Experiences with Tracing Causality in Networked Services

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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

...
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
Outline

• Tracing causality with X-Trace
• Case studies
  – 802.1X Authentication Service
  – CoralCDN and OASIS anycast service
• Challenges
• Conclusion
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
• **Task graph** capturing task execution
  – Nodes: events across layers, devices
  – Edges: causal relations between events
Each event uniquely identified within a task: 
\[[\text{TaskId}, \text{EventId}]\]

- [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
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!

189 seconds
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Same symptoms, very different causes
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Hidden Channels

• Example: CoralCDN DNS Calls

  Tasks
  
  A
  B
  C
  
  DNS resolve

  DNS Resolver
  
  resolve(foo, *)

  foo
  *

  Send
  Receive

• 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
• 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
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