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# Maximizing Performance

with

# GraalVM™

Thomas Wuerthinger (@thomaswue)
Senior Research Director
Oracle Labs
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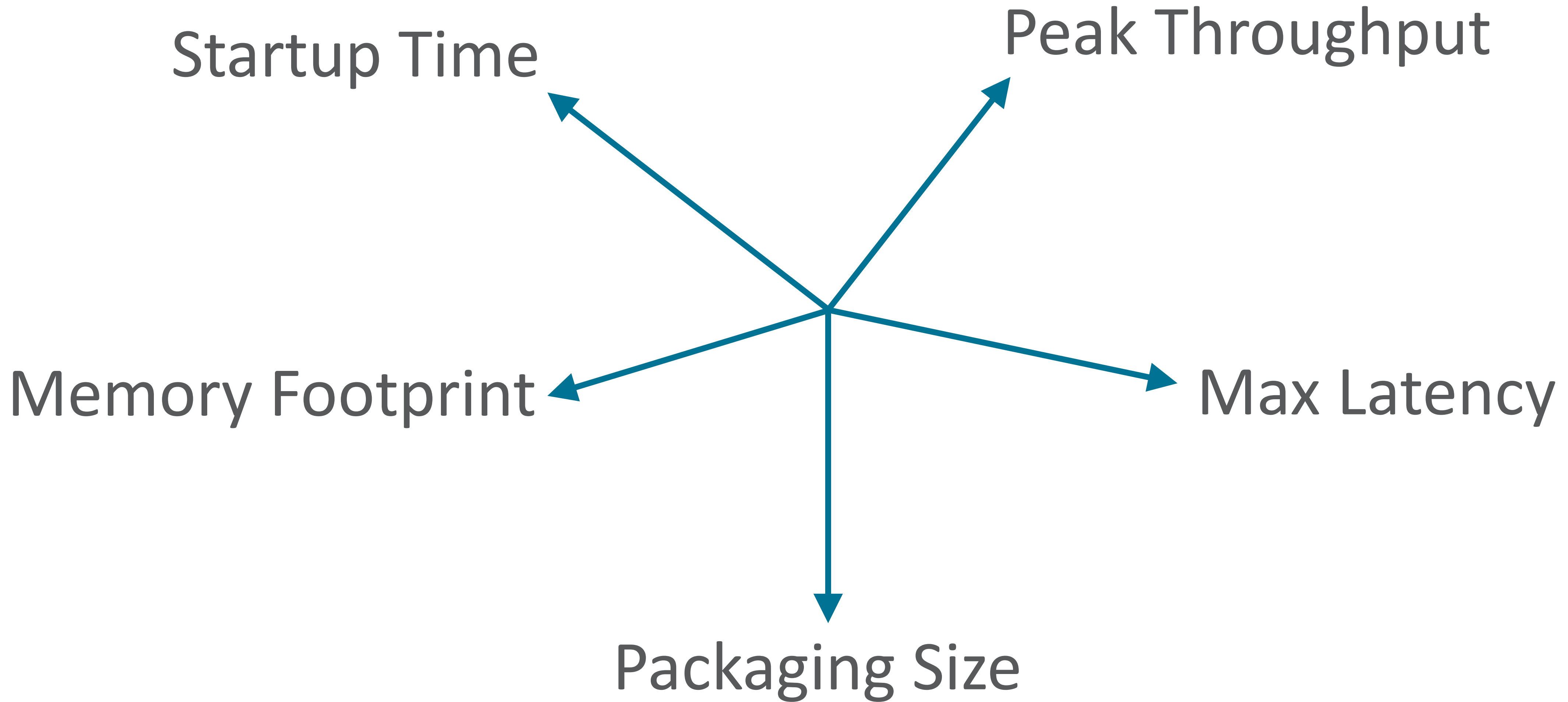


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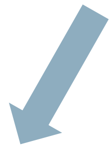

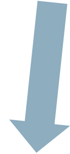

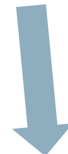

OpenJDK

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DATABASE

standalone

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## Community Edition (CE)

GraalVM CE is available for free for development and production use. It is built from the GraalVM sources available on GitHub. We provide pre-built binaries for GraalVM CE for Linux on x86 64-bit systems.

DOWNLOAD FROM GITHUB

## Enterprise Edition (EE)

GraalVM EE provides additional performance, security, and scalability relevant for running critical applications in production. It is free for evaluation uses and available for download from the Oracle Technology Network. We provide binaries for GraalVM EE for Linux or Mac OS X on x86 64-bit systems.

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GraalVM™

JIT

AOT

java MyMainClass

OpenJDK™

native-image MyMainClass
./mymainclass

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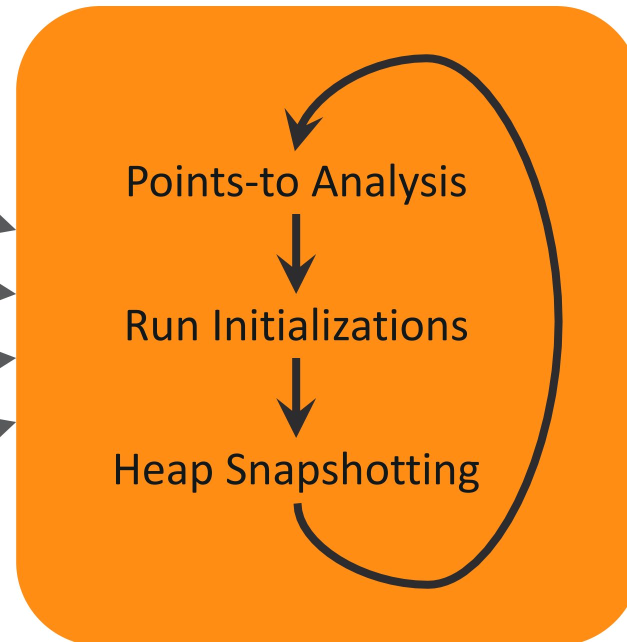
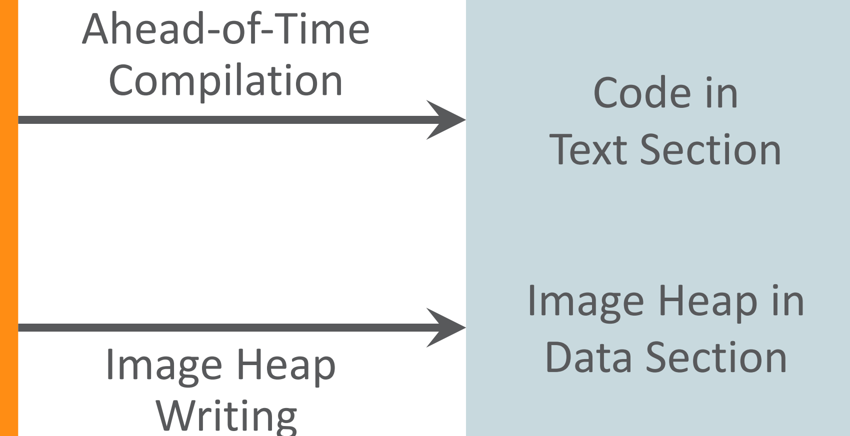
# GraalVM AOT for Native Images

Input:
All classes from application,
libraries, and VM




Iterative analysis until
fixed point is reached

Output:
Native executable

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# 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

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# AOT vs JIT: Startup Time

| | GraalVM AOT | GraalVM JIT |
|---|---|---|
| Helidon | 35 ms | 988 ms |
| Micronaut | 37 ms | 2101 ms |
| Quarkus | 16 ms | 940 ms |

0 ms 500 ms 1000 ms 1500 ms 2000 ms 2500 ms

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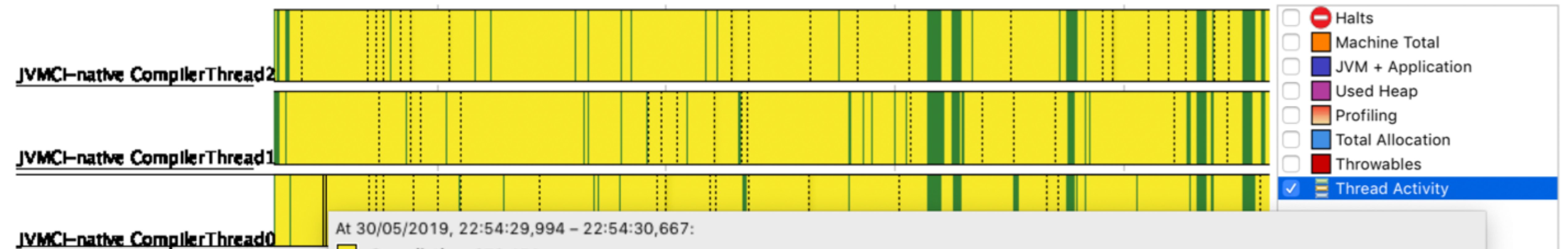
# Java Flight Recorder Compilation Information

Java Application

<No Selection> Aspect: <No Selection> Show concurrent: Contained Same threads Time Range: Set Clear

| Thread | Profiling Samples | Total I/O Time | Total Blocked Time | Class Loading Time | Total Allocati |
|---|---|---|---|---|---|
| Reference Handler | 10 | | | | |
| JVMCI-native CompilerThread2 | | | | | 34,4 M |
| JVMCI-native CompilerThread1 | | | | | 34,8 M |
| JVMCI-native CompilerThread0 | | | | | 23,6 M |
| JFR request timer | 2 | | | | 10,3 M |




At 30/05/2019, 22:54:29,994 – 22:54:30,667:

**Compilation**: 673,451 ms
Thread: JVMCI-native CompilerThread0
Java Method: Object org.scalastyle.scalariform.VisitorHelper$$anonfun$org$scalastyle$scalariform$VisitorHelper$$myVisit$1.apply(Object)
Compilation ID: 9.633
Compilation Level: 4
Succeeded: true
On Stack Replacement: false
Compiled Code Size: 35,2 KiB
Inlined Code Size: 11,3 KiB

At -∞ – ∞:

Thread Lifespan of JVMCI-native CompilerThread0: N/A

Stack Trace

Stack Trace
- Pattern$CharProperty java.util.regex.Pa
- Pattern$Node java.util.regex.Pattern.se
- Pattern$Node java.util.regex.Pattern.exp
- Pattern$Node java.util.regex.Pattern.group0() 3178

# 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

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# AOT vs JIT: Memory Footprint

| | GraalVM AOT | GraalVM JIT |
|---|---|---|
| Helidon | 31 MB | 106 MB |
| Micronaut | 41 MB | 180 MB |
| Quarkus | 17 MB | 121 MB |

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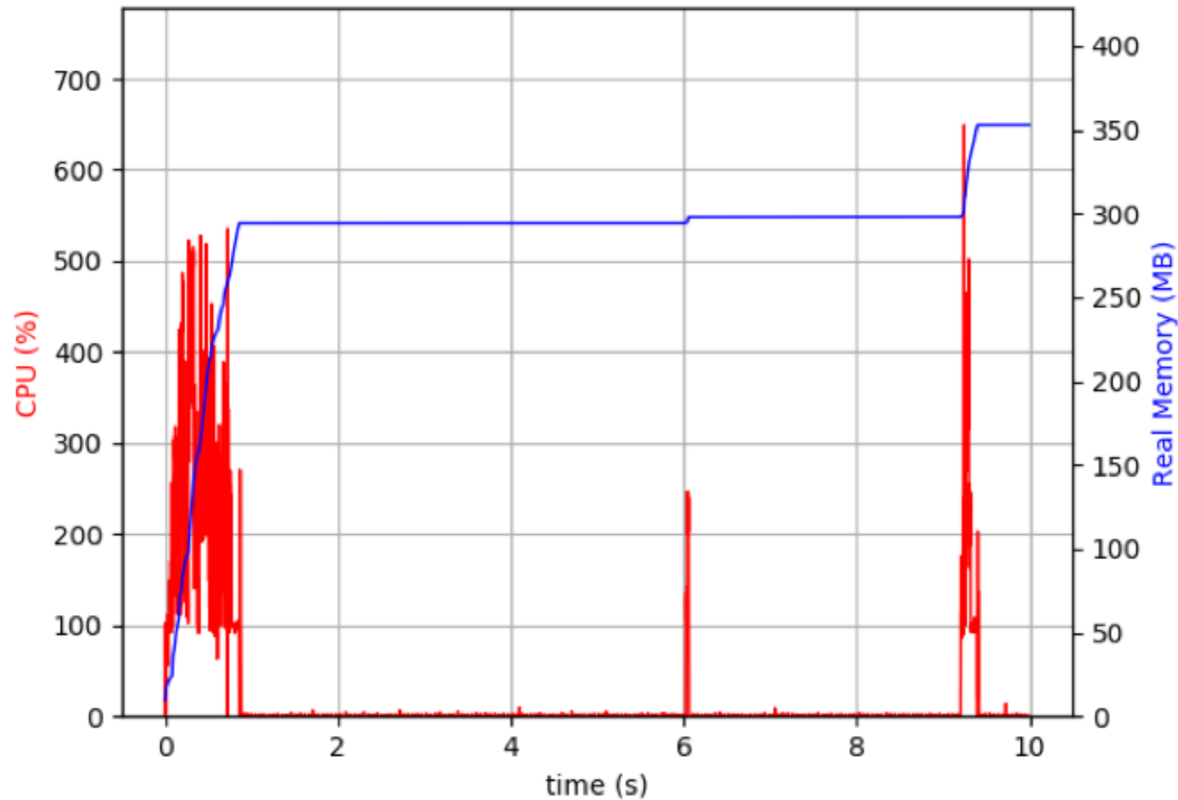
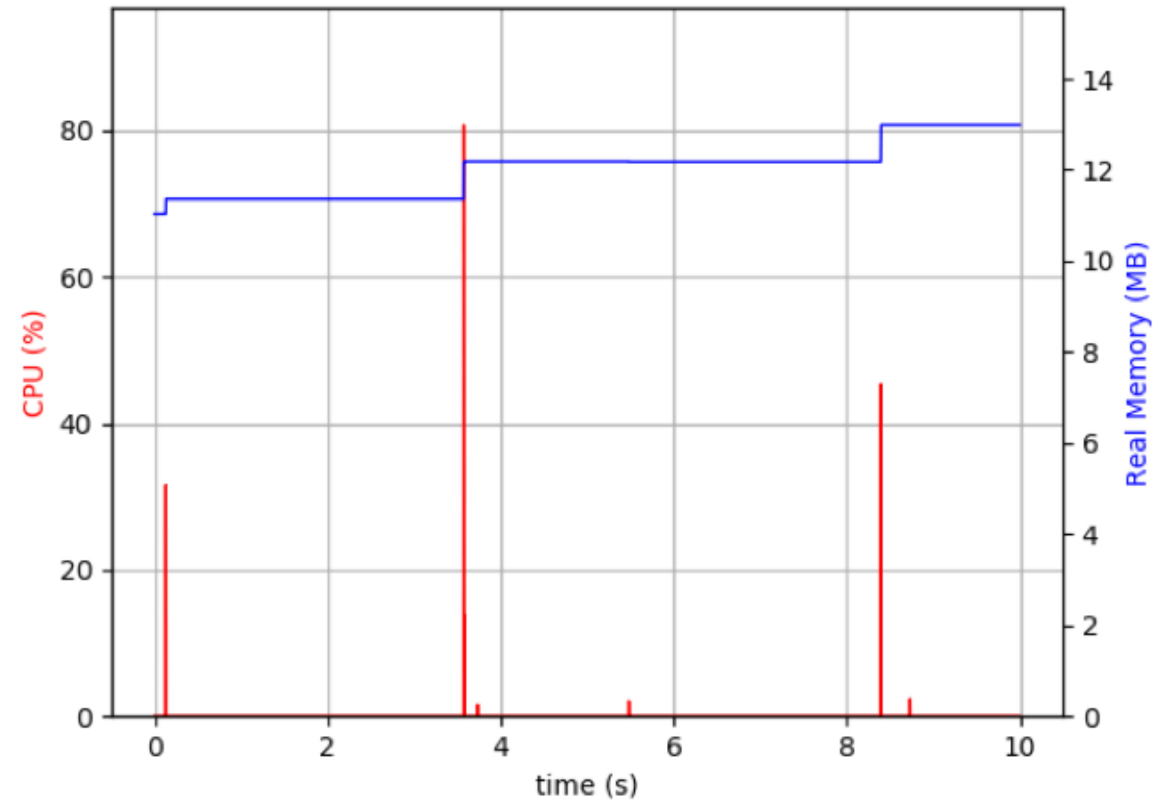
# Web Server Startup and Memory Footprint

Starting up and serving 2 requests in the first 10s

- **JIT 800ms / 350Mb**




- **AOT 8ms / 13Mb**

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# Which is fastest?

```
int negate1(int a) {
    return -a;
}

int negate2(int a) {
    int b = a + 0;
    return -b * 1;
}

int negate3(int a) {
    Object[] array = new Object[] {Integer.valueOf(a)};
    return -(Integer)array[0];
}
```

```
static Object[] cachedArray = new Object[1];
int negate4(int a) {
    cachedArray[0] = Integer.valueOf(a);
    return -(Integer)cachedArray[0];
}
```

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# Performance is hard to measure

↓ apparat (ms)

metric.value:AVG

6000 5000 4000 3000 2000 1000 0

12/02/2019 20:33:20 | 24/02/2019 10:20:00 | 08/03/2019 00:06:40 | 19/03/2019 13:53:20 | 31/03/2019 04:40:00 | 11/04/2019 18:26:40 | 23/04/2019 08:13:20 | 04/05/2019 22:00:00 | 16/05/2019 11:46:40 | 28/05/2019 01:33:20 | 08/06/2019 15:20:00 | 20/06/2019 05:06:40

commit.committer-ts

commit.committer-ts 1561363624:
▲server,graal-enterprise: ▲ 5506.774193548387

↓ apparat (ms)

metric.value:AVG

15000 10000 5000 0

17/05/2017 07:46:40 | 14/07/2017 04:40:00 | 10/09/2017 01:33:20 | 06/11/2017 21:26:40 | 03/01/2018 18:20:00 | 02/03/2018 15:13:20 | 29/04/2018 13:06:40 | 26/06/2018 10:00:00 | 23/08/2018 06:53:20 | 20/10/2018 03:46:40 | 16/12/2018 23:40:00 | 12/02/2019 20:33:20 | 11/04/2019 18:26:40 | 08/06/2019 15:20:00

commit.committer-ts

commit.committer-ts 1561363624:
▲server,graal-enterprise: ▲ 5506.774193548387

click to pin at 24/06/2019 10:07:04, and show more info
server,graal-enterprise ▲ Value: 5506.774193548387 ms ± 182.12 ms (type: n/a) Δ: -42.645 ms Δ%: -0.77%

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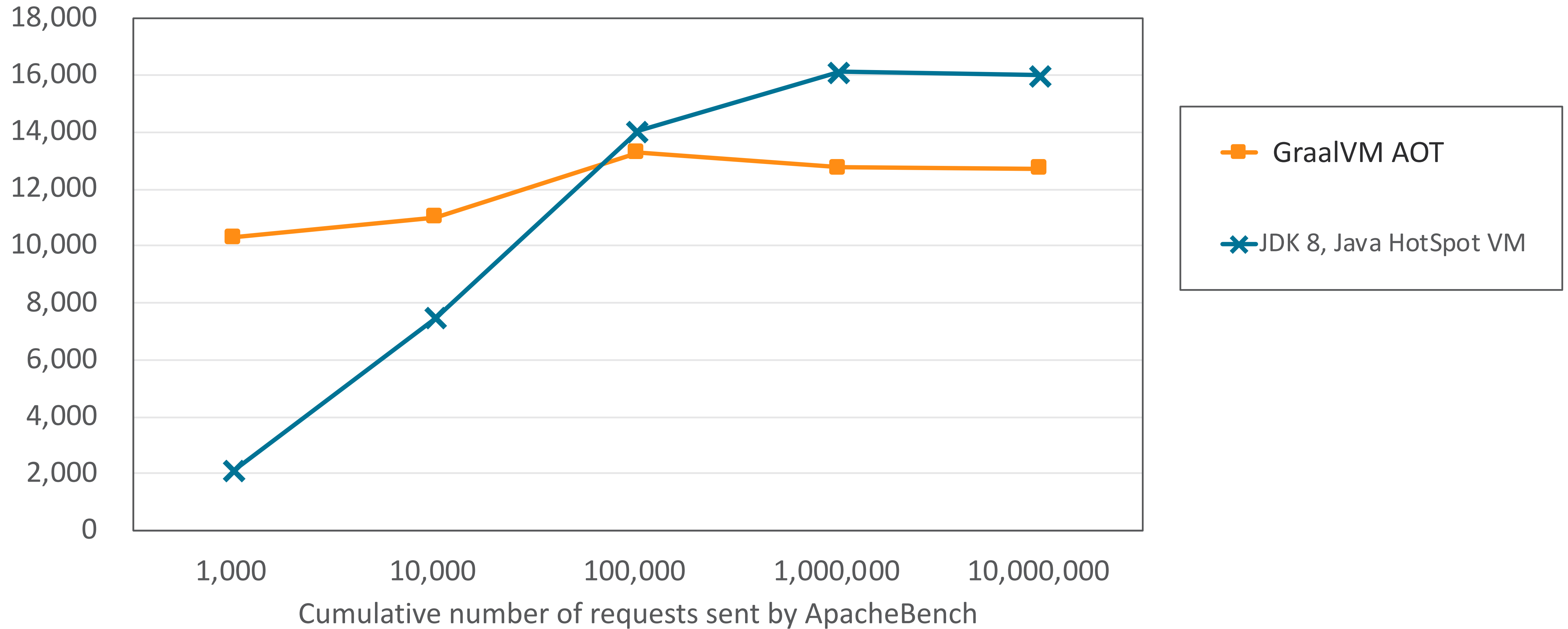
# AOT vs JIT: Throughput

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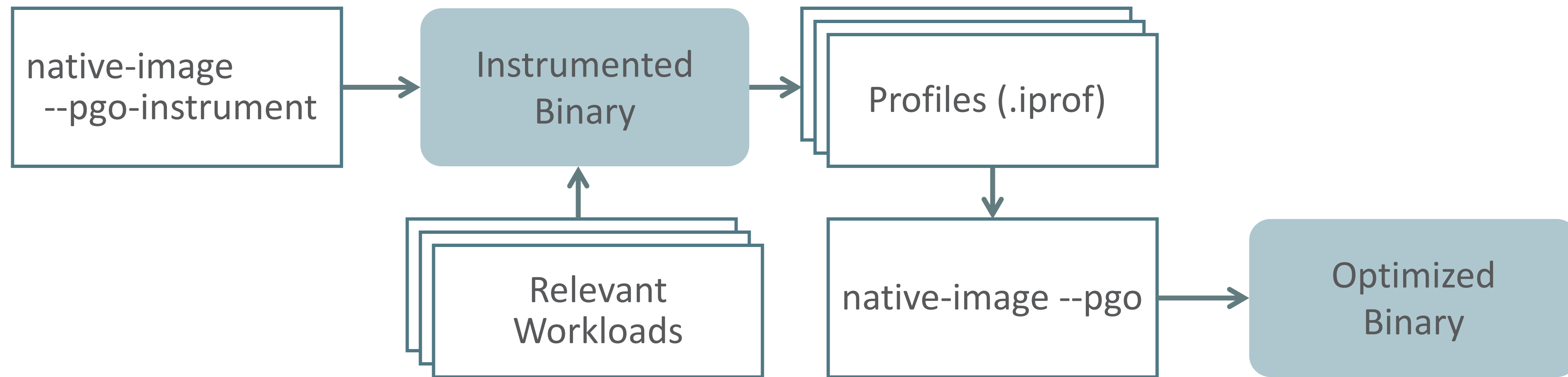
# Profile-Guided Optimizations (PGO)

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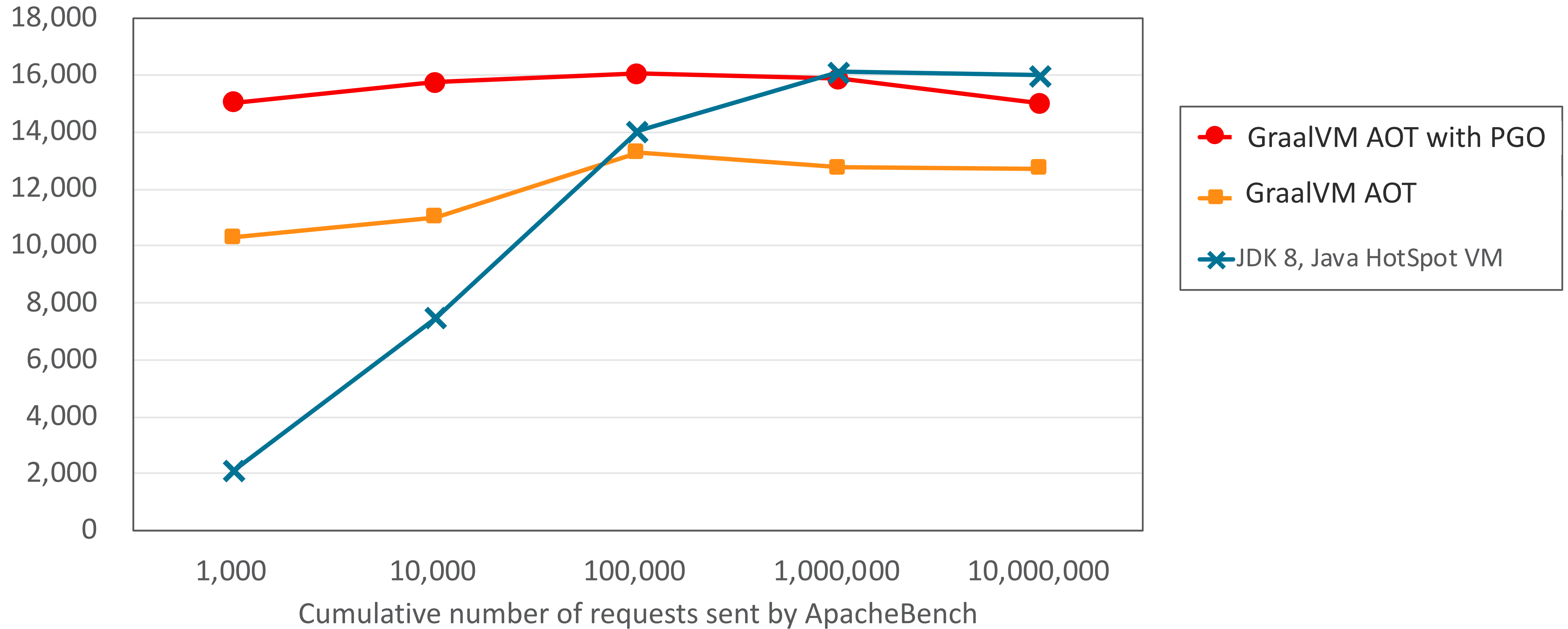
# AOT vs JIT: Throughput

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# AOT vs JIT: Peak Performance

- JIT
  - Profiling at startup enabled 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

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# More Benchmarks…

- Optimizing a compiler for too few benchmarks results in typical overfitting problems
- Therefore we started together with academic collaborators https://renaissance.dev
- All benchmark data can be interesting; careful with conclusions though.

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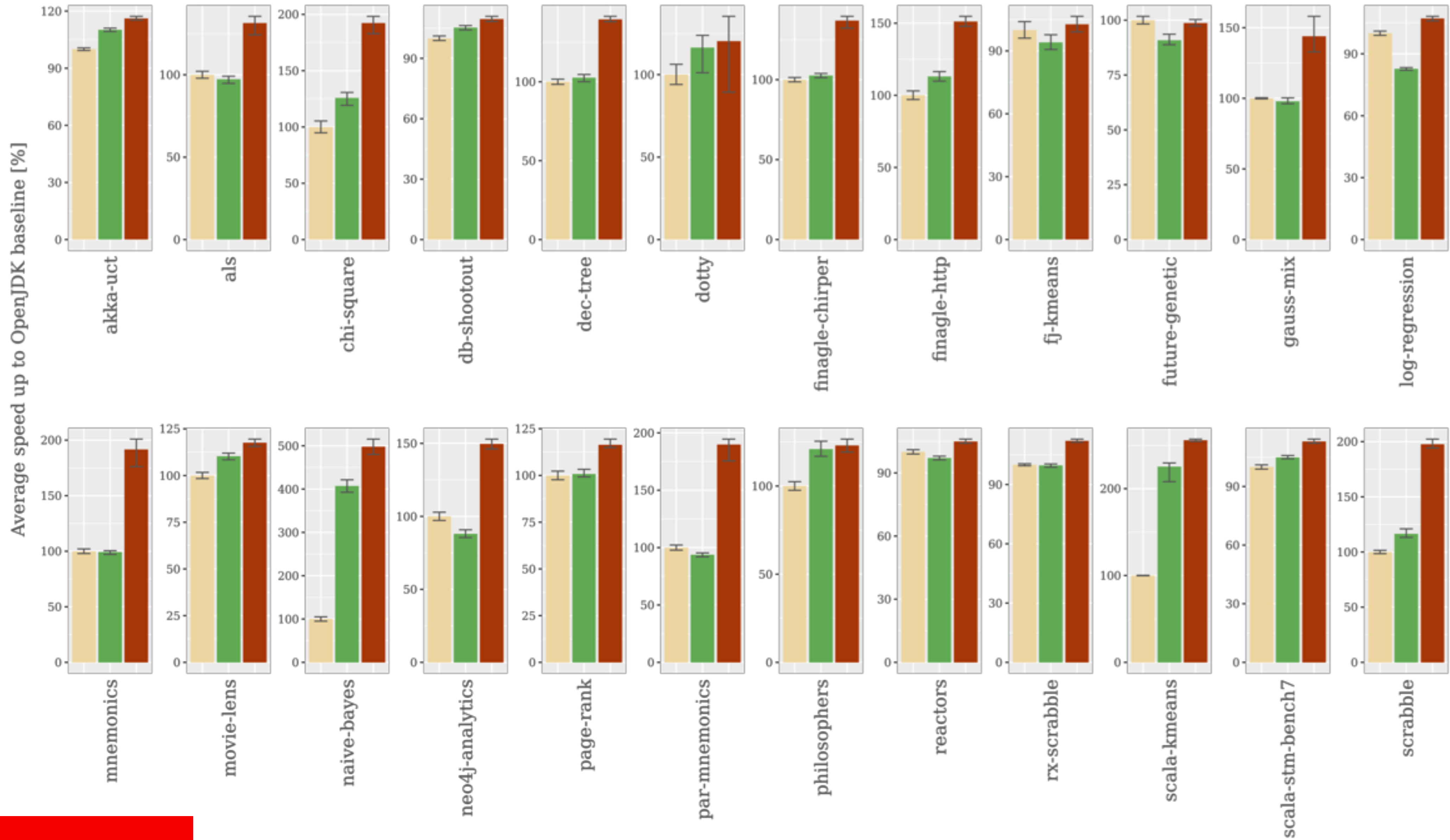
# Rennaissance.dev




JVM Implementation OpenJDK 8 GraalVM 19 CE GraalVM 19 Enterprise

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# AOT vs JIT: Max Latency

- JIT
  - Many low latency GC options available
    - G1
    - CMS
    - ZGC
    - Shenandoah
- AOT
  - Only regular stop© collector
  - Assumes small heap configuration
  - Can quickly restart; could use load balancer instead of GC

- Peak vs max latency trade-offs:
  - Loop safepoints
  - Parallel stop-the-world GC

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# AOT vs JIT: Packaging Size

- JIT
  - Use jlink for smaller package
  - Lightweight docker image (e.g., alpine linux)
- AOT
  - Everything in single binary
  - Can run on bare metal docker
  - Substantially smaller constant overhead

- Peak vs packaging trade-offs:
  - Inlining
  - Code duplication

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# GraalVM JIT

Peak Throughput

Max Latency

No Configuration

# GraalVM AOT

Startup Time

Memory Footprint

Packaging Size

## Can AOT get better?

- Collecting profiles up-front
- Low-latency GC option
- Tracing agent for configuration

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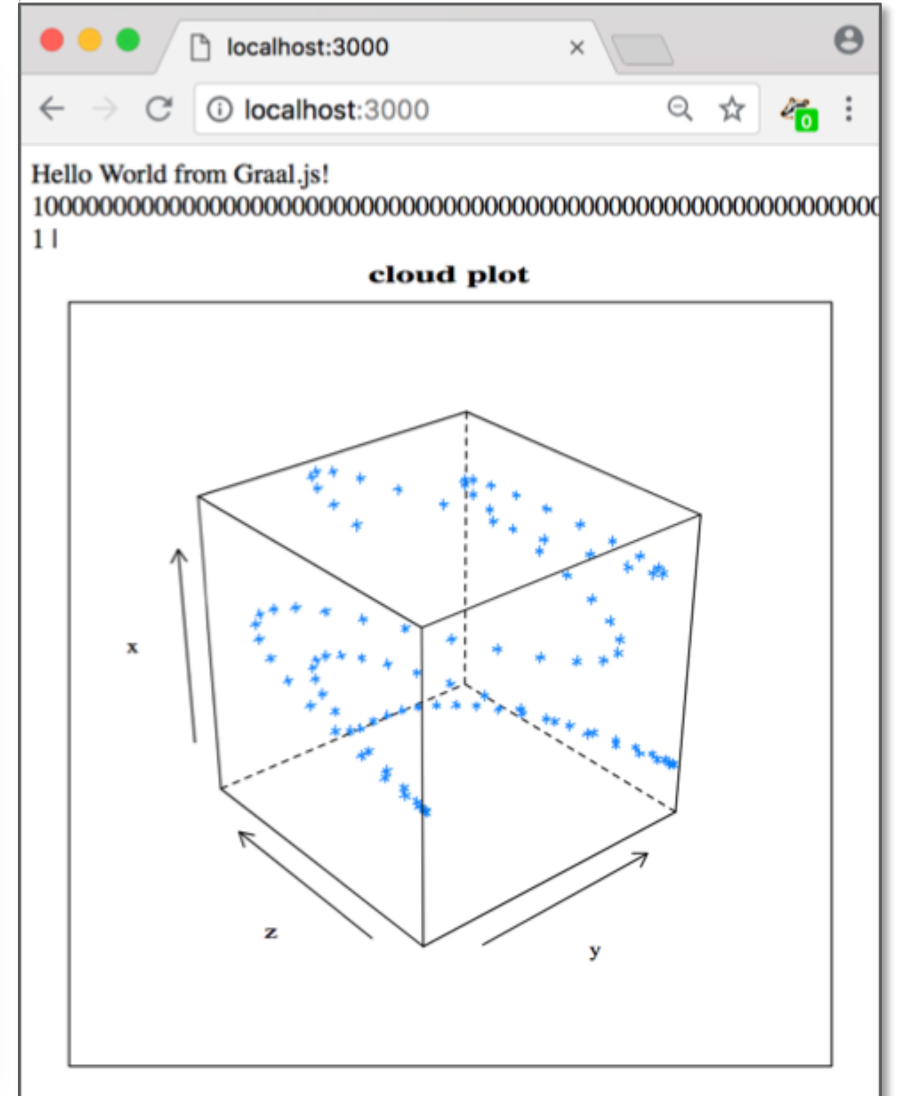
# GraalVM can do much more…

```
const express = require('express');
const app = express();
app.listen(3000);
app.get('/', function(req, res) {
  var text = 'Hello World!';
  const BigInteger = Java.type(
    'java.math.BigInteger');
  text += BigInteger.valueOf(2)
    .pow(100).toString(16);
  text += Polyglot.eval(
    'R', 'runif(100)')[0];
  res.send(text);
})
```



# Multiplicative Value-Add of GraalVM Ecosystem

**Add your own language or emedding or language-agnostic tools!**

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# GraalVM Community

- https://www.graalvm.org
- Open source on GitHub at https://github.com/oracle/graal

oracle / graal

Unwatch 376 | Unstar 8,448 | Fork 528

Code | Issues 265 | Pull requests 31 | Insights | Settings

GraalVM: Run Programs Faster Anywhere 🚀 https://www.graalvm.org

Edit

polyglot vm java javascript python r ruby c Manage topics

34,809 commits | 7 branches | 126 releases | 1 environment | 124 contributors | View license

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# Q/A

@graalvm

@thomaswue

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# Integrated Cloud

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