The Missing Benchmark Metric: Memory

#java #benchmark #JMH #memory #metrics #GC
#caching #optimizethewhole #bigpicture

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About Me

- Jens Wilke
- Performance Fan(atic)
- Author of cache2k
- 70+ answered questions on StackOverflow about Caching
- JCache / JSR107 Contributor
- Tiny contributions to JMH
- @cruftex / cruftex.net

cache2k

https://cache2k.org

Content

- Why?
- How to gather memory metrics?
- How (not) to gather memory metrics from a running JMH benchmark?
- Real benchmark results …
  …. to get a feeling whether this is worthwhile
- Happyness?!

- Please ask questions right away!

Motivation

- Compare different caching libraries in identical scenario (access sequence, cache size (entries!), CPU and JDK) with JMH
- Primary result: Throughput in **ops/s**
- But: Compare **caching libraries** and ignore memory consumption?!
- Space vs. Time trade off
- But:
  no mechanism in JMH to record memory usage metrics (yet…)

Metric: Object Graph Traversing

- EHCache sizeof
- Java Agent for Memory Measurements

Pro:

- No actual usage long running benchmark needed, just fill up the data scructures
- No complex setup (dedicated hardware)

Con:

- How to choose the root object / traverse the whole heap?
- Static result
- heap objects only
- Needs time

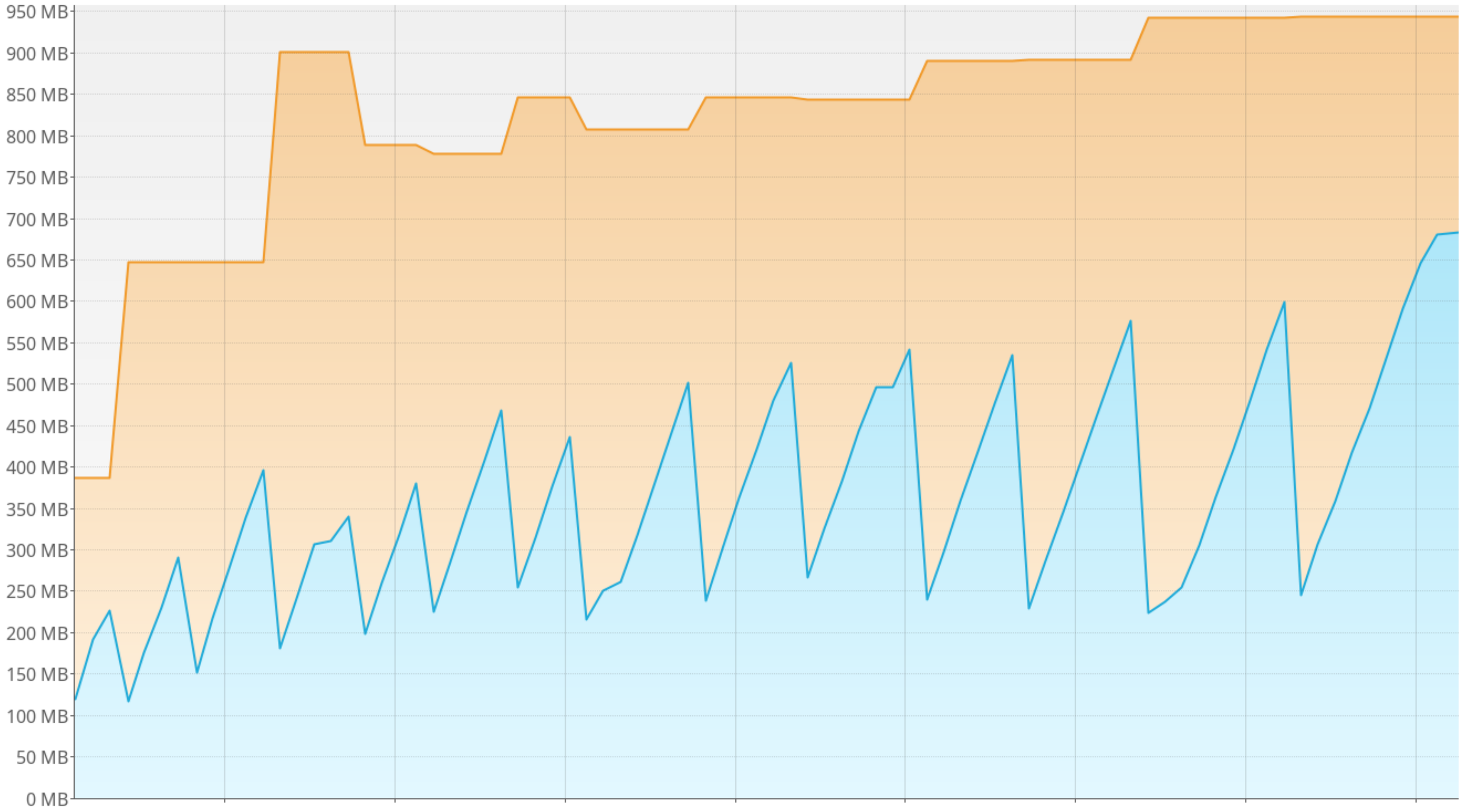
Metric: Heap Dump / Heap Historgram

- e.g. use jmap to get a heap dump or histogram

  Pro:
  - Same as before, we don‘t need a real benchmark run
  - Accurate value of used heap space
  - Additional information in the histogram or dump

  Con:
  - Costly
  - Static value of heap objects only

Let it Run!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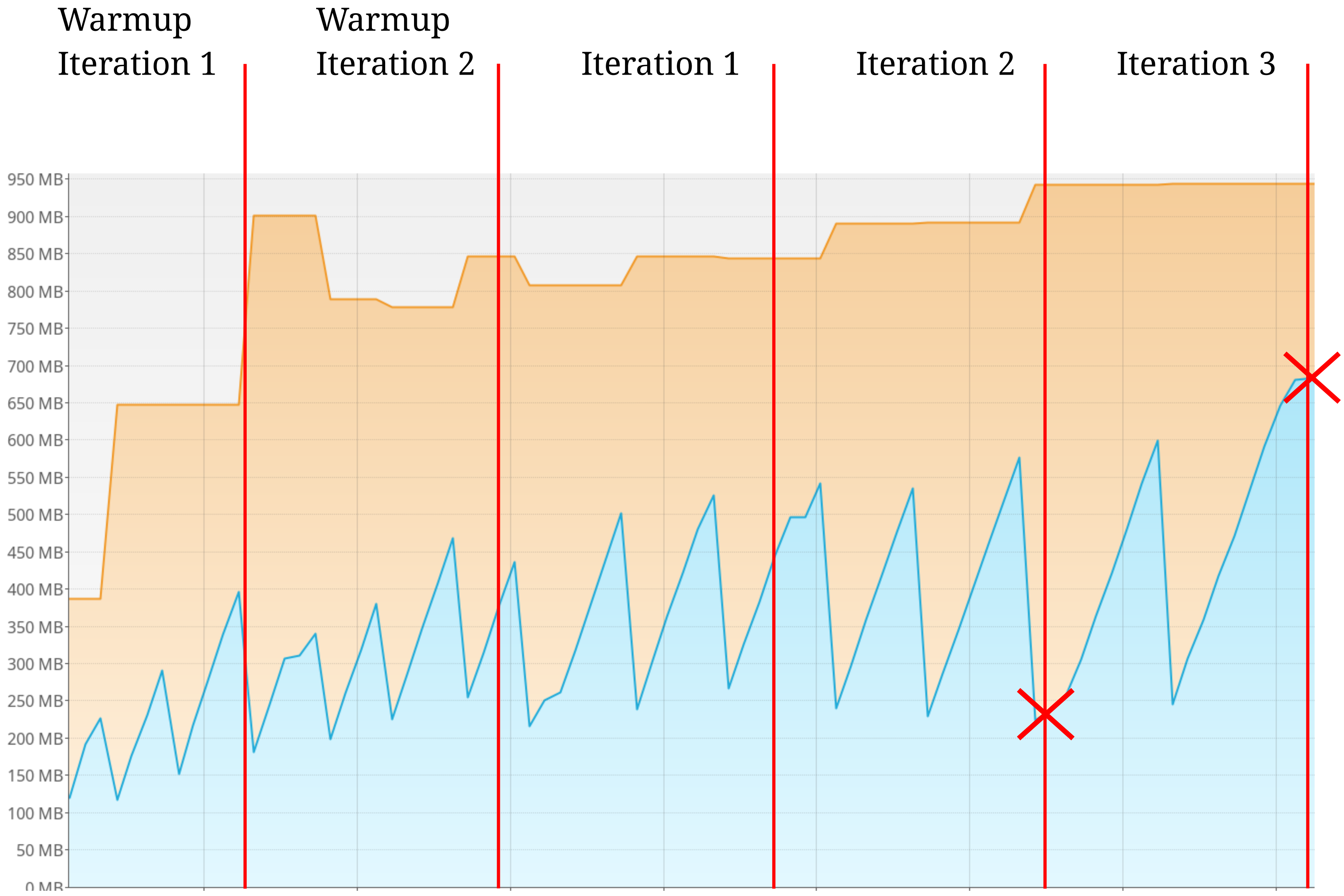
How to Extract a (single) Metric?



Warmup Iteration 1

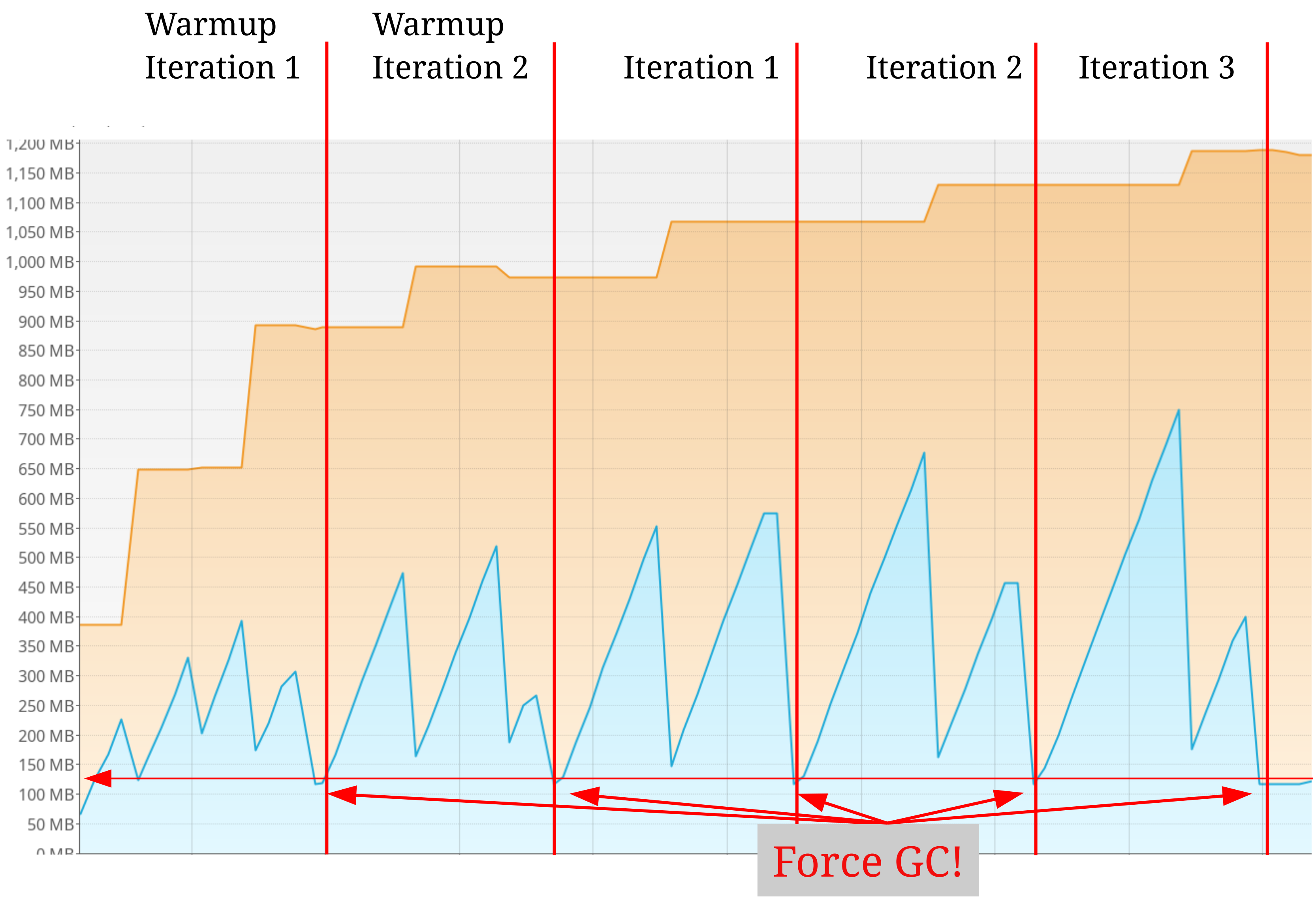
Warmup Iteration 2

Iteration 1

Iteration 2

Iteration 3

Fore GC?



Warmup Iteration 1

Warmup Iteration 2

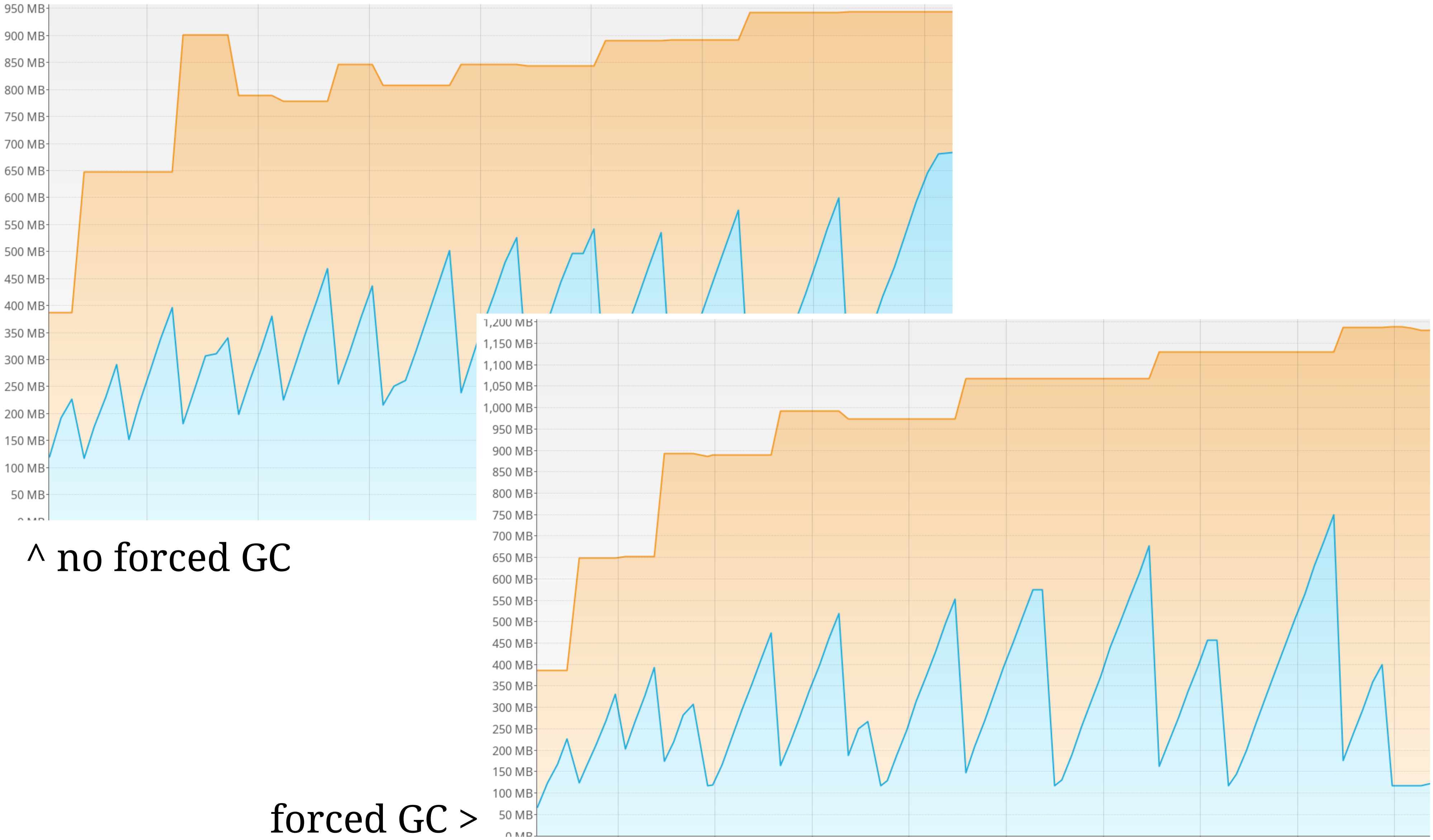
Iteration 1

Iteration 2

Iteration 3

Force GC!

Side to Side Comparison



^ no forced GC

forced GC >

Wait a minute….

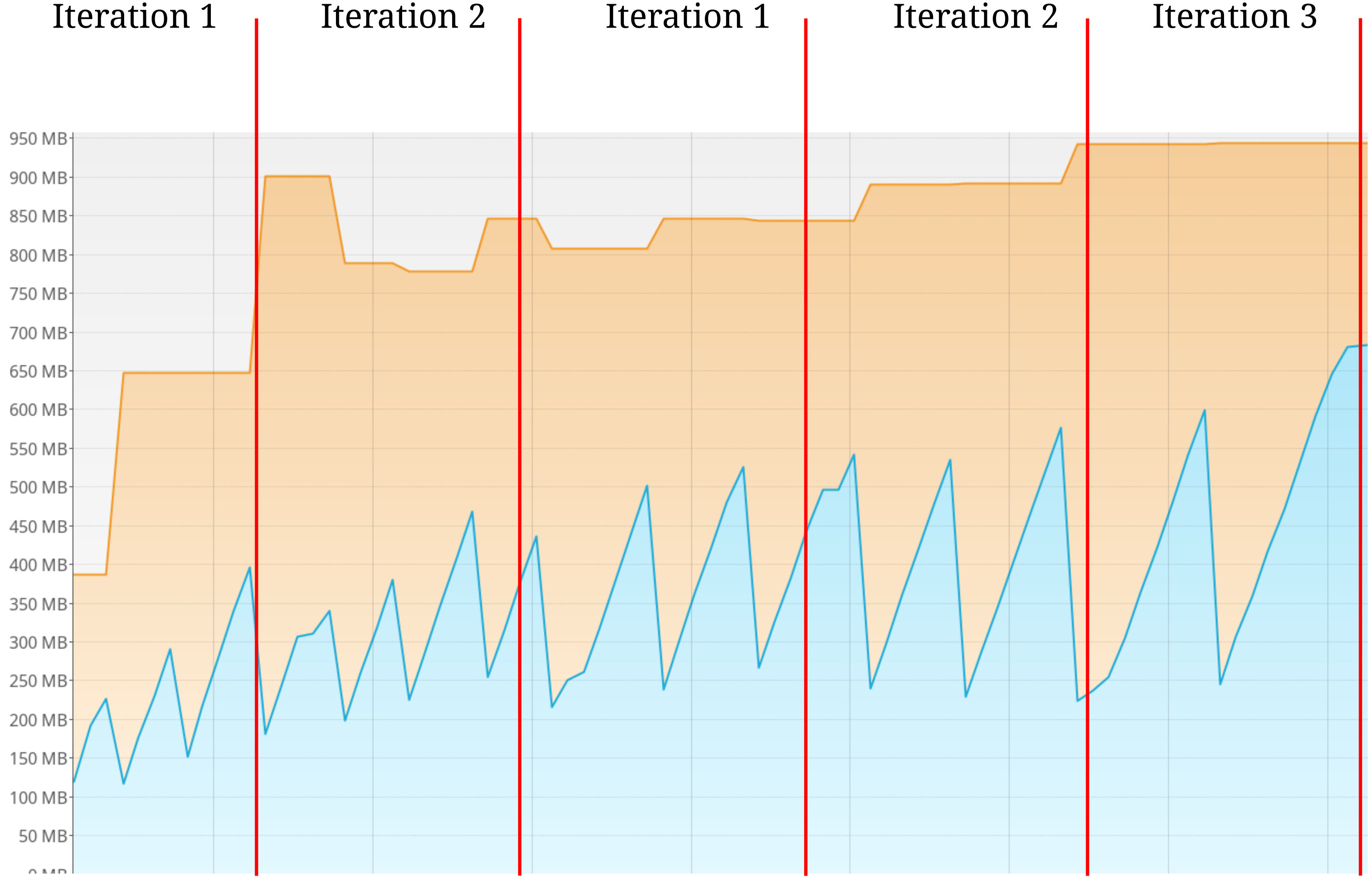
Warmup
Iteration 1

Warmup
Iteration 2

Iteration 1

Iteration 2

Iteration 3



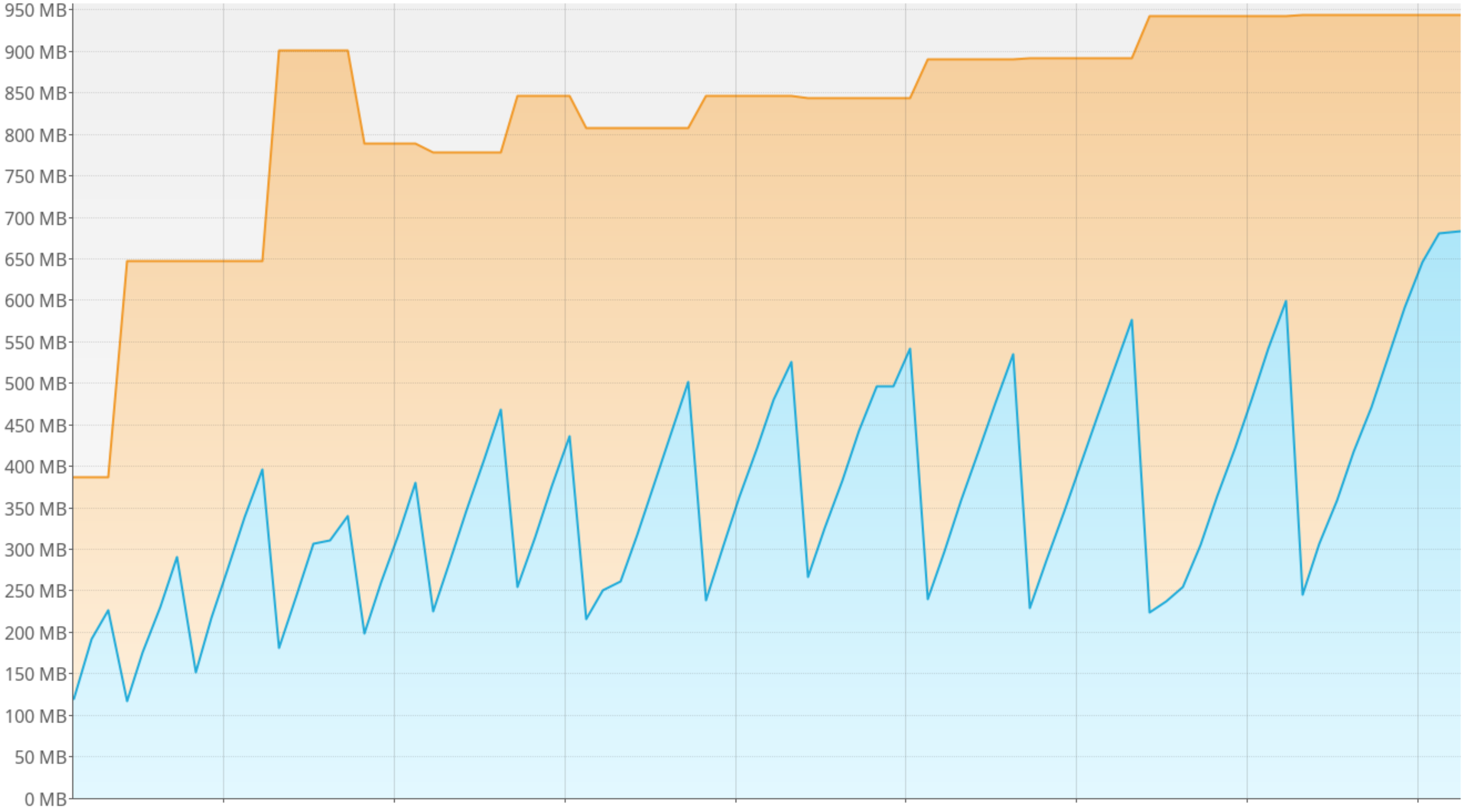
Sidenote:
GC and Micro Benchmarks

- Micro-Microbenchmark: GC might happen during an iteration
  - Single GC occurence causes skewed result
  - Use JMH parameter `-gc true` or Zero GC

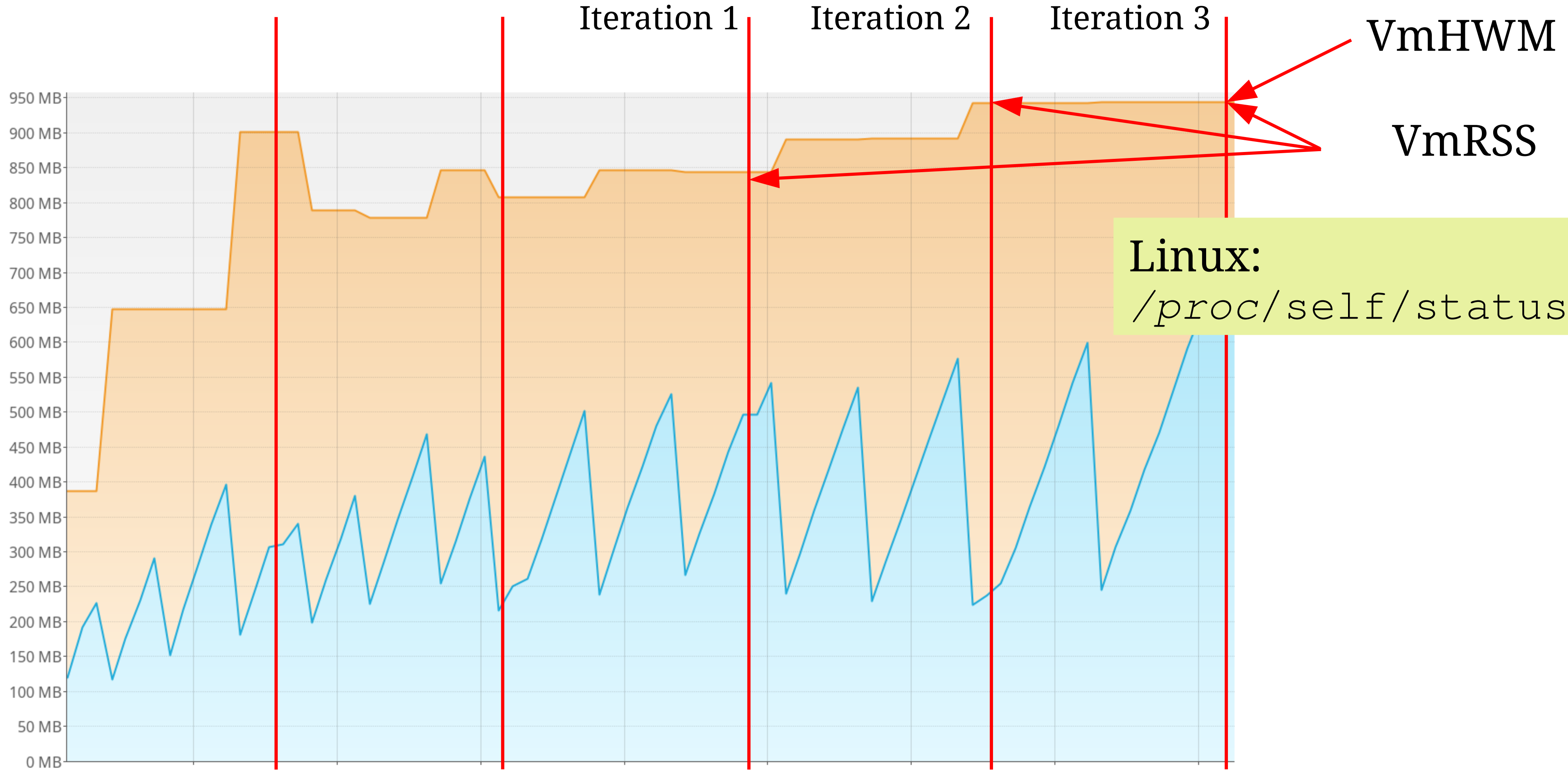
  => Get garbage collector out of the equation
- NotSo-Microbenchmark: GC happens always during an iteration
  - Make sure a lot of GCs happen, JMH parameter: `-prof gc`
  - Increase warmup and iteration time
  - „Know your GC“ ↔ „Get to know your GC“

  => You cannot avoid the GC. Make it go steady.

A Metric? Some Metrics!



Linux OS Metrics: VmRSS, VmHWM



Iteration 1

Iteration 2

Iteration 3

VmHWM

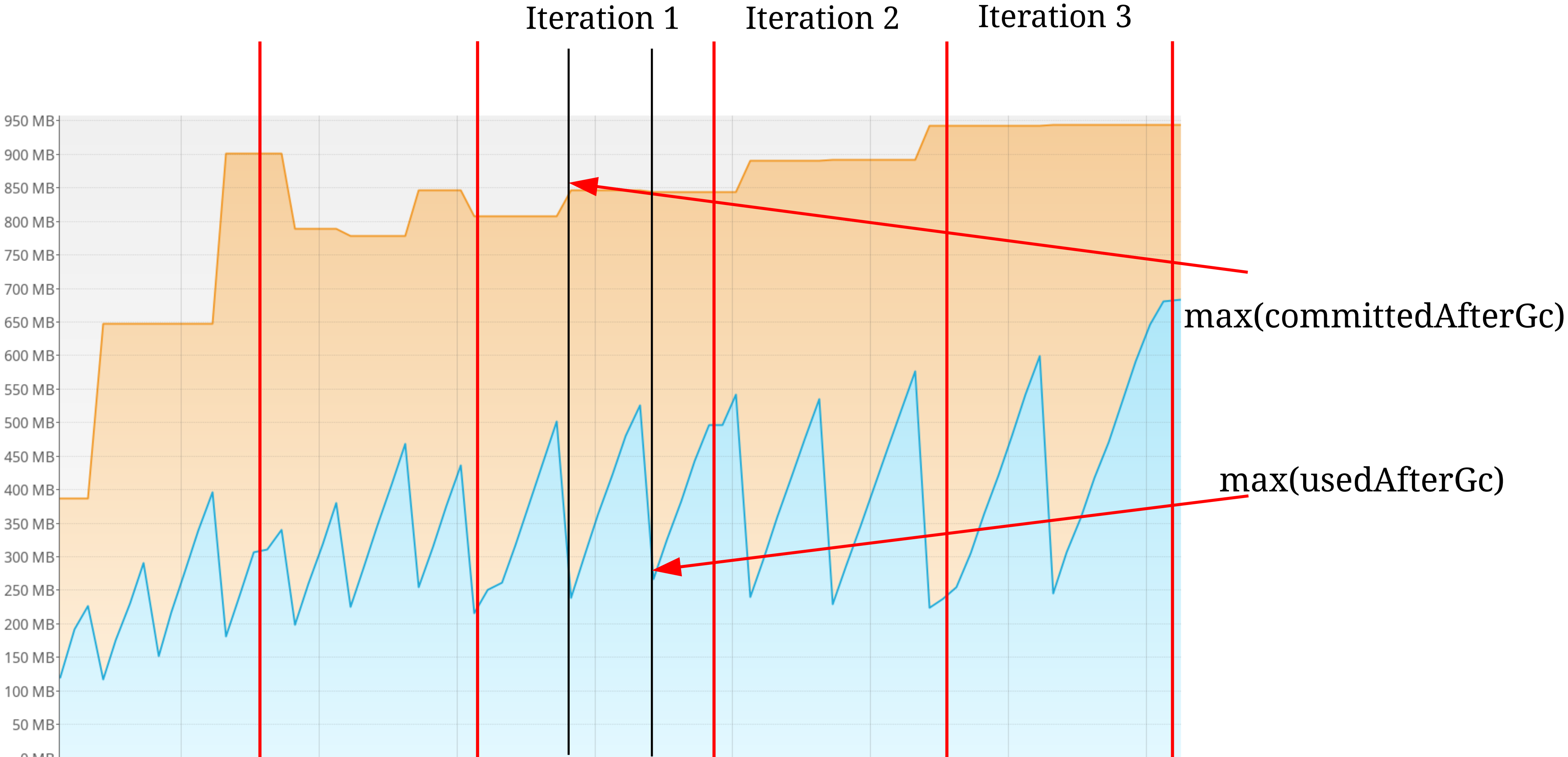
VmRSS

Linux:
`/proc/self/status`

GC Notifications

- Notification after GC run (via `GarbageCollectionNotificationInfo`)
- Contains memory usage before and after GC

  (examples only shows notification in iteration 2)

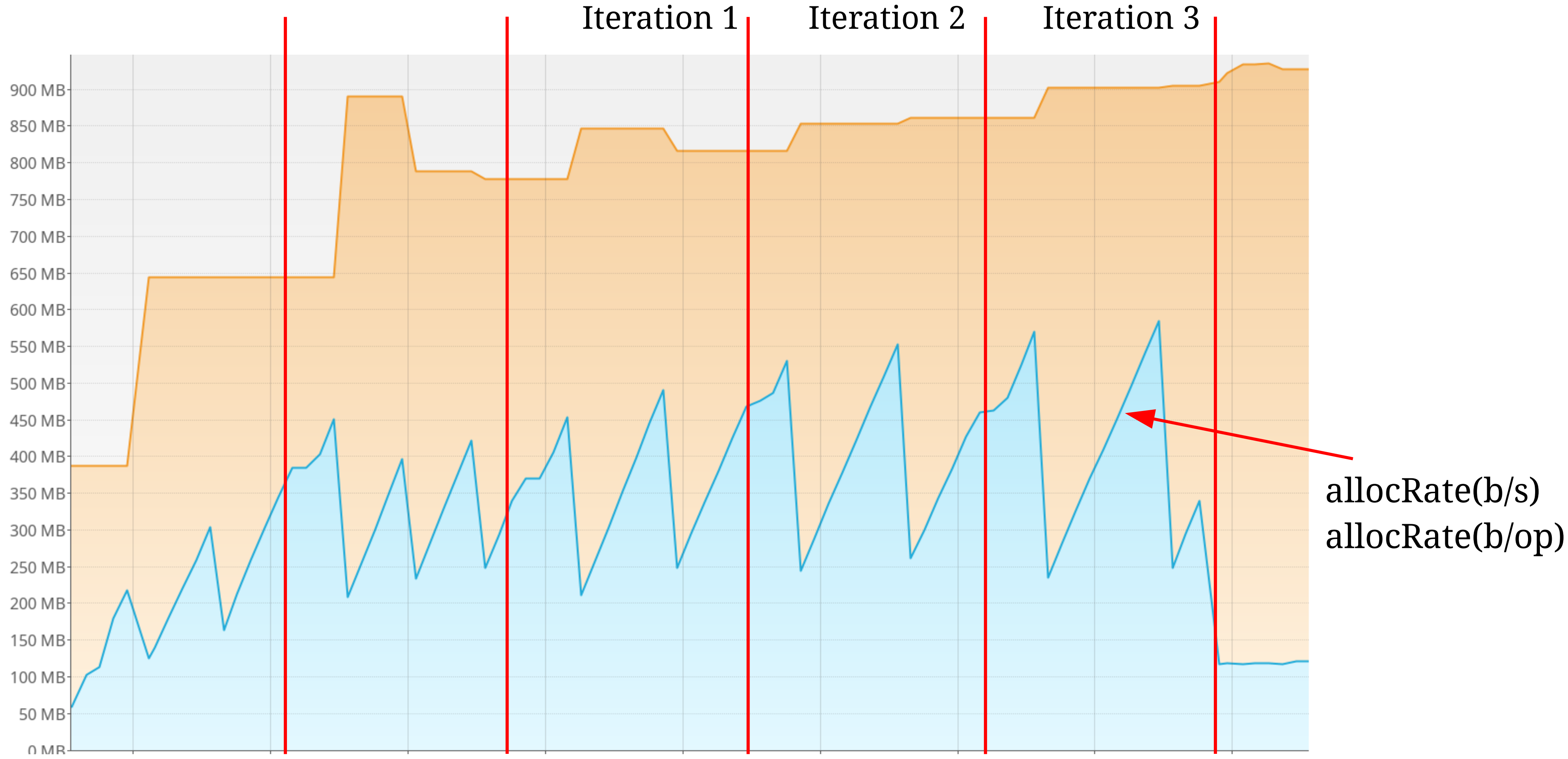


Iteration 1 Iteration 2 Iteration 3

max(committedAfterGc)

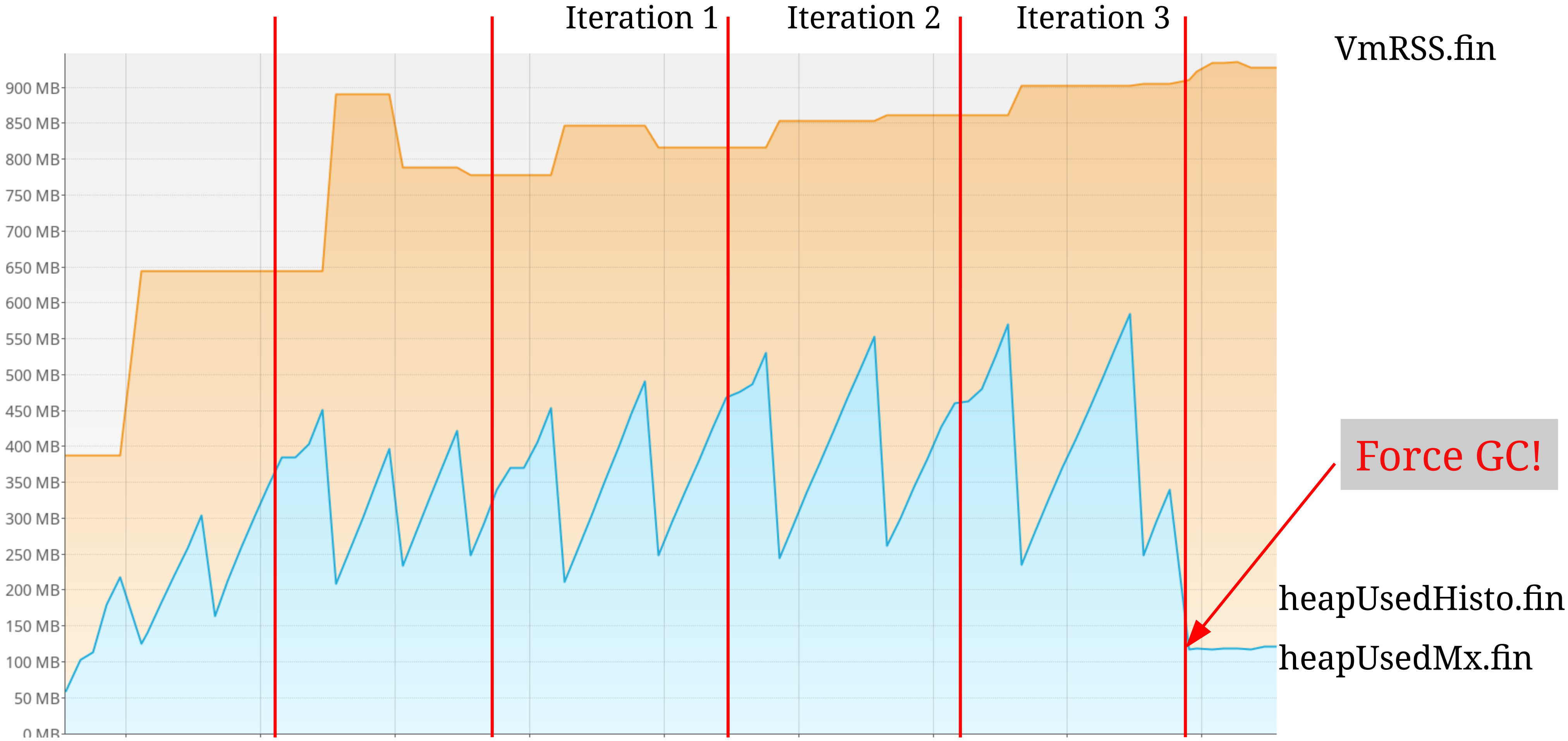
max(usedAfterGc)

Allocation Rate



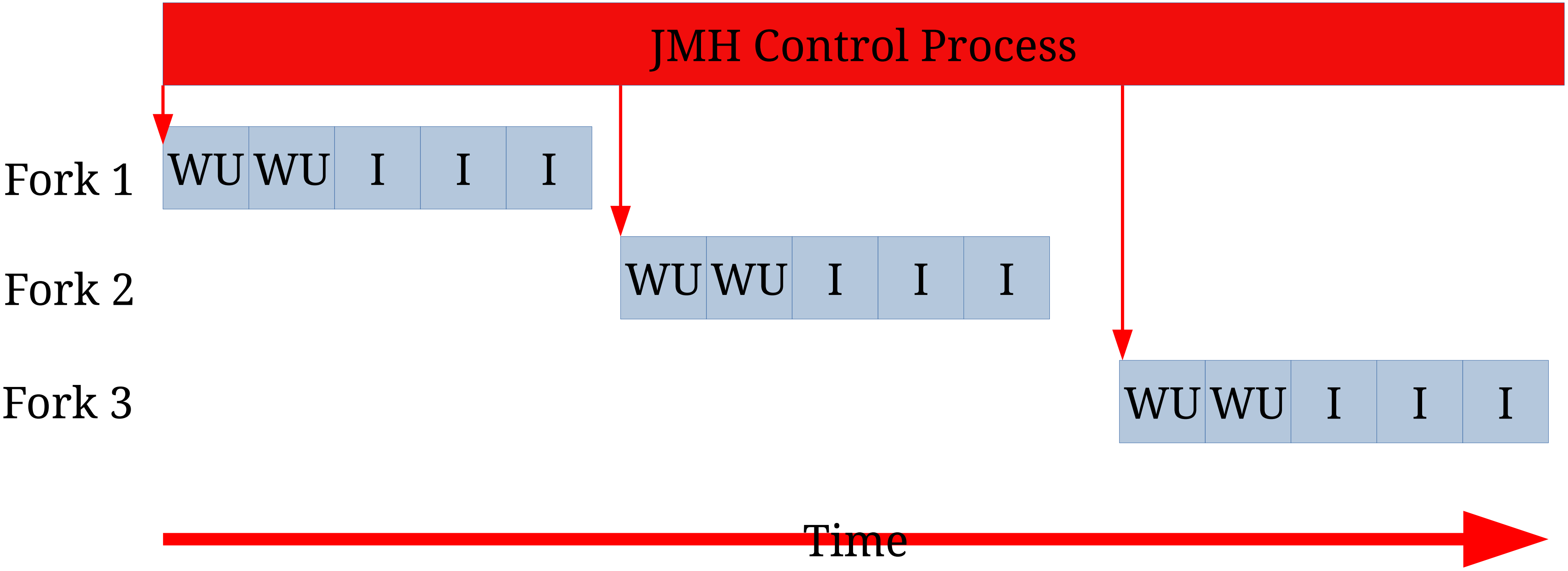
Minimal Memory at the End

- JMH can run multiple VMs after another (forks)
- at end of each fork the invasive collectors could happen (force GC, heap histogram)



Example JMH Running Scheme

- JMH can run multiple VMs after another (forks)
- 9 iterations to collect results
- 3 forks, at end of each fork the invasive collectors happen (force GC, heap histogram)
- Parameters: `-f 3 -wi 3 -i 3`



Results

JMH Benchmark

```
public int factor = 5;
public int entryCount = 100_000;

@State(Scope.Thread)
public static class ThreadState {

  ZipfianPattern pattern;

  @Setup(Level.Iteration)
  public void setup(ZipfianSequenceLoadingBenchmark benchmark) {
    pattern = new ZipfianPattern(benchmark.offsetSeed.nextLong(),
      benchmark.entryCount * benchmark.factor);
  }

}

@Benchmark @BenchmarkMode(Mode.Throughput)
public long operation(ThreadState threadState, HitCountRecorder rec) {
  // TODO: JMH should return the raw number of operations somewhere...
  rec.opCount++;
  Integer v = cache.get(threadState.pattern.next());
  return v;
}

public Integer load(final Integer key) {
  missCount.increment();
  Blackhole.consumeCPU(1000);
  return key * 2 + 11;
}
```

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(fast) Zipfian sequence generator per thread

Skewed random pattern, yields around 90% hitrate

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On miss, cache will invoke a load function(read-trough)

Load function has penalty, via Blackhole.consumeCPU()

=> a lot can happens on cache.get()

=> Cache eviction and autoboxing

Benchmark Setup

Environment:

- CPU: Intel(R) Xeon(R) CPU E3-1240 v5 @ 3.50GHz, **4 physical cores**
  - Benchmarks run with 4 thread, 4 cores (limited via CPU hotplug)
- Oracle JDK 11, PrallelGC and G1
- Ubuntu 18.04

Cache Library Versions:

- Google Guava Cache, Version 26
- Caffeine, Version 2.6.2
- cache2k, Version 1.2.0.Final
- EHCache, Version 3.6.1

Code is at:

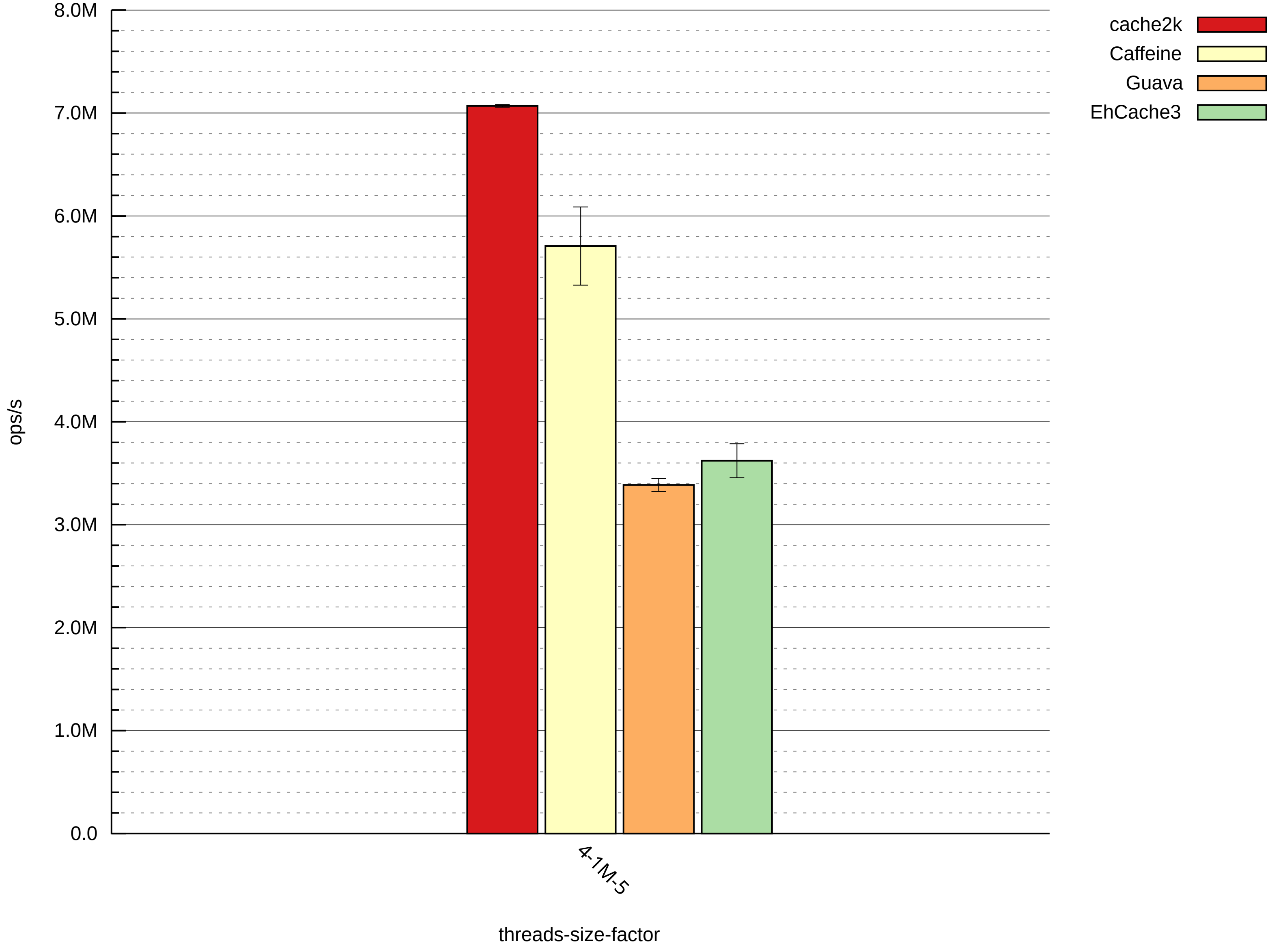
https://github.com/cache2k/cache2k-benchmark

JMH Parameters

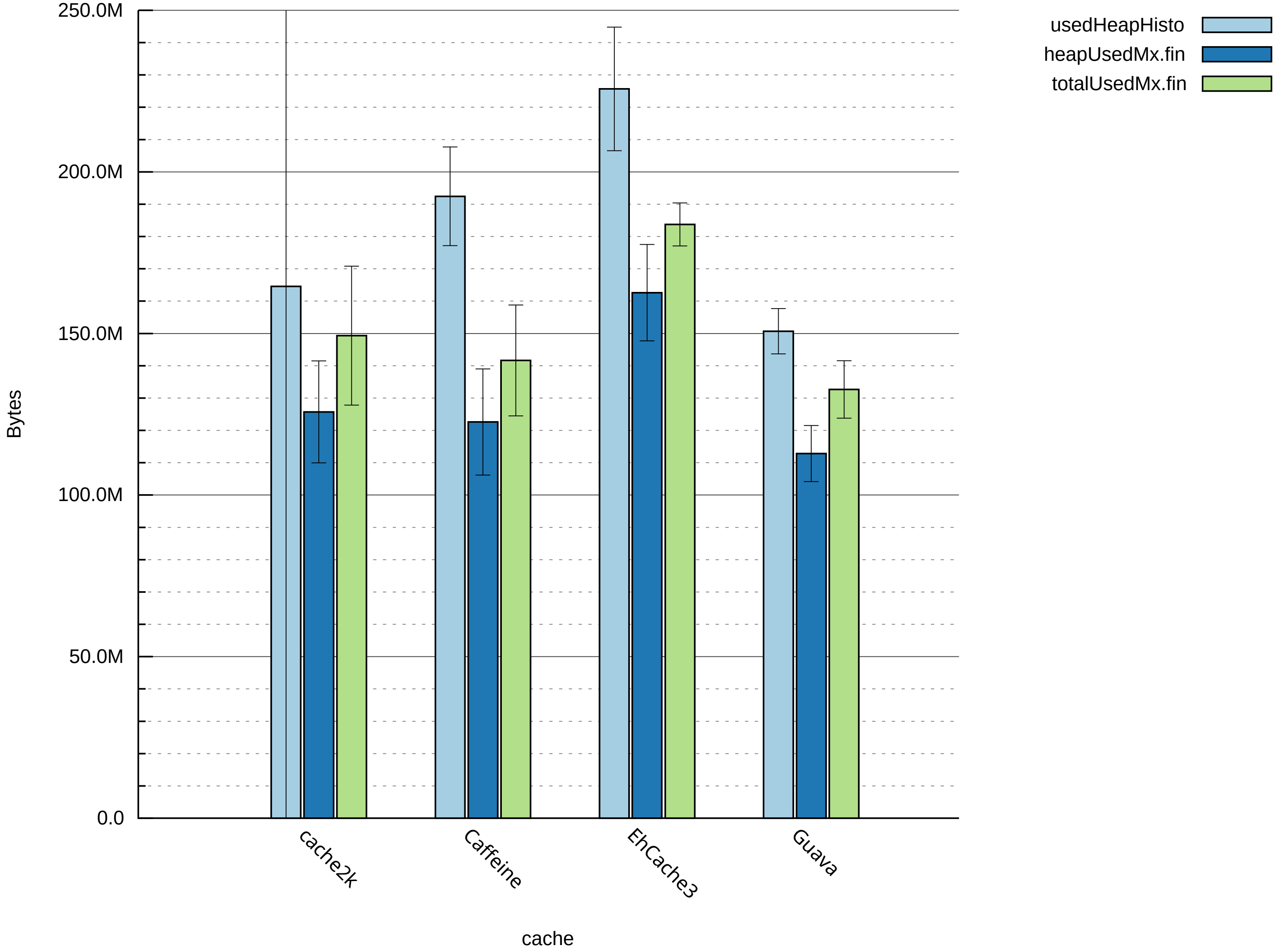
- JMH Parameters:
  - 3 forks, 2 warmup iterations, 3 measurement iterations, 60 seconds iterations time

  => 9 measurement iterations
- Graphs show the confidence interval
- Confidence interval is at 99.9% confidence level!

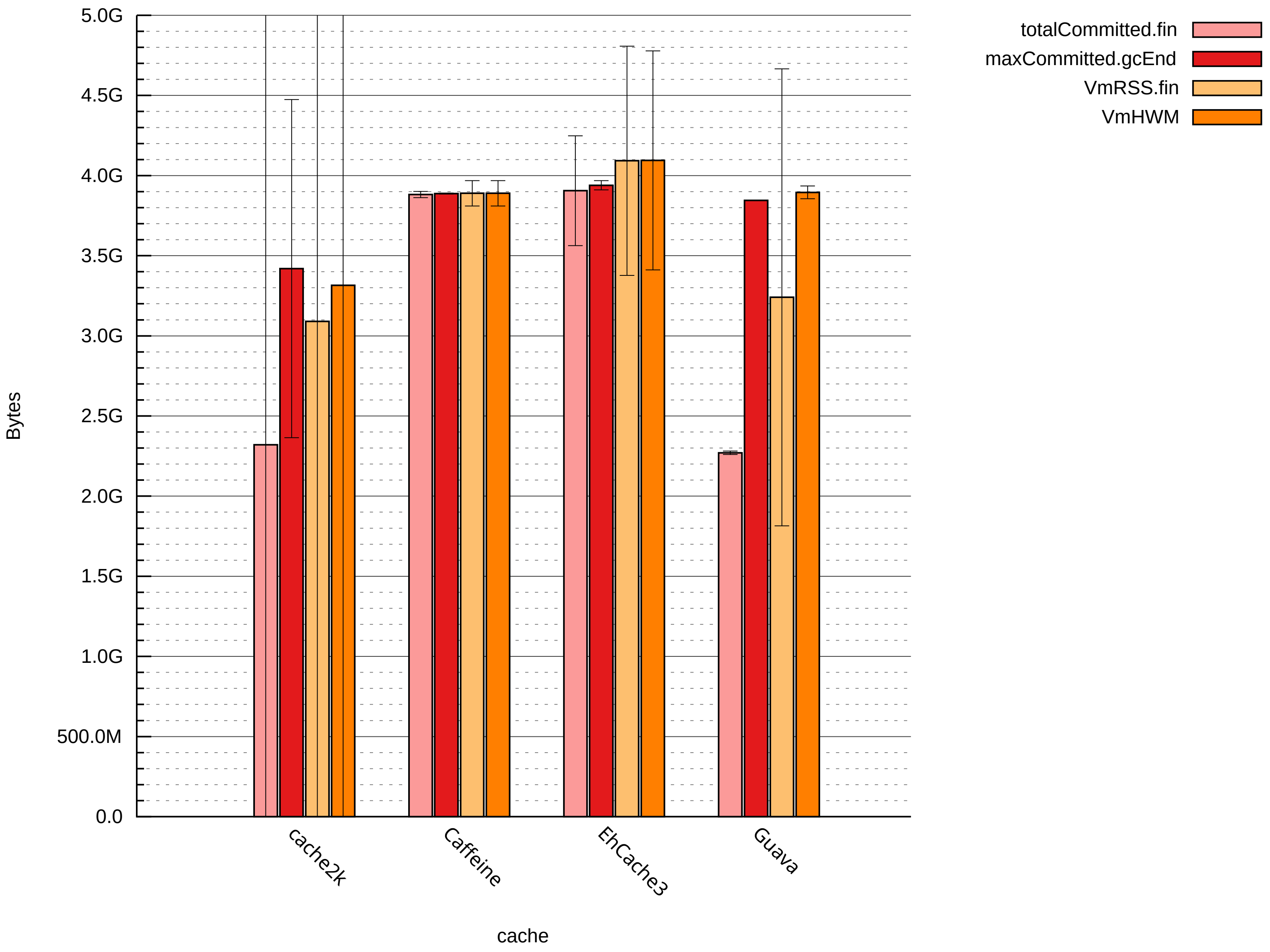
Parllel GC: ops/s



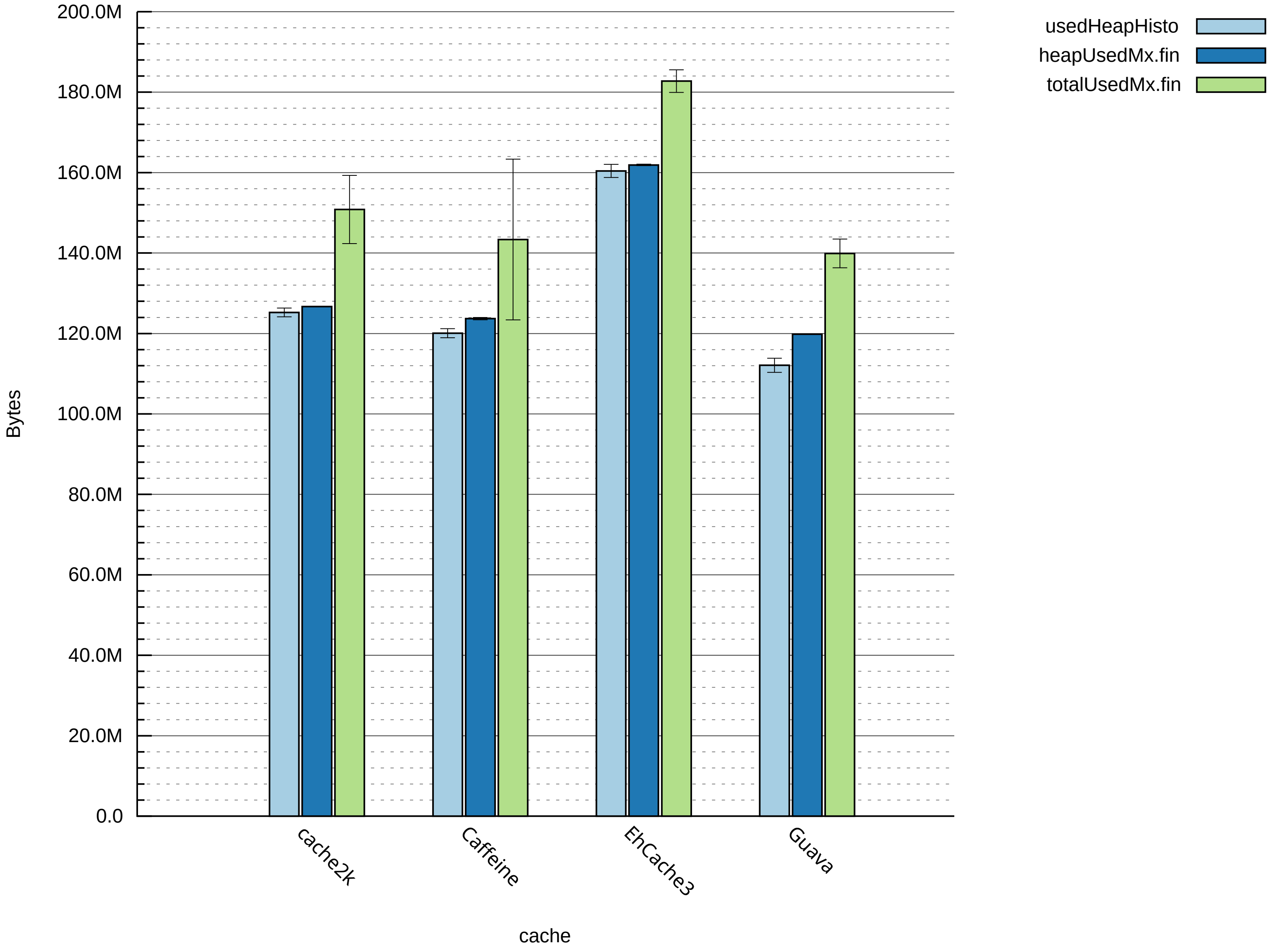
Parallel GC: heap usage



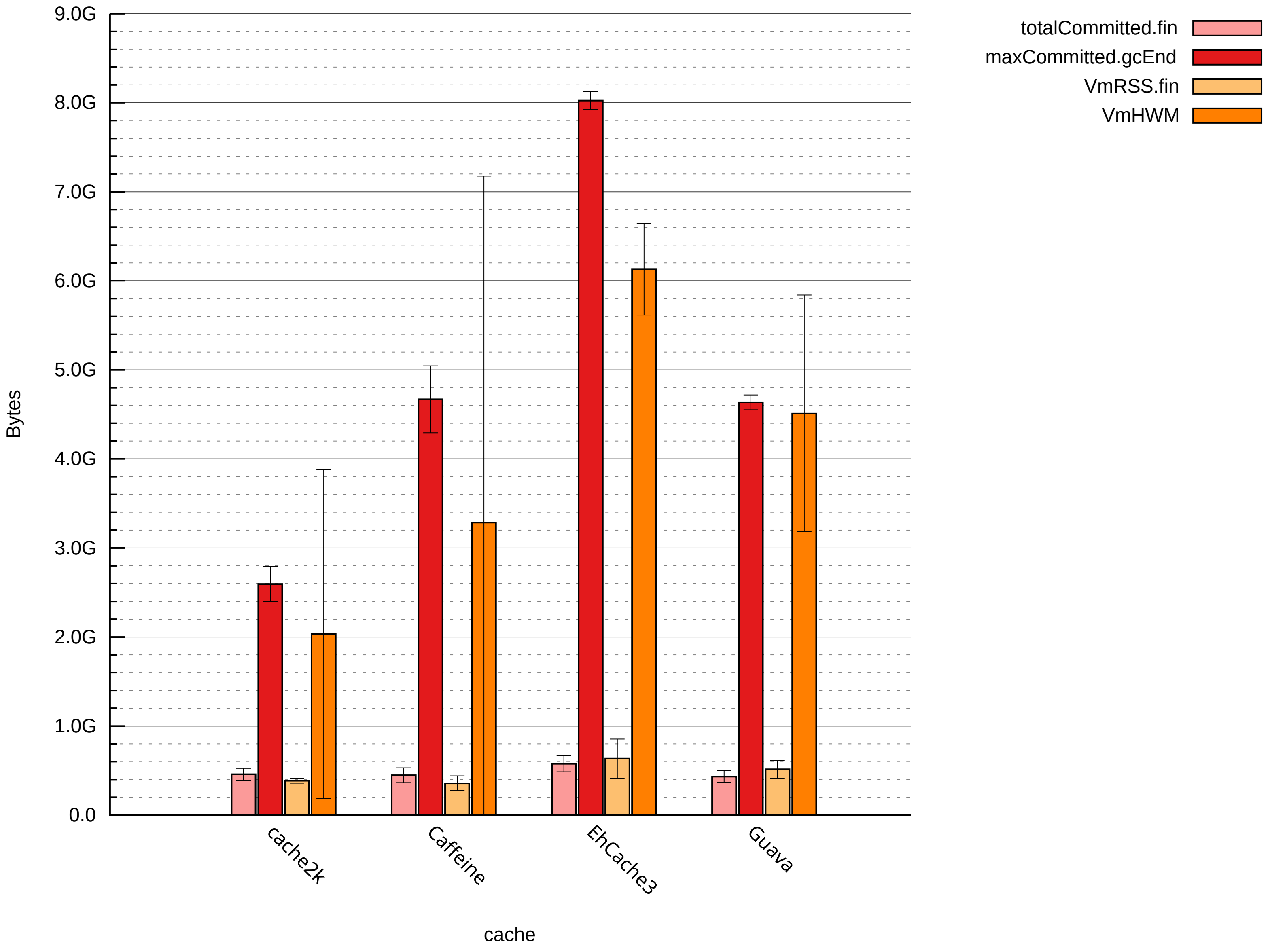
Parallel GC: Total / RSS



G1: heap usage

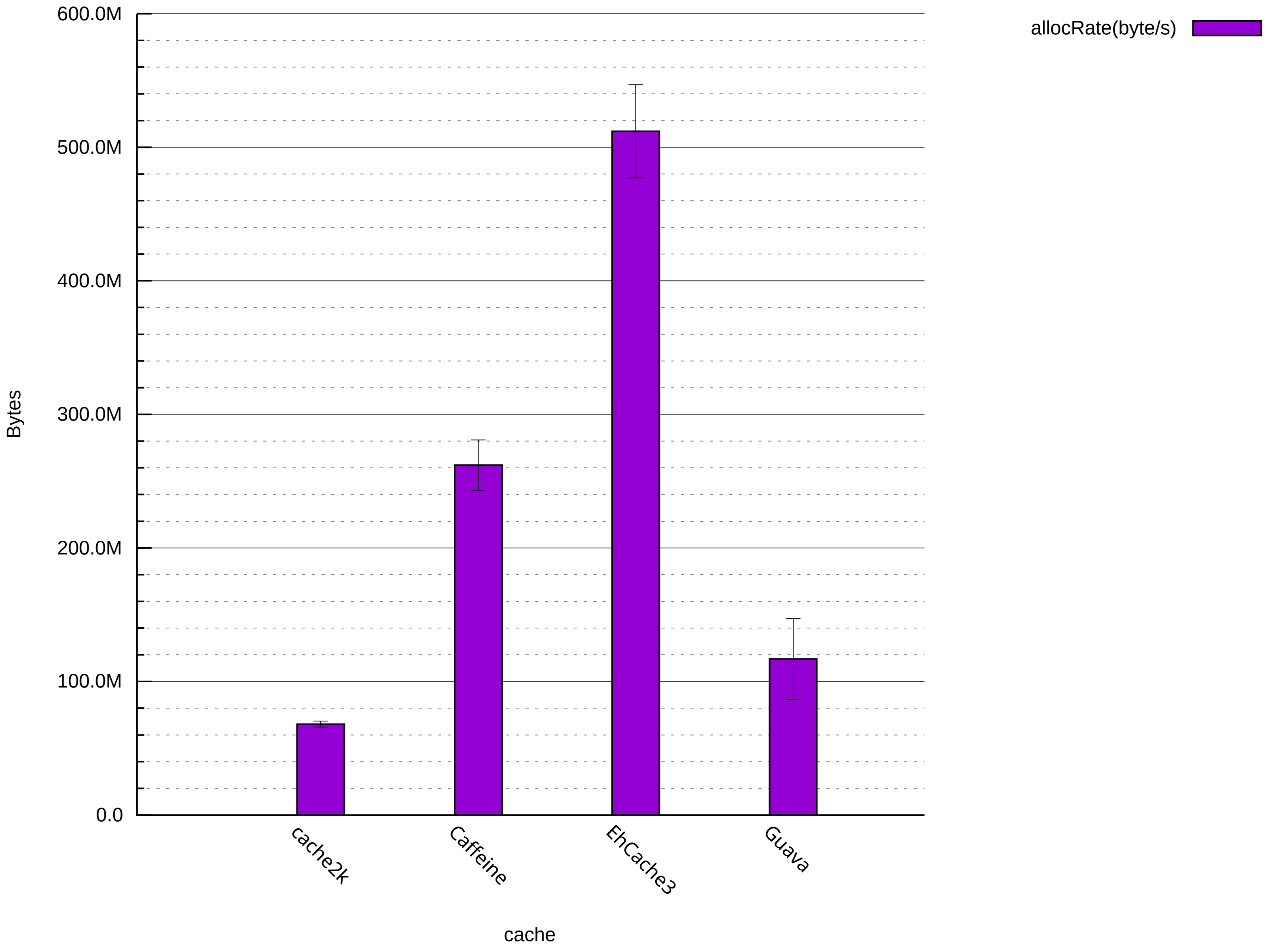


G1: Total / RSS

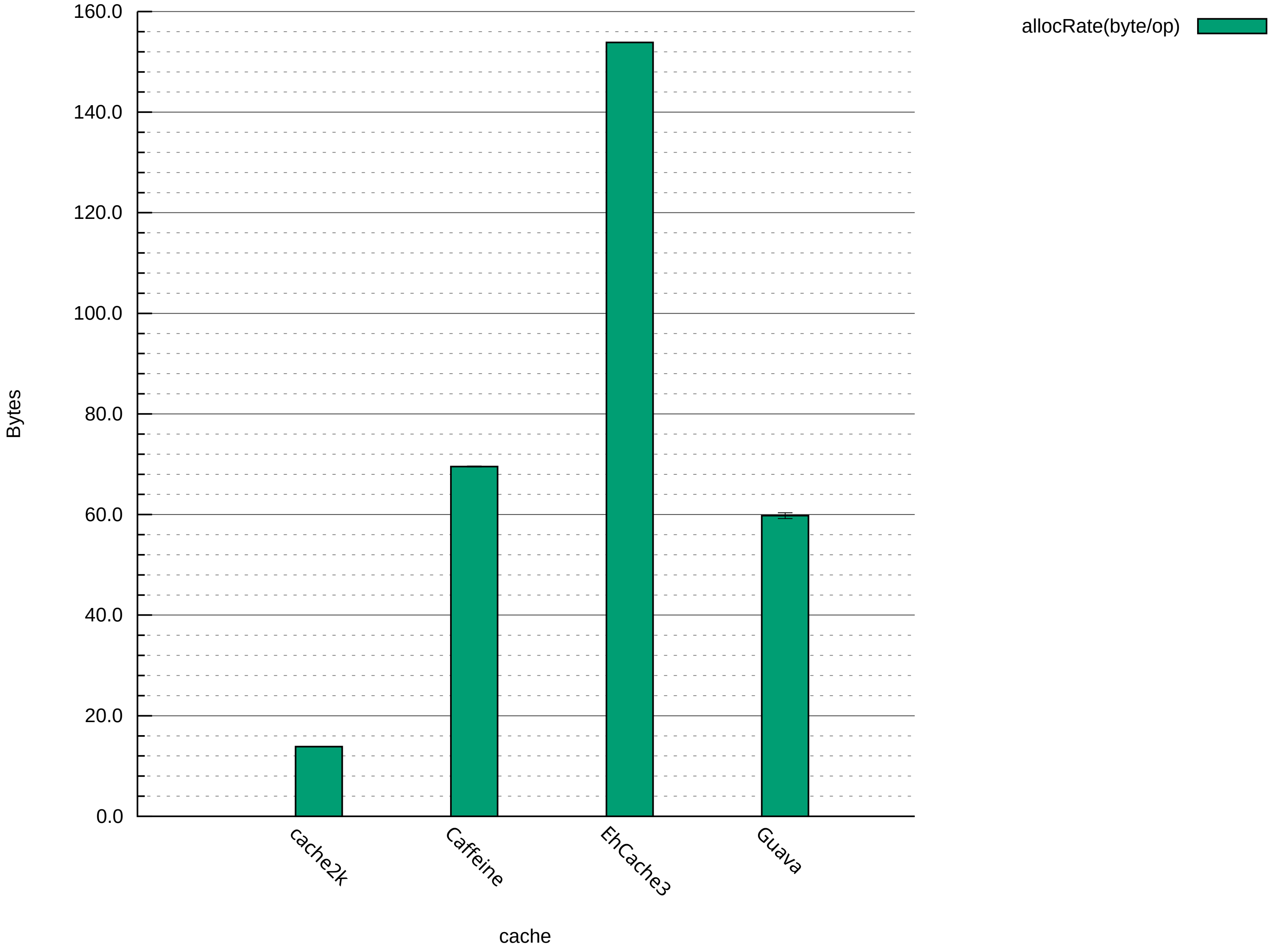


totalCommitted.fin
maxCommitted.gcEnd
VmRSS.fin
VmHWM
Bytes
9.0G
8.0G
7.0G
6.0G
5.0G
4.0G
3.0G
2.0G
1.0G
0.0
cache2k
Caffeine
EhCache3
Guava
cache

G1: allocation rate op/s



G1: allocation rate byte/op



Conclusion

- If GC is happening, also record memory usage in your JMH results
- JVM / OS memory metrics can be utilized, with varying degree of truth and consistency
- If GC is happening, your „micro“benchmarks need to run longer => Bigger heap, longer running time
- JMH can also be used to construct benchmarks to evaluate (peak) memory consumptions
- Be aware of the different GC implementations and behaviors

Thanks & Enjoy Live!

- JMH extensions available at: `github.com/cache2k/cache2k-benchmark`
  - `ForcedGcMemoryProfiler`
  - `LinuxVmProfiler`
  - Allocation rate via: `-prof gc`
- Plan/idea: discuss and add it into the JMH code base
- Please like:

  `github.com/cache2k/cache2k`

Notes

- How to start visualvm with bigger font size to make screenshots:

  ```
  visualvm -J-Dsun.java2d.uiScale=1.0 --fontsize 18
  ```

- First VisualVm heap graph from:

  ```
  java-11 -jar jmh-suite/target/benchmarks.jar \\.ZipfianSequenceLoadingBenchmark -jvmArgs -server\ -Xmx10G\ -XX:BiasedLockingStartupDelay=0\ -verbose:gc\ -XX:+UseParallelGC -f 1 -wi -w 15s -i 3 -r 15s -prof comp -prof gc -prof hs_rt -prof hs_gc -prof org.cache2k.benchmark.jmh.LinuxVmProfiler -prof org.cache2k.benchmark.jmh.MiscResultRecorderProfiler -prof org.cache2k.benchmark.jmh.GcProfiler -t 4 -p factor=5 -p entryCount=1000000 -p cacheFactory=org.cache2k.benchmark.Cache2kFactory -rf json -rff /run/shm/jmh-result/result-Cache2kFactory-ZipfianSequenceLoadingBenchmark-4.json
  ```

- Second VisualVm heap graph, additional parameters:

  ```
  -prof org.cache2k.benchmark.jmh.ForcedGcMemoryProfiler -gc true
  ```