Low Pause Garbage Collection in HotSpot

John Oliver - john@jclarity.com

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Outline

Introduction

What are our goals.

- Control pause times
- Control heap size
- Control throughput
- Not OOM

What HotSpot GCs are there.

- Serial
- Parallel
- CMS
- iCMS
- G1
- Shenandoah

State of Java GC

Recent Changes

Permgen to Metaspace.

- Permanent stuff is now held in native space
- Simplify configuration
- JEP 156: G1 GC: Reduce need for full GCs
- Strings moved to the heap
- Can tune with:
  - **–XX:MaxMetaspaceSize**
  - **–XX:MetaspaceSize**

G1 Ready

- Stabilised
- Producing consistent results
- Not crashing

Future

The future of GC

- JEP 248: Make G1 the Default Garbage Collector
  - Fundamentally changes the default behavior from high throughput to low pause
- JEP 192: String Deduplication in G1

The future of GC

- JEP 189: Shenandoah: An Ultra-Low-Pause-Time Garbage Collector

Remove Old GC combinations

- JEP 173: Retire Some Rarely-Used GC Combinations
- JEP 214: Remove GC Combinations Deprecated in JDK 8
  - DefNew + CMS
  - ParNew + SerialOld
  - Incremental CMS

Speculative

- JEP draft: Parallelize the Full GC Phase in CMS
  - `https://bugs.openjdk.java.net/browse/JDK-8130200`
- JEP 271: Unified GC Logging

Under The Hood

Other Collectors

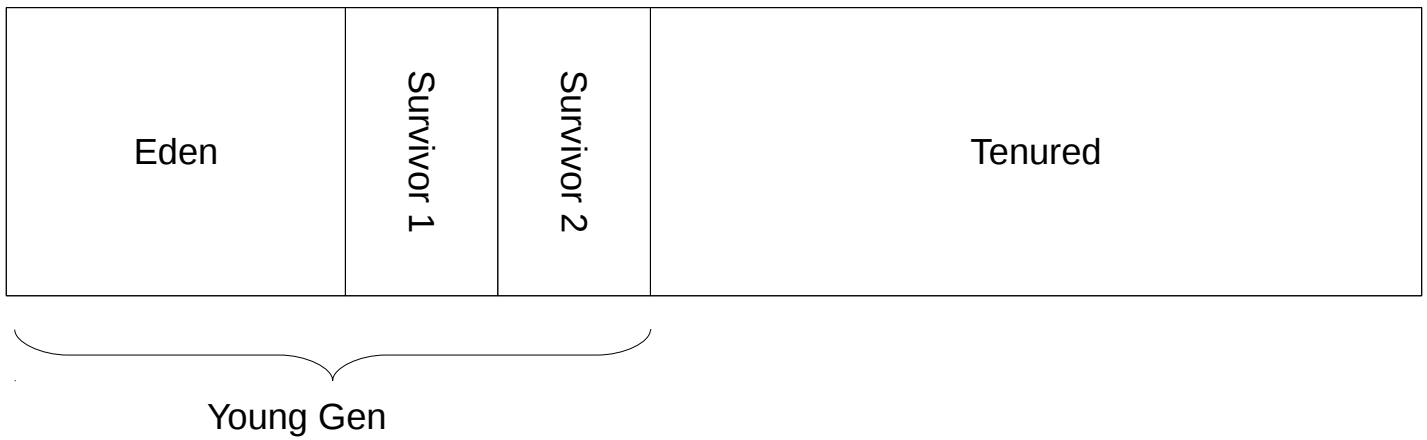
Parallel - High throughput
CMS - Low pause

G1

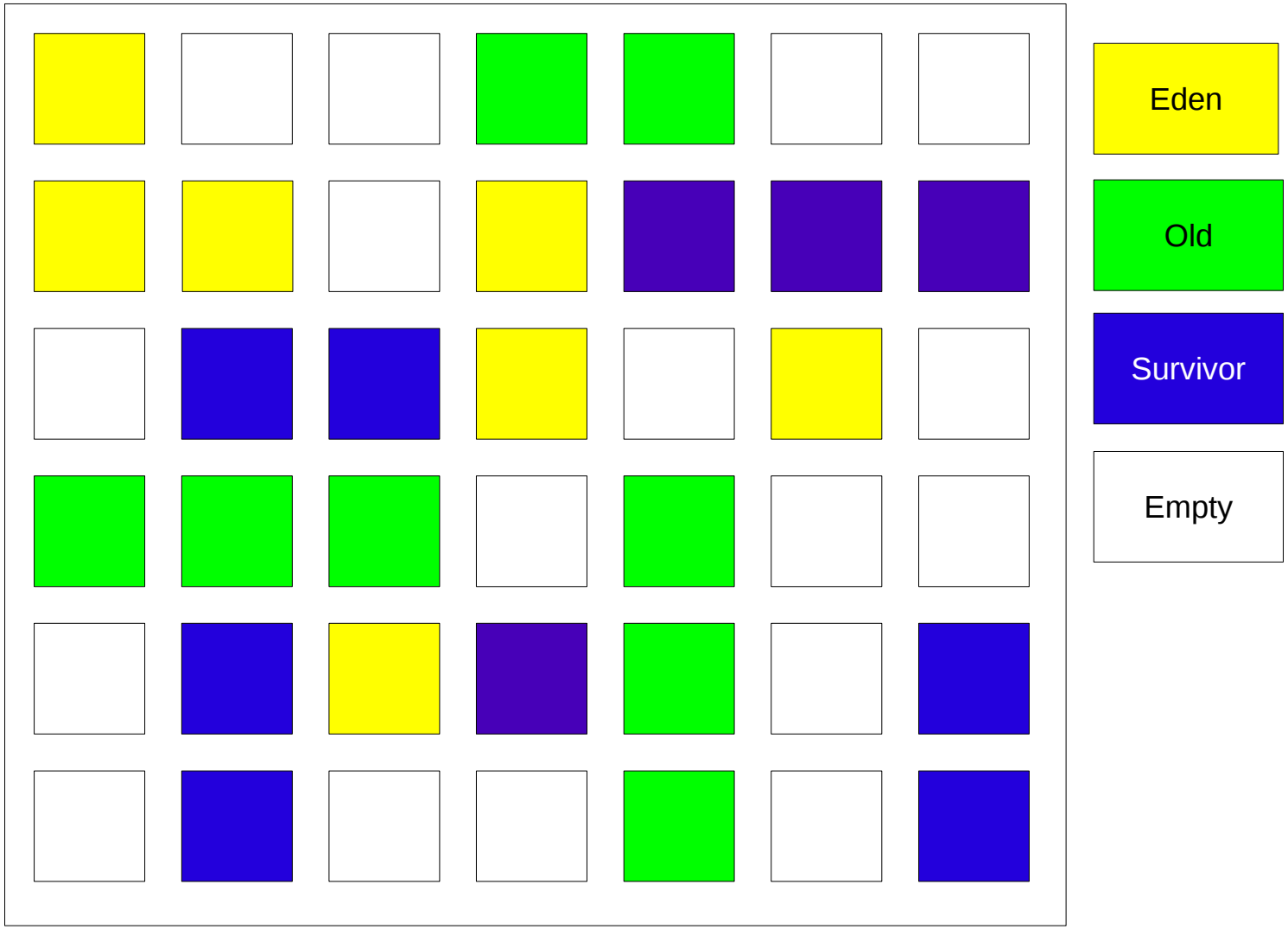
The Rise of G1

- Easier to tune (-**XX:MaxGCPauseMillis=N**)
- Can set pause goals
- Compacting

Heap Layout And GC



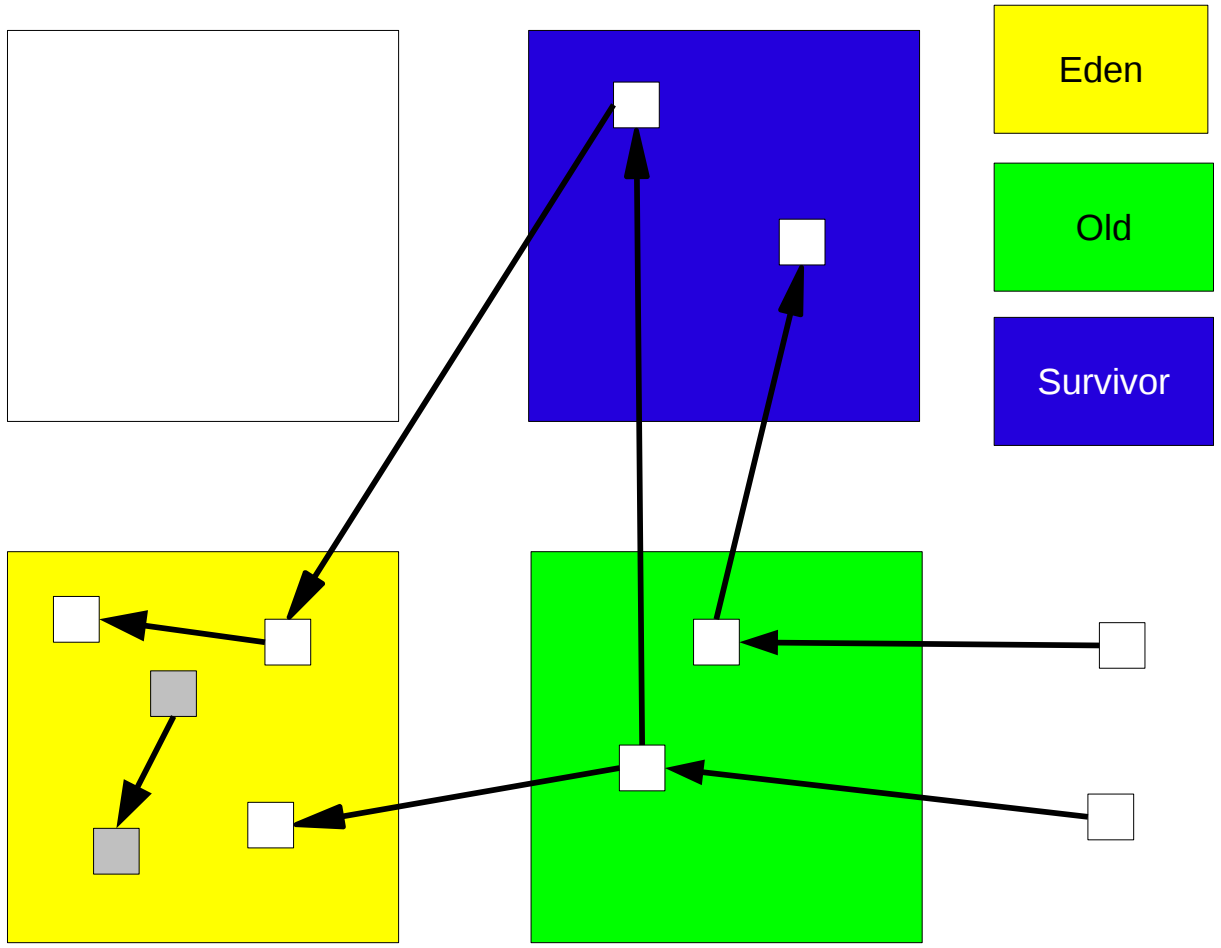
G1 Heap



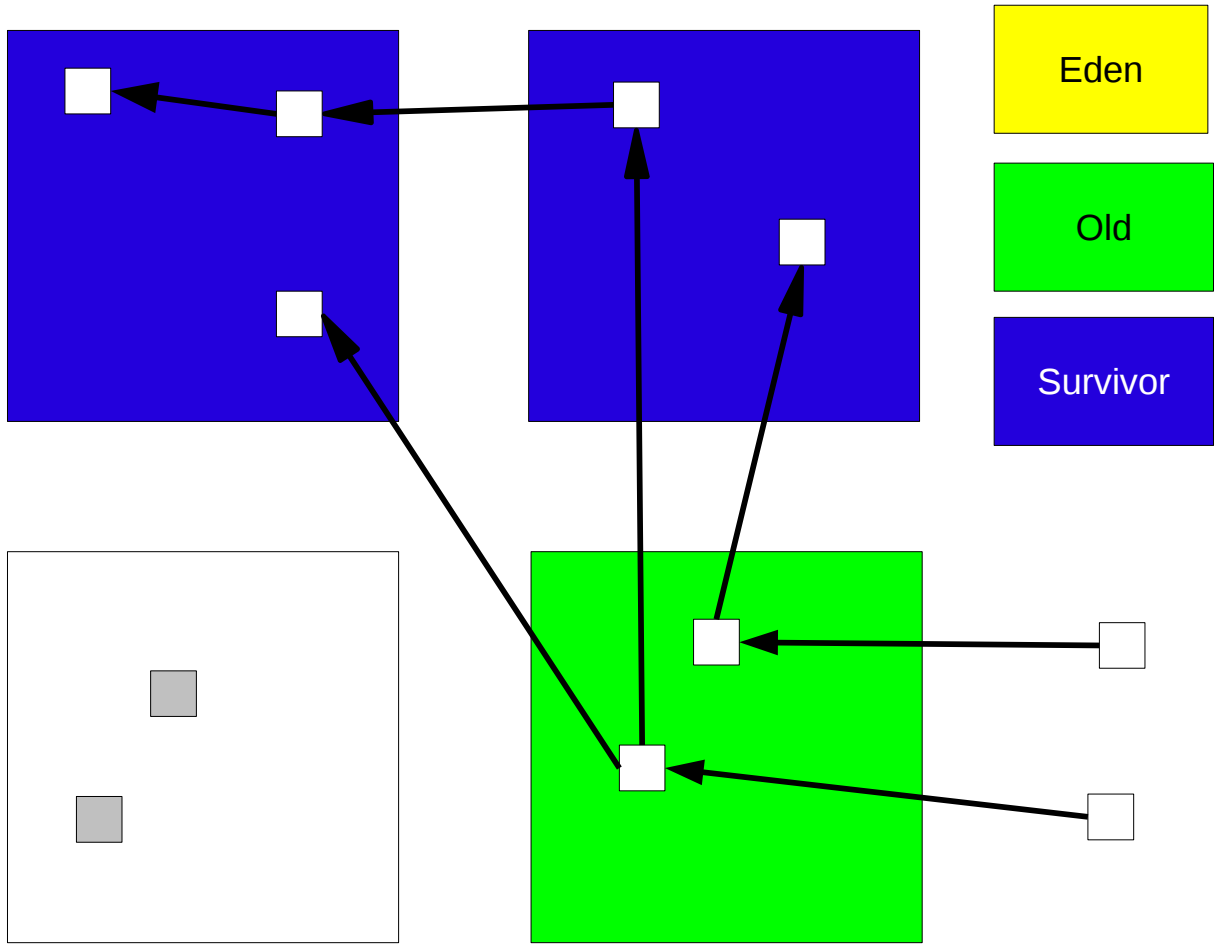
G1 How it works

- Mark and evacuate style
- Snapshot at the beginning
  - Scan from roots
  - Track mutations in the graph

G1 Heap



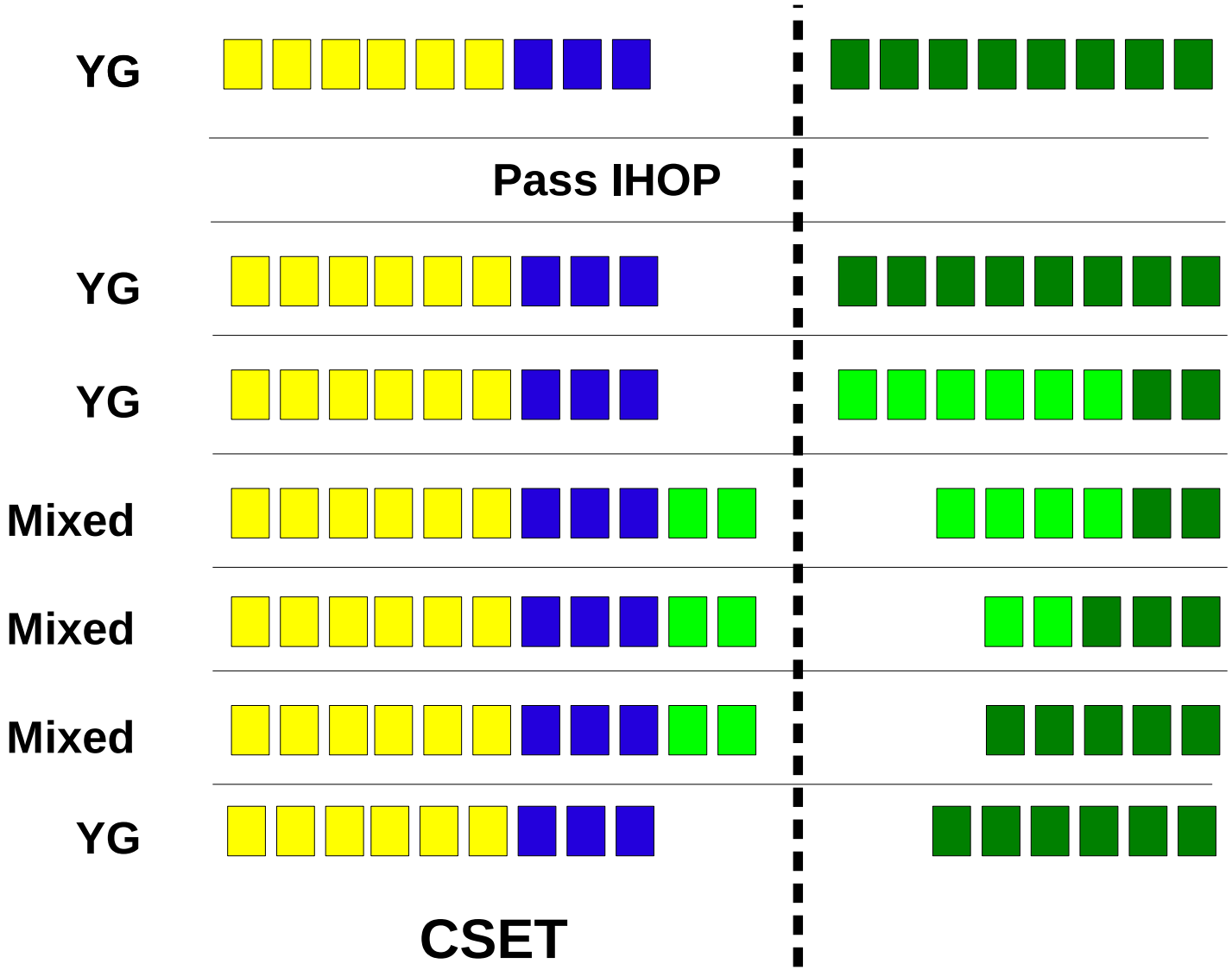
G1 Heap Evacuation



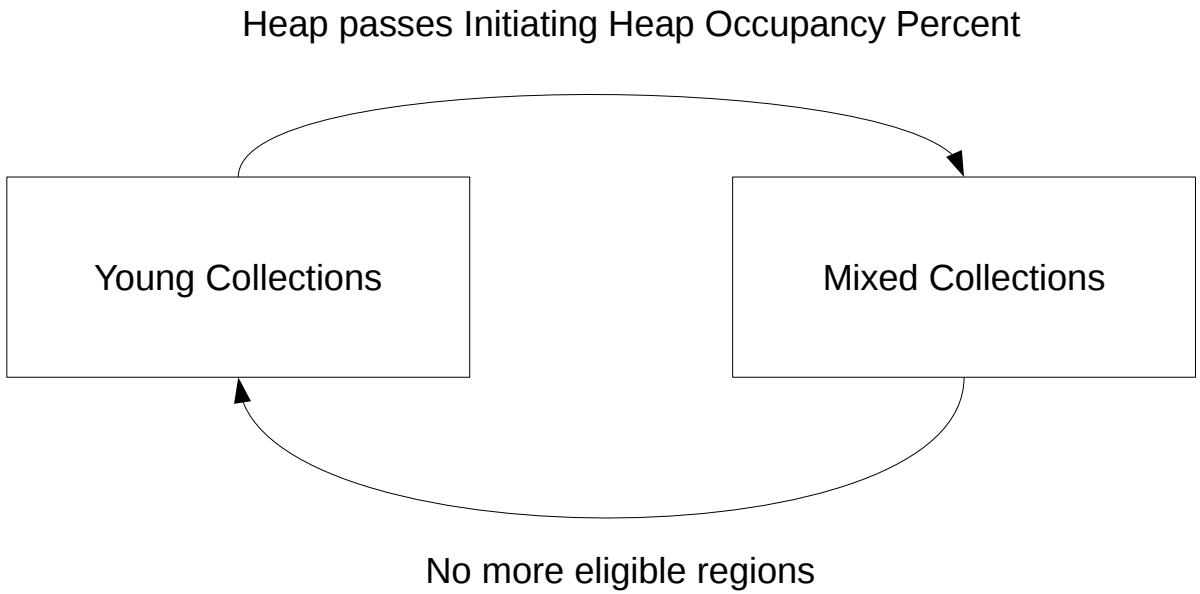
G1 How it works

- Mark concurrently
- Pause to evacuate
- Don't evacuate all at once
- Divide the evacuation work up and every time we have a YG pause, do a bit of OG work

G1 How it works



G1 How it works



G1 How it works

- Start Marking
  - **-XX:InitiatingHeapOccupancyPercent=n**
- Mixed GC until no more eligible regions
  - **-XX:G1MixedGCLiveThresholdPercent**

Tuning Parameters

Xmx/Xms	Heap Size
MaxGCPauseMillis	Target pause limit
G1MixedGcCountTarget	Target number of mixed garbage collections
G1OldCSetRegionThresholdPercent	Limit on the number of old regions in a cset
G1MixedGCLiveThresholdPercent	Threshold for an old region to be included in a mixed garbage collection cycle
G1HeapWastePercent	Level of floating garbage you are ok with

Ref: `http://www.oracle.com/technetwork/articles/java/g1gc-1984535.html` (`http://bit.ly/1AC7JDZ`)

The problem

- The whole of YG is cleaned during every GC
- YG is a low bound on how low you can get your pauses
- If Ergonomics does not reduce YG sufficiently, sucks to be you
- Only way to fix this is reduce the YG workload
- Best way found to do this is forcibly reduce the size of YG.

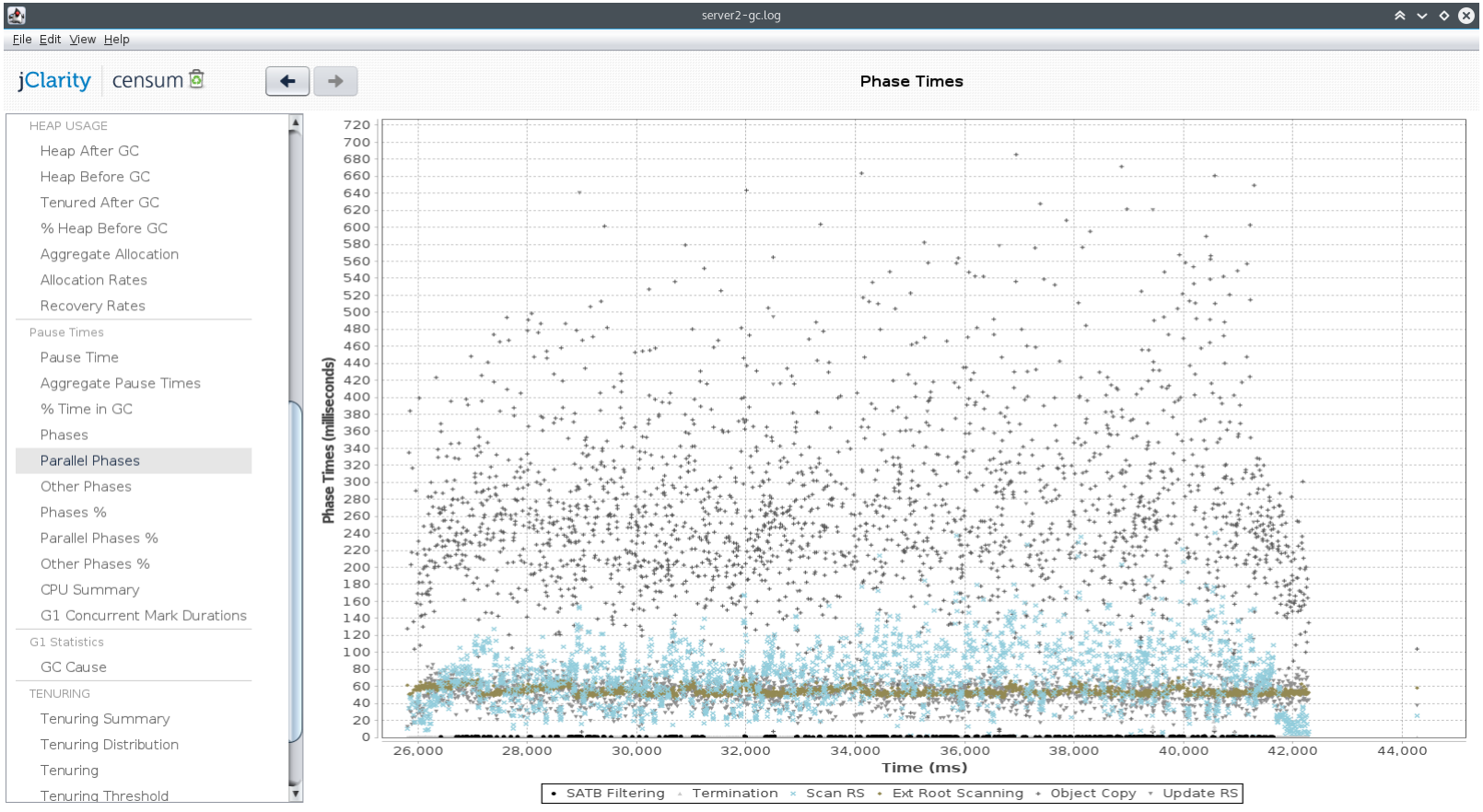
The problem

- “Object Copy” and “Ext Root Scanning” tend to dominate
- Object copy: Time spent copying live objects, when evacuating regions.
- Ext Root Scanning: Time spent scanning external roots (registers, thread stacks, etc)

The problem

- On our log DB (many of these are older logs):
  - 40% of all "Parallel Time" is spent in Object Copy
  - 50% in Ext Root Scanning
- However Object Copy seems to dominate apps that are under GC pressure
- Little can be done to speed up this process.

The problem


server2-gc.log
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Phase Times
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Heap After GC
Heap Before GC
Tenured After GC
% Heap Before GC
Aggregate Allocation
Allocation Rates
Recovery Rates
Pause Times
Pause Time
Aggregate Pause Times
% Time in GC
Phases
Parallel Phases
Other Phases
Phases %
Parallel Phases %
Other Phases %
CPU Summary
G1 Concurrent Mark Durations
G1 Statistics
GC Cause
TENURING
Tenuring Summary
Tenuring Distribution
Tenuring
Tenuring Threshold
Phase Times (milliseconds)
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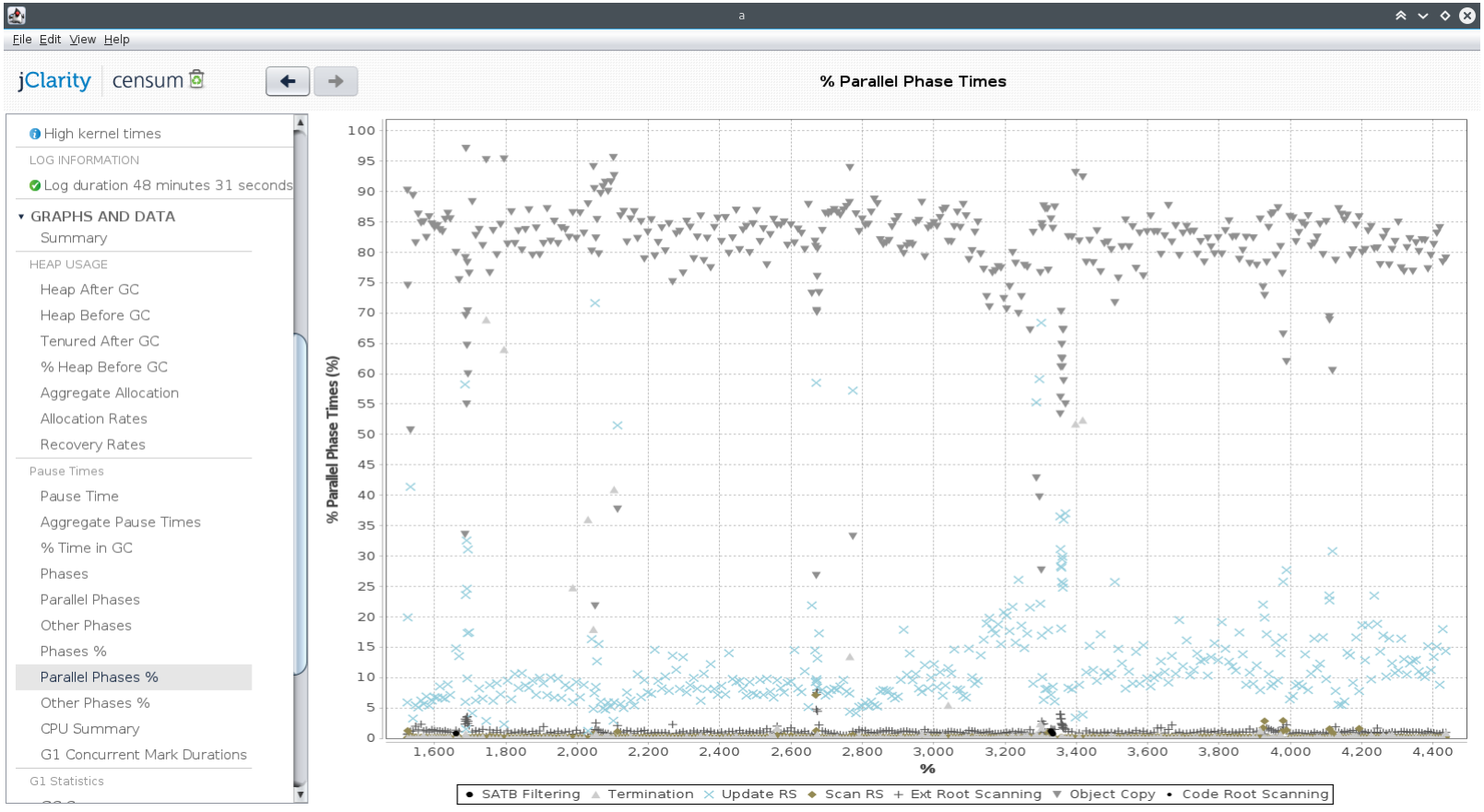
26,000 28,000 30,000 32,000 34,000 36,000 38,000 40,000 42,000 44,000
Time (ms)
SATB Filtering
Termination
Scan RS
Ext Root Scanning
Object Copy
Update RS

The problem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% Parallel Phase Times
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Log duration 48 minutes 31 seconds
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Heap After GC
Heap Before GC
Tenured After GC
% Heap Before GC
Aggregate Allocation
Allocation Rates
Recovery Rates
Pause Times
Pause Time
Aggregate Pause Times
% Time in GC
Phases
Parallel Phases
Other Phases
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CPU Summary
G1 Concurrent Mark Durations
G1 Statistics
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4,400
%
SATB Filtering
Termination
Update RS
Scan RS
Ext Root Scanning
Object Copy
Code Root Scanning

Conclusion

- Easier to tune
- Bound by Object copy
  - Have to pause to evacuate
  - Need concurrent relocation

Shenandoah

Shenandoah

- Compacting
- Concurrently relocates objects
- “Goal is to have $<$ 10ms pause times for 100gb+ heaps.”
- “If you are running with a heap of 20GB or less or if you are running with fewer than eight cores, you are probably better off with one of the current GC algorithms”

Shenandoah

- Roman Kennke - https://rkennke.wordpress.com/
- Christine H. Flood - https://christineflood.wordpress.com/
- http://openjdk.java.net/jeps/189

Shenandoah

- Regional heap similar to G1
- Evacuate areas with high garbage (garbage first)
- Non-generational

Shenandoah Phases

- Mark
- Evacuate

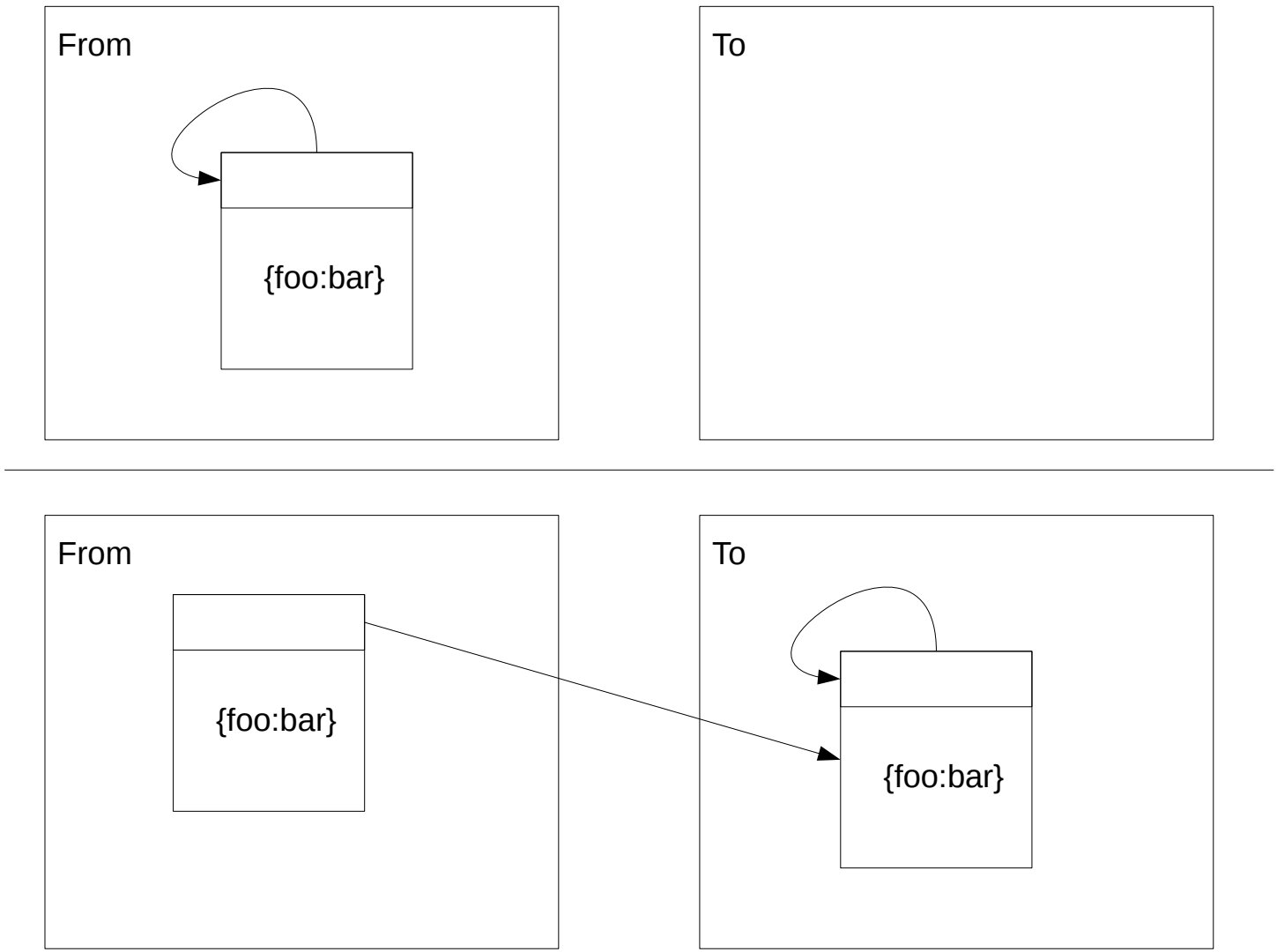
Concurrent Mark

- Snapshot at the beginning
- Full heap

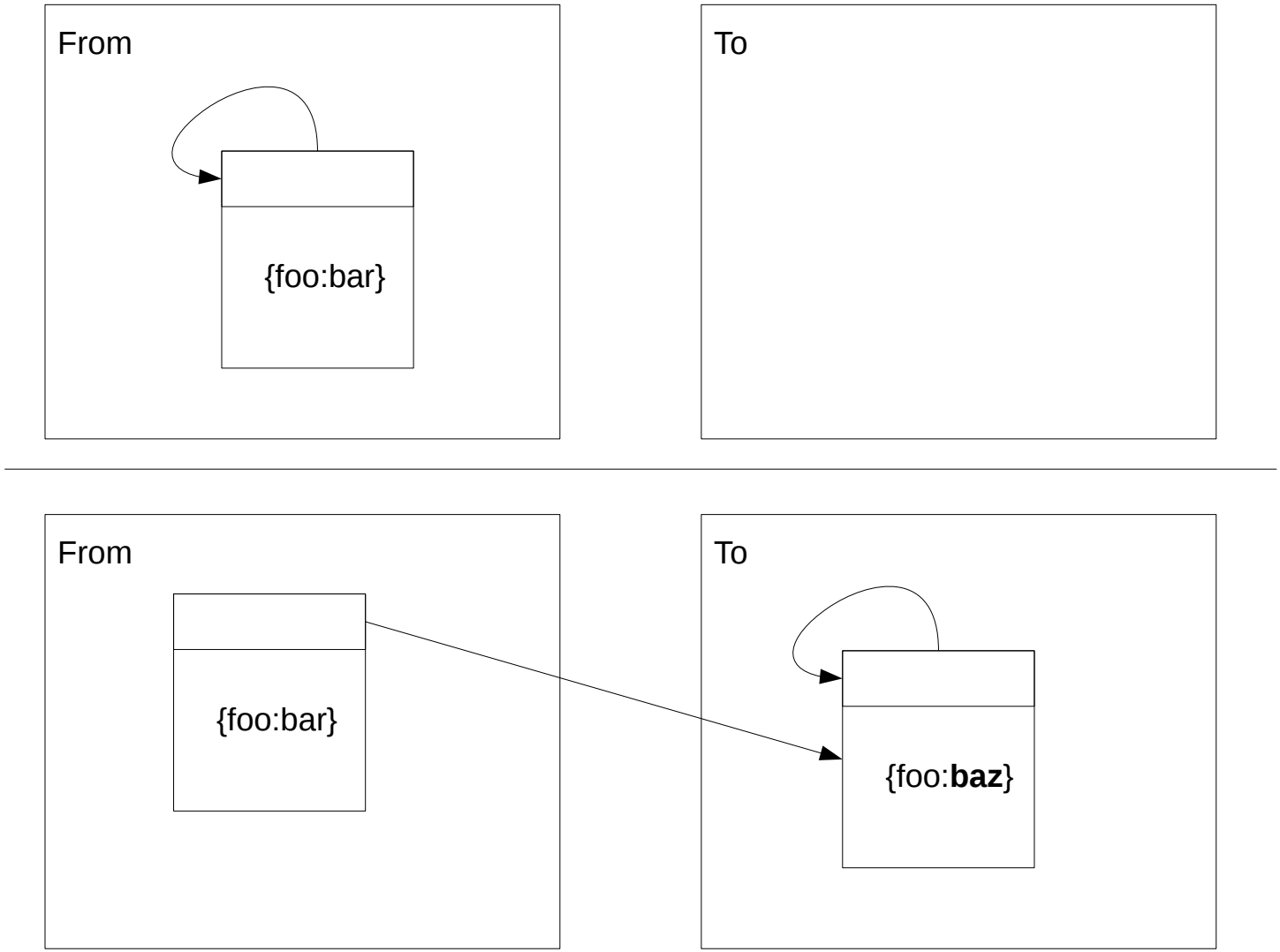
Concurrent Relocation

- Use Brooks pointers
  - All objects have a pointer that normally point to themselves
  - When relocated pointer updated to point to new location
  - Reading and writing threads follow pointer to the “real” object

Brooks Pointers



Brooks Pointers



Brooks Pointers

- Read(Read(pointer))
- Objects evacuated from “From” spaces, to “To” spaces
- Objects relocated on a write
- Pointer in old object updated via CAS operation

Fixing Up Pointers

- 2 Options
  - Fix up pointers in the next mark (default)
    - May require a lot of head room in the heap
    - Pay a cost of indirection on relocated objects between GC's
    - Cache miss?
  - Accept another pause
- No remembered sets

Write Barrier

- Enforce only write in To space
- Perform relocation if needed
  - Avoid read relocation storm
- Ensure previous pointers are still marked

Costs

- Extra heap space for forwarding pointer
- Read/Write barrier
- Pointer chasing may make memory access pattern unpredictable
- Shenandoah devs believe overhead can be kept reasonably low

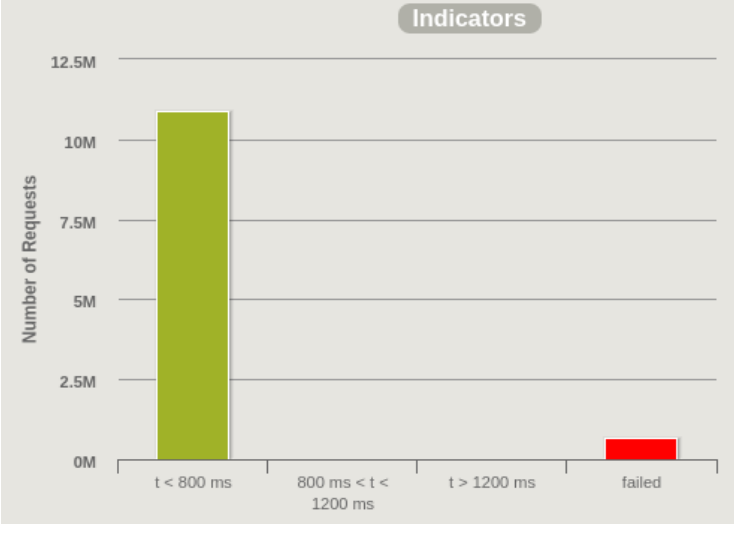
G1 vs Shenandoah

Tests

- Shenandoah
  - **-XX:+UseShenandoahGC**
    -XX:-ClassUnloadingWithConcurrentMark
    -XX:MaxHeapSize=25G
- G1
  - **-XX:+UseG1GC -XX:MaxGCPauseMillis=100**
    -XX:MaxHeapSize=25G
- Environment
  - Spring web app
  - Load test from external machine running Gatling
  - AWS, 8 core, 32GB ram

G1 vs Shenandoah

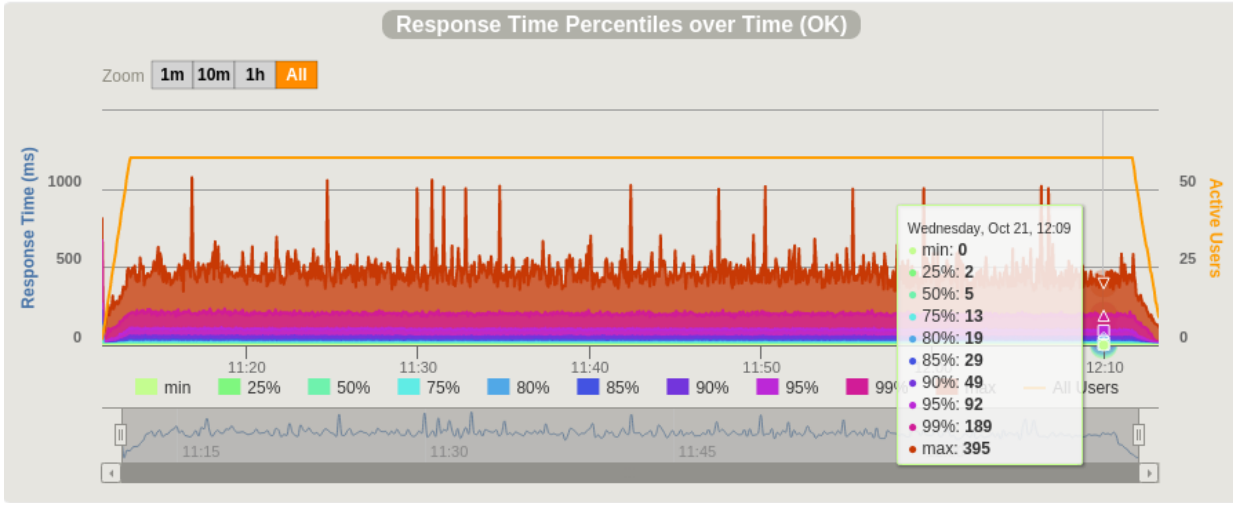
G1



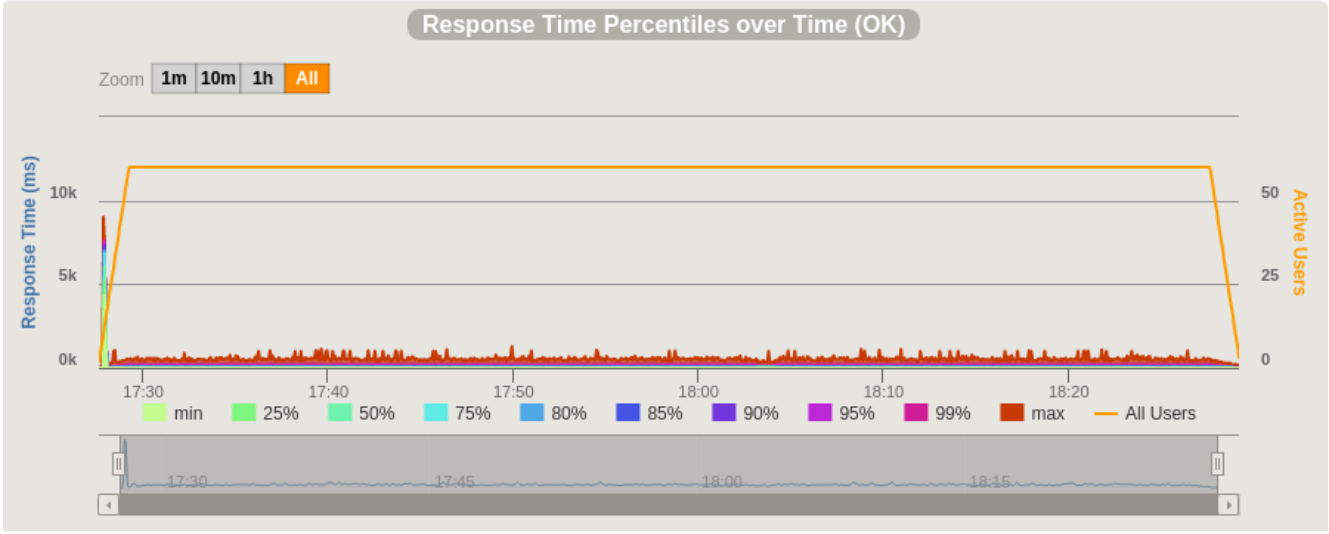
Shenandoah

G1 vs Shenandoah - Response Times

G1

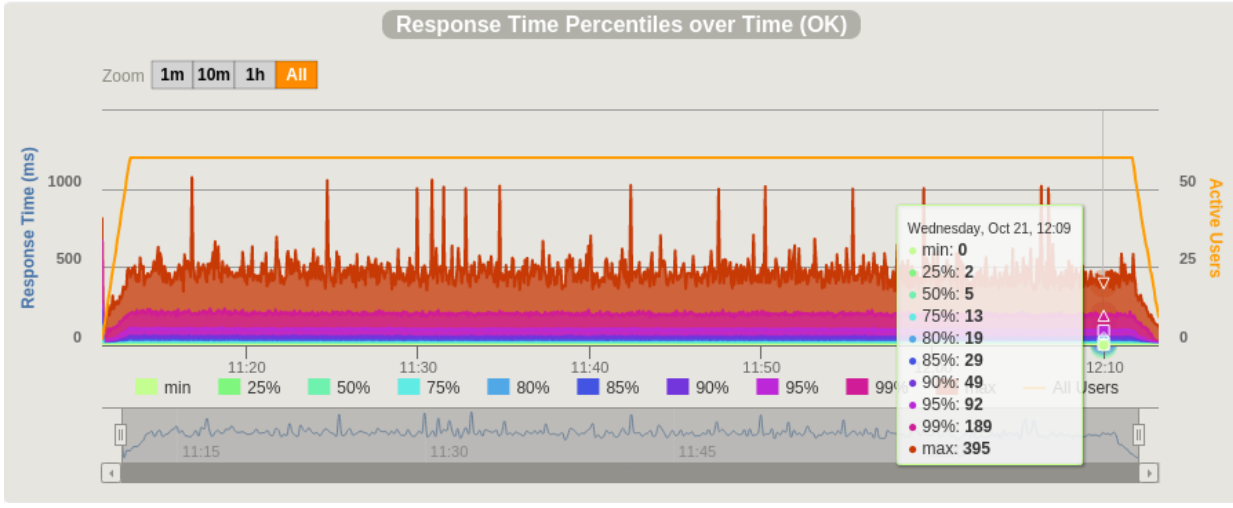


Shenandoah



G1 vs Shenandoah- Response Times (No Full GC)

G1



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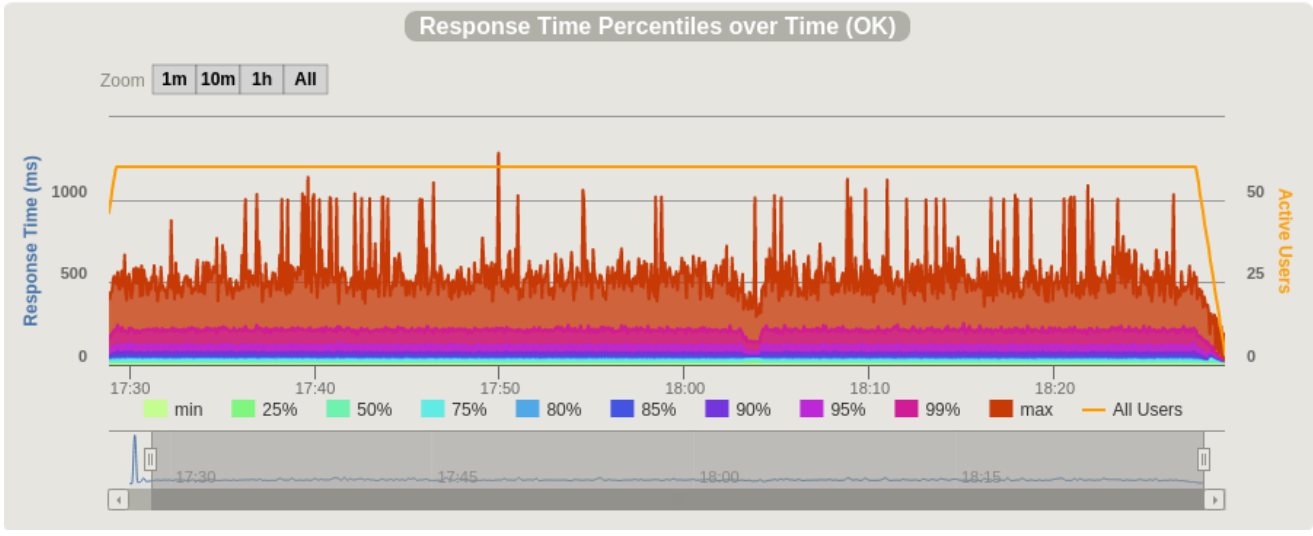
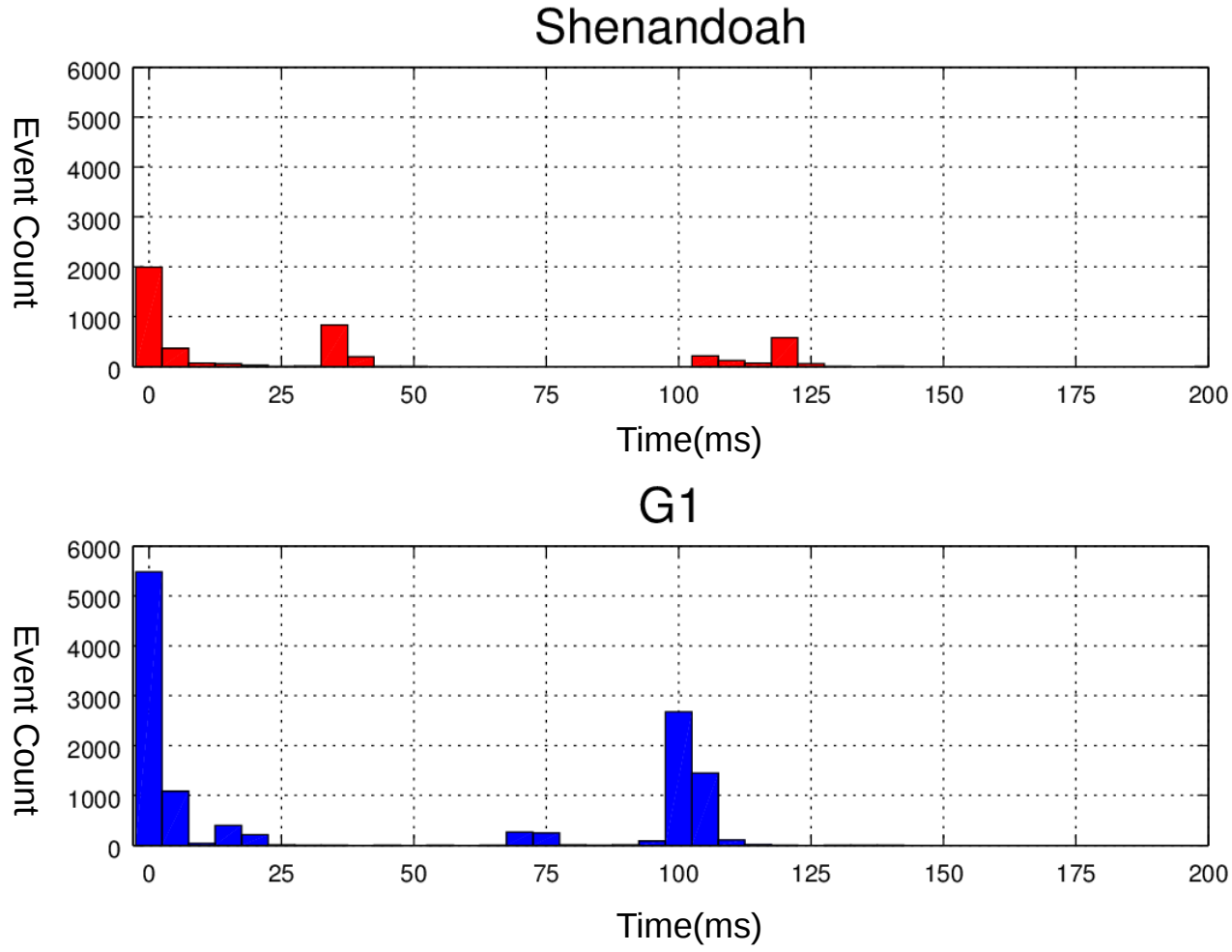
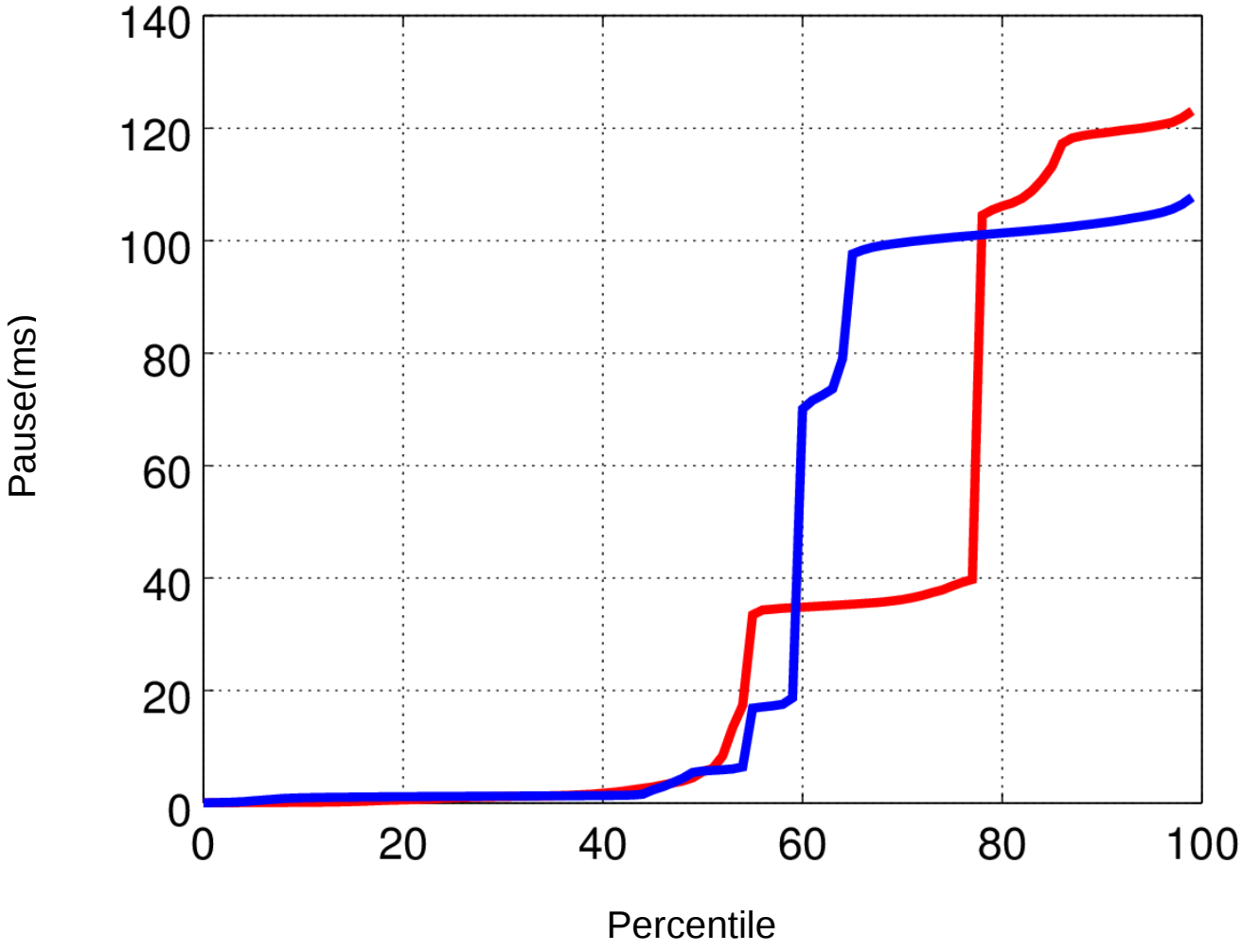


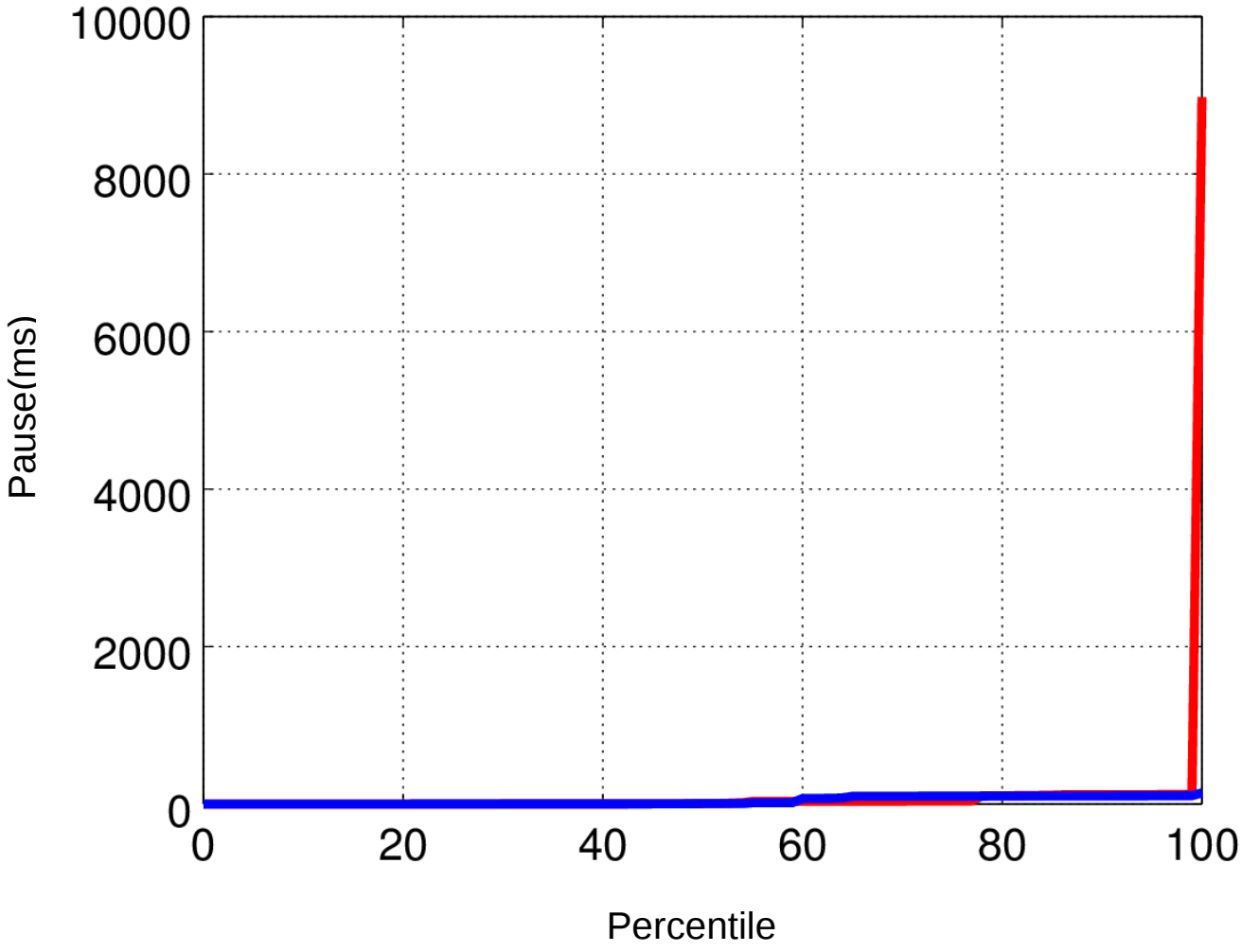
G1 vs Shenandoah - GC event counts



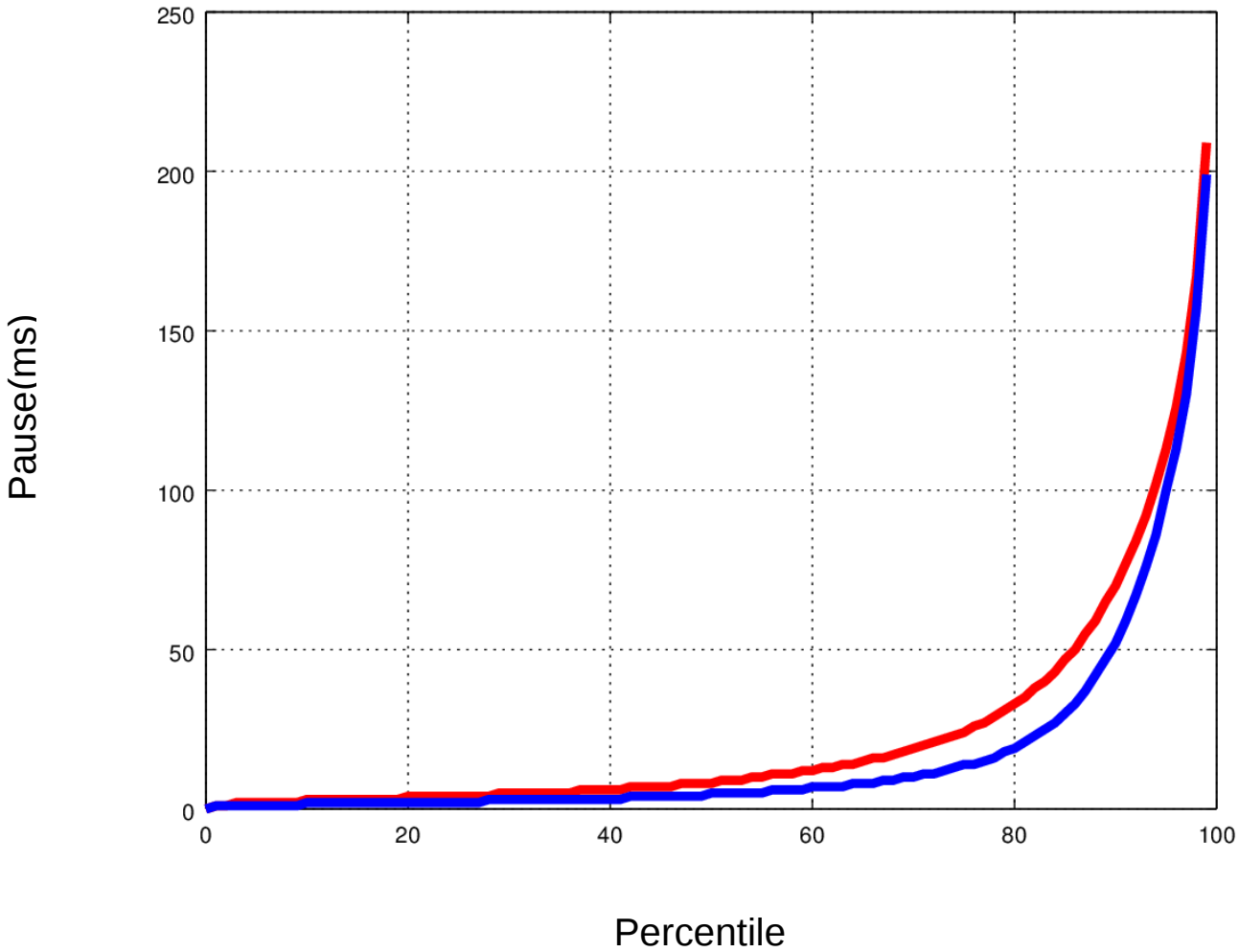
G1 vs Shenandoah Pause Times, 0-99th Percentile



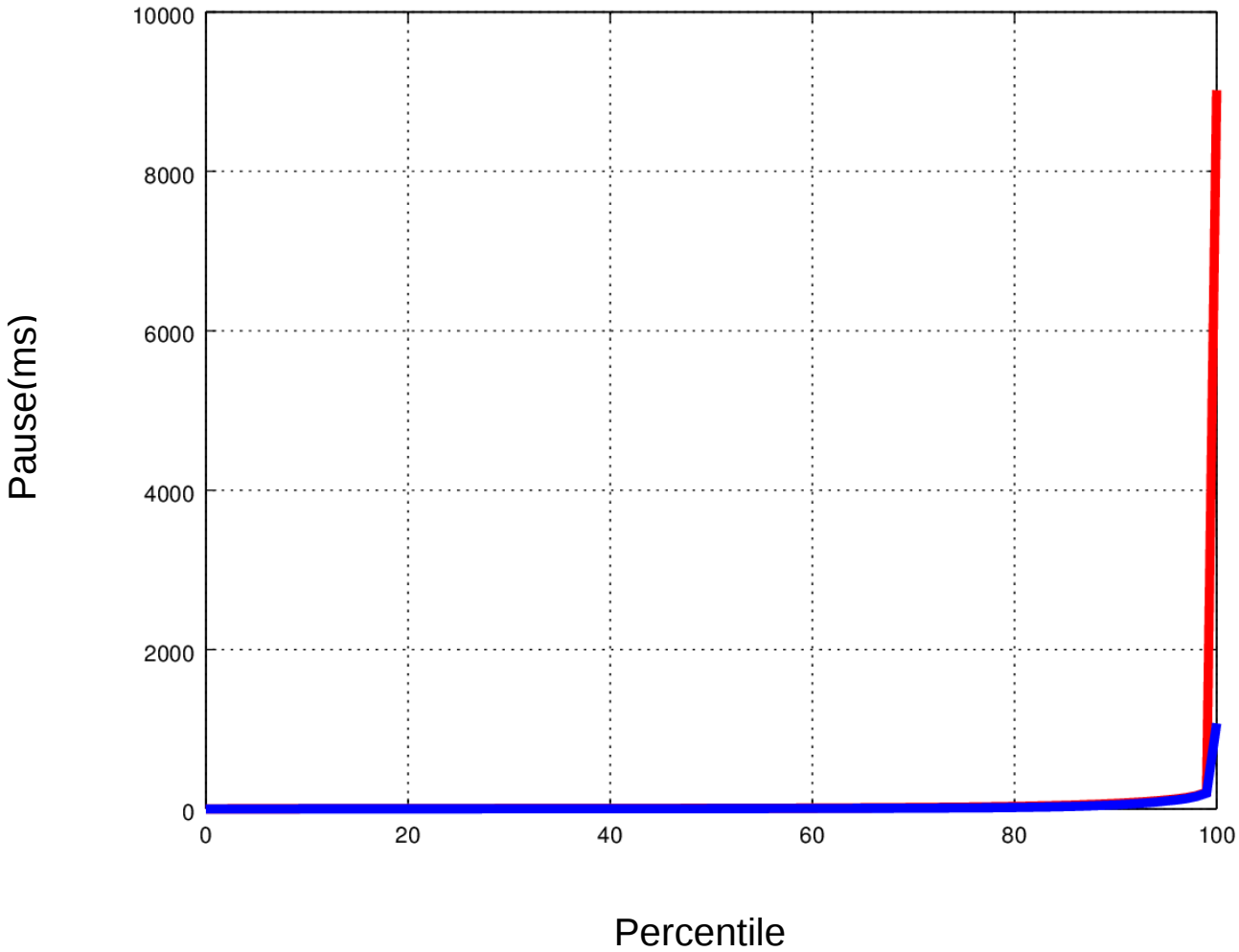
G1 vs Shenandoah Pause Times, 0-100th Percentile



G1 vs Shenandoah Response Times, 0-99th Percentile



G1 vs Shenandoah Response Times, 0-100th Percentile



Results

- Still very early days for Shenandoah
  - Far younger than G1 and far less engineering time
  - Has comparable results to G1
- Beware of single benchmarks and results
  - Application stopped time
- STOP THE PRESSES
  - Since performing this talk, following advice from Roman Kennke I have managed to produce stable results with <60ms pauses at the 99th percentile and no full GCs.

Conclusion

Conclusion

- G1
  - Production ready
  - Bound by object copy
- Shenandoah
  - Looks very promising but not ready yet
  - Will remove the bound on object copy
  - Java 10
- Join Friends of jClarity - friends@jclarity.com
- Send in your GC logs

Questions

- john@jclarity.com
- Friends of jClarity - friends@jclarity.com