Experiences with Tracing Causality in Networked Services

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INM/WREN

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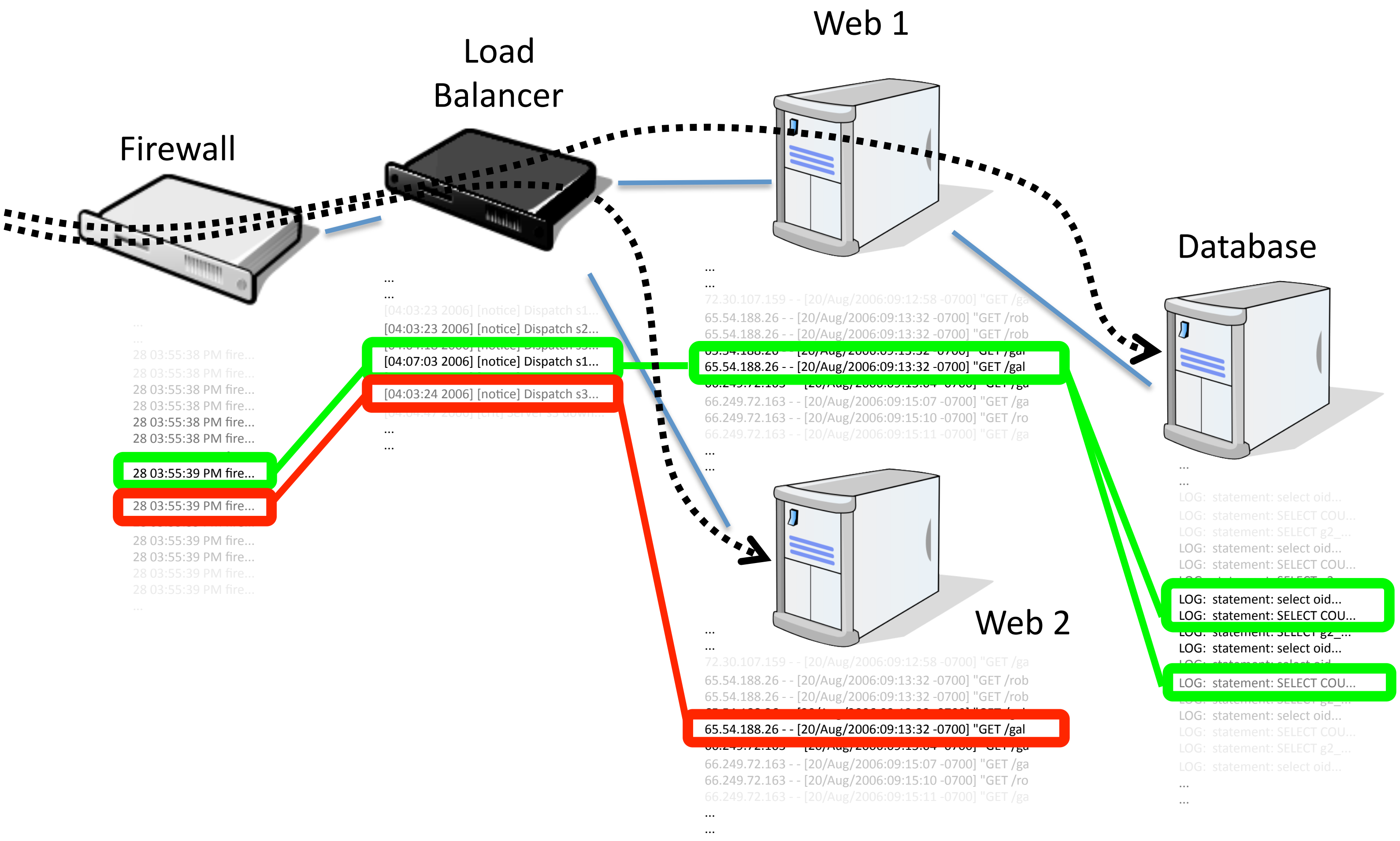
Which way to Bangalore?

Troubleshooting Networked Systems

- Hard to develop, debug, deploy, troubleshoot
- No standard way to integrate debugging, monitoring, diagnostics

Status quo: device centric



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28 03:55:38 PM fire…
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28 03:55:39 PM fire…
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[04:03:23 2006] [notice] Dispatch s1…
[04:03:23 2006] [notice] Dispatch s2…
[04:04:18 2006] [notice] Dispatch s3…
[04:07:03 2006] [notice] Dispatch s1…
[04:03:24 2006] [notice] Dispatch s3…
[04:04:47 2006] [crit] Server s3 down…
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…
72.30.107.159 - - [20/Aug/2006:09:12:58 -0700] "GET /ga
65.54.188.26 - - [20/Aug/2006:09:13:32 -0700] "GET /rob
65.54.188.26 - - [20/Aug/2006:09:13:32 -0700] "GET /rob
65.54.188.26 - - [20/Aug/2006:09:13:32 -0700] "GET /gal
65.54.188.26 - - [20/Aug/2006:09:13:32 -0700] "GET /gal
66.249.72.163 - - [20/Aug/2006:09:13:04 -0700] "GET /ga
66.249.72.163 - - [20/Aug/2006:09:15:07 -0700] "GET /ga
66.249.72.163 - - [20/Aug/2006:09:15:10 -0700] "GET /ro
66.249.72.163 - - [20/Aug/2006:09:15:11 -0700] "GET /ga
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72.30.107.159 - - [20/Aug/2006:09:12:58 -0700] "GET /ga
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66.249.72.163 - - [20/Aug/2006:09:15:07 -0700] "GET /ga
66.249.72.163 - - [20/Aug/2006:09:15:10 -0700] "GET /ro
66.249.72.163 - - [20/Aug/2006:09:15:11 -0700] "GET /ga
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LOG:  statement: select oid…
LOG:  statement: SELECT COU…
LOG:  statement: SELECT g2_…
LOG:  statement: select oid…
LOG:  statement: SELECT COU…
LOG:  statement: SELECT g2_…
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LOG:  statement: select oid…
…
…
```

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Status quo: device centric

- Determining paths:
  - Join logs on time and ad-hoc identifiers
- Relies on
  - well synchronized clocks
  - extensive application knowledge
- Requires *all* operations logged to guarantee complete paths

This talk

- Causality Tracking: an alternative
- Many previous frameworks:
  - X-Trace, PIP, Whodunit, Magpie, Google's Dapper…
- Experiences integrating and using X-Trace

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Outline

- Tracing causality with X-Trace
- Case studies
  - 802.1X Authentication Service
  - CoralCDN and OASIS anycast service
- Challenges
- Conclusion

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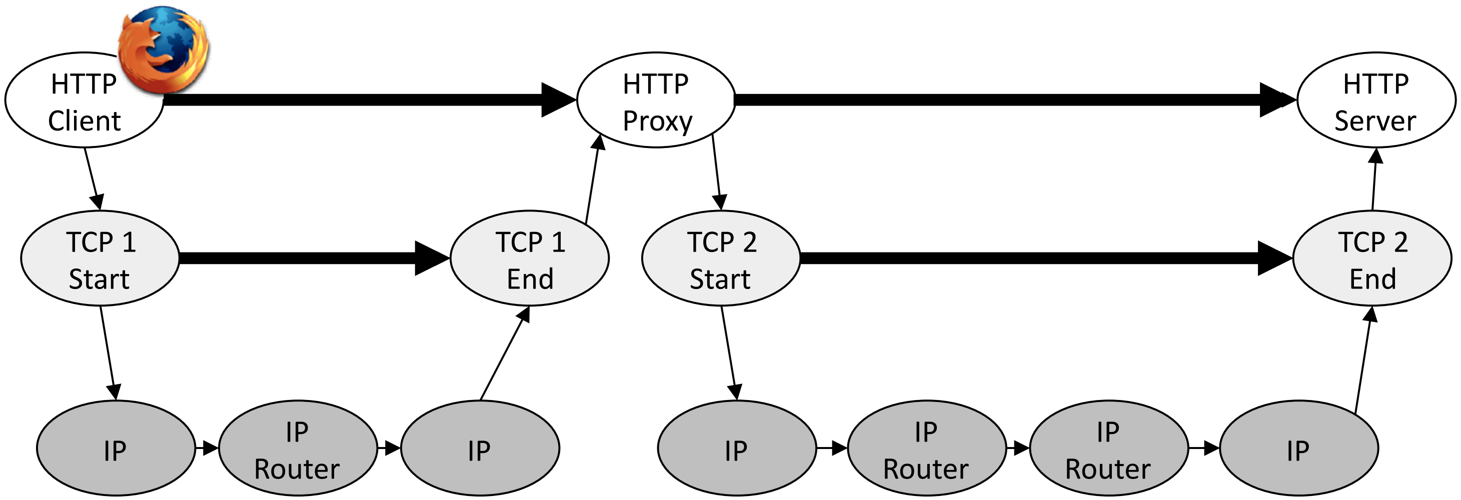
X-Trace

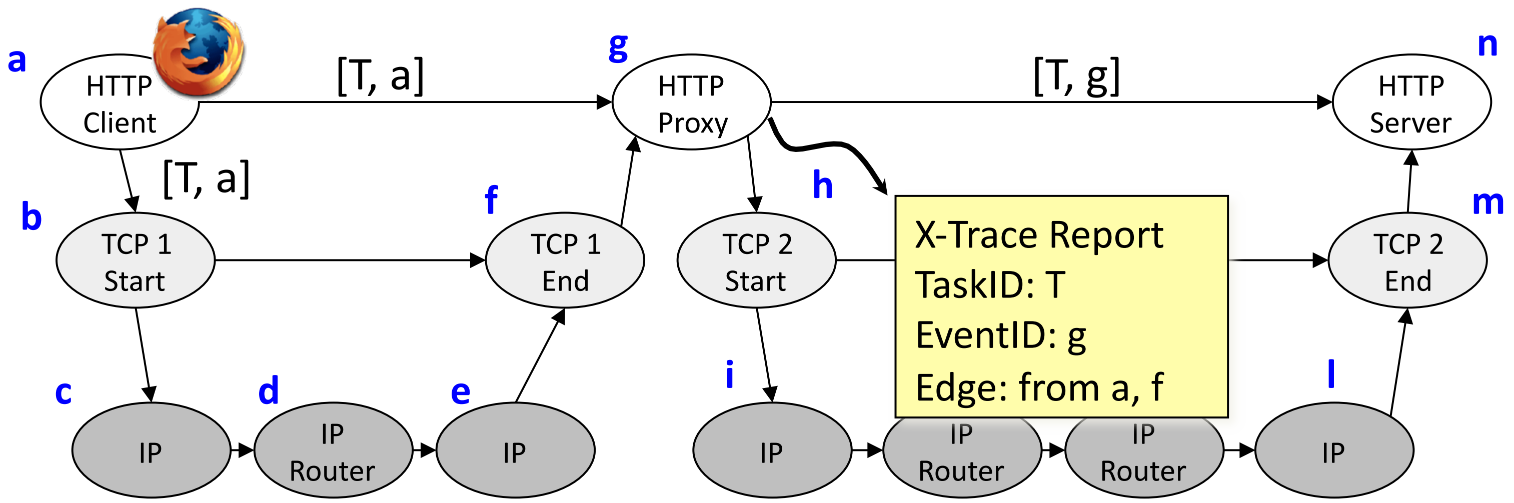
- X-Trace records **events** in a distributed execution and their causal relationship
- Events are grouped into **tasks**
  - Well defined starting event and all that is causally related
- Each event generates a **report**, binding it to one or more preceding events
- Captures full *happens-before* relation

X-Trace Output



- *Task graph* capturing task execution
  - Nodes: events across layers, devices
  - Edges: causal relations between events

Basic Mechanism



X-Trace Report
TaskID: T
EventID: g
Edge: from a, f

- Each event uniquely identified within a task: [***TaskId, EventId***]
- [TaskId, EventId] **propagated** along execution path
- For each event create and log an X-Trace **report**
  – Enough info to reconstruct the task graph

X-Trace Library API

- Handles propagation within app
- Threads / event-based (*e.g.,* libasync)
- Akin to a logging API:
  - Main call is **logEvent(message)**
- Library takes care of event id creation, binding, reporting, etc
- Implementations in C++, Java, Ruby, Javascript

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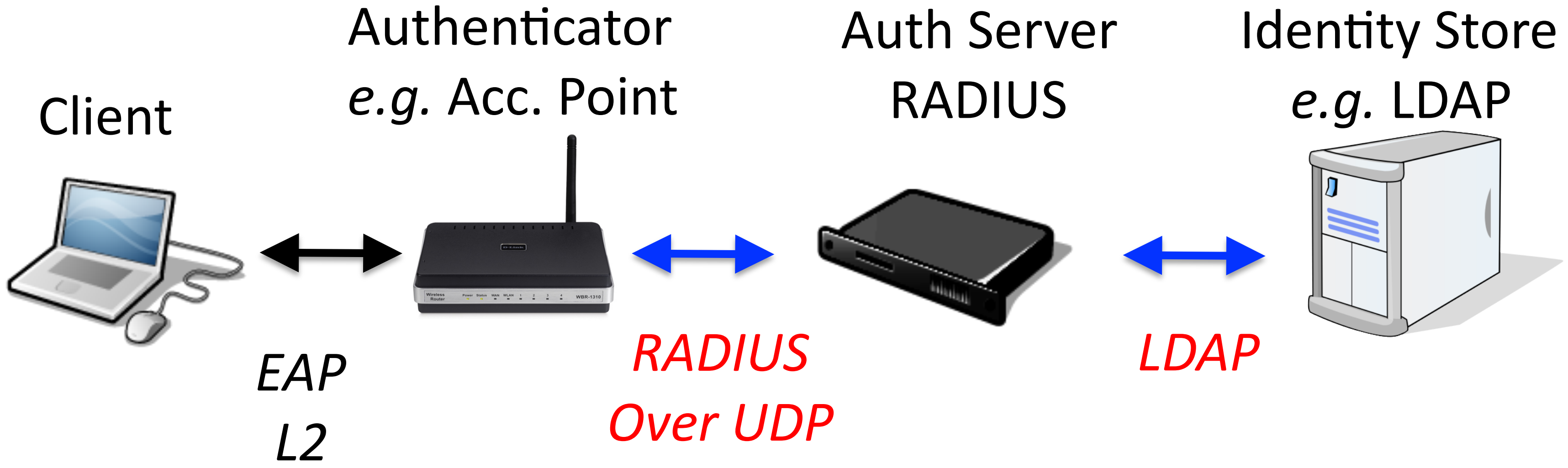
802.1X Authentication Service



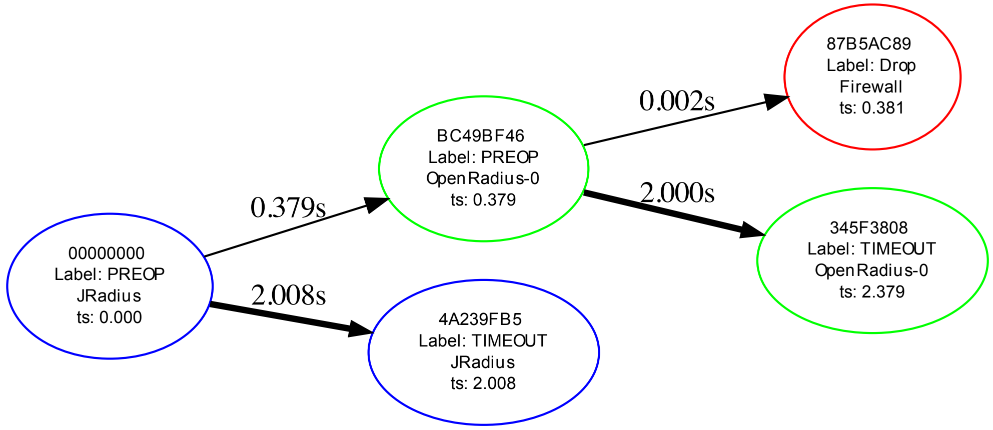
- Identified 5 common authentication issues from vendor logs
- Added a few X-Trace instrumentation points sufficient to differentiate these faults
- Introduced faults in a test environment

802.1X Authentication Service

- Instrumentation was easy:
  - Nested invocations
  - No in-task concurrency
  - Extensible protocols (RADIUS, LDAP)
  - Modular, request-oriented server software

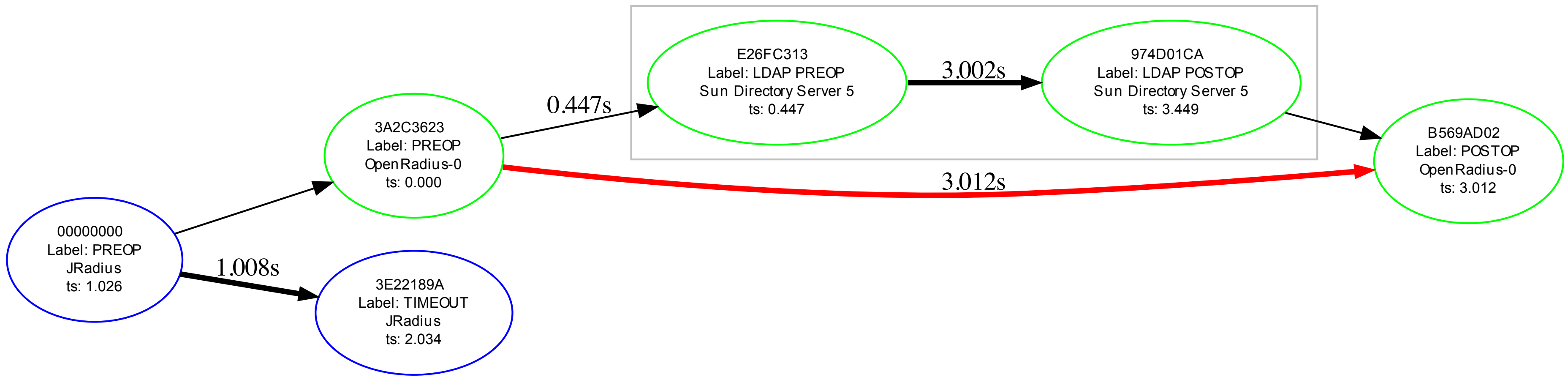
802.1X Example Faults

- Misconfigured Firewall: no LDAP



802.1X Example Faults

- Misconfigured Firewall: no LDAP
- Miscalibrated Timeout Value



- Key: multiple correlated vantage points
  - Can help tune timeout values

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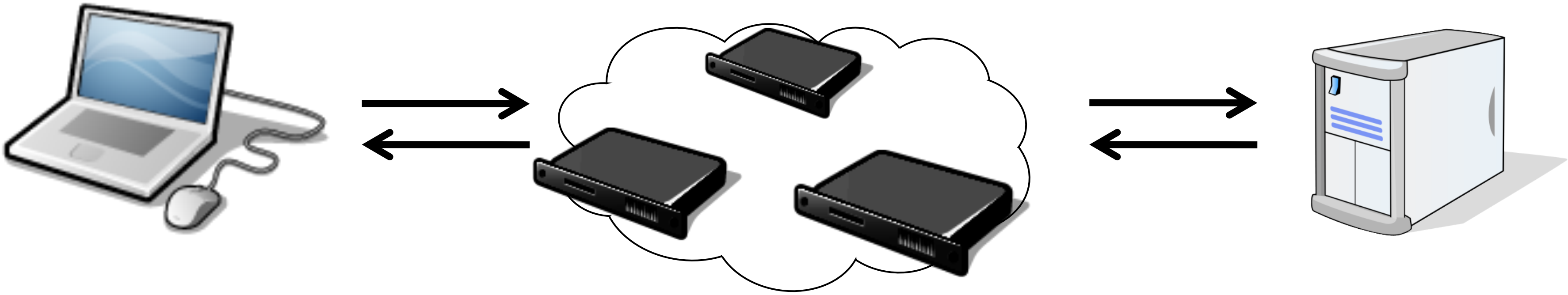
CoralCDN and OASIS

- Instrumented production deployment
- Heavy use of sampling:
  - 0.1% of requests to CoralCDN traced
- Leveraged libasync, libarpc X-Trace instrumentation
- Much more complex program flow
  - E.g. windowed parallel RPC calls, variable timeouts
- Found bugs, performance problems, clock skews…

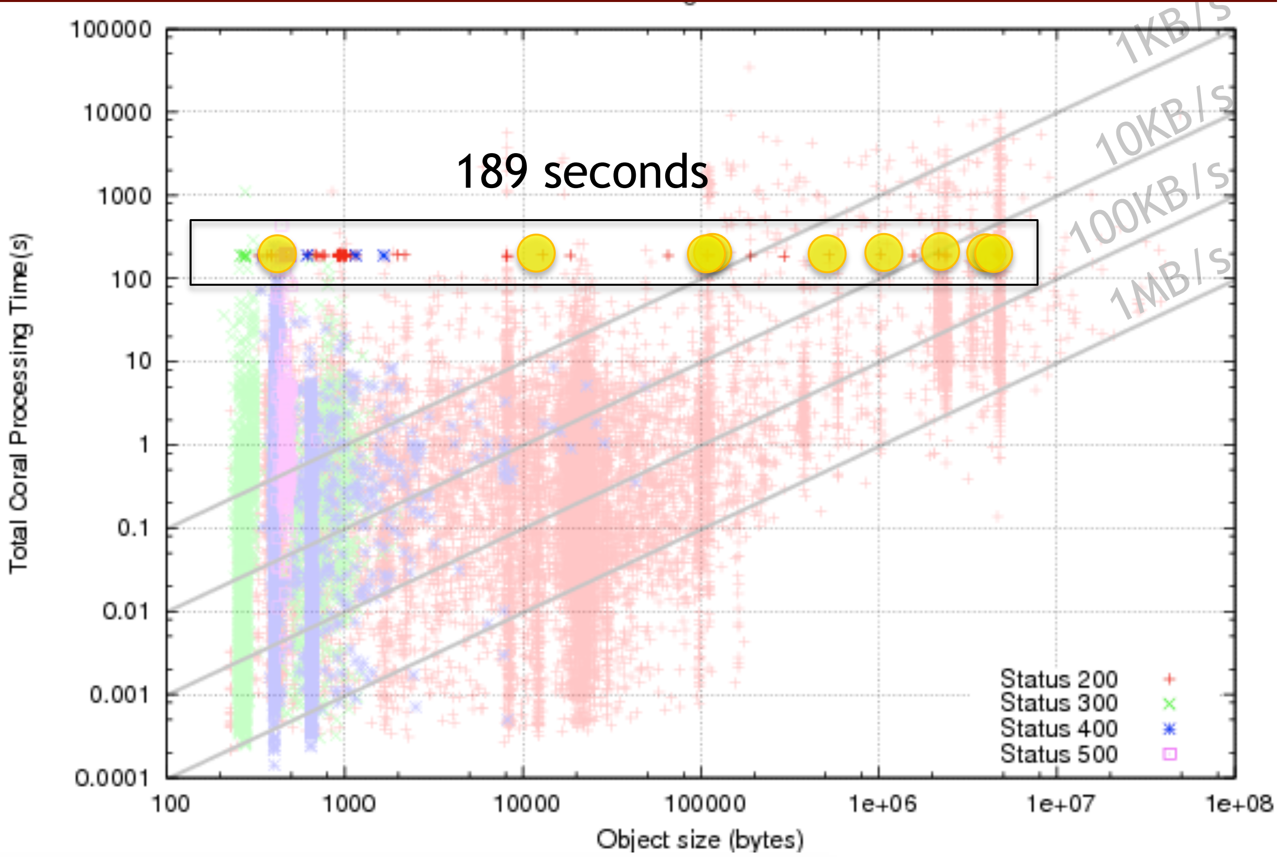
CoralCDN

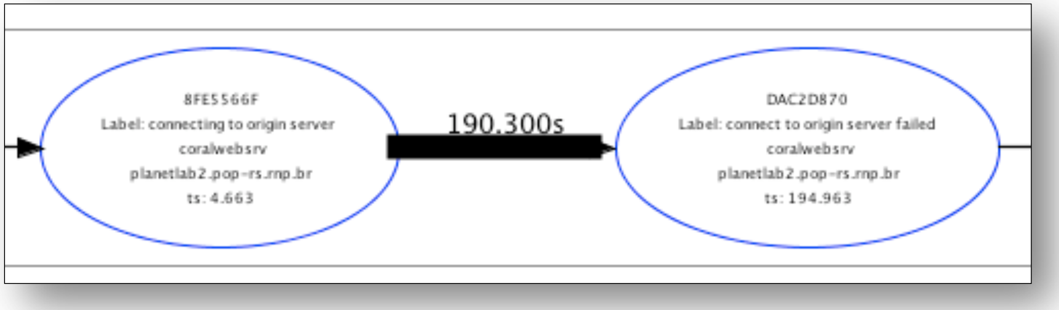
CoralCDN Distributed HTTP Cache



CoralCDN Response Times

- 189s: Linux TCP Timeout connecting to origin
- Slow connection Proxy -> Client
- Slow connection Origin -> Proxy
- Timeout in RPC, due to slow Planetlab node!





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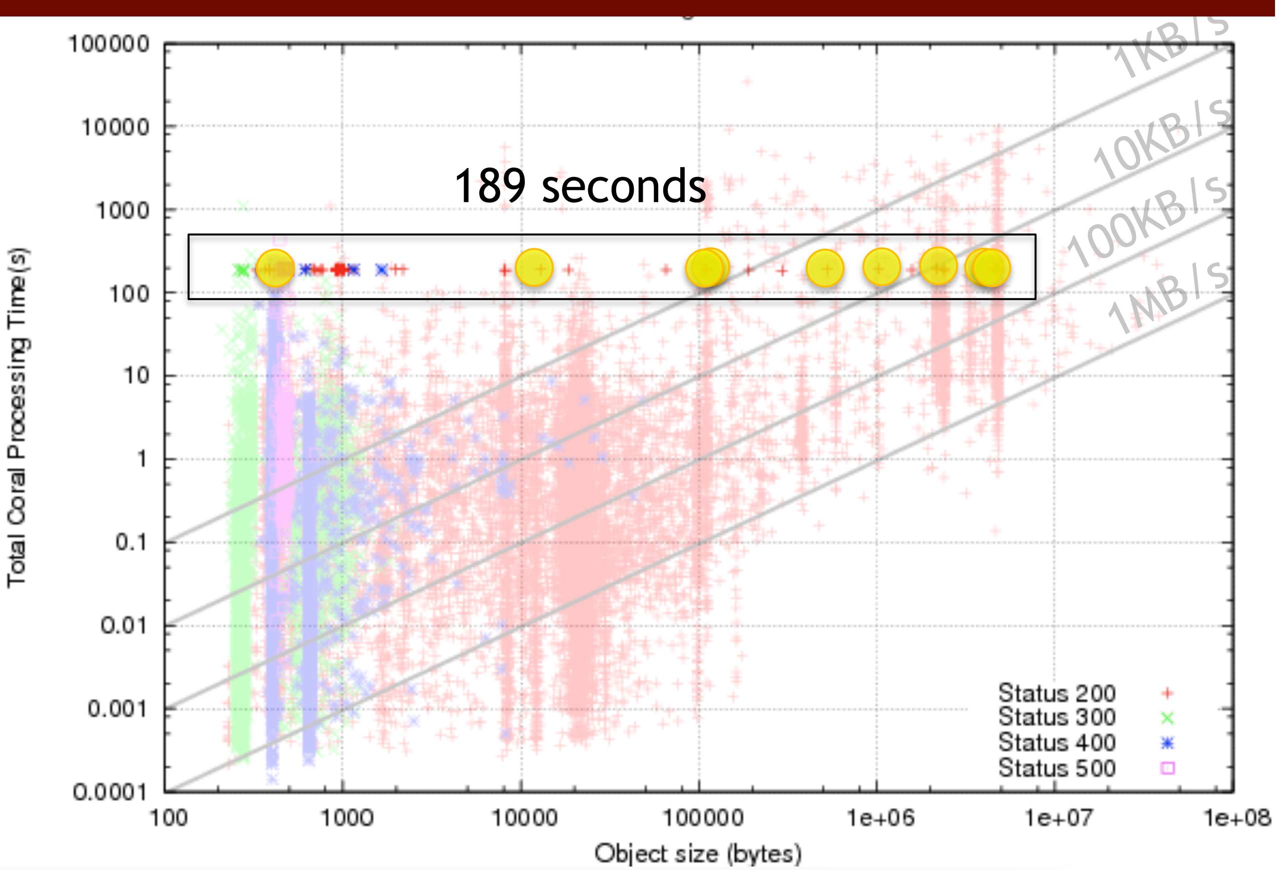

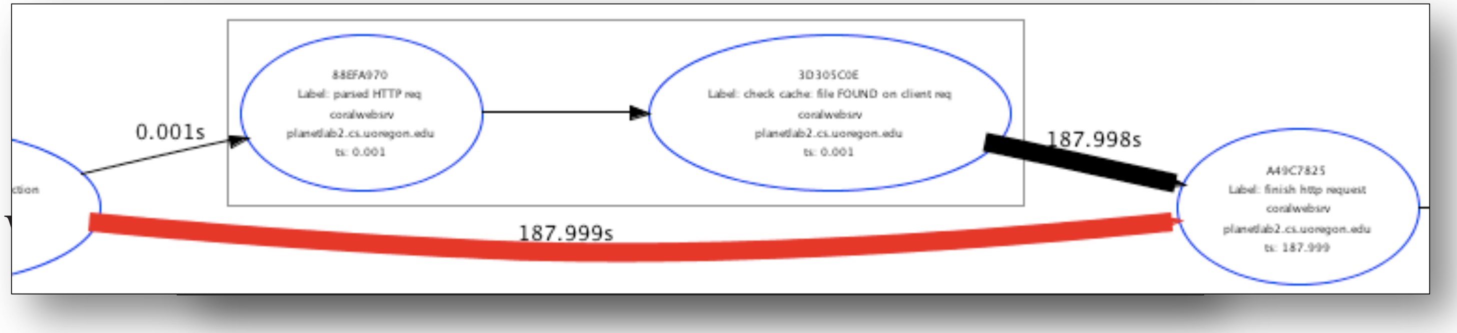
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Label: parsed HTTP req
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ts: 0.001
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Label: check cache: file FOUND on client req
coralwebsrv
planetlab2.cs.uoregon.edu
ts: 0.001
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Label: finish http request
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ts: 187.999
187.999s

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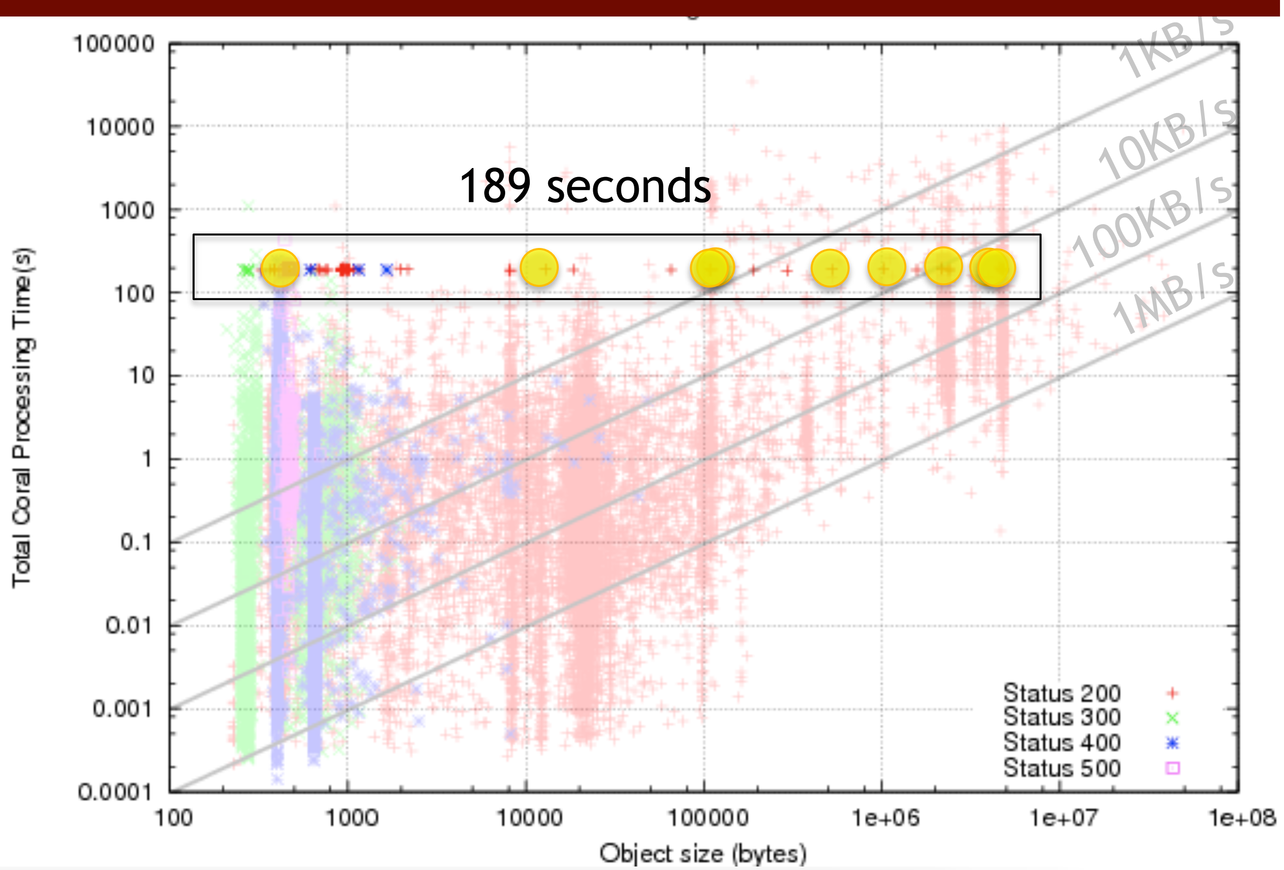

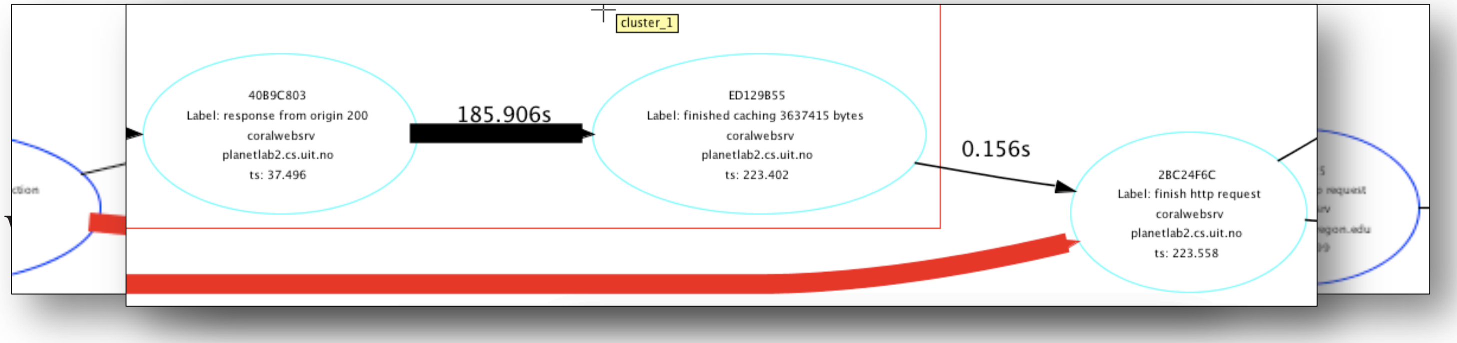

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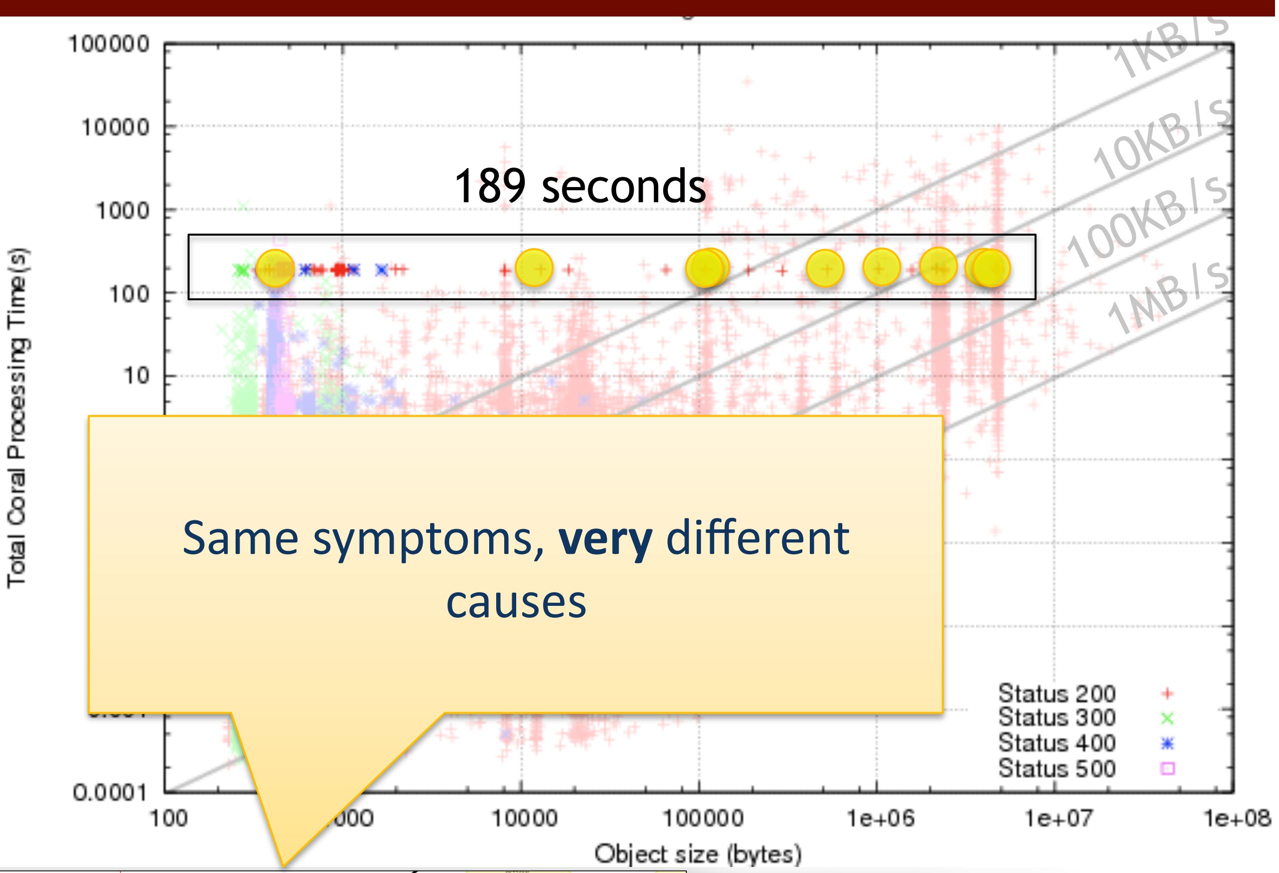
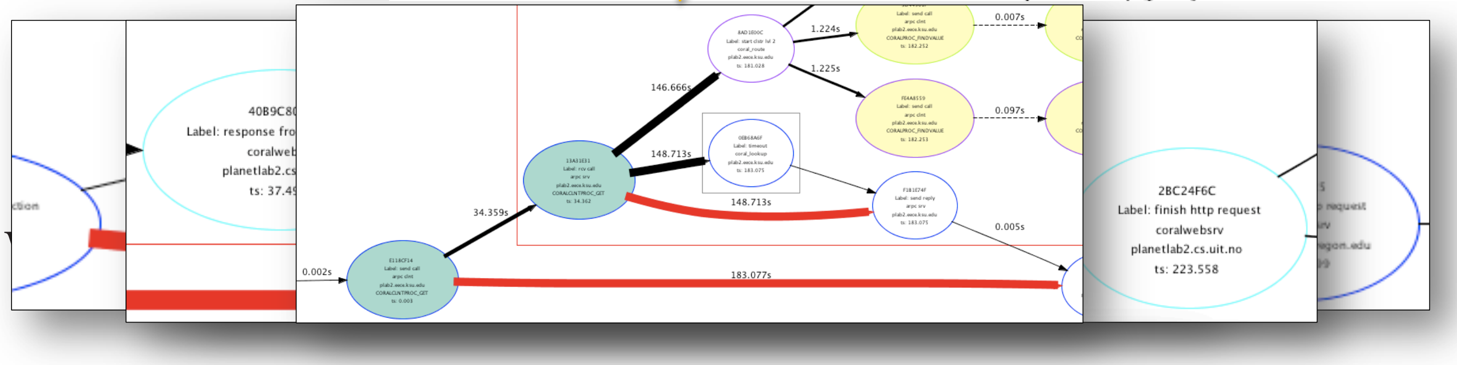


Same symptoms, **very** different causes



Outline

- Brief X-Trace Intro
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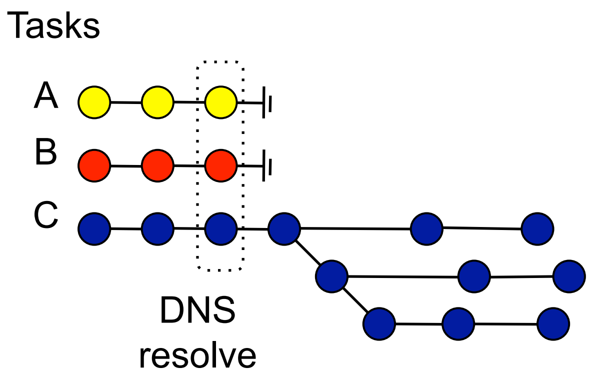
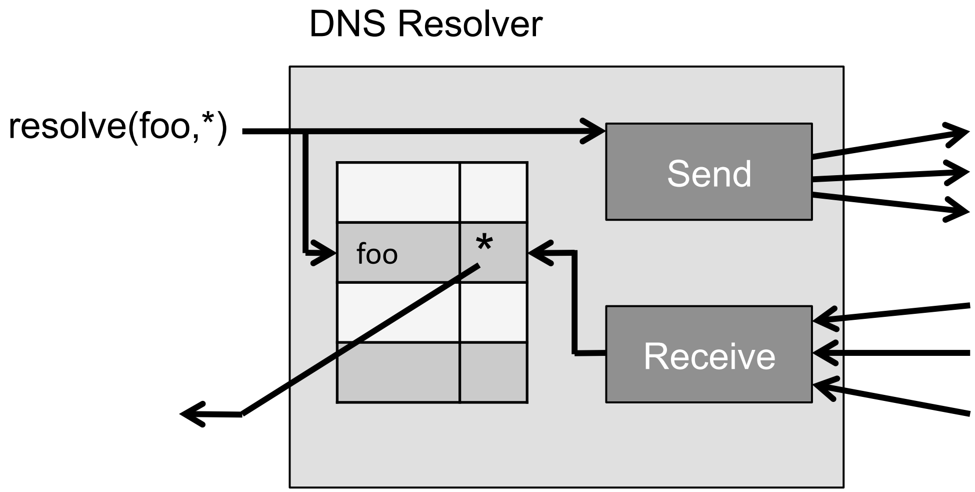
Hidden Channels

- Example: CoralCDN DNS Calls

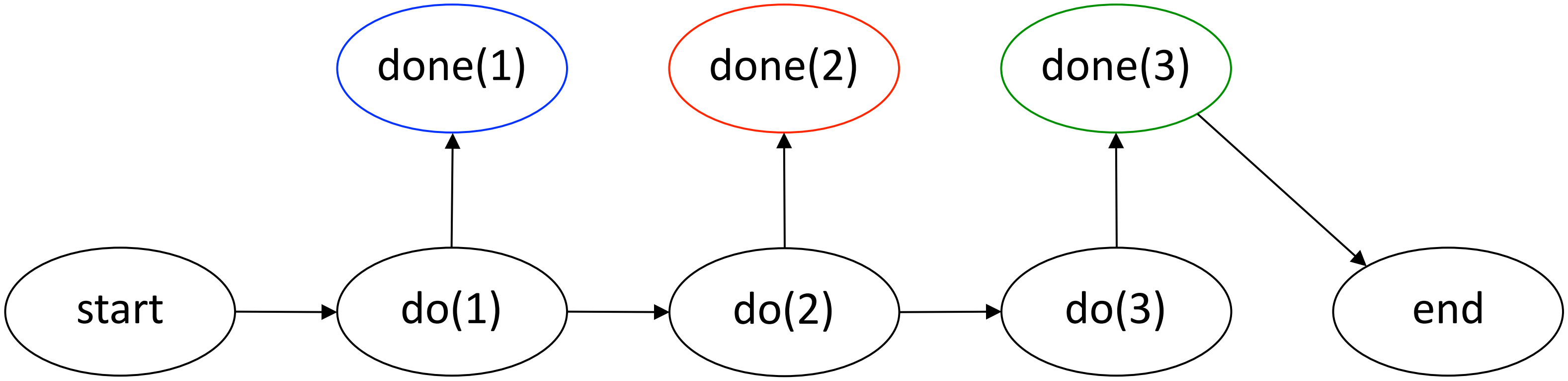




- In general: deferral structures
  - E.g., queues, thread pools, continuations
  - Store metadata with the structure
- Often encapsulated in libraries, high leverage

Incidental vs. Semantic Concurrency

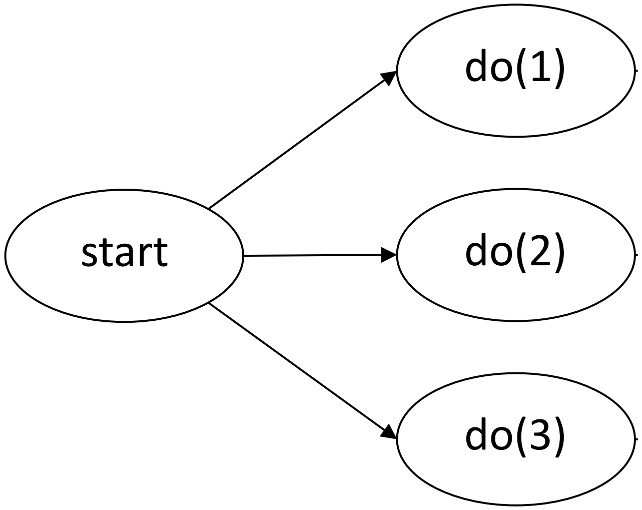
- Forks and joins tricky for naïve instrumentation



  - Non-intuitive fork
  - Incorrect join

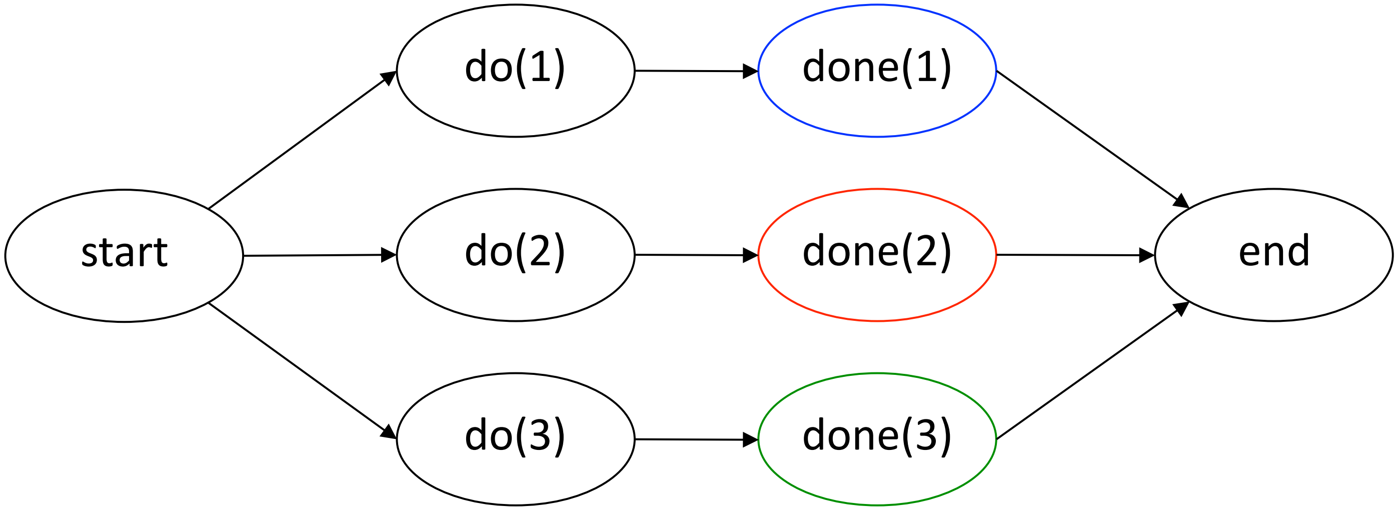
Incidental vs. Semantic Concurrency

- Extra code annotation fixes the problem
  - – Manually change parent of do() events

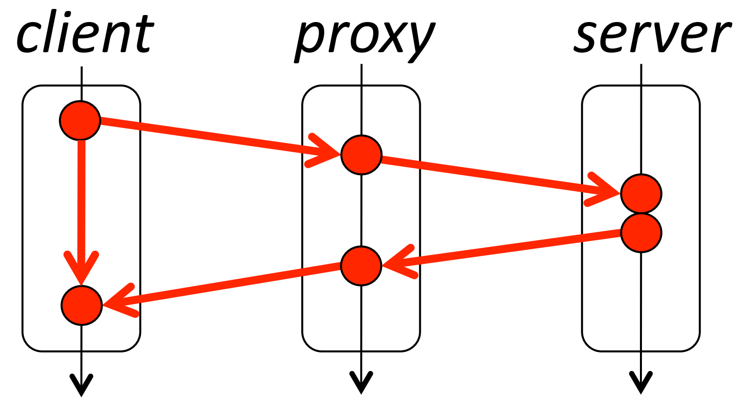


Incidental vs. Semantic Concurrency

- Extra code annotation fixes the problem
  - Manually change parent of do() events
  - Manually add edges from done() to end

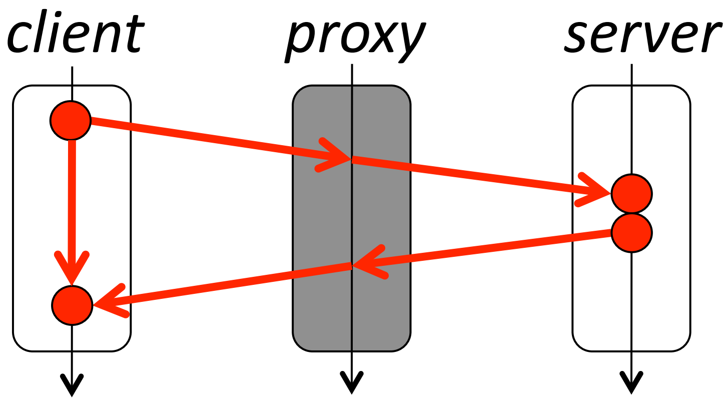


Dealing with Black Boxes



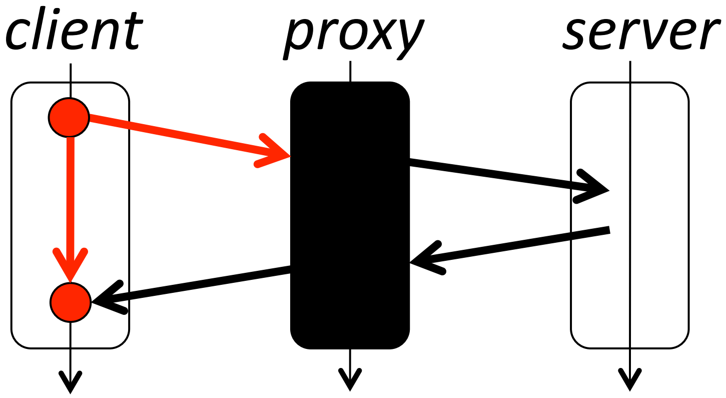
- Ideal scenario: all components instrumented with X-Trace
  - Log all events

Dealing with Black Boxes



- Gray-box proxy: passes X-Trace metadata on
  - Log events on the client and server
  - Layering does this automatically

Dealing with Black Boxes



- Black box proxy: drops X-Trace metadata
  - No X-Trace events on proxy or server
  - Can always trace around black box, in client

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Revisiting Troubleshooting

Device-centric Logs

- Depends on well sync'd clocks
- Joins on ad-hoc identifiers
- Needs all ops logged for complete traces
- No modifications to existing code

Task-centric traces

- Does not depend on clocks (can actually fix them)
- Deterministic joins on standardized ids
- Sample-based tracing possible
- Requires instrumentation

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X-Trace Instrumentation

- Instrumenting is easy in most cases
- A few key libraries go a long way
- Can be done iteratively
  - Refining expectations (*a la* Pip)
- Partial annotation still useful
- Independent instrumentation feasible
- Huge benefits

Conclusions

- Simple, uniform *task graphs* useful in debugging, troubleshooting, diagnostics
- Instrumentation is feasible

Causal tracing should be a first-class concept in networked systems

Thank you

- More details on paper

- For more info:

www.x-trace.net

www.coralcdn.org