Java for Real-Time Systems

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What is a real-time system?

- Reactive system
  - Bounded response time to events
- Soft real-time:
  - Jitter is OK
- Hard real-time:
  - Jitter == failure
- Throughput != Performance
  - We care about worst-case latency

Why should we care?

- Real-time systems are everywhere!
  - Planes, Trains and Automobiles
- Increasing complexity
  - Network connectivity, GUIs
- Shorter design cycle
- C is (almost) all we have

Java is Good and Bad

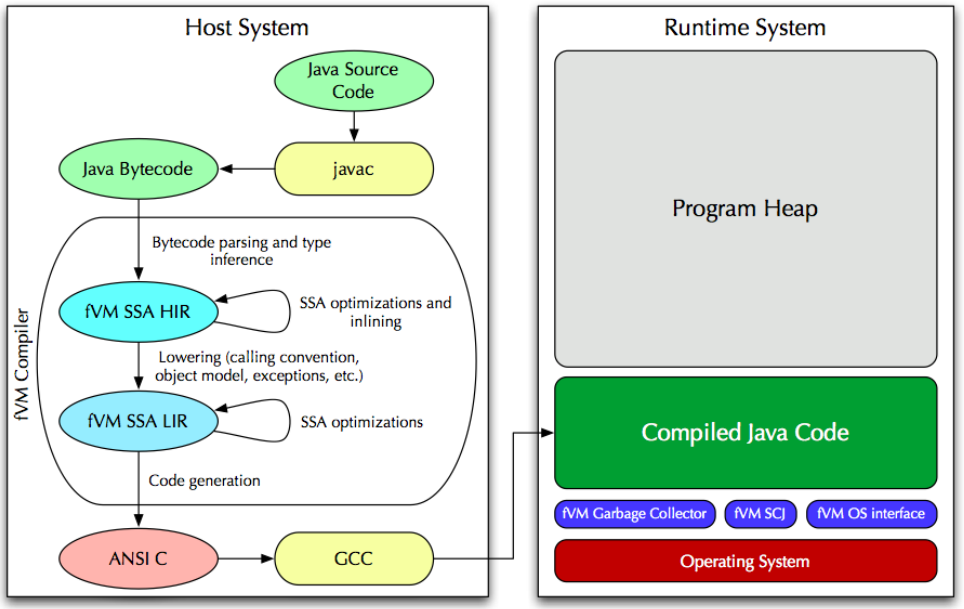
- No guarantees about timeliness
  - Interpretation
  - On-the-fly compilation
  - Dynamic dispatch
  - Stop-the-world garbage collection
- But affords great productivity
  - Modularity
  - Expressiveness
  - Safety

How do we make it work?

- A RT Java system must:
  - Support all or defined subset of the Java language (obvious)
  - Guarantee timeliness of RT operations
  - Provide deterministic, non-interfering garbage collection

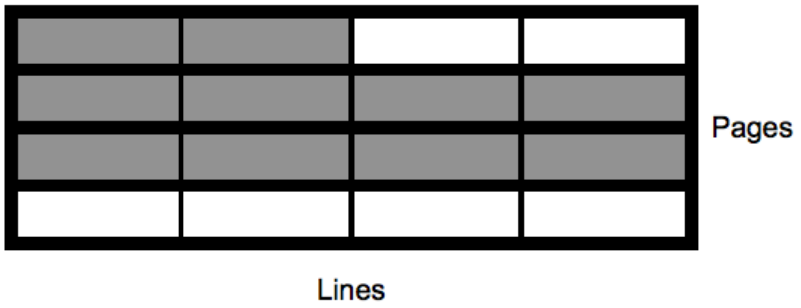
The Fiji VM

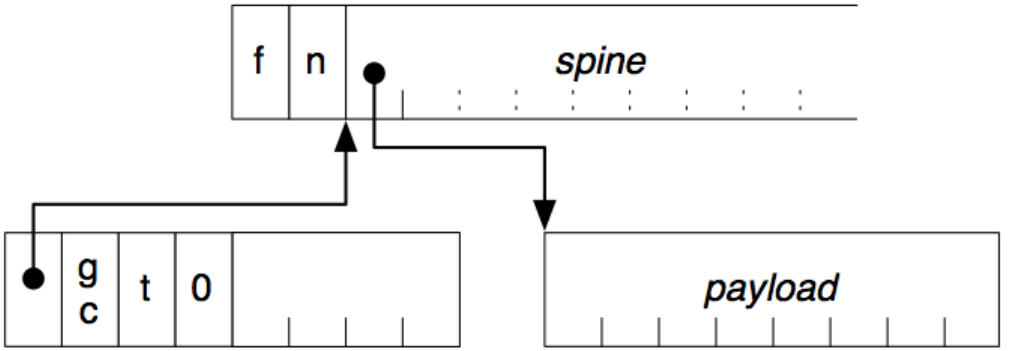
- A real-time Java VM from Purdue / Fiji Systems, Inc.
- Java support and timeliness:
  - Compile/optimize ahead-of-time



The Fiji VM (cont.)

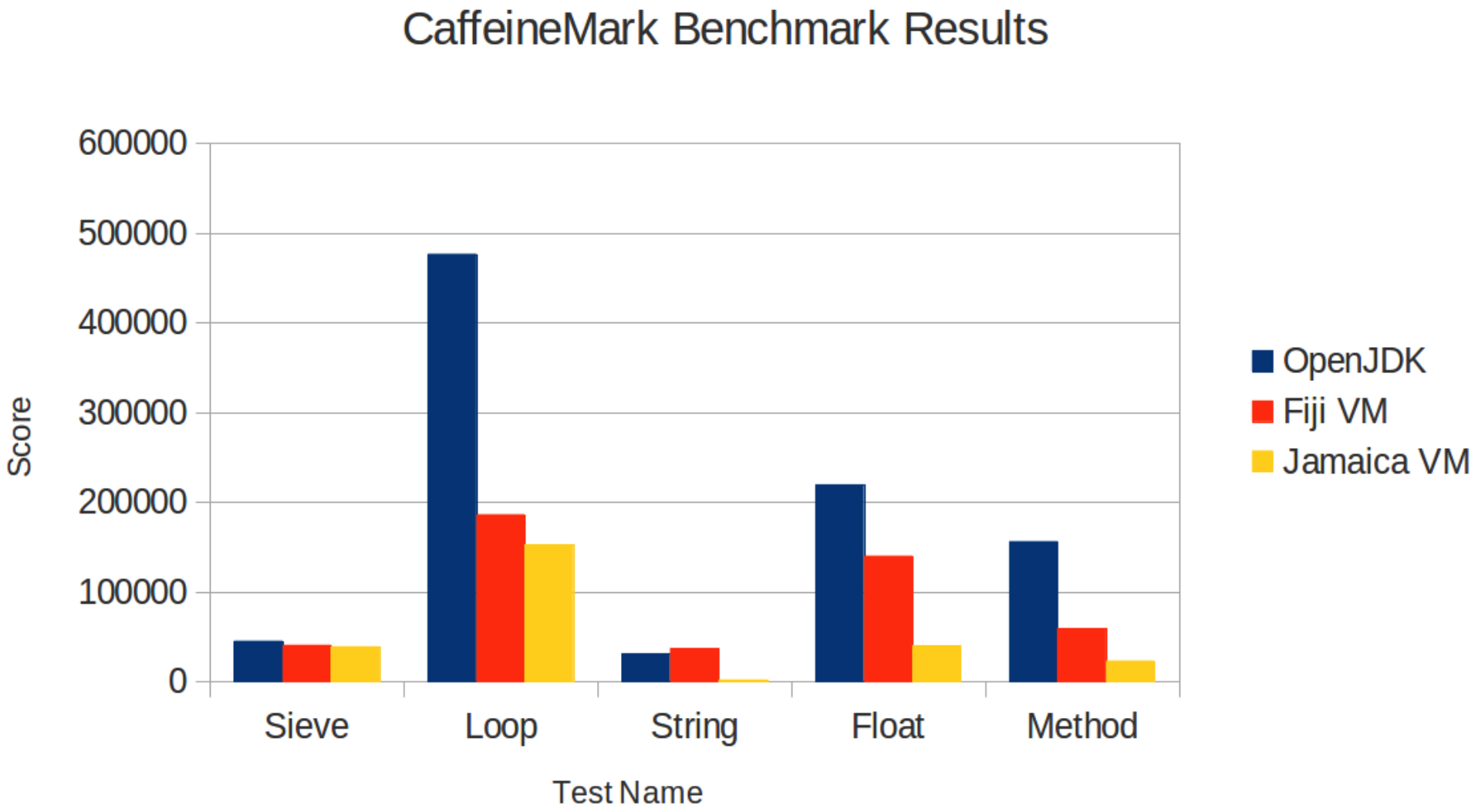
- Deterministic, non-interfering garbage collection:
  - 70% of heap: Fragmented, mark-region collector
  - 30% of heap: Object *spines*, copy-collected
  - Minimizes fragmentation, but allows constant-time access





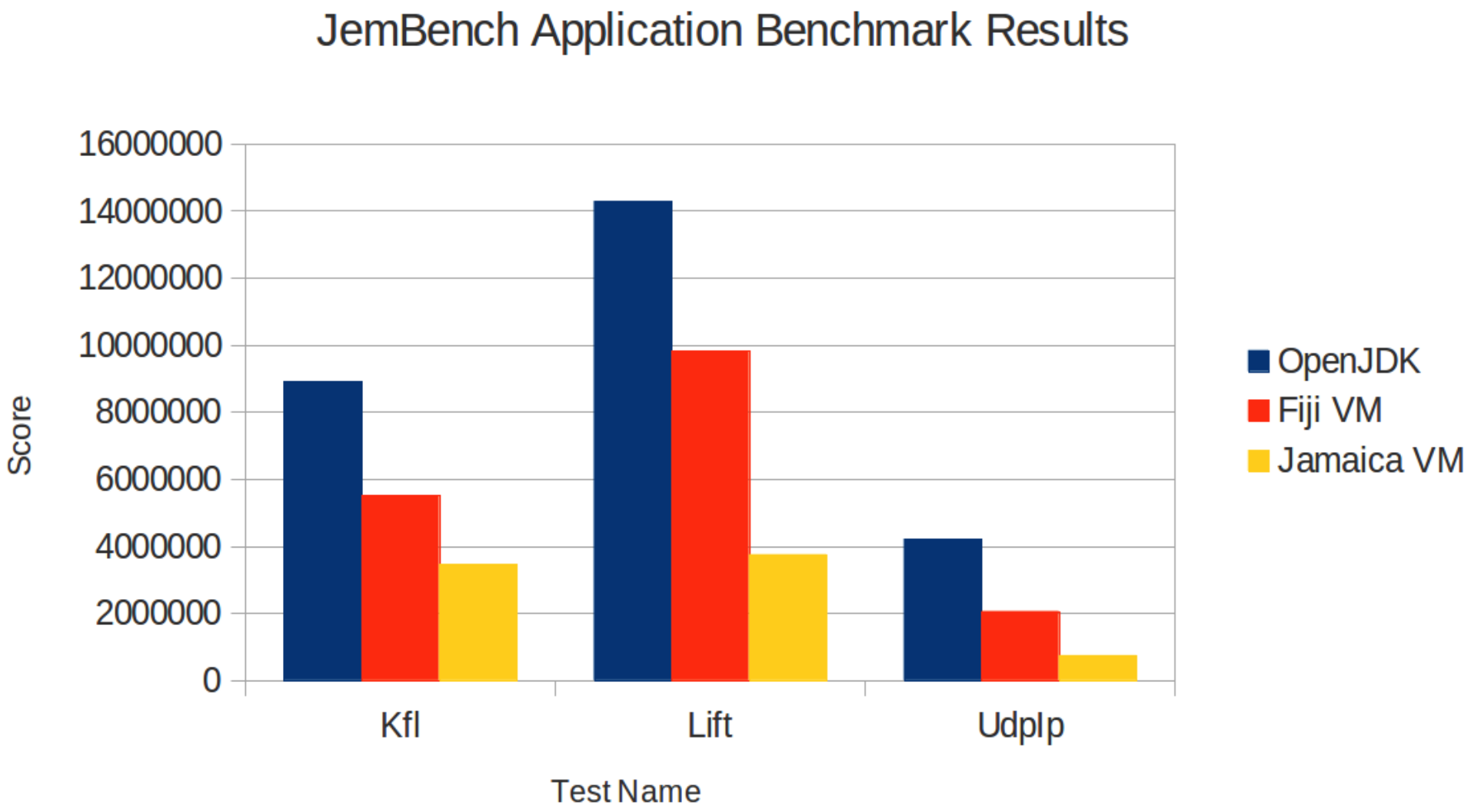
Benchmarking Fiji

CaffeineMark



Benchmarking Fiji

JemBench



Benchmarks are Misleading

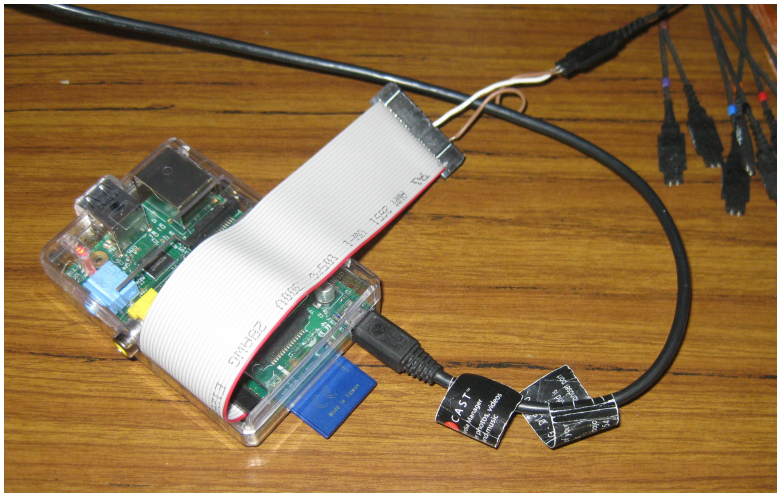
- Capture the steady-state
  - We care about worst-case
- Measure throughput (iterations/second)
  - Again, we care about worst-case
- Execute same thing over and over
  - Is this realistic for a real-time system?

A Simple Real-time Benchmark

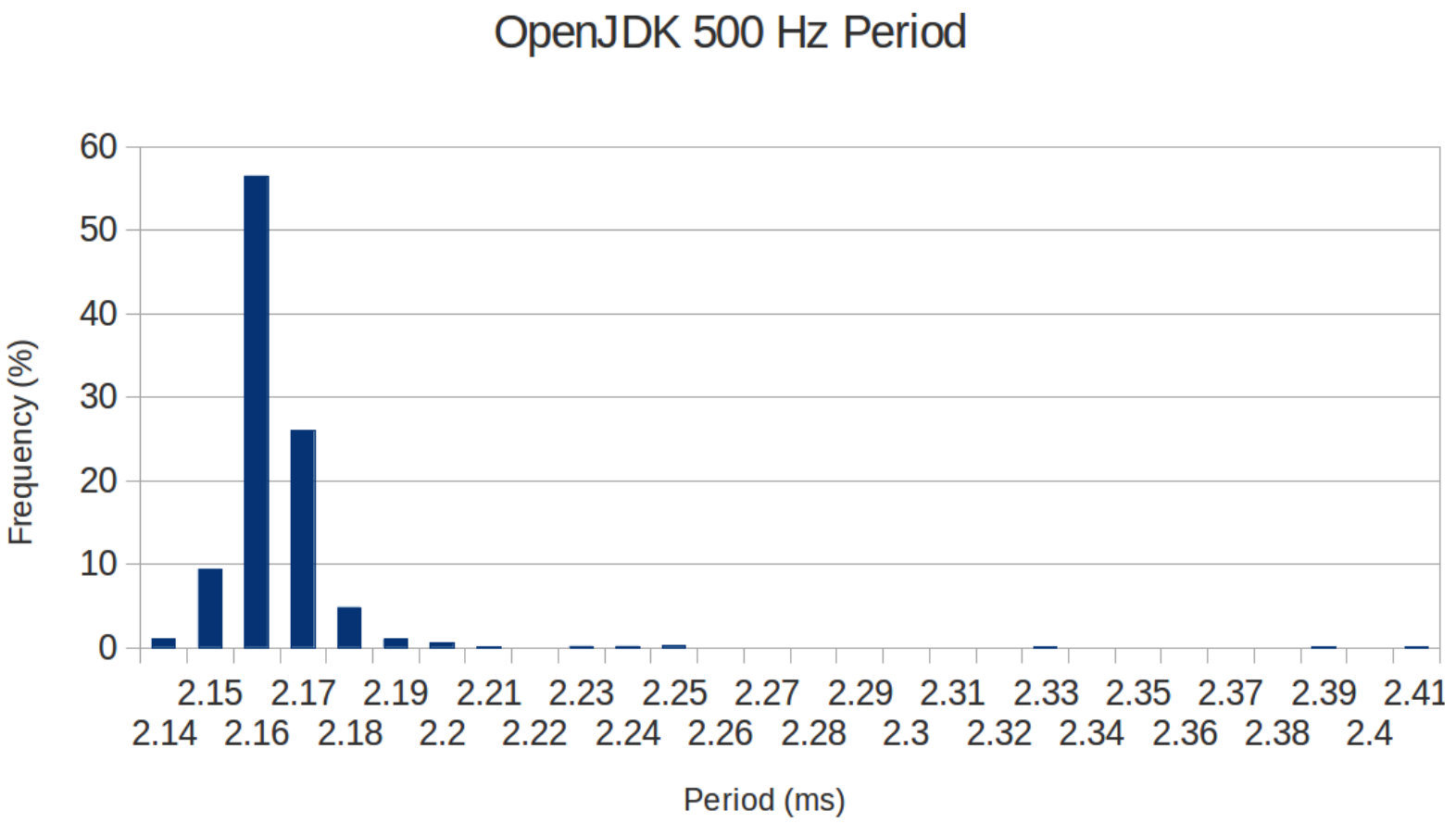
- Generate a 500 Hz pulse in software
- Measure the actual period of the pulse
- Why?
  - Simple, but measures timeliness of *every* event
  - Used for servo motors, PWM motors, etc.

A Simple Real-time Benchmark

- Compare OpenJDK and Fiji VM for three scenarios:
  - 500 Hz Pulse, no system stress
  - 500 Hz Pulse, GC stress
  - 500 Hz Pulse, dynamic dispatch stress
- Equipment: Raspberry Pi, TLA 700 Logic Analyzer



500 Hz, No Stress Test

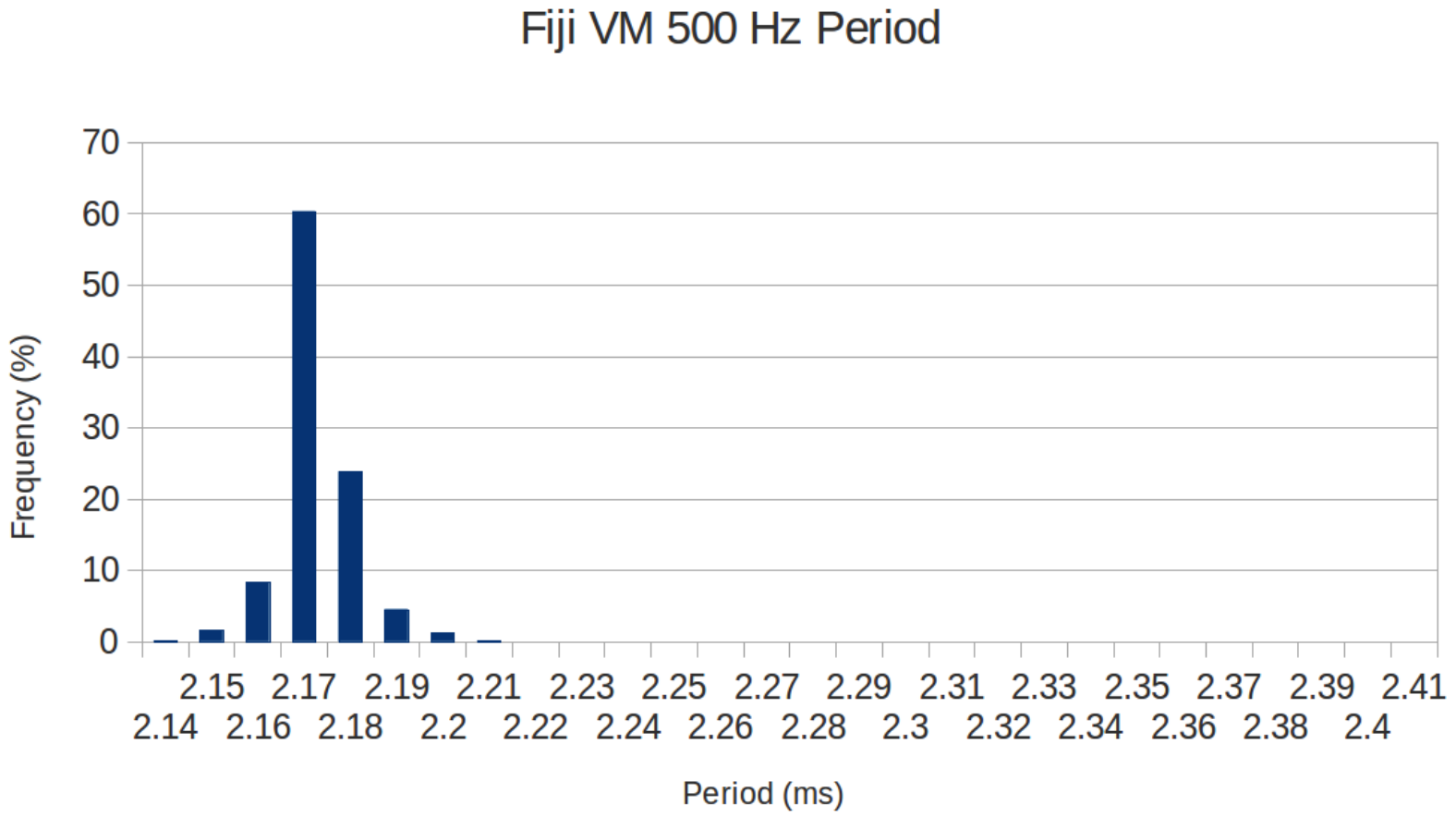


Avg: 2.17ms

Max/Min: 2.41 / 2.15ms

Stddev: 0.014

500 Hz, No Stress Test

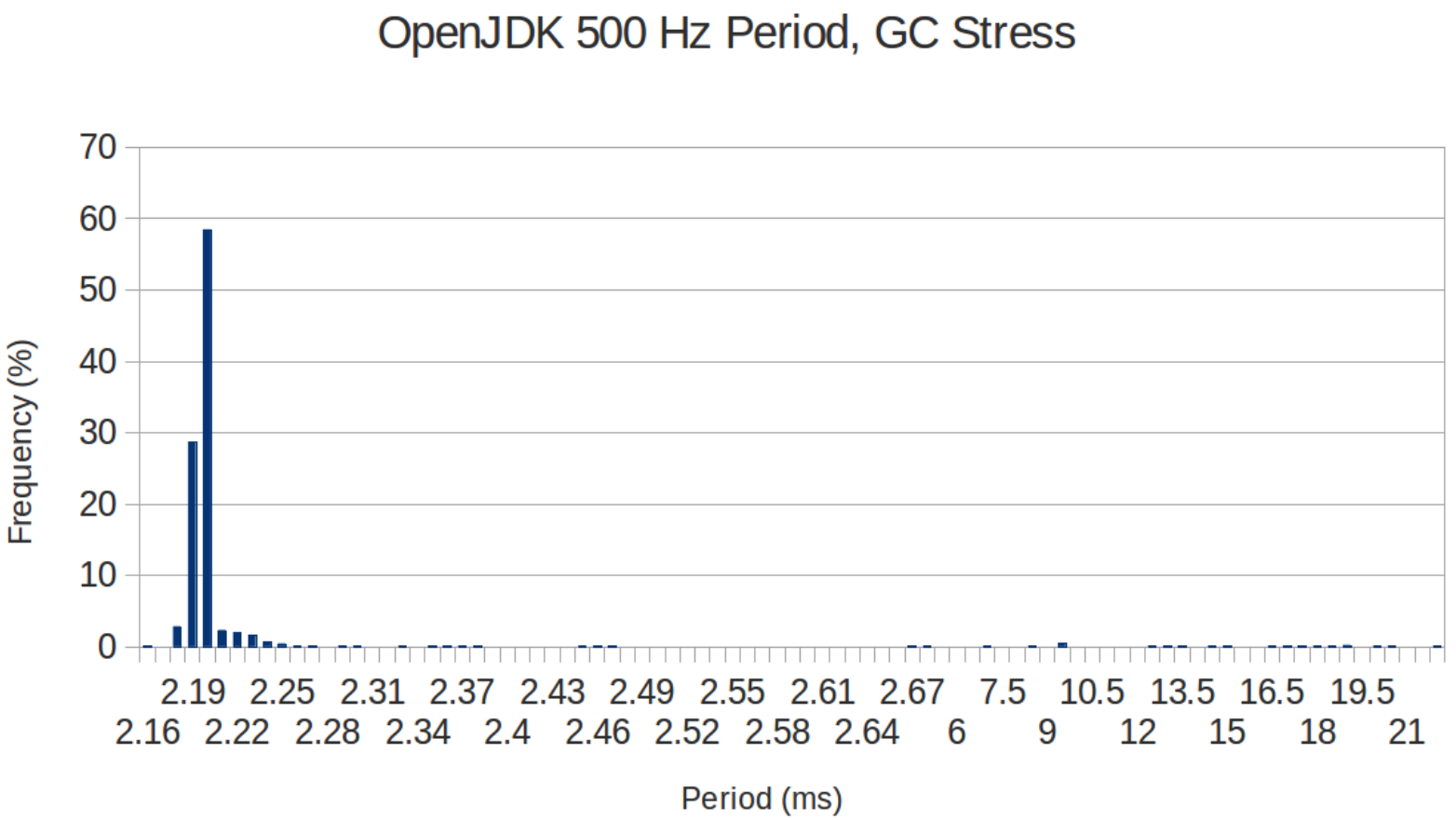


Avg: 2.18ms

Max/Min: 2.21 / 2.15ms

Stddev: 0.008

500 Hz, GC Stress Test

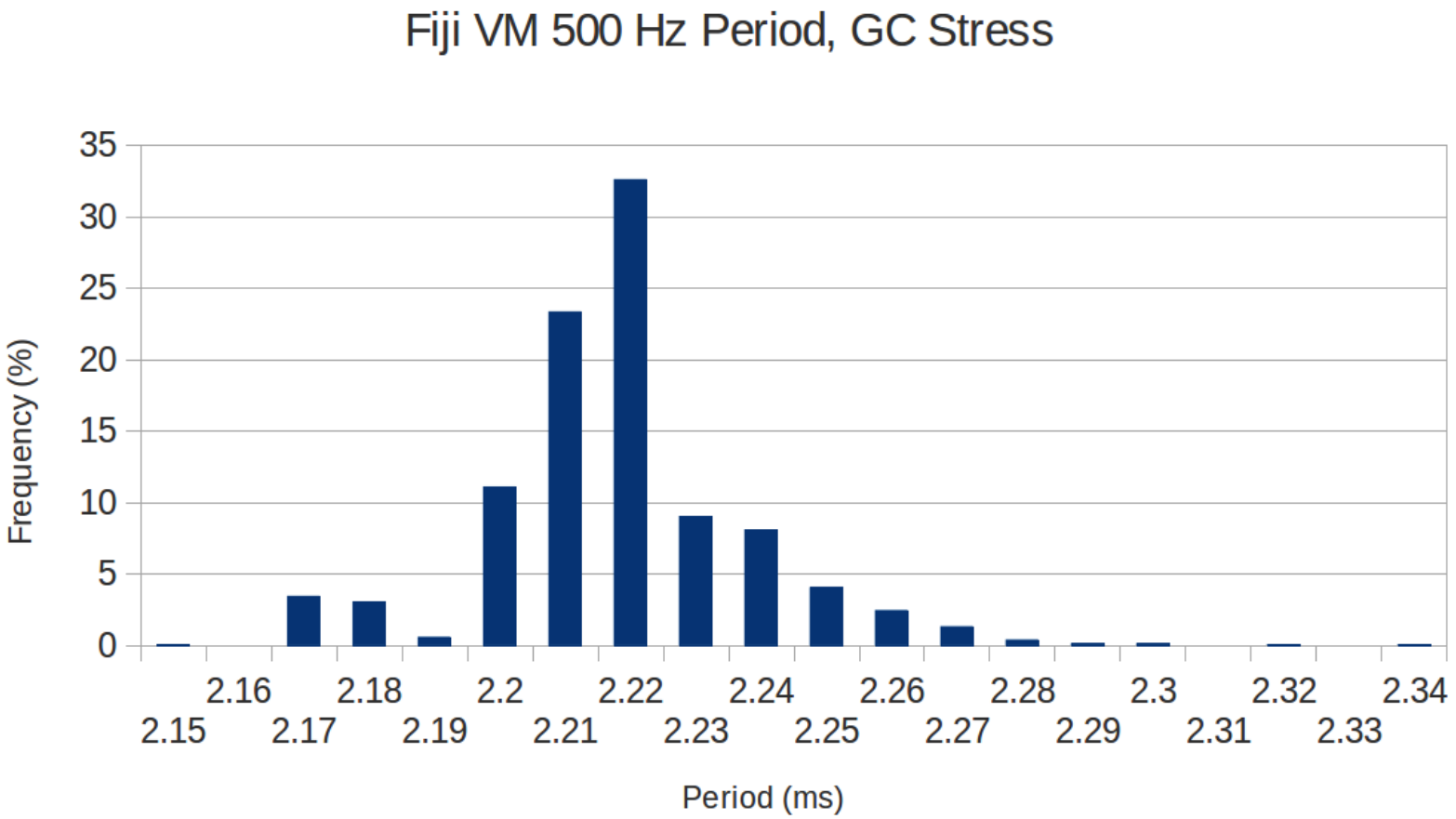


Avg: 2.45ms

Max/Min: 22.35 / 2.17ms

Stddev: 1.83

500 Hz, GC Stress Test

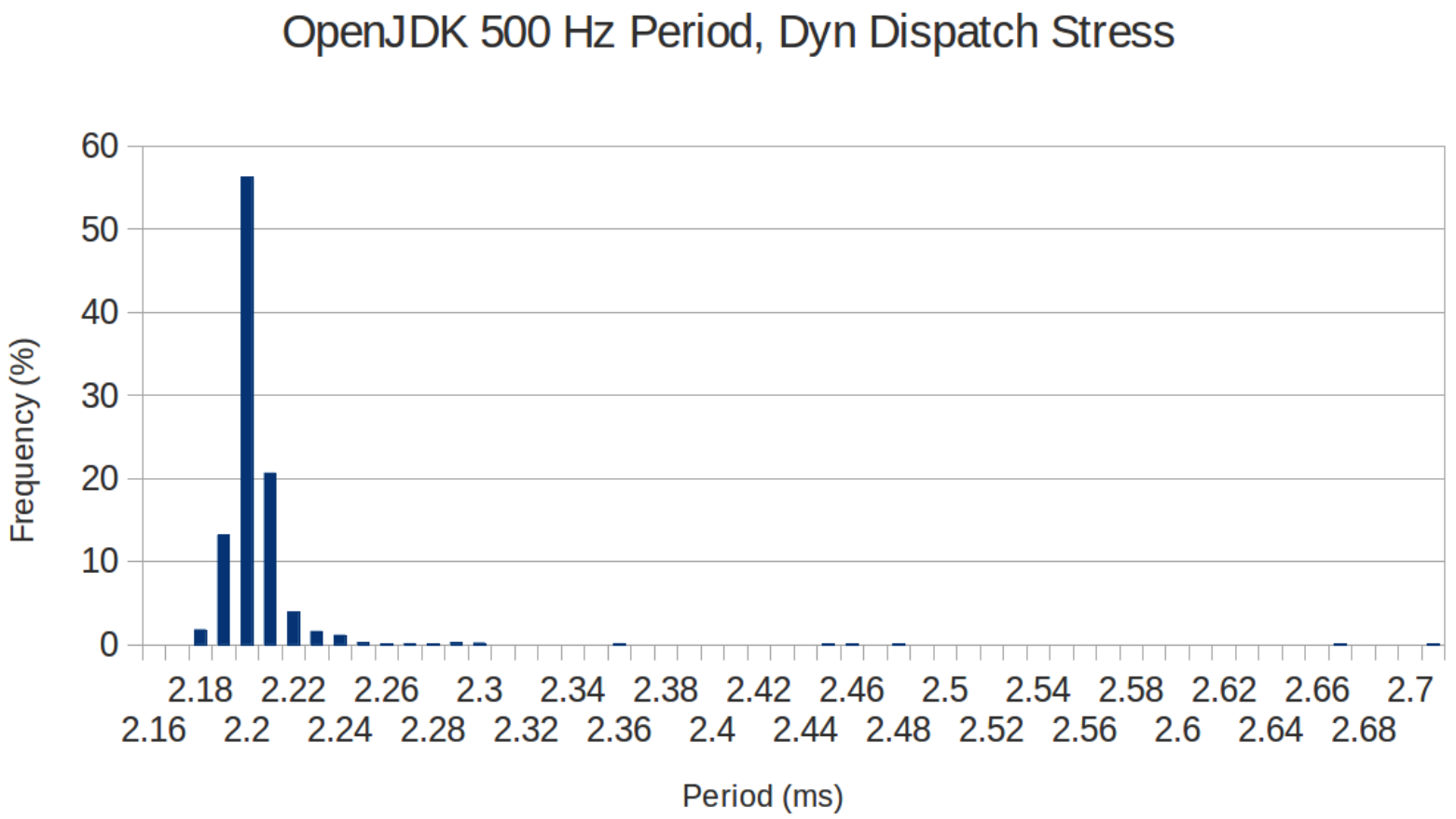


Avg: 2.22ms

Max/Min: 2.35 / 2.16ms

Stddev: 0.02

500 Hz, DD Stress Test

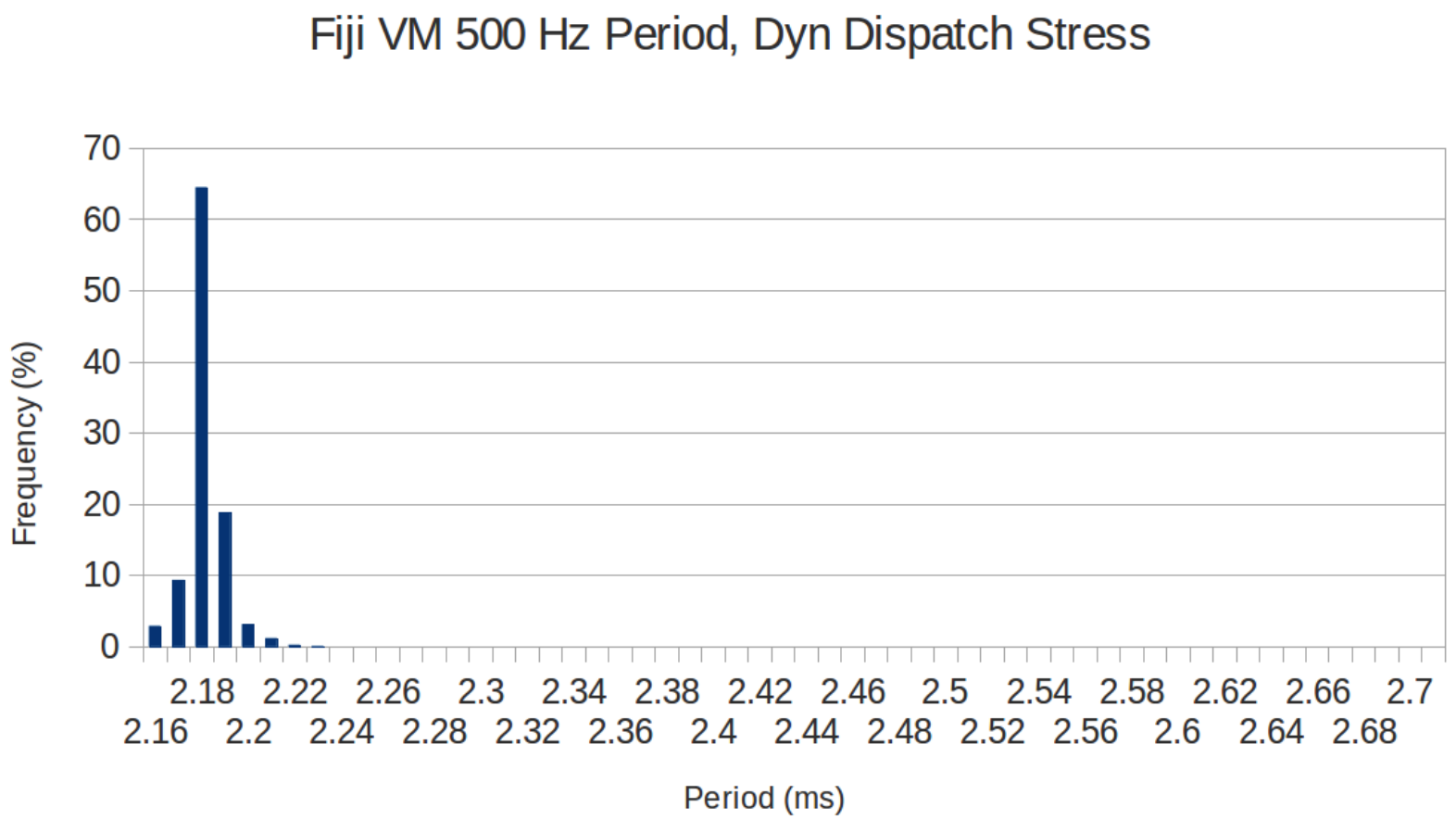


Avg: 2.21ms

Max/Min: 2.71 / 2.18ms

Stddev: 0.03

500 Hz, DD Stress Test



Avg: 2.19ms

Max/Min: 2.24 / 2.17ms

Stddev: 0.008

Going Beyond 500 Hz

- Can we do 96kHz?
- Why?
  - Sample audio from A/D converter
  - Filter it, transmit over network
  - In a single Java application
- Need a Real-time OS
  - Linux won't cut it:
    - Avg: 102us
    - Max: 186us

(Not) Going Beyond 500 Hz

- RTEMS
  - Fiji allows for Java timer interrupts:

```
final Timer t=new Timer();
t.fireAfter(10 /* ticks */,new Runnable(){
   public void run() {
      ...
      t.fireAfter(10, this); // next iteration
   }
});
```

- But
  - Hard real-time support not available in Fiji academic release
  - Had to resort to thread.sleep()
    - Fastest sleep: 10ms

Conclusion

- Fiji allows:
  - Integration of hard real-time code into a Java app
  - Predictable, timely execution of h.r.t. code
- But:
  - No class loading / reflection
  - Memory footprint: 8.7 MB
  - Doesn't solve all of your timing problems:
    - Bus contention, OS interrupts, etc.
  - Still need to know what you're doing!

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