USCOPE: A SCALABLE UNIFIED TRACER FROM KERNEL TO USER SPACE

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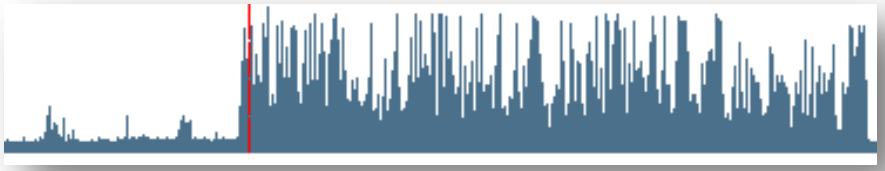
Motivation

- Complex IT services face diverse functional and non-functional issues due to complexity of software and usage of underlying components.

- OS kernel event tracing is a convenient method to monitor and debug system operations without hard dependency on application layers (e.g., Libraries, program binaries).
  - Example: System call trace

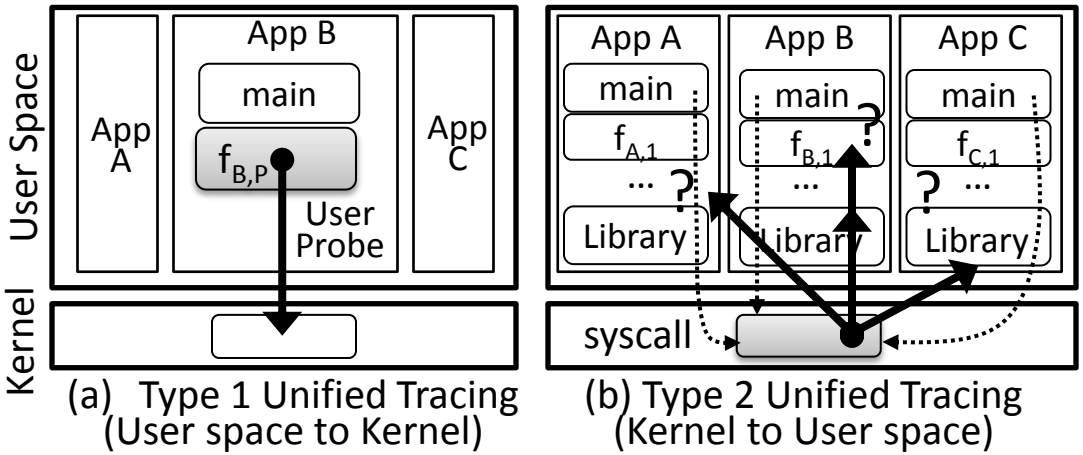


- However, OS events can be triggered by diverse programs and code. Therefore there is semantic gap to understand application program behavior from OS events.

Unified Tracing

- Trace logs across the boundary of kernel and user space
  - Examples: Dtrace, Windows ETW, System Tap

- Two types of Unified Tracing



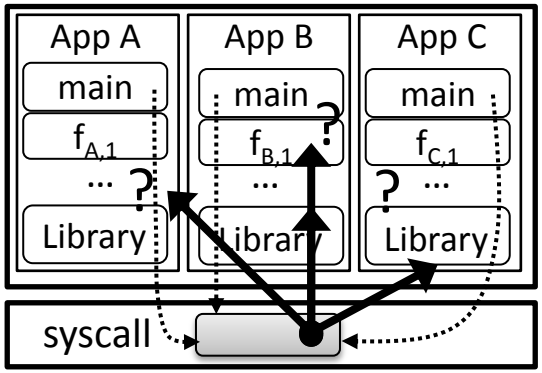
(a) Type 1 Unified Tracing (User space to Kernel)

(b) Type 2 Unified Tracing (Kernel to User space)

	Trigger	**Traced Target**
Type 1	User code	Trace the execution of known user code
Type 2	Kernel code	Trace unknown user code triggering kernel code

Type 2 Unified Tracing

- Service problems can be caused from **any program/layers**. Type 2 unified tracers can cover such unknown cases.
- A typically used technique to collect user space code information is **stack walking**.
- Tracer finds the user process stack in the current context and scan stack frames from the stack pointer address.
- Examples
  - Ustack of Dtrace, Stackwalking of Microsoft ETW
- These solutions have been generally used for debugging scenarios. How we can lower overhead?

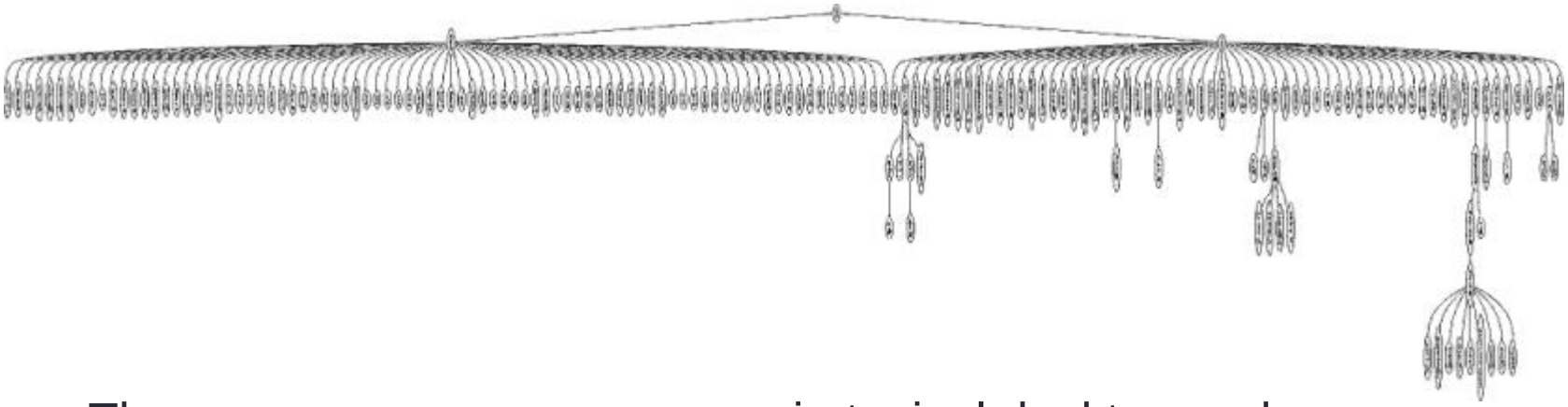


Type 2 Unified Tracing
(Kernel to User space)

Challenges : Tracing Focus

- **Tracing all programs?**

Figure: A hierarchy of live processes in an idle desktop machine



- There are numerous processes in typical desktop and server systems at runtime for various purposes (e.g., multitasking, administration, accounting, updating software, users' daemons).
- Unless the user does not know which program to diagnose, tracing all processes is not ideal.

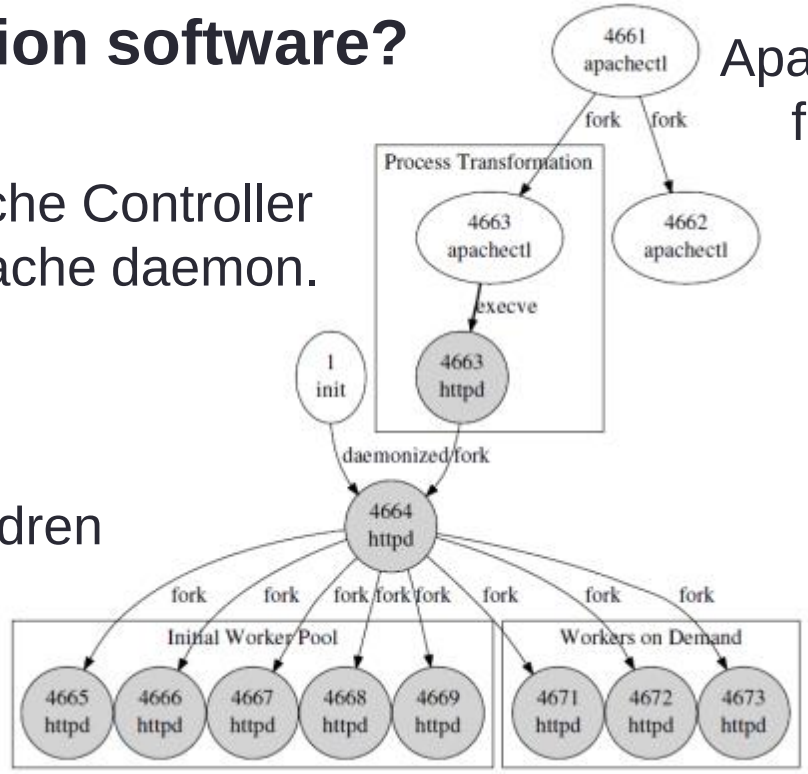
Challenges : Tracing Focus

- **Tracing an application software?**

Apache Controller forks a child

Child of the Apache Controller becomes the Apache daemon.

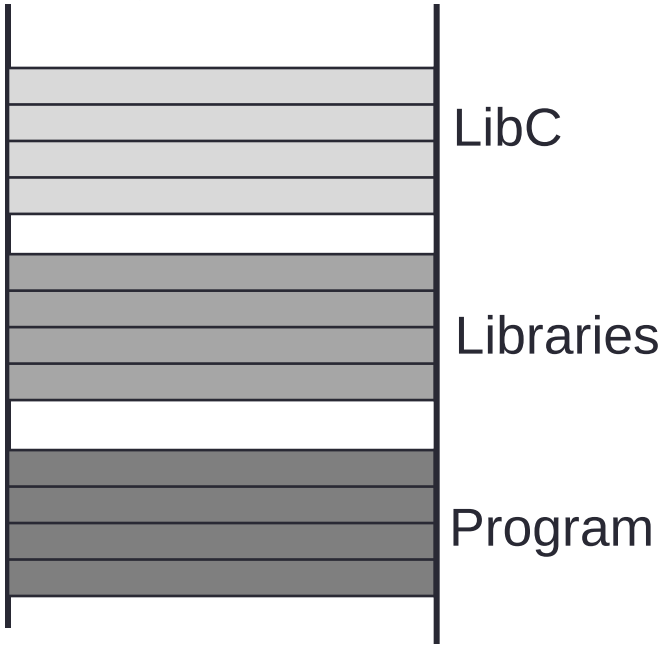
Apache daemon forks children on demand.



- Programs create and kill many sub processes dynamically.
- Some processes change their identity (execve system calls).
- How to systematically track all processes from their start? (instead of giving PIDs to tracers)

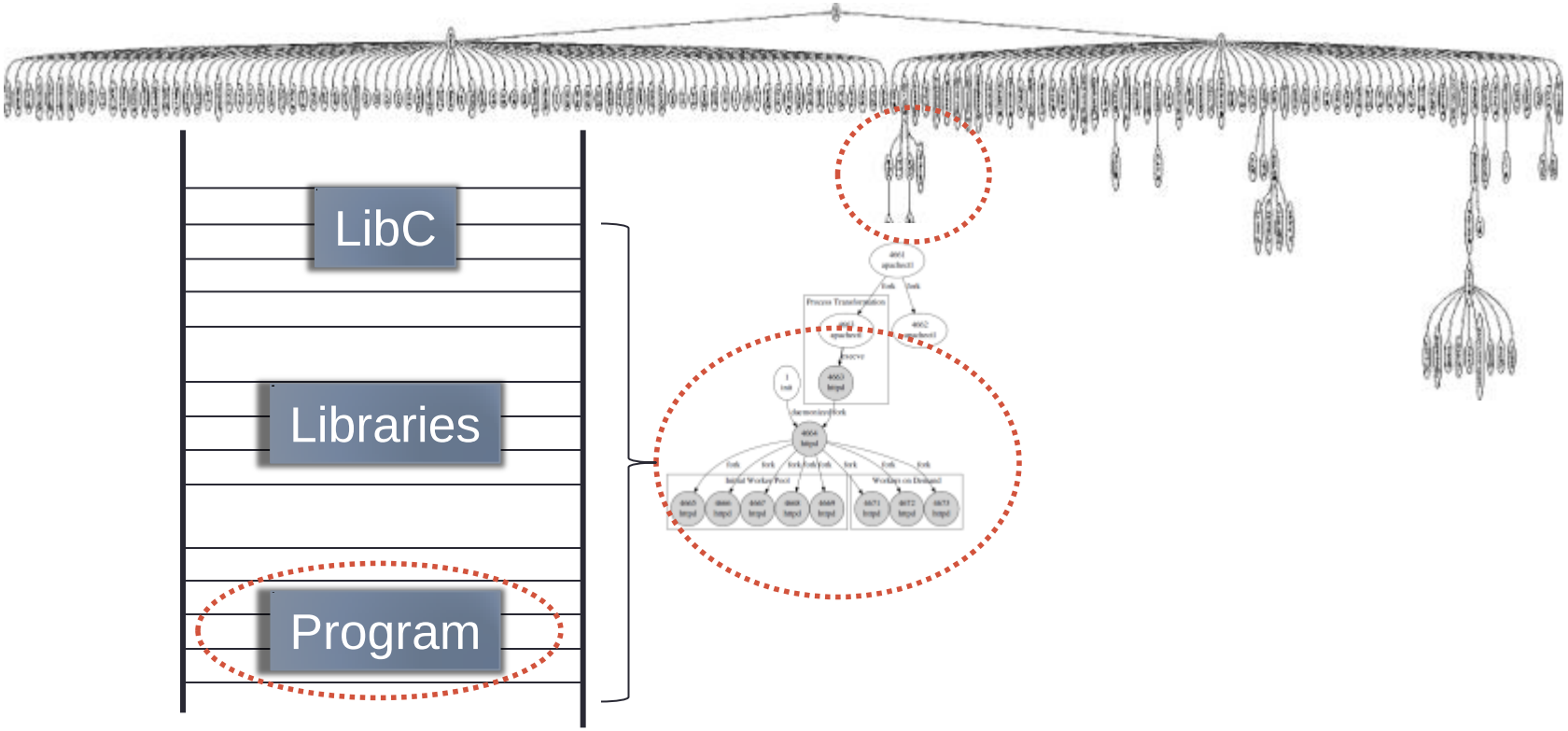
Challenges : Tracing Focus

- **Tracing the whole stack?**
  - Programs may have deep stacks. ECLIPSE project reported that the collected stack trace ranged from 1 ~ 1024 stack frames.
  - A stack includes function call information of multiple software layers (programs, libraries, middleware, and kernel etc.)
  - Not every stack layer may be in users' interest.

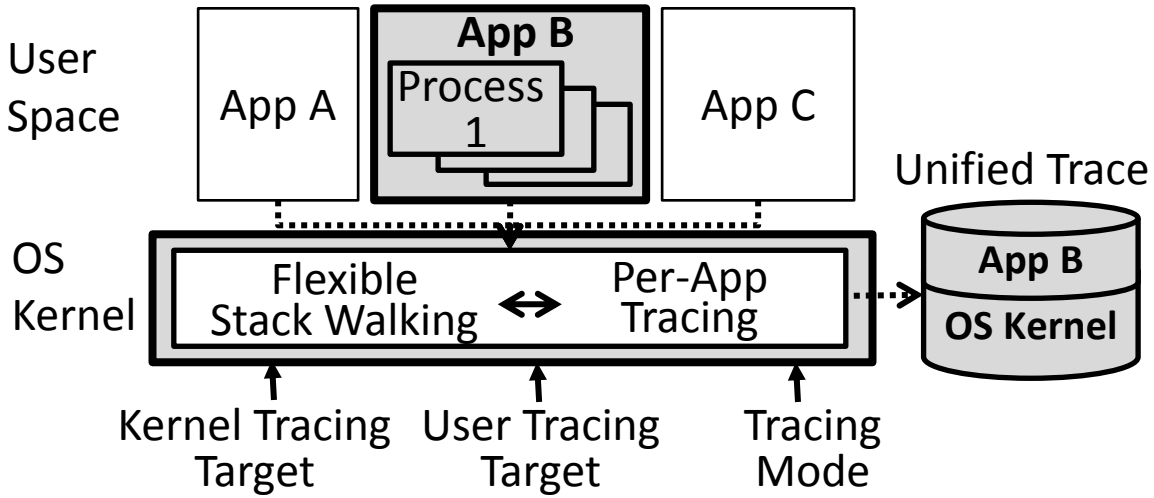


Uscope: Systematic Unified Tracer

- **Flexible and configurable tracing scopes**
  - Efficient per-application tracing
  - Systematic tracking of dynamic processes
  - A highly configurable focus within the call stack

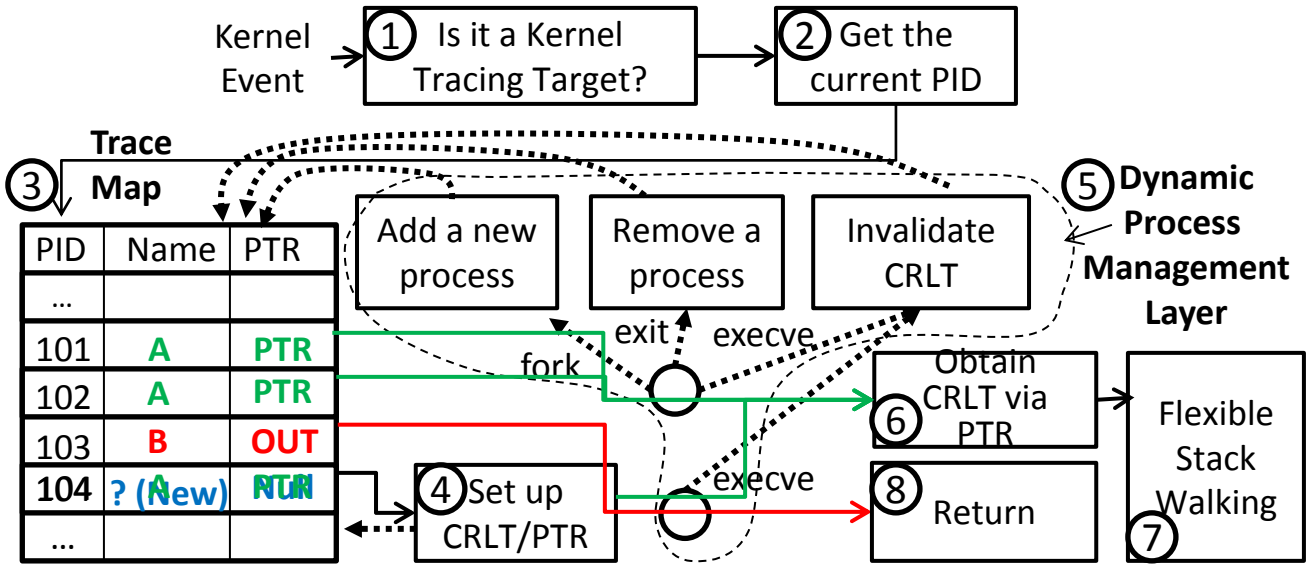


Uscope Architecture



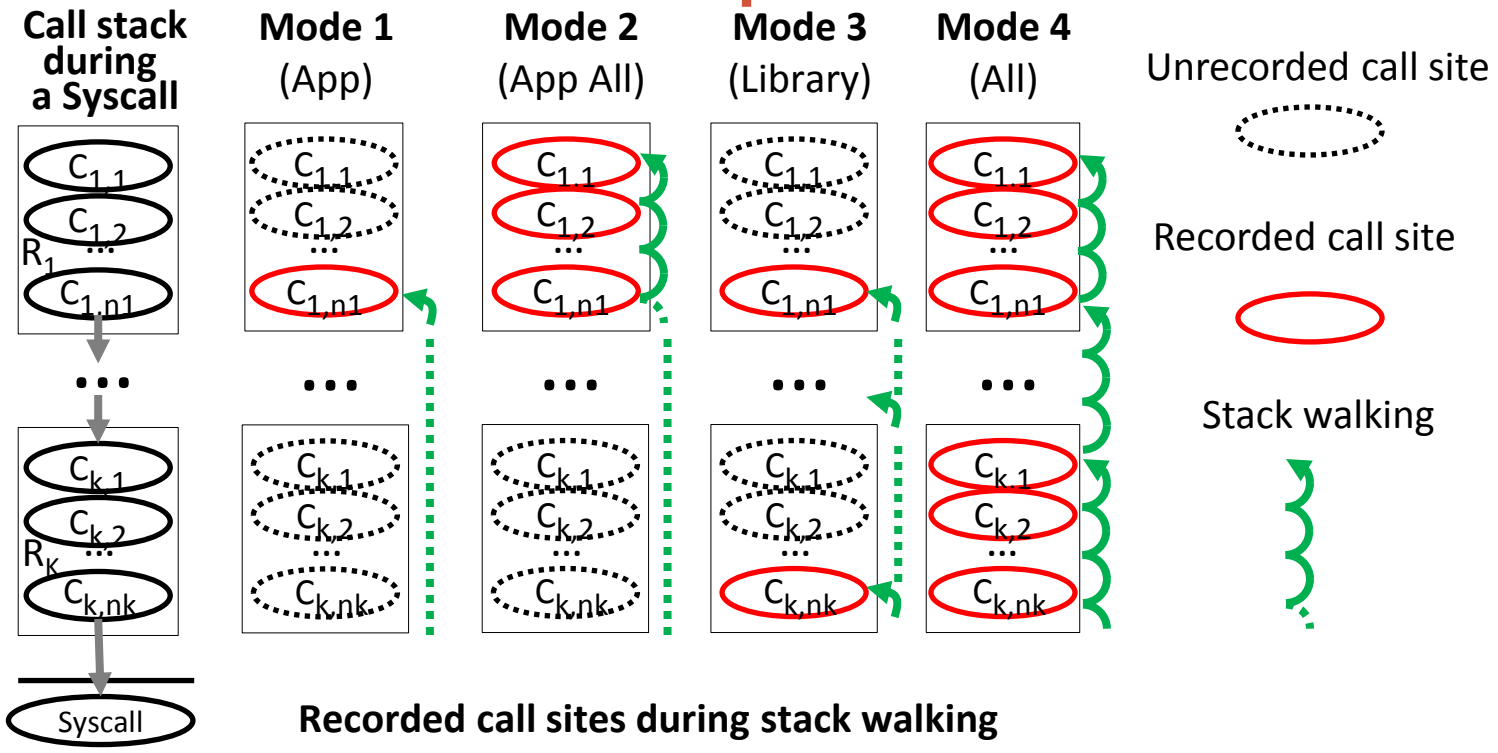
- Input:
  1. Kernel Tracing Target : the kernel events that generate log events
  2. User Tracing Target : the application software to be traced
  3. Tracing Mode : specification on the call stack focus to be traced
- Output:
  - Unified Trace for the user tracing target

Per-Application Tracing Logic



- This diagram shows the logic how Uscope performs per-application tracing and systematic tracking of dynamic processes.
- Trace map maintains the sets of processes in three states: (1) **unknown**, (2) **to be traced**, and (3) **not to be traced**.
- Kernel events making dynamic changes of processes (e.g., fork, exit, execve) trigger corresponding changes on the trace map.

Flexible Call Stack Scope



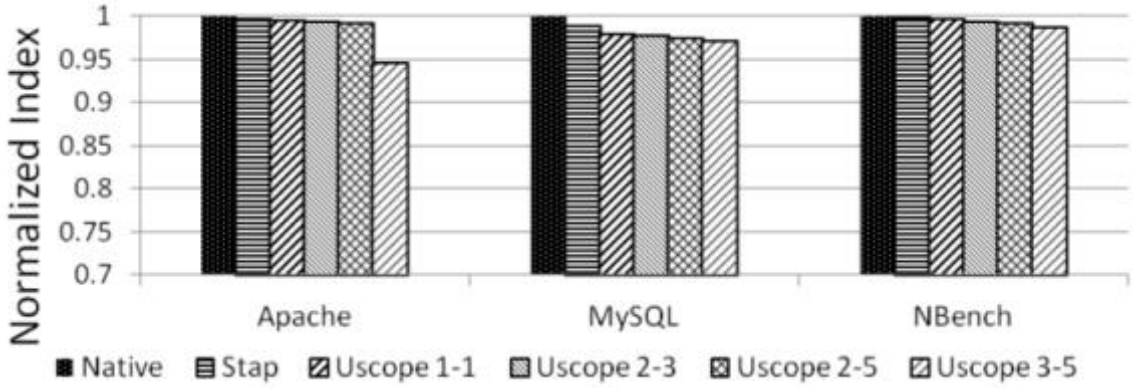
- Uscope provides flexible call stack scopes in tracing.
- Maximum budge S. Further fine control is available.

	Binary config	In-Binary config
Mode 1	App binary	The last stack frame
Mode 2	App binary	All stack frames
Mode 3	All binaries, libraries	Last stack frames
Mode 4	All binaries, libraries	All stack frames

Implementation

- Tracer
  - Implemented by extending SystemTap.
  - SystemTap hooks system calls to generate log events.
  - Trace map and tracing logic is implemented as a kernel module.
  - Redhat Enterprise Linux 5 is supported.
- Input:
  1. Kernel Tracing Target : System call events
  2. User Tracing Target : Apache webserver (Server workload), MySQL database (Server workload), Nbench (computation)
- Uscope can be dynamically attached and detached to the kernel at runtime. When it is detached, there is no overhead.

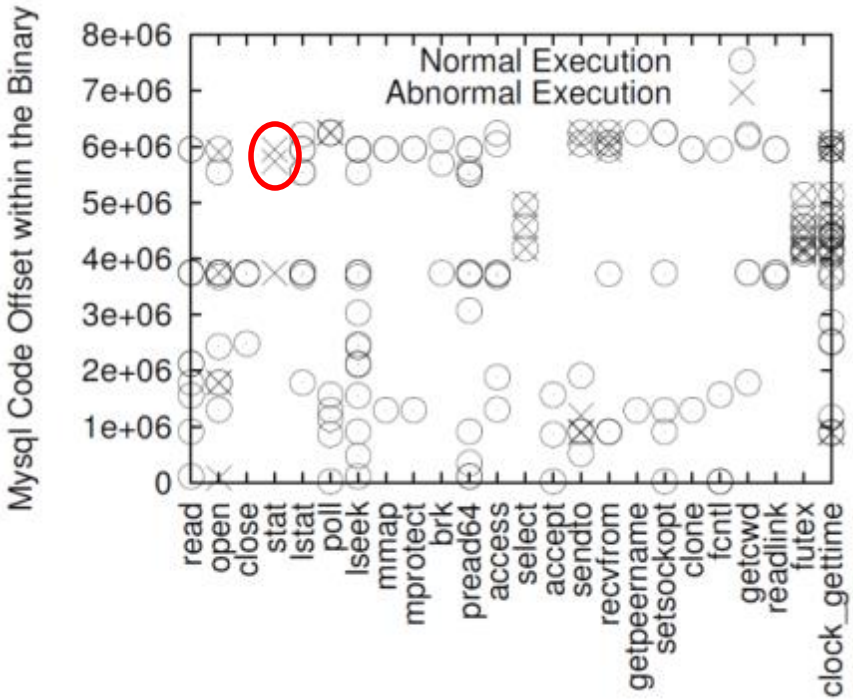
Runtime Overhead



- Workload
  - Apache : Apache HTTP Benchmark tool (ab), 100 concurrency, 10^6 requests
  - MySQL : MySQL Benchmark suite (alter-table, ATIS, big-tables, connect, create, insert, select, transactions, and wisconsin)
  - Nbench : Linux/Unix of BYTE's Native Mode Benchmarks (verison 2.2.3). "Memory Index", "Integer Index", and "FP Index" are used.
- Tracing Modes :
  1. Mode 1 : application call stack layer, the last stack frame
  2. Mode 2 : application call stack layer, 3 or 5 last stack frames
  3. Mode 3 : all layers, the last stack frames up to 5
- Less than 6% overhead in three benchmarking cases

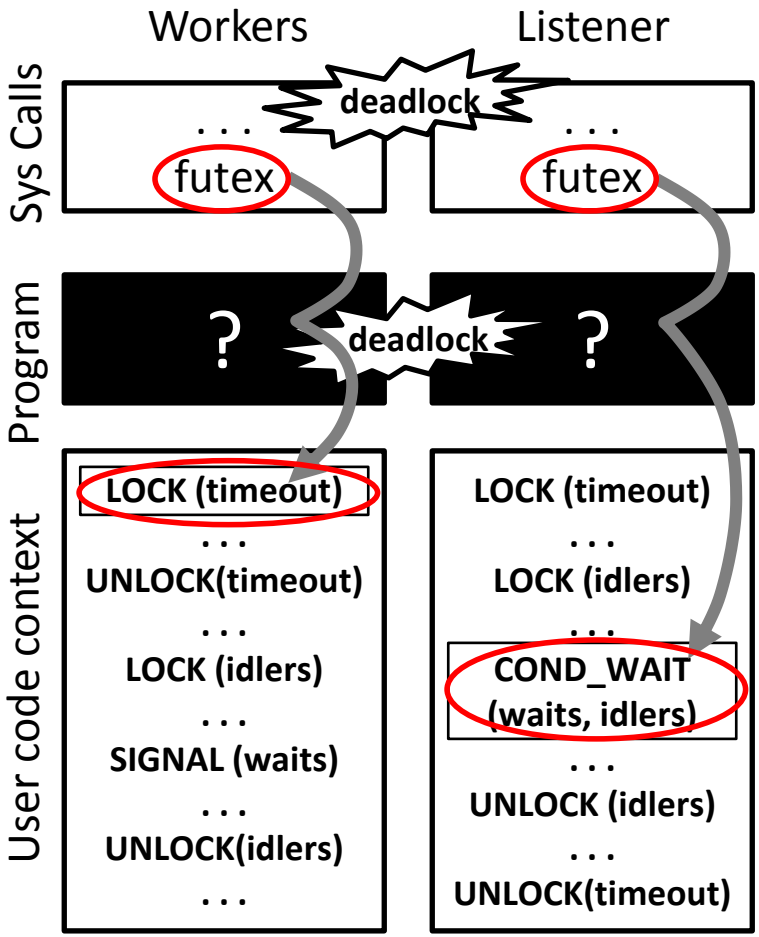
Case Study Application 1

- **Testbed**
  - Three tier PetStore system (Apache, Jboss, MySQL)
- **Symptom**
  - Web requests failed.
- **Tracing**: Mode 2 (S=3)
- **Dual Space Analysis**
  - X axis shows different types of system calls and Y axis shows application code (i.e., triggers).
  - Unique events in normal case
    - Read: **`my_read`**
    - Accept: **`handle_connections_socket`**
    - More..
  - Unique events in abnormal case
    - **Stat: `archive_discover`**
  - => Problem in accessing the database file



Case Study Application 2

- **Testbed**
  - Apache Webserver
- **Symptom**
  - Concurrency error that threads are in a deadlock condition (Case number: Apache #42031)
- **Tracing**: Mode 2 (S=5)
- **Call Stack Analysis**
  - Call stacks on **`futex`** system calls are captured and analyzed.
  - Worker Thread
    - **`apr_thread_mutex_call`** (a wrapper of **`pthread_mutex_call`**)
  - Listener Thread
    - **`apr_thread_cond_wait`** (a wrapper of **`pthread_cond_wait`**)
  - => Deadlock conditions are identified.



Conclusion

- Uscope provides efficient type 2 unified tracing for kernel and unknown user code.
- Uscope provides per-application tracing, systematic tracking of dynamic processes, and flexible specification on call stack scopes to be traced.
- Our prototype has 6% overhead compared to native execution in several benchmarks.
- Also we showed two case studies illustrating how unified tracers can be used for diagnosing service systems.

Thank you

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