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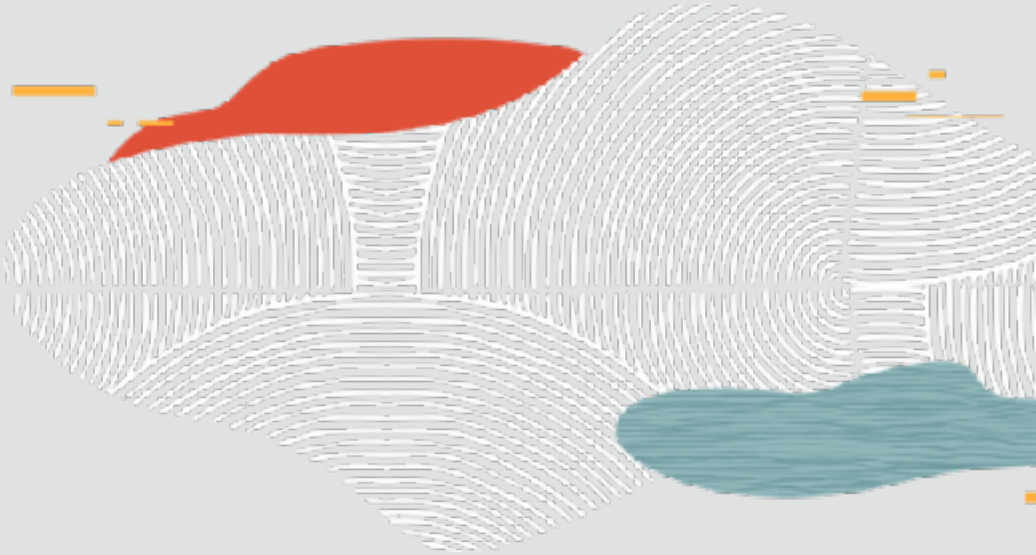

# Optimizing Performance with GraalVM

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Oracle Labs

November 11, 2019

# Safe harbor statement

The following is intended to outline our general product direction. It is intended for information purposes only, and may not be incorporated into any contract. It is not a commitment to deliver any material, code, or functionality, and should not be relied upon in making purchasing decisions. The development, release, timing, and pricing of any features or functionality described for Oracle's products may change and remains at the sole discretion of Oracle Corporation.

GraalVM Native Image Early Adopter Status

GraalVM Native Image technology (including SubstrateVM) is early adopter technology. It is available only under an early adopter license and remains subject to potentially significant further changes, compatibility testing and certification

# Agenda

1. Performance metrics
2. JIT compilation
3. AOT compilation
4. Demo: JIT and AOT
5. Tools

# Performance metrics

## How to measure performance?

- Throughput
- Latency
- Capacity
- Utilization
- Efficiency
- Scalability
- Degradation

*https://learning.oreilly.com/library/view/optimizing-java - by Chris Newland, James Gough, Benjamin J Evans*

## Performance metrics

- Throughput
- Efficiency
- Scalability

# Optimizing performance with GraalVM

## Universal Virtual Machine

GraalVM™

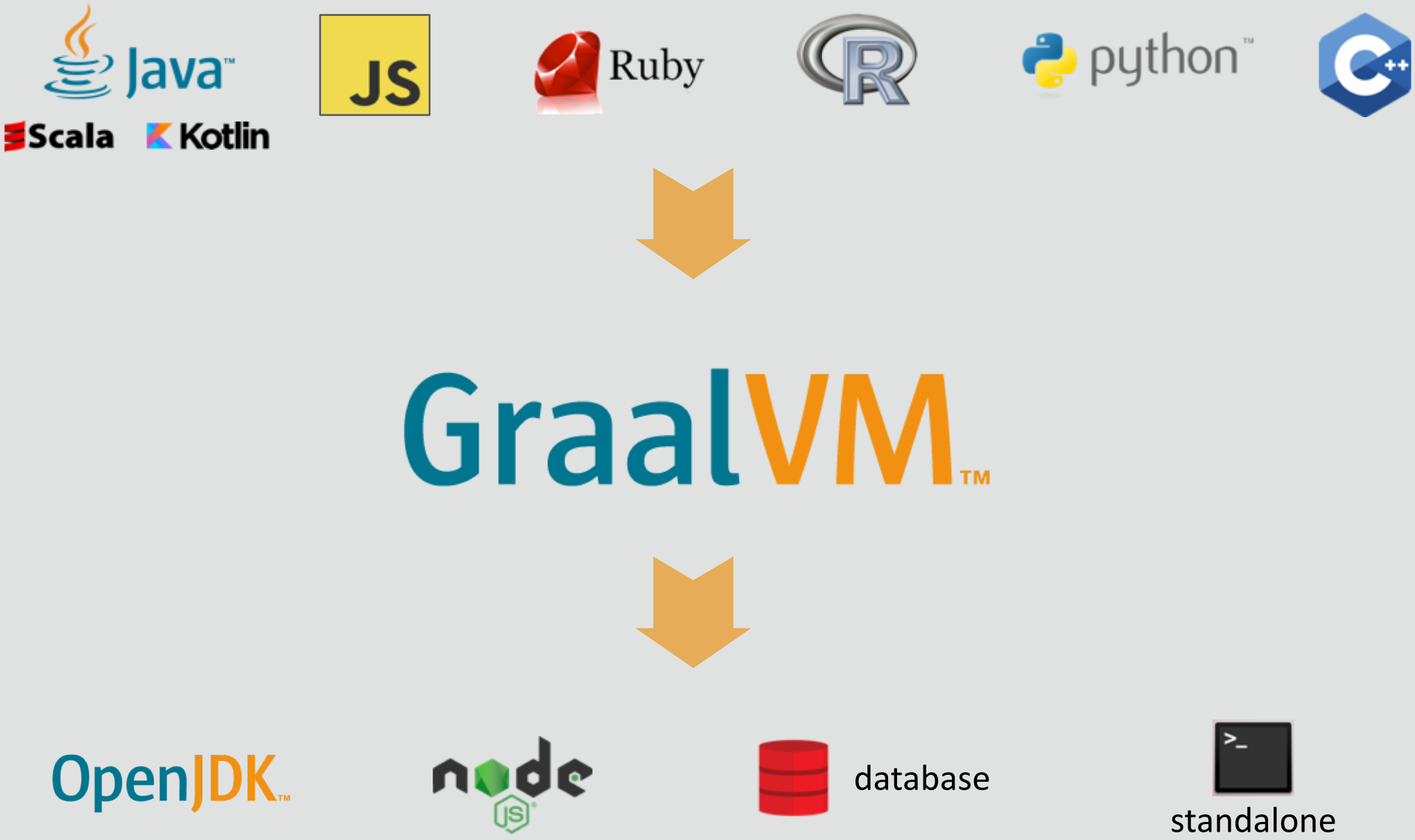
1. Run programs more efficient
2. Make developers more productive

## GraalVM Compiler

- Brand new compiler written itself in Java;
- Adds new optimizations on top of traditional ones;
- Supports multiple languages and platforms;
- Can work in JIT & AOT modes.

## GraalVM Project Goals

1. High performance for abstractions of any language
2. Low-footprint ahead-of-time mode for JVM-based languages
3. Convenient language interoperability and polyglot tooling
4. Simple embeddability in native and managed programs


Java
Scala
Kotlin
JS
Ruby
python
GraalVM
OpenJDK
node
database
standalone


GraalVM™

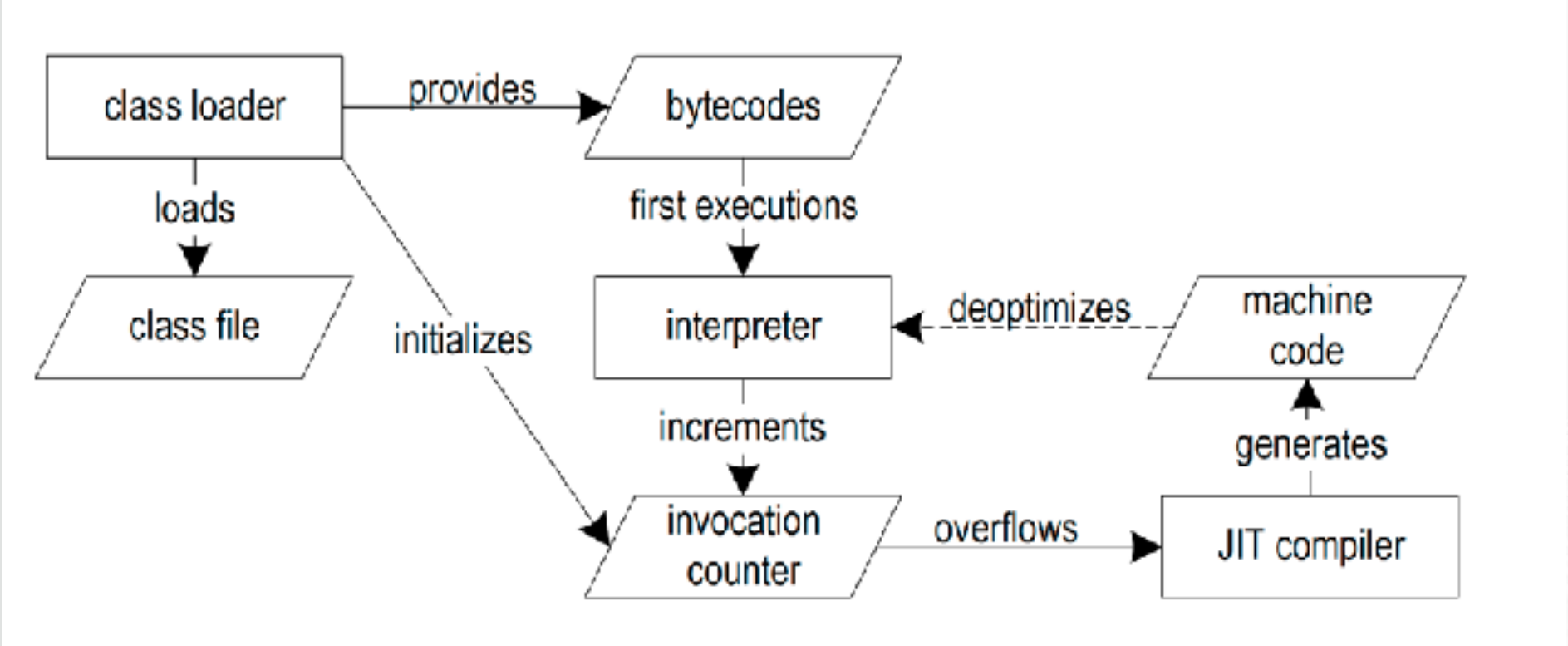
## JIT

java MyMainClass

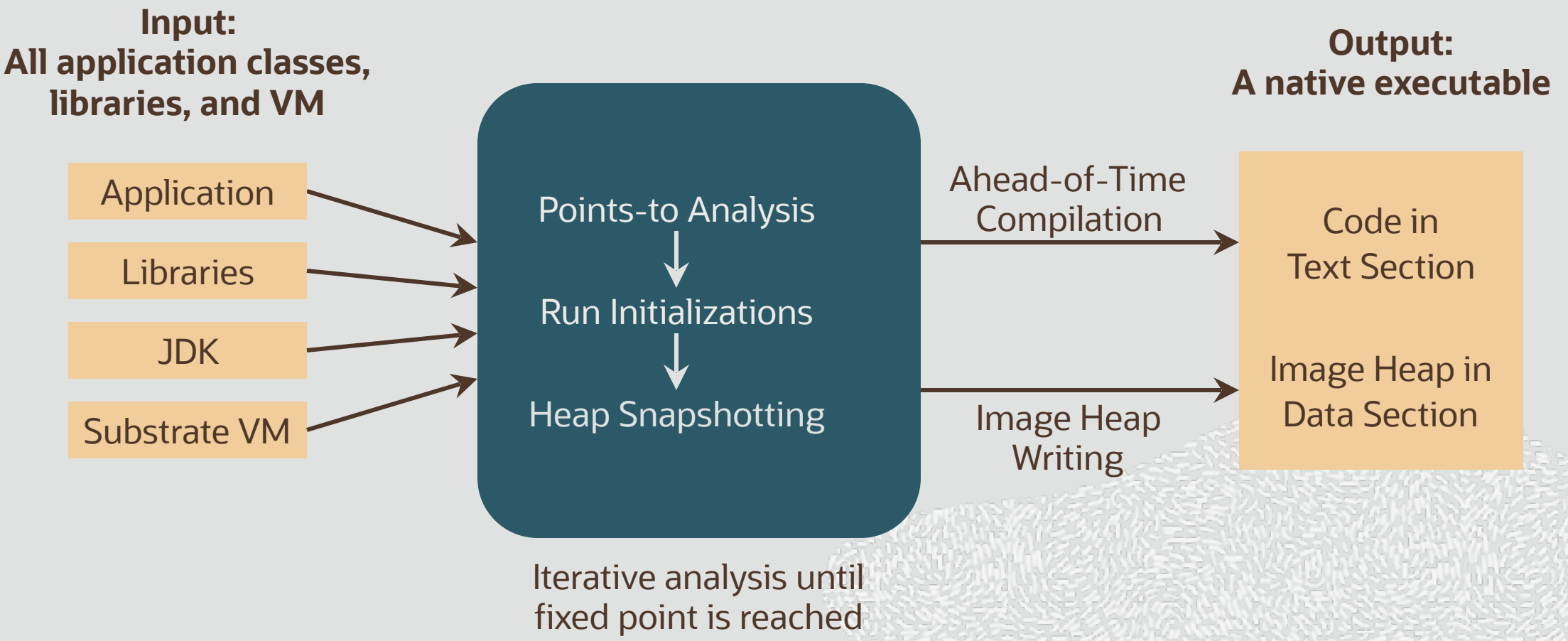
## AOT

native-image MyMainClass
./mymainclass

# Java Dynamic Execution



# How GraalVM AOT works



# AOT vs JIT: Startup Time

JIT

- Load JVM executable
- Load classes from file system
- Verify bytecodes
- Start interpreting
- Run static initializers
- First tier compilation (C1)
- Gather profiling feedback
- Second tier compilation (GraalVM or C2)
- Finally run with best machine code

AOT

- Load executable with prepared heap
- Immediately start with best machine code

# AOT vs JIT: Memory Footprint

JIT

- Loaded JVM executable
- Application data
- Loaded bytecodes
- Reflection meta-data
- Code cache
- Profiling data
- JIT compiler data structures

AOT

- Loaded application executable
- Application data

# Demo: startup and memory footprint

# AOT vs JIT: Peak Throughput

JIT

- Profiling at startup enables better optimizations
- Can make optimistic assumptions about the profile and deoptimize

AOT

- Needs to handle all cases in machine code
- Profile-guided optimizations help
- Predictable performance

# Demo: peak performance

# How to achieve even more with native images: PGO

The GraalVM compiler is built ground-up with profiles in mind

Collecting profiles is essential for performance of native images

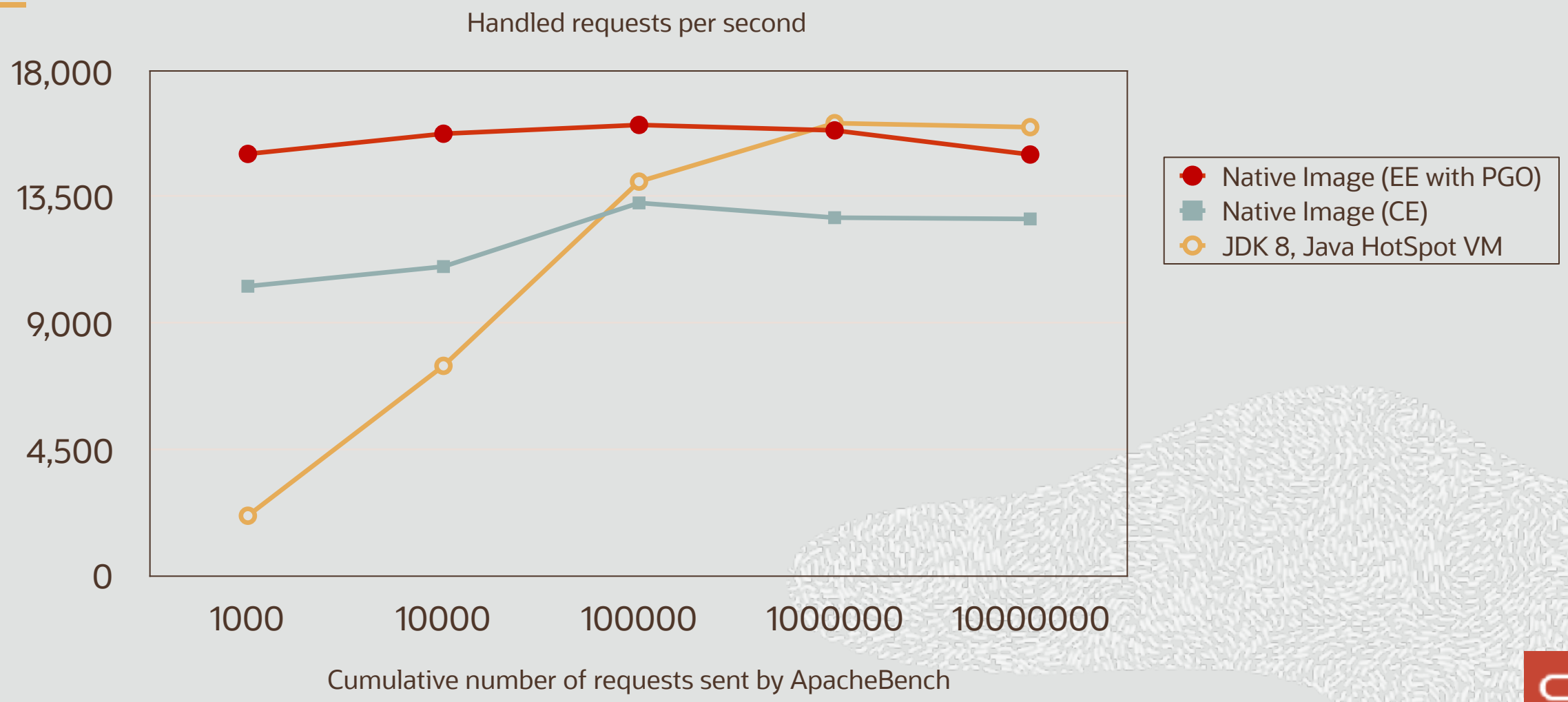
Profile guided optimizations requires running relevant workloads before building an image

```
$ java -Dgraal.PGOInstrument=myclass.iprof MyClass
```

```
$ native-image --pgo=myclass.iprof MyClass
```

```
$ ./myclass
```

# Native Image: Profile-Guided Optimizations (PGO)



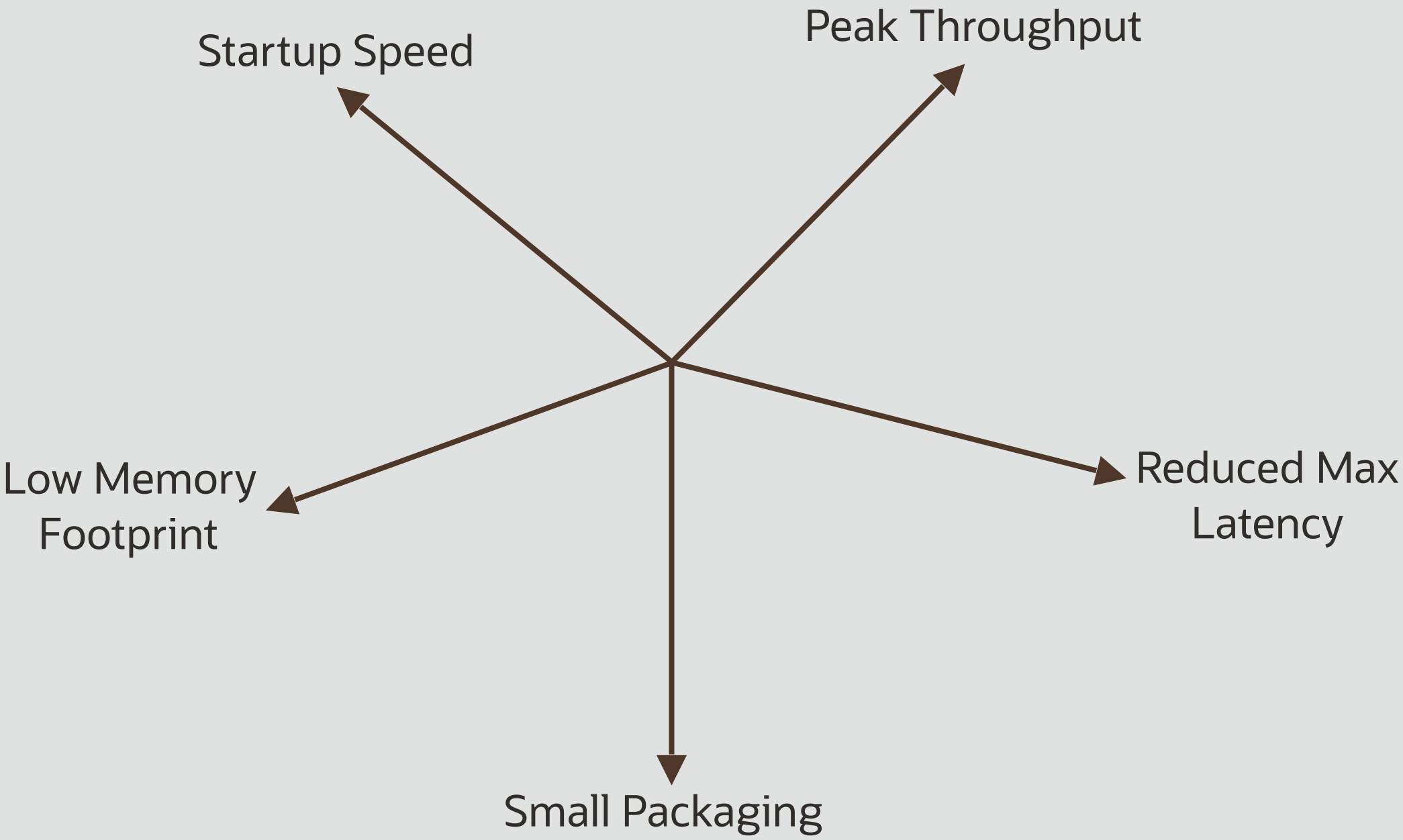
# AOT vs JIT: Max Latency

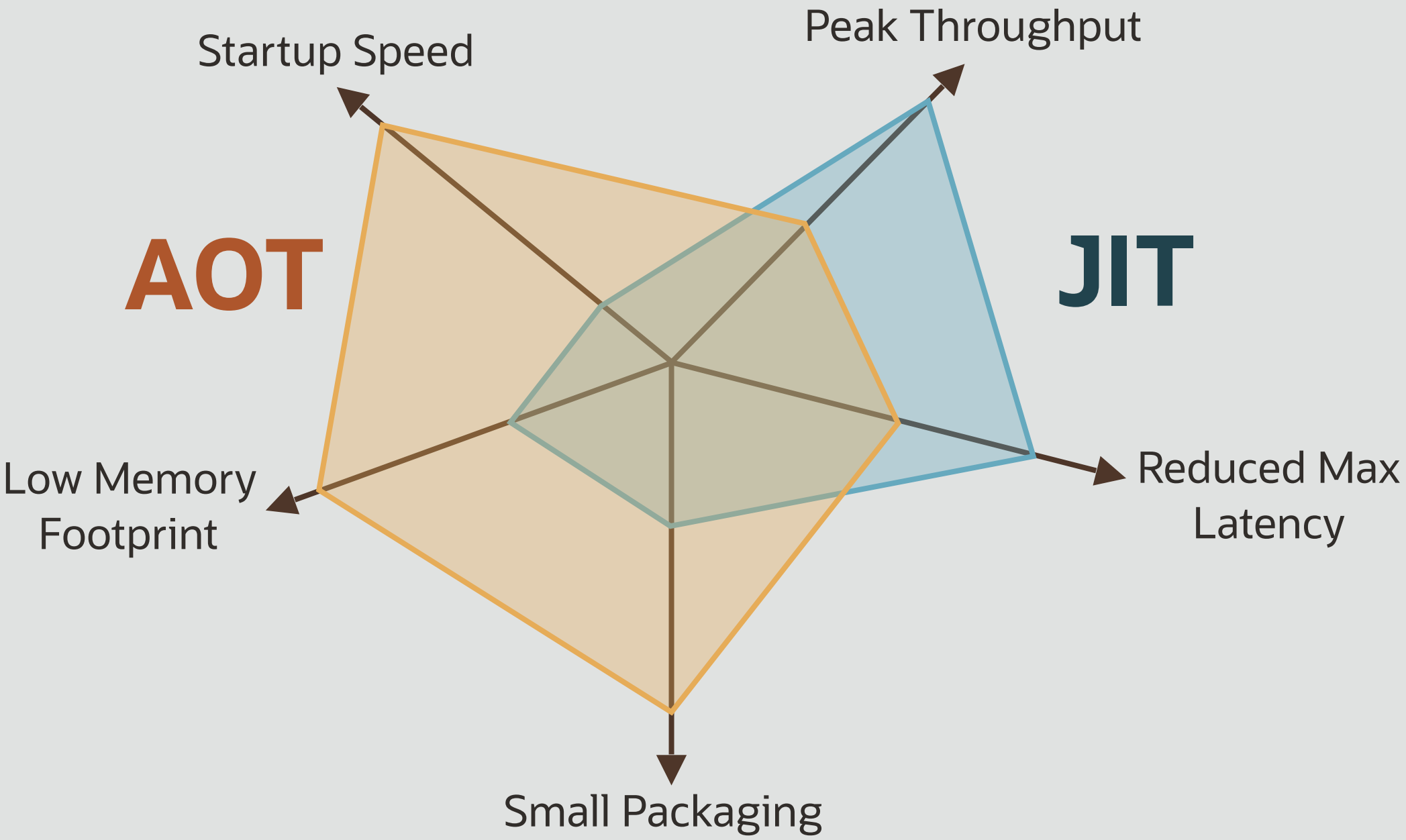
JIT

- Many low latency GC options available
- G1
- CMS
- ZGC
- Shenandoah

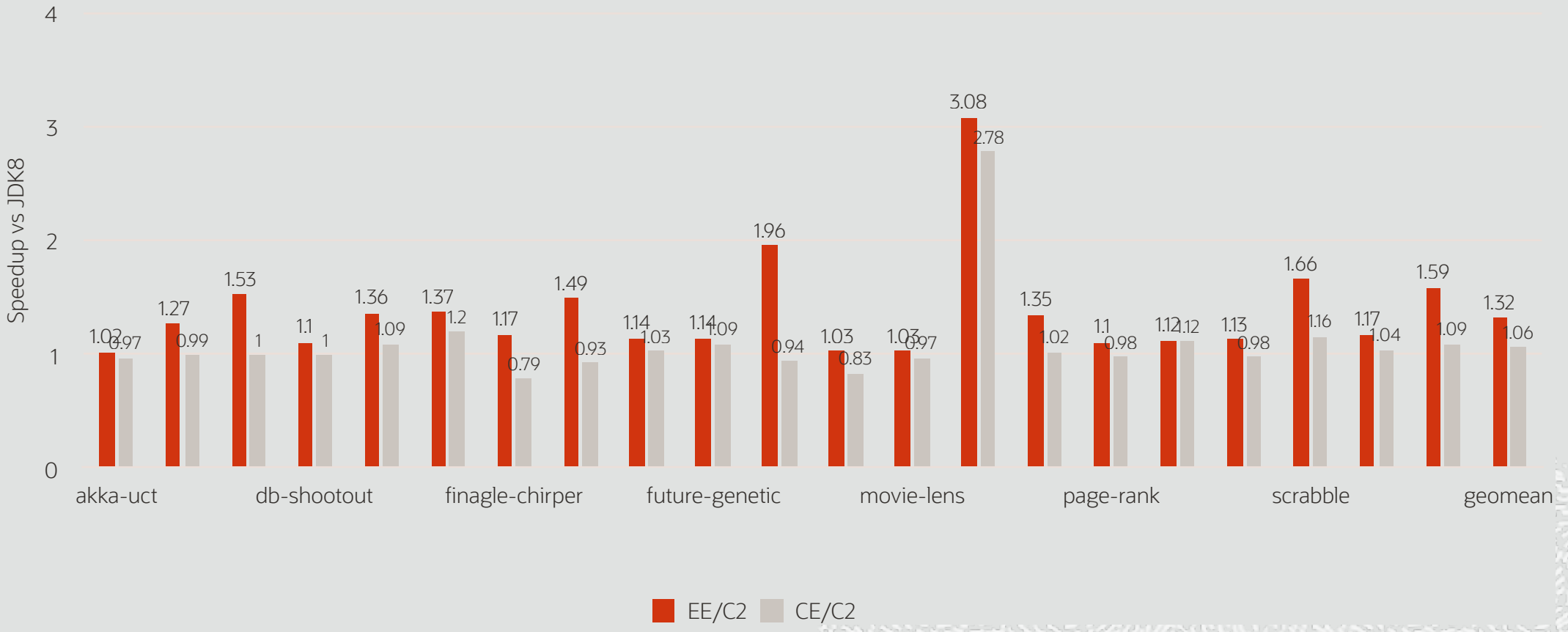
AOT

- Only regular stop&copy collector
- Assumes small heap configuration
- Can quickly restart; could use load balancer instead of GC

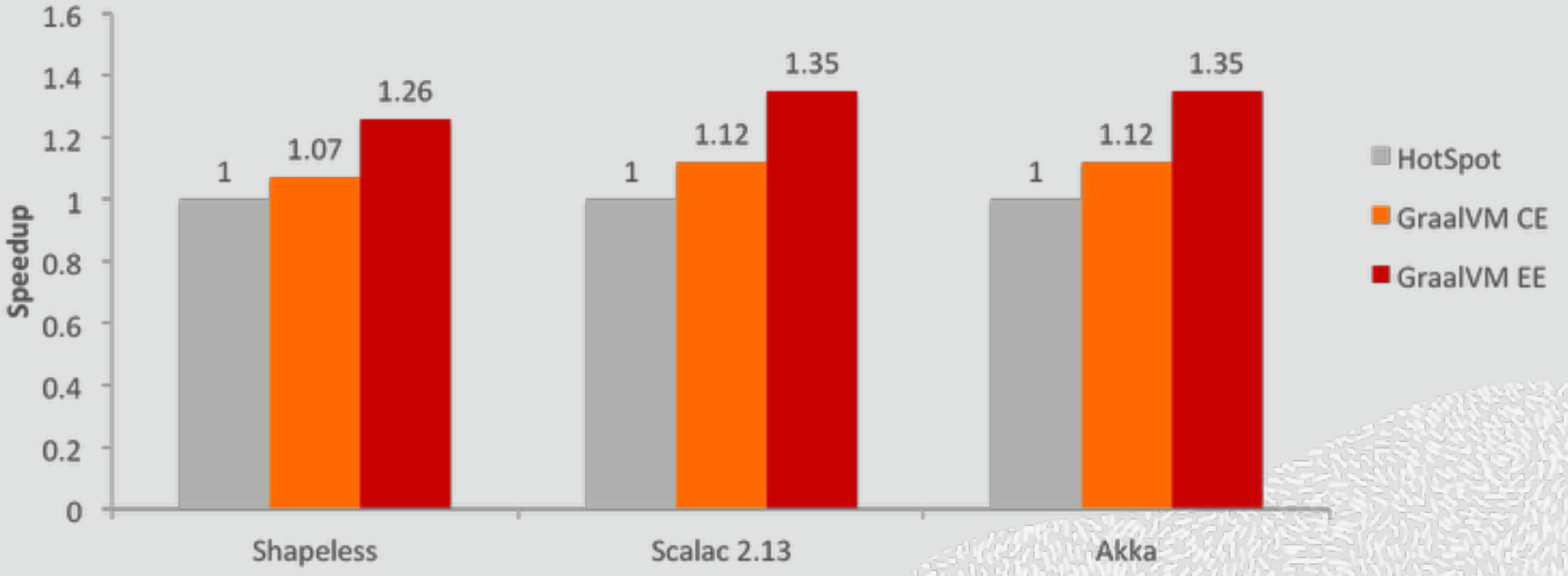

Startup Speed
Peak Throughput
Low Memory Footprint
Reduced Max Latency
Small Packaging


Startup Speed
Peak Throughput
AOT
JIT
Low Memory Footprint
Reduced Max Latency
Small Packaging

# GraalVM JIT Performance: Renaissance.dev

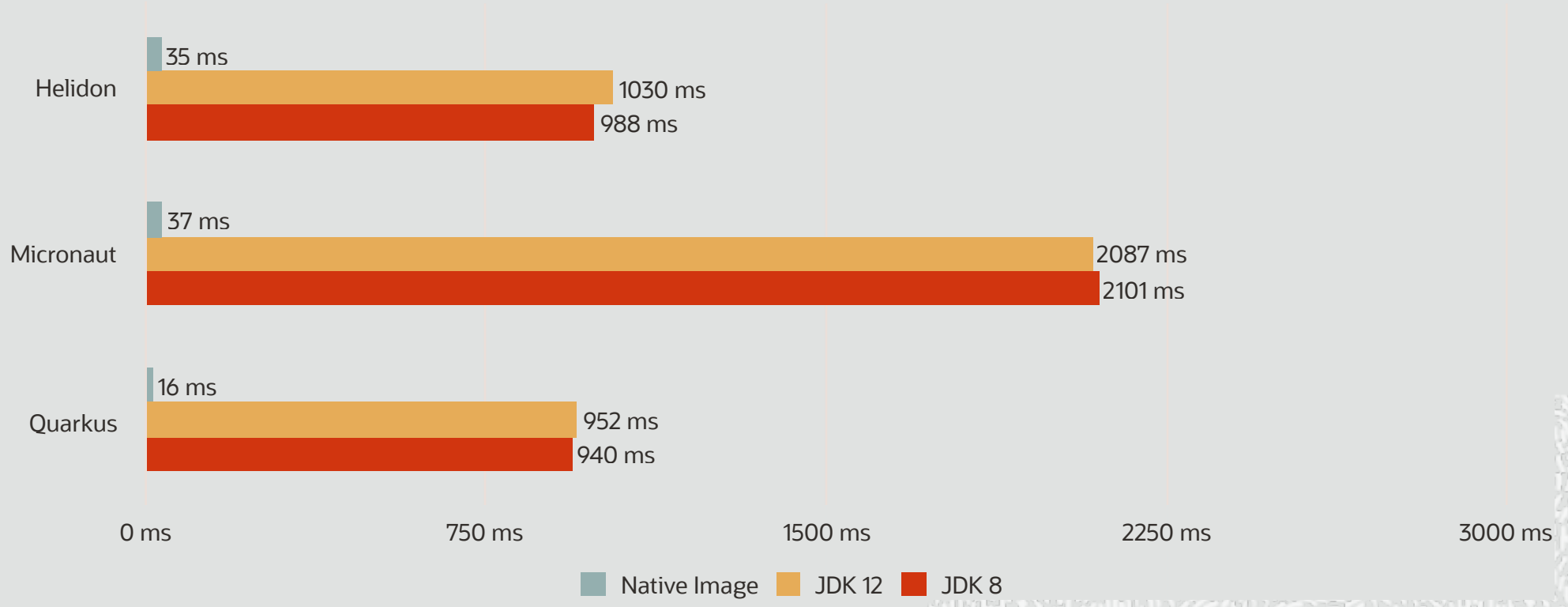


# Scala Performance

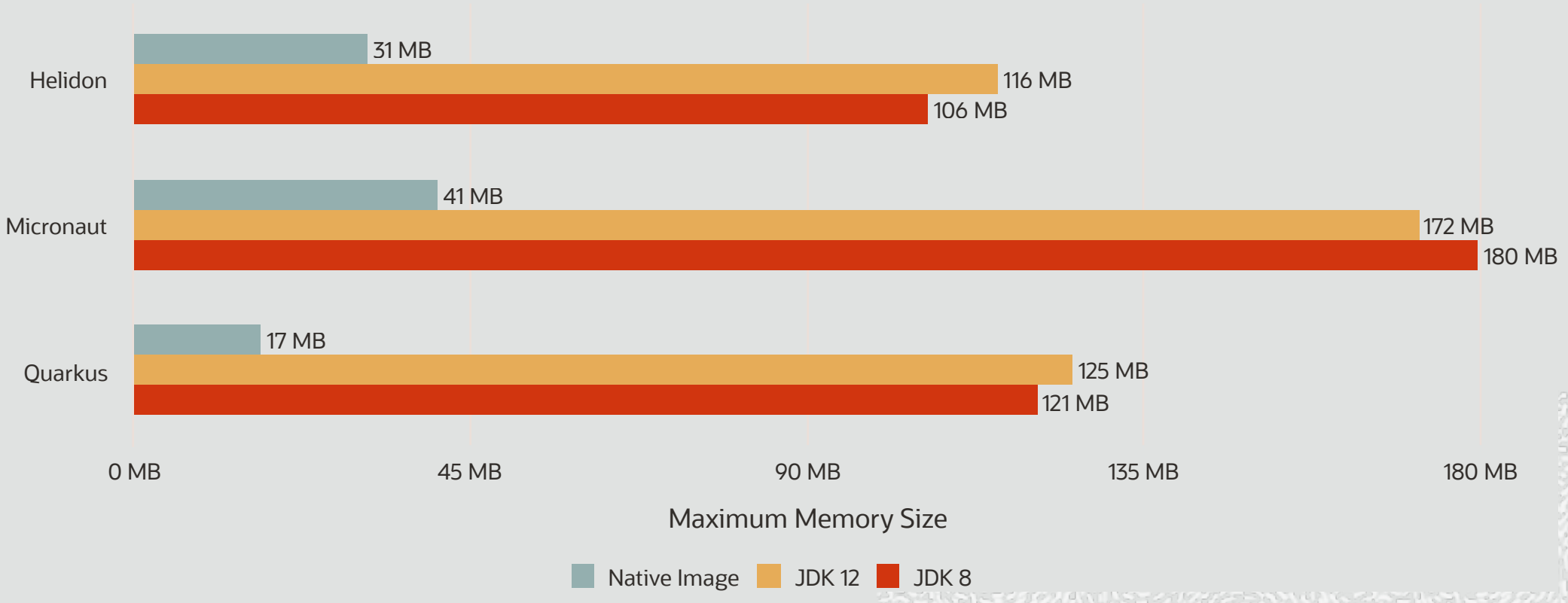



https://medium.com/graalvm/compiling-scala-faster-with-graalvm-86c5c0857fa3

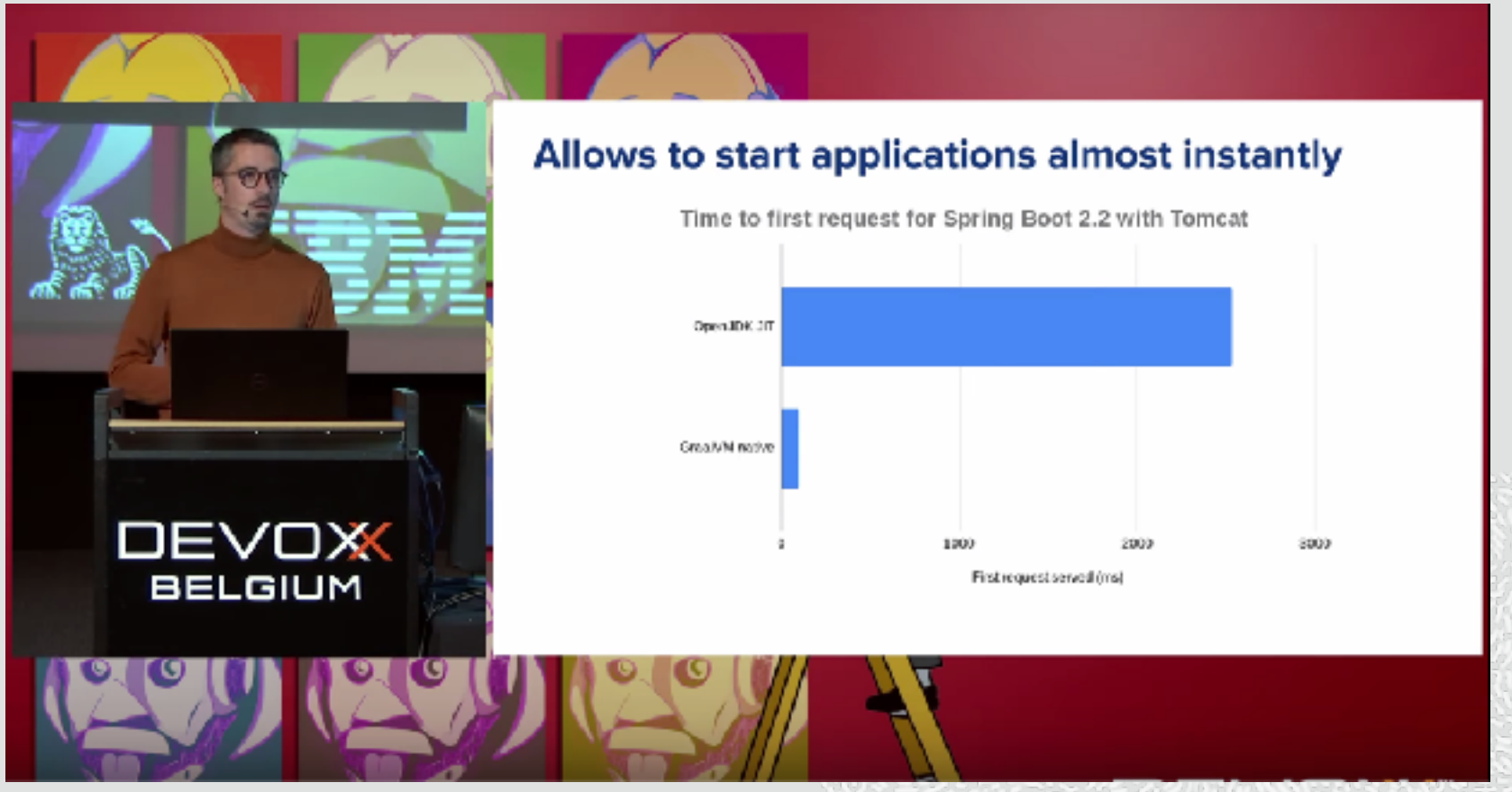
# Microservice Frameworks: Startup Time



# Microservice Frameworks: Memory Usage



# Spring Boot Applications as GraalVM Native Images




https://www.youtube.com/watch?v=3eoAxphAUIg

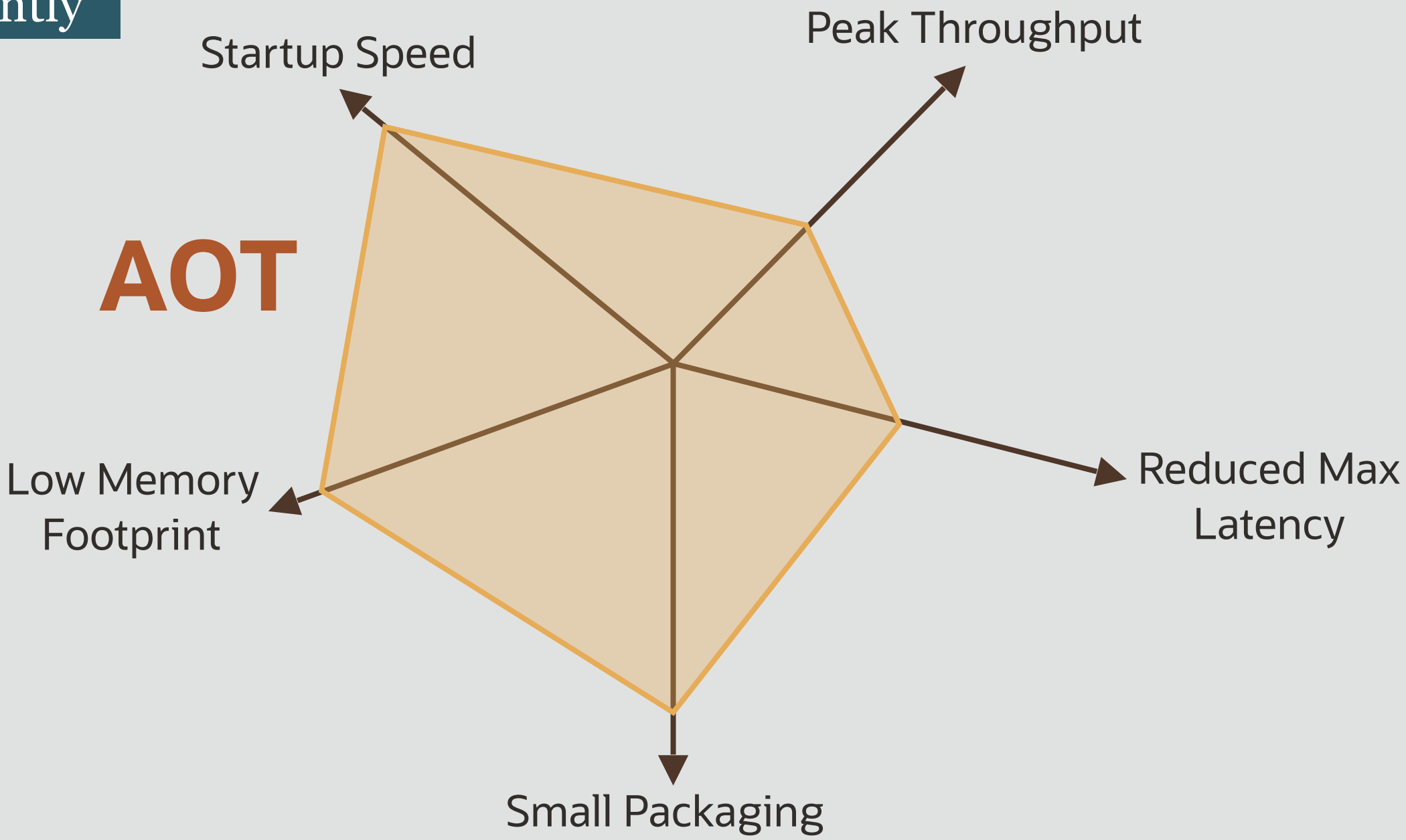
# Spring Boot Applications as GraalVM Native Images

"Spring Graal Native" project: https://github.com/spring-projects-experimental/spring-graal-native

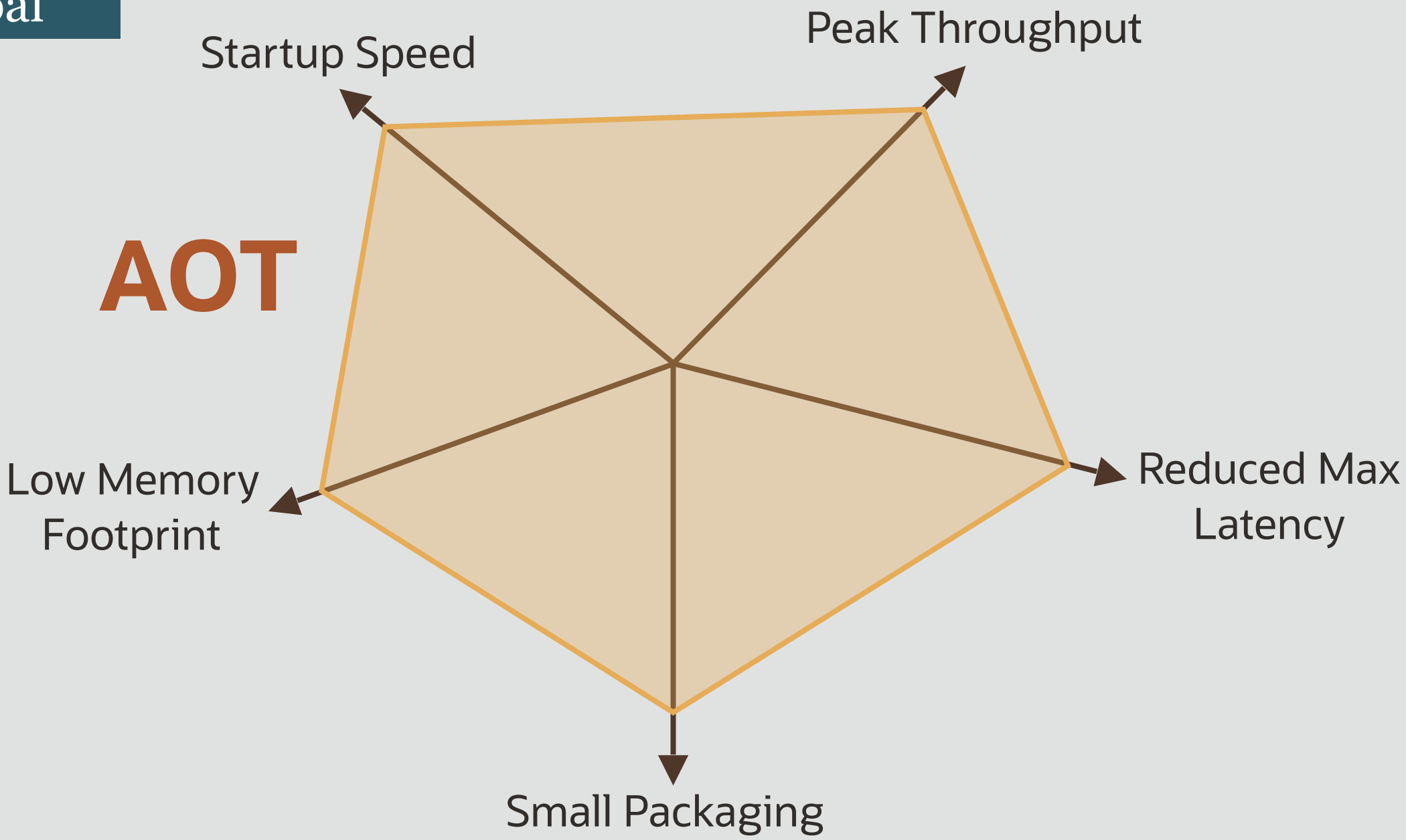
```
Alinas-MacBook-Pro:~/spring-graal-native/spring-graal-native-samples$ ls
commandlinerunner        spring-petclinic-jpa    vanilla-orm2
commandlinerunner-maven  springmvc-tomcat        vanilla-rabbit
kotlin-webmvc            vanilla-grpc            vanilla-thymeleaf
logger                   vanilla-jpa             vanilla-tx
messages                 vanilla-orm             webflux-netty
```

# Demo:  native Spring Boot app

# Currently


AOT
Startup Speed
Peak Throughput
Reduced Max Latency
Small Packaging
Low Memory Footprint

# Goal


AOT
Startup Speed
Peak Throughput
Low Memory Footprint
Reduced Max Latency
Small Packaging

# Simplifying the Native Image Configuration

```
mkdir -p META-INF/native-image

$JAVA_HOME/bin/java -agentlib:native-image-agent=config-output-
dir=META-INF/native-image HelloReflection foo xyz
```

```
[
  {
    "name":"HelloReflection",
    "methods":[{ "name":"foo", "parameterTypes":[] }]
  }
]
```

https://medium.com/graalvm/introducing-the-tracing-agent-simplifying-graalvm-native-image-configuration-c3b56c486271

# Continue Learning About GraalVM Native Images

- Reference manual: graalvm.org/docs/reference-manual/aot-compilation/
- Improving performance of GraalVM native images with PGO: https://medium.com/graalvm/improving-performance-of-graalvm-native-images-with-profile-guided-optimizations-9c431a834edb
- GraalVM Native Images: The Best Startup Solution for Your Applications: https://www.youtube.com/watch?v=z0jedLjcWjI

# GraalVM Performance Workshop: Thursday, 1 PM - 4 PM

## Summary

### GraalVM JIT

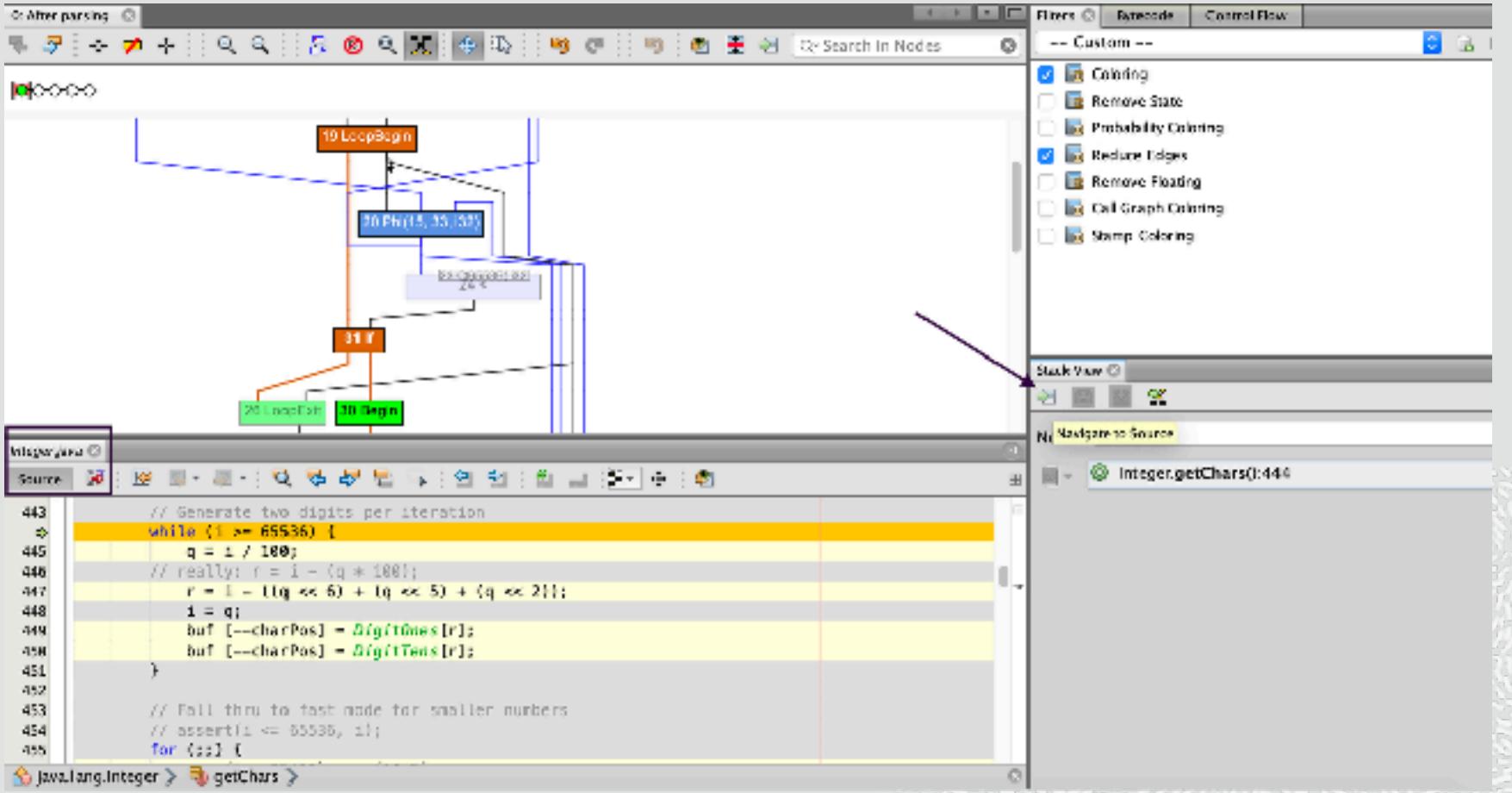
- Peak throughput
- Max Latency
- No configuration

### GraalVM AOT

- Startup Time
- Memory footprint
- Packaging size

# Tools

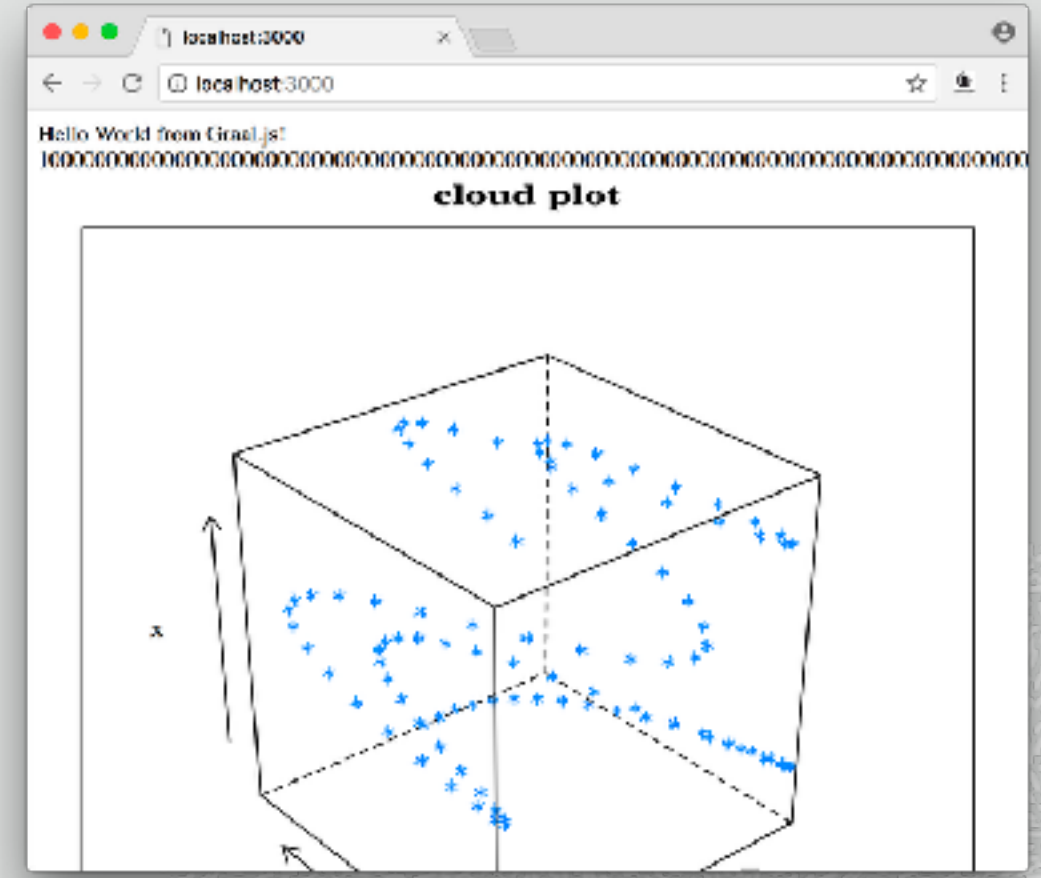
# Ideal Graph Visualizer



# Do even more with GraalVM

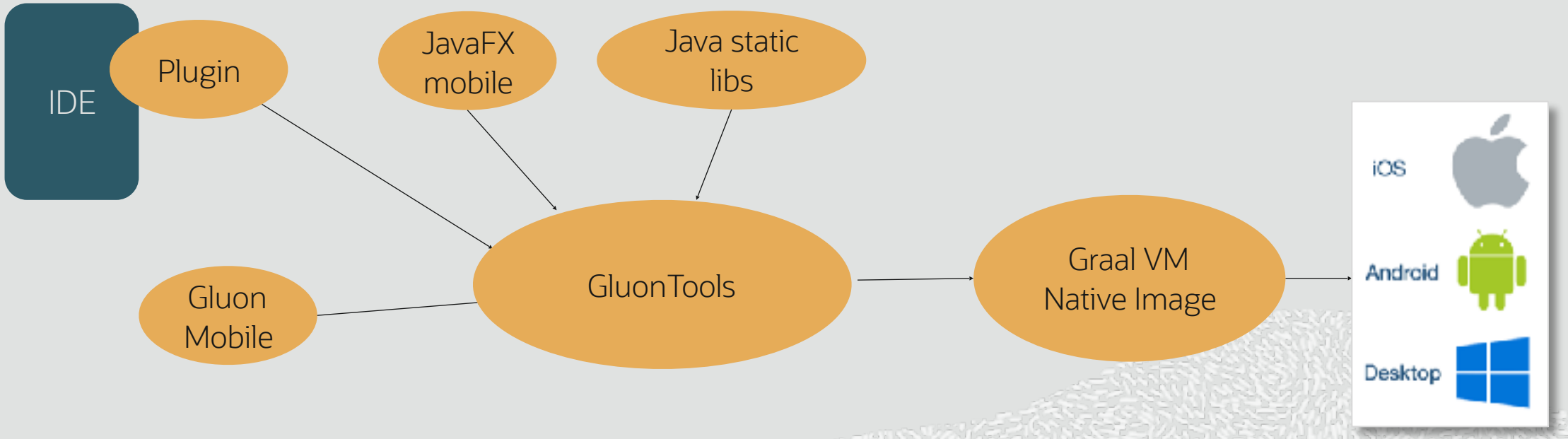
# JavaScript + Java + R

```
JS server.js

const express = require('express')
const app = express()

const BigInteger = Java.type('java.math.BigInteger')


app.get('/', function (req, res) {
  var text = '<h1>Hello from Graal.js!</h1>'

  // Using Java standard library classes
  text += BigInteger.valueOf(10).pow(100)
          .add(BigInteger.valueOf(43)).toString() + '<br>'

  // Using R methods to return arrays
  text += Polyglot.eval('R',
    'ifelse(1 > 2, "no", paste(1:42, c="|"))') + '<br>'

  // Using R interoperability to create graphs
  text += Polyglot.eval('R',
    `svg();
     require(lattice);
     x <- 1:100
     y <- sin(x/10)
     z <- cos(x^1.3/(runif(1)*5+10))
     print(cloud(x~y*z, main="cloud plot"))
     grDevices:::svg.off()
    `);
```



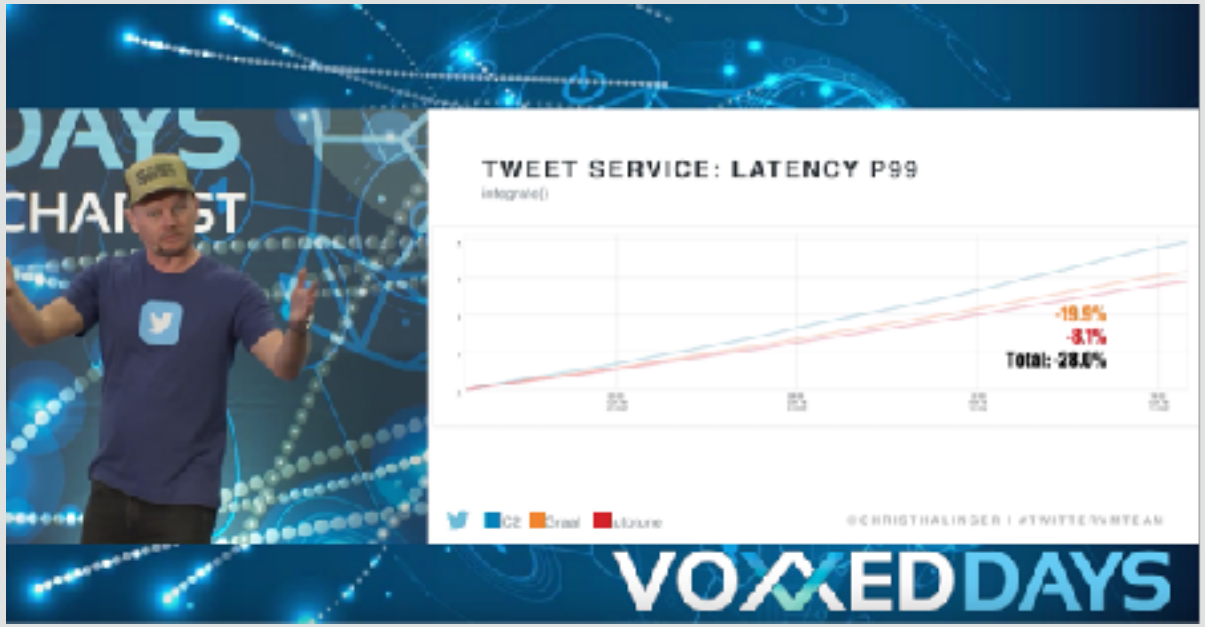
# Demo: Java + JavaScript

# Do even more with GraalVM: Cross-Platform Development



# Industry Use Cases

Twitter uses GraalVM compiler in production to run their Scala microservices



- Peak performance: +10%
- Garbage collection time: -25%
- Seamless migration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Cloud Infrastructure

The rich ecosystem of CUDA-X libraries is now available for GraalVM applications.

GPU kernels can be directly launched from GraalVM languages such as R, JavaScript, Scala and other JVM-based languages.

# What’s next for GraalVM

# What’s next for GraalVM

- JDK-11 based builds;
- ARM64 and Windows support;
- Low-latency, high-throughput, and parallel GC for native images;
- Work with the community to support important libraries;
- New languages and platforms;
- Your choice – contribute!

# Get Started


- Downloads
- Documentation
- Community support

# GraalVM Versions

## Community Edition

GraalVM Community is available for free for evaluation, development and production use. It is built from the GraalVM sources available on GitHub. We provide pre-built binaries for Linux, macOS X, and Windows platforms on x86 64-bit systems. Windows support is experimental.

DOWNLOAD FROM GITHUB

## Enterprise Edition

GraalVM Enterprise provides additional performance, security, and scalability relevant for running applications in production. It is free for evaluation uses and available for download from the Oracle Technology Network. We provide binaries for Linux, macOS X, and Windows platforms on x86 64-bit systems. Windows support is experimental.

DOWNLOAD FROM OTN

# What’s next for you

- Download:

  graalvm.org/downloads

- Follow updates:

  @GraalVM / #GraalVM

- If you need help:
- graalvm.org/community
- graalvm-users @oss.oracle.com

## Key Takeaways

- Write small methods;
- Local allocations are free, global data structures expensive;
- Don’t hand optimize, unless you have studied the compiler graph;
- For best throughput use **GraalVM JIT**,
- for best startup & footprint use **GraalVM AOT**.

# Thank you!

**Alina Yurenko / @alina_yurenko**

GraalVM
Oracle Labs