RaceMob: Crowdsourced Data Race Detection

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Data Races

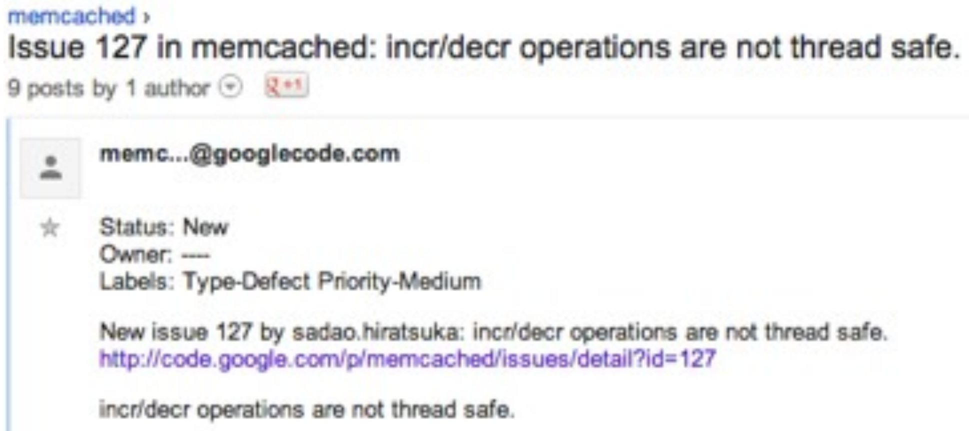
- Accesses to shared memory location
  - *By multiple threads*
  - *At least one of the accesses is a write*
  - *Synchronization operations do not enforce an order among the accesses*

`shared x`

Thread 1	**Thread 2**
`x = 1`	`x = 2`

Spectrum of Data Races

Kept for performance



memcached ›

Issue 127 in memcached: incr/decr operations are not thread safe.

9 posts by 1 author

memc...@googlecode.com

Status: New
Owner: ----
Labels: Type-Defect Priority-Medium

New issue 127 by sadao.hiratsuka: incr/decr operations are not thread safe.
http://code.google.com/p/memcached/issues/detail?id=127

incr/decr operations are not thread safe.

???

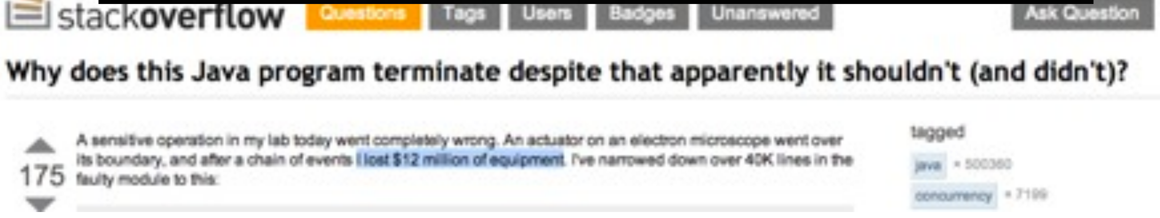
Caused massive losses

An Investigation of the Therac-25 Accidents

Nancy
Clark

Reprint

2003 Blackout



Why does this Java program terminate despite that apparently it shouldn't (and didn't)?

175

A sensitive operation in my lab today went completely wrong. An actuator on an electron microscope went over its boundary, and after a chain of events I lost $12 million of equipment. I've narrowed down over 40K lines in the faulty module to this:

tagged

java × 500360

concurrency × 7199

Pitfalls

- Programs with data races are incorrect according to POSIX & C/C++ standards
- Compilers can break correctness of programs with data races [HotPar'11]
    - *Harmless data races can become harmful*

Developers need to know every true data race

How to Find All Data Races?

- Static race detectors
  - ***Full path analysis*** ✓
  - ***Cheap*** *(0 runtime overhead)*✓
  - ***Few false negatives*** ✓
  - ***Many false positives*** *(~80%)*✗

- Dynamic race detectors
  - ***Per-run analysis*** ✗
  - ***Expensive*** *(≤ 200x)*✗
  - ***Many false negatives*** ✗
  - ***Few false positives*** *(~0%)* ✓

Existing detectors are not practical

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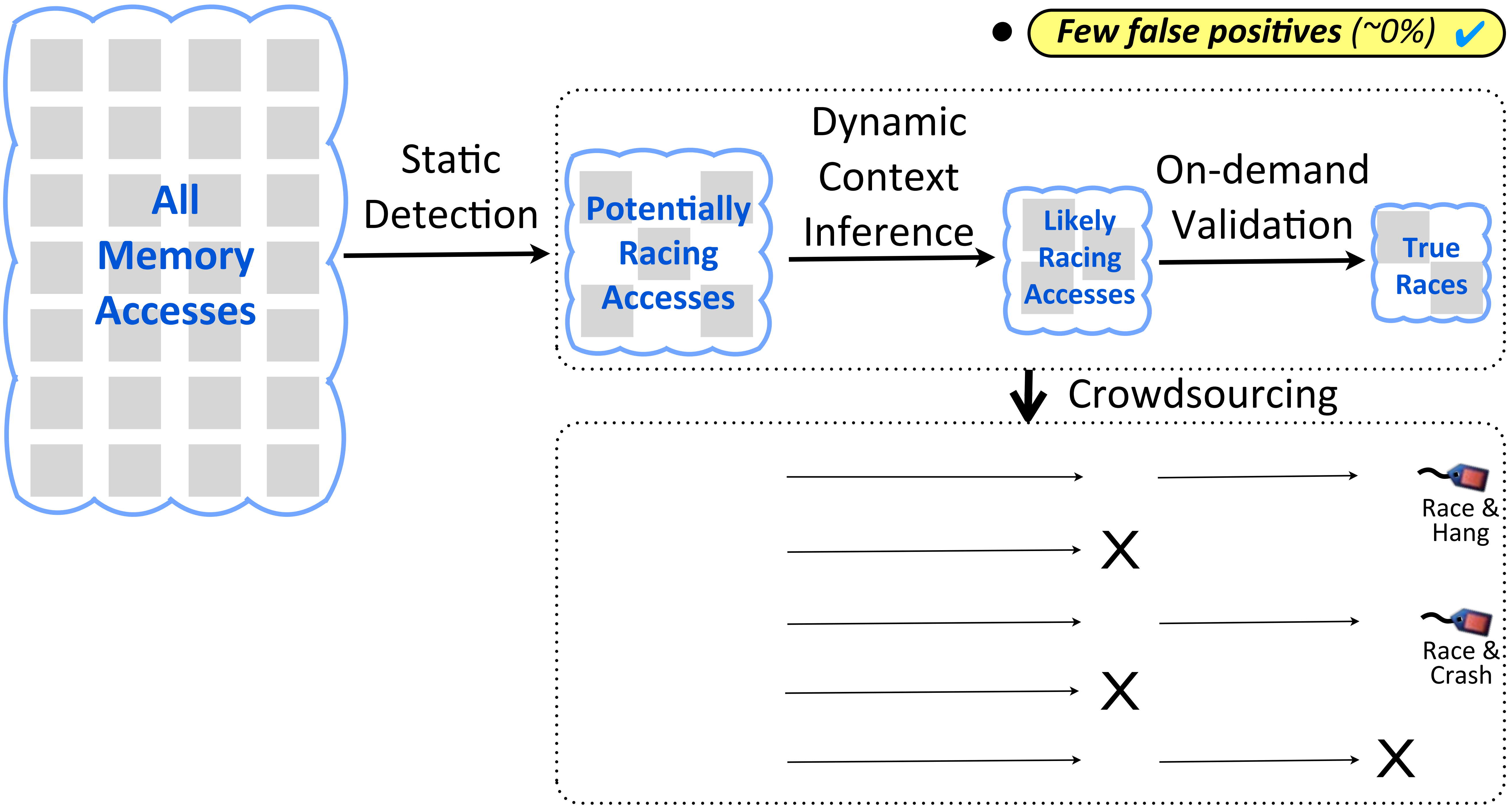
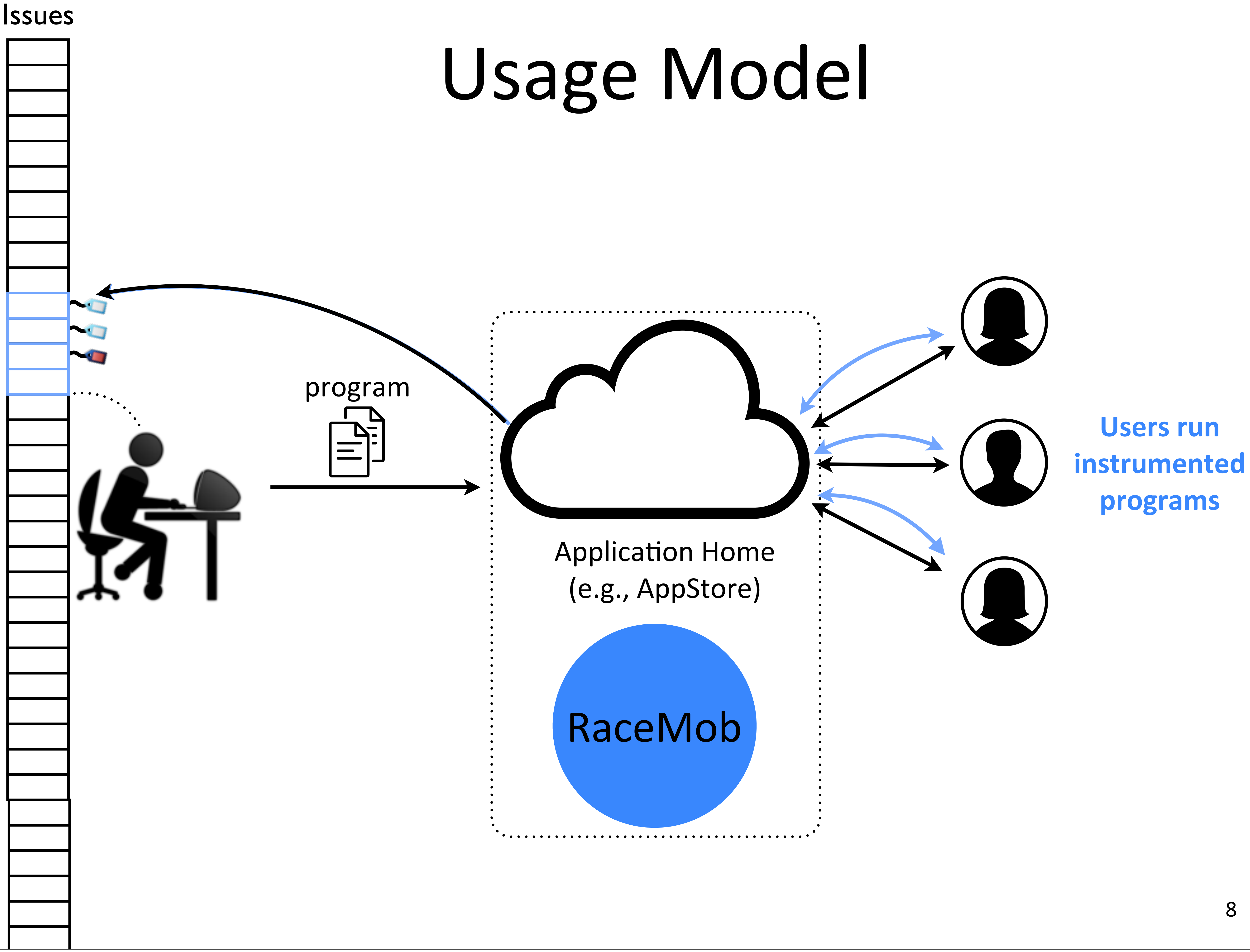
- ***Few false positives** (~0%)* ✓



Usage Model



Issues

program

Application Home
(e.g., AppStore)

RaceMob

Users run instrumented programs

Insights

- Use static race detection to prune memory accesses that need not be monitored
- Cost of dynamic detection can be amortized across many users
- Using the crowd, we can detect races that ”matter”

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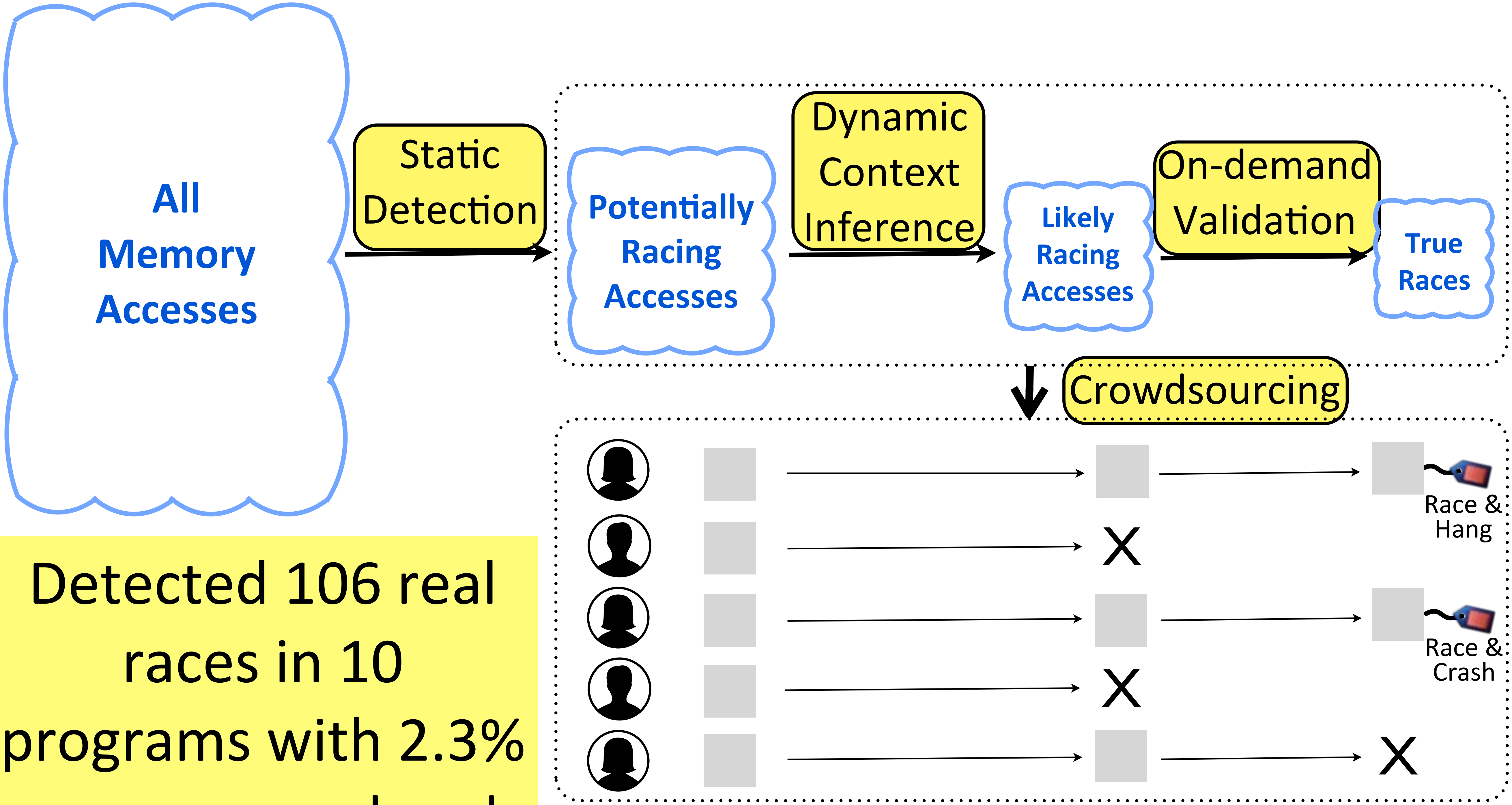


All Memory Accesses

Static Detection

Potentially Racing Accesses

Dynamic Context Inference

Likely Racing Accesses

On-demand Validation

True Races

Crowdsourcing

Race & Hang

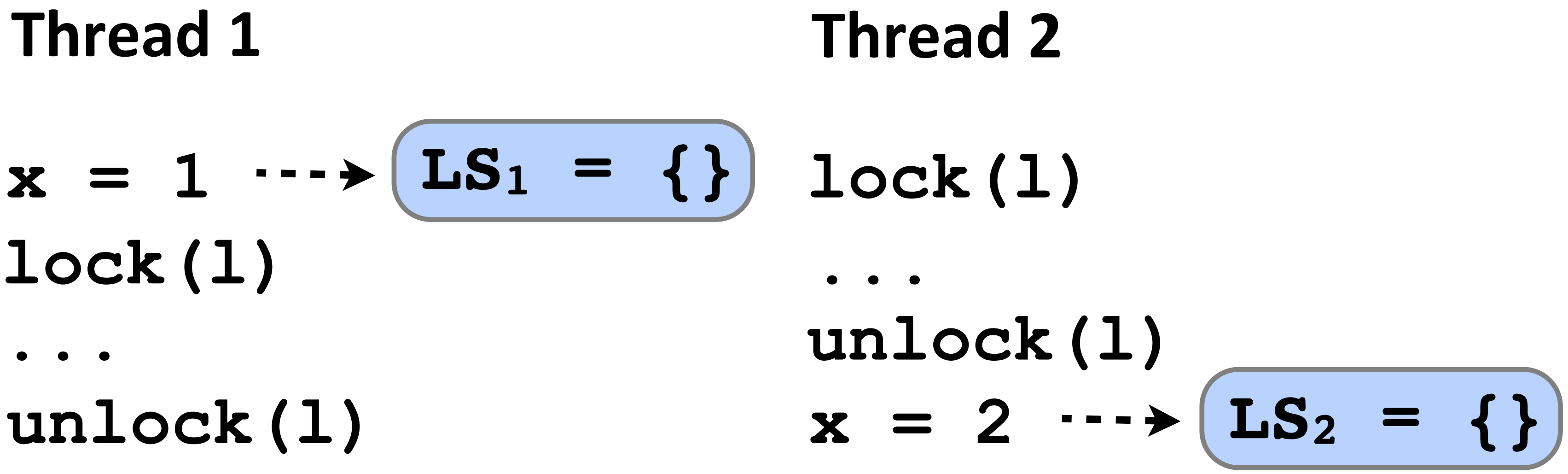
Race & Crash

Detected 106 real races in 10 programs with 2.3% average overhead

Static Data Race Detection

- We use RELAY [FSE’07]
  - *Analyzes entire program paths at once*
  - *Computes & composes per-function summaries to scale*
  - *Tracks locks*

Example



Thread 1

```
x = 1 ---> LS1 = {}
lock(l)
...
unlock(l)
```

Thread 2

```
lock(l)
...
unlock(l)
x = 2 ---> LS2 = {}
```

x = 1 and x = 2 are potentially racing

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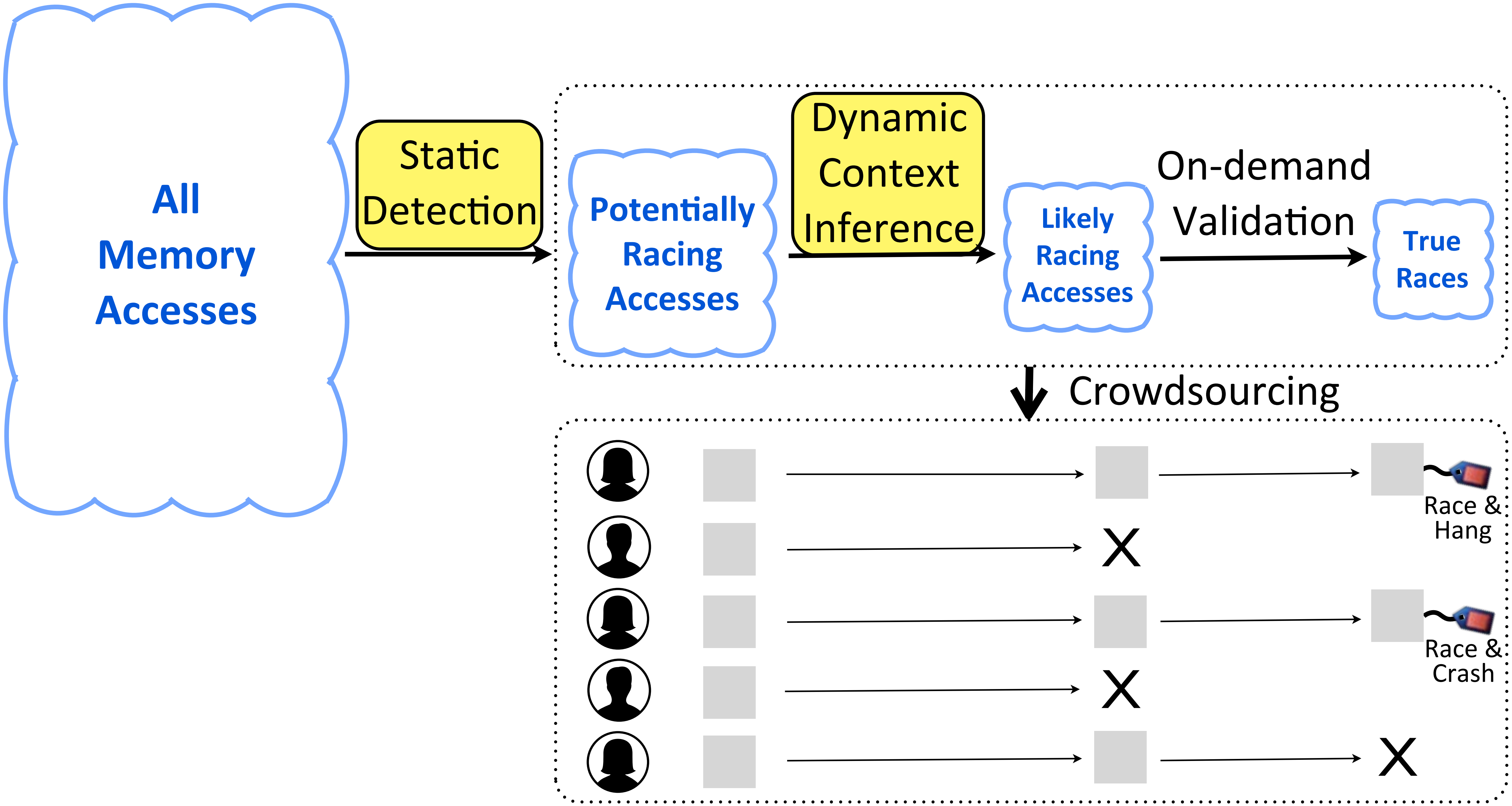

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Dynamic Context Inference (DCI)

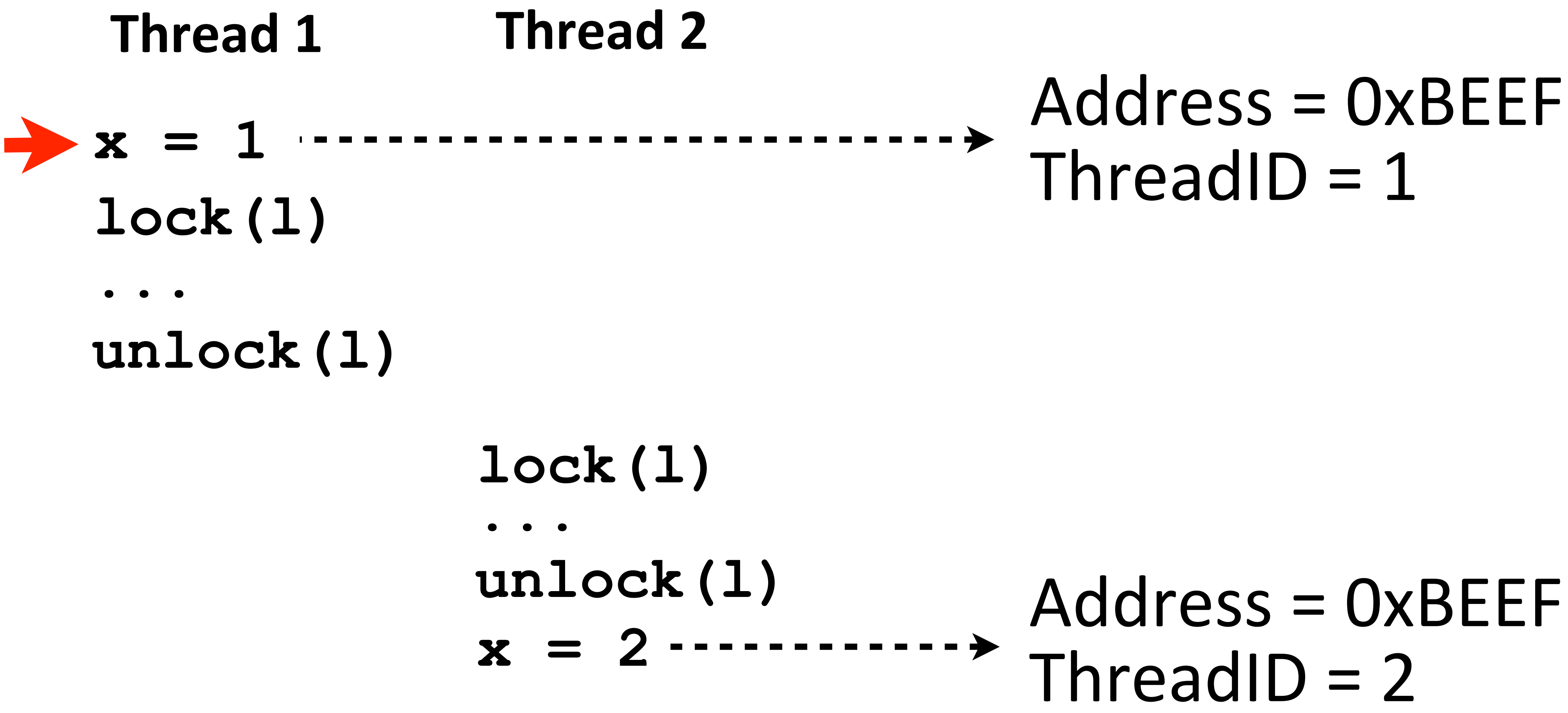
- Inaccuracy in static data race detection
  - *Pointer alias analysis errors*
  - *Inability to infer multithreaded program context*
- DCI checks at runtime:
  - *If accesses are from different threads*
  - *If accesses alias*

} If yes, accesses are likely racing

Dynamic context inference reduced the set of accesses to monitor by 53%

DCI Example

Alice



Thread 1 **Thread 2**

```
x = 1
lock(l)
...
unlock(l)
```

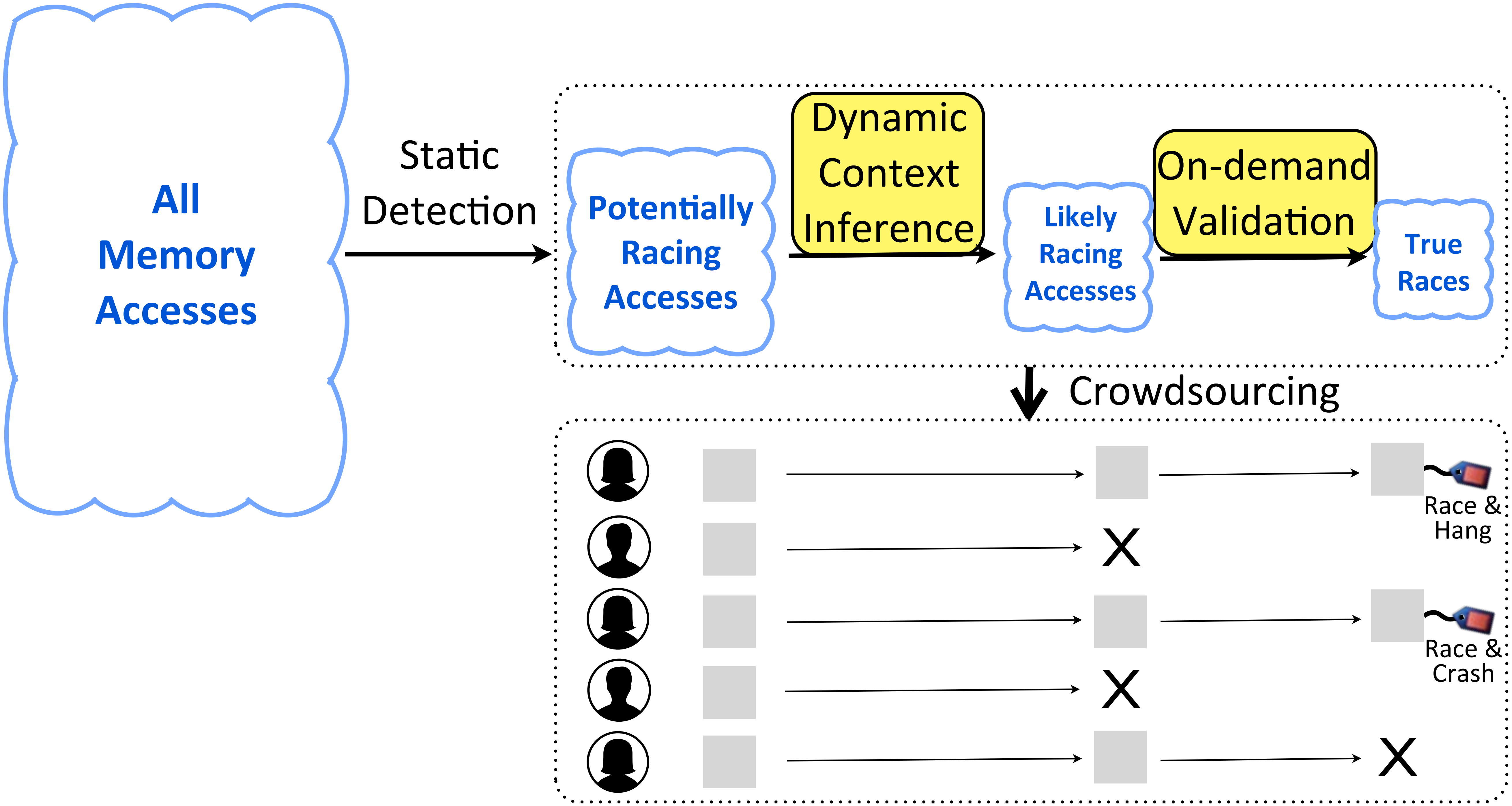
Address = 0xBEEF
ThreadID = 1

```
lock(l)
...
unlock(l)
x = 2
```

Address = 0xBEEF
ThreadID = 2

Proceed to on-demand data race validation

RaceMob


All Memory Accesses
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Crowdsourcing
X
X
X
Race & Hang
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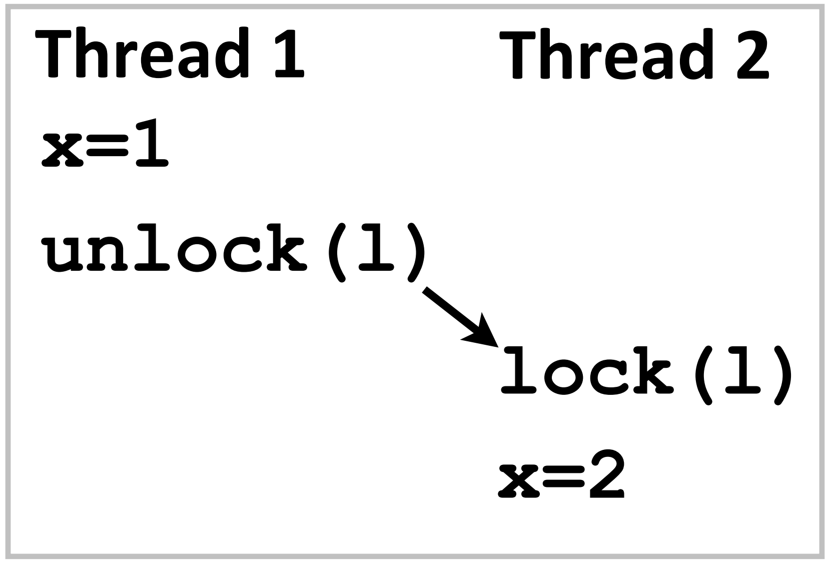
On-demand Data Race Validation

- Happens-before based
  - *Track synchronization*
  - *Few false positives*
- Minimal tracking
  - *Only memory accesses of the target data race*
  - *Synchronization in between these accesses*
    - Until enough happens-before edges form
- Steers thread schedule to expose races



On-demand Validation Example

Alice

```
Thread 1          Thread 2

x = 1
lock(l)
...
unlock(l)   HB
                  lock(l)
                  ...
                  unlock(l)
                  x = 2
```

No Race

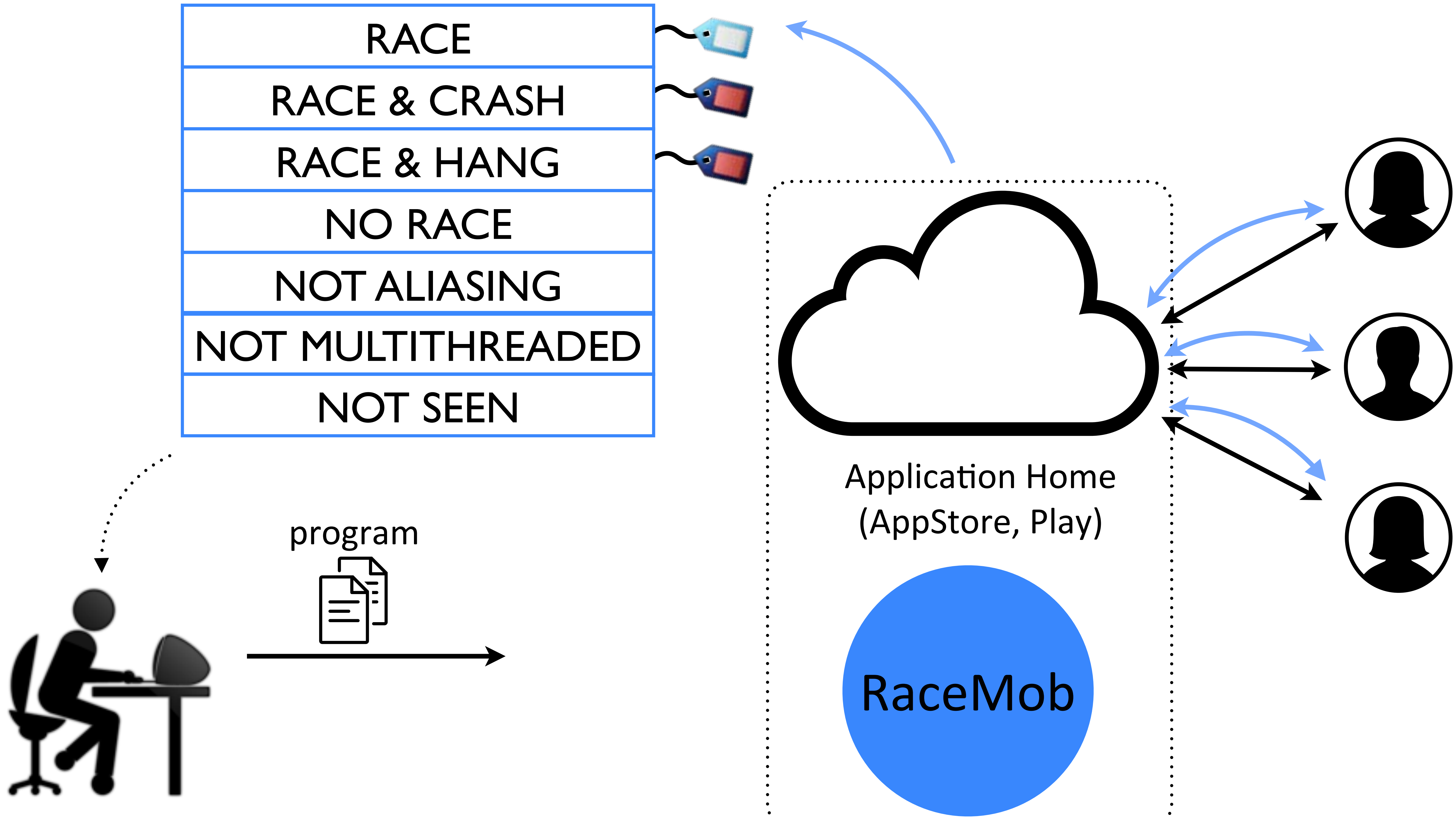
Bob

```
Thread 1          Thread 2

x = 1             lock(l)
                  ...
                  unlock(l)
     No HB        x = 2
x = 1
lock(l)
...
unlock(l)
```

Race

Detection Results



RACE

RACE & CRASH

RACE & HANG

NO RACE

NOT ALIASING

NOT MULTITHREADED

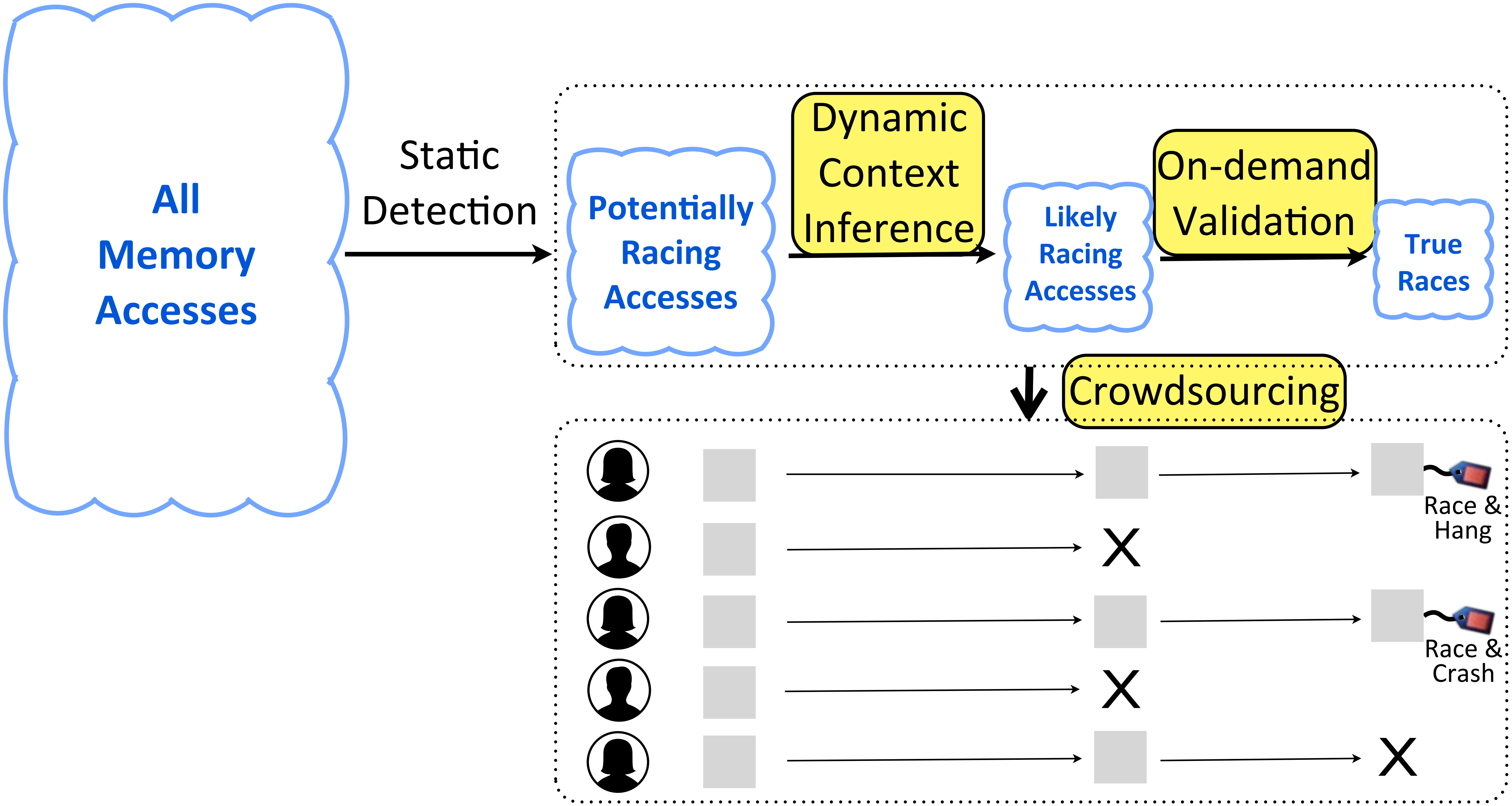
NOT SEEN

program

Application Home
(AppStore, Play)

RaceMob

RaceMob



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Evaluation

memcached

Pbzip2 Ctrace

Apache SQLite pfscan SPLASH-2

- Detection effectiveness
- Contribution of techniques to reducing overhead
- Breakdown of overhead
- Comparison to other detectors
- Comparison to concurrency testing tools
- Scalability analysis

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pfscan

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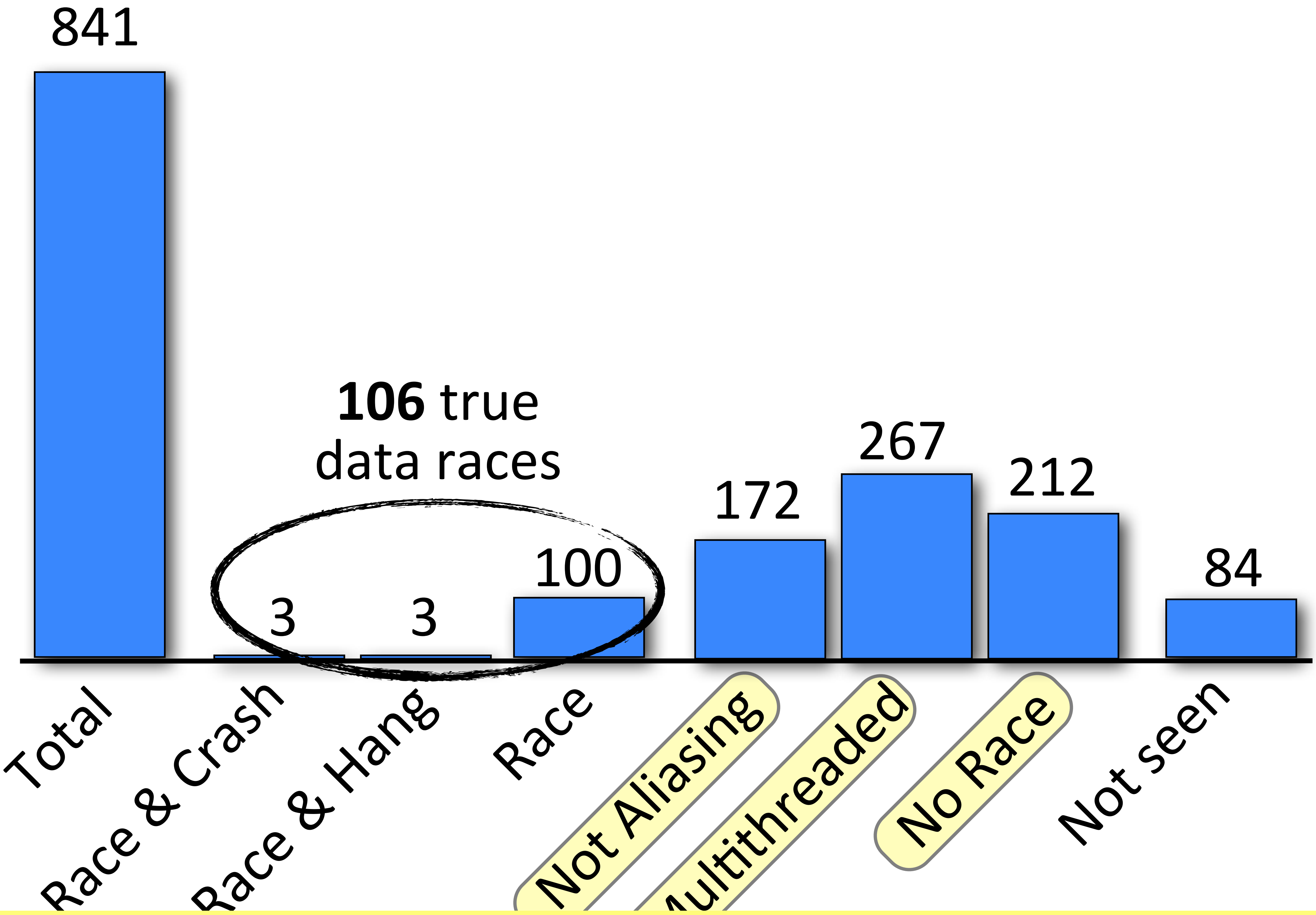
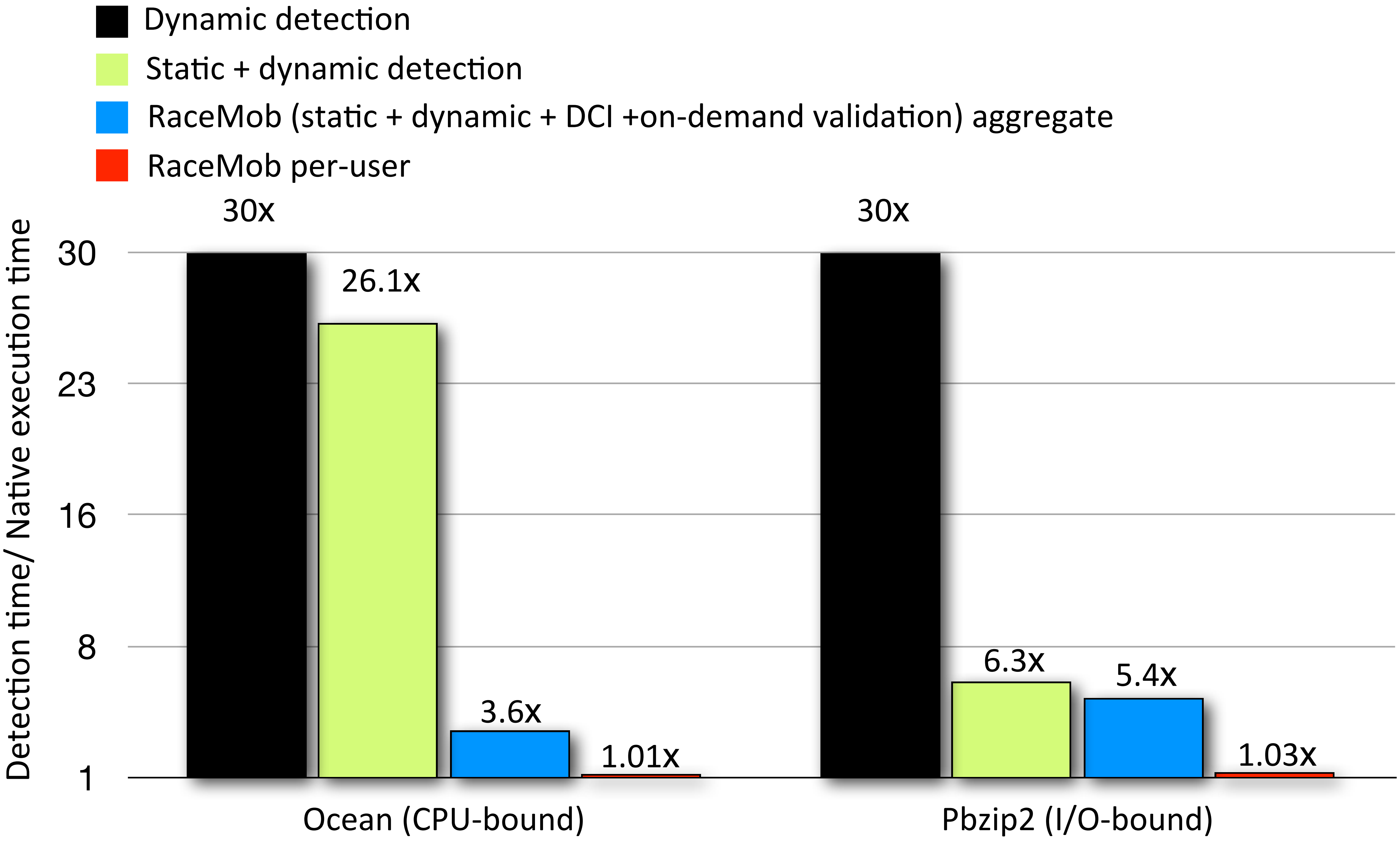
Detection Effectiveness



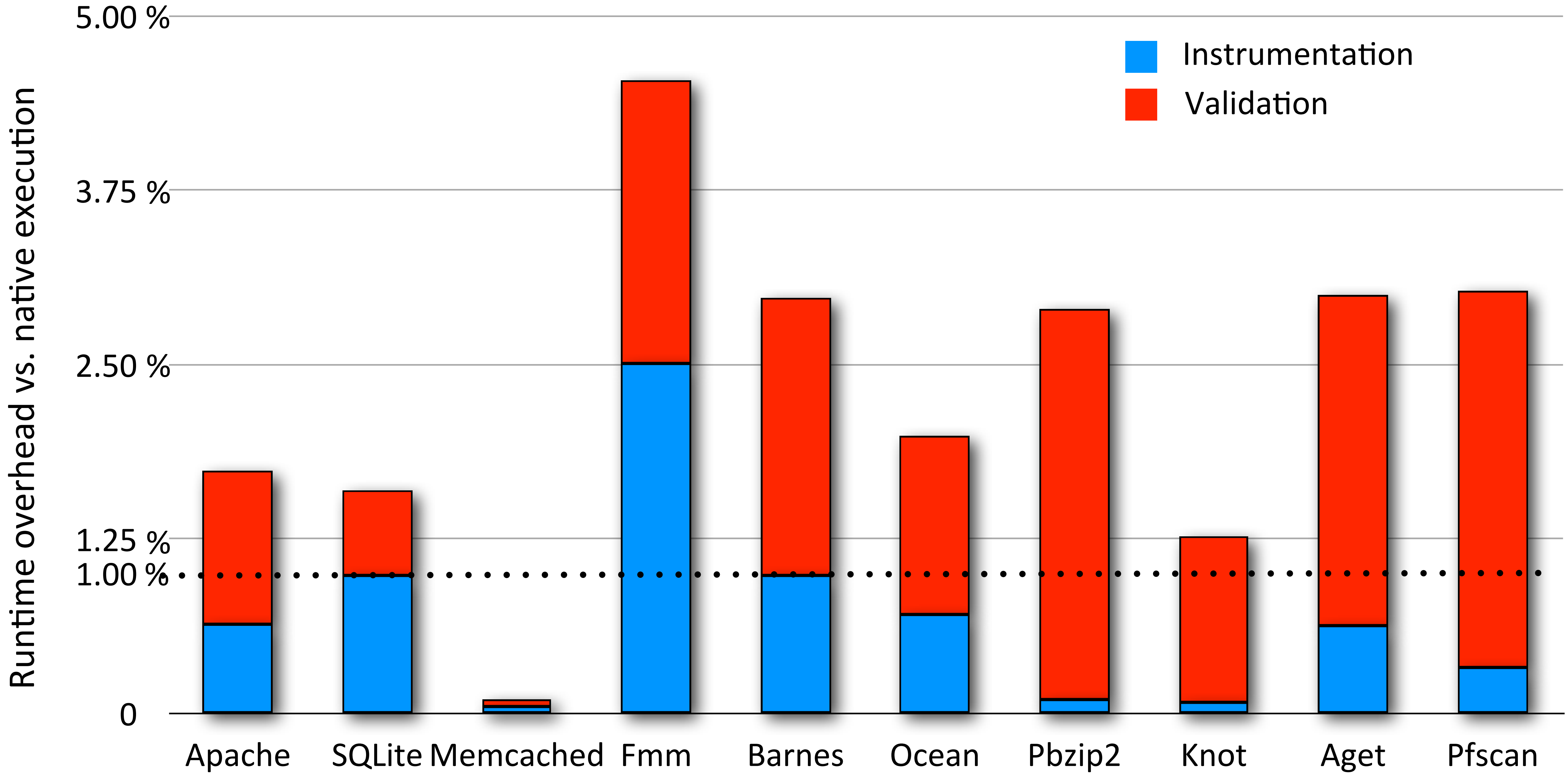
RaceMob detected and confirmed 106 data races

How Does Each Technique Lower the Overhead ?



All techniques are required for low overhead

Breakdown of overhead



2.3% average runtime overhead per-user

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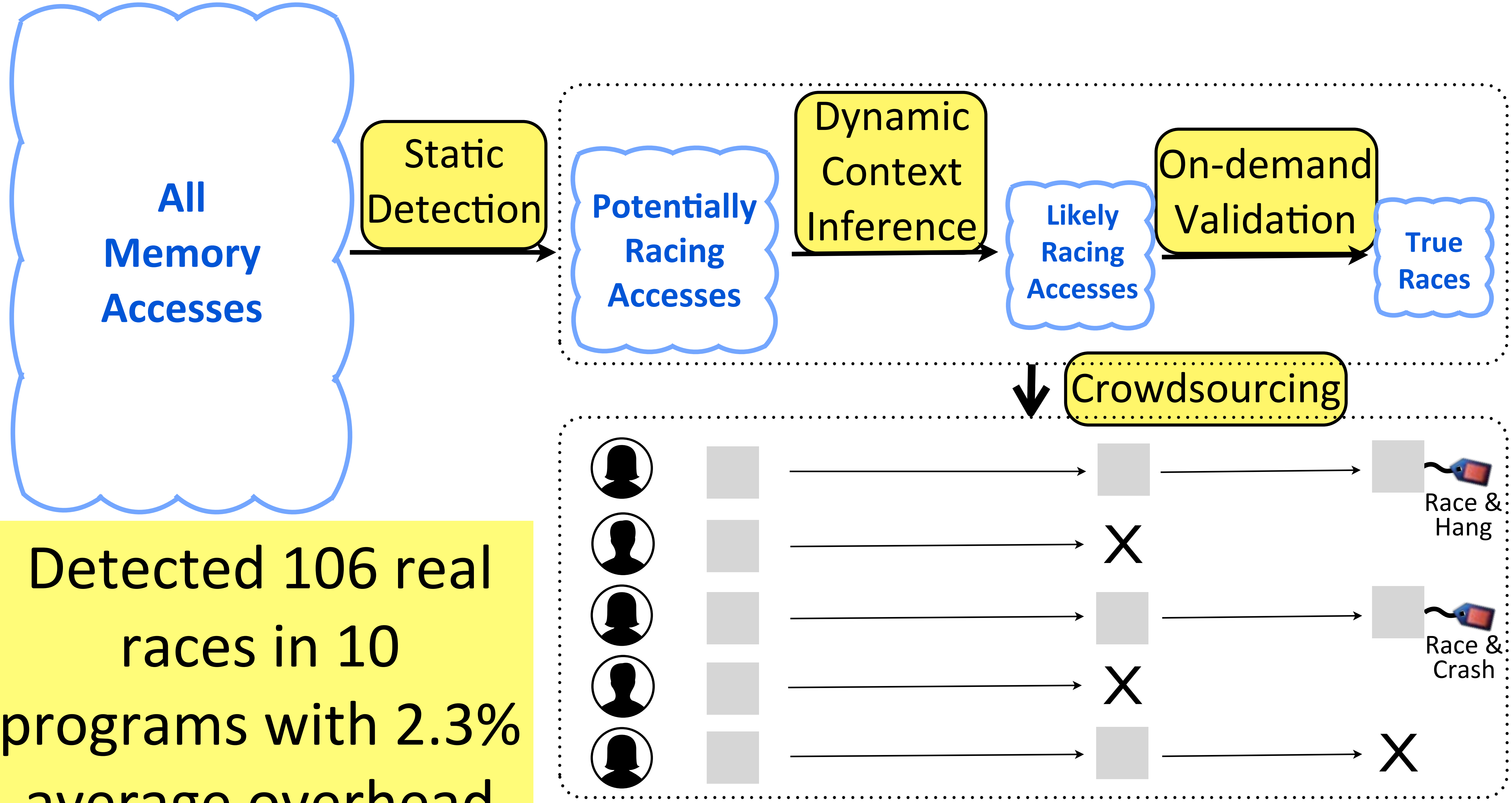

Detected 106 real races in 10 programs with 2.3% average overhead