Failure Sketches:
A Better Way to Debug

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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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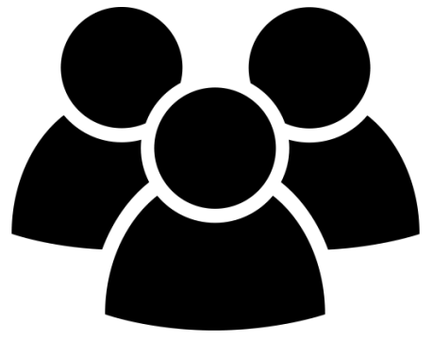

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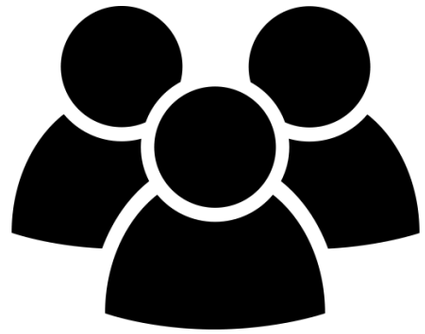

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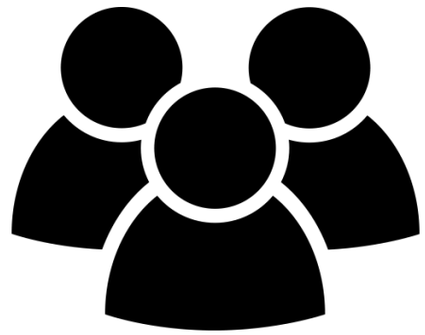

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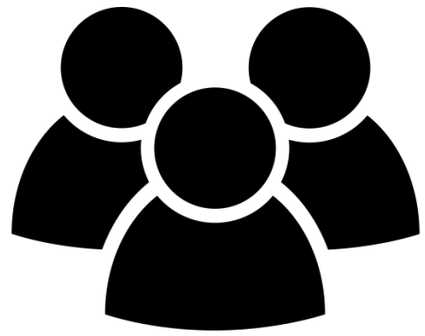

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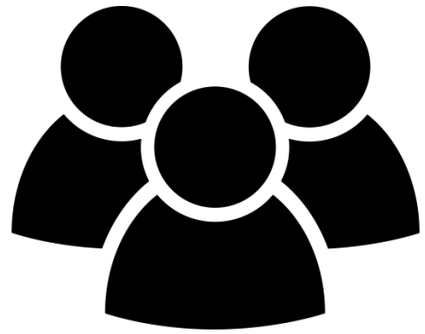

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Tackling the Debugging Challenge

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

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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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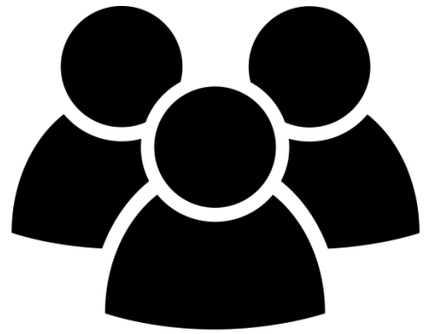

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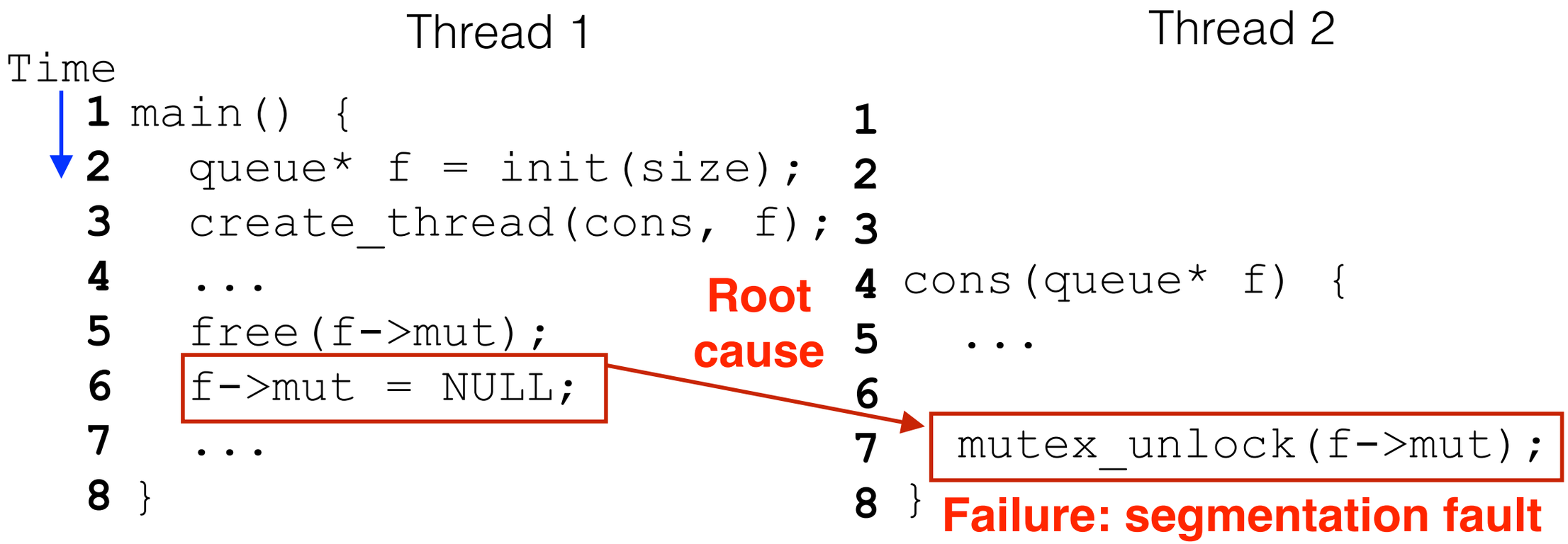

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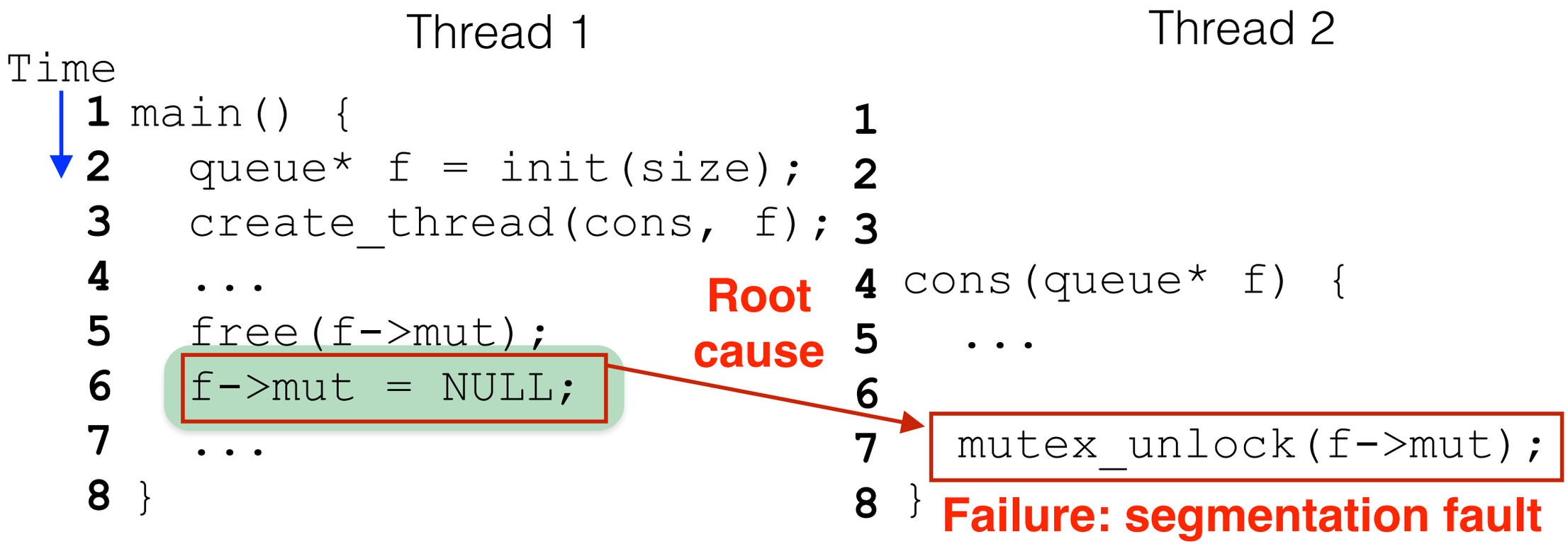

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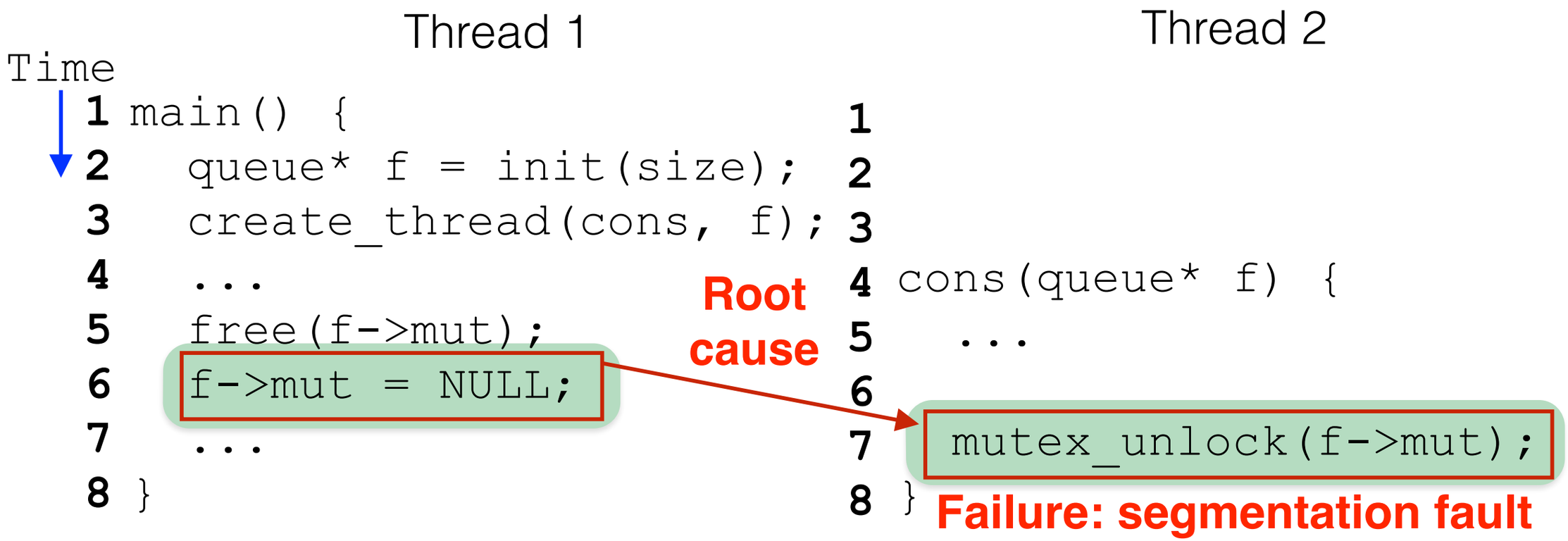

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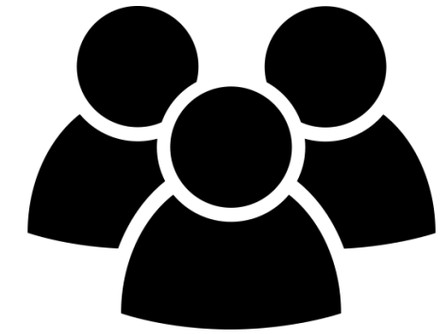

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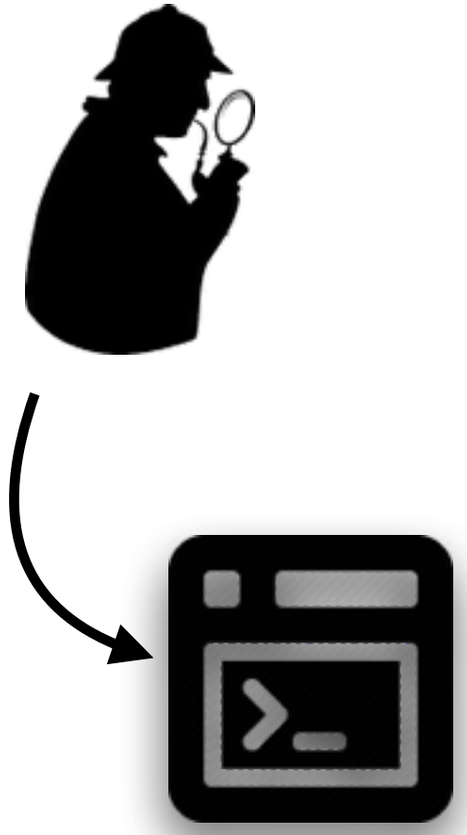

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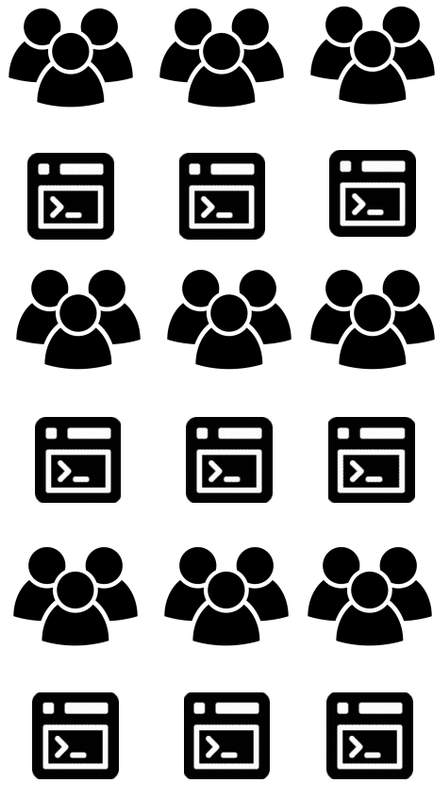

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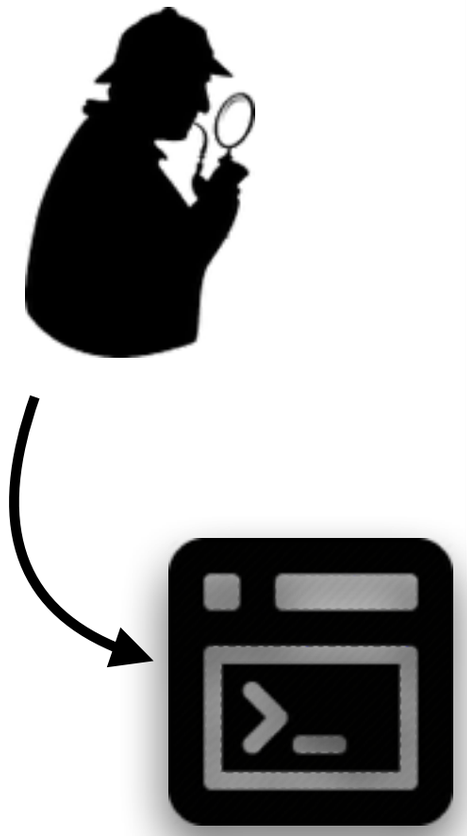
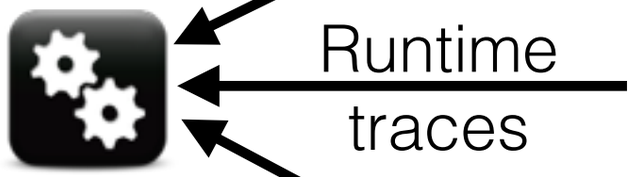
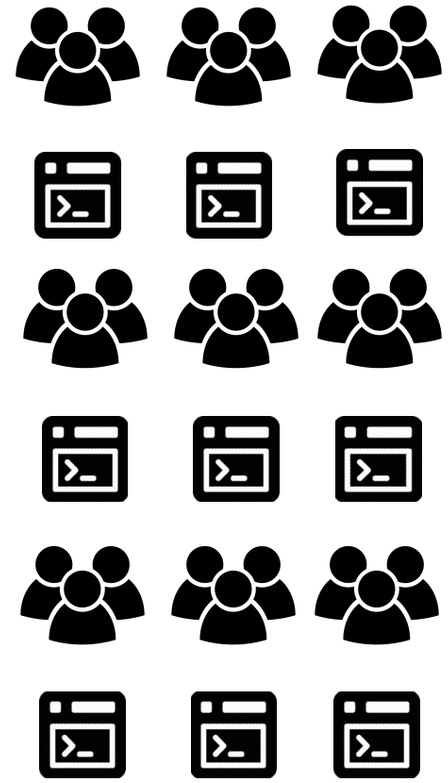


Reproduce the problem



Runtime traces



Failure Sketch Use Case

Understand root cause

Thread 1

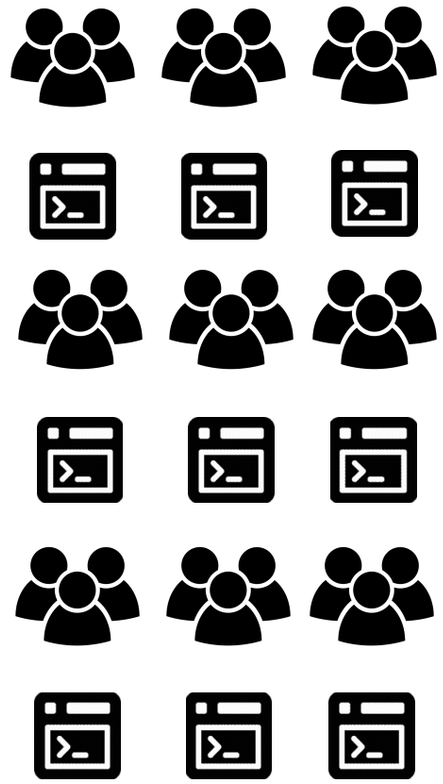
```
Time
  1 main() {
  2   queue* f = init(size);
  3   create_thread(cons, f);
  4   ...
  5   free(f->mut);
  6   f->mut = NULL;
  7   ...
  8 }
```

Thread 2

```
1
2
3
4 cons(queue* f) {
5   ...
6
7   mutex_unlock(f->mut);
8 }
```

Failure: segmentation fault

Runtime traces



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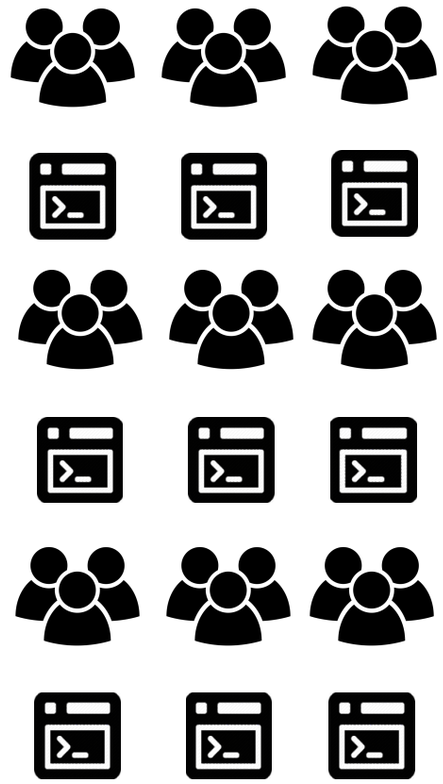

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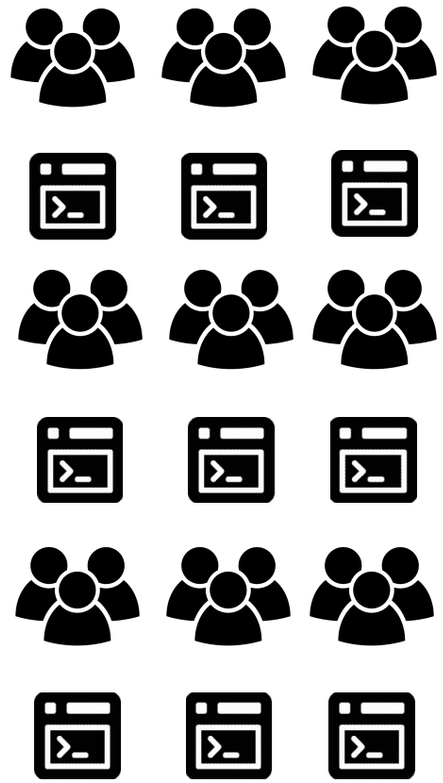

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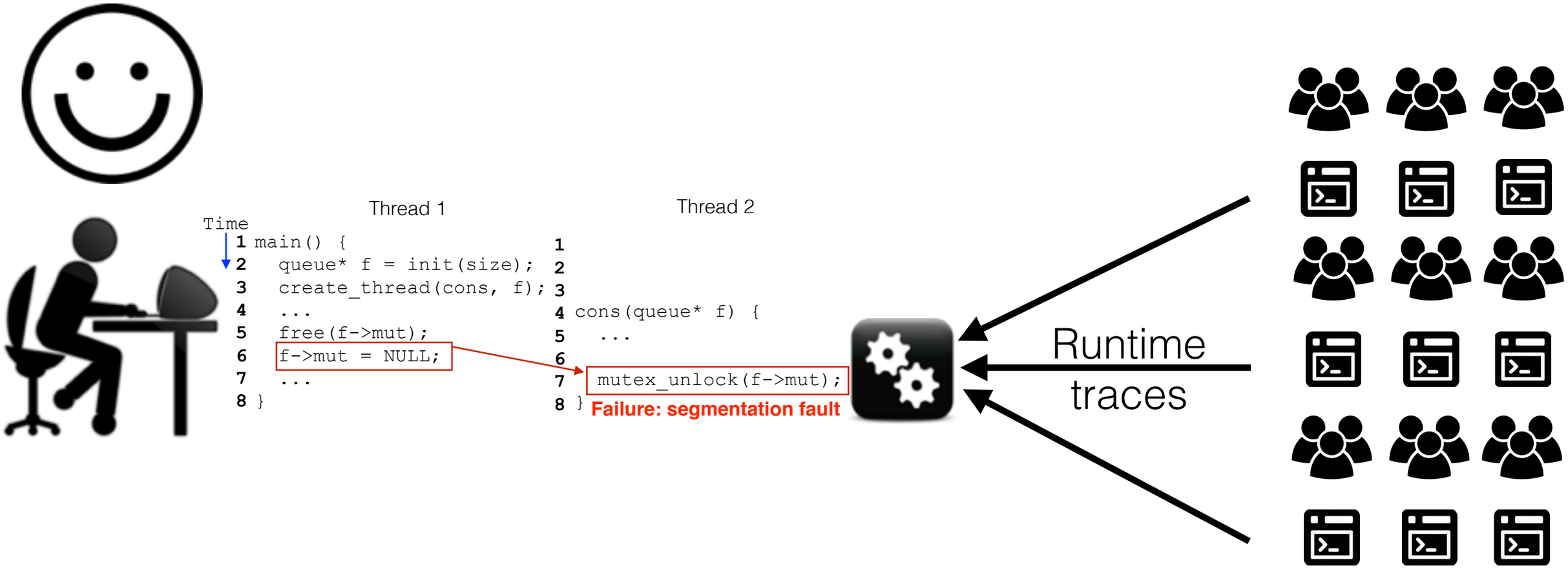
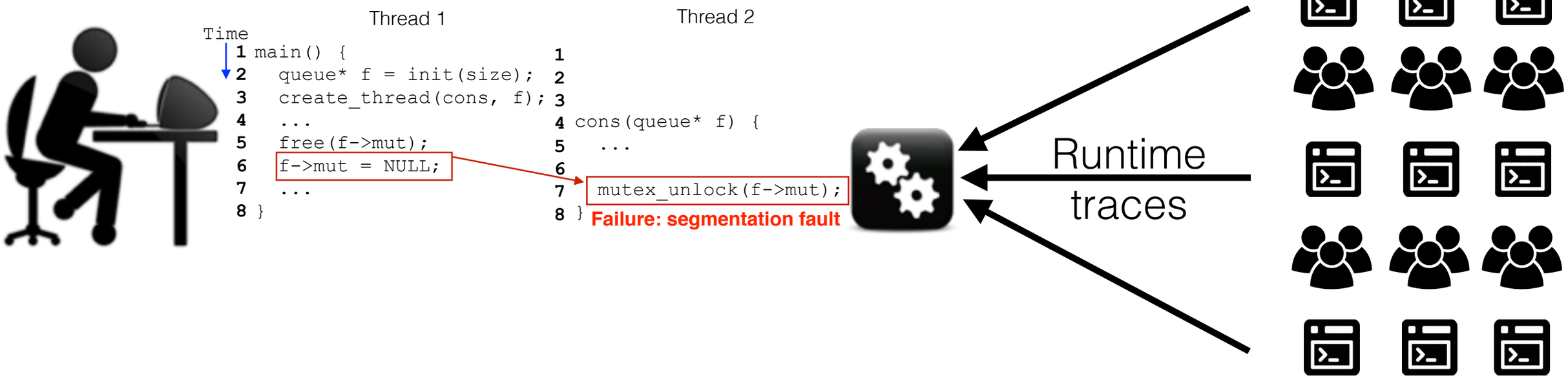


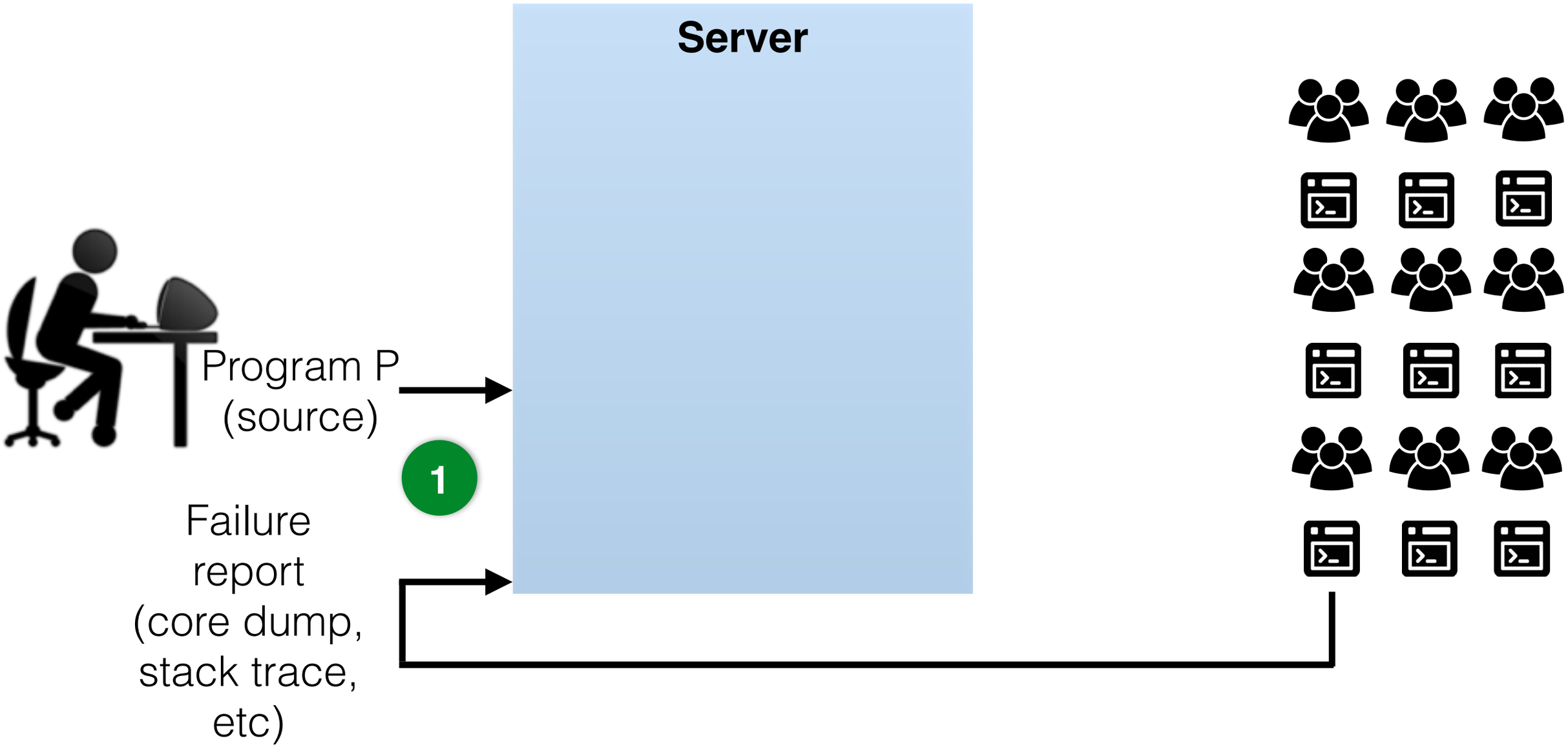
Research Challenges

- 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

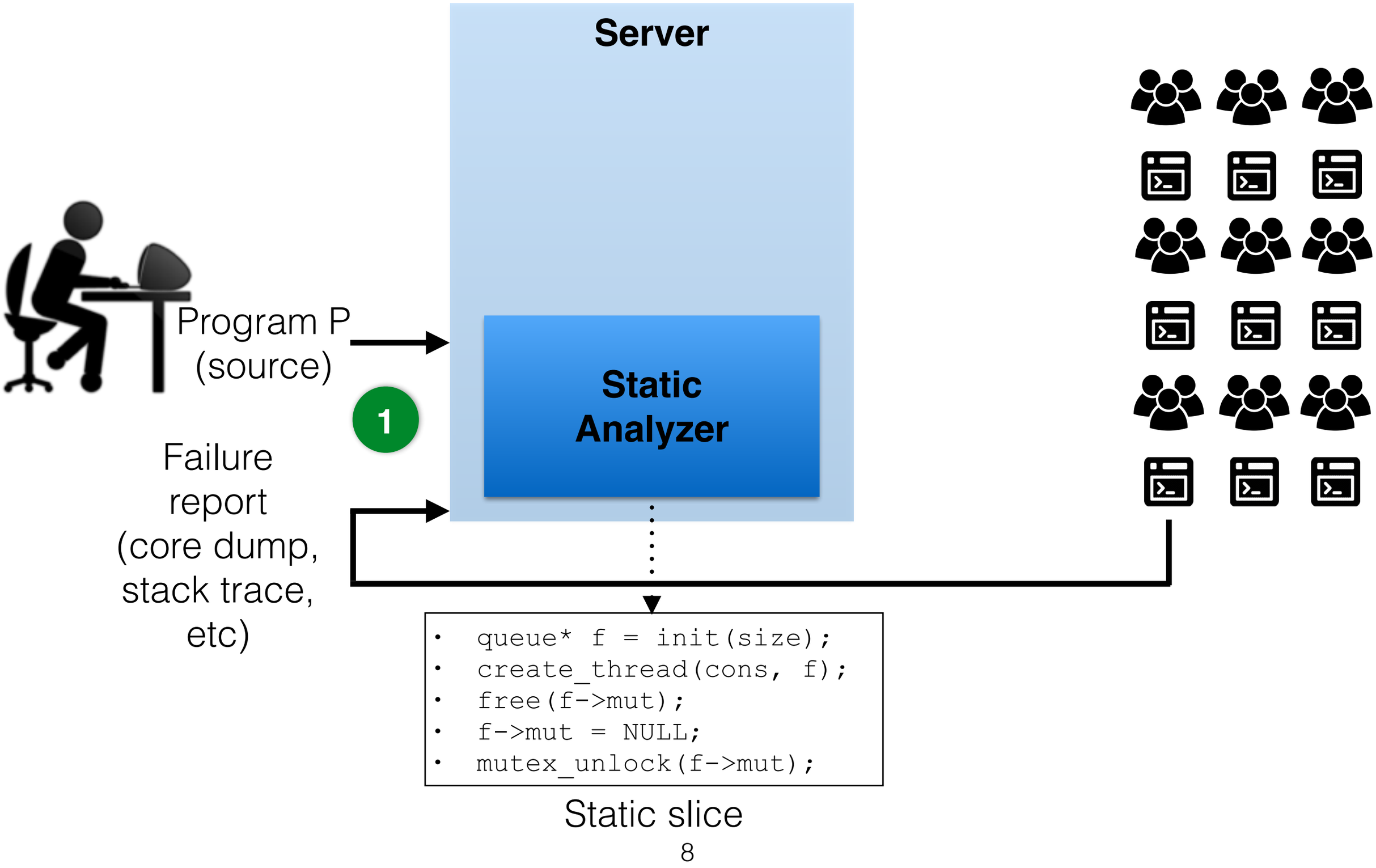
System Architecture



System Architecture



System Architecture



System Architecture

Tracking control and data flow

Program P (source)

1

Failure report (core dump, stack trace, etc)

Server

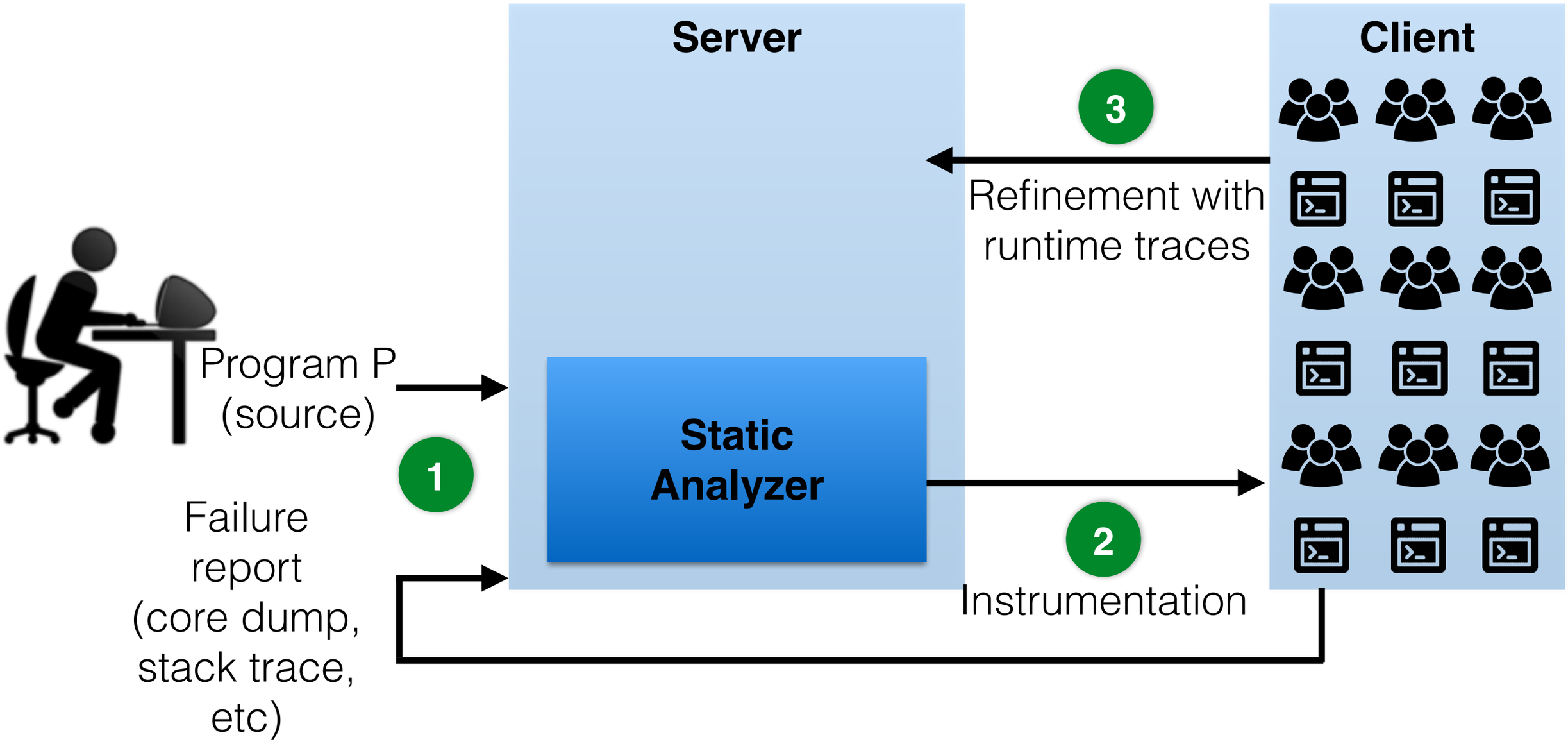
Static Analyzer

2

Instrumentation

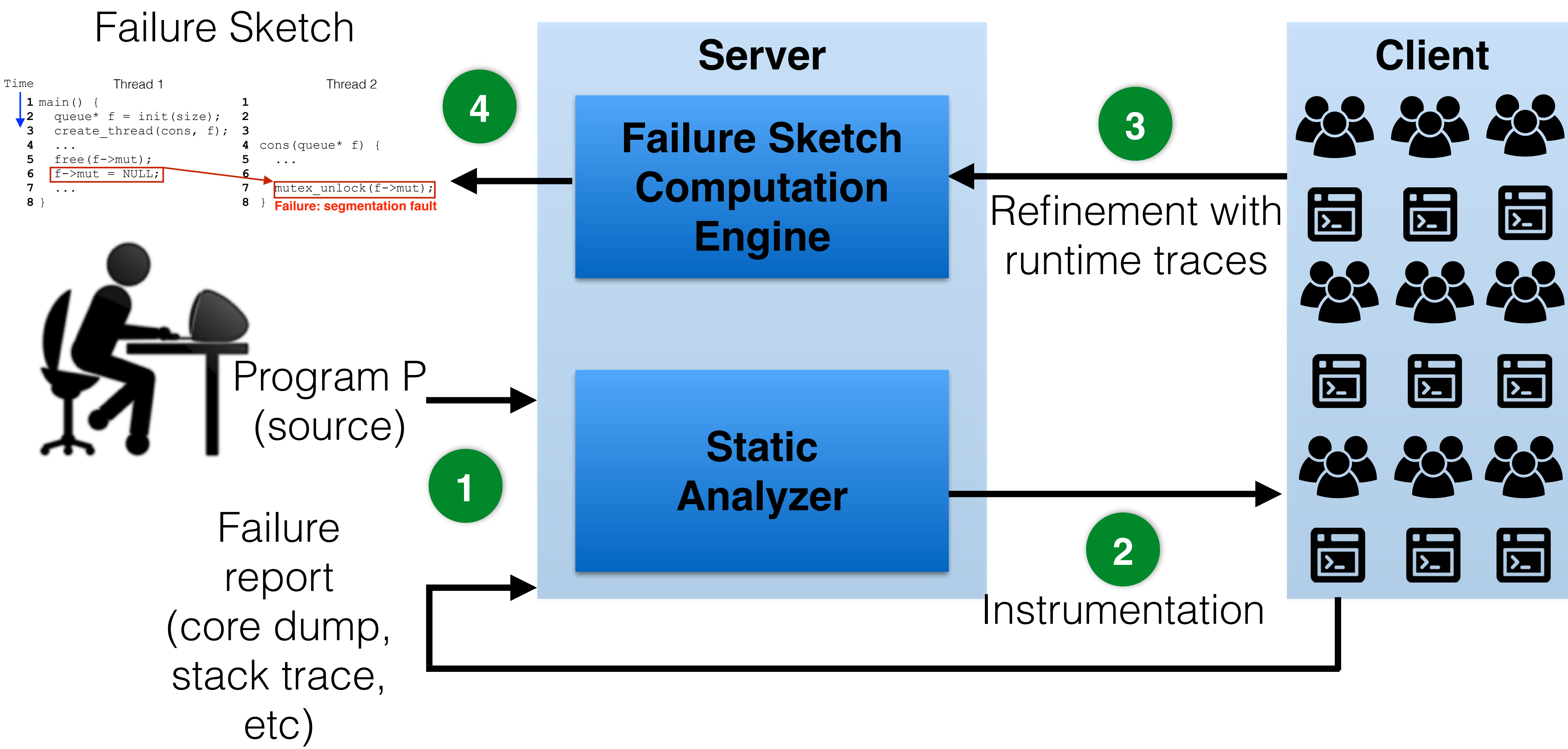
Client

System Architecture

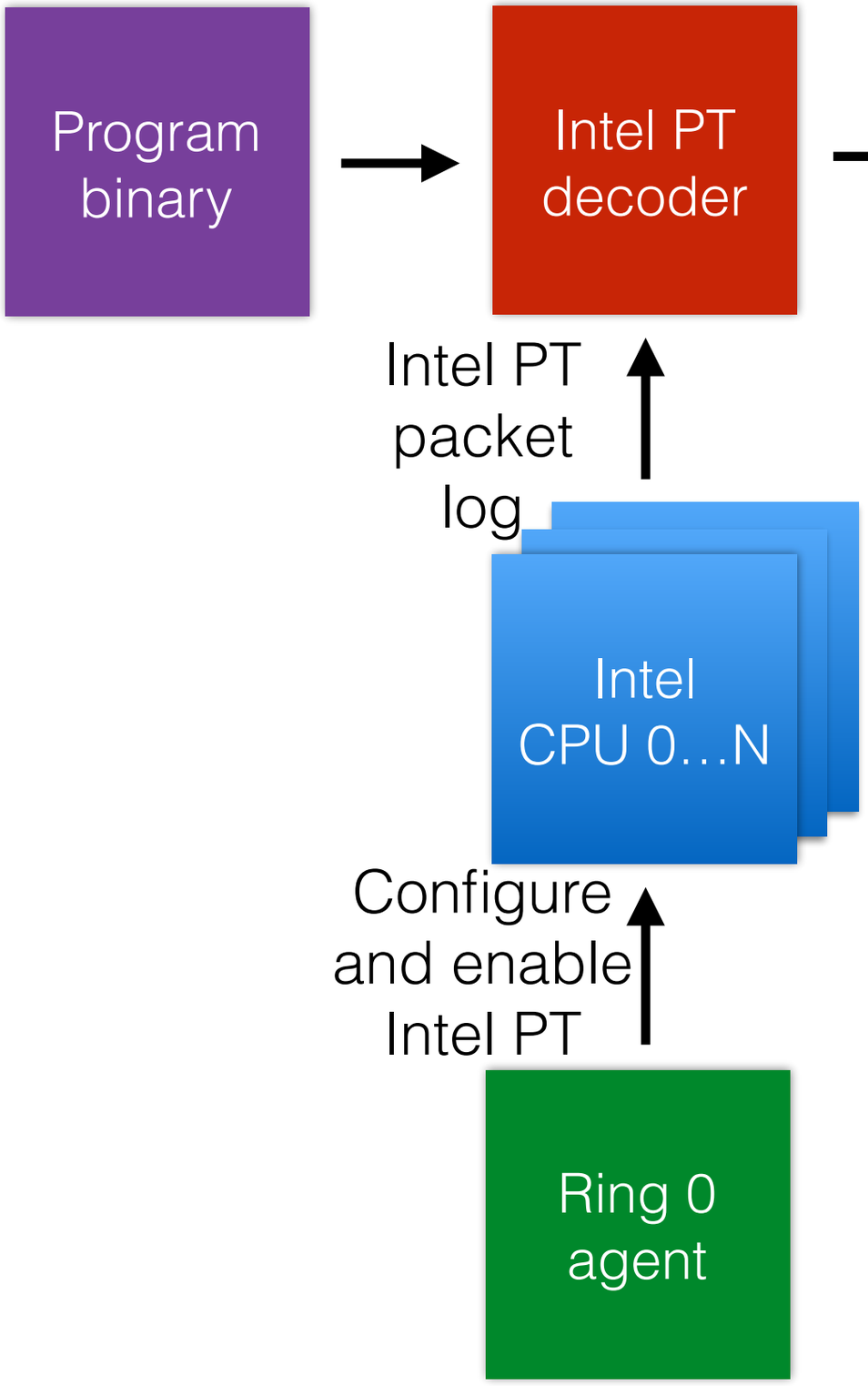


System Architecture

Tracking control and data flow



Intel Processor Trace (Intel PT)



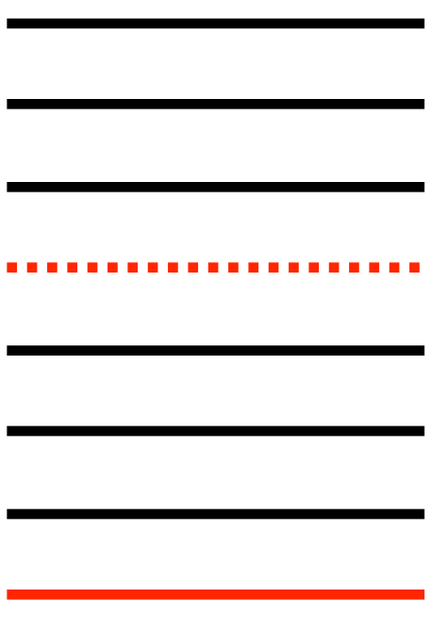
Control flow information

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

Tracking Control Flow Using Intel PT

Tracking Control Flow Using Intel PT

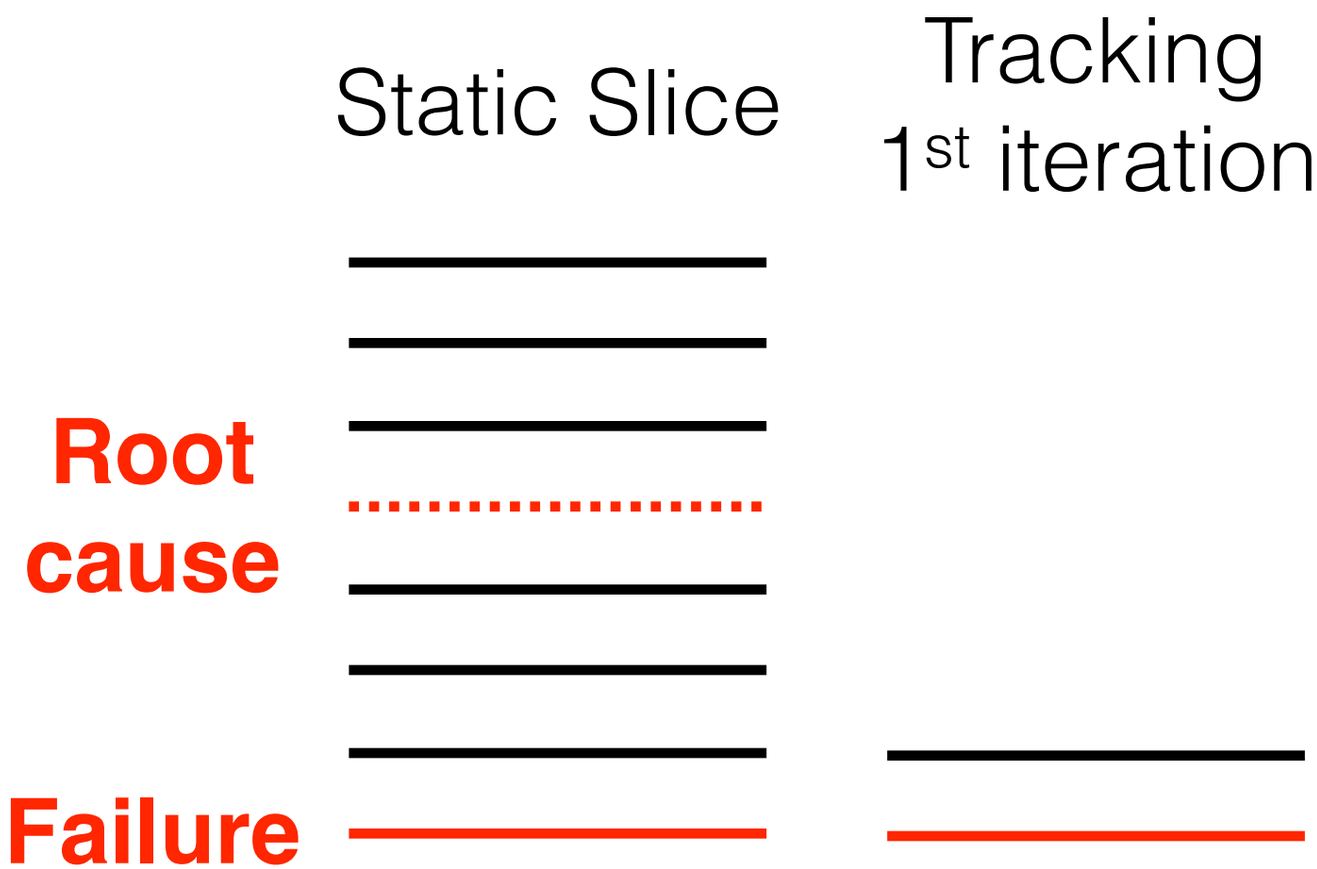
Static Slice



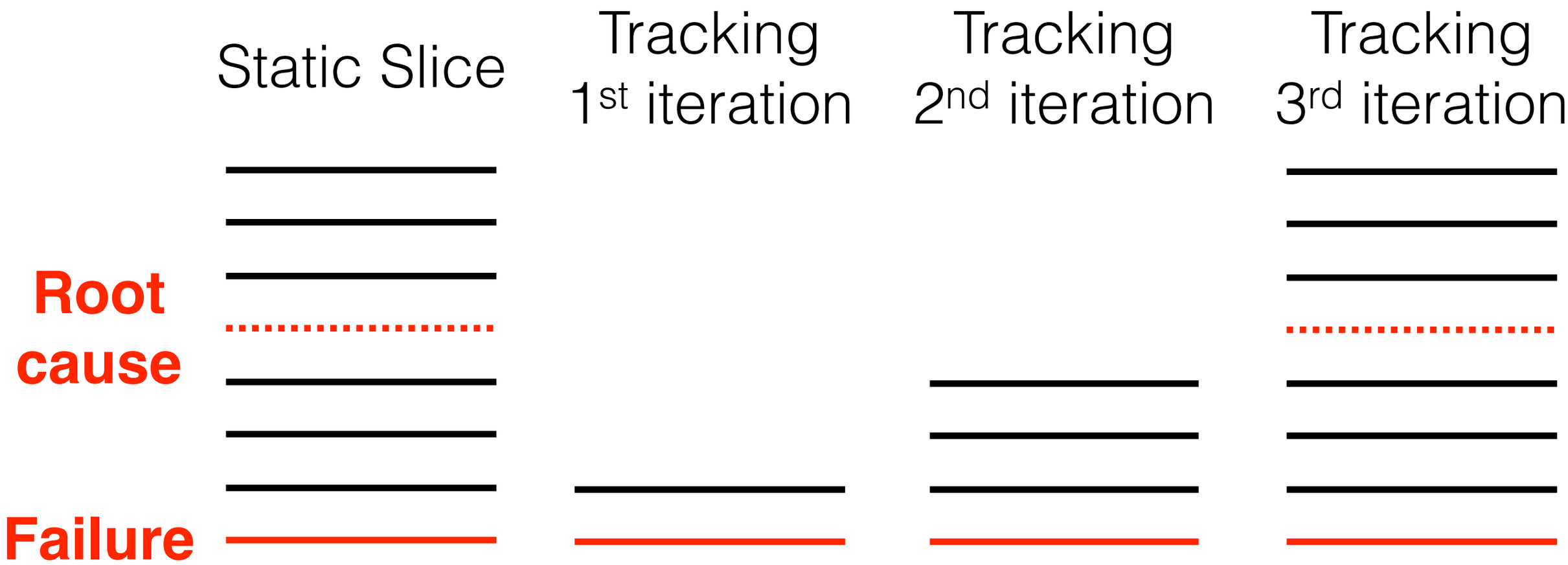
Root cause

Failure

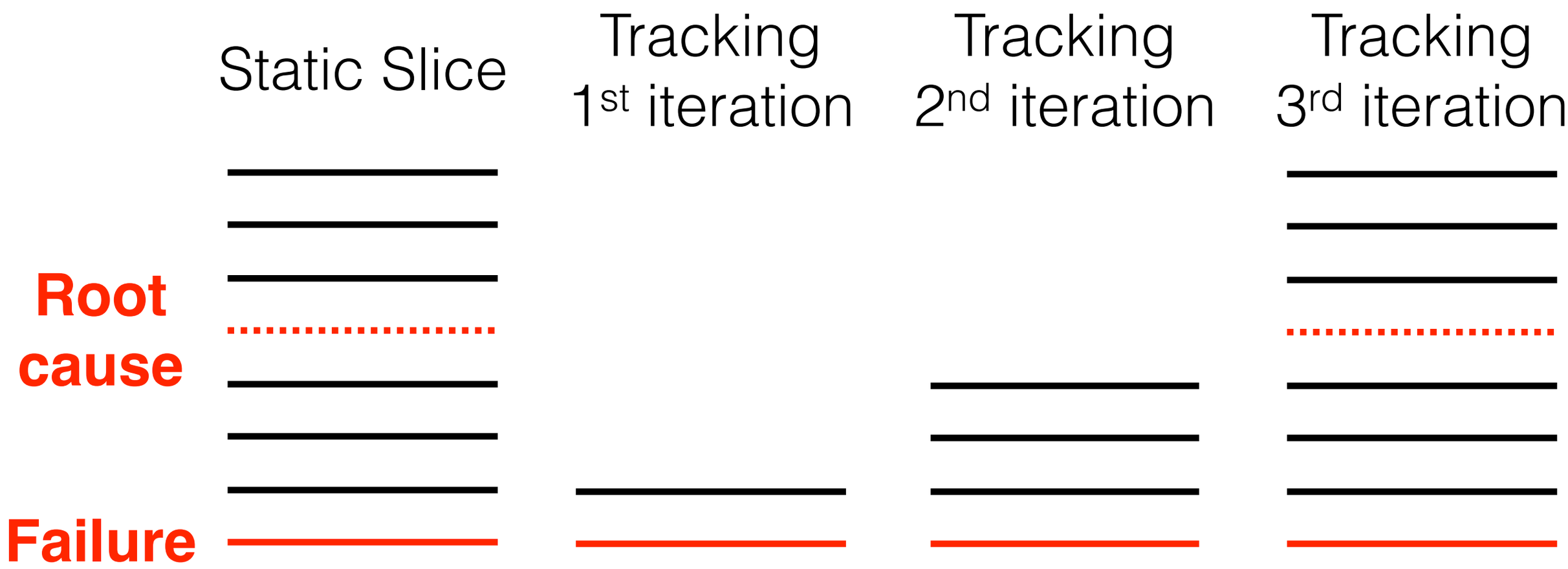
Tracking Control Flow Using Intel PT



Tracking Control Flow Using Intel PT



Tracking Control Flow Using Intel PT



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

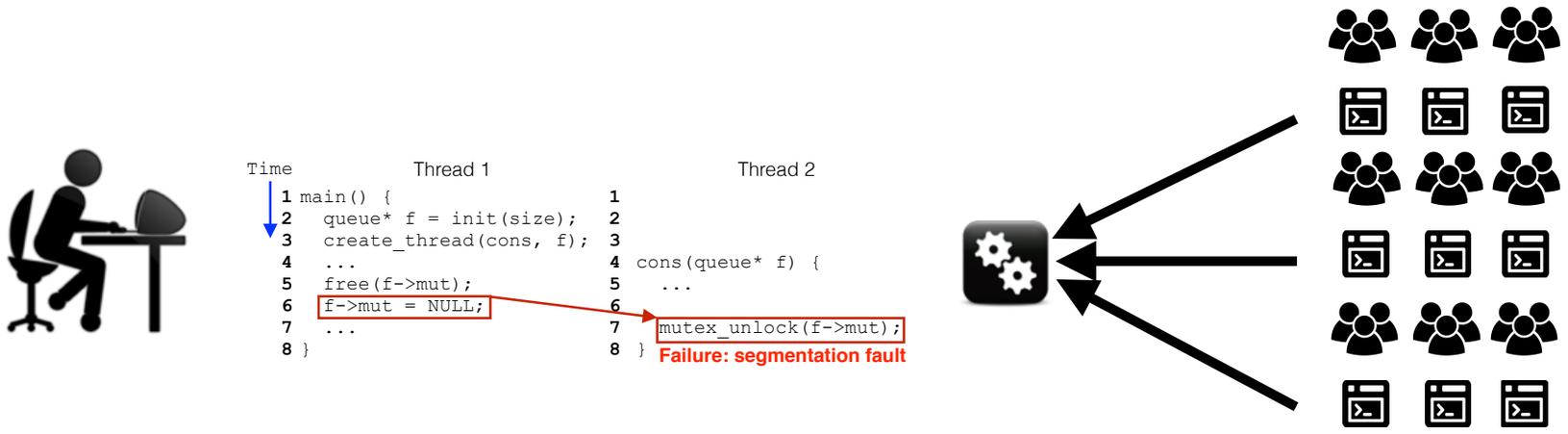
[2]F. Qin et al., Rx: Treating bugs as allergies a safe method to survive software failures. SOSP 2005

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