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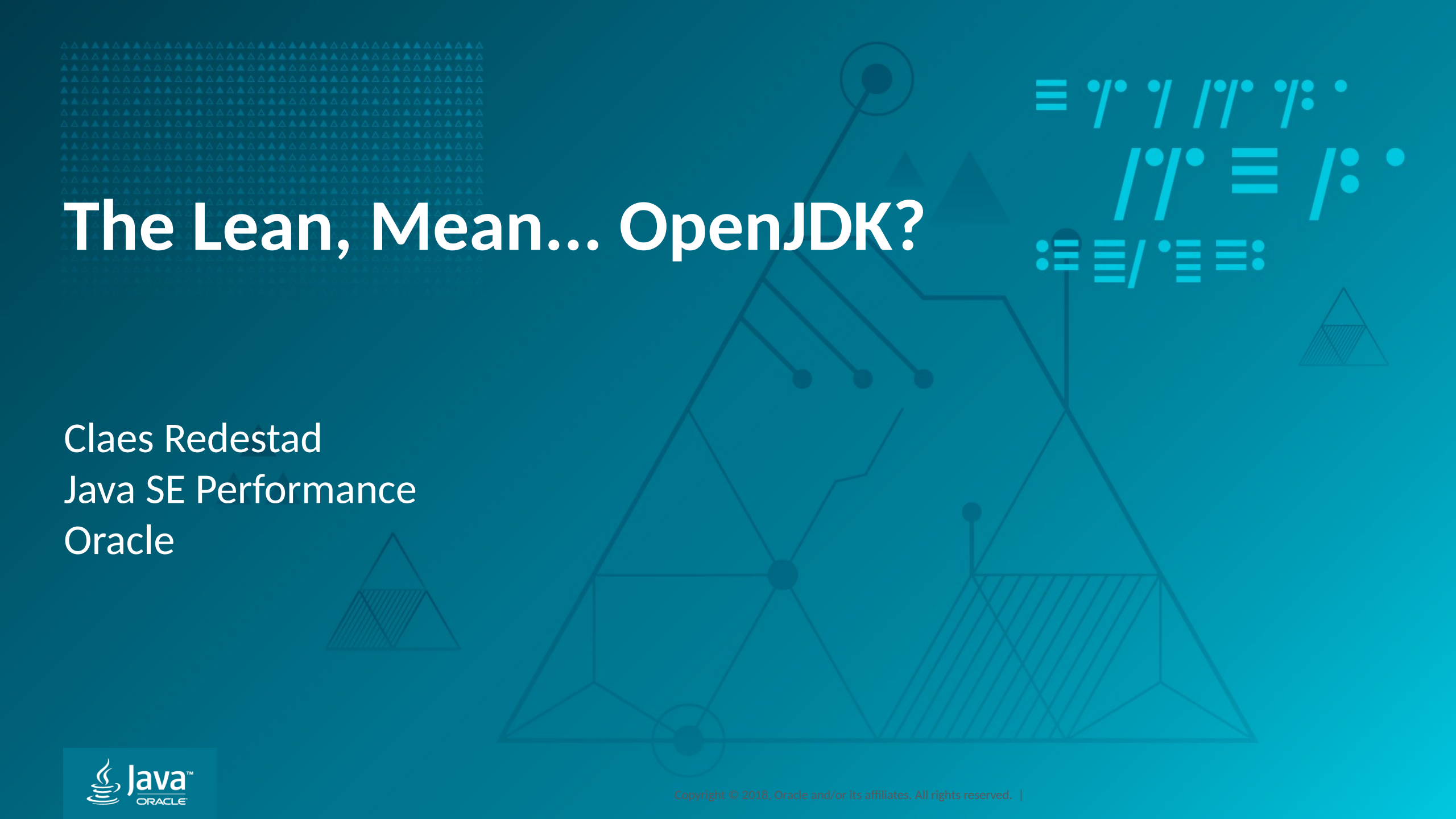
The Lean, Mean… OpenJDK?

Claes Redestad
Java SE Performance
Oracle



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The Lean, Mean… OpenJDK?

Who am I?

- Performance engineer at Oracle since 2012
- OpenJDK: redestad
- Blog: https://cl4es.github.io
- Twitter: @cl4es

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What is OpenJDK?

- The OpenJDK project started in 2006 as an open sourcing effort of the Sun JDK
- OpenJDK has been the basis of all Sun/Oracle proprietary JDK distributions since then
- Starting with JDK 11, OpenJDK and the proprietary Oracle JDK have fully converged: proprietary and/or commercial features that were only in the Oracle JDK are now *freely* available and part of the OpenJDK

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Did you say free?

Yes! Oracle provides OpenJDK builds for *free* here:

https://jdk.java.net/

The latest release will continue to be free and unrestricted

https://blogs.oracle.com/java-platform-group/

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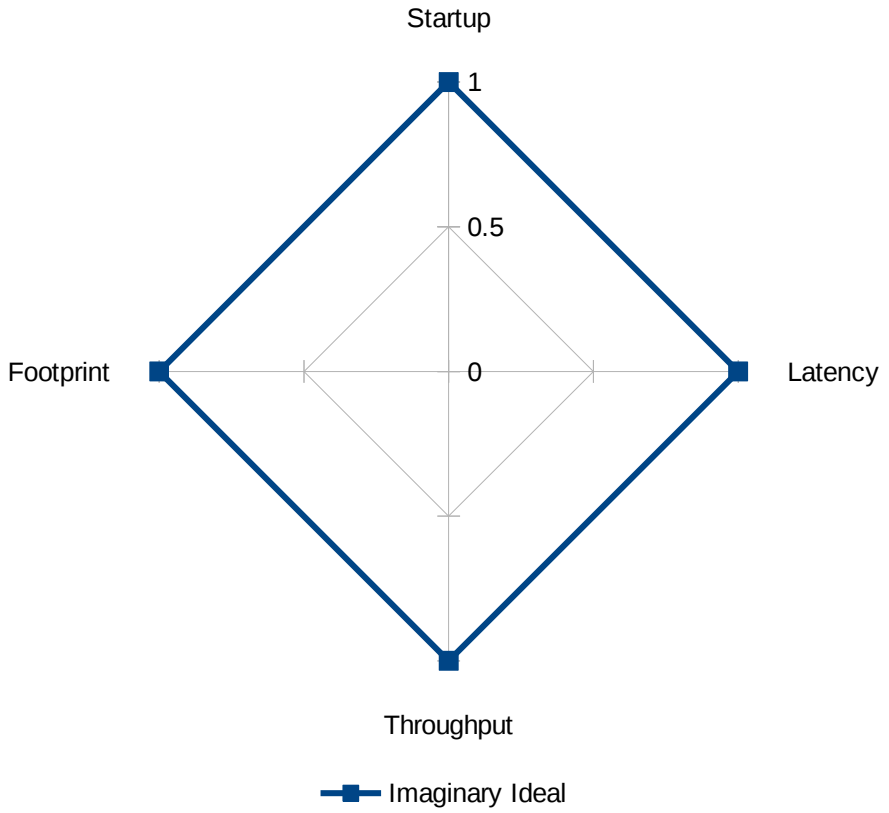
What is performance?

- Throughput
  - The total amount of work a system can do in some given time
- Latency
  - The time it takes to do some unit of work
- Footprint
  - Memory and storage requirements
- Startup
  - The time and resources needed to get ready for action



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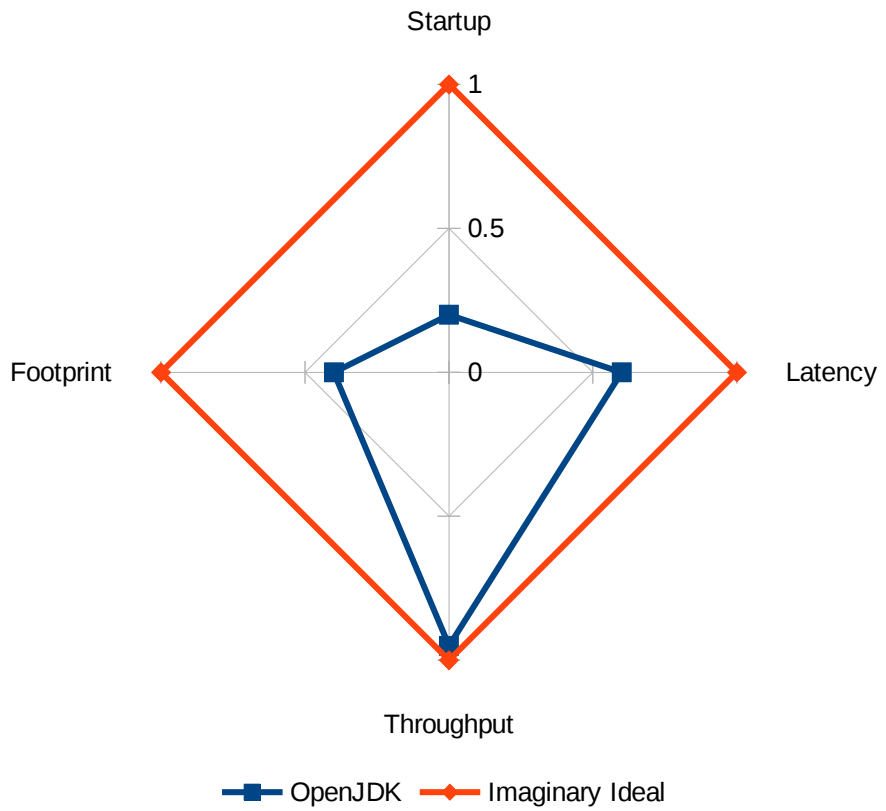
Trade-offs and the ergonomic JDK

- Out-of-the-box we ergonomically seek to strike a good balance between all performance concerns

- Historically the JDK has favored peak throughput
  - Some industry shift towards favoring low latency, especially as workloads scale up
  - To some extent tuning allow users to choose different trade-offs

… goal to make (most) tuning unnecessary



Source: Data and qualified guesses

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Where to start?

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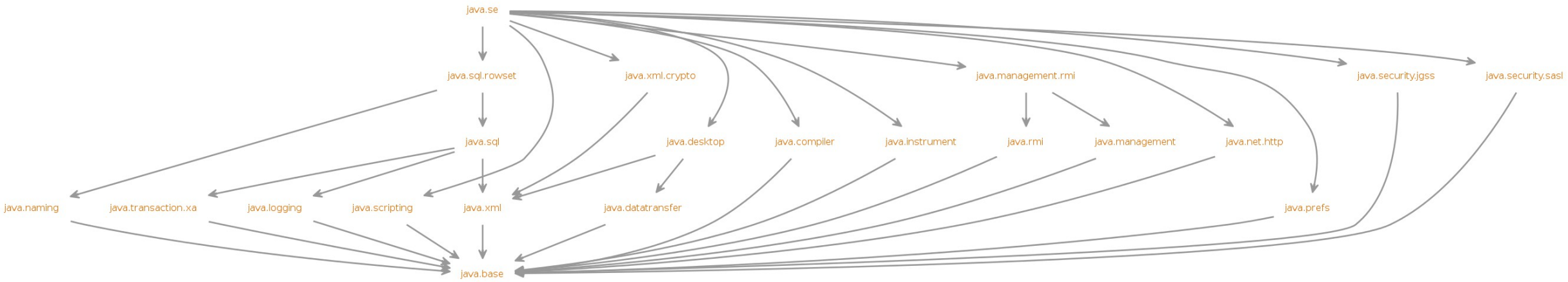
The modular JDK



JDK 9 *modularized* the JDK

Modules enable better control for developers to encapsulate internals

Consolidate embedded JDKs projects into the mainline

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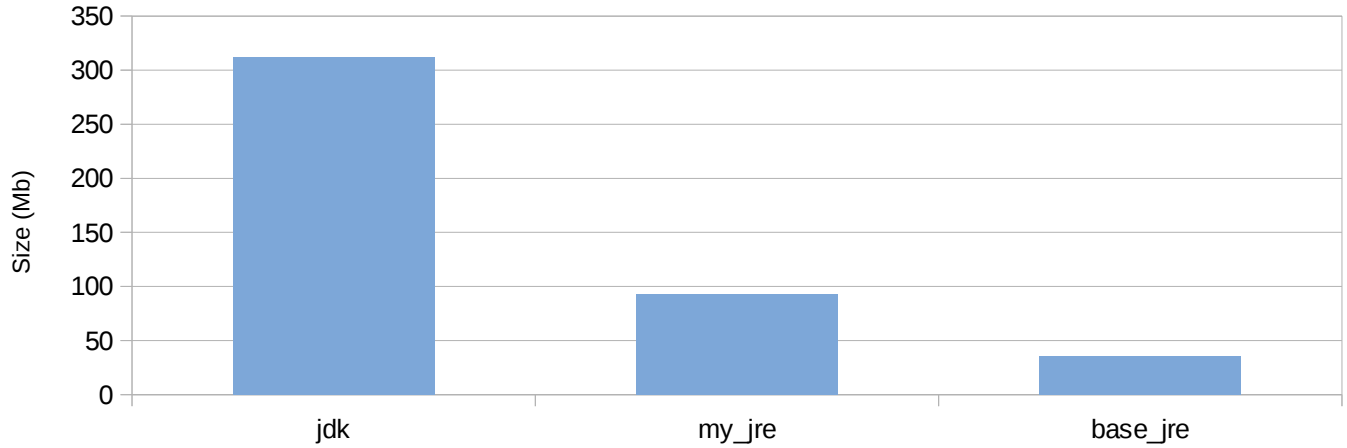
The modular JDK allows us to scale down…

jlink can be used to build custom JRE images from a subset of JDK modules, down to the bare minimum




```
$ bin/jlink --add-modules java.se,jdk.jfr --module-path jmods --output my_jre

$ bin/jlink --compress=2 --add-modules java.base --module-path jmods --output base_jre
```

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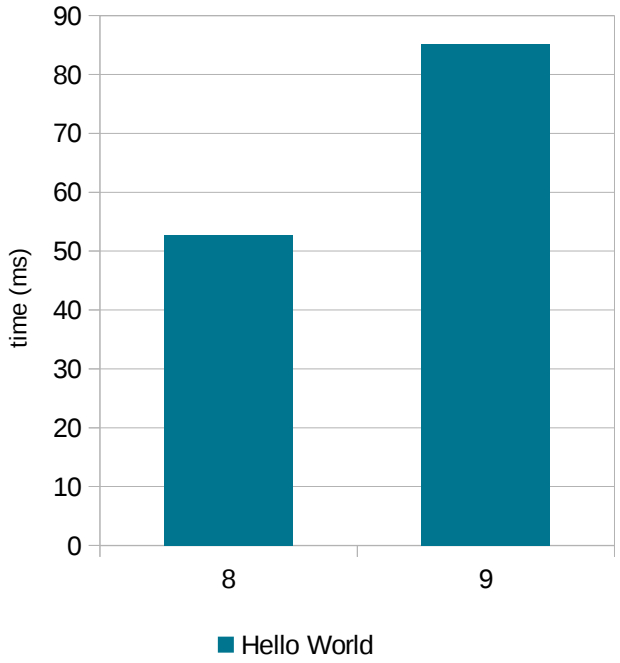
Hello World(s)!

- Out of the box, the module system caused some bootstrap regressions in JDK 9
- Especially running on a JRE with all JDK modules

```
Hello World:

 System.out.println("Hello World!");
```



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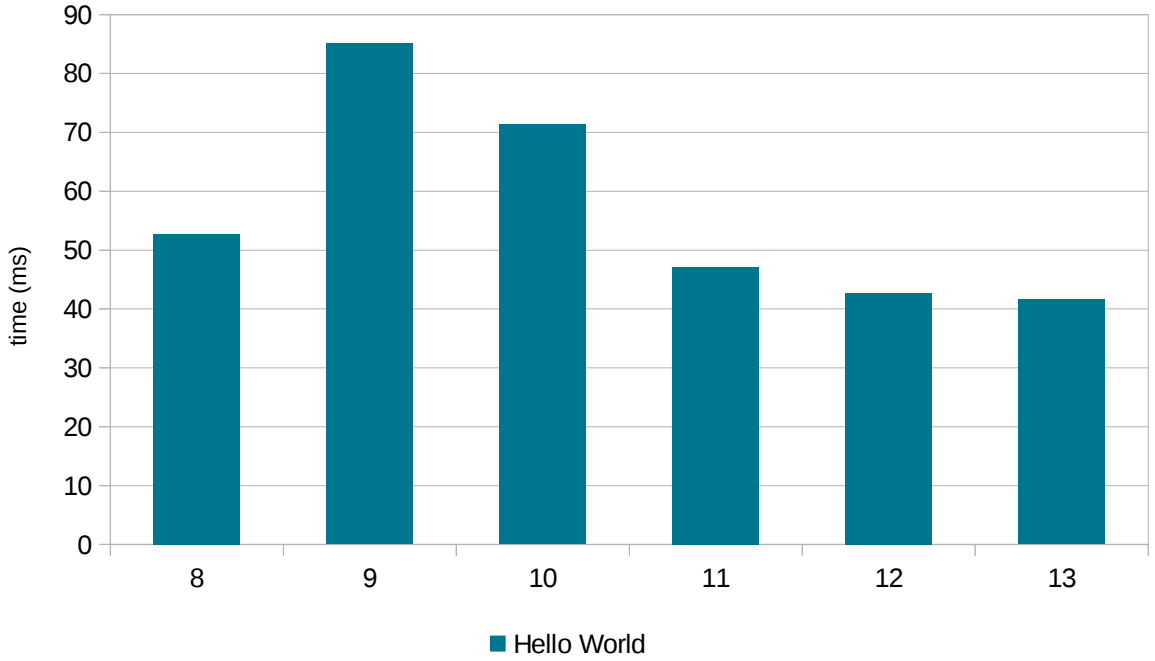
Hello World(s)!

- We fixed many of those regressions…
- *… and kept on fixing*
  - 120+ startup-related enhancements resolved in JDK 10 through JDK 13

```
Hello World:

 System.out.println("Hello World!");
```



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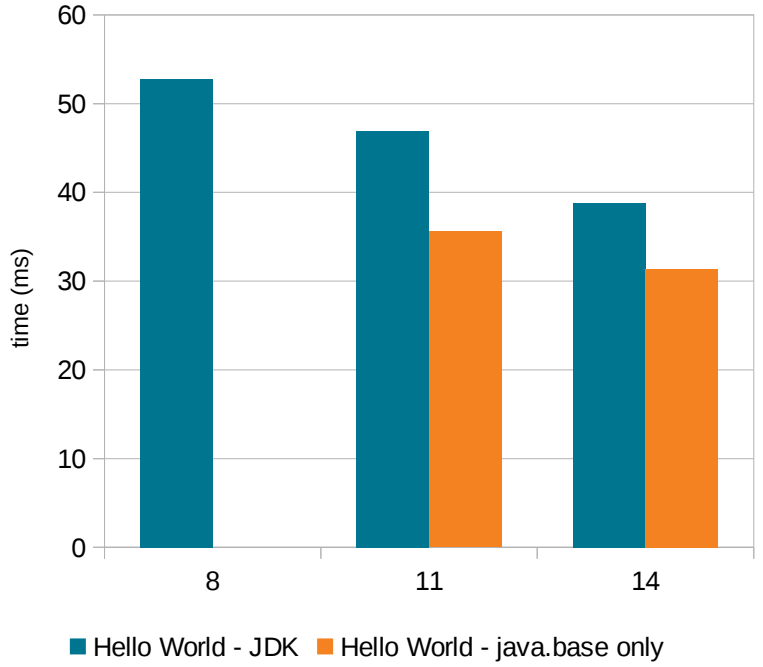
Hello World(s)!

- **Bonus:** slightly better when leaving out unneeded modules

```
Hello World:

 System.out.println("Hello World!");
```



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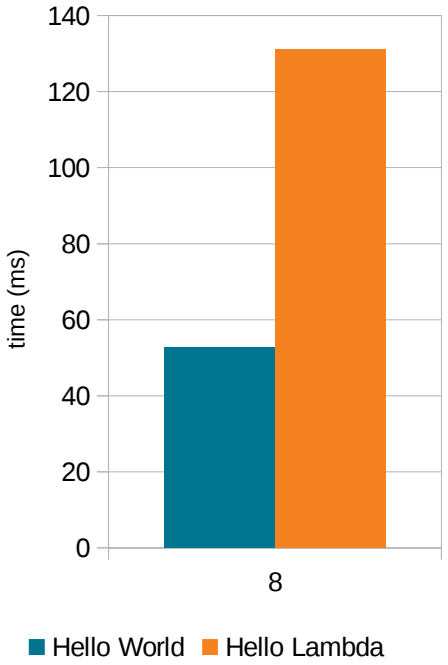
Bootstraps, all the way up!

- In JDK 8, bootstrapping the first lambda expression took longer time than starting up the entire JVM(!)
- Early prototypes of the module system saw use of lambdas during bootstrap
- It seemed prudent to deal with this to avoid even larger *regressions*

```
Hello Lambda:

  Consumer<String> println =
    System.out::println;
  println.accept("Hello World!");
```



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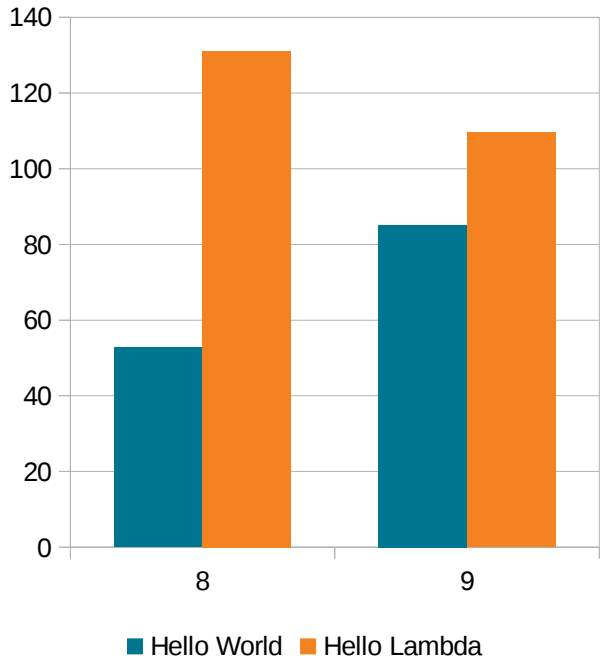
Bootstraps, all the way up!

- For JDK 9, we spent some time cleaning things up
  - Just removing a few unnecessary things and making various things initialize more lazily got us quite far
- With the new **jlink** tool in the works we have a new means to move work from runtime to link time
  - A **jlink** plugin to generate some commonly used classes cut the overhead of lambda bootstrap roughly in half

```
Hello Lambda:

  Consumer<String> println =
    System.out::println;
  println.accept("Hello World!");
```



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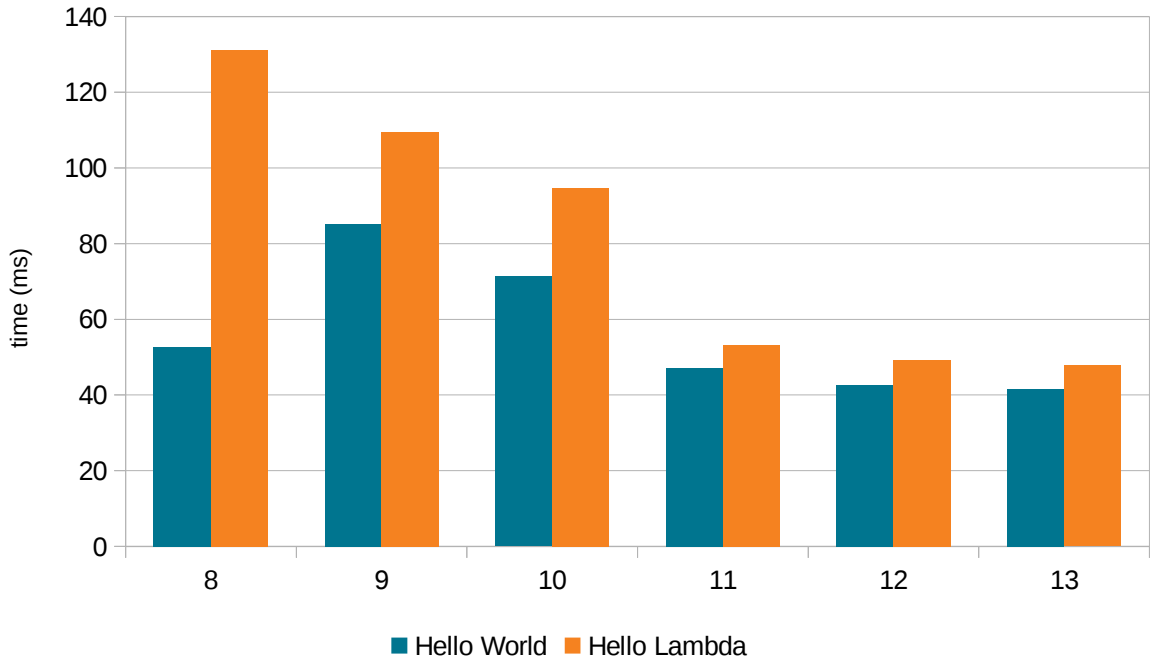
… and all the way down…

- In JDK 11 we got rid of most of the one-off overheads
- "Hello Lambda" now faster than "Hello World" was on JDK 8



Great success! But lambdas aren't the only thing that might require expensive bootstrapping…

JDK-8198418

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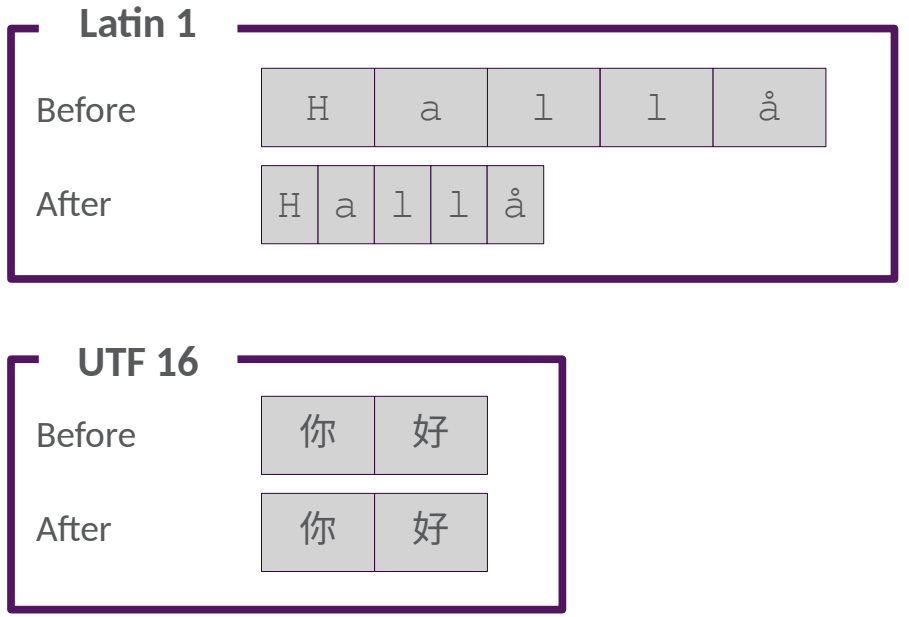
But first… Compact Strings!

- Enable denser storage of Strings
  - Internal storage changed from `char[]` to `byte[]`
  - Any string that can be encoded using Latin 1 will use one byte per character instead of two
  - Other strings will encode their chars into two bytes as before
- Obvious footprint wins
  - Most applications have a significant number of Latin 1 encodable strings
- Surprising(?) throughput improvements



https://openjdk.java.net/jeps/254

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Indified String concatenation

- JEP 280 introduced indified String concatenation, **ISC**
  - Use **dynamic** bootstrapping of String concatenation expressions
- Large throughput and latency wins
- "Most optimal ISC strategies do 2.9x better, and 6.4x less garbage"
  - Aleksey Shipilëv, JFokus 2016

```
@Param("4711")
public int intValue;

@Benchmark
public String concat() {
  return "string" + intValue +
         "string" + intValue;
}

           time        alloc
-----------------------------
JDK 8      44.0ns/op   80B/op
JDK 13     24.5ns/op   64B/op
```

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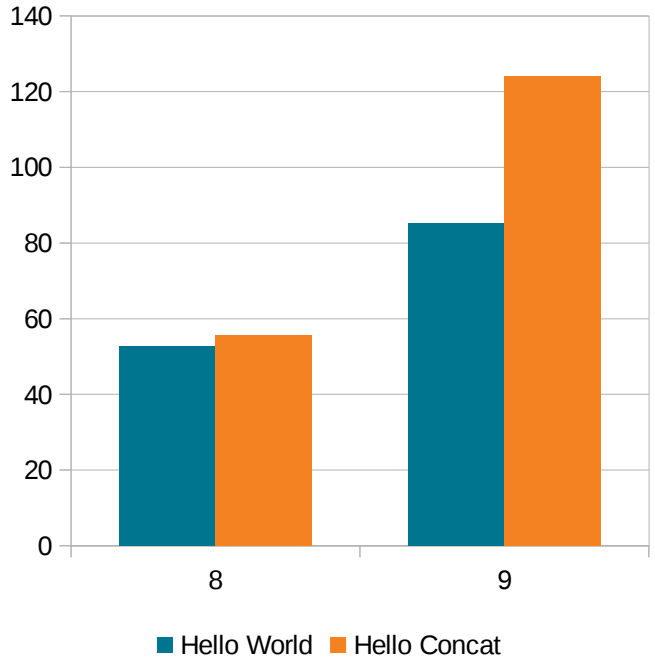
String Concat Redux

- ISC is cause for some bootstrap overheads of string concatenation expressions in JDK 9
- Some work done before JDK 9 release to lessen the startup blow
  - The **jlink** plugin that helped lambda bootstrapping plays a large role here

```
Hello Concat:

  String foo = ...
  System.out.println("Hello 1: " + foo);
  System.out.println("Hello 2: " + foo);
  ...
  System.out.println("Hello 10: " + foo);
```



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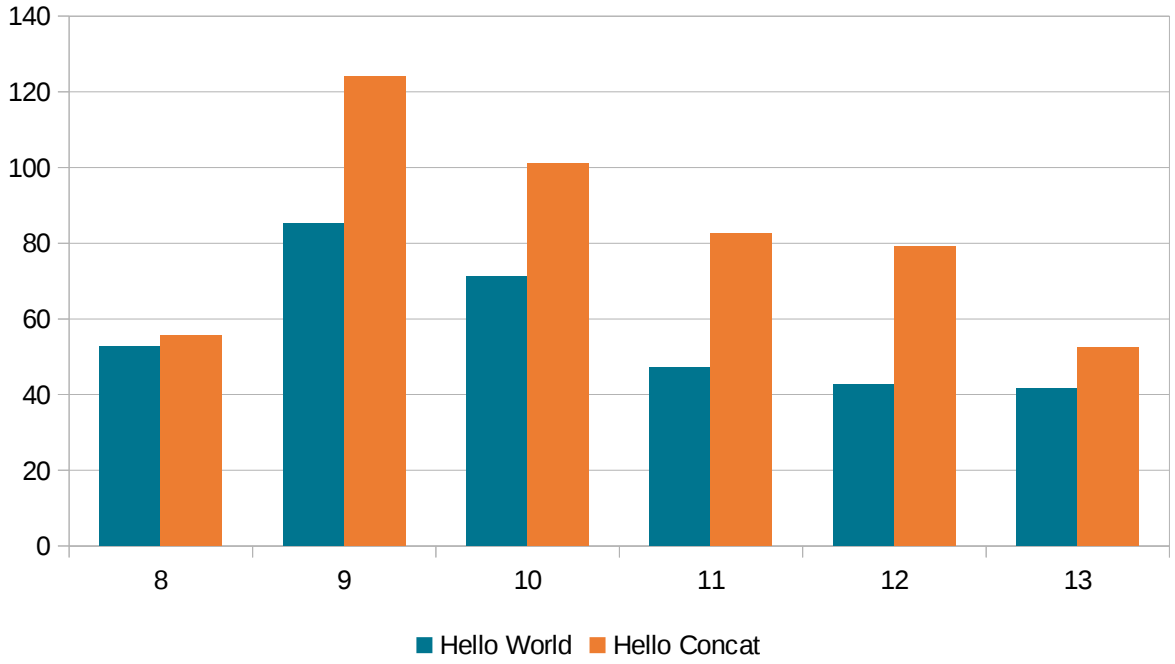
String Concat Redux

- There were some improvements in JDK 10 through 12 for specific cases
- Speeding up bootstrapping of ISC expressions in general proved harder than expected
- Not until JDK 13 did we manage to cut down the overheads more generally

But we now have a robust framework for building more of these ***dynamic*** and ***performant*** things into Java (and other JVM languages) while only paying a small price for them up front



https://cl4es.github.io/2019/05/14/String-Concat-Redux.html

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And now for something completely different…

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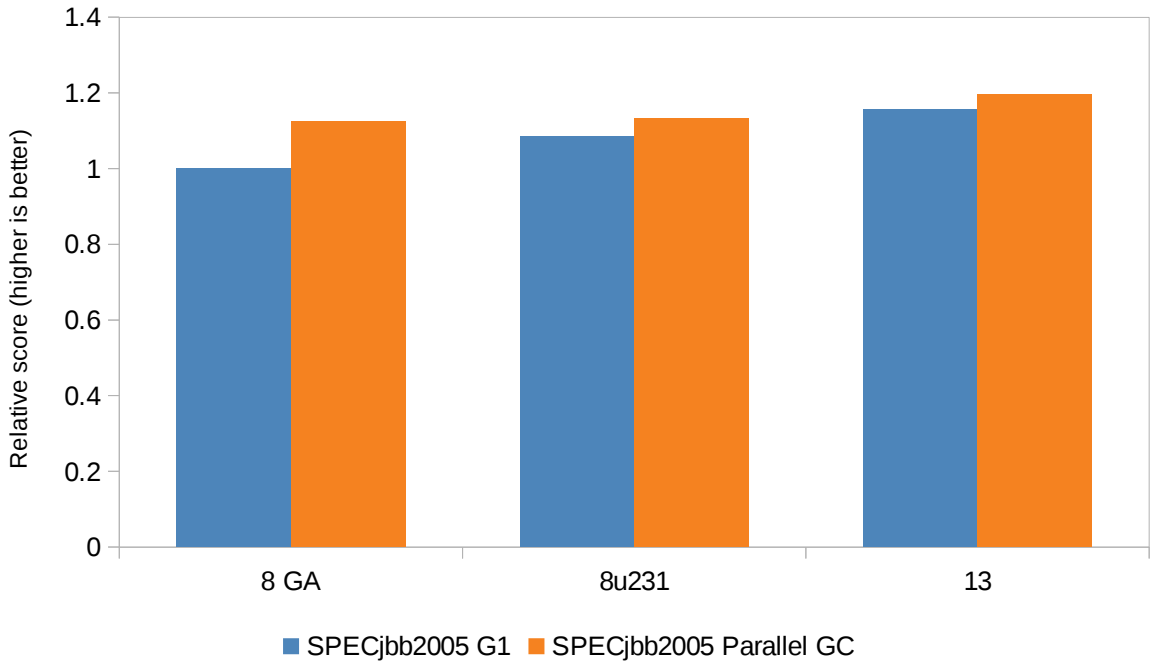
The G1 garbage collector saw a lot of improvements

- G1 was still lagging behind ParallelGC
  - At least on throughput-oriented benchmarks!
- Over the course of 8 updates and more recent releases, the gap has been shrinking
- Just being a few percent behind on *throughput* is great for a GC that is meant to optimize more for *latency!*



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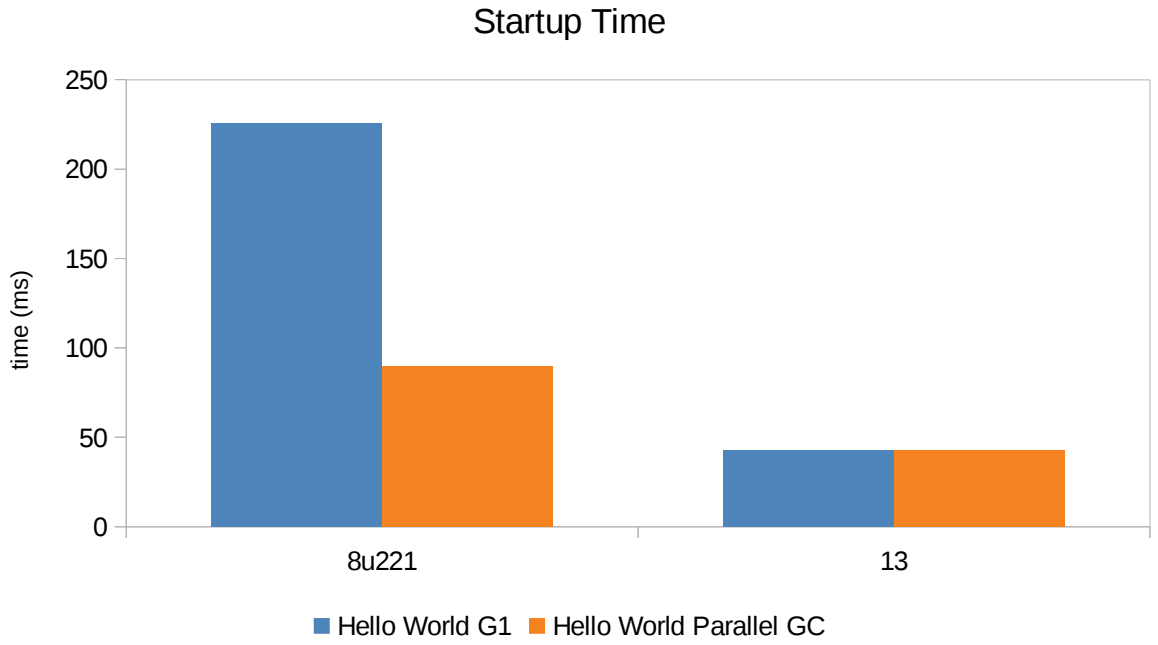
The G1 garbage collector saw a lot of improvements

- A great number of issues affecting startup time in G1 was addressed
  - Getting parity on out-of-the-box with simpler GCs
  - Cutting minutes off of startup in extremer cases (> 1TB heap)



The numbers shown may somewhat exaggerate the *startup* overhead when running G1 on 8, since some of it was related to an issue with unnecessary delays when shutting down the JVM

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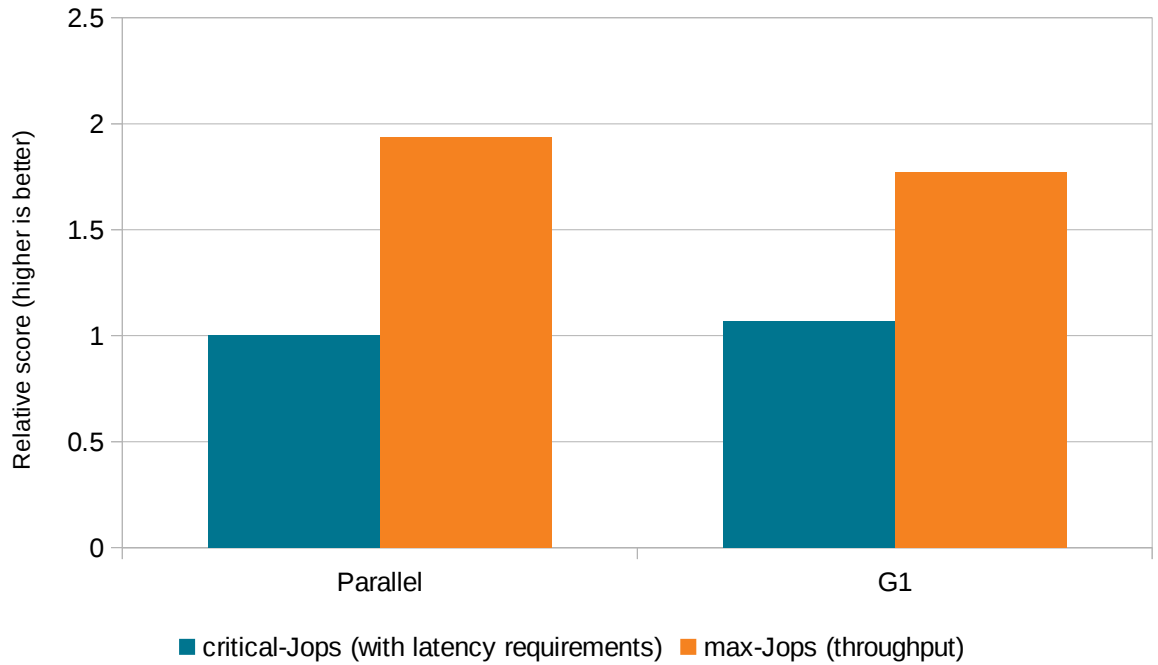
… and was made default in JDK 9

- Throughput penalties around 3-10% are common
- More extreme corner cases exist
- Still a good trade-off
  - Trade some raw throughput to reduce risk of really long pauses



Mode: Composite **Heap Size:** 128G **OS:** Oracle Linux 7.5
HW: Intel Xeon E5-2690 2.9GHz 2 sockets, 16 cores (32 hw-threads)

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The Z Garbage Collector

- Scalable, concurrent low-latency GC
- Pause times **below** 10ms - often below **1** ms
- Scale from hundreds of Mb to **16*** terabytes (* from JDK 13)
- Experimental: `-XX:+UnlockExperimentalVMOptions -XX:+UseZGC`
- Goal is to complement the other GCs:
  - **Parallel GC** optimizes for *throughput*
  - **G1** strives for a balance between *throughput* and *low pause* times
  - **ZGC** spares no expense to attain as *low pause times* as possible

https://wiki.openjdk.java.net/display/zgc

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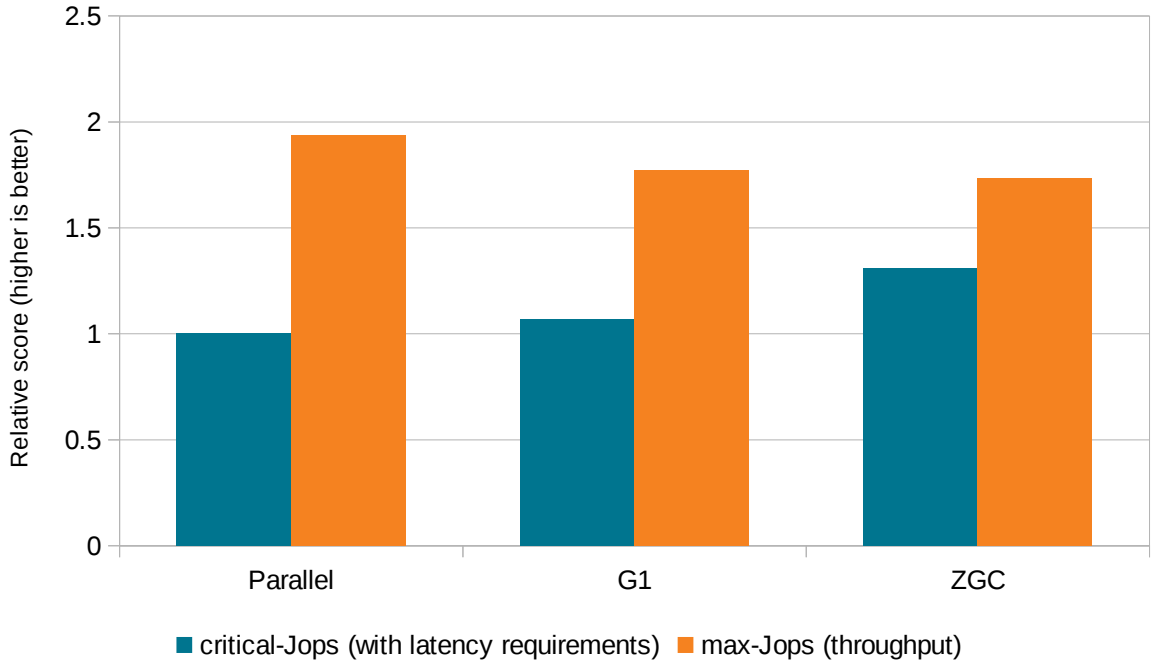
The Z Garbage Collector



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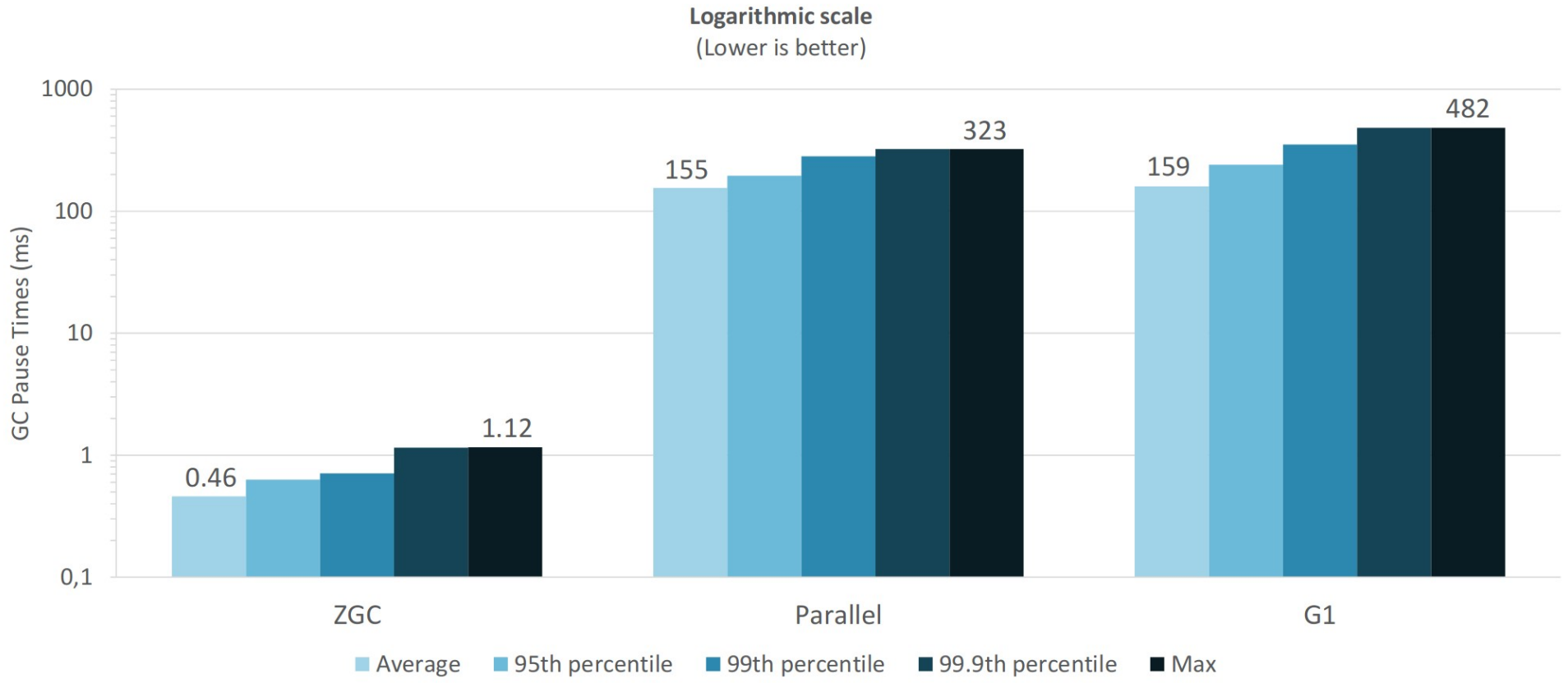
The Z Garbage Collector



https://cr.openjdk.java.net/~pliden/slides/ZGC-PLMeetup-2019.pdf

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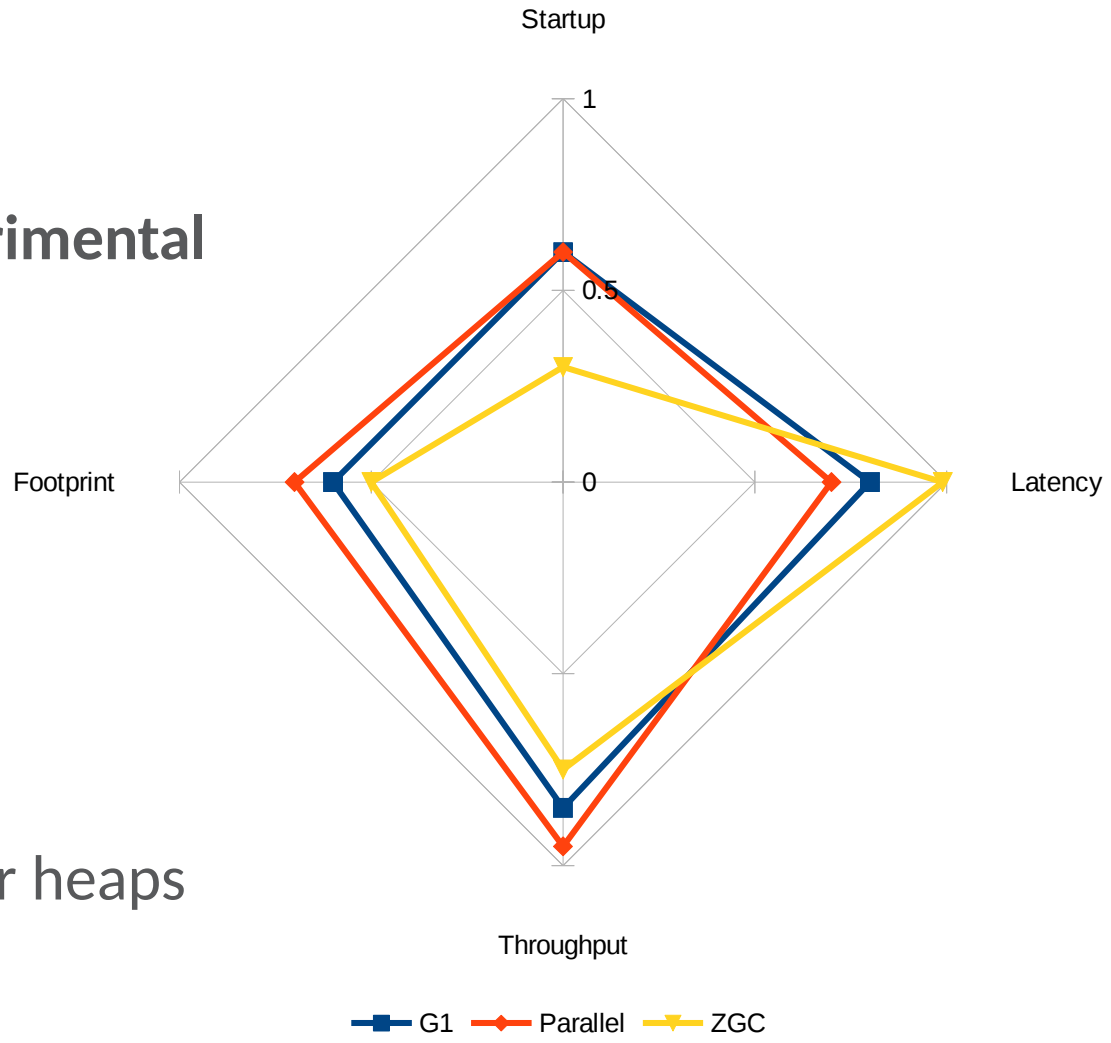
Some ZGC caveats

- Support: Linux only, x64 and AArch64
- Mostly feature complete in 13, but still **experimental**
- No compressed pointers
  - Higher footprint on smaller heaps
- Potentially heavy startup cost
  - No ***CDS*** support
  - Memory initialization overheads on larger heaps



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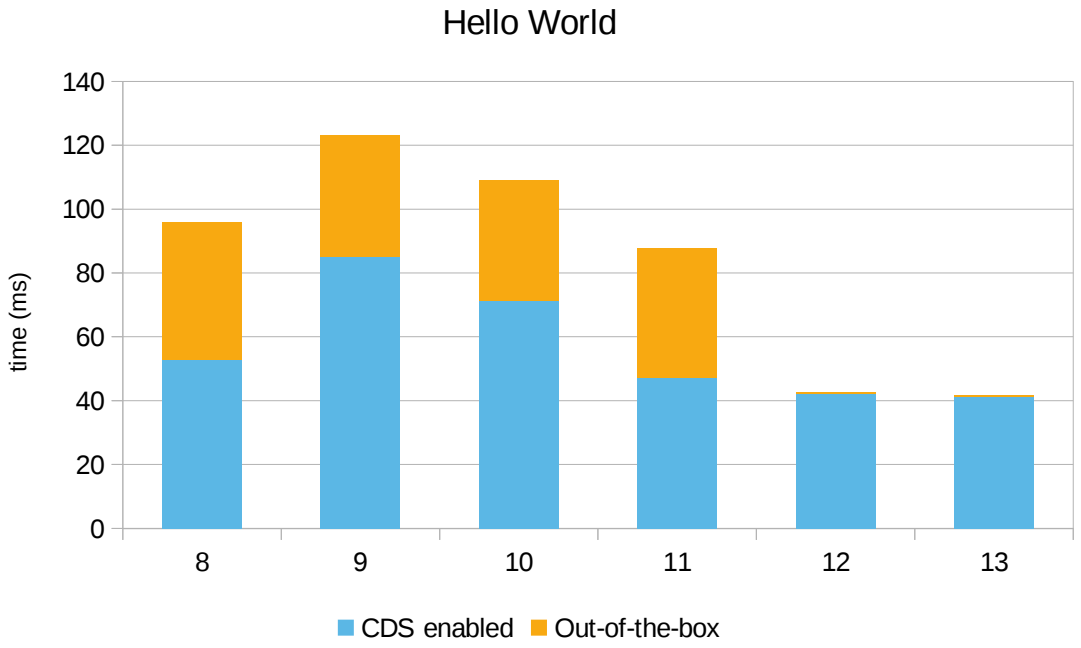
"CDS?"

- Class-Data Sharing
  - Turns class loading from a time-consuming task into a simple matter of mapping in memory
  - Support for archiving part of the heap
- Run `java -Xshare:dump` once to enable
- Since JDK 12 CDS enabled and prepared *out of the box*



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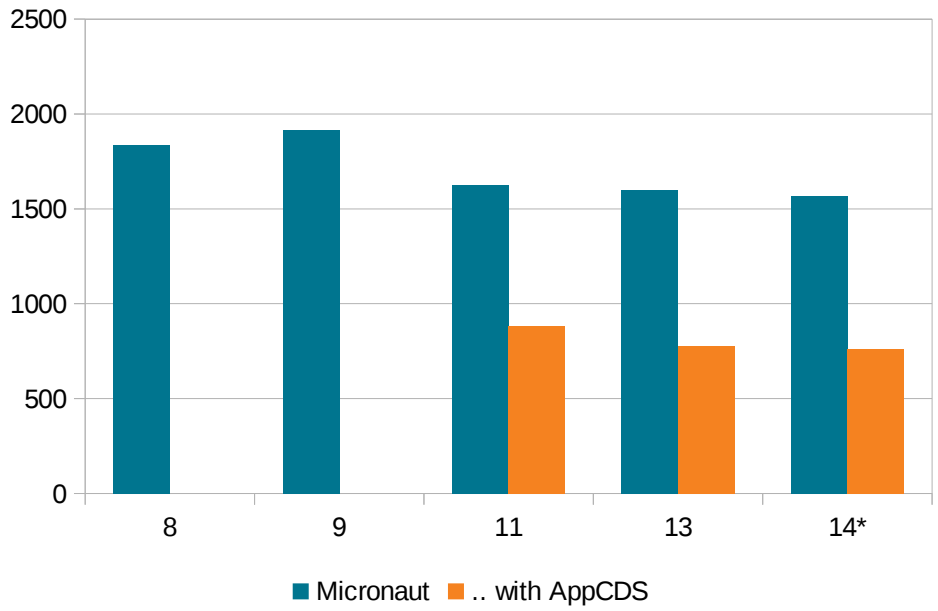
Bring your own SharedArchiveFile

- Application Class-Data Sharing - AppCDS - was contributed to the OpenJDK in JDK 10
- Typically cuts 20-50% off startup numbers
- Gradually improved since inception
- Dynamic CDS (JDK 13) makes it easy to use:

```
# Generate archive with a training run
java -XX:ArchiveClassesOnExit=MyApp.jsa MyApp

# Ship it!
java -XX:SharedArchiveFile=MyApp.jsa MyApp
```



https://openjdk.java.net/jeps/310
https://openjdk.java.net/jeps/350

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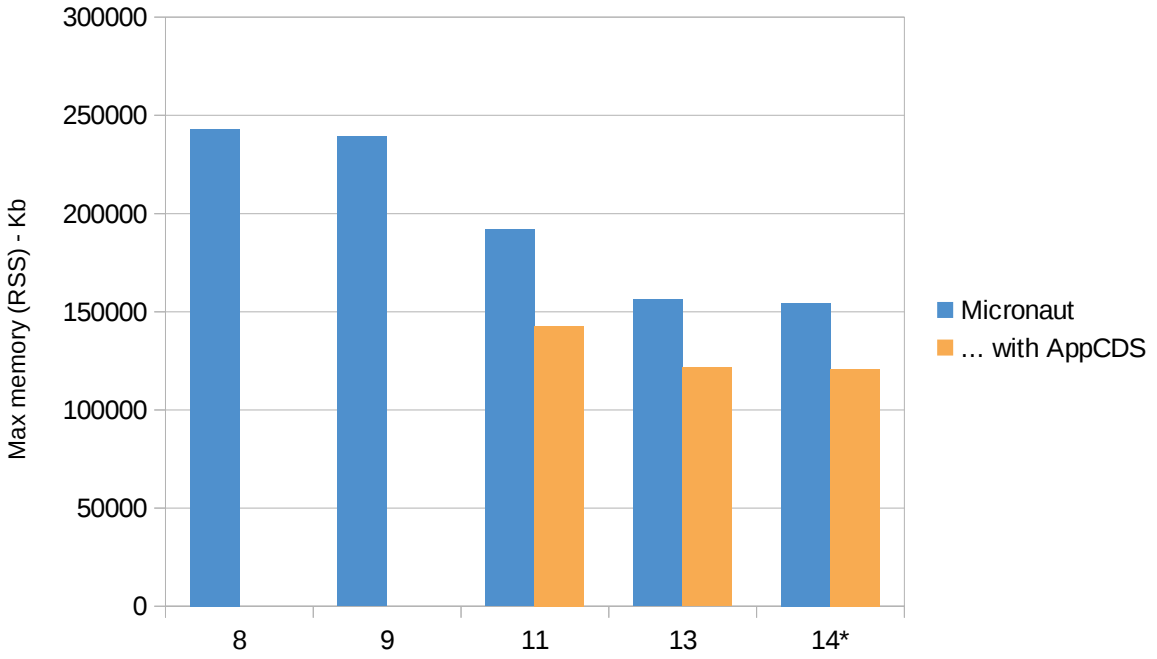
Footprint improvements to boot!

- Startup improvements/features often go hand in hand with footprint improvements
- AppCDS helps, too, partly by removing the need to do bytecode verification at runtime



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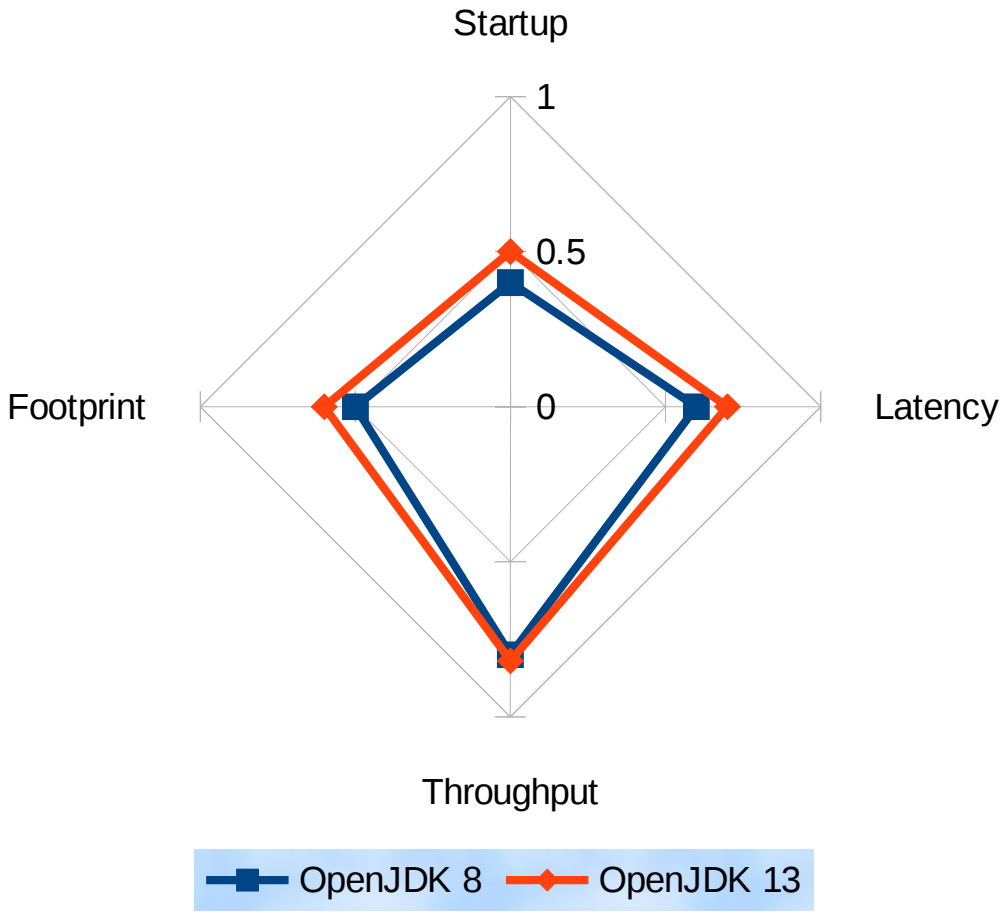
The Story So Far… from JDK 8 to 13

- Numerous startup and footprint improvements to the out-of-the-box experience
- Performance features like Compact Strings have potential to improve performance in general
- While still experimental, work on ZGC already benefit **production** GCs like G1 and Parallel GC

YMMV



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"The best feature pipeline ever!"

- Project Valhalla
  - Value types for the JVM
  - Enable "flattening" objects, which improves density, which speeds up throughput
- Project Loom
  - Make it simple to write highly concurrent applications
- Project Amber
  - Umbrella for adding smaller productivity-oriented features to the java language
  - `var` delivered in 11
  - Switch expressions, text blocks being previewed in 13 - much more coming!
- Project Panama
  - Better (faster) and simpler native code interaction

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Potential startup plays

- JWarmup: https://openjdk.java.net/jeps/8203832
  - Record profiling information in one execution
  - Feed profile information into JVM during subsequent executions
  - Shortens the "warmup" phase by enabling JITs to do the Right Thing up front
- Constant folding, lazy finals, etc…
  - Language level support could enable (javac) compile time constant folding

    https://www.youtube.com/watch?v=iSEjlLFCS3E
  - VM support for dynamic creation of constants could enable lazy finals

    https://openjdk.java.net/jeps/8209964
- CRIU
- AOT?

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AOT vs. JIT

- An *Ahead-of-Time* compiler compiles source code into some target binary form
- The OpenJDK primarily uses *Just-In-Time compilers* to optimize the bytecode it executes *at runtime*
- JIT compilers solve three problems:
  - Not knowing *exactly* what hardware you're going to run on
  - Not knowing *exactly* what OS you're going to run on
  - Not knowing *how* your code is going to run
- JIT compilation can consume a lot of memory and CPU

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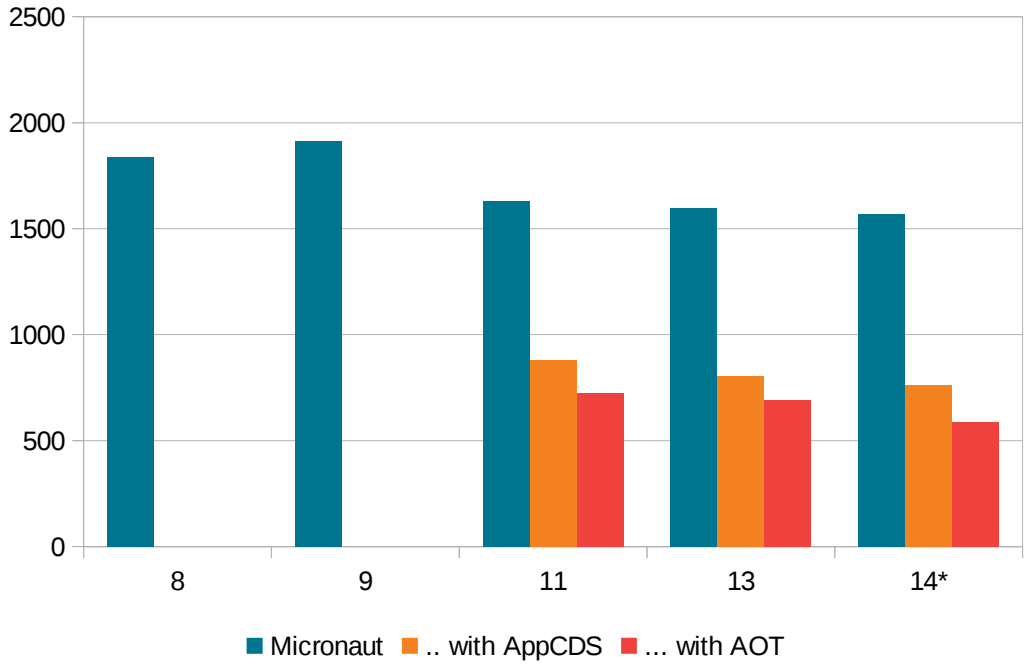
Experiments in AOT

- JDK 9 added the `jaotc` tool to enable AOT compilation
- Startup improvements…?
  - Main gain is reducing CPU and memory overhead of early JIT activity
  - Noticeable improvements for sufficiently complex applications
- Rough edges
  - Need to `--compile-for-tiered` to not cause substantial throughput penalty
  - Hard to fine-tune what to AOT to get good results
  - Relatively large binary sizes



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The GraalVM compiler - your next JIT?

- Since JDK 9, OpenJDK contains a version of the GraalVM compiler
- Used to implement the `jaotc` tool
- Can be used as a replacement for the C2 compiler *today:*

```
-XX:+UnlockExperimentalVMOptions -XX:+UseJVMCICompiler
```

- Outperforms C2 on some workloads
- Written in Java

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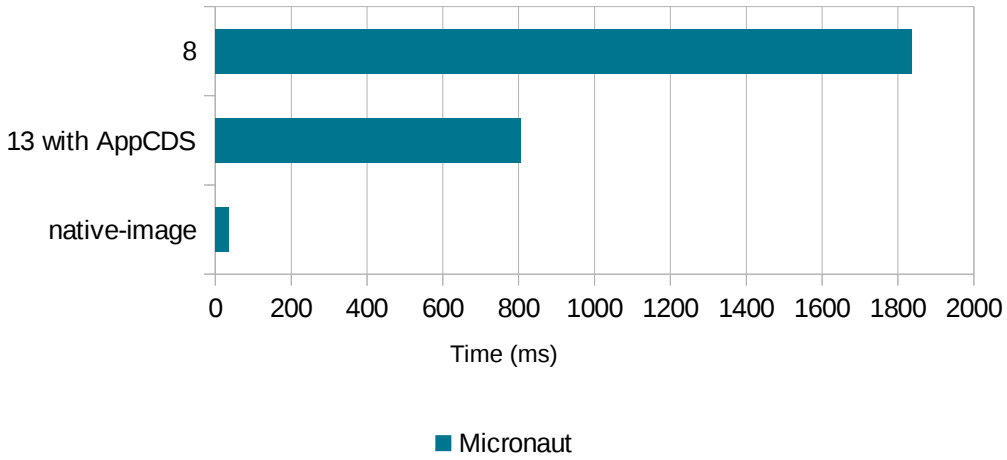
GraalVM native-image

- "Substrate VM is a framework that allows ahead-of-time (AOT) compilation of Java applications under **closed-world assumption** into executable images or shared objects"
- In short: programs/shared libraries that start/load really fast
  - Not having a JIT also means tiny footprint compared to a HotSpot JVM



https://github.com/oracle/graal/tree/master/substratevm

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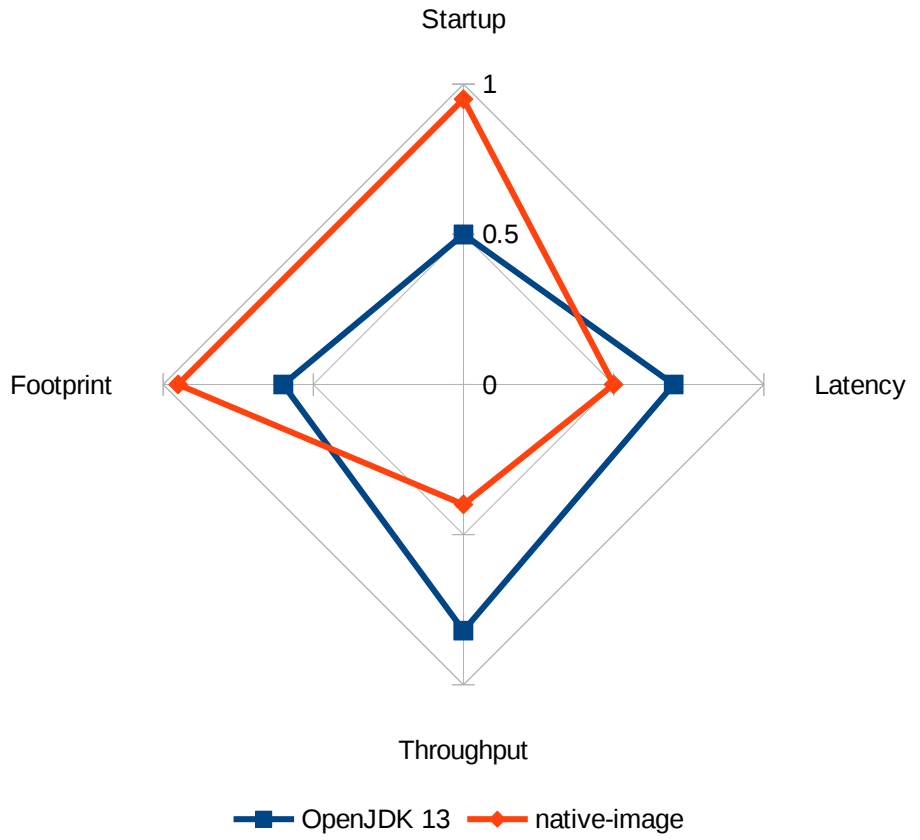
GraalVM native-image

- **Closed-world** assumption means that everything must be given up front to the compiler
  - Makes reflection, indy, condy… *complicated*
  - Native binaries, not a JVM
    - No JIT, limited GC, debugging and monitoring options, …
- Compiling the GraalVM compiler itself as a shared library resolve most startup and footprint issues when used as a JIT by HotSpot
  - Implemented in GraalVM, but not yet in OpenJDK mainline



https://www.youtube.com/watch?v=RMtukctD220

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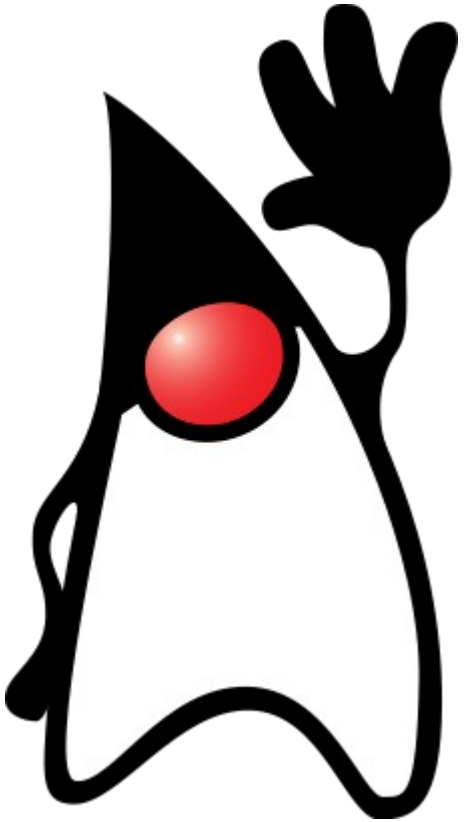
In conclusion

- OpenJDK 13 is great!
  - … but it's just a bit better than OpenJDK 12
  - … which in turn is just a bit better than OpenJDK 11
- It will keep getting better!
- (Opinion) Releasing a new feature release every six months has revitalized the OpenJDK project
  - Projects delivered when done, and in smaller increments
  - Minimal risk of something holding up the release
  - This means less stress
  - More opportunities for smaller enhancements to actually get done



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Q & A

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