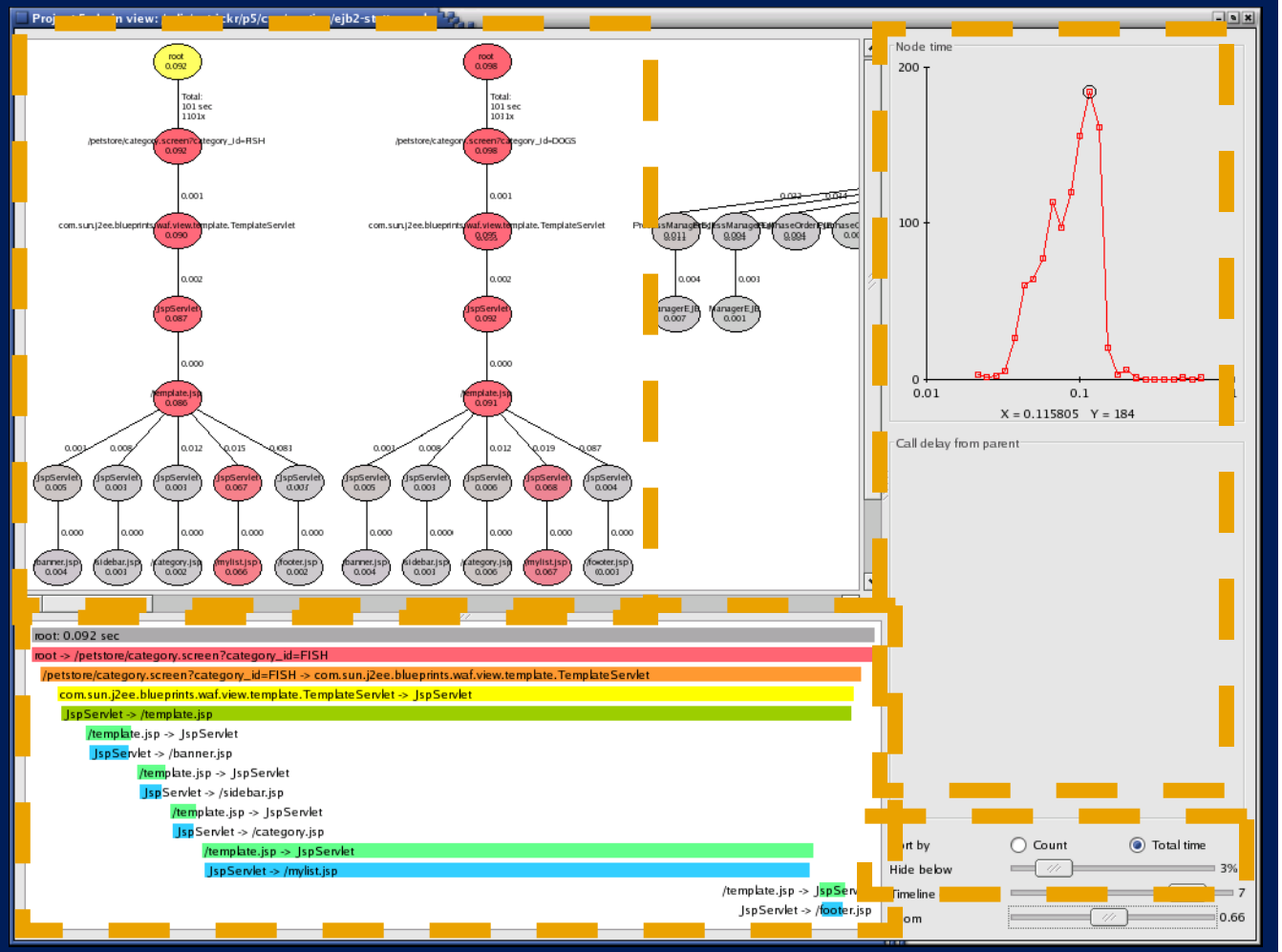


Other results for nesting algorithm

- Clock skew
  - Little effect on accuracy with skew • delays of interest
- Drop rate
  - Little effect on accuracy with drop rates • 5%
- Delay variance
  - Robust to • 30% variance
- Noise in the trace
  - Only matters if same nodes send noise
  - Little effect on accuracy with • 15% noise

Visualization GUI

- Goal: highlight dominant paths
- Paths sorted
  - By frequency
  - By total time
- Red highlights
  - High-cost nodes
- Timeline
  - Nested calls
  - Dominant subcalls
- Time plots
  - Node time
  - Call delay



Related work

- Systems that trace end-to-end causality via modified middleware using modified JVM or J2EE layers
  - Magpie (Microsoft Research), aimed at performance debugging
  - Pinpoint (Stanford/Berkeley), aimed at locating faults
  - Products such as AppAssure, PerformaSure, OptiBench
- Systems that make inferences from traces
  - Intrusion detection (Zhang & Paxson, LBL) uses traces + statistics to find compromised systems

Future work

- Automate trace gathering and conversion
- Sliding-window versions of algorithms
  - Find phased behavior
  - Reduce memory usage of nesting algorithm
  - Improve speed of convolution algorithm
- Validate usefulness on more complicated systems
- What are limits of our approach?

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 distributions
  - Two very different algorithms get similar results
  - Passively collected traces have sufficient information
- For more information
  - http://www.hpl.hp.com/research/project5/
- Contact us if you have multi-hop message traces!