

Native Java with GraalVMTM

A gentle introduction to the native image generation

You will learn today...

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what is the difference between Graal and **GraalVM**TM

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what is the difference between Graal and **GraalVM**TM

how to use **native-image** command line tool

You will learn today...

what is the difference between Graal and **GraalVM**TM

how to use `native-image` command line tool

when it makes sense to use native images



whoami

Hello, my name is

Szymon Stepniak

I blog @ e.printstacktrace.blog

Continuous Delivery Architect @ **upwork**TM

 @wololock

Part 1: Graal vs GraalVMTM

Graal - a **JIT*** compiler written in Java

* just-in-time

JEP 243: Java-Level JVM Compiler Interface

<https://openjdk.java.net/jeps/243>





```
$ java
```



```
$ java -XX:+PrintFlagsFinal
```



```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions
```

```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions \  
-XX:+EnableJVMCI
```

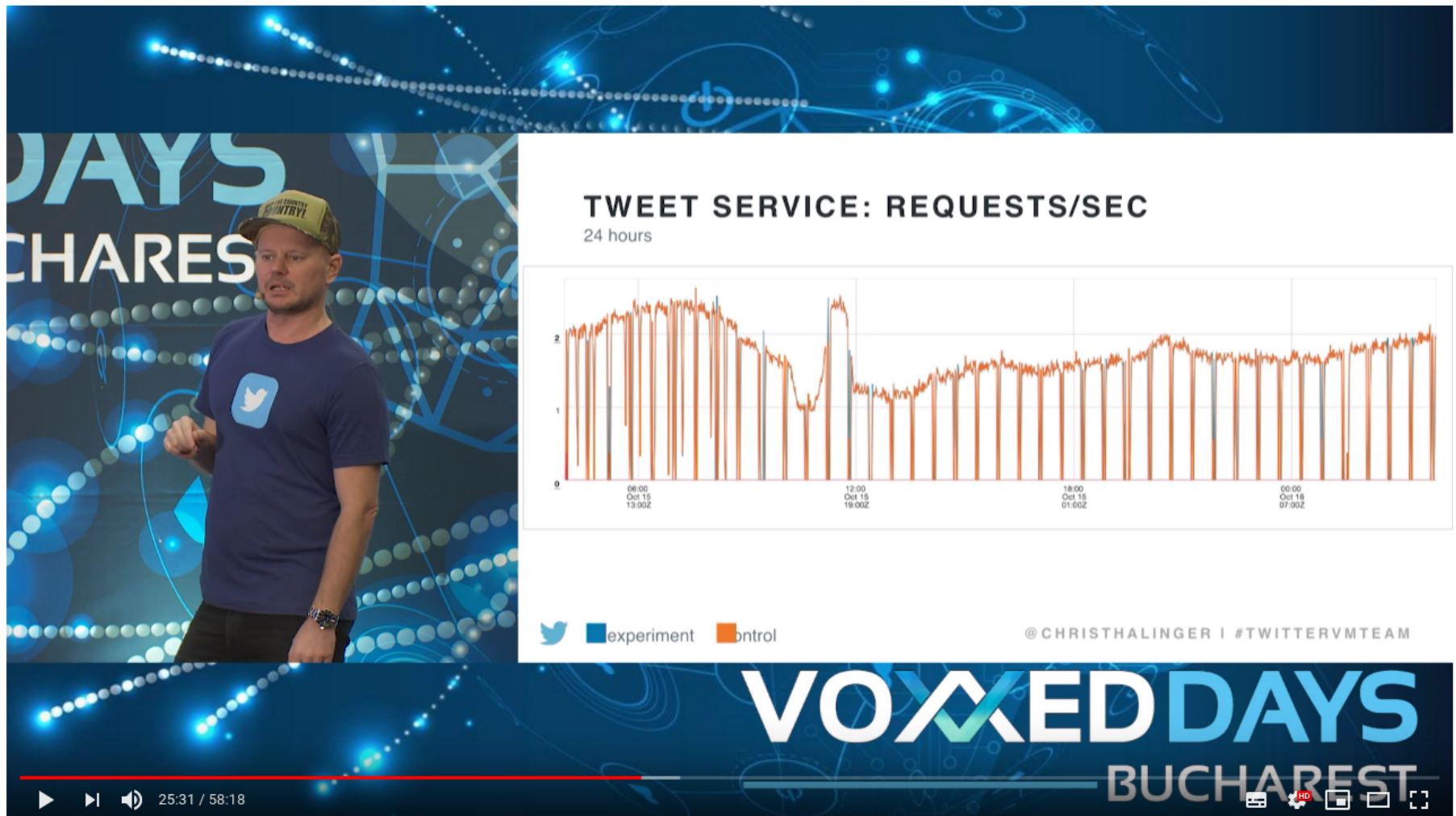
```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions \  
-XX:+EnableJVMCI -XX:+UseJVMCICompiler
```

```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions \  
-XX:+EnableJVMCI -XX:+UseJVMCICompiler -version
```



```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions \  
-XX:+EnableJVMCI -XX:+UseJVMCICompiler -version | grep -i jvmci
```

```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions \
  -XX:+EnableJVMCI -XX:+UseJVMCICompiler -version | grep -i jvmci
bool BootstrapJVMCI                = false      {JVMCI experimental} {default}
bool EnableJVMCI                   = true       {JVMCI experimental} {command}
intx JVMCICounterSize              = 0         {JVMCI experimental} {default}
bool JVMCICountersExcludeCompiler = true      {JVMCI experimental} {default}
intx JVMCIHostThreads              = 1         {JVMCI experimental} {default}
intx JVMCINMethodSizeLimit         = 655360    {JVMCI experimental} {default}
bool JVMCIPrintProperties           = false      {JVMCI experimental} {default}
intx JVMCIThreads                  = 1         {JVMCI experimental} {default}
intx JVMCITraceLevel               = 0         {JVMCI experimental} {default}
intx MethodProfileWidth            = 0         {JVMCI experimental} {default}
bool PrintBootstrap                = true       {JVMCI experimental} {default}
bool UseJVMCICompiler              = true       {JVMCI experimental} {command}
openjdk version "9.0.4"
OpenJDK Runtime Environment (build 9.0.4+11)
OpenJDK 64-Bit Server VM (build 9.0.4+11, mixed mode)
```



A video frame showing a presentation at Voxxed Days Bucharest. On the left, Chris Thalinger, wearing a blue Twitter t-shirt and a yellow cap, stands in front of a blue background with abstract light patterns. On the right, a slide titled "TWEET SERVICE: REQUESTS/SEC" displays a 24-hour line graph. The graph compares two data series: "experiment" (blue line) and "control" (orange line). The y-axis represents requests per second, ranging from 0 to 2. The x-axis shows time from 06:00 on Oct 15 to 07:00 on Oct 16. The "control" line shows high volatility with frequent spikes, while the "experiment" line is significantly lower and more stable. Below the graph, a legend identifies the blue line as "experiment" and the orange line as "ontrol". Social media handles "@CHRISTHALINGER" and "#TWITTERVMTEAM" are listed. The video player interface at the bottom shows a progress bar at 25:31 / 58:18 and standard playback controls.

TWEET SERVICE: REQUESTS/SEC
24 hours

experiment ontrol

@CHRISTHALINGER | #TWITTERVMTEAM

VOXXED DAYS
BUCHAREST

25:31 / 58:18

Chris Thalinger - Performance tuning Twitter services with Graal and Machine Learning

Source: https://www.youtube.com/watch?v=W-5kUG8_mbk

GraalVMTM

<https://www.graalvm.org>

High-performance polyglot **VM**

High-performance polyglot **VM**

A **universal** virtual machine for running: JavaScript, Python, Ruby, R, JVM-based languages, and LLVM-based languages.

High-performance polyglot **VM**

A **universal** virtual machine for running: JavaScript, Python, Ruby, R, JVM-based languages, and LLVM-based languages.

Zero overhead **interoperability** between programming languages.

High-performance polyglot **VM**

A **universal** virtual machine for running: **JavaScript**, **Python**, **Ruby**, **R**, **JVM**-based languages, and **LLVM**-based languages.

Zero overhead **interoperability** between programming languages.

Supports **native image** **ahead-of-time** compilation.

High-performance polyglot **VM**

A **universal** virtual machine for running: JavaScript, Python, Ruby, R, JVM-based languages, and LLVM-based languages.

Zero overhead **interoperability** between programming languages.

Supports **native image** **ahead-of-time** compilation.

And even **much** more. → <https://graalvm.org>

Substrate VM

Substrate VM is an **embeddable VM** for, and written in, a **subset of Java** optimized to **execute Truffle*** languages **ahead-of-time compiled** using Graal integrating with **native development tools**.

Christian Wimmer, "Safe and Efficient Hybrid Memory Management for Java", JVMLS 2015

* A language implementation framework for creating languages and instrumentations for GraalVM.

**Substrate VM ~~does~~ doesn't
support...**

Substrate VM ~~does~~ doesn't support...

Dynamic Class Loading / Unloading

Substrate VM ~~does~~ doesn't support...

~~Dynamic Class Loading / Unloading~~

InvokeDynamic Bytecode and Method Handles

Substrate VM ~~does~~ doesn't support...

~~Dynamic Class Loading / Unloading~~

~~InvokeDynamic Bytecode and Method Handles~~

Finalizers

Substrate VM ~~does~~ doesn't support...

~~Dynamic Class Loading / Unloading~~

~~InvokeDynamic Bytecode and Method Handles~~

~~Finalizers~~

Security Manager `java.lang.SecurityManager`

Substrate VM ~~does~~ doesn't support...

~~Dynamic Class Loading / Unloading~~

~~InvokeDynamic Bytecode and Method Handles~~

~~Finalizers~~

~~Security Manager~~ `java.lang.SecurityManager`

JVMTI, JMX, other native VM interfaces

Substrate VM ~~does~~ doesn't support...

~~Dynamic Class Loading / Unloading~~

~~InvokeDynamic Bytecode and Method Handles~~

~~Finalizers~~

~~Security Manager~~ `java.lang.SecurityManager`

~~JVMTI, JMX, other native VM interfaces~~

<https://github.com/oracle/graal/blob/master/substratevm/LIMITATIONS.md>

Native Image Java Limitations

Native Image does not support all features of Java to keep the implementation small and concise, and also to allow aggressive ahead-of-time optimizations. This page documents the limitations.

What	Support Status
Dynamic Class Loading / Unloading	Not supported
Reflection	Supported (Requires Configuration)
Dynamic Proxy	Supported (Requires Configuration)
Java Native Interface (JNI)	Mostly supported
Unsafe Memory Access	Mostly supported
Class Initializers	Supported
InvokeDynamic Bytecode and Method Handles	Not supported
Lambda Expressions	Supported
Synchronized, wait, and notify	Supported
Finalizers	Not supported
References	Mostly supported
Threads	Supported
Identity Hash Code	Supported
Security Manager	Not supported
JVMTI, JMX, other native VM interfaces	Not supported
JCA Security Services	Supported

Dynamic Class Loading / Unloading

Support Status: Not Supported

What: Loading new classes that were not available at native image build time; dynamically generating new bytecodes and



\$ _



```
$ sdk install java 19.0.0-gr1
```



```
$ sdk install java 19.0.0-grl
```

```
$ _
```



```
$ sdk install java 19.0.0-gr1
```

```
$ sdk use java 19.0.0-gr1
```



```
$ sdk install java 19.0.0-grl
```

```
$ sdk use java 19.0.0-grl
```

```
$ _
```



```
$ sdk install java 19.0.0-grl
```

```
$ sdk use java 19.0.0-grl
```

```
$ java -version
```


...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ _

...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ _

...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ _

...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ gu install native-image

...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ gu install native-image

\$ _

...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ gu install native-image

\$ native-image --version

...
\$ sdk install java 19.0.0-grl

\$ sdk use java 19.0.0-grl

\$ java -version

openjdk version "1.8.0_212"

OpenJDK Runtime Environment (build 1.8.0_212.buildslave.jdk8u-src-tar--b03)

OpenJDK GraalVM CE 19.0.0 (build 25.212-b03-jvmci-19-b01, mixed mode)

\$ gu install native-image

\$ native-image --version

GraalVM Version 19.0.0 CE

\$ _



\$ _



```
$ ls $JAVA_HOME/bin
```

\$ ls \$JAVA_HOME/bin

appletviewer	jcmd	jstatd	rmic
clhsdb	jconsole	jvisualvm	rmid
extcheck	jdb	keytool	rmiregistry
gu	jdeps	lli	schemagen
hsdb	jhat	native2ascii	serialver
idlj	jinfo	native-image	servertool
jar	jjs	native-image-configure	tnameserv
jarsigner	jmap	node	unpack200
java	jps	npm	wsgen
javac	jrunscript	orbd	wsimport
javadoc	js	pack200	xjc
javah	jsadebugd	policytool	
javap	jstack	polyglot	
java-rmi.cgi	jstat	rebuild-images	

Part 2: `native-image`

Compiling `Groovy` program to a native image

```
...  
// RandomNumber.groovy  
import groovy.transform.CompileStatic  
  
@CompileStatic  
class RandomNumber {  
    static void main(String[] args) {  
        def random = new Random().nextInt(1000)  
  
        println "The random number is: $random"  
  
        def sum = (0..random).sum { int num -> num * 2 }  
  
        println "The doubled sum of numbers between 0 and $random is $sum"  
    }  
}
```



\$ _



```
$ time groovy RandomNumber.groovy
```

...
\$ time groovy RandomNumber.groovy

The random number is: 146

The doubled sum of numbers between 0 and 146 is 21462

real 0m0,959s

user 0m1,879s

sys 0m0,205s

\$ _

...
\$ **time groovy RandomNumber.groovy**

The random number is: 146

The doubled sum of numbers between 0 and 146 is 21462

real **0m0,959s**

user 0m1,879s

sys 0m0,205s

\$ _



\$ _



```
$ groovyc RandomNumber.groovy
```



```
$ groovyc RandomNumber.groovy
```

```
$ _
```



```
$ groovyc RandomNumber.groovy
```

```
$ ls -lah *.class
```

...
\$ groovyc RandomNumber.groovy

\$ ls -lah *.class

```
-rw-rw-r-- 1 user user 2,8K 05-14 23:00 'RandomNumber$_main_closure1.class'  
-rw-rw-r-- 1 user user 3,8K 05-14 23:00 RandomNumber.class
```

\$ _

```
$ groovyc RandomNumber.groovy
```

```
$ ls -lah *.class
```

```
-rw-rw-r-- 1 user user 2,8K 05-14 23:00 'RandomNumber$_main_closure1.class'  
-rw-rw-r-- 1 user user 3,8K 05-14 23:00 RandomNumber.class
```

```
$ time java -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" RandomNumber
```

```
$ groovyc RandomNumber.groovy
```

```
$ ls -lah *.class
```

```
-rw-rw-r-- 1 user user 2,8K 05-14 23:00 'RandomNumber$_main_closure1.class'  
-rw-rw-r-- 1 user user 3,8K 05-14 23:00 RandomNumber.class
```

```
$ time java -cp "::$GROOVY_HOME/lib/groovy-2.5.7.jar" RandomNumber
```

```
The random number is: 167
```

```
The doubled sum of numbers between 0 and 167 is 28056
```

```
real    0m0,354s
```

```
user    0m0,808s
```

```
sys     0m0,088s
```

```
$ _
```

```
$ groovyc RandomNumber.groovy
```

```
$ ls -lah *.class
```

```
-rw-rw-r-- 1 user user 2,8K 05-14 23:00 'RandomNumber$_main_closure1.class'  
-rw-rw-r-- 1 user user 3,8K 05-14 23:00 RandomNumber.class
```

```
$ time java -cp "::$GROOVY_HOME/lib/groovy-2.5.7.jar" RandomNumber
```

```
The random number is: 167
```

```
The doubled sum of numbers between 0 and 167 is 28056
```

```
real    0m0,354s  
user    0m0,808s  
sys     0m0,088s
```

```
$ _
```




\$ _



```
$ native-image
```



```
$ native-image --no-server
```

```
$ native-image --no-server \  
-cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar"
```

```
$ native-image --no-server \  
-cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
RandomNumber
```

```
$ native-image --no-server \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:32448]    classlist:    2,436.23 ms
[randomnumber:32448]    (cap):        815.31 ms
[randomnumber:32448]    setup:        1,976.01 ms
[randomnumber:32448]    analysis:     8,237.69 ms
Warning: Aborting stand-alone image build. Unsupported features in 2 methods
Detailed message:
Error: com.oracle.svm.hosted.substitute.DeletedElementException: Unsupported
java.lang.ClassLoader.defineClass(String, byte[], int, int, ProtectionDomain)
To diagnose the issue, you can add the option --report-unsupported-elements-
...
Warning: Image 'randomnumber' is a fallback image that requires a JDK
for execution (use --no-fallback to suppress fallback image generation).

$ _
```

```
$ native-image --no-server \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:32448]    classlist:    2,436.23 ms
[randomnumber:32448]    (cap):        815.31 ms
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To diagnose the issue, you can add the option --report-unsupported-elements
...
Warning: Image 'randomnumber' is a fallback image that requires a JDK
for execution (use --no-fallback to suppress fallback image generation).

$ _
```

```
$ native-image --no-server \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:32448]    classlist:    2,436.23 ms
[randomnumber:32448]    (cap):        815.31 ms
[randomnumber:32448]    setup:        1,976.01 ms
[randomnumber:32448]    analysis:     8,237.69 ms
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To diagnose the issue, you can add the option --report-unsupported-elements
...
Warning: Image 'randomnumber' is a fallback image that requires a JDK
for execution (use --no-fallback to suppress fallback image generation)

$ _
```



```
$ native-image --no-server \  
-cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:15459]    classlist:    2,421.91 ms
[randomnumber:15459]    analysis:    15,830.52 ms
Error: Unsupported features in 3 methods
Detailed message:
Error: com.oracle.graal.pointsto.constraints.UnresolvedElementException:
Discovered unresolved method during parsing:
org.codehaus.groovy.control.XStreamUtils.serialize(java.lang.String, java.la
To diagnose the issue you can use the --allow-incomplete-classpath option.

$ _
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:15459]    classlist:    2,421.91 ms
[randomnumber:15459]    analysis:    15,830.52 ms
Error: Unsupported features in 3 methods
Detailed message:
Error: com.oracle.graal.pointsto.constraints.UnresolvedElementException:
Discovered unresolved method during parsing:
org.codehaus.groovy.control.XStreamUtils.serialize(java.lang.String, java.la
To diagnose the issue you can use the --allow-incomplete-classpath option.

$ _
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:25925]    classlist:    2,415.95 ms
[randomnumber:25925]    analysis:    33,234.24 ms
Error: Unsupported features in 6 methods
Detailed message:
Error: com.oracle.graal.pointsto.constraints.UnsupportedFeatureException:
Invoke with MethodHandle argument could not be reduced to at most
a single call: java.lang.invoke.MethodHandle.bindTo(Object)
...
Error: type is not available in this platform: org.graalvm.nativeimage.hosted
Trace:  object java.lang.Class[]
        object java.lang.invoke.MethodType
        object java.lang.invoke.MethodType$ConcurrentWeakInternSet$WeakEntry
        object java.util.concurrent.ConcurrentHashMap$Node
        object java.lang.invoke.MethodType$ConcurrentWeakInternSet
        method java.lang.invoke.MethodType.makeImpl(Class, Class[], boolean)

$ _
```



```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:31487]    classlist:    2,445.92 ms
[randomnumber:31487]    (cap):        816.43 ms
[randomnumber:31487]    setup:        1,983.95 ms
Warning: class initialization of class org.codehaus.groovy.control.XStreamUt
Warning: class initialization of class groovy.grape.GrapeIvy failed with exc
[randomnumber:31487]    analysis:    25,234.32 ms
...
[randomnumber:31487]    compile:    26,199.19 ms
[randomnumber:31487]    image:      1,896.69 ms
[randomnumber:31487]    write:       345.78 ms
[randomnumber:31487]    [total]:    60,623.87 ms

$ _
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
[randomnumber:31487]    classlist:    2,445.92 ms
[randomnumber:31487]    (cap):        816.43 ms
[randomnumber:31487]    setup:        1,983.95 ms
Warning: class initialization of class org.codehaus.groovy.control.XStreamUt
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[randomnumber:31487]    analysis:    25,234.32 ms
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[randomnumber:31487]    compile:    26,199.19 ms
[randomnumber:31487]    image:      1,896.69 ms
[randomnumber:31487]    write:       345.78 ms
[randomnumber:31487]    [total]:    60,623.87 ms

$ _
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
  RandomNumber
```

```
[randomnumber:31487]    classlist:    2,445.92 ms
[randomnumber:31487]      (cap):        816.43 ms
[randomnumber:31487]      setup:       1,983.95 ms
```

```
Warning: class initialization of class org.codehaus.groovy.control.XStreamU
```

```
Warning: class initialization of class groovy.grape.GrapeIvy failed with exc
```

```
[randomnumber:31487]    analysis:    25,234.32 ms
```

```
...
```

```
[randomnumber:31487]    compile:    26,199.19 ms
[randomnumber:31487]      image:      1,896.69 ms
[randomnumber:31487]      write:       345.78 ms
[randomnumber:31487]    [total]:    60,623.87 ms
```

```
$ _
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy
-cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
RandomNumber
[randomnumber:28584]      classlist:    2,407.72 ms
[randomnumber:28584]      (cap):         828.62 ms
[randomnumber:28584]      setup:         1,932.60 ms
[randomnumber:28584]      (typeflow):    11,163.81 ms
[randomnumber:28584]      (objects):     13,111.40 ms
....
[randomnumber:28584]      compile:       25,751.85 ms
[randomnumber:28584]      image:         2,175.32 ms
[randomnumber:28584]      write:          317.75 ms
[randomnumber:28584]      [total]:       61,381.94 ms

$ _
```



```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy
-cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
RandomNumber
[randomnumber:28584]    classlist:    2,407.72 ms
[randomnumber:28584]    (cap):        828.62 ms
[randomnumber:28584]    setup:        1,932.60 ms
[randomnumber:28584]    (typeflow):   11,163.81 ms
[randomnumber:28584]    (objects):    13,111.40 ms
....
[randomnumber:28584]    compile:    25,751.85 ms
[randomnumber:28584]    image:      2,175.32 ms
[randomnumber:28584]    write:      317.75 ms
[randomnumber:28584]    [total]:    61,381.94 ms

$ _
```



\$ _



```
$ ls -lah randomnumber
```

...
\$ ls -lah randomnumber

-rwxrwxr-x 1 wololock wololock 21M 05-14 23:29 randomnumber

\$ _

• • •
\$ ls -lah randomnumber

-rwxrwxr-x 1 wololock wololock 21M 05-14 23:29 randomnumber

\$./randomnumber

```
$ ls -lah randomnumber
-rwxrwxr-x 1 wololock wololock 21M 05-14 23:29 randomnumber
```

```
$ ./randomnumber
```

```
The random number is: 624
```

```
Exception in thread "main" groovy.lang.MissingMethodException: No signature
of method: RandomNumber$_main_closure1.doCall() is applicable for argument t
Possible solutions: findAll(), findAll(), isCase(java.lang.Object), isCase(j
    at org.codehaus.groovy.runtime.metaclass.ClosureMetaClass.invokeMeth
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:1041)
    at groovy.lang.Closure.call(Closure.java:405)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroov
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroov
    at RandomNumber.main(RandomNumber.groovy:7)
```

```
$ _
```

```
$ ls -lah randomnumber
-rwxrwxr-x 1 wololock wololock 21M 05-14 23:29 randomnumber
```

```
$ ./randomnumber
```

```
The random number is: 624
```

```
Exception in thread "main" groovy.lang.MissingMethodException: No signature
of method: RandomNumber$_main_closure1.doCall() is applicable for argument
Possible solutions: findAll(), findAll(), isCase(java.lang.Object), isCase(j
    at org.codehaus.groovy.runtime.metaclass.ClosureMetaClass.invokeMethod
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:1041)
    at groovy.lang.Closure.call(Closure.java:405)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMethods.java:1041)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMethods.java:1041)
    at RandomNumber.main(RandomNumber.groovy:7)
```

```
$ _
```

```
...  
// RandomNumber.groovy  
import groovy.transform.CompileStatic  
  
@CompileStatic  
class RandomNumber {  
    static void main(String[] args) {  
        def random = new Random().nextInt(1000)  
  
        println "The random number is: $random"  
  
        def sum = (0..random).sum { int num -> num * 2 }  
  
        println "The doubled sum of numbers between 0 and $random is $sum"  
    }  
}
```



```
...  
// RandomNumber.groovy  
import groovy.transform.CompileStatic  
  
@CompileStatic  
class RandomNumber {  
    static void main(String[] args) {  
        def random = new Random().nextInt(1000)  
  
        println "The random number is: $random"  
  
        def sum = (0..random).sum { int num -> num * 2 }  
  
        println "The doubled sum of numbers between 0 and $random is $sum"  
    }  
}
```

```
$ ls -lah randomnumber
-rwxrwxr-x 1 wololock wololock 21M 05-14 23:29 randomnumber
```

```
$ ./randomnumber
```

```
The random number is: 624
```

```
Exception in thread "main" groovy.lang.MissingMethodException: No signature
of method: RandomNumber$_main_closure1.doCall() is applicable for argument
Possible solutions: findAll(), findAll(), isCase(java.lang.Object), isCase(j
    at org.codehaus.groovy.runtime.metaclass.ClosureMetaClass.invokeMeth
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:1041)
    at groovy.lang.Closure.call(Closure.java:405)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroov
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroov
    at RandomNumber.main(RandomNumber.groovy:7)
```

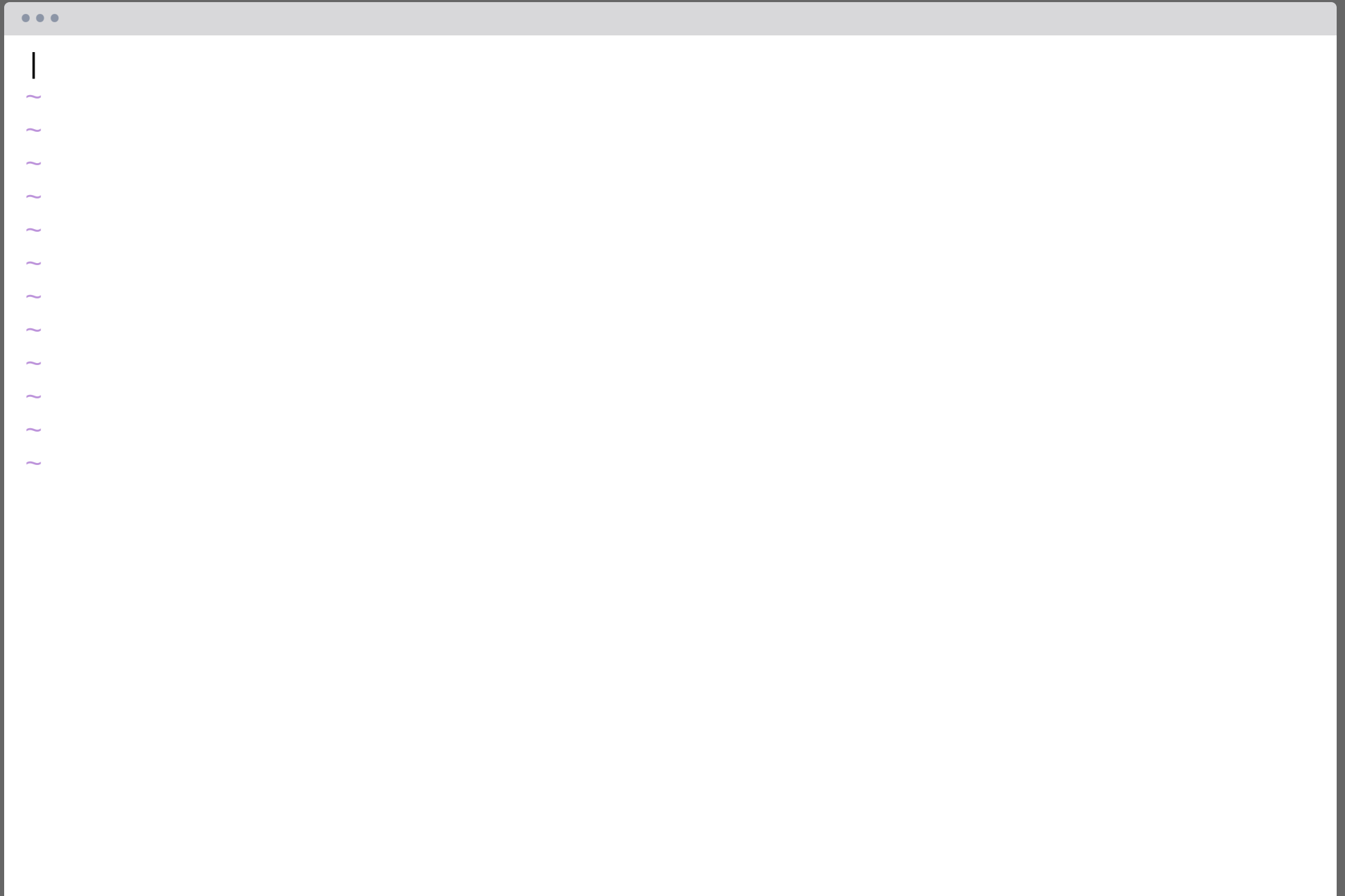
```
$ _
```



\$ _



```
$ vim reflections.json
```



```
[
  {
    "name": "RandomNumber$_main_closure1",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }
]
~
~
~
~
```



```
$ vim reflections.json
```

```
$ _
```

```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```



```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
[randomnumber:7680]    classlist:    2,368.40 ms  
[randomnumber:7680]      (cap):      890.32 ms  
[randomnumber:7680]      setup:      2,025.75 ms  
[randomnumber:7680]    (typeflow): 11,078.72 ms
```

```
...
```

```
[randomnumber:7680]    compile:    30,400.57 ms  
[randomnumber:7680]      image:      2,603.14 ms  
[randomnumber:7680]      write:       317.86 ms  
[randomnumber:7680]    [total]:    67,206.07 ms
```

```
$ _
```

```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

[randomnumber:7680]	classlist:	2,368.40 ms
[randomnumber:7680]	(cap):	890.32 ms
[randomnumber:7680]	setup:	2,025.75 ms
[randomnumber:7680]	(typeflow):	11,078.72 ms

```
...
```

[randomnumber:7680]	compile:	30,400.57 ms
[randomnumber:7680]	image:	2,603.14 ms
[randomnumber:7680]	write:	317.86 ms
[randomnumber:7680]	[total]:	67,206.07 ms

```
$ _
```



\$ _



```
$ ./randomnumber
```

\$./randomnumber

The random number is: 30

```
java.lang.ClassNotFoundException: org.codehaus.groovy.runtime.dgm$521
    at com.oracle.svm.core.hub.ClassForNameSupport.forName(ClassForNameSupport.java:1041)
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:1041)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMethods.java:1041)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMethods.java:1041)
    at RandomNumber.main(RandomNumber.groovy:7)
Exception in thread "main" groovy.lang.GroovyRuntimeException: Failed to create proxy
    at org.codehaus.groovy.reflection.GeneratedMetaMethod$Proxy.createProxy(GeneratedMetaMethod$Proxy.java:1041)
    at RandomNumber.main(RandomNumber.groovy:7)
Caused by: java.lang.ClassNotFoundException: org.codehaus.groovy.runtime.dgm$521
    at com.oracle.svm.core.hub.ClassForNameSupport.forName(ClassForNameSupport.java:1041)
    at java.lang.ClassLoader.loadClass(Target_java_lang_ClassLoader.java:131)
    at org.codehaus.groovy.reflection.GeneratedMetaMethod$Proxy.createProxy(GeneratedMetaMethod$Proxy.java:1041)
    ... 12 more
```

\$ _

\$./randomnumber

The random number is: 30

```
java.lang.ClassNotFoundException: org.codehaus.groovy.runtime.dgm$521
    at com.oracle.svm.core.hub.ClassForNameSupport.forName(ClassForNameSupport.java:1041)
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:1041)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMethods.java:1041)
    at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMethods.java:1041)
    at RandomNumber.main(RandomNumber.groovy:7)
Exception in thread "main" groovy.lang.GroovyRuntimeException: Failed to create proxy
    at org.codehaus.groovy.reflection.GeneratedMetaMethod$Proxy.createProxy(GeneratedMetaMethod$Proxy.java:1041)
    at RandomNumber.main(RandomNumber.groovy:7)
Caused by: java.lang.ClassNotFoundException: org.codehaus.groovy.runtime.dgm$521
    at com.oracle.svm.core.hub.ClassForNameSupport.forName(ClassForNameSupport.java:1041)
    at java.lang.ClassLoader.loadClass(Target_java_lang_ClassLoader.java:131)
    at org.codehaus.groovy.reflection.GeneratedMetaMethod$Proxy.createProxy(GeneratedMetaMethod$Proxy.java:1041)
    ... 12 more
```

\$ _



\$ _



```
$ vim reflections.json
```

```
[
  {
    "name": "RandomNumber$_main_closure1",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }
]
~
~
~
~
```

```
[
  {
    "name": "RandomNumber$_main_closure1",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }, {
    "name": "org.codehaus.groovy.runtime.dgm$521",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }
]
```

```
[
  {
    "name": "RandomNumber$_main_closure1",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }, {
    "name": "org.codehaus.groovy.runtime.dgm$521",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }, {
    "name": "org.codehaus.groovy.runtime.dgm$1180",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  }
]
```



```
$ vim reflections.json
```

```
$ _
```

```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
[randomnumber:28896]    classlist:    2,496.04 ms  
[randomnumber:28896]      (cap):      875.97 ms  
[randomnumber:28896]      setup:      2,010.72 ms  
[randomnumber:28896] (typeflow): 10,719.53 ms
```

```
...
```

```
[randomnumber:28896]    compile:    27,489.45 ms  
[randomnumber:28896]      image:      2,182.01 ms  
[randomnumber:28896]      write:       345.20 ms  
[randomnumber:28896] [total]:    62,006.46 ms
```

```
$ _
```

```
$ vim reflections.json
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

[randomnumber:28896]	classlist:	2,496.04 ms
[randomnumber:28896]	(cap):	875.97 ms
[randomnumber:28896]	setup:	2,010.72 ms
[randomnumber:28896]	(typeflow):	10,719.53 ms

```
...
```

[randomnumber:28896]	compile:	27,489.45 ms
[randomnumber:28896]	image:	2,182.01 ms
[randomnumber:28896]	write:	345.20 ms
[randomnumber:28896]	[total]:	62,006.46 ms

```
$ _
```




\$ _



```
$ ./randomnumber
```

...
\$./randomnumber

The random number is: 109

The doubled sum of numbers between 0 and 109 is 11990

\$ _

...

```
$ ./randomnumber
```

```
The random number is: 109
```

```
The doubled sum of numbers between 0 and 109 is 11990
```

```
$ time ./randomnumber
```

...
\$./randomnumber

The random number is: 109

The doubled sum of numbers between 0 and 109 is 11990

\$ time ./randomnumber

The random number is: 534

The doubled sum of numbers between 0 and 534 is 285690

real 0m0,007s

user 0m0,004s

sys 0m0,003s

\$ _

...
\$./randomnumber

The random number is: 109

The doubled sum of numbers between 0 and 109 is 11990

\$ time ./randomnumber

The random number is: 534

The doubled sum of numbers between 0 and 534 is 285690

real 0m0,007s

user 0m0,004s

sys 0m0,003s

\$ _

...
\$./randomnumber

The random number is: 109

The doubled sum of numbers between 0 and 109 is 11990

\$ time ./randomnumber

The random number is: 534

The doubled sum of numbers between 0 and 534 is 285690

real 0m0,007s vs. 0m0,959s

user 0m0,004s

sys 0m0,003s

\$ _

\$./randomnumber

The random number is: 109

The doubled sum of numbers between 0 and 109 is 11990

\$ time ./randomnumber

The random number is: 534

The doubled sum of numbers between 0 and 534 is 285690

real 0m0,007s vs. 0m0,959s vs. 0m0,354s

user 0m0,004s

sys 0m0,003s

\$ _



\$ _

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ReflectionConfigurationFiles=reflections.json \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy
H:ReflectionConfigurationFiles=reflections.json \
-cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
RandomNumber
```



\$ _



```
$ java -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" RandomNumber
```

```
$ java -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
-agentlib:native-image-agent=config-output-dir=conf/ \  
RandomNumber
```

```
$ java -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
    -agentlib:native-image-agent=config-output-dir=conf/ \  
    RandomNumber
```

The random number is: 670

The doubled sum of numbers between 0 and 670 is 449570

\$ _

```
$ java -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
    -agentlib:native-image-agent=config-output-dir=conf/ \  
    RandomNumber
```

The random number is: 670

The doubled sum of numbers between 0 and 670 is 449570

```
$ tree conf/
```



```
$ java -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
    -agentlib:native-image-agent=config-output-dir=conf/ \
    RandomNumber
```

The random number is: 670

The doubled sum of numbers between 0 and 670 is 449570

```
$ tree conf/
```

conf

```
|— jni-config.json
|— proxy-config.json
|— reflect-config.json
|— resource-config.json
```

0 directories, 4 files

```
$ _
```

```
$ native-image --no-server \
  --no-fallback \
  --report-unsupported-elements-at-runtime \
  --allow-incomplete-classpath \
  --initialize-at-build-time \
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy
H:ReflectionConfigurationFiles=reflections.json \
-cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \
RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy  
  -H:ConfigurationFileDirectories=conf/ \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  RandomNumber
```

```
$ native-image --no-server \  
  --no-fallback \  
  --report-unsupported-elements-at-runtime \  
  --allow-incomplete-classpath \  
  --initialize-at-build-time \  
  --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy \  
  -H:ConfigurationFileDirectories=conf/ \  
  -cp ".$GROOVY_HOME/lib/groovy-2.5.7.jar" \  
  -jar RandomNumber.jar
```



\$ _



```
$ native-image --help
```



```
$ native-image --help
```

```
$ native-image --help-extra
```



```
$ native-image --help
```

```
$ native-image --help-extra
```

```
$ native-image --expert-options
```


\$ native-image --help

\$ native-image --help-extra

\$ native-image --expert-options

-H:±AllowIncompleteClasspath

-H:±AllowVMInspection

-H:CPUFeatures=...

-H:CStandard="**C89**"

-H:Class=""

-H:ClassInitialization=...

-H:CompilerBackend="**lir**"

...

Allow image building with an incomplete first time, instead of during image build

Enables features that allow the VM to be

Comma separated list of CPU features that are enabled by default. Other available SSE4_1, SSE4_2, POPCNT, LZCNT, TSC, TSC1

AVX512PF, AVX512ER, AVX512CD, AVX512BW.

C standard to use **in** header files. Possible

Class containing the default entry point

A comma-separated list of classes appended

Default: None

Backend used by the compiler.

Part 3: **benchmark**

Is native image a better choice for our applications?

Methodology

We will use `ab` to benchmark application in 4 different stages

`Stateless` web app with **16 threads** to handle incoming requests.



\$ _



```
$ curl -i localhost:5050
```

```
...  
$ curl -i localhost:5050  
HTTP/1.1 200 OK  
content-type: application/json  
content-length: 27
```

```
{"message": "Hello, World!"}%
```

```
$ _
```

```
$ curl -i localhost:5050
```

```
HTTP/1.1 200 OK
```

```
content-type: application/json
```

```
content-length: 27
```

```
{"message": "Hello, World!"}%
```

```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ curl -i localhost:5050
```

```
HTTP/1.1 200 OK
```

```
content-type: application/json
```

```
content-length: 27
```

```
{"message": "Hello, World!"}%
```

```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```



```
$ curl -i localhost:5050
```

```
HTTP/1.1 200 OK
```

```
content-type: application/json
```

```
content-length: 27
```

```
{"message": "Hello, World!"}%
```

```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

```
$ curl -i localhost:5050
```

```
HTTP/1.1 200 OK
```

```
content-type: application/json
```

```
content-length: 27
```

```
{"message": "Hello, World!"}%
```

```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

Oracle JDK 1.8.0_201



\$ _



```
$ java -jar build/libs/ratpack-graalvm-demo-all.jar -Xmx1024m
```

```
$ java -jar build/libs/ratpack-graalvm-demo-all.jar -Xmx1024m
[main] INFO ratpack.server.RatpackServer - Starting server...
[main] INFO ratpack.server.RatpackServer - Building registry...
[main] INFO ratpack.server.RatpackServer - Ratpack started for http://localhost
```



\$ _



```
$ ab -c 1 -n 1 http://localhost:5050/
```



```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
Time taken for tests: 0.085 seconds
```

```
Requests per second: 11.70 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	85	85 0.0	85	85
Waiting:	84	84 0.0	84	84
Total:	85	85 0.0	85	85

```
$ ab -c 1 -n 1 http://localhost:5050/
```

Time taken **for** tests: **0.085 seconds**

Requests per second: 11.70 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	85	85 0.0	85	85
Waiting:	84	84 0.0	84	84
Total:	85	85 0.0	85	85



```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
Time taken for tests:    0.226 seconds  
Requests per second:    4422.47 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	2 5.5	0	17
Processing:	1	27 15.4	23	90
Waiting:	1	26 15.3	23	89
Total:	1	29 15.9	26	104

Percentage of the requests served within a certain time (ms)

50%	26
66%	33
75%	37
80%	39
90%	48
95%	59
98%	70
99%	93
100%	104 (longest request)

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
Time taken for tests: 0.226 seconds
Requests per second: 4422.47 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	2 5.5	0	17
Processing:	1	27 15.4	23	90
Waiting:	1	26 15.3	23	89
Total:	1	29 15.9	26	104

Percentage of the requests served within a certain time (ms)

50%	26
66%	33
75%	37
80%	39
90%	48
95%	59
98%	70
99%	93
100%	104 (longest request)

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

Time taken **for** tests: **0.226 seconds**
Requests per second: **4422.47** [#/sec] (mean)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	2 5.5	0	17
Processing:	1	27 15.4	23	90
Waiting:	1	26 15.3	23	89
Total:	1	29 15.9	26	104

Percentage of the requests served within a certain time (ms)

50%	26
66%	33
75%	37
80%	39
90%	48
95%	59
98%	70
99%	93
100%	104 (longest request)



```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

```
Time taken for tests:    0.907 seconds  
Requests per second:    11019.85 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 2.9	4	20
Processing:	0	8 7.5	6	108
Waiting:	0	7 7.7	5	108
Total:	1	12 8.0	10	124

Percentage of the requests served within a certain time (ms)

50%	10
66%	11
75%	12
80%	13
90%	18
95%	24
98%	33
99%	41
100%	124 (longest request)


```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

Time taken **for** tests: **0.907** seconds

Requests per second: 11019.85 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 2.9	4	20
Processing:	0	8 7.5	6	108
Waiting:	0	7 7.7	5	108
Total:	1	12 8.0	10	124

Percentage of the requests served within a certain time (ms)

50%	10
66%	11
75%	12
80%	13
90%	18
95%	24
98%	33
99%	41
100%	124 (longest request)

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

Time taken **for** tests: **0.907** seconds

Requests per second: **11019.85** [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 2.9	4	20
Processing:	0	8 7.5	6	108
Waiting:	0	7 7.7	5	108
Total:	1	12 8.0	10	124

Percentage of the requests served within a certain time (ms)

50%	10
66%	11
75%	12
80%	13
90%	18
95%	24
98%	33
99%	41
100%	124 (longest request)



```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

```
Time taken for tests:    28.555 seconds  
Requests per second:    17509.85 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	29 59.5	25	1096
Processing:	0	28 16.1	27	268
Waiting:	0	18 16.1	16	257
Total:	0	57 61.2	54	1118

Percentage of the requests served within a certain time (ms)

50%	54
66%	56
75%	57
80%	58
90%	60
95%	62
98%	65
99%	69
100%	1118 (longest request)

```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

Time taken **for** tests: **28.555** seconds

Requests per second: 17509.85 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	29 59.5	25	1096
Processing:	0	28 16.1	27	268
Waiting:	0	18 16.1	16	257
Total:	0	57 61.2	54	1118

Percentage of the requests served within a certain time (ms)

50%	54
66%	56
75%	57
80%	58
90%	60
95%	62
98%	65
99%	69
100%	1118 (longest request)

```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

Time taken **for** tests: **28.555** seconds

Requests per second: **17509.85** [#/sec] (mean)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	29 59.5	25	1096
Processing:	0	28 16.1	27	268
Waiting:	0	18 16.1	16	257
Total:	0	57 61.2	54	1118

Percentage of the requests served within a certain time (ms)

50%	54
66%	56
75%	57
80%	58
90%	60
95%	62
98%	65
99%	69
100%	1118 (longest request)

Native image



\$ _



```
$ ./ratpack-graalvm-demo -Xmx1024m
```

```
$ ./ratpack-graalvm-demo -Xmx1024m
[main] INFO ratpack.server.RatpackServer - Starting server...
[main] INFO ratpack.server.RatpackServer - Building registry...
[main] INFO ratpack.server.RatpackServer - Ratpack started for http://localhost
```



```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ ab -c 1 -n 1 http://localhost:5050/
```

Time taken **for** tests: 0.002 seconds

Requests per second: 531.63 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	2	2 0.0	2	2
Waiting:	2	2 0.0	2	2
Total:	2	2 0.0	2	2

```
$ ab -c 1 -n 1 http://localhost:5050/
```

Time taken **for** tests: **0.002** seconds

Requests per second: 531.63 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	2	2 0.0	2	2
Waiting:	2	2 0.0	2	2
Total:	2	2 0.0	2	2



```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

```
Time taken for tests:    0.085 seconds  
Requests per second:    11798.71 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 3.5	3	15
Processing:	1	6 4.1	4	22
Waiting:	1	5 4.0	3	21
Total:	4	10 6.7	7	35

Percentage of the requests served within a certain time (ms)

50%	7
66%	8
75%	10
80%	10
90%	25
95%	28
98%	29
99%	30
100%	35 (longest request)

```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

Time taken **for** tests: **0.085** seconds

Requests per second: 11798.71 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 3.5	3	15
Processing:	1	6 4.1	4	22
Waiting:	1	5 4.0	3	21
Total:	4	10 6.7	7	35

Percentage of the requests served within a certain time (ms)

50%	7
66%	8
75%	10
80%	10
90%	25
95%	28
98%	29
99%	30
100%	35 (longest request)


```
$ ab -c 1000 -n 1000 http://localhost:5050/
```

Time taken **for** tests: **0.085** seconds

Requests per second: **11798.71** [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 3.5	3	15
Processing:	1	6 4.1	4	22
Waiting:	1	5 4.0	3	21
Total:	4	10 6.7	7	35

Percentage of the requests served within a certain time (ms)

50%	7
66%	8
75%	10
80%	10
90%	25
95%	28
98%	29
99%	30
100%	35 (longest request)



```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

```
Time taken for tests:    0.607 seconds  
Requests per second:    16485.46 [#/sec] (mean)
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 2.1	4	16
Processing:	0	4 1.7	4	16
Waiting:	0	3 1.7	3	15
Total:	1	8 3.2	7	30

Percentage of the requests served within a certain time (ms)

50%	7
66%	8
75%	8
80%	8
90%	9
95%	10
98%	22
99%	27
100%	30 (longest request)

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

Time taken **for** tests: **0.607** seconds

Requests per second: 16485.46 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 2.1	4	16
Processing:	0	4 1.7	4	16
Waiting:	0	3 1.7	3	15
Total:	1	8 3.2	7	30

Percentage of the requests served within a certain time (ms)

50%	7
66%	8
75%	8
80%	8
90%	9
95%	10
98%	22
99%	27
100%	30 (longest request)

```
$ ab -c 1000 -n 10000 http://localhost:5050/
```

Time taken **for** tests: **0.607** seconds

Requests per second: **16485.46** [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	4 2.1	4	16
Processing:	0	4 1.7	4	16
Waiting:	0	3 1.7	3	15
Total:	1	8 3.2	7	30

Percentage of the requests served within a certain time (ms)

50%	7
66%	8
75%	8
80%	8
90%	9
95%	10
98%	22
99%	27
100%	30 (longest request)



```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

Time taken **for** tests: 31.884 seconds

Requests per second: 15681.79 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	42 183.6	18	3089
Processing:	0	21 18.7	20	901
Waiting:	0	14 18.3	13	899
Total:	0	63 185.1	39	3109

Percentage of the requests served within a certain time (ms)

50%	39
66%	43
75%	46
80%	48
90%	52
95%	57
98%	1041
99%	1081
100%	3109 (longest request)

```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

Time taken **for** tests: **31.884** seconds

Requests per second: 15681.79 [*#/sec*] (*mean*)

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	42 183.6	18	3089
Processing:	0	21 18.7	20	901
Waiting:	0	14 18.3	13	899
Total:	0	63 185.1	39	3109

Percentage of the requests served within a certain time (ms)

50%	39
66%	43
75%	46
80%	48
90%	52
95%	57
98%	1041
99%	1081
100%	3109 (longest request)


```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

Time taken **for** tests: **31.884** seconds

Requests per second: **15681.79** [*#/sec*] (*mean*)

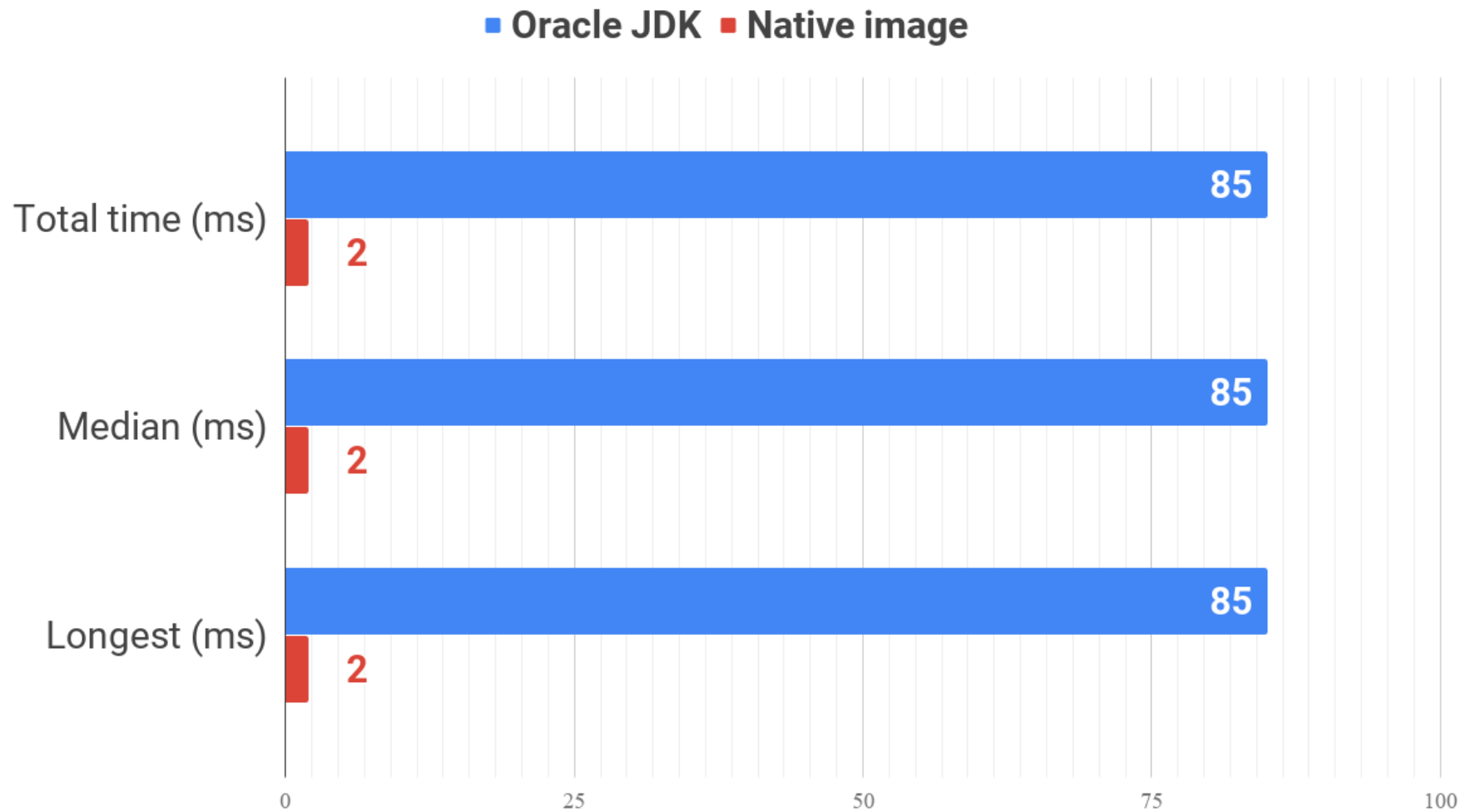
Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	42 183.6	18	3089
Processing:	0	21 18.7	20	901
Waiting:	0	14 18.3	13	899
Total:	0	63 185.1	39	3109

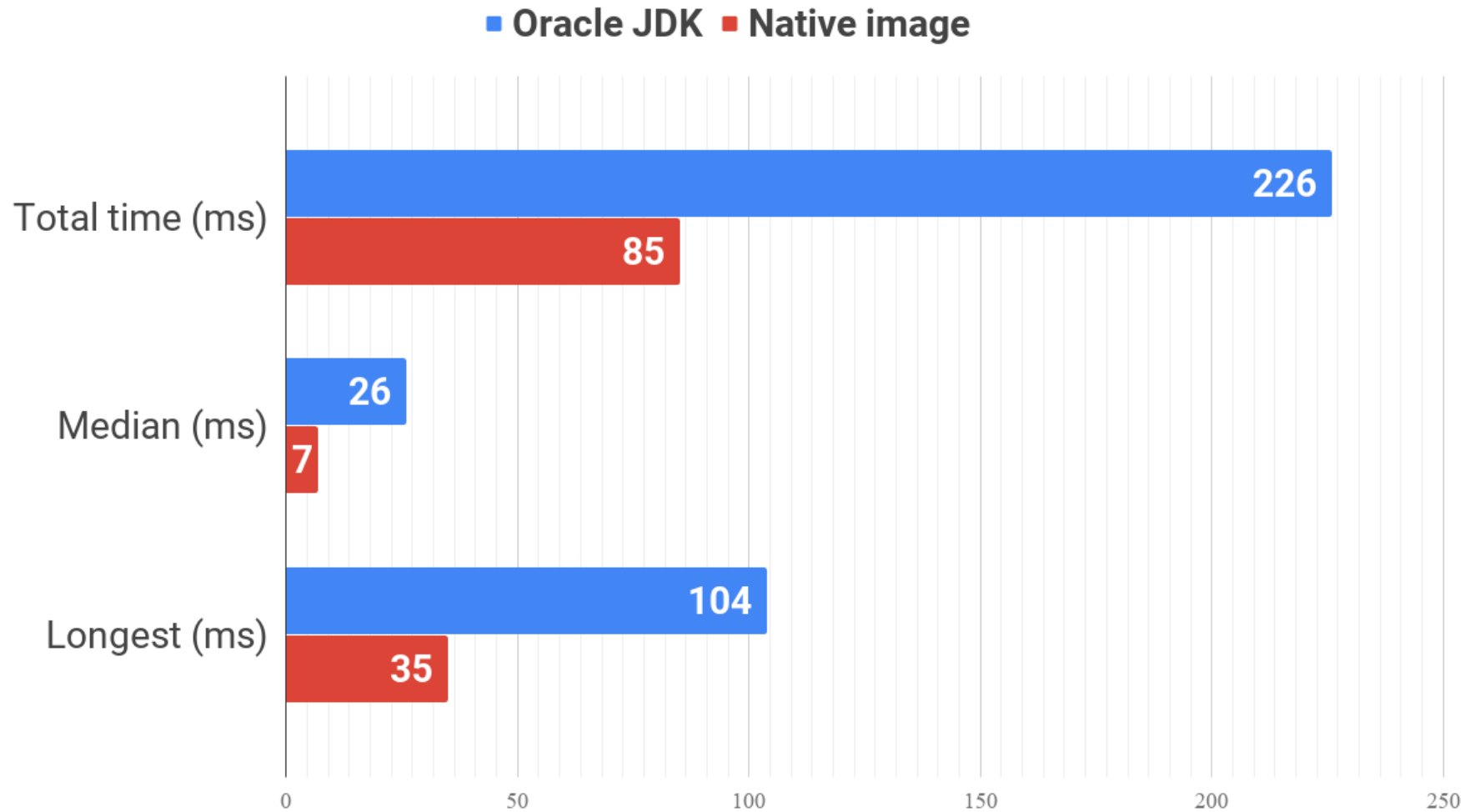
Percentage of the requests served within a certain time (ms)

50%	39
66%	43
75%	46
80%	48
90%	52
95%	57
98%	1041
99%	1081
100%	3109 (longest request)

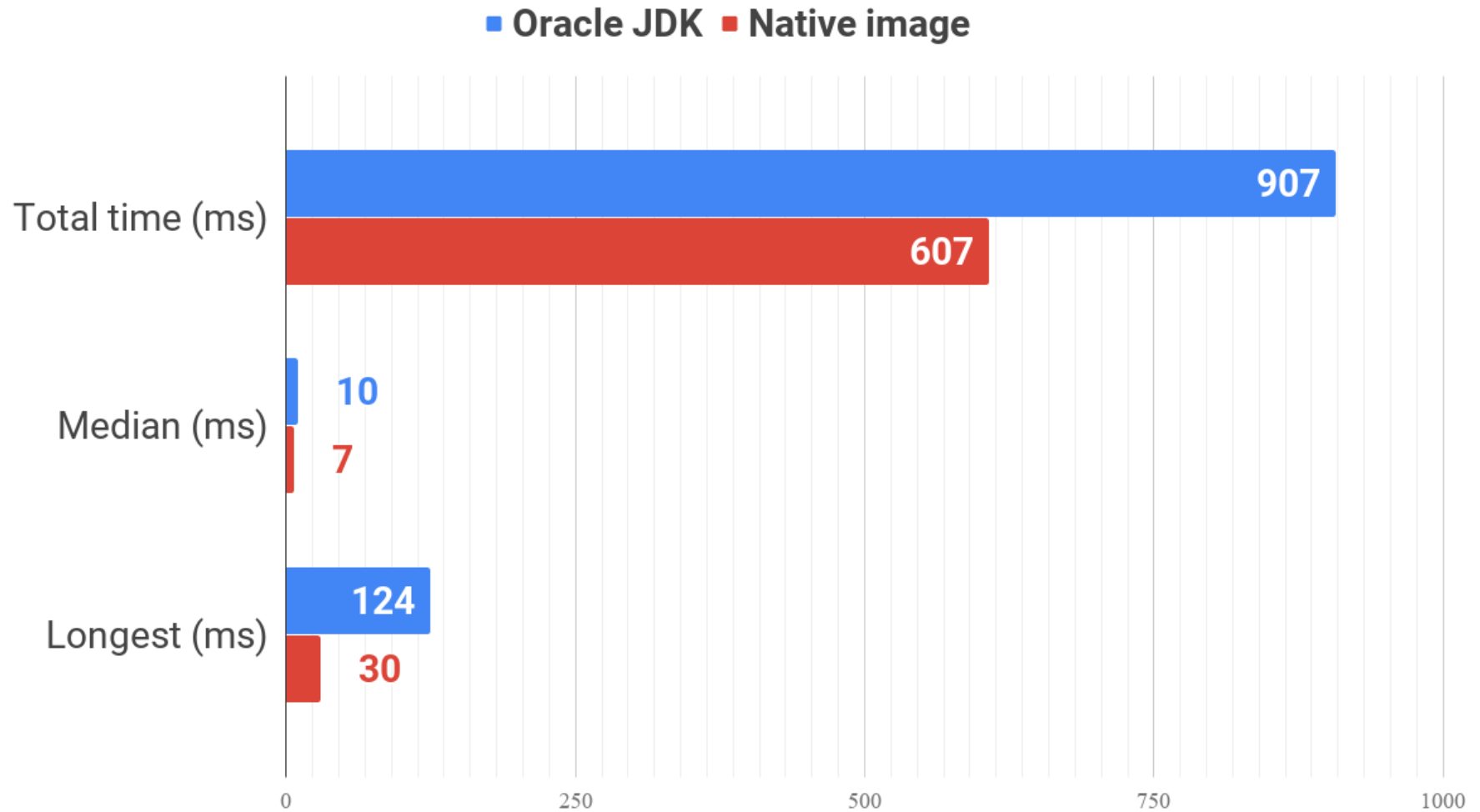
1 req (total: 1)



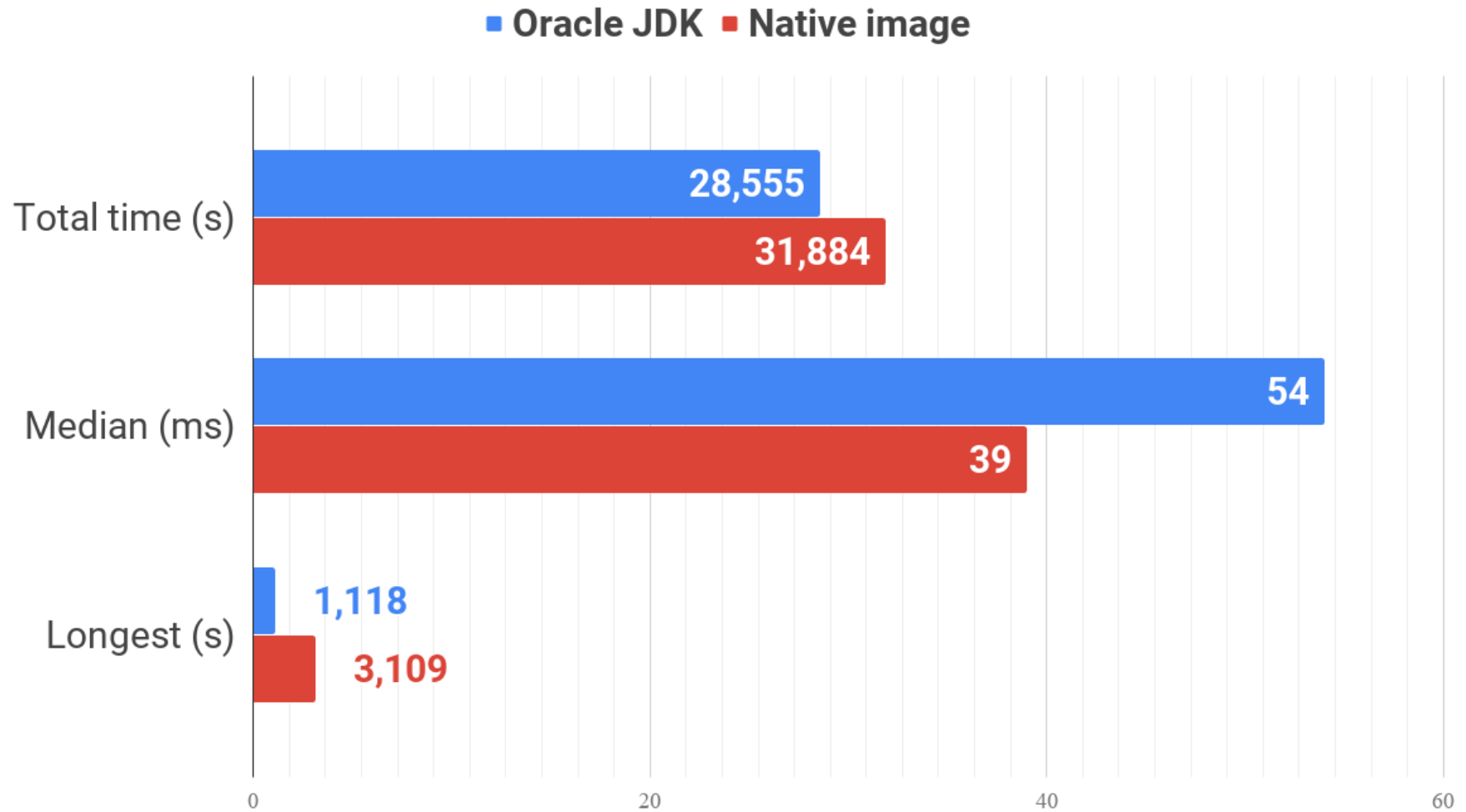
1k conc req (total: 1k)



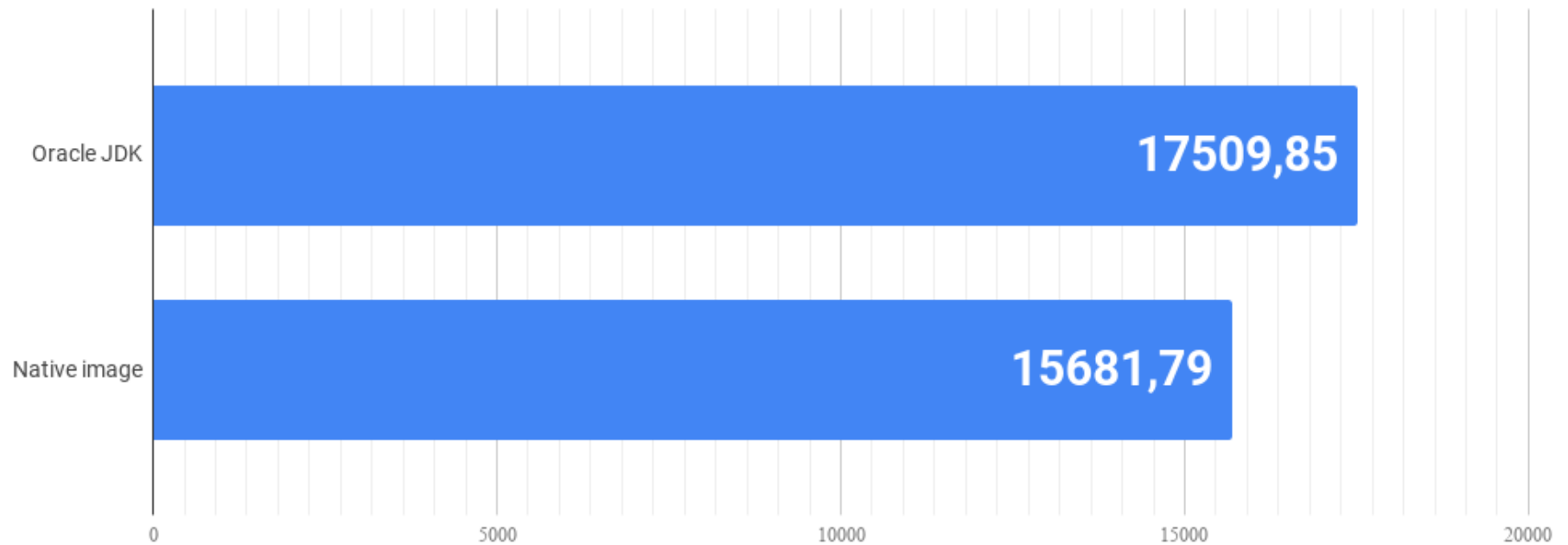
1k conc req (total: 10k)



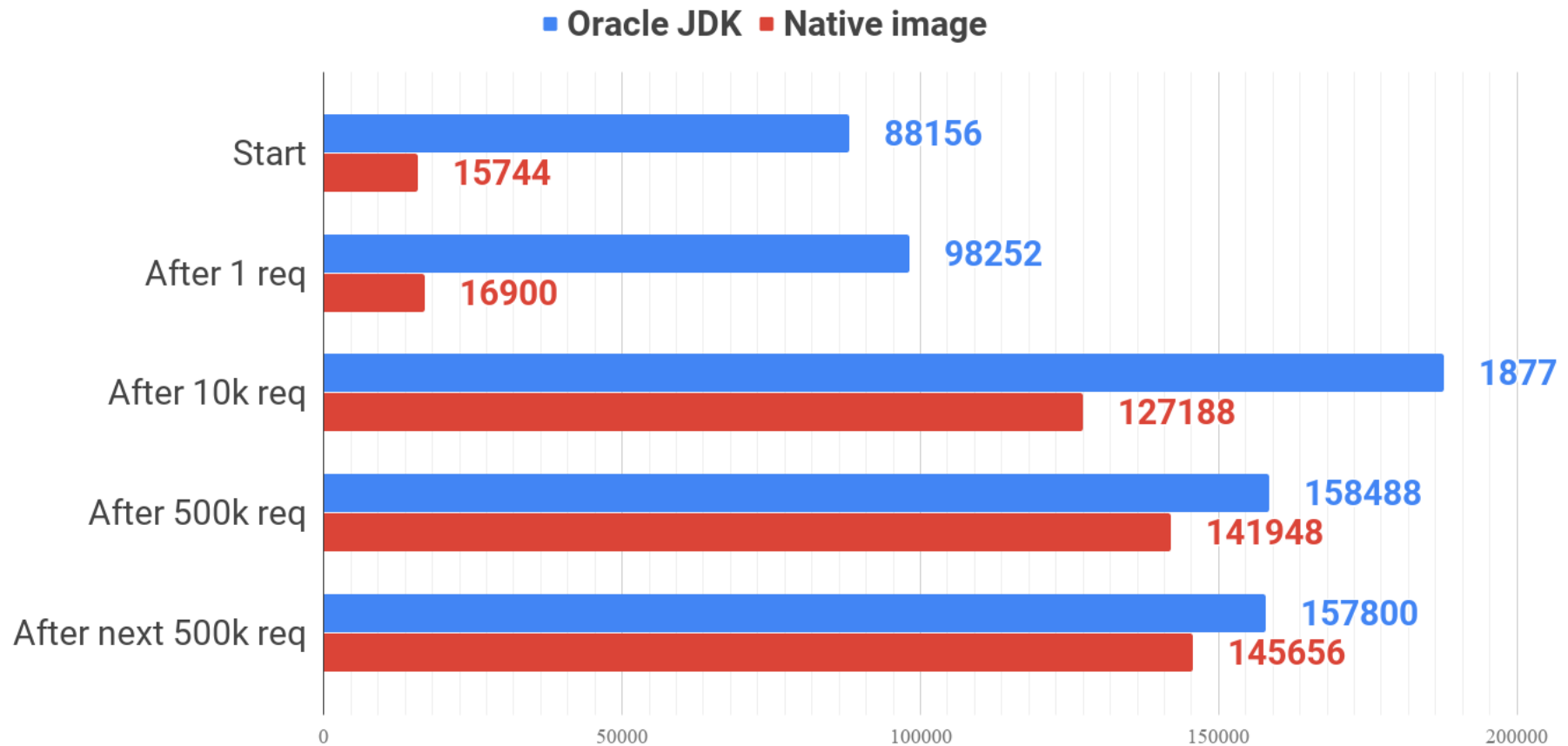
1k conc req (total: 500k)



RPS, 1k conc req (total: 500k)



Memory consumption (bytes)



Conclusions

Fast startup and low memory footprint – **confirmed.**

Fast startup and low memory footprint – **confirmed**.

JVM still does a bit better in the **long run**.

Fast startup and low memory footprint – **confirmed**.

JVM still does a bit better in the **long run**.

CLI tools, FaaS can benefit from the **native image**.

Fast startup and low memory footprint – **confirmed**.

JVM still does a bit better in the **long run**.

CLI tools, FaaS can benefit from the **native image**.

 Native image is still in **the experimental** stage! 



\$ _



```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
Time taken for tests:    0.001 seconds
Requests per second:    1375.52 [#/sec] (mean)
Time per request:       0.727 [ms] (mean)
Time per request:       0.727 [ms] (mean, across all concurrent requests)
Transfer rate:          157.16 [Kbytes/sec] received
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	1	1 0.0	1	1
Waiting:	0	0 0.0	0	0
Total:	1	1 0.0	1	1


```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
Time taken for tests:    0.001 seconds
Requests per second:    1375.52 [#/sec] (mean)
Time per request:       0.727 [ms] (mean)
Time per request:       0.727 [ms] (mean, across all concurrent requests)
Transfer rate:          157.16 [Kbytes/sec] received
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	1	1 0.0	1	1
Waiting:	0	0 0.0	0	0
Total:	1	1 0.0	1	1

```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
Time taken for tests:    0.001 seconds
Requests per second:    1375.52 [#/sec] (mean)
Time per request:       0.727 [ms] (mean)
Time per request:       0.727 [ms] (mean, across all concurrent requests)
Transfer rate:          157.16 [Kbytes/sec] received
```

Connection Times (ms)

	min	mean[+/-sd]	median	max
Connect:	0	0 0.0	0	0
Processing:	1	1 0.0	1	1
Waiting:	0	0 0.0	0	0
Total:	1	1 0.0	1	1

Your JVM after warming up with 500k requests



Thank you!

That's all, folks!

Do you have any **questions**?

Handout, slides, and all materials are available:

<https://github.com/wololock/native-java-with-graalvm>