Why You Should Upgrade Your Java In Containers Right Now

Ben Evans, New Relic (He / Him)

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About Me – Career

- New Relic, Lead Architect
- jClarity, Co-founder
  - Sold to Microsoft
- Deutsche Bank
  - Chief Architect (Listed Derivatives)
- Morgan Stanley
  - Google IPO
- Sporting Bet
  - Chief Architect

About Me – Community

- Java Champion
- JavaOne Rock Star Speaker
- Java Community Process Executive Committee
- London Java Community
  - Organising Team
  - Co-founder, AdoptOpenJDK

Today's Talk

- How We Got Here
- Introduction to New Relic
- Current State of Java
- Why is 11 better in containers?
- JFR
- Conclusions

How We Got Here

- Java & OpenJDK History
- New Release & Support Model
- Mainline dev
- OpenJDK 8 & 11

A Brief History of Java

- Sun release Java in beta to much hype (1995)
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- Java 7: First release based on OSS codebase (2011)
- Java 8: "Classic" Long-Term Support Release (2014)
- Java 9: New release model (2017)
- Java 11: Current Long-Term Support Release (2018)

New Release Model

- Feature Releases
  - Every 6 months
  - Only supported for 6 months by Oracle
    - Other vendors may offer other options
- Long-Term Support releases (LTS)
  - Every 3 years
  - Java 8 & 11 are LTS (& 17 will be)
  - **Java 9, 10, 12, 13, 14, 15 & 16 are NOT LTS**

What has Changed in Java?

- Paid support options
  - Oracle (LTS only)
  - Azul, various other OpenJDK vendors

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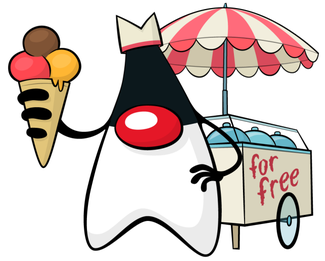
  - Azul, various other OpenJDK vendors
- Free updates are still available from:
  - Oracle (must upgrade every 6 months)
  - OpenJDK vendors (for LTS versions only)
- Oracle’s Java market share is diminishing
  - OpenJDK is gaining greater prominence

Who are the New Players?

- Eclipse Adoptium (AdoptOpenJDK)
- Amazon (Corretto)
- Microsoft
- Red Hat (IcedTea)
- Azul Systems (Zulu)
- AliBaba (Dragonwell)
- IBM (OpenJ9)



Mainline Dev

- OpenJDK now uses a mainline dev model
- Features are merged only when code complete
- Releases occur on a strict time cadence
- Late features are held over for the next release
- Trunk / mainline is always releasable
  - Emergency fixes can be pushed out immediately
- Longer-term projects explore / research future directions

OpenJDK 8 & 11

- OpenJDK 8 & 11 now run by the community
  - Oracle engineers no longer contribute directly
- Oracle are still producing security patches for $$$
  - Same patches must also appear in OpenJDK
- Adoptium have committed to support 8 until 2023
  - At least...

Ongoing Maintenance

- “Housekeeping updates”
  - Japanese Era
  - Xcode 10+ (Mac)
  - Timezone database
  - TLS 1.3
- Selected bug fixes backported (e.g. security)
- Some potential for (very small) features
  - Features may not change semantics
  - JFR

Introduction to New Relic

- New Relic is a performance monitoring company
- Billions of events handled per minute

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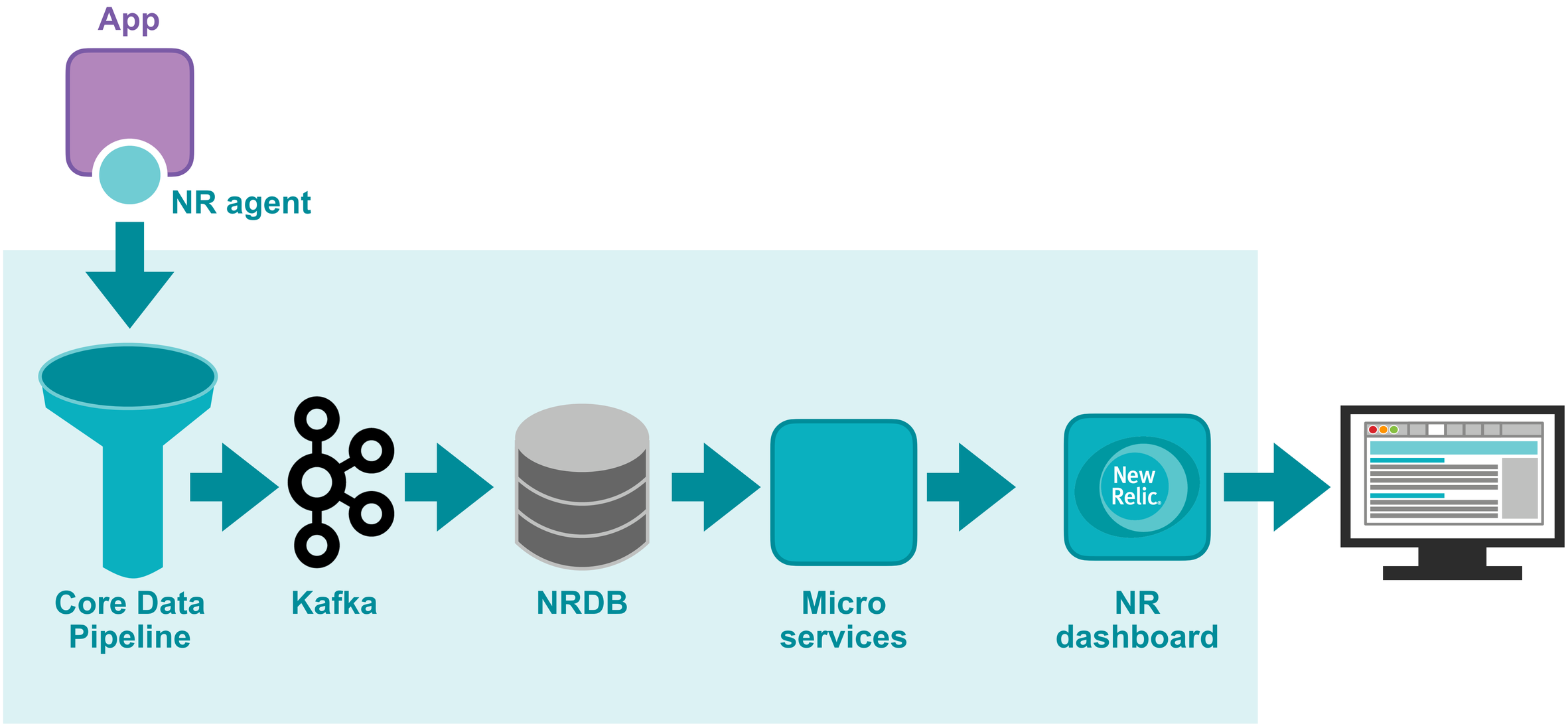
Introduction to New Relic

- New Relic is a performance monitoring company
- Billions of events handled per day
- New Relic One
  - Market's first Observability Platform
- Recently open-sourced $700M of our code
- Java is the majority of our services
  - One of the biggest Kafka installs in the world!
  - We also use the Kotlin language extensively

High-Level Product Architecture



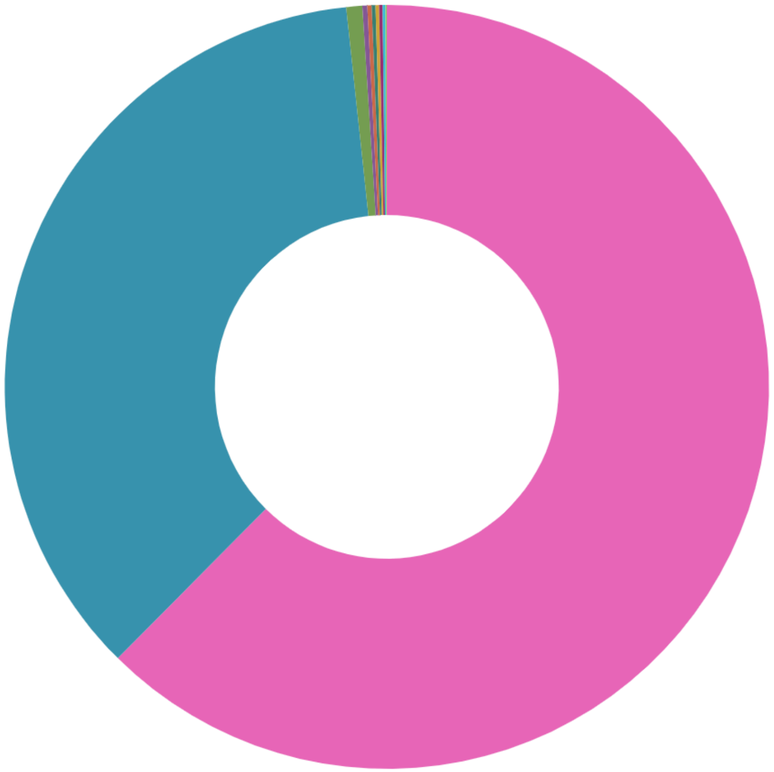
Current State of Java

- New Relic aggregates data from our customers
- Reveals trends about the shape of the market
  - Which versions, which vendors etc people use
- Live data, accurately reported from customers VMs
- Analyst estimates: ~1% of Java SE VMs worldwide

Java Versions

Since 1 week ago

Share



JVMMETADATASUMMARIES

8	62.43 %
11	35.87 %
13	0.68 %
14	0.21 %
9	0.18 %
15	0.16 %
10	0.15 %
7	0.15 %
6	0.12 %
12	0.056 %

Java Vendors

Since 1 week ago

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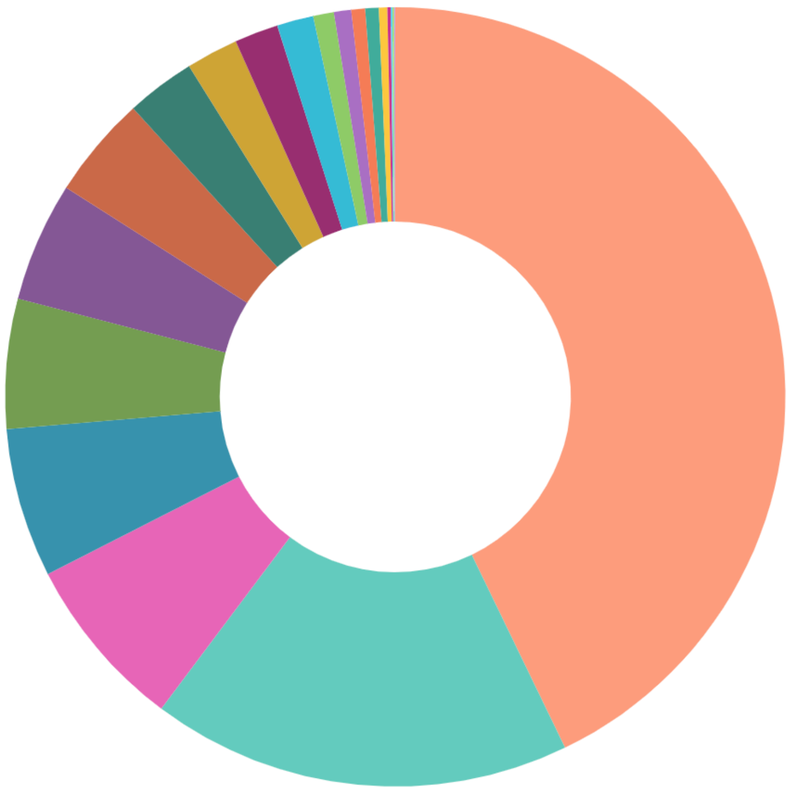

JVMMETADATASUMMARIES

Oracle Corporation	42.83 %
AdoptOpenJDK	17.4 %
Azul Systems, Inc.	7.25 %
Red Hat, Inc.	6.2 %
Ubuntu	5.38 %
IcedTea	4.95 %
Amazon.com Inc.	4.26 %
BellSoft	2.87 %
IBM Corporation	2.15 %
Private Build	1.82 %
Tableau	1.51 %
N/A	0.85 %
Pivotal Software Inc	0.72 %
Eclipse OpenJ9	0.57 %
GraalVM Community	0.56 %
Debian	0.35 %
SAP SE	0.14 %

Vendors and Versions

Since 1 week ago

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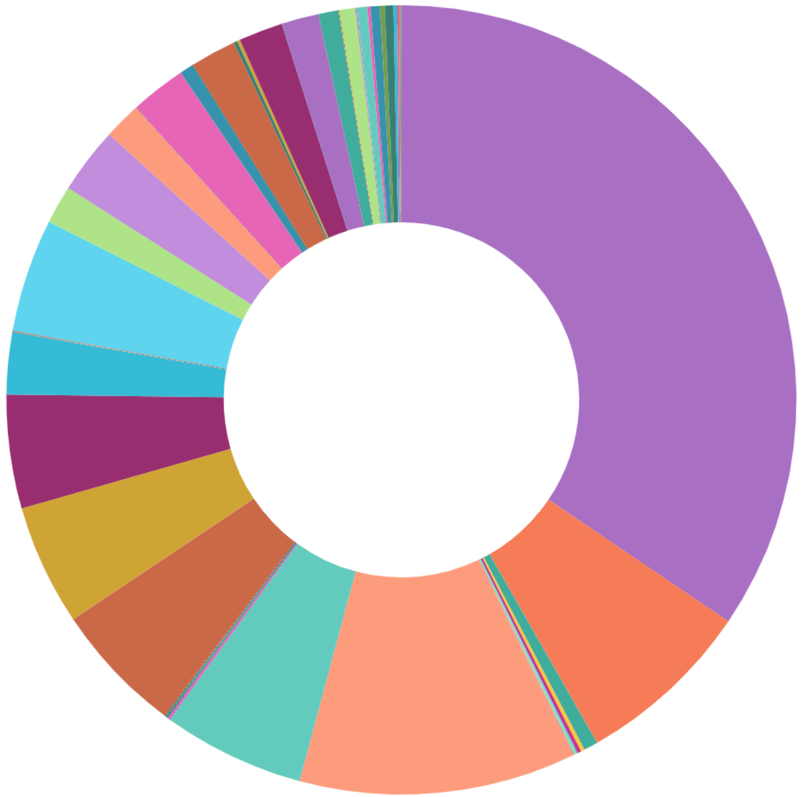


JVMMETADATASUMMARIES

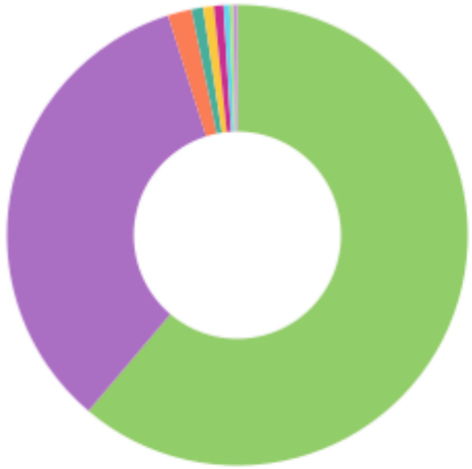
Oracle Corporation, 8	34.49 %
AdoptOpenJDK, 11	11.32 %
Oracle Corporation, 11	7.27 %
AdoptOpenJDK, 8	5.83 %
Ubuntu, 11	5.38 %
IcedTea, 8	4.95 %
Azul Systems, Inc., 11	4.66 %
Red Hat, Inc., 8	4.64 %
Amazon.com Inc., 8	2.73 %
Azul Systems, Inc., 8	2.53 %
BellSoft, 8	2.29 %
IBM Corporation, 8	1.89 %
Private Build, 8	1.81 %
Red Hat, Inc., 11	1.56 %
Amazon.com Inc., 11	1.52 %
Tableau, 11	1.51 %

Containers

Containerized JVMs
Since Feb 10, 06:29 ...

62.92 %
Percentage

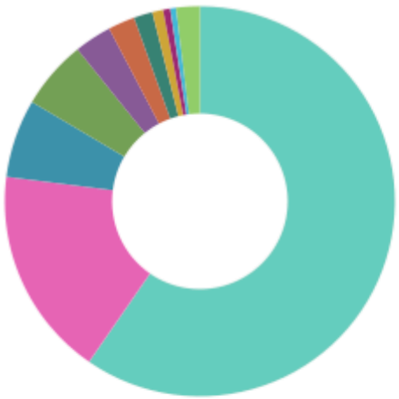
Java Versions in Containers
Since Feb 10, 06:29 am until Feb 11, 07:22 am



8	61.19 %
11	33.95 %
12	1.67 %
14	0.82 %
13	0.75 %
7	0.66 %
15	0.42 %

CPUs & Memory In Use

CPUs in Containers
Since Feb 10, 06:29 am until Feb 11, 07:22 am



1	59.62 %
2	17.38 %
8	6.51 %
4	5.7 %
3	3.09 %
16	2.22 %
Other	1.94 %

-Xmx Ranges in Containers
Since Feb 10, 06:29 am until Feb 11, 07:22 am

<= 1GB	41.5 %
Not Set	27.64 %
<=2GB	10.71 %
<=3GB	8.38 %
>4GB	8.03 %
<=4GB	3.74 %

Other GC Parameters

JVM Heap Sizing in Containers
Since Feb 10, 06:29 am until Feb 11, 07:22 am

72.36 %
-Xmx

8.47 %
-XX:MaxRAMPercentage

Explicitly Configured GC Threads
Since Feb 10, 06:29 am until Feb 11...

6.13 %
Percentage

Who Actively Selects A GC?

Since 1 week ago

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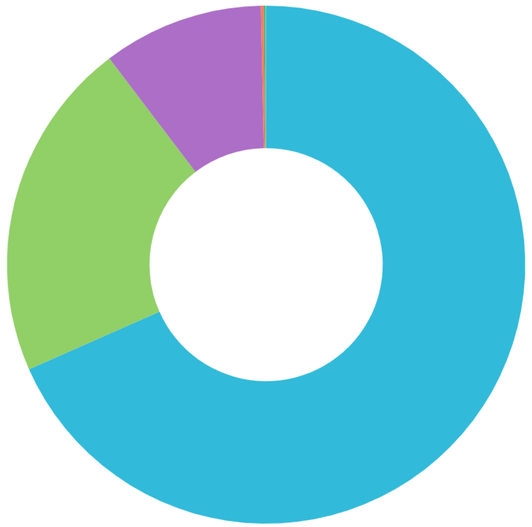
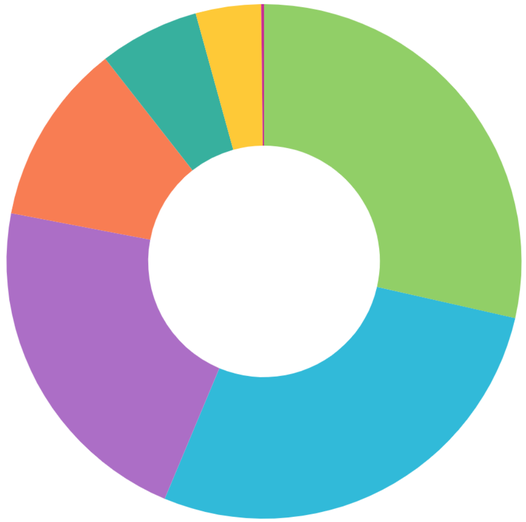


JVMMETADATASUMMARIES

Unconfigured	68.38 %
G1	21.28 %
CMS	10.01 %
Parallel	0.18 %
ZGC	0.11 %
Shenandoah	0.032 %

Since 1 week ago

Share



JVMMETADATASUMMARIES

Unknown	28.54 %
G1	27.76 %
Serial	21.7 %
CMS	11.42 %
Parallel	6.29 %
gencon	4.11 %
Other	0.18 %

Why is 11 better in containers?

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- Main reasons:
  - `var`
  - Modules
  - HTTP/2

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- Main reasons:
  - `var`
  - Modules
  - HTTP/2

- Just Kidding...

Real Reasons for Using 11 in Containers?

- "Container-Aware"
- Decent version of G1GC
- Compact Strings & Heap Reduction
- JDK Flight Recorder

"Container-Aware"

- Containers requires thought about:
  - GC algorithms and selections
  - Memory usage
  - CPU Usage
- What does `Runtime.getAvailableProcessors()` return?

How Is A GC selected?

- "GC Ergonomics"
- Depends upon
  - Java version
  - "Server" or "client" class determination
  - CPU count

Selecting a GC

```
GCArguments* GCConfig::select_gc() {
  // Fail immediately if an unsupported GC is selected
  fail_if_non_included_gc_is_selected();

  if (is_no_gc_selected()) {
    // Try select GC ergonomically
    select_gc_ergonomically();

    if (is_no_gc_selected()) {
      // Failed to select GC ergonomically
      vm_exit_during_initialization("Garbage collector not selected "
                                    "(default collector explicitly disabled)", NULL);
    }

    // Succeeded to select GC ergonomically
    _gc_selected_ergonomically = true;
  }
```

Max Heap Size

- By default, on bare metal, 1/4 physical memory

```
$ java -XX:+PrintFlagsFinal -version | grep -iE 'MaxHeapSize'
    size_t MaxHeapSize   = 4294967296  {product} {ergonomic}
```

- But what about in a container?

Max Heap Size

- By default, on bare metal, 1/4 physical memory

```
$ java -XX:+PrintFlagsFinal -version | grep -iE 'MaxHeapSize'
    size_t MaxHeapSize   = 4294967296  {product} {ergonomic}
```

- But what about in a container?

- It depends...
  - Early versions of 8 can't see the container
  - 8u191 improves the situation somewhat

Memory in Containers

- Container memory consists of:
  - Java Heap memory
  - Offheap
    - Metaspace
    - JFR data
    - General book-keeping
  - Memory for auxiliary processes
- Not setting heap memory size means potential OOM
  - ~20% of containers are in this situation

Java 8 CPU Limits

- Java 8 is not well-suited for deploying in containers
  - Prior to 8u131 cgroups settings are not respected at all
  - Post-8u131 a fixed approx, based on cpu_shares, is used
  - Post-8u191 more support is backported
- Need to be careful of
  - # of GC threads used for parallel (& concurrent) GC phases
  - # of threads in auto-sized, VM-managed thread pools
- Consider explicitly setting flags to size these exactly

New Garbage Collector - G1

New version of G1GC

- “Garbage First” collector
  - experimental in 7
  - supported in 8
  - production-quality in 8u40
  - default in 9
  - very improved in 11
- Originally intended to be low-pause
  - replacement for CMS
- Ended up as a general-purpose collector
  - replacement for Parallel collectors

Tradeoffs Between Collectors

- No “one size fits all” for GC
- Different metrics are important for different apps
  - Pause time
  - Throughput (%age)
  - Pause frequency
  - Reclamation efficiency
  - Pause consistency

G1

- Design aims of G1
  - scalable to larger heaps
  - better control of pause times
  - easy to tune (`-XX:MaxGCPauseMillis`)
  - Predictable

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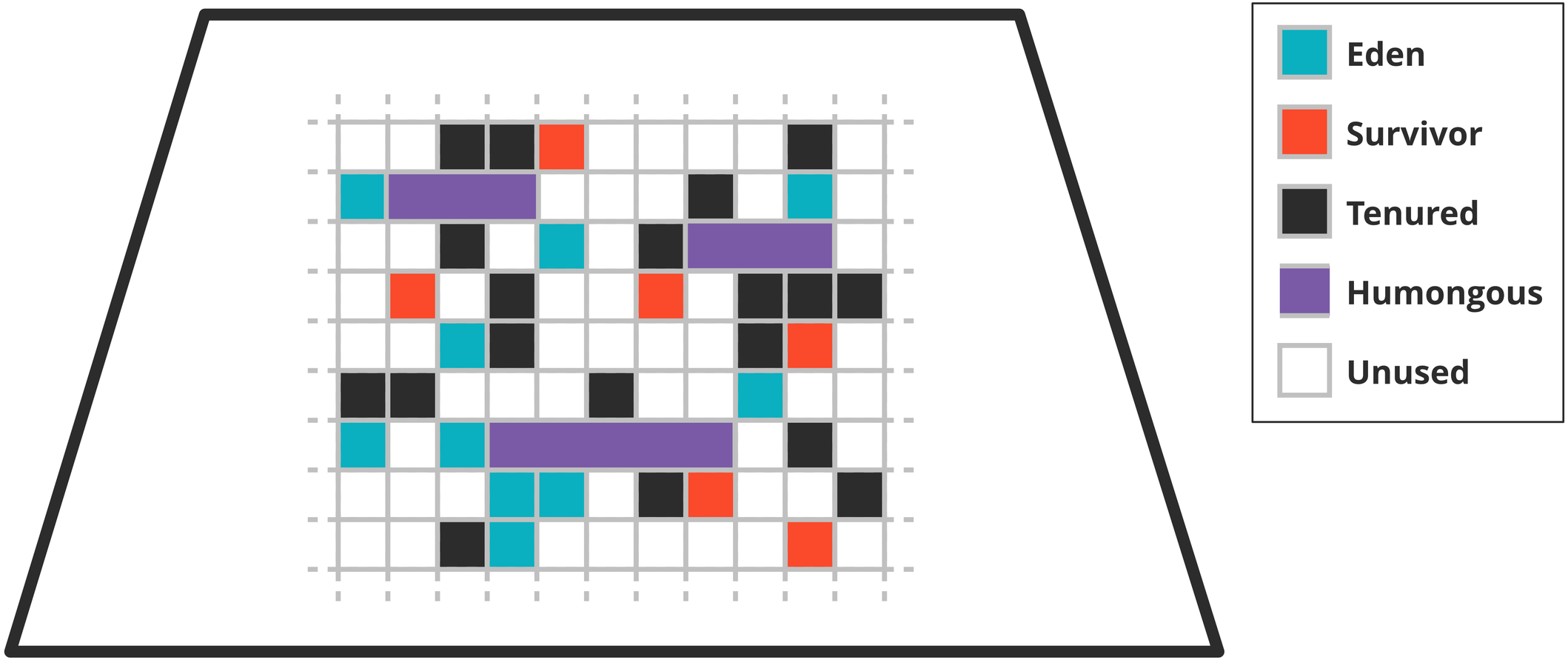
  - scalable to larger heaps
  - better control of pause times
  - easy to tune (`-XX:MaxGCPauseMillis`)
  - Predictable
- As a collector, G1 is...
  - Parallel
  - Concurrent (for marking)
  - Exact
  - Evacuating
  - "Statistically Compacting"

G1 – Regional Collection

- G1 uses regions for collection
  - not hemispherical heap (like Parallel & CMS)
- Regions
  - allow GC cycles to "partially clean" & then restart app threads
  - can be 1 - 64M in size (1M default for small heaps)
- Generational Collection
  - regions still belong to generations
  - generations are not contiguous
  - heap is still contiguous

The G1 Heap



G1 Heap

Remembered Sets (RSets)

- Similar idea to GC "card tables"
  - track pointers between regions
- If app thread mutates
  - change is put on a “refinement queue”
  - reduce work done on app thread
  - separate threads drain refinement queues
- Example of “balancing between allocator & collector”

G1 – The Bad News

- Can interfere with application throughput
  - write barriers, RSet update threads and back pressure
- Concurrent GC - uses cores while GC is running
  - Full STW Fallback can still occur
  - e.g. if allocation greatly exceeds reclamation
- Full predictability of G1 pauses is still lacking
  - 200ms goal is easy to achieve
  - Guaranteed <50ms not at all easy
- G1 not a true compacting collector

Java 11 & G1

- Java 11's G1 is significantly better
  - Has a Parallel fallback STW collector
  - Better able to meet pause time guarantees
- Algorithm is significantly different between versions
  - Ensure that tuning advice relates to the correct version
- Most apps see benefit from G1 on Java 11
  - But overall CPU utilization may increase slightly
- Other changes in 11 may also help GC performance

New Default GC

- Java 9 switched the default GC from Parallel to G1
  - This refers to the GC used to collect “old” objects
  - Both GCs use STW collection to collect “young” objects
- G1 is a concurrent GC
  - Parallel is STW
- G1 will use more CPU than Parallel
  - In exchange for shorter pause times
  - Default G1 pause is 200ms

Compact Strings

Practical Impacts

- Before Java 9 Strings are represented as char[]
  - 2 bytes per char (UTF-16)
  - In Western European langs, this wastes 50% storage
  - First byte is always zero

Practical Impacts

- Before Java 9 Strings are represented as char[]
  - 2 bytes per char (UTF-16)
  - In Western European langs, this wastes 50% storage
  - First byte is always zero
- Java 9 introduces a per-string choice
  - Latin-1
  - UTF-16
- Internal representation moves to bytes
  - Saves space in common case

Compact Strings

```
private final byte[] value;

/**
 * The identifier of the encoding used to encode the bytes in
 * {@code value}. The supported values in this implementation are
 *
 * LATIN1
 * UTF16
 *
 * @implNote This field is trusted by the VM, and is a subject to
 * constant folding if String instance is constant. Overwriting this
 * field after construction will cause problems.
 */
private final byte coder;

static final byte LATIN1 = 0;
static final byte UTF16  = 1;
```

JDK Flight Recorder (JFR)

- A profiling tool to gather diagnostics & profiling data
  - From an in-flight Java application
- Proprietary tool in Java 8, OSS in Java 11
  - Now backported to OpenJDK 8u262+
- Low overhead
  - Oracle claim ~1% impact to steady state performance
  - We observe ~3% on a useful data profile
- GUI console available - Mission Control (JMC)

Using Flight Recorder

- JFR is started with a command line flag
- Generates an output file

```
java -XX:+FlightRecorder
 -XX:StartFlightRecording=duration=200s,filename=flight.jfr Klass
```

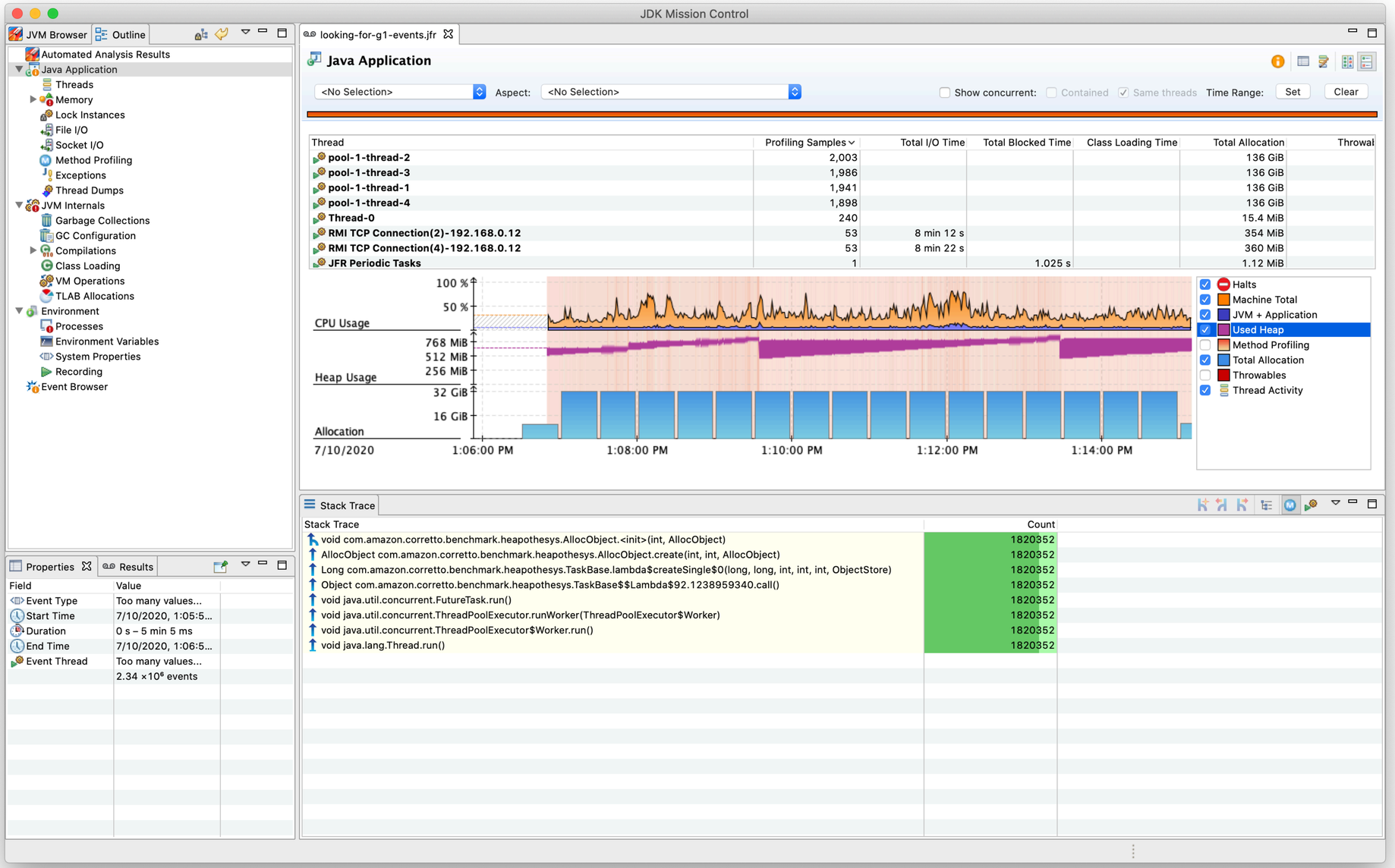
- Can be challenging to work with in containers
- Streaming solution exists (in Java 14, but not LTS)

Using jcmd

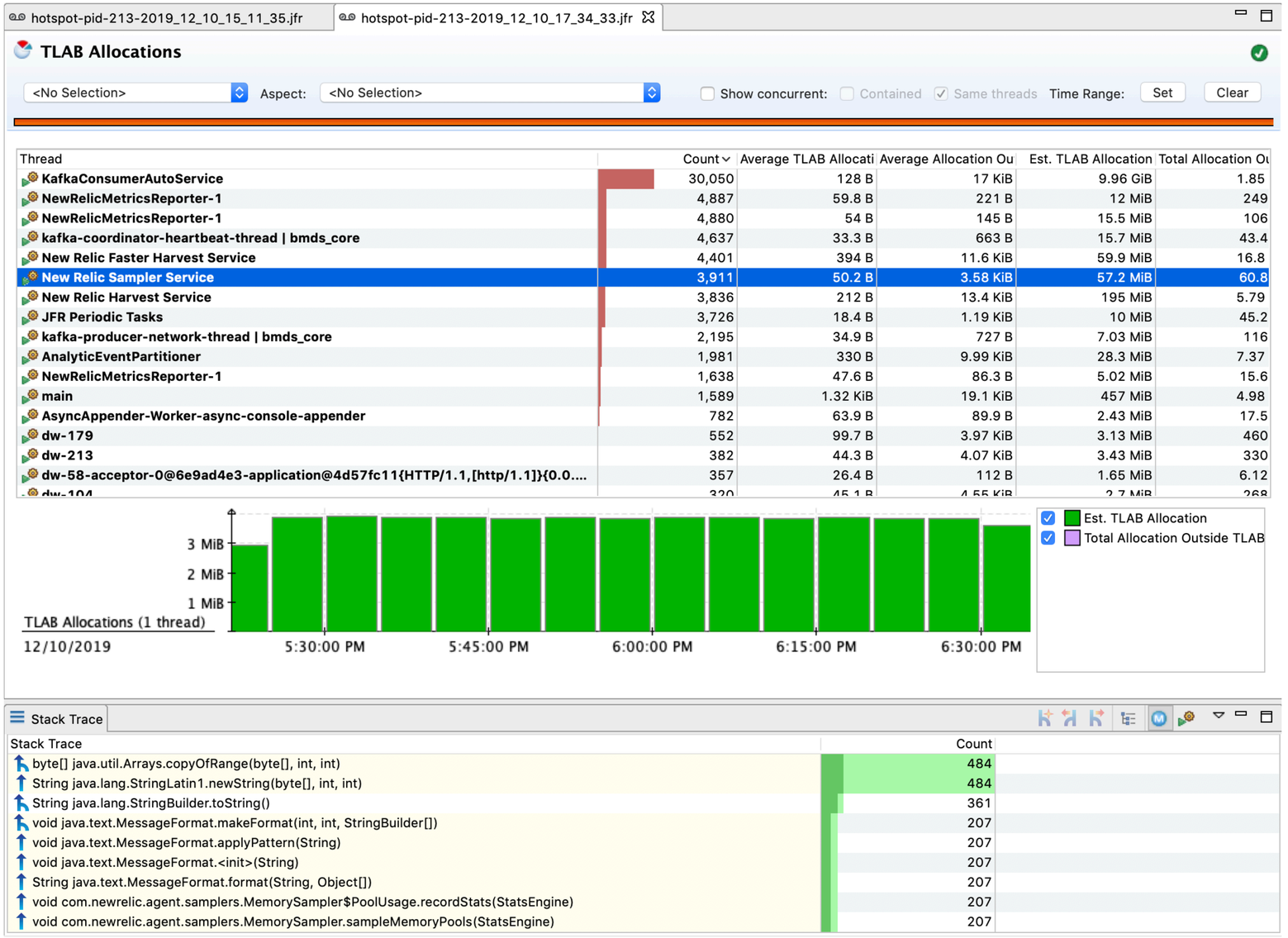
- The Java command - jcmd can be used to control JFR
- Can start and stop
- Dump a current snapshot

```
$ jcmd <pid> JFR.start name=Recording1 settings=default
$ jcmd <pid> JFR.dump filename=recording.jfr
$ jcmd <pid> JFR.stop
```

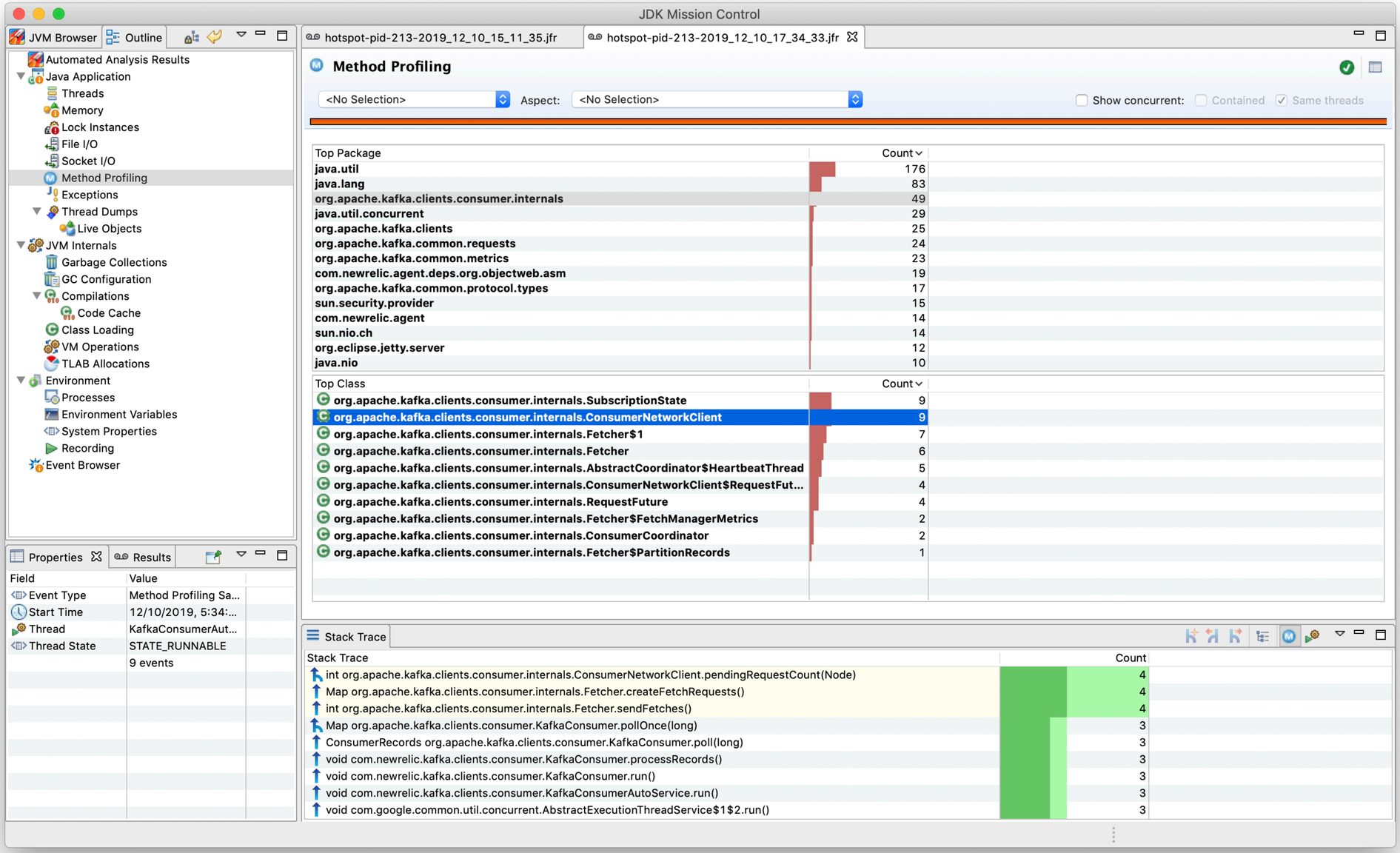
Using Mission Control



Allocation Detail (TLAB)



Method Profiling



New Relic.

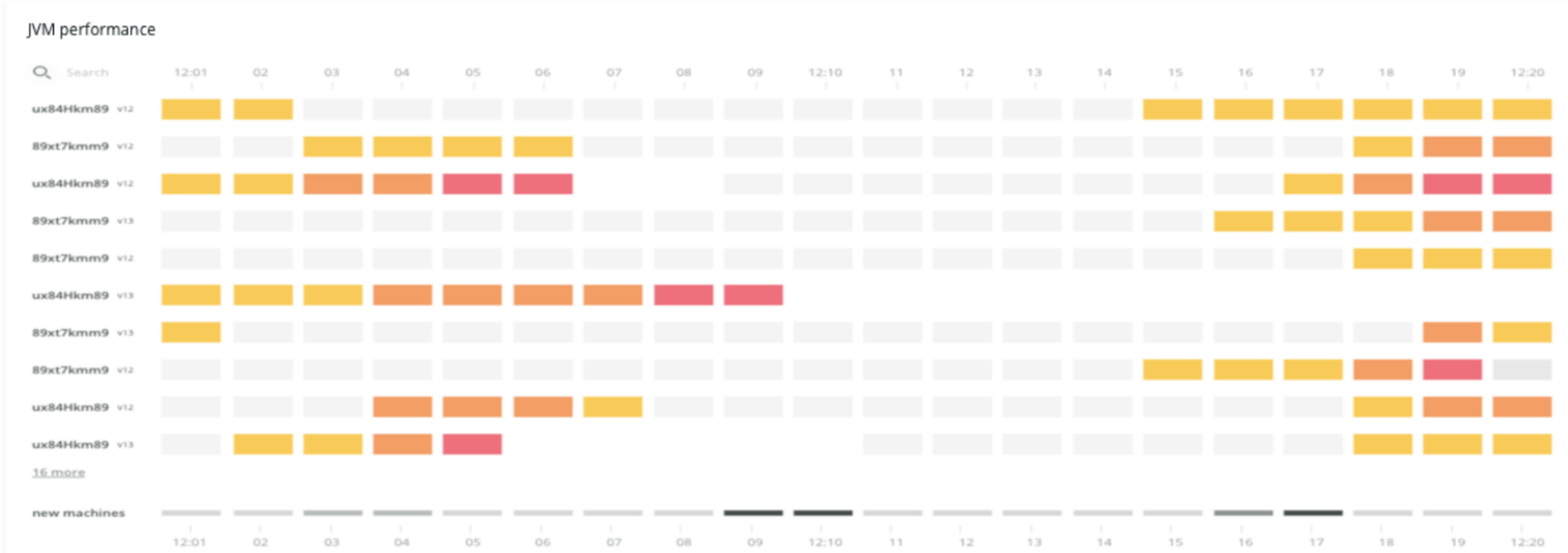
Best Practices

- Use JFR as a “ring buffer”
- Use jcmd to dump the file as required
- Allows you to ssh in & dump the buffer
  - Allows you to “go back in time”
- Not ideal
  - Need sshd running
  - Not very "DevOps Pro"

New Relic: Real-Time Profiling for Java

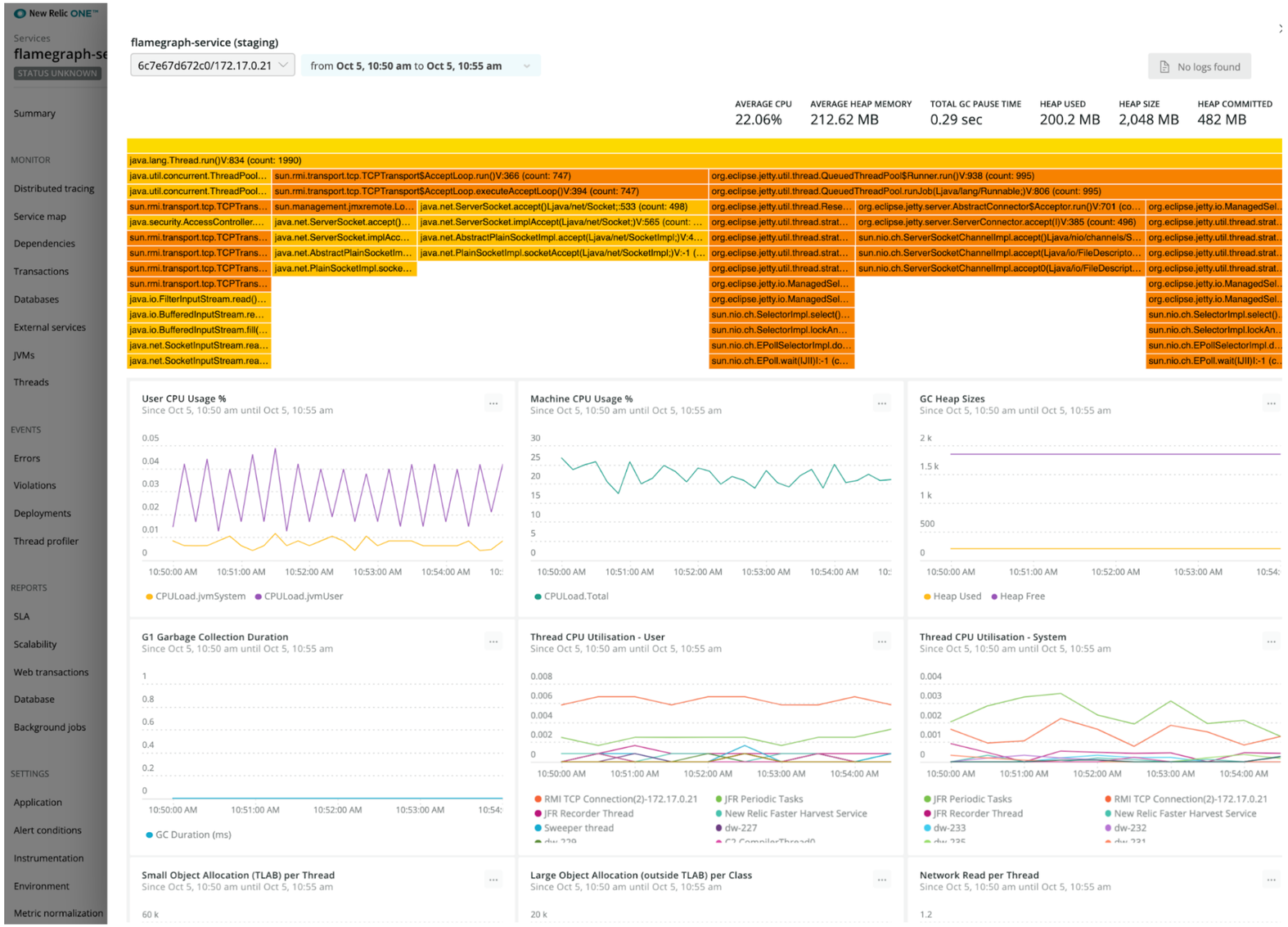
- New Relic released GA support for JFR
  - Called "Real-Time Profiling For Java"
- Open-source codebase
  - https://github.com/newrelic/newrelic-jfr-core
  - Version 1.1.0 out now
- Support for jlink'd deployments is coming
- https://newrelic.com/signup
  - 100GB / month free forever

Cluster Explorer Timeline

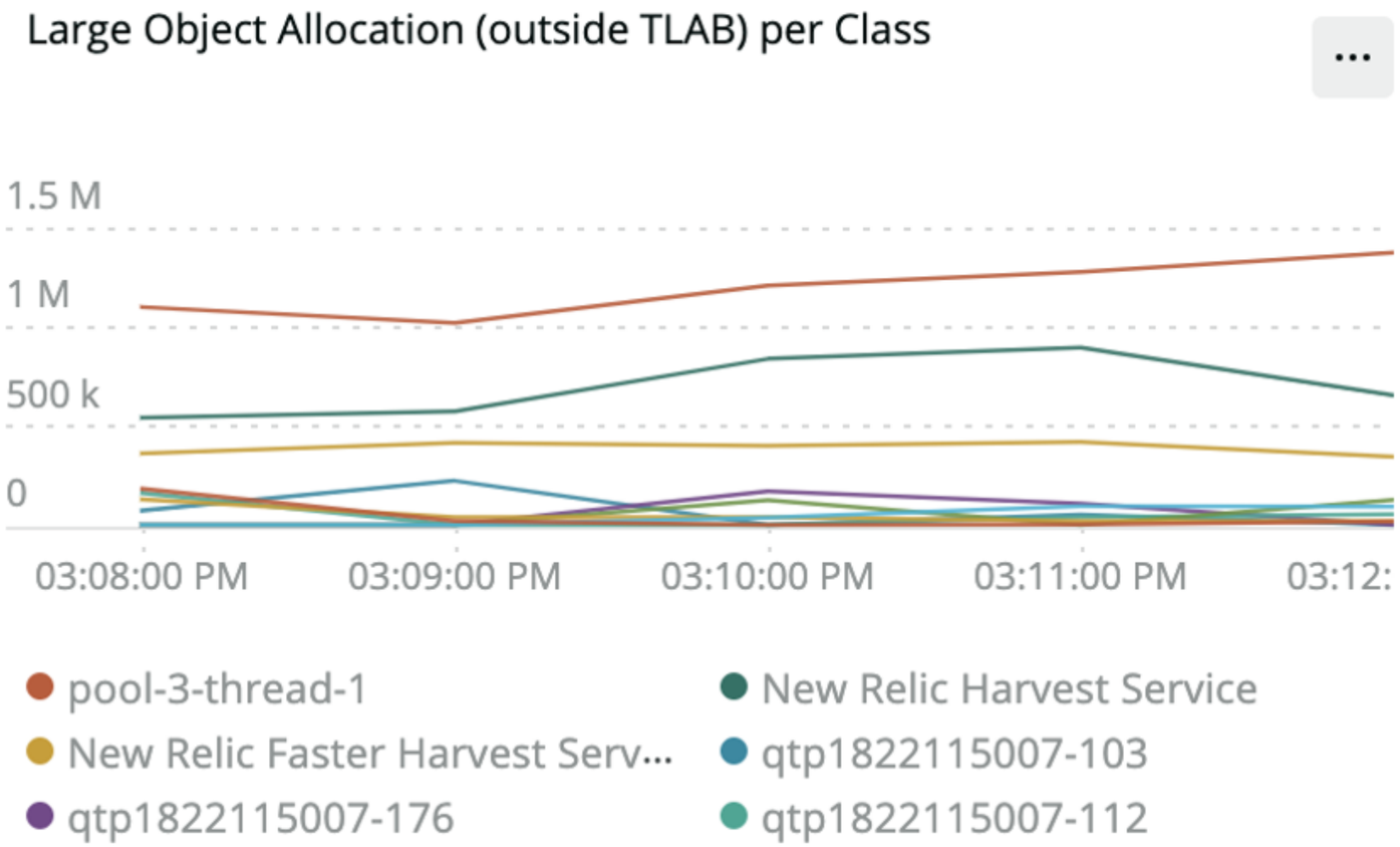


JVM	APDEX	RESPONSE TIME	THROUGHPUT	CPU	MEMORY (MB)
005dd73ff9e3 10.18.36.143:30652 005dd73ff9e3:11350	1.00	0.525 ms	11 rpm	19.3%	24,956
005dd73ff9e3 10.18.36.143:30652 005dd73ff9e3:11350	1.00	0.525 ms	11 rpm	19.3%	24,956
005dd73ff9e3 10.18.36.143:30652 005dd73ff9e3:11350	1.00	0.525 ms	11 rpm	19.3%	24,956
005dd73ff9e3 10.18.36.143:30652 005dd73ff9e3:11350	1.00	0.525 ms	11 rpm	19.3%	24,956

Execution Flamegraph



Deep Dive Graphs



JFR & Open Instrumentation

- Java Flight Recorder
  - Oracle technology (open-sourced as of Java 11)
  - Backport of the tech to OpenJDK 8
- JFR is key piece of the ecosystem - not all of it
  - Part of the pivot towards Open Instrumentation
  - JFR can be bridged to OpenTracing and other OSS tools

`jlink` & GraalVM

- Further frontiers for fast startup
  - GraalVM Native mode
  - Quarkus
  - jlink'd binaries
- Challenges
  - Full modularization
  - Closed world assumption

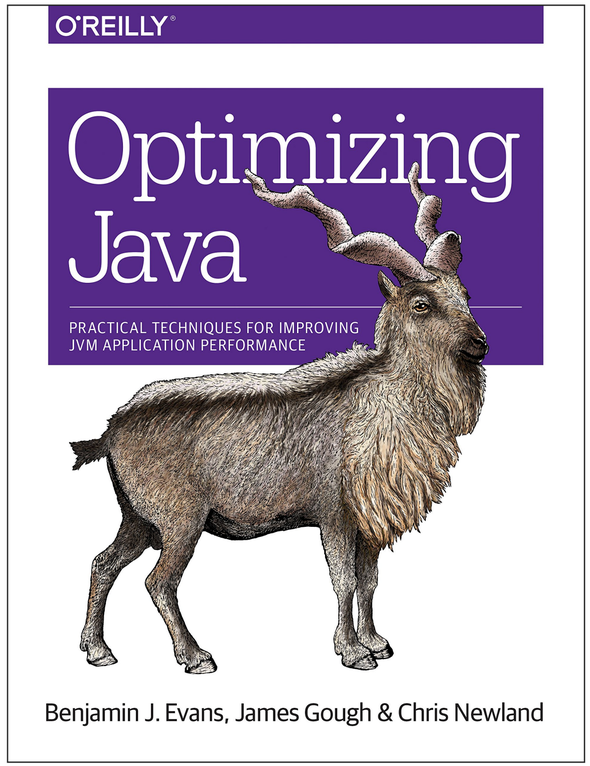
Conclusions

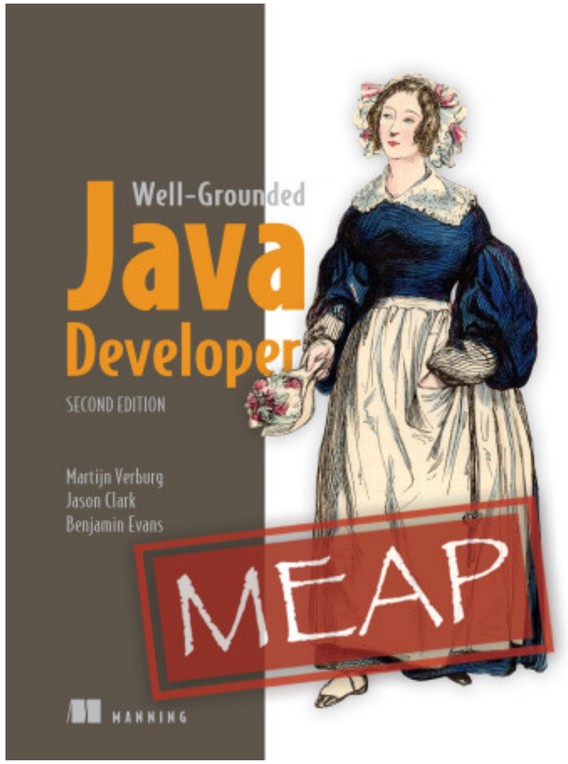
- Upgrade to 11
- Size your container correctly
- Don't use single-core containers
- Explicitly choose your memory & GC flags
  - Use a concurrent GC
- Enable JFR

Why Are We Going to 11?

- It’s the long-term support release (through 2023)
- Move from 8 … then don’t have to upgrade again
- Smaller footprint, cloud friendly, cool new tech
- Teams are using:
  - Version 11 for new apps
  - Version 8 for sustaining / BAU apps
- Upgrades are occurring at teams own pace
  - Almost all major New Relic systems have started migration

Questions & Thank You





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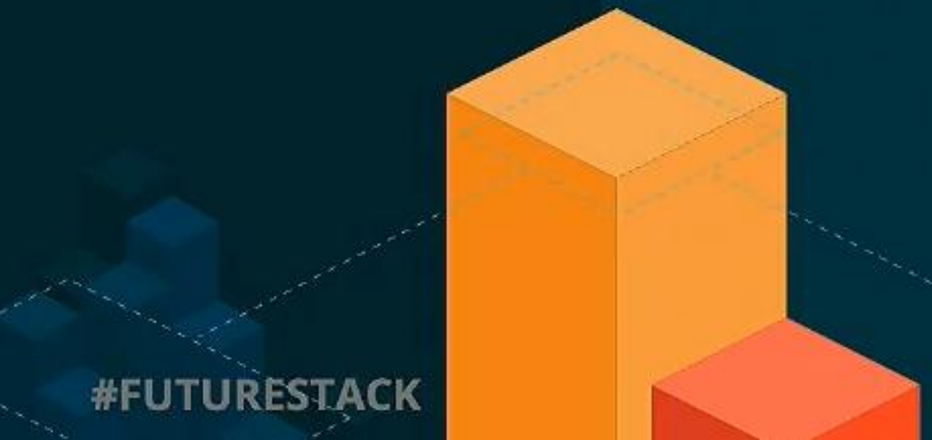

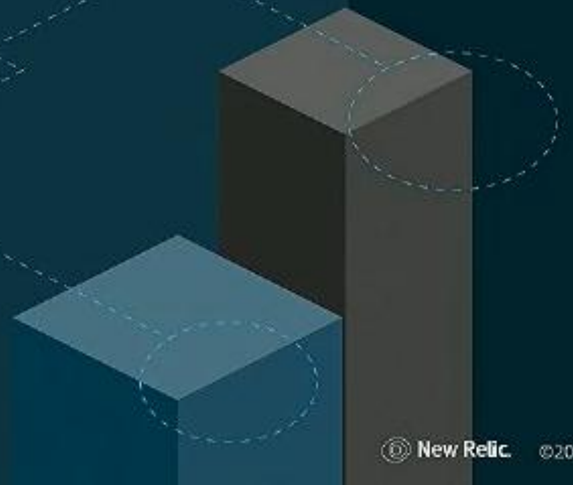

#FUTURESTACK