Failure Sketches: A Better Way to Debug

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Benjamin Schubert, Madan Musuvathi, George Candea

Failure and Root Cause

- Failure
  - Violation of a program specification
  - Memory errors, hangs, etc
- Root cause
  - “The real reason” behind the failure
  - When removed from the program, the failure does not recur

Debugging In-Production Software Failures Today

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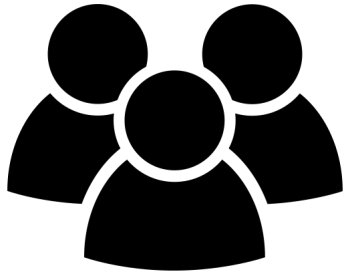

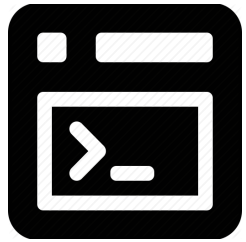

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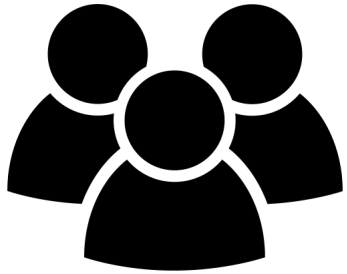
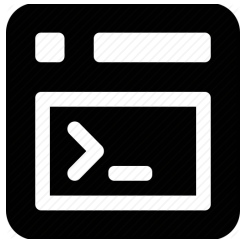
```
#0  0x00007f51abae820b in raise (sig=11) at ../nptl/
sysdeps/unix/sysv/linux/pt-raise.c:37
#1  0x000000000042d289 in ap_buffered_log_writer
(r=0x7f51a40053d0, handle=0x20eeba0,
strs=0x7f51a4003578, strl=0x7f51a40035e8, nelts=14,
len=82) at mod_log_config.c:1368
#2  0x000000000042b10d in config_log_transaction
(r=0x7f51a40053d0, cls=0x20b9d50,
default_format=0x20ee370) at mod_log_config.c:930
#3  0x000000000042aad6 in multi_log_transaction
(r=0x7f51a40053d0) at mod_log_config.c:950
#4  0x000000000046cb2d in ap_run_log_transaction
(r=0x7f51a40053d0) at protocol.c:1563
#5  0x0000000000436e81 in ap_process_request
(r=0x7f51a40053d0) at http_request.c:312
#6  0x000000000042e9da in ap_process_http_connection
(c=0x7f519c000b68) at http_core.c:293
#7  0x0000000000465cdd in ap_run_process_connection
(c=0x7f519c000b68) at connection.c:85
#8  0x00000000004661f5 in ap_process_connection
(c=0x7f519c000b68, csd=0x7f519c000a20) at
connection.c:211
#9  0x0000000000451ba0 in process_socket
(p=0x7f519c0009b8, sock=0x7f519c000a20,
my_child_num=0, my_thread_num=0,
bucket_alloc=0x7f51a4001348) at worker.c:632
#10 0x0000000000451221 in worker_thread
(thd=0x210fa90, dummy=0x7f51a40008c0) at worker.c:946
#11 0x00007f51ac87c555 in dummy_worker
(opaque=0x210fa90) at thread.c:127
#12 0x00007f51abae0182 in start_thread
(arg=0x7f51aa8ef700) at pthread_create.c:312
#13 0x00007f51ab80d47d in clone () at ../sysdeps/
unix/sysv/linux/x86_64/clone.S:111
```





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Understand root cause

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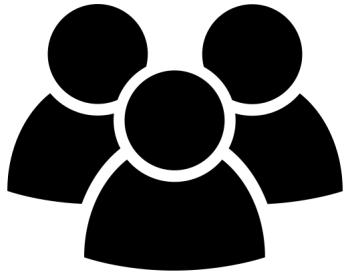

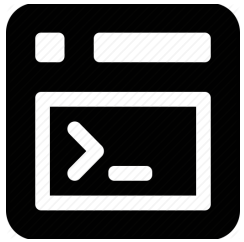

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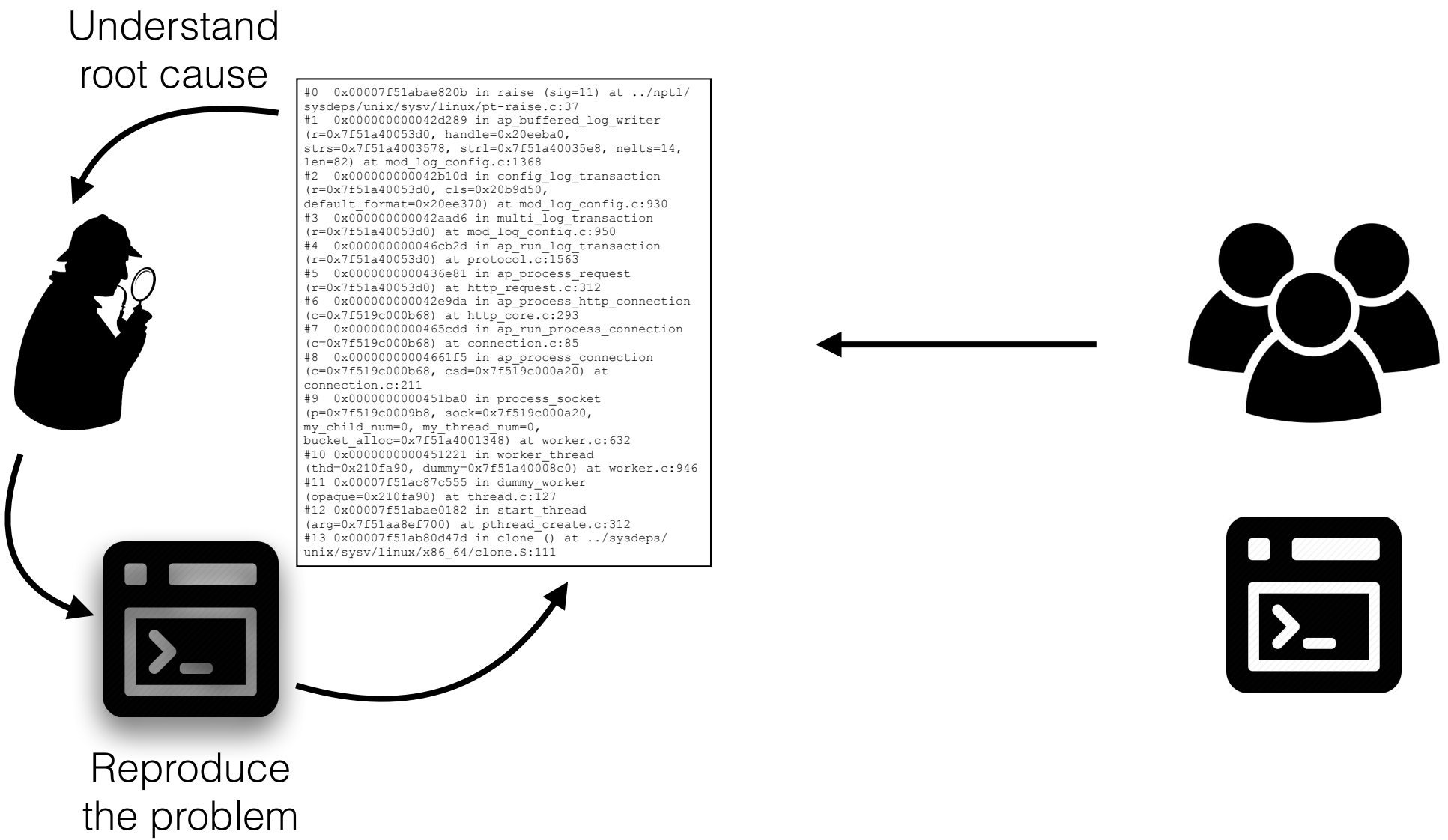

Tackling the Debugging Challenge

- Record/replay
- Special runtime support[1]
  - VM checkpointing
- Custom hardware[2]
  - Not widely available

[1] J. Tucek et al., Triage: Diagnosing Production Run Failures at the User's Site, SOSP 2007

[2] G. Pokam et al., QuickRec: prototyping an intel architecture extension for record and replay of multithreaded programs, ISCA 2013

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Existing tools don't help debugging in-production failures[3]

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[3] C. Sadowski et al. ,How developers use data race detection tools, Workshop on Evaluation and Usability of Programming Languages and Tools 2014

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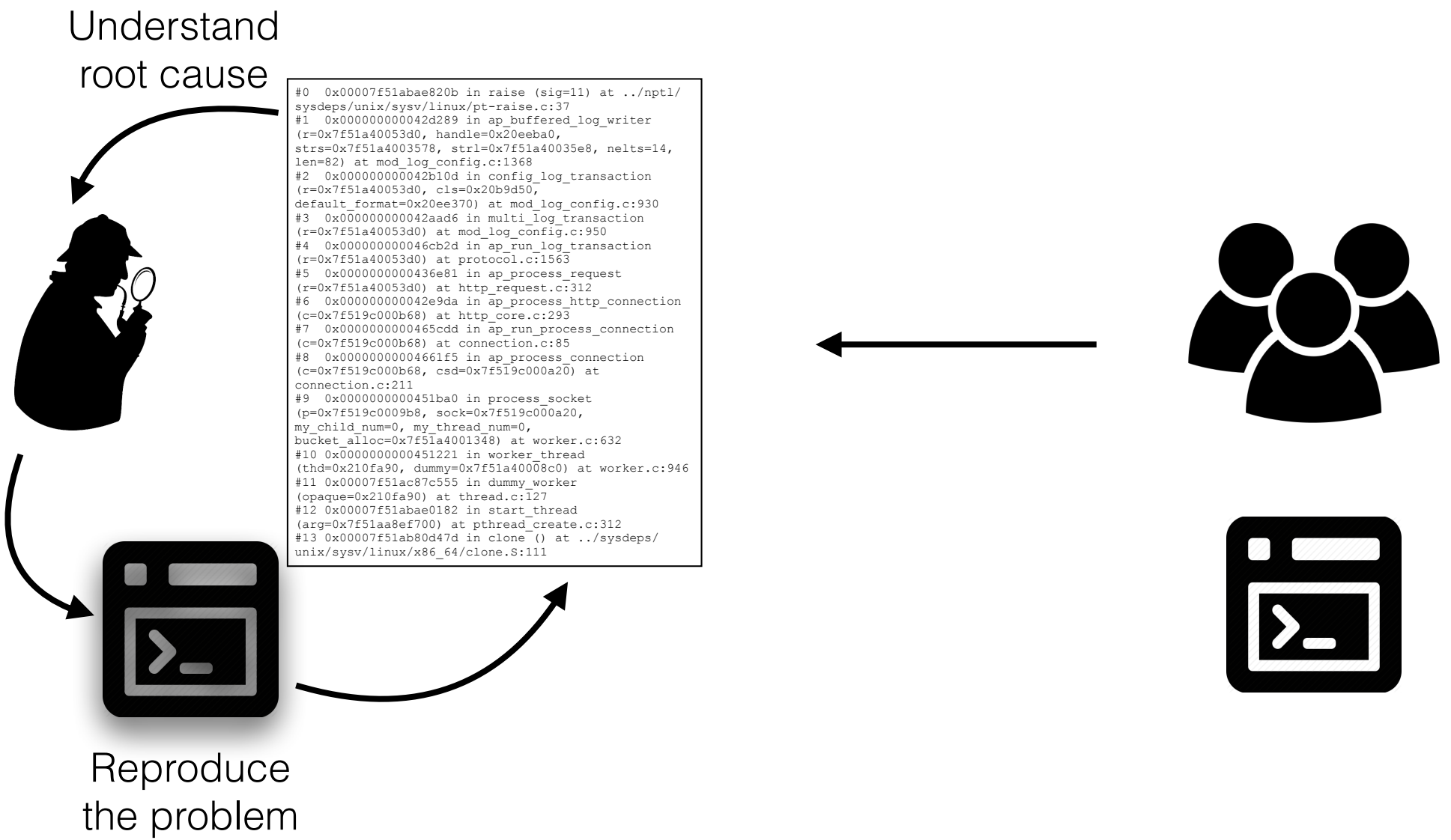
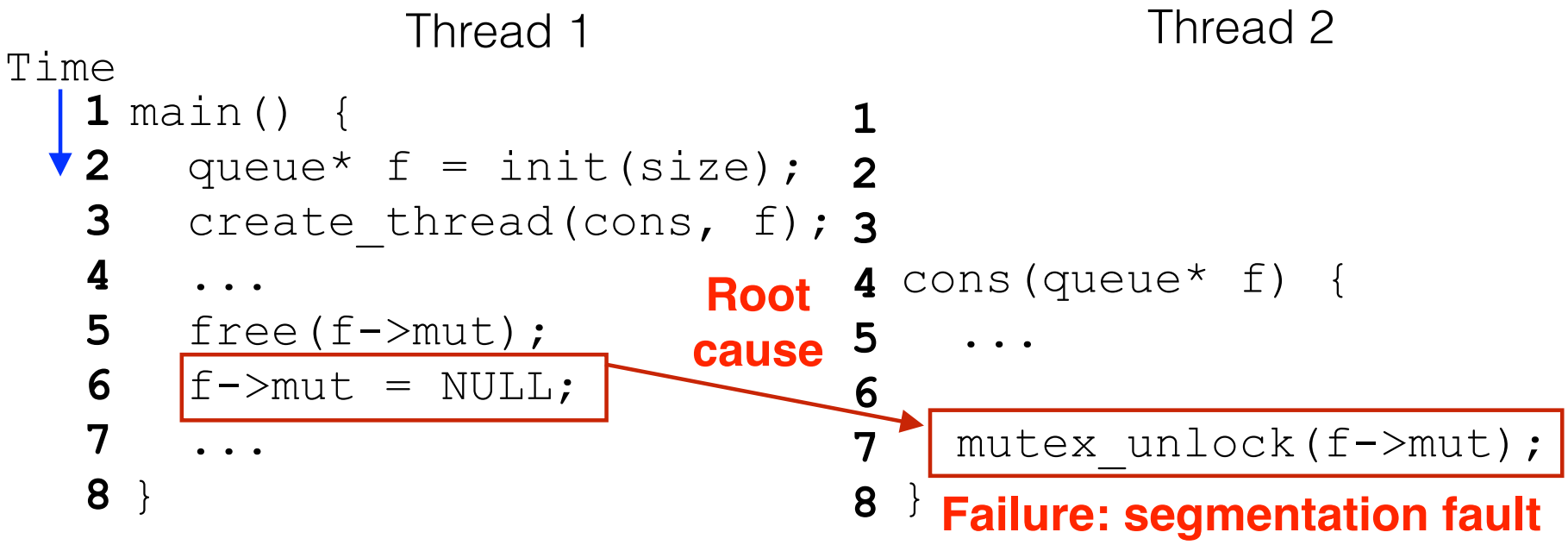


Failure Sketch



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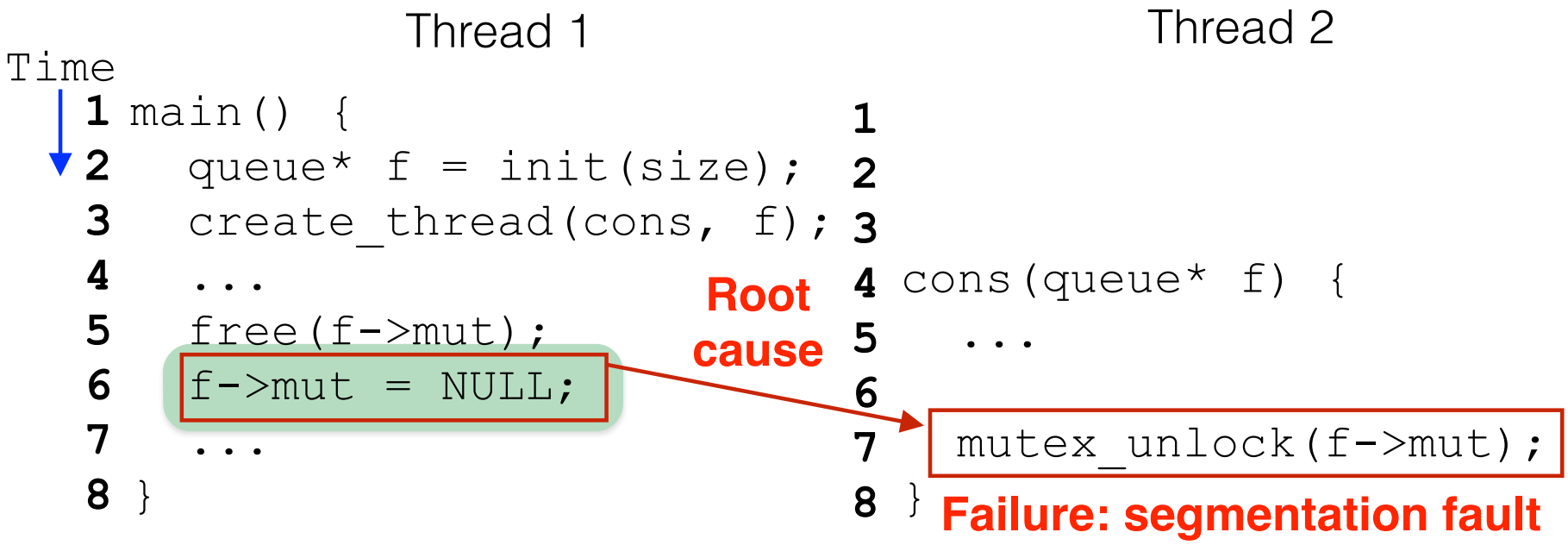

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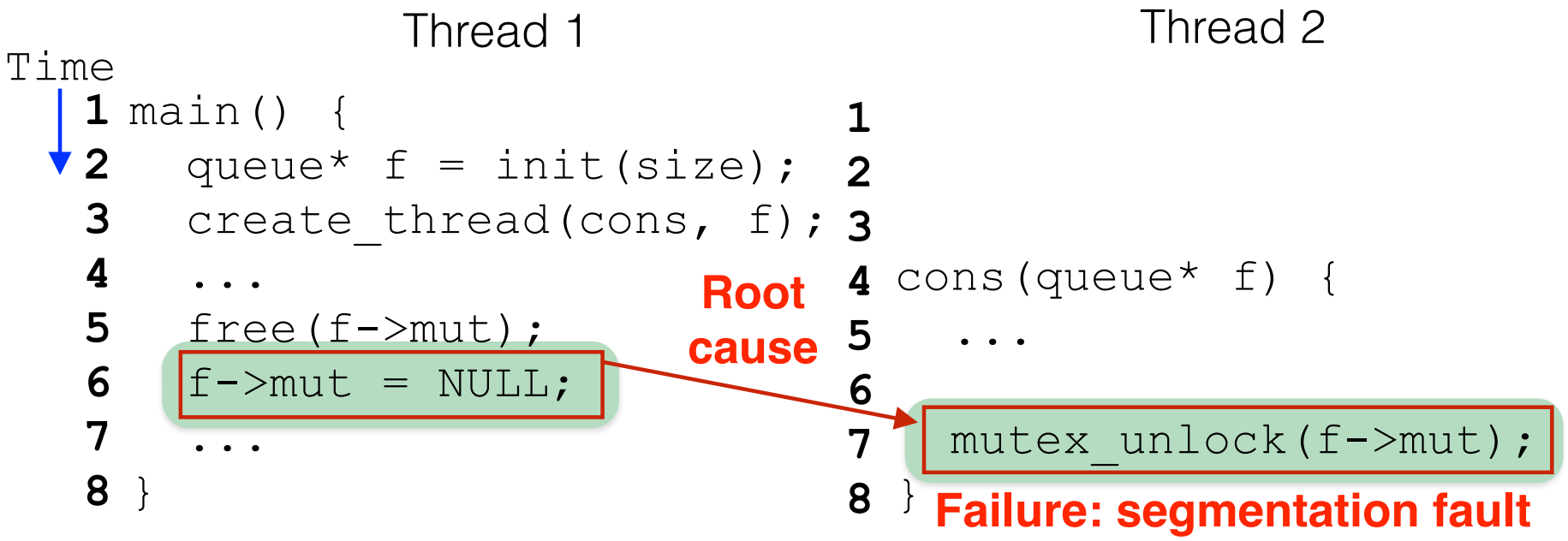
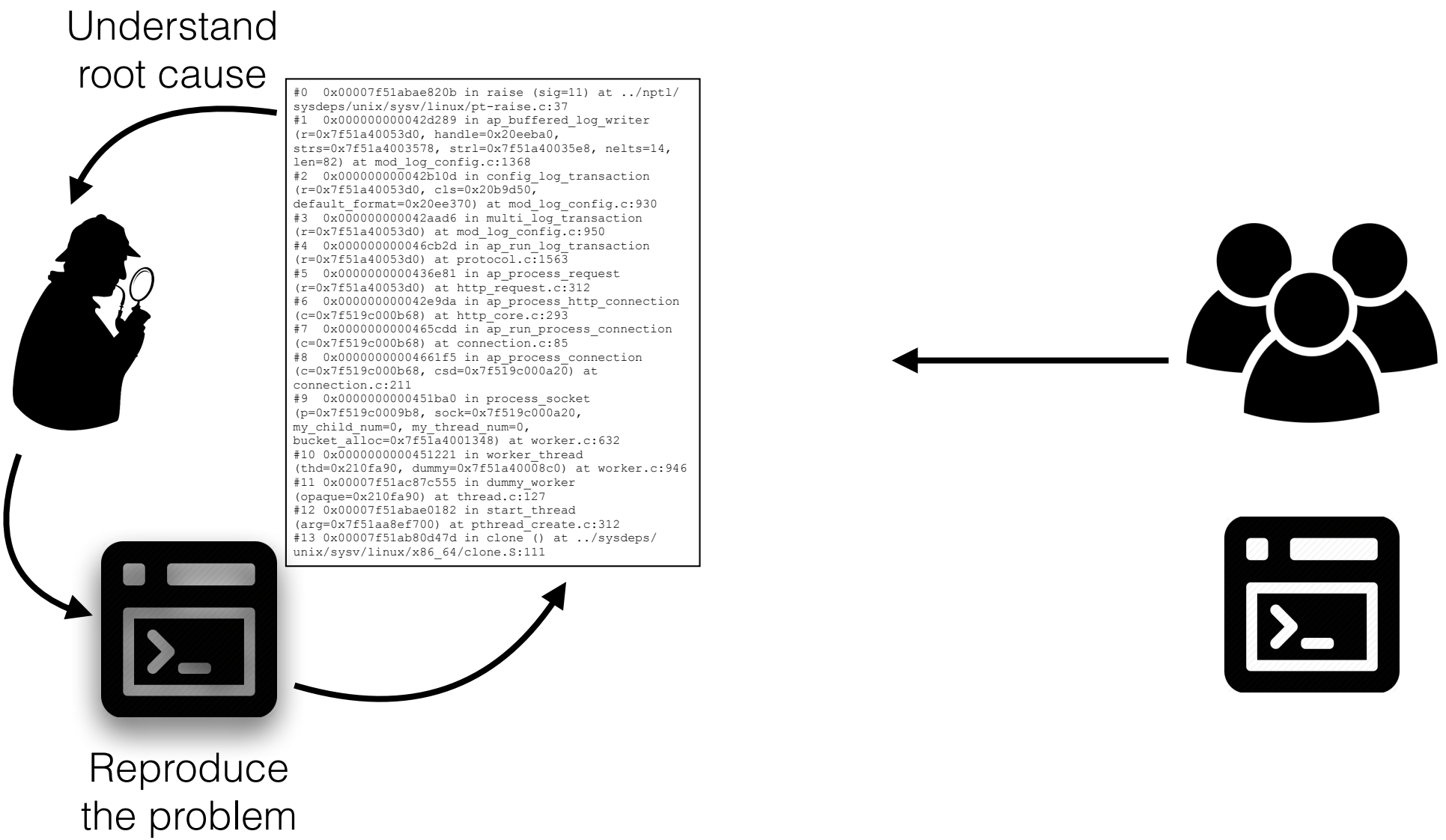


Failure Sketch Use Case



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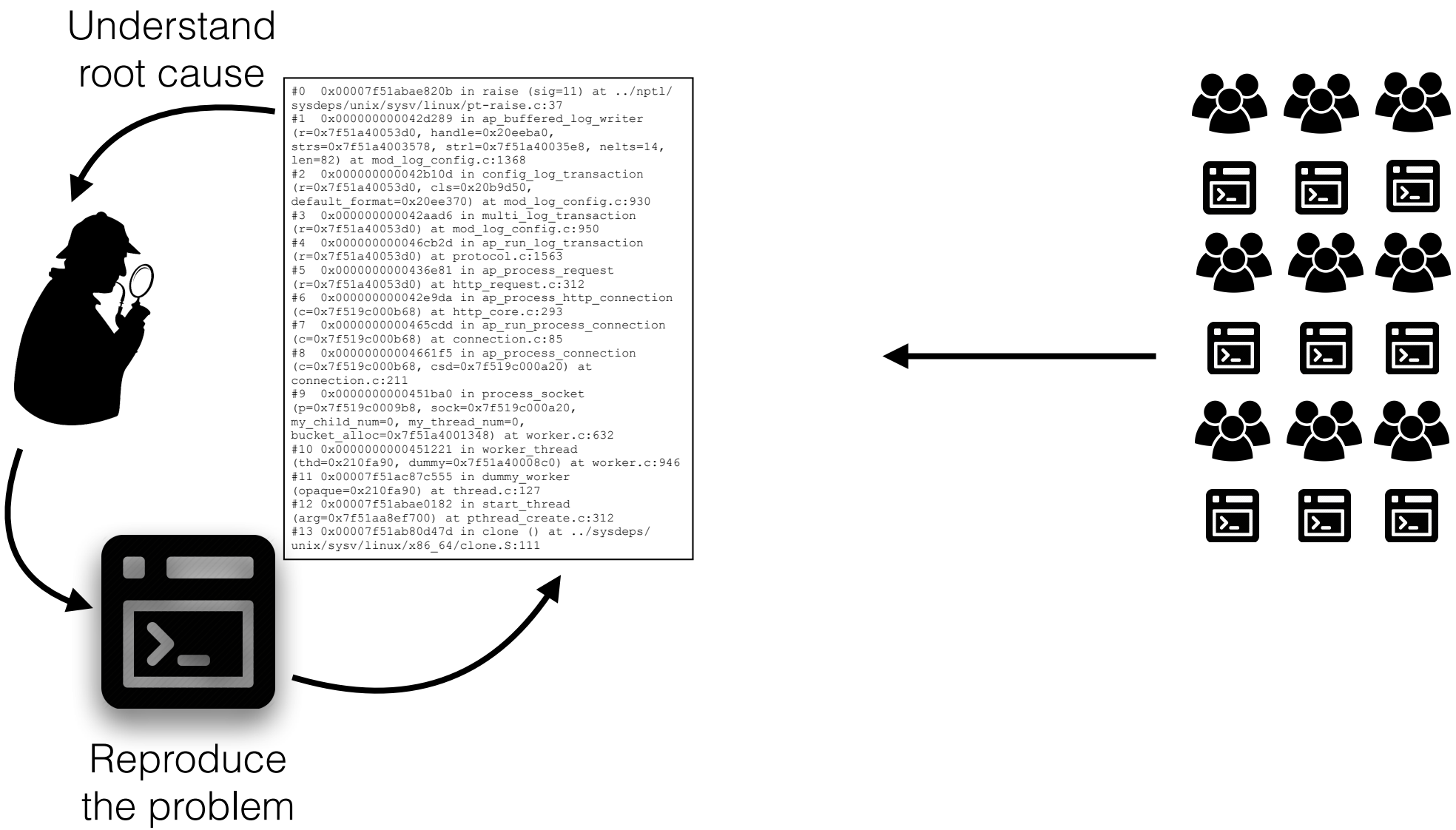

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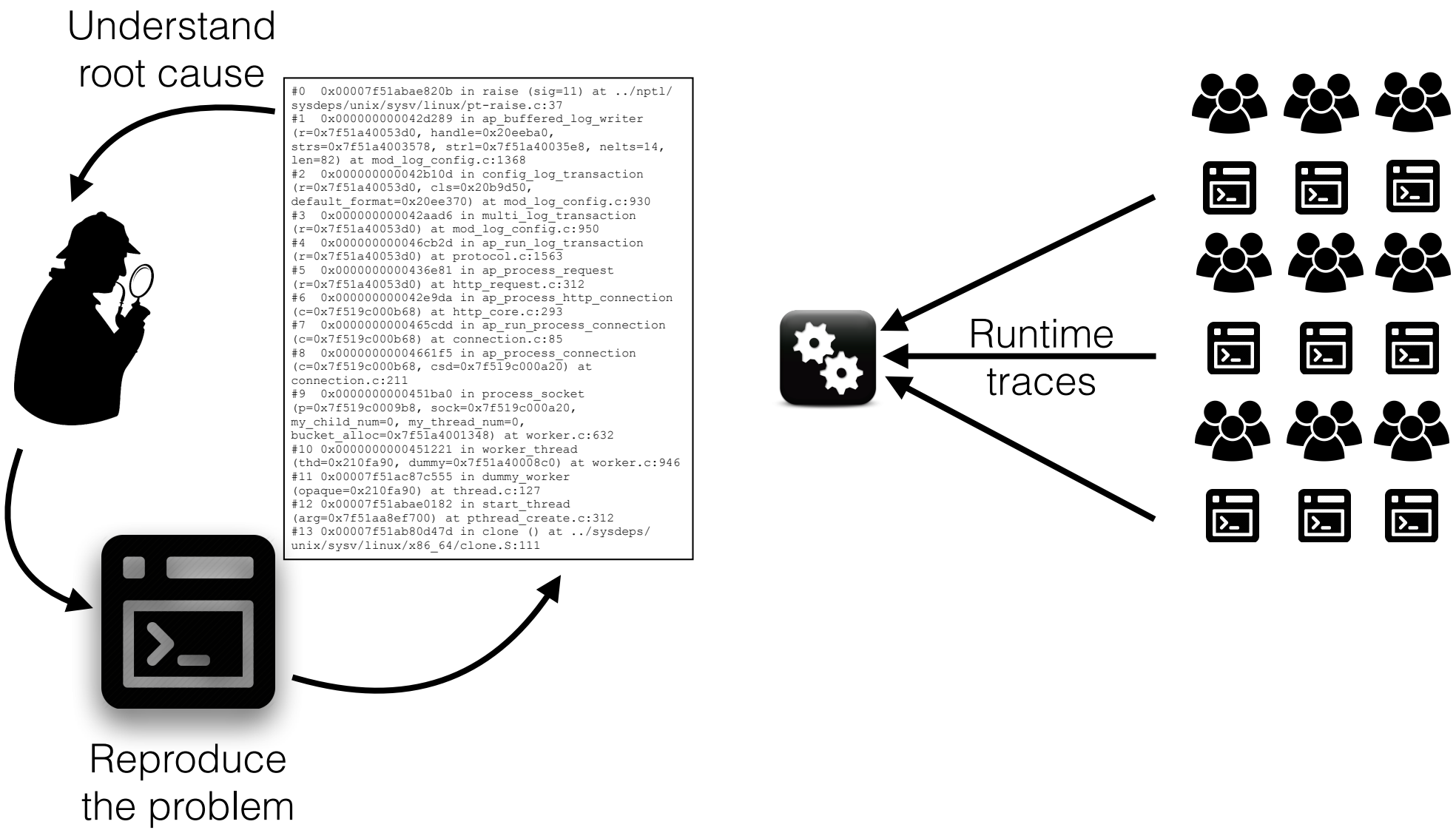

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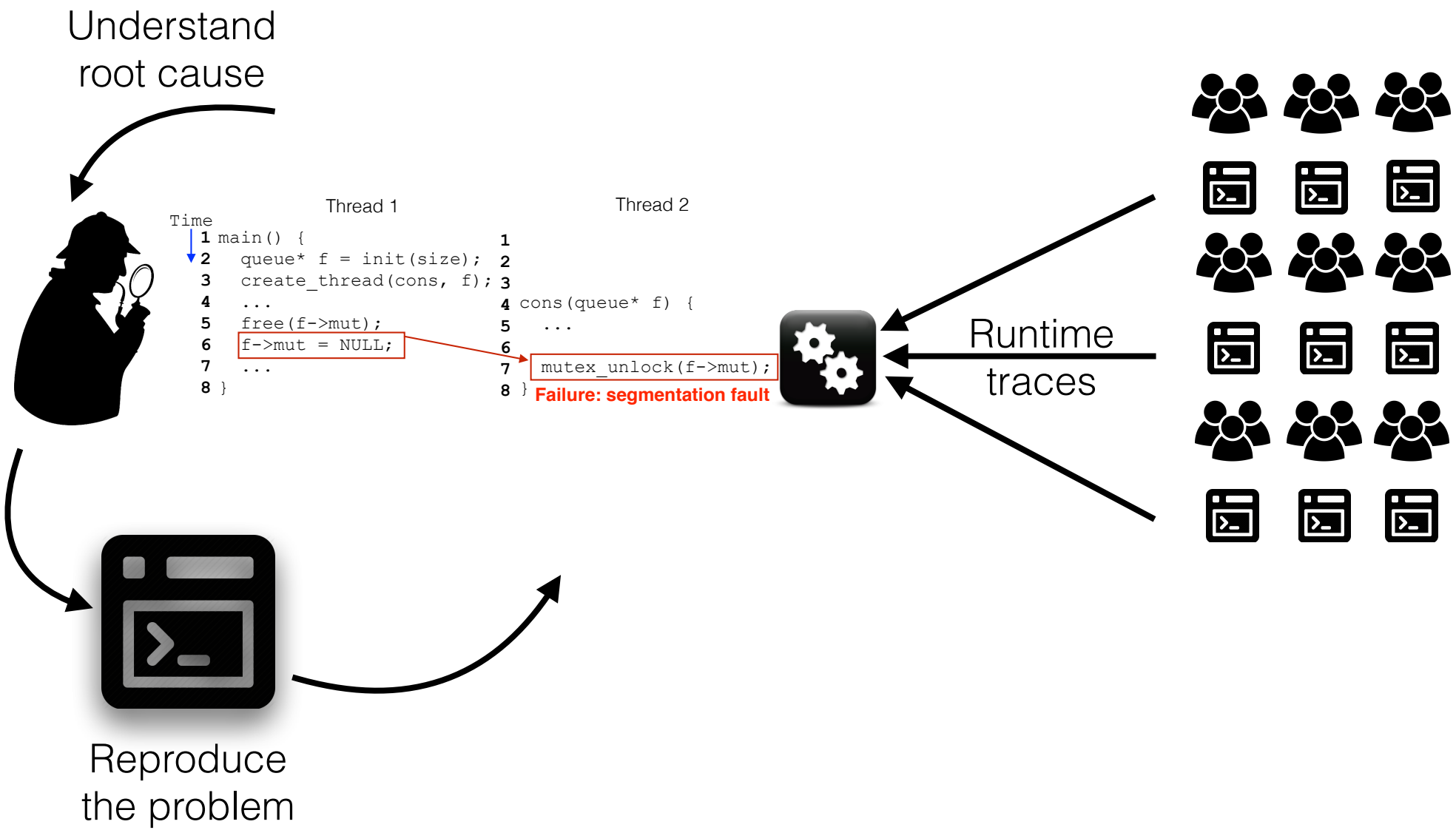

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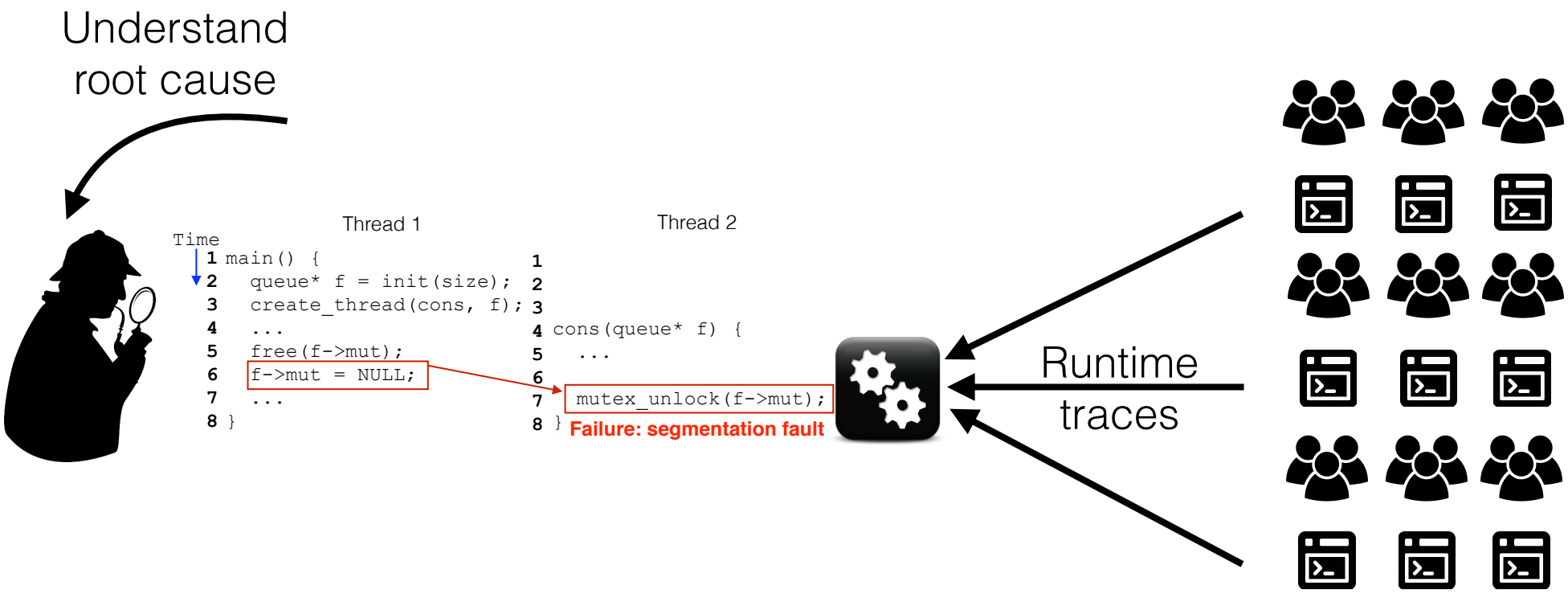

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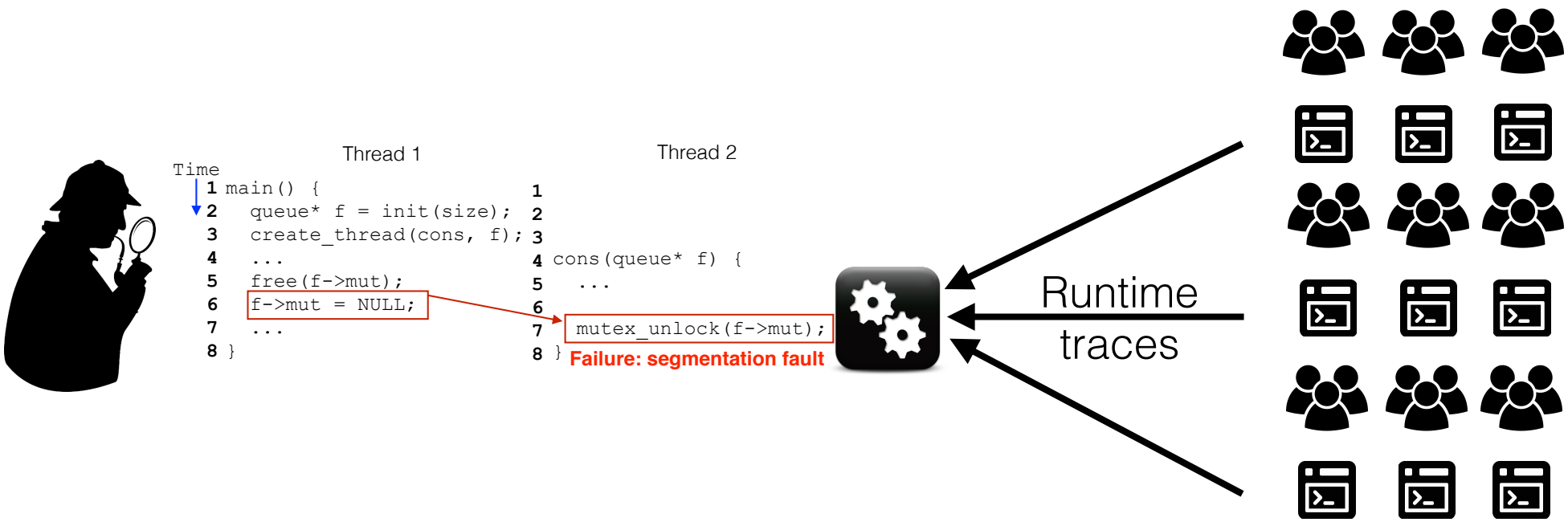

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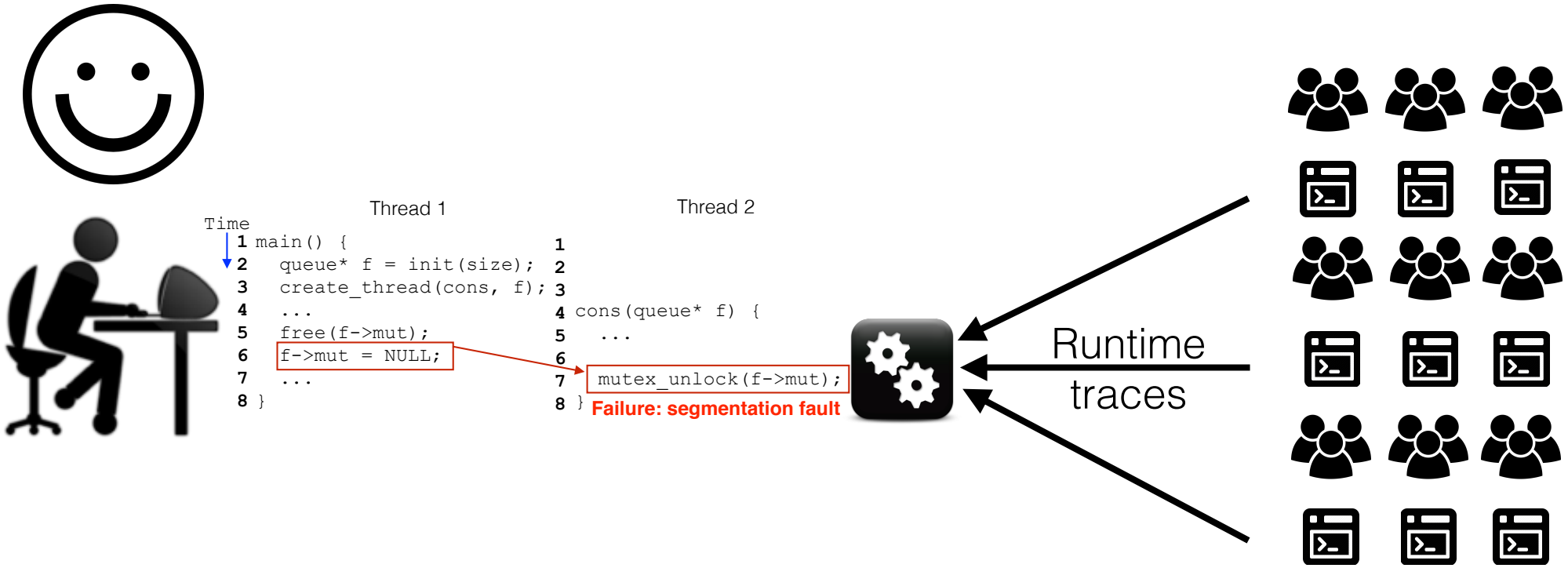
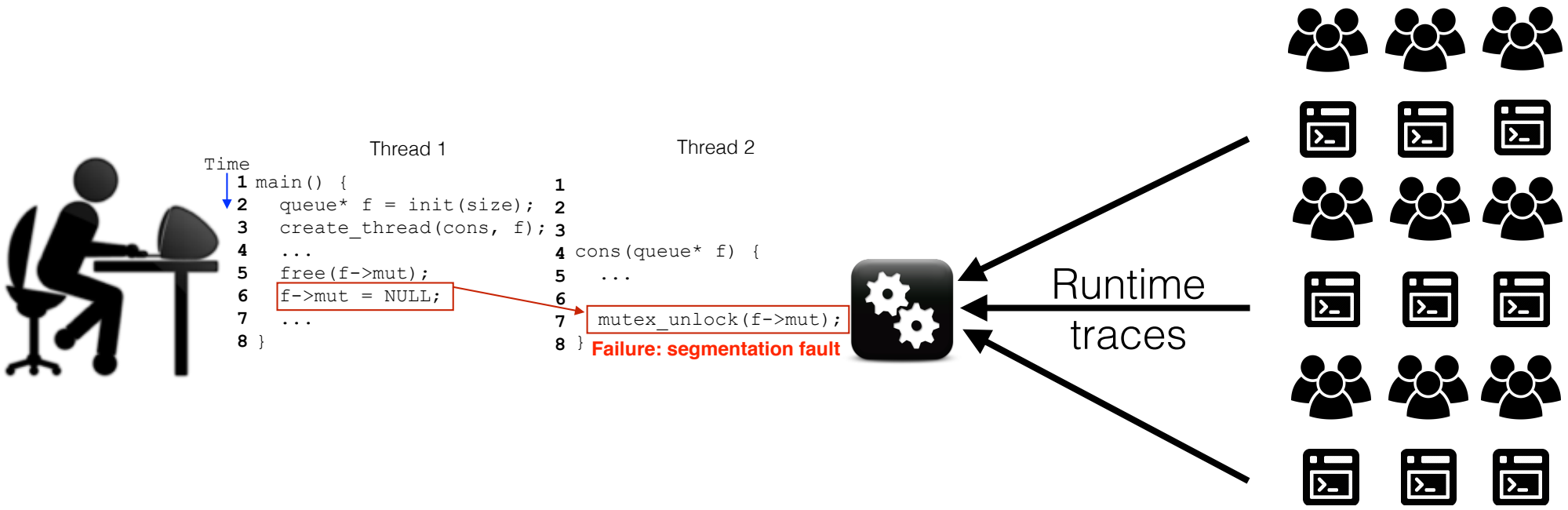


Research Challenges

- Hard-to-reproduce failures
  - Recur only a few times in production
- Accuracy of failure sketches
  - No extraneous elements in the failure sketch
- Latency of failure sketch computation
  - Developers can’t wait forever for failure sketches

System Architecture



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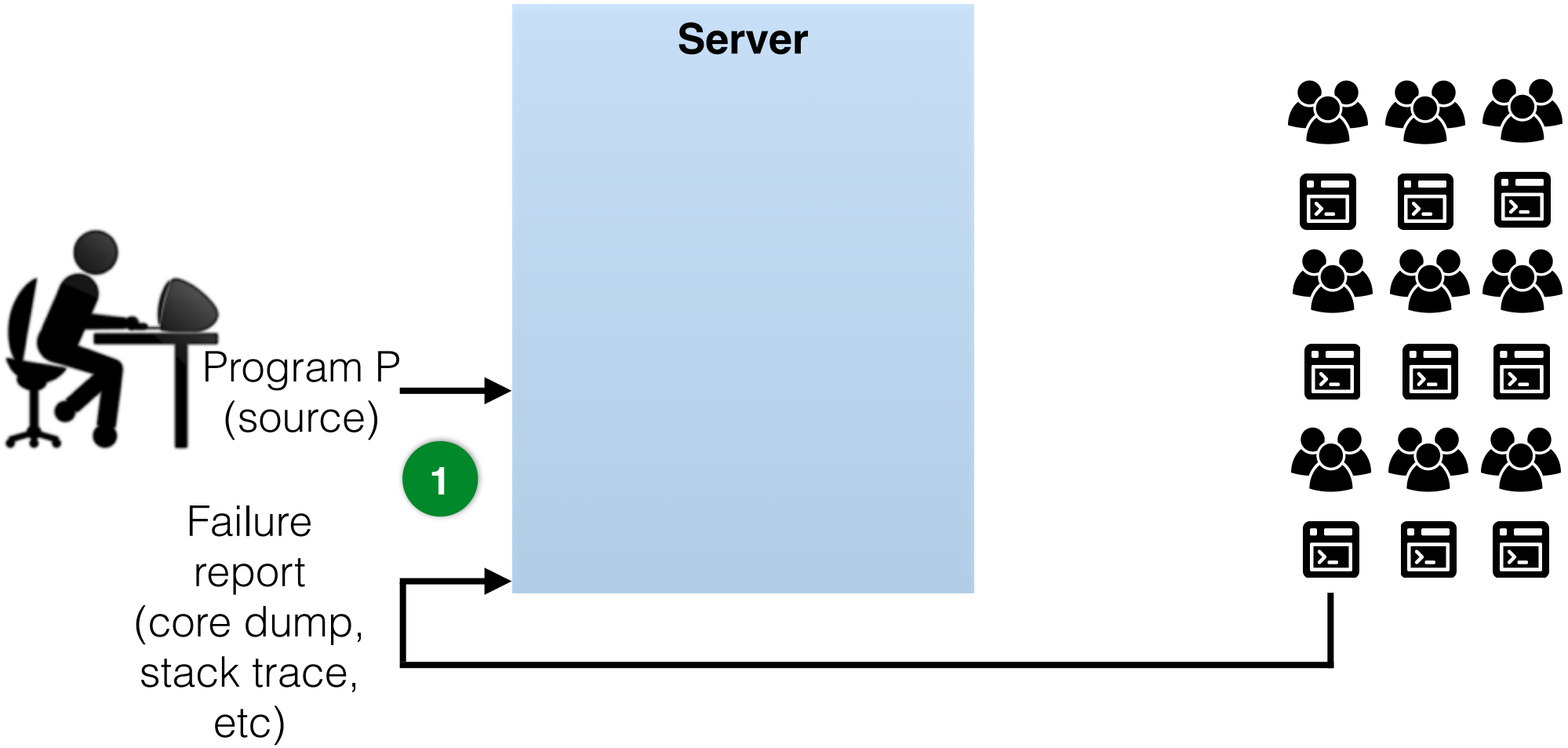

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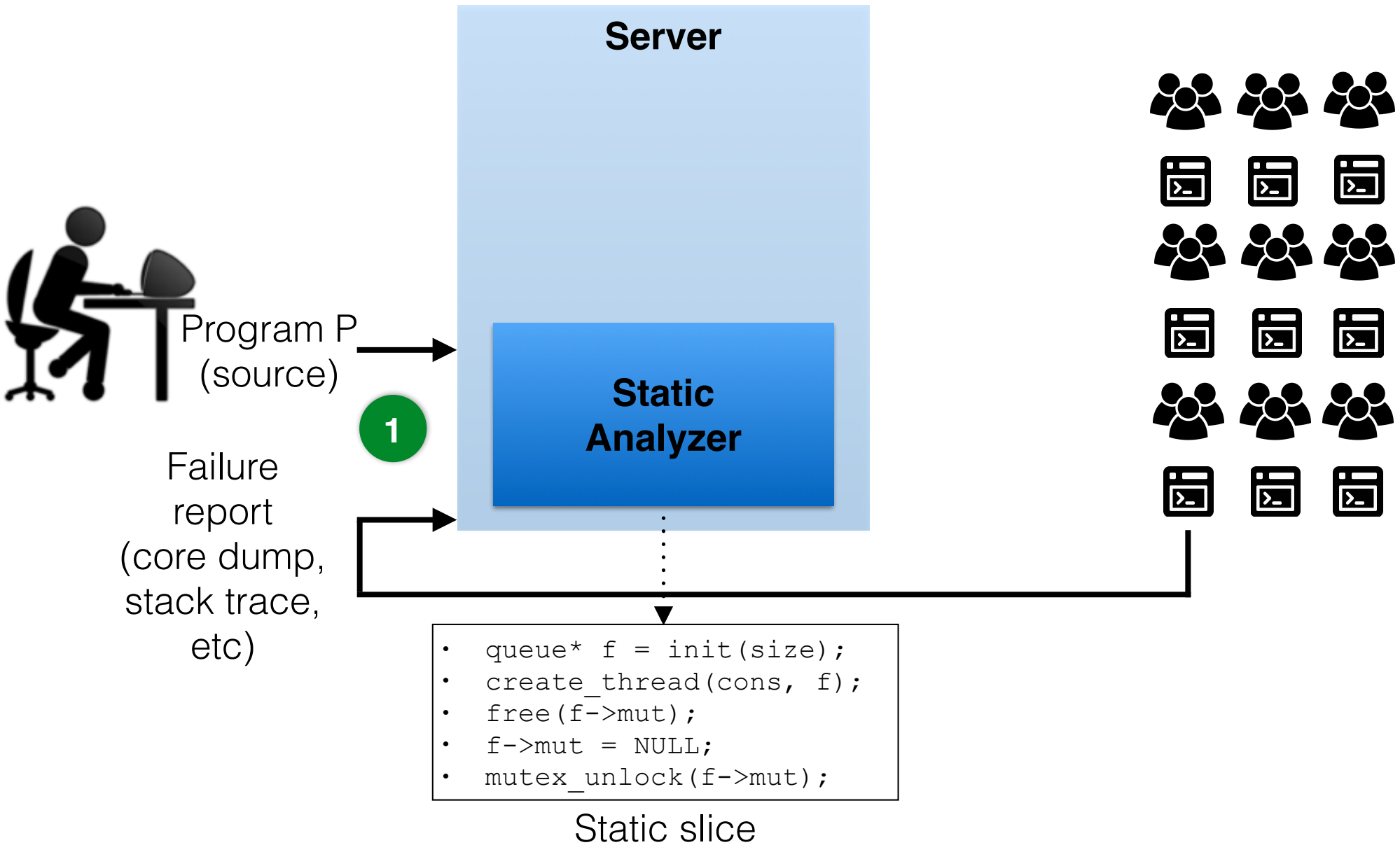

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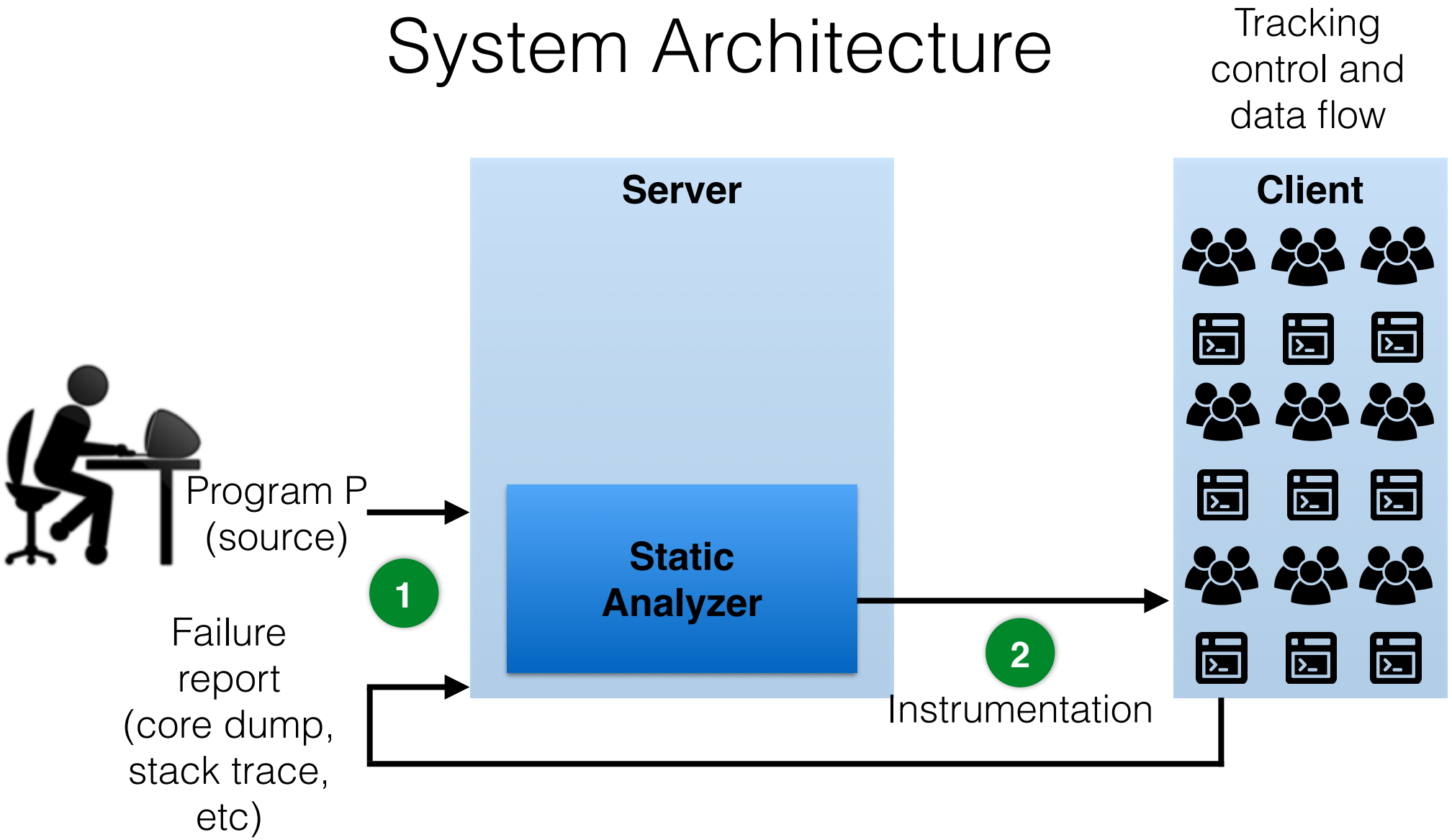

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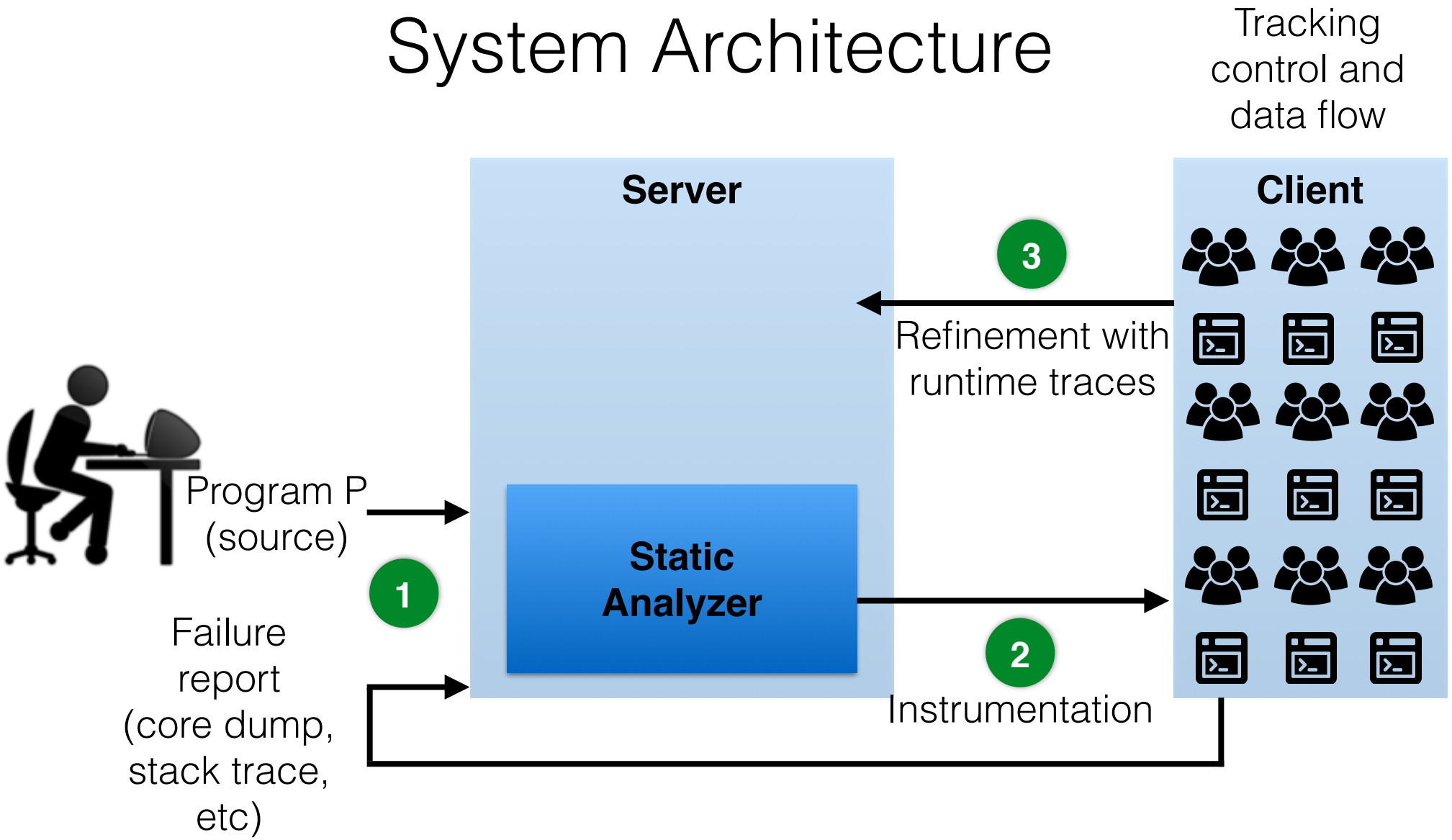
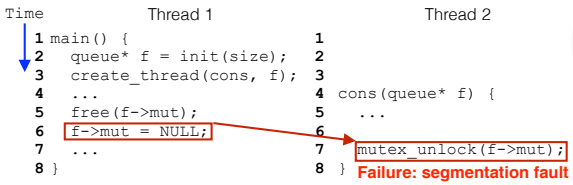


System Architecture

Tracking control and data flow

Failure Sketch



Program P (source)

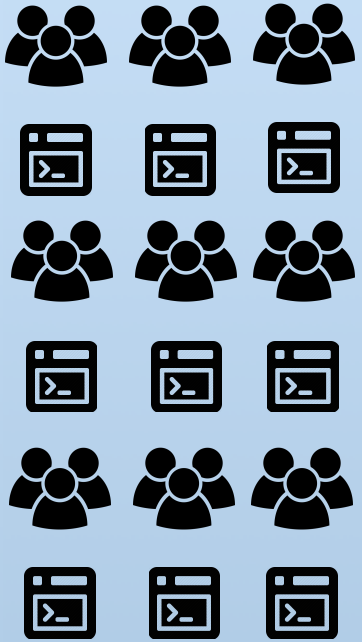
Failure report (core dump, stack trace, etc)

Server

Failure Sketch Computation Engine

Static Analyzer

Client

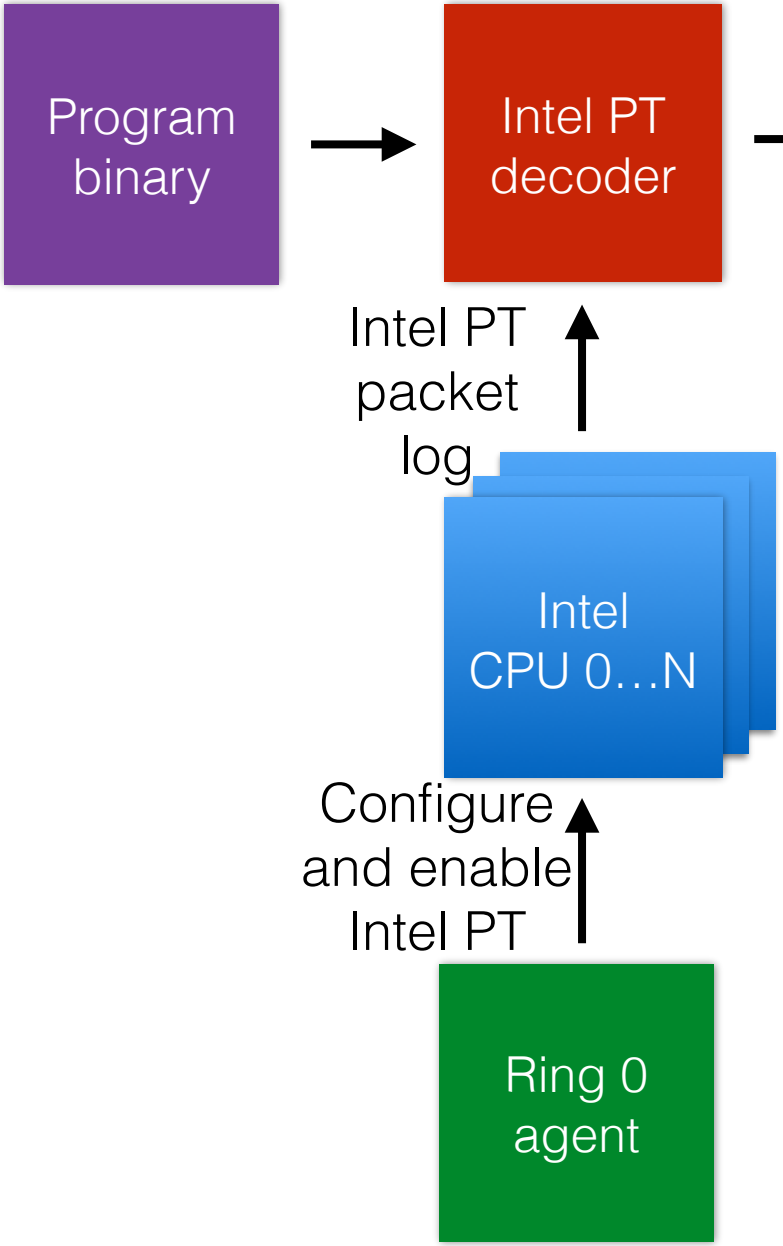


Refinement with runtime traces

Instrumentation

1 2 3 4

Intel Processor Trace (Intel PT)



Control flow information

- Compressed trace of branches taken (~1 bit per instruction)
- Low overhead (~40% **full** tracing overhead)

Tracking Control Flow Using Intel PT

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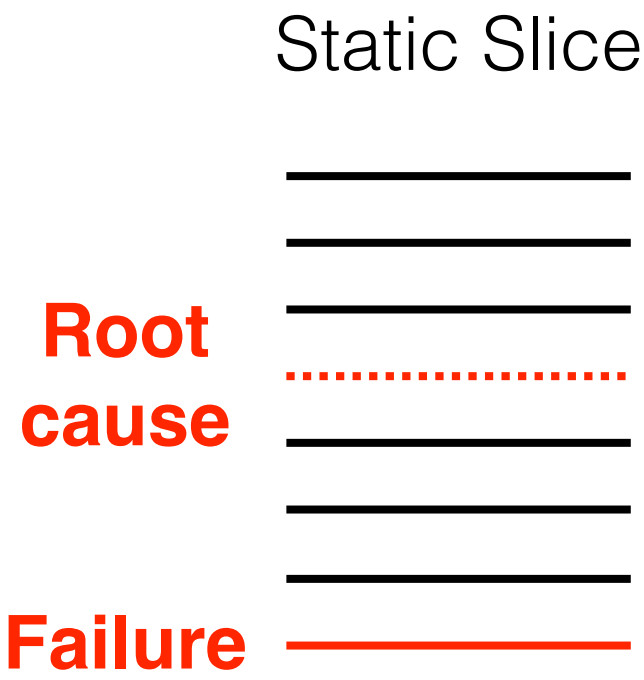

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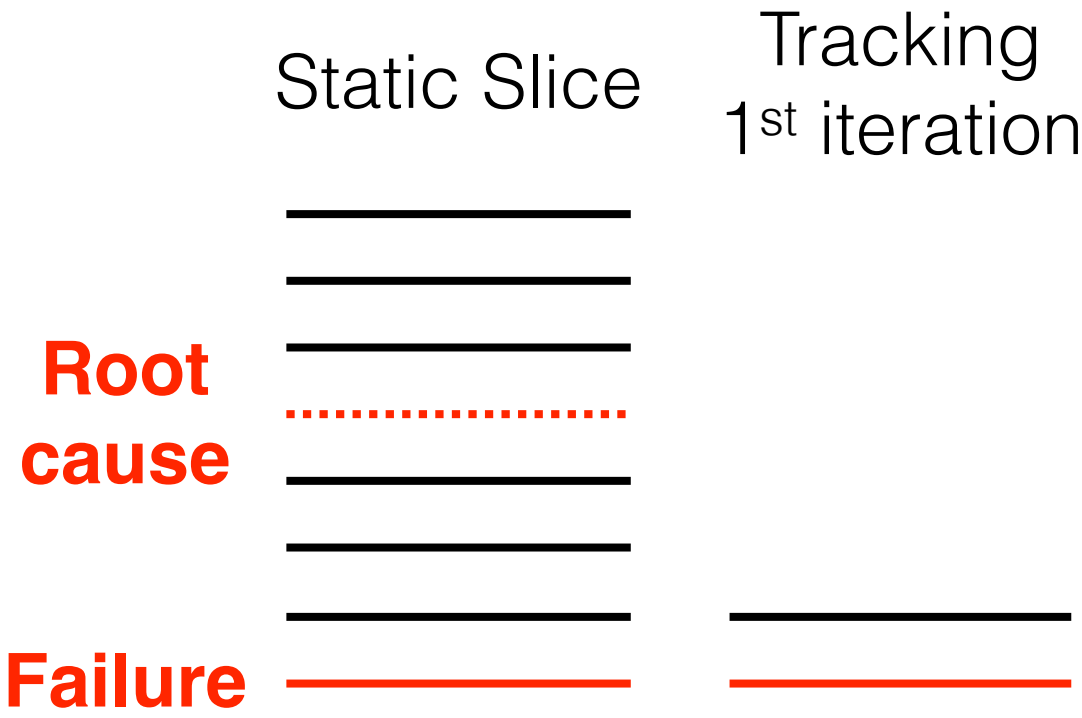

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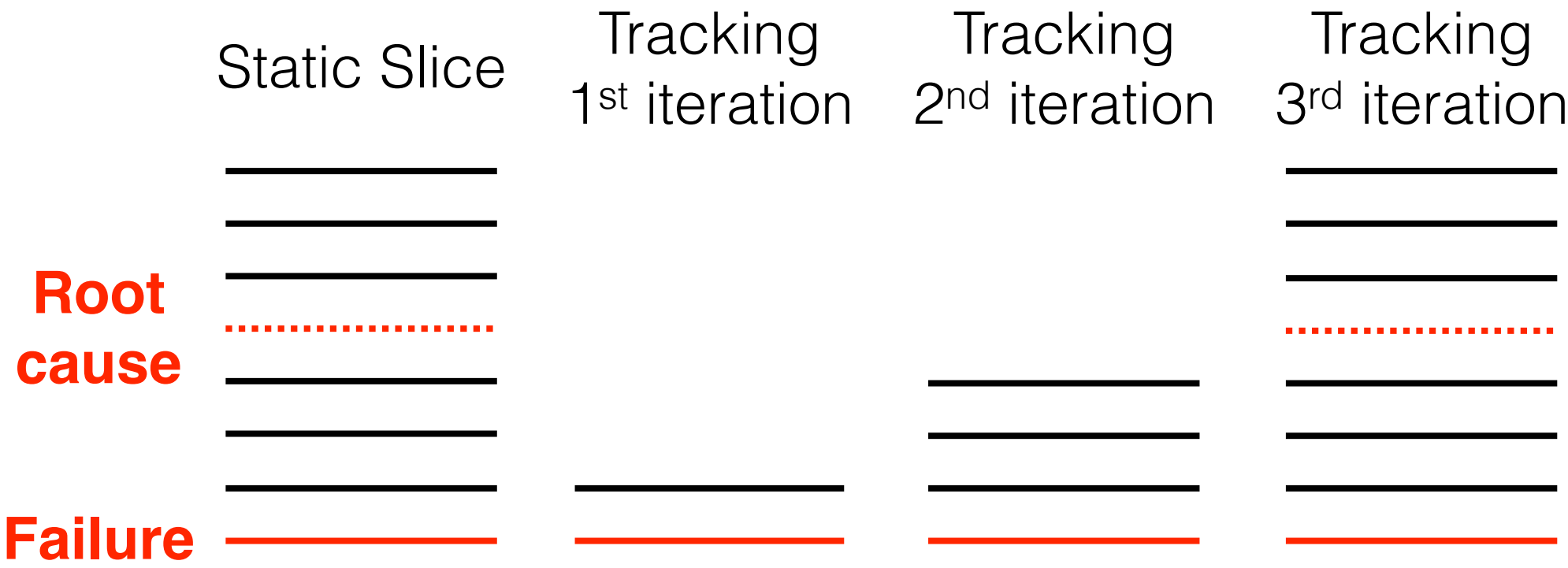

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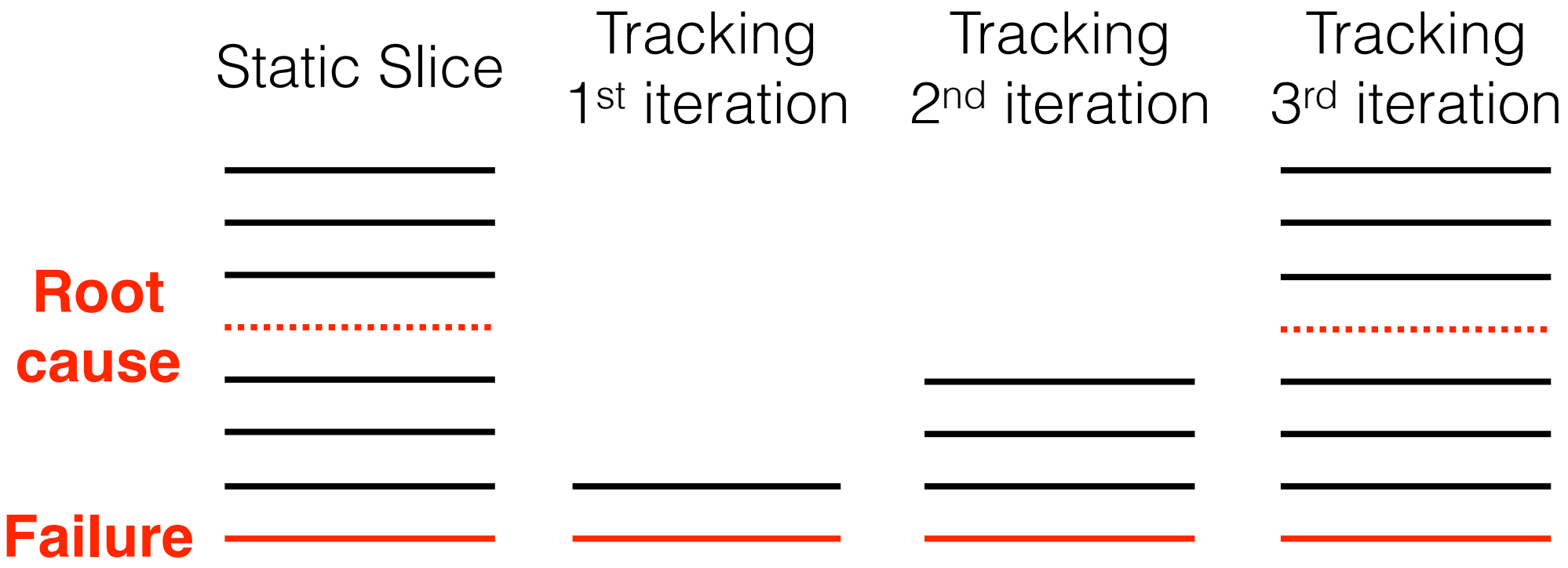


Monitoring small portions of a slice works well because most failures have nearby root causes[1,2]

[1]W. Zhang et al., ConSeq: Detecting concurrency bugs through sequential errors. ASPLOS 2011

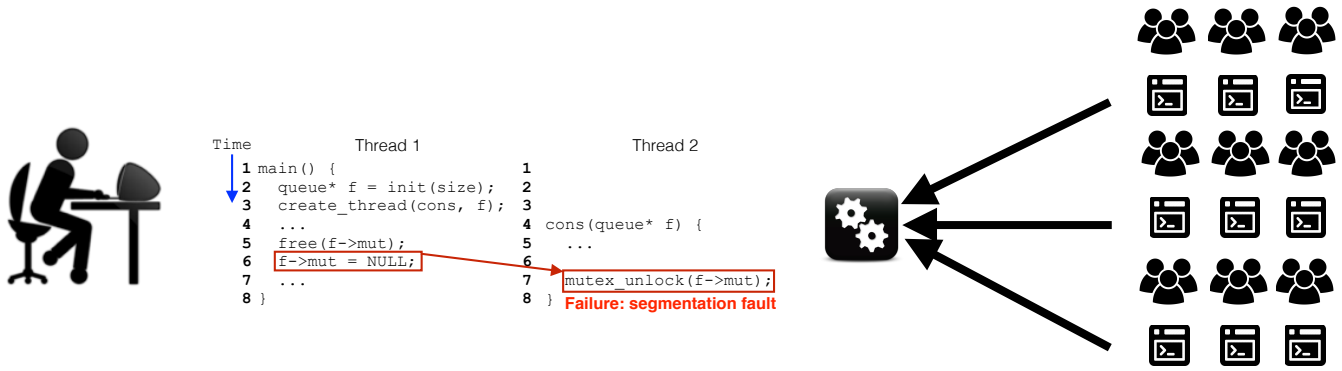
[2]F. Qin et al., Rx: Treating bugs as allergies a safe method to survive software failures. SOSP 2005

Discussion

- Intrusiveness
  - Currently, we do static instrumentation
  - Dynamic instrumentation is less intrusive
- Privacy
  - Use anonymization
  - Forgo data monitoring when privacy requirements are very strict

Future Work

- Diagnosing performance problems
  - Correlating control flow with slowdowns
- Speeding up program analysis
  - Use control flow information to tackle path explosion
- Using failure sketches for test case generation



- Failure sketches
  - Summary explaining failure root causes
- Application of hardware-based monitoring
  - Enabler for building failure sketches
  - Many potential use cases