# Kuda:
# The Split
# Race Checker

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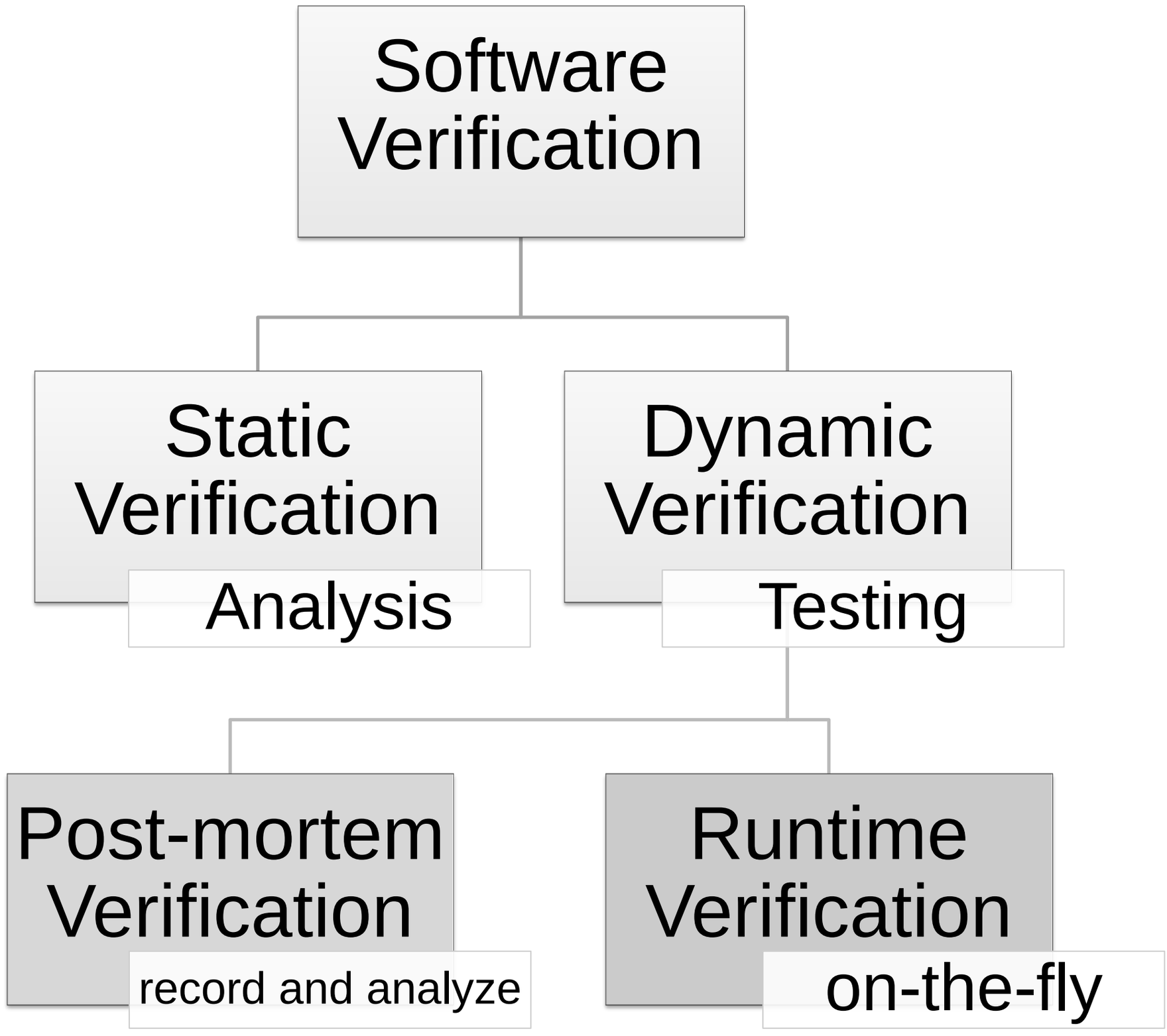
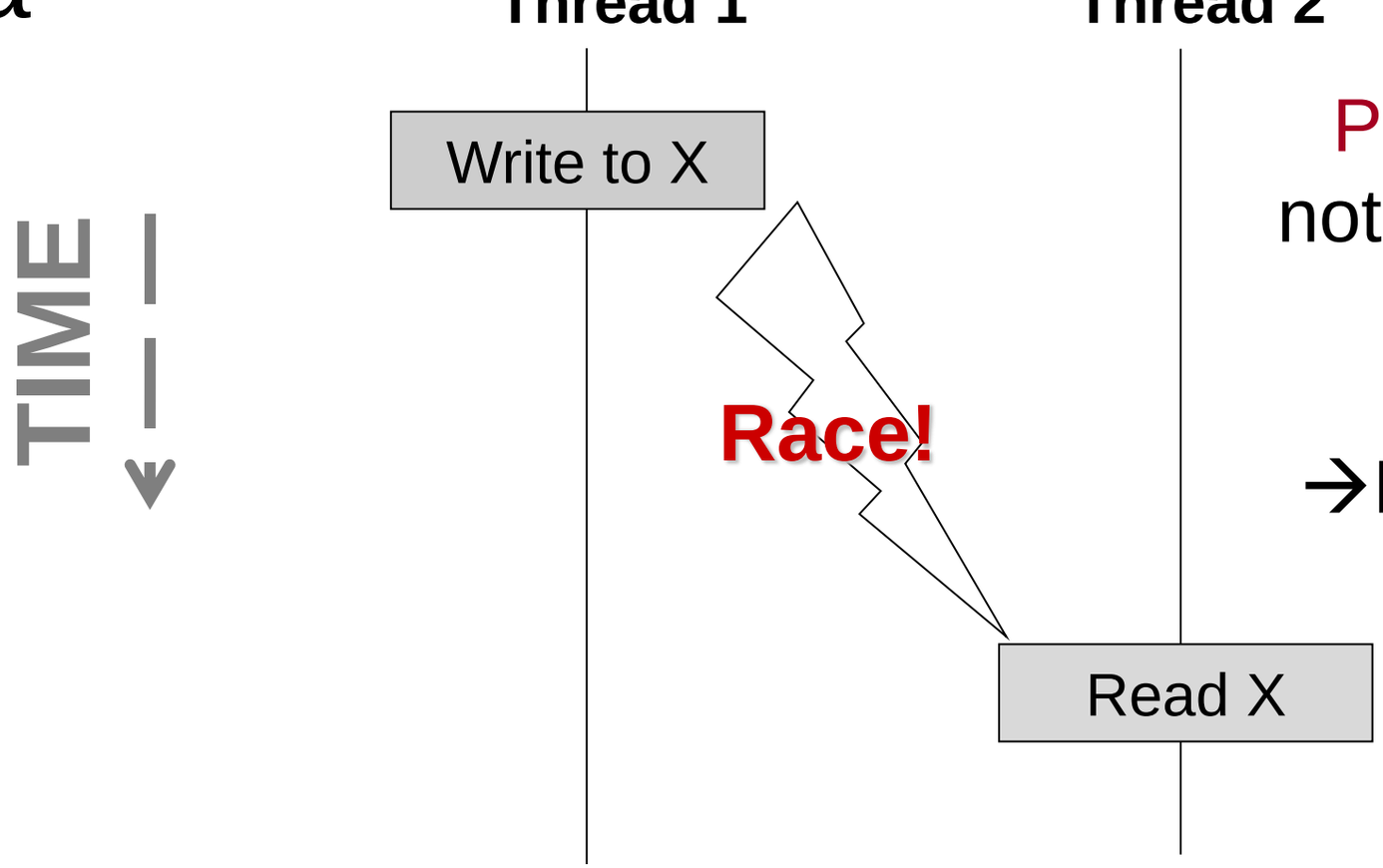

Software Verification
Static Verification
Analysis
Dynamic Verification
Testing
Post-mortem Verification
record and analyze
Runtime Verification
on-the-fly

# Data Races

It is **not** standardized for each memory model yet But here it goes:

Conflicting, unsynchronized accesses to shared data



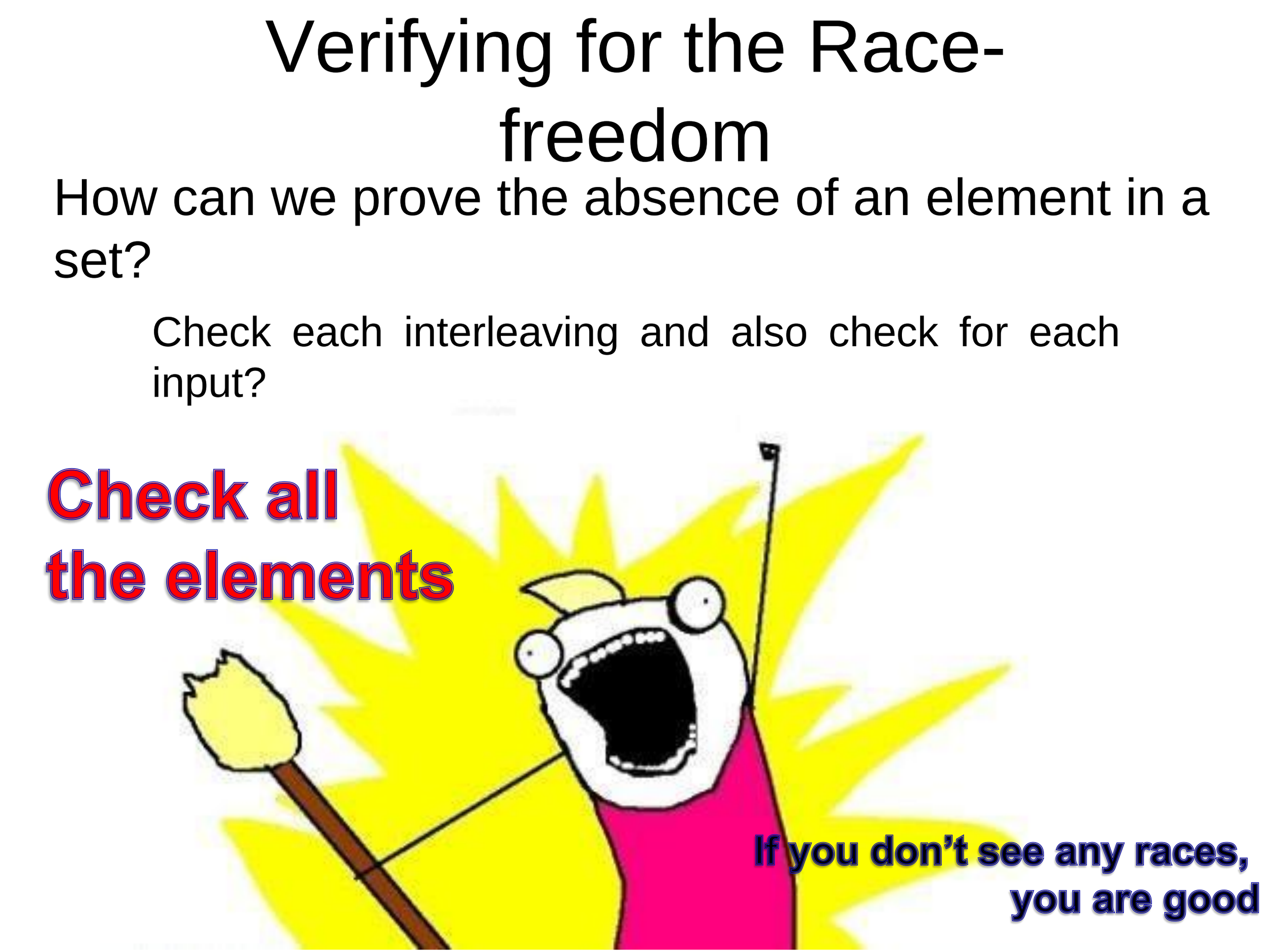

Problem: Thread 2 may not be aware of the update Thread1 performed.

→Non-deterministic read.

# Verifying for the Race-freedom

How can we prove the absence of an element in a set?

Check each interleaving and also check for each input?



# “Verifying” the Absence of (Data) Races in Runtime

Bad news:

It is not practical to check each interleaving and each input

Good news:

You can *convince* yourself that your coverage is good -and interesting- enough ☺

Conclusion:

It is not *formal* verification, but bosses like the idea

i.e. the less bugzilla entries after the software launch, the better

Result:

Stress Testing

# On-the-fly Race Checking

## Traditional Race Checking

Thread 1

| a1: Write(x) |
|---|
| Record(a1) |
| Analyze(a1) |
| a2:Read(y) |
| Record(a2) |
| Analyze(a2) |
| a3: Lock(l) |
| Record(a3) |
| Analyze(a3) |
| a4: Read(x) |
| Record(a4) |
| Analyze(a4) |
| a5: Unlock(l) |
| Record(a5) |
| Analyze(a5) |
| … |

Thread 2

| b1: Write(y) |
|---|
| Record(b1) |
| Analyze(b1) |
| b2:Read(z) |
| Record(b2) |
| Analyze(b2) |
| b3: Write(x) |
| Record(b3) |
| Analyze(b3) |
| … |

## Race Checking in Parallel

Thread 1

| a1 |
|---|
| Record |
| a2 |
| Record |
| a3 |
| Record |
| a4 |
| Rec |
| a5 |
| Rec |
| … |

Thread 2

| b1 |
|---|
| Rec |
| b2 |
| Rec |
| b3 |
| Rec |
| … |

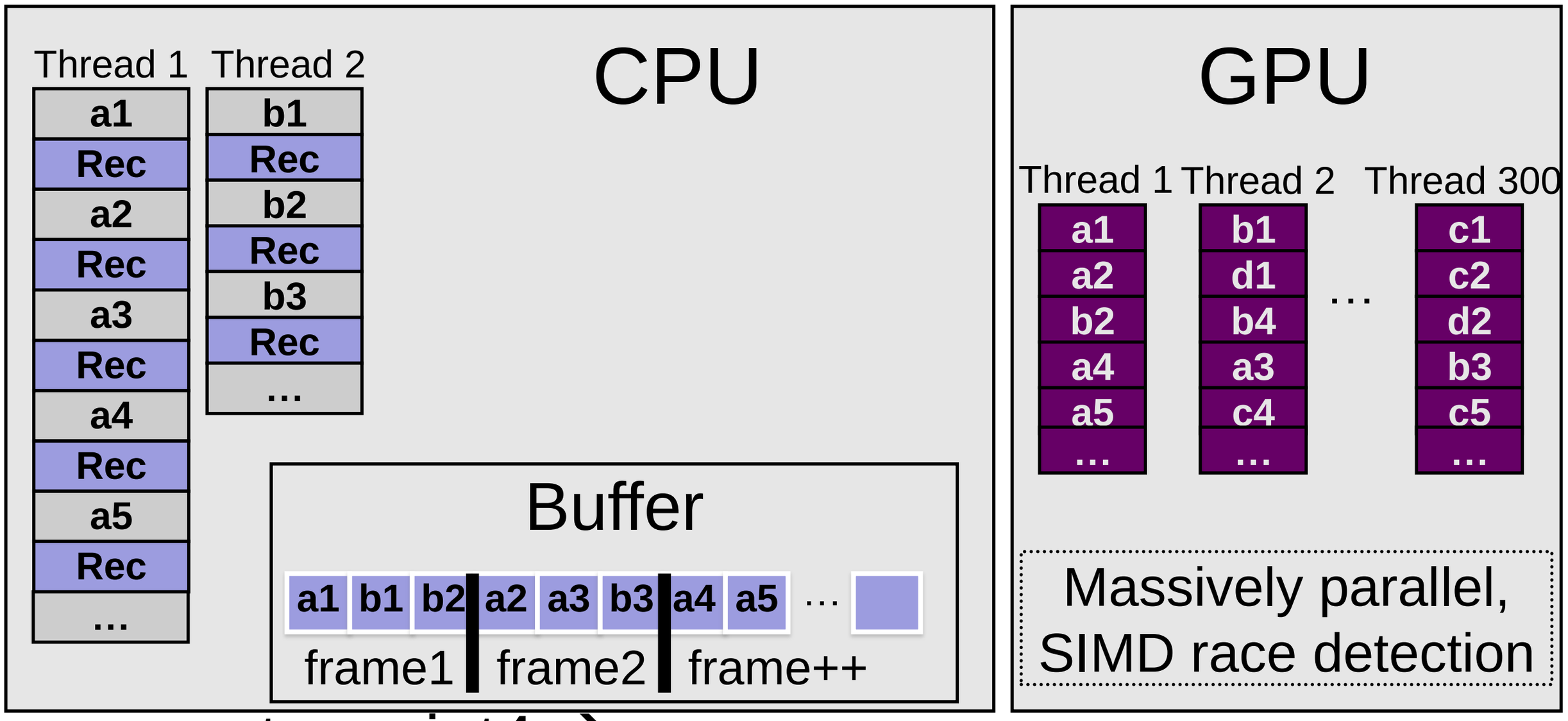
Helper thread

| A(a1) |
|---|
| A(b1) |
| A(a2) |
| A(a3) |
| A(b2) |
| A(b3) |
| A(a4) |
| A(a5) |
| … |

Looks so nice!

**Intel's** *Thread Checker,* **Google's** *ThreadSanitizer and* **Helgrind** → each tool may cause several hundreds times slowdown! (see papers)

# Producer/Consumer Relation on all CPU Records




an event = int4 → event{varID,threadID,type,index}

a frame = 1024 events

the buffer = 2048 frames = 16 MB

# Does It Work?

Baseline Program (computation only) — 3.8 sec

\+ Runtime instrumentation — 3x

\+ Cheap Algorithm (on CPU)

- Eraser – Simple/Fast & Imprecise — ~400x

\+ Event buffering — 78x

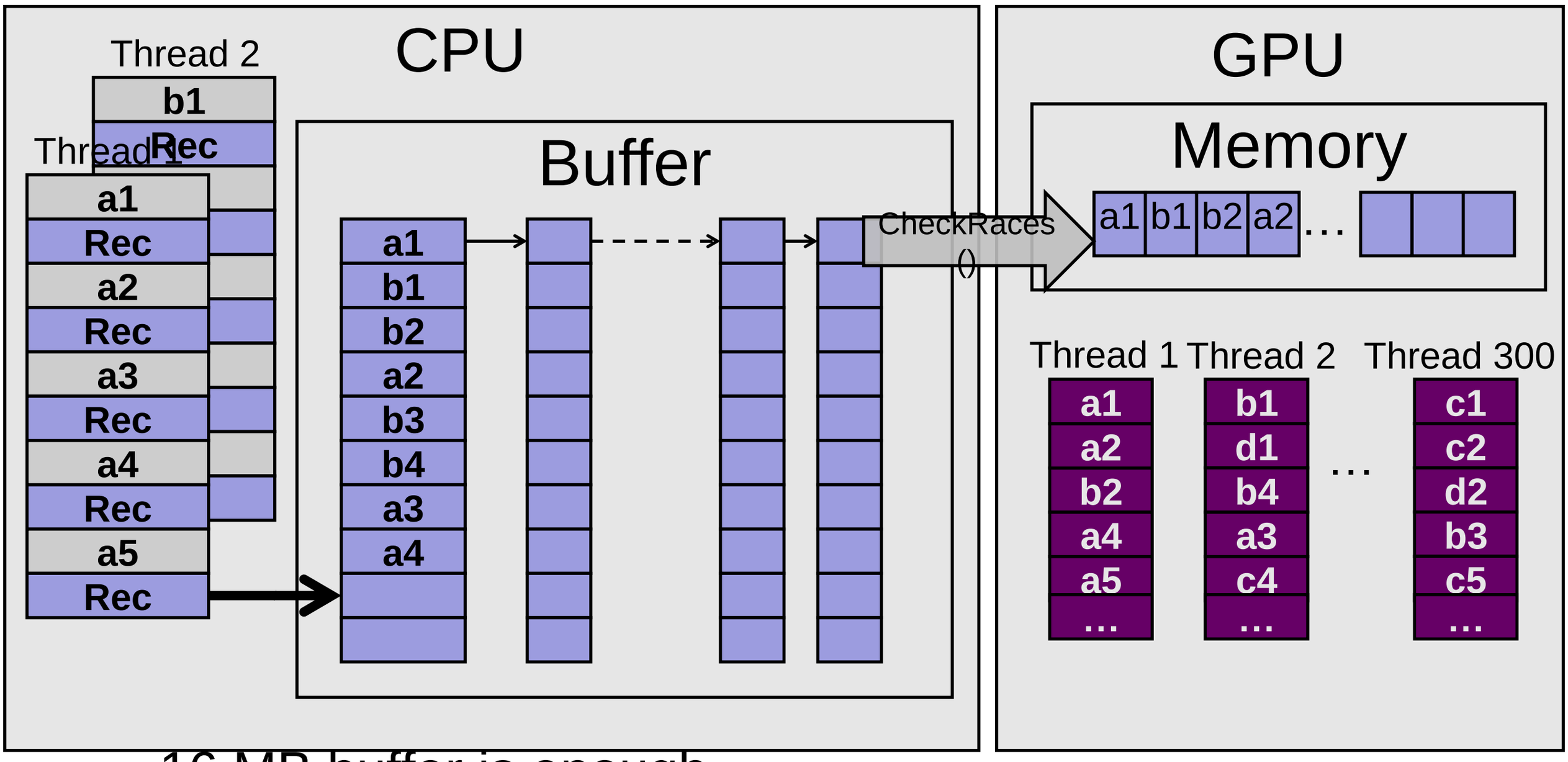
\+ Expensive Algorithm (on GPU)

- Goldilocks – Complex & Precise — 83.6x

= Precise race detection on GPU is 5x faster than imprecise race detection on CPU

(see experiments, 2 slides later)

# Non-blocking, Lock-free Buffer




16 MB buffer is enough

Always room for the next event to be recorded (GPU is fast)

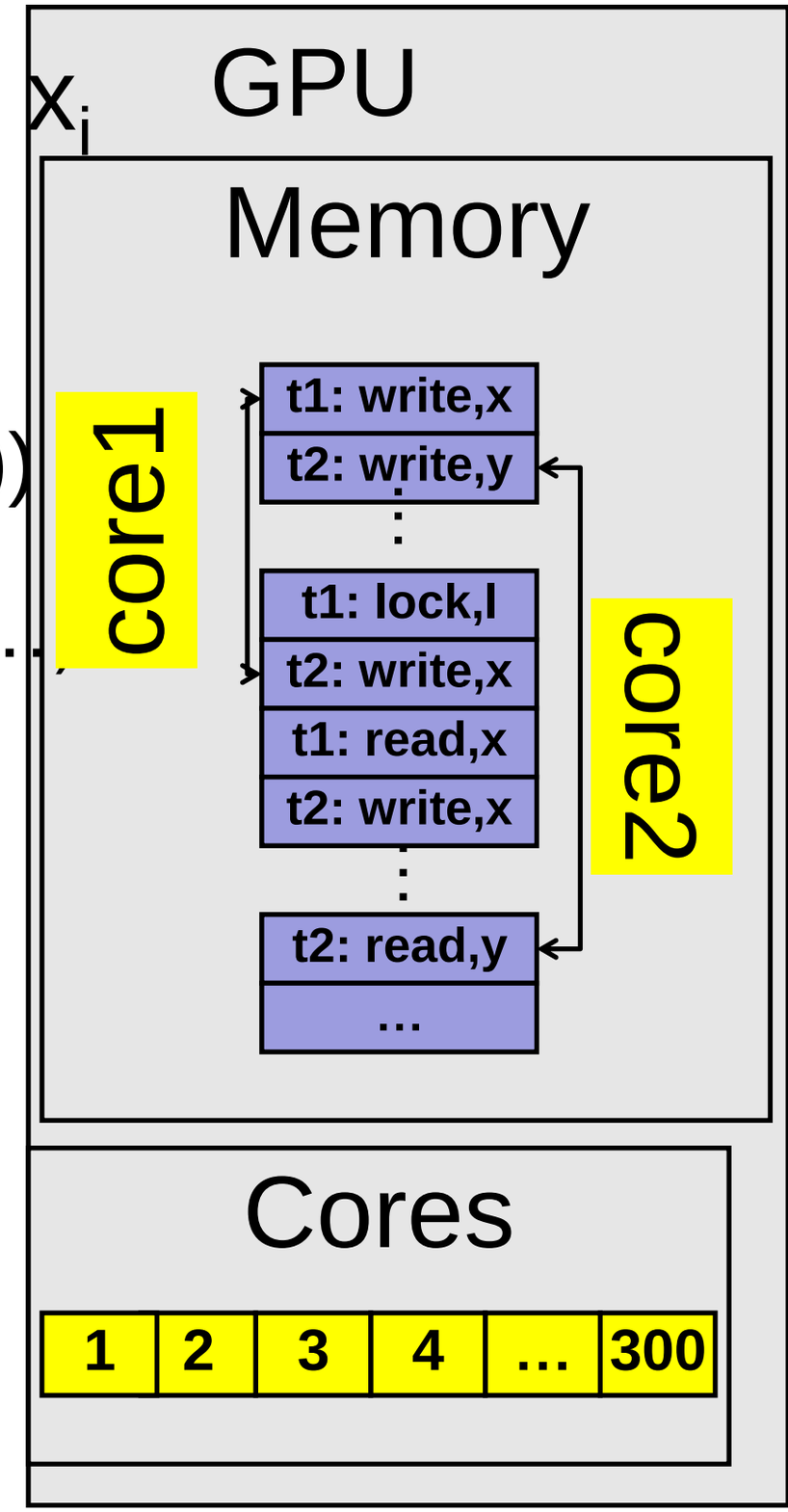
# Parallel Race Checking

- Suppose event[i] accesses var $x_i$
- GPU core[i]

→ handle(event[i] *until* next_event($x_i$))

when done → handle(event[i+N]…)

- Read-only device memory!
- No shared data besides the frame



| Benchmarks | Normal exe | Instrumented | Eraser@CPU | Event buffer | Goldilocks@GPU |
|---|---|---|---|---|---|
| | Reference | Slowdown | Slowdown | Slowdown | **Slowdown** |
| blackscholes | 1 | 2.1 | 101 | 14.7 | **21.1** |
| bodytrack | 1 | 2.6 | 251 | 72.5 | **75.6** |
| canneal | 1 | 1.6 | 47 | 6.9 | **7.4** |
| dedup | 1 | 3.1 | 429 | 88 | **101.6** |
| fluidanimate | 1 | 2.5 | 308 | 83.9 | **88.1** |
| raytrace | 1 | 2 | 123.7 | 5.7 | **6.2** |
| swaptions | 1 | 3 | 437 | 117.5 | **119.9** |
| x264 | 1 | 7.1 | 645.2 | 151.7 | **155.8** |
| barnes | 1 | 4 | 499.1 | 111.5 | **116.1** |
| cholesky | 1 | 3.2 | 216.2 | 32.4 | **33.2** |
| fmm | 1 | 2.9 | 1455.8 | 89.6 | **98.6** |
| fft | 1 | 2.1 | 222.7 | 45.3 | **48.1** |
| lu | 1 | 5.9 | 742.2 | 190 | **201.9** |
| ocean | 1 | 4 | 301.6 | 63.4 | **68.1** |
| radix | 1 | 2 | 126.6 | 31.1 | **33.1** |
| raytrace | 1 | 2 | 122.2 | 6.9 | **7.2** |
| water-n2 | 1 | 3.5 | 707.6 | 182.1 | **191.4** |
| w-spatial | 1 | 4.6 | 485.2 | 114.9 | **131.5** |
| **average** | **1x** | **3.2x** | **401x** | **78x** | **83x** |

# Future Work

- Profiling + Pruning of thread local vars
- Compare state-of-the-art RC in C(Fast-track)
- Offloading other concurrent analysis to GPU
- Reduce slowdown due to buffering
  - Custom HW

# Q&A

Our codebase is online:

kuda.codeplex.com

# Some Links

msrc.ku.edu.tr

We need new graduate students

rv2012.ku.edu.tr

International Runtime Verification Conference in Istanbul