Native Java with GraalVM™

A gentle introduction to the native image generation

You will learn today...

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what is the difference between Graal and GraalVM™

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what is the difference between Graal and GraalVM™

how to use `native-image` command line tool

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what is the difference between Graal and GraalVM™

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™

@wololock

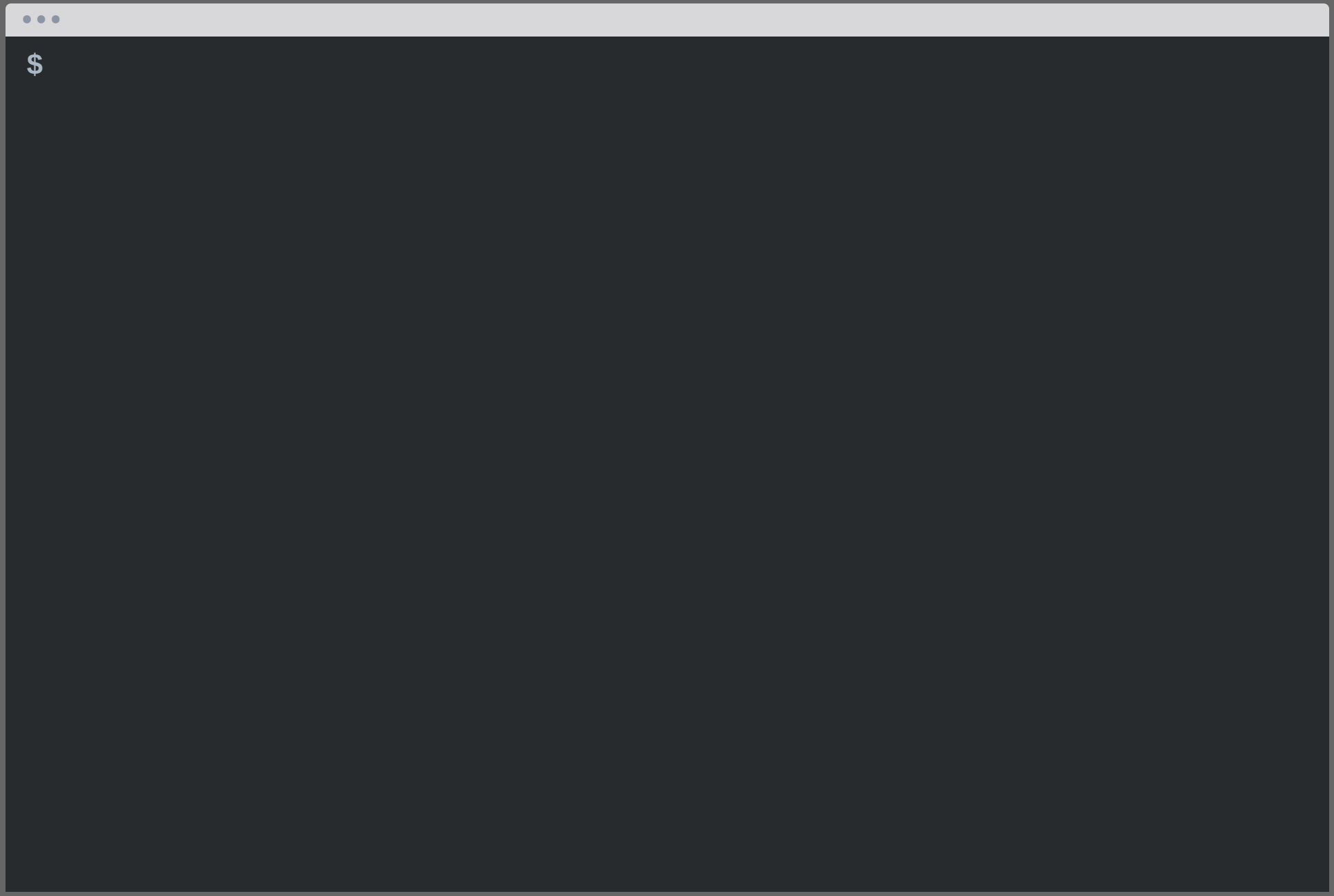
Part 1: Graal vs GraalVM™

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
```

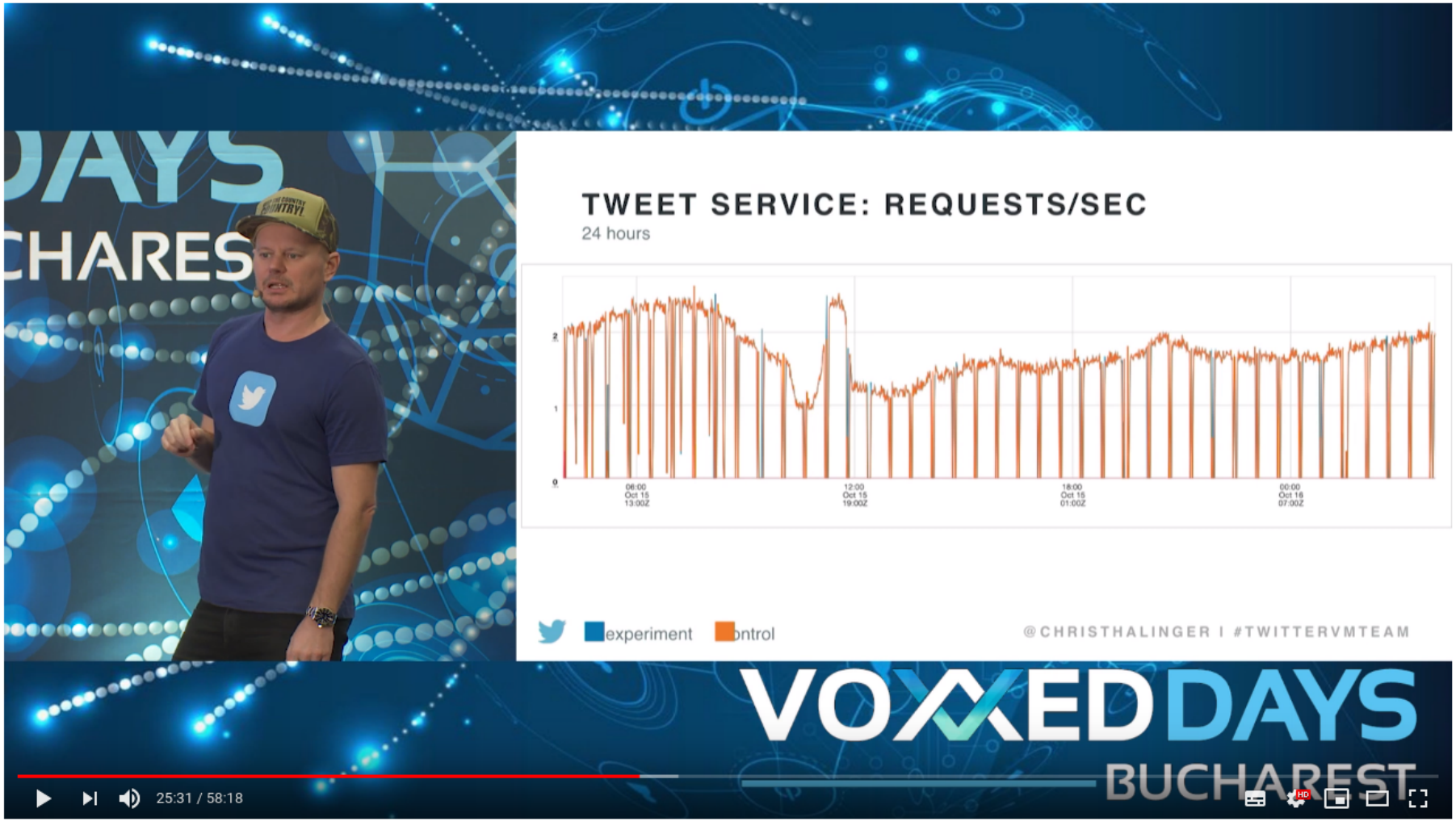
```
$ java -XX:+PrintFlagsFinal -XX:+UnlockExperimentalVMOptions \
    -XX:+EnableJVMCI
```

```
$ 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} {defaul
  bool EnableJVMCI                   = true     {JVMCI experimental} {comman
  intx JVMCICounterSize              = 0        {JVMCI experimental} {defaul
  bool JVMCICountersExcludeCompiler  = true     {JVMCI experimental} {defaul
  intx JVMCIHostThreads              = 1        {JVMCI experimental} {defaul
  intx JVMCINMethodSizeLimit         = 655360   {JVMCI experimental} {defaul
  bool JVMCIPrintProperties          = false    {JVMCI experimental} {defaul
  intx JVMCIThreads                  = 1        {JVMCI experimental} {defaul
  intx JVMCITraceLevel               = 0        {JVMCI experimental} {defaul
  intx MethodProfileWidth            = 0        {JVMCI experimental} {defaul
  bool PrintBootstrap                = true     {JVMCI experimental} {defaul
  bool UseJVMCICompiler              = true     {JVMCI experimental} {comman
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)
```



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

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

GraalVM™

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.

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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...

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Dynamic Class Loading / Unloading

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InvokeDynamic Bytecode and Method Handles

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Finalizers

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~~Finalizers~~

Security Manager `java.lang.SecurityManager`

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

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~~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

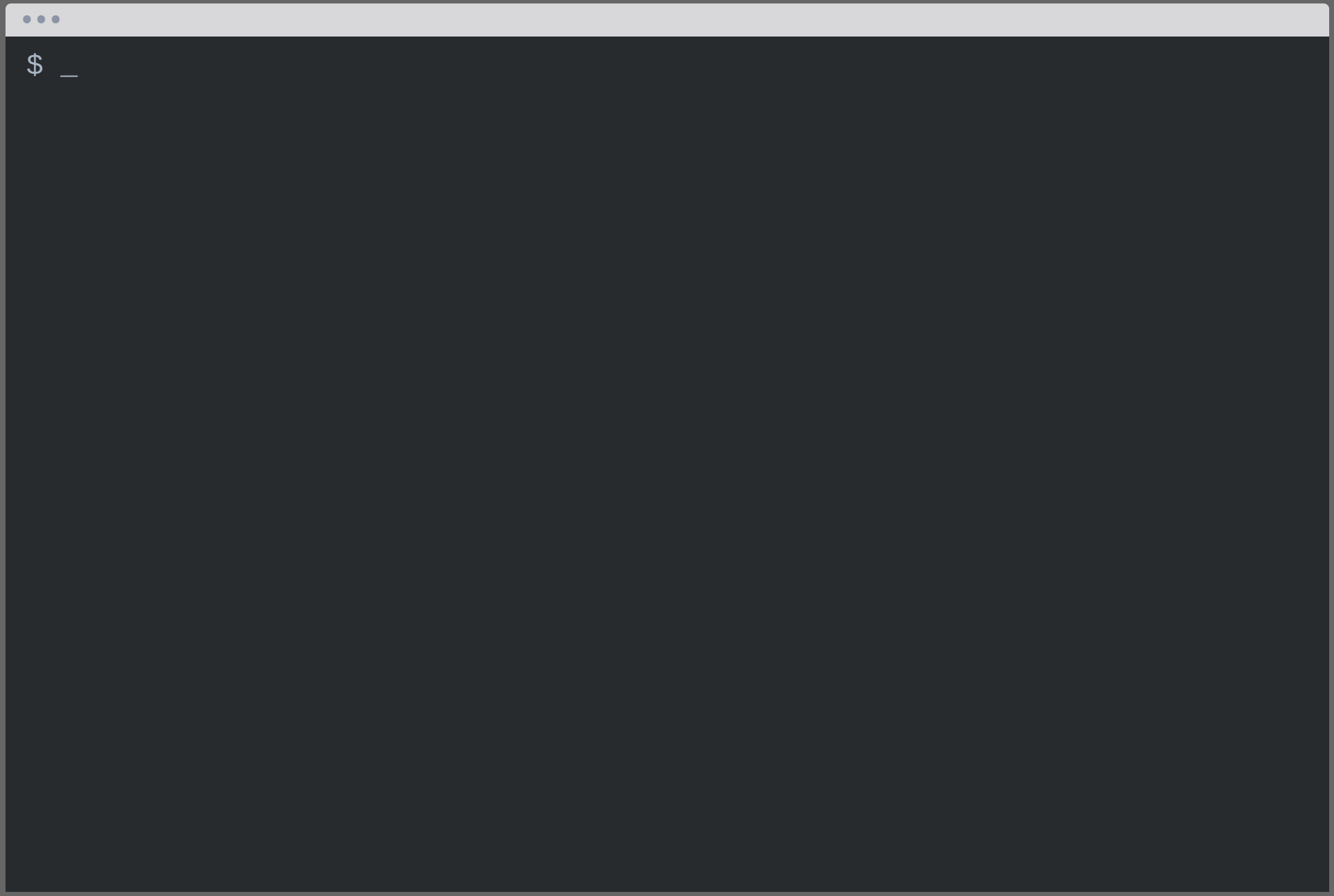
Native Image does not support all features of Java to keep the implementation small and concise, and also to allow aggressive ahead-of-time optimizations. This page documents the limitations.

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

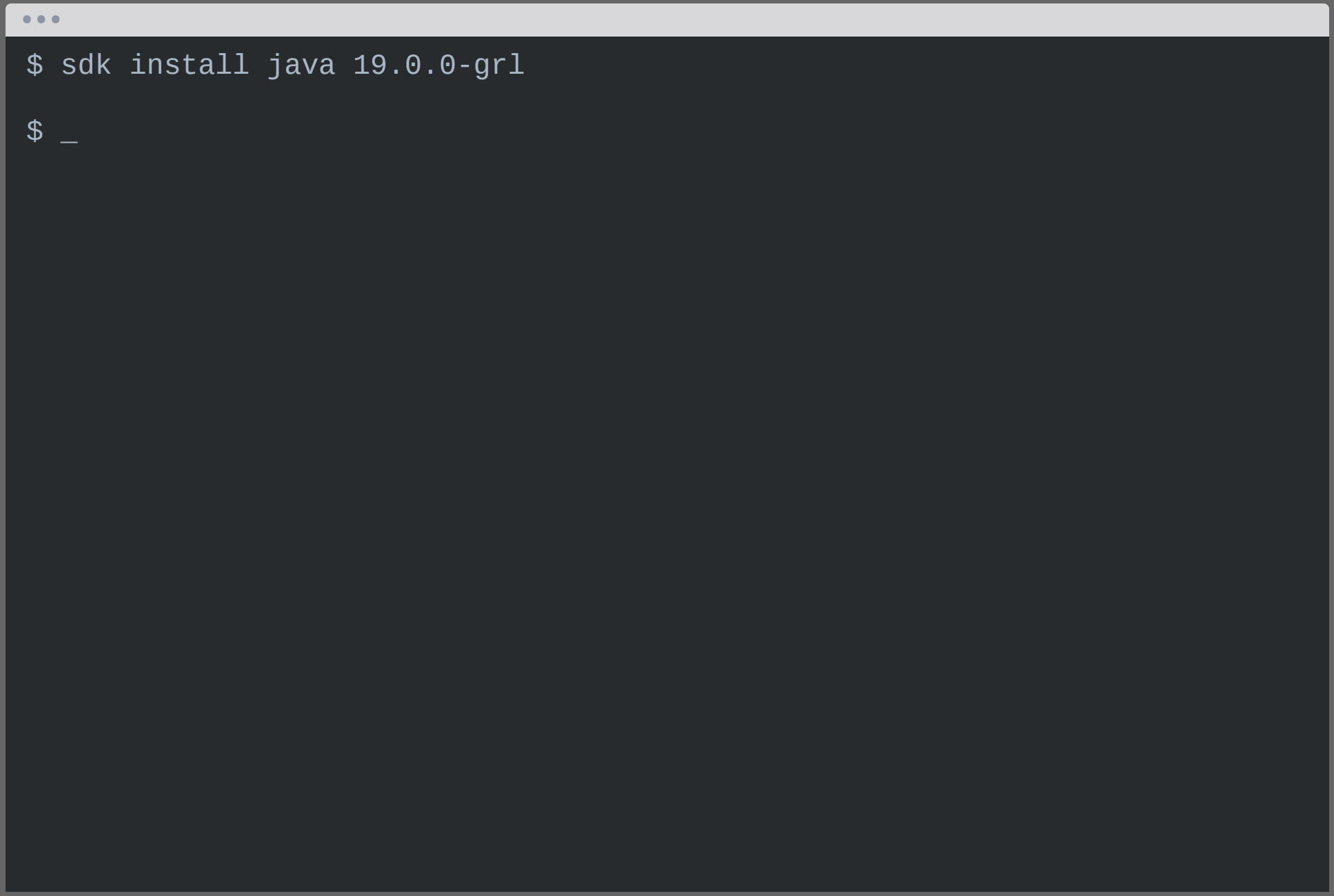
Dynamic Class Loading / Unloading

Support Status: Not Supported

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



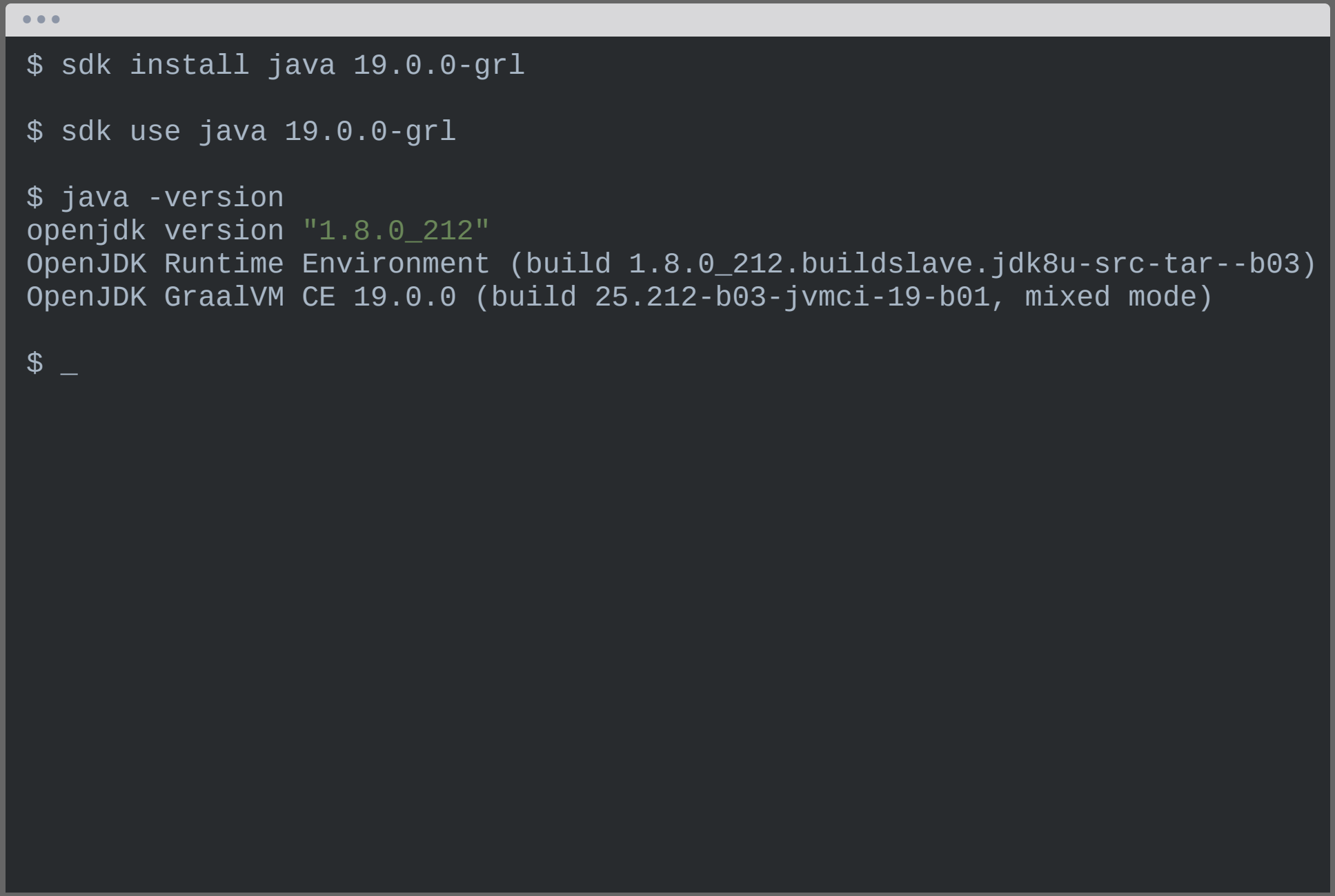
```
$ sdk install java 19.0.0-grl
```


$ sdk install java 19.0.0-grl
$ _

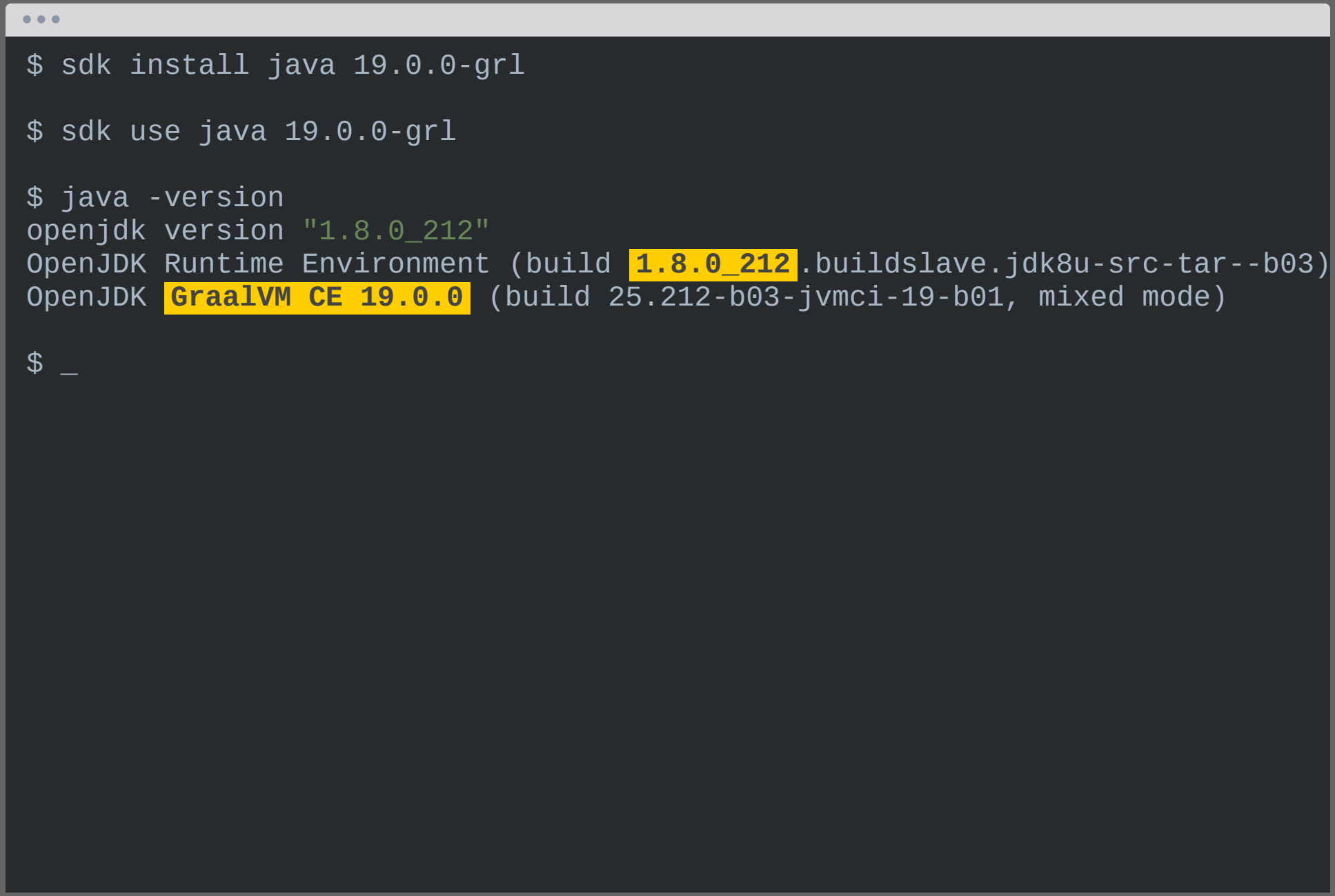
```
$ sdk install java 19.0.0-grl

$ sdk use java 19.0.0-grl
```

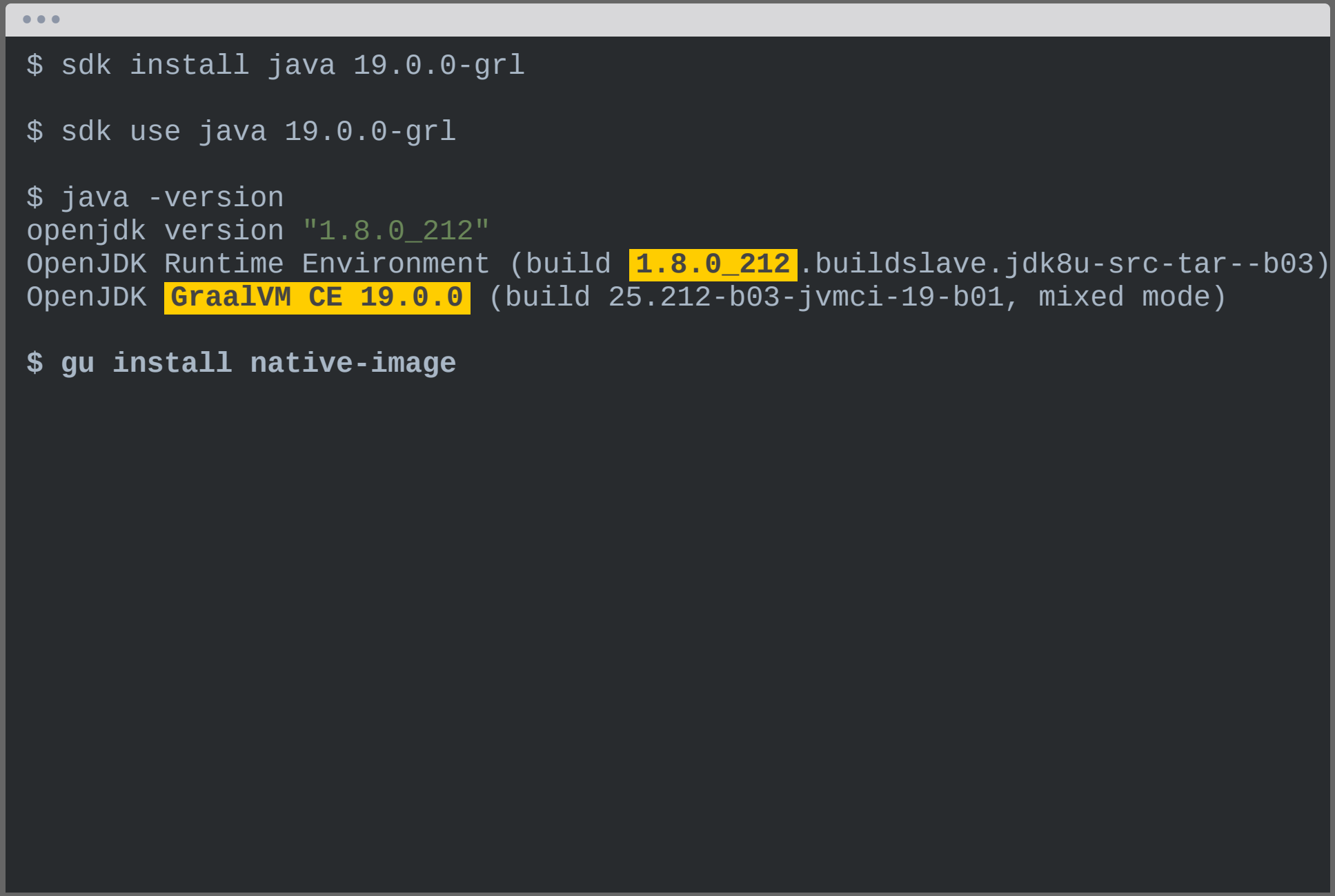
```
$ sdk install java 19.0.0-grl

$ sdk use java 19.0.0-grl

$ _
```

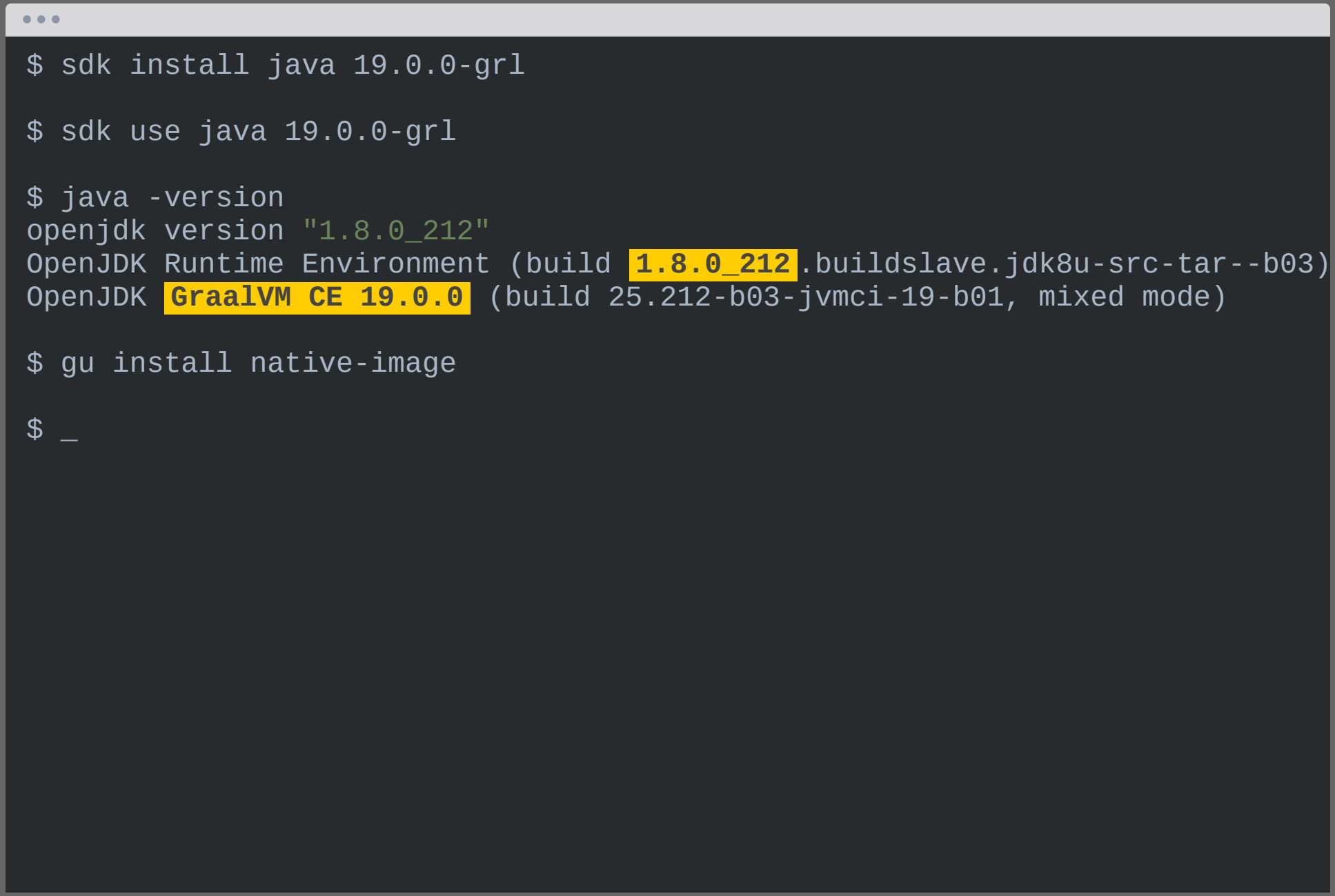
```
$ sdk install java 19.0.0-grl

$ 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)
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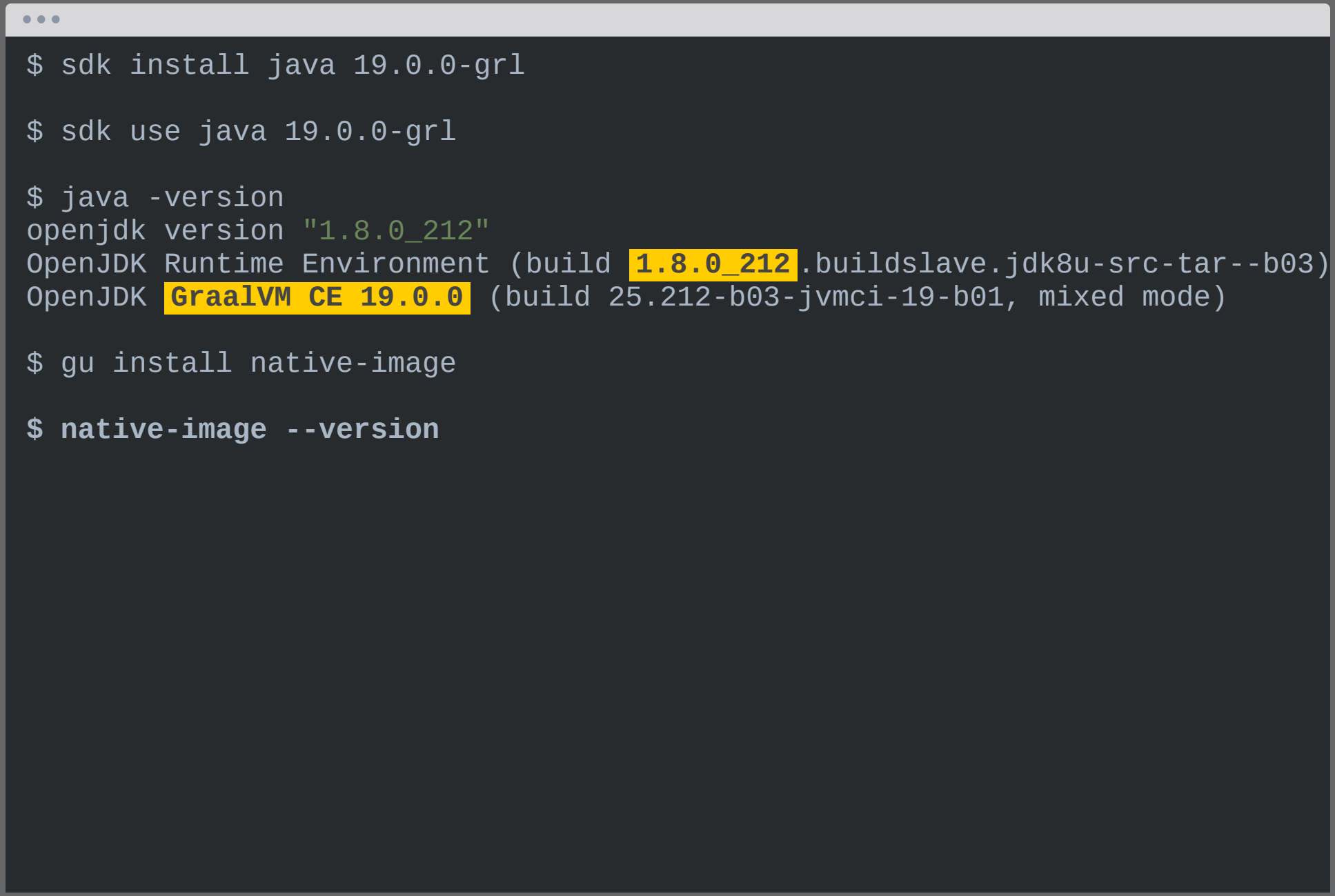
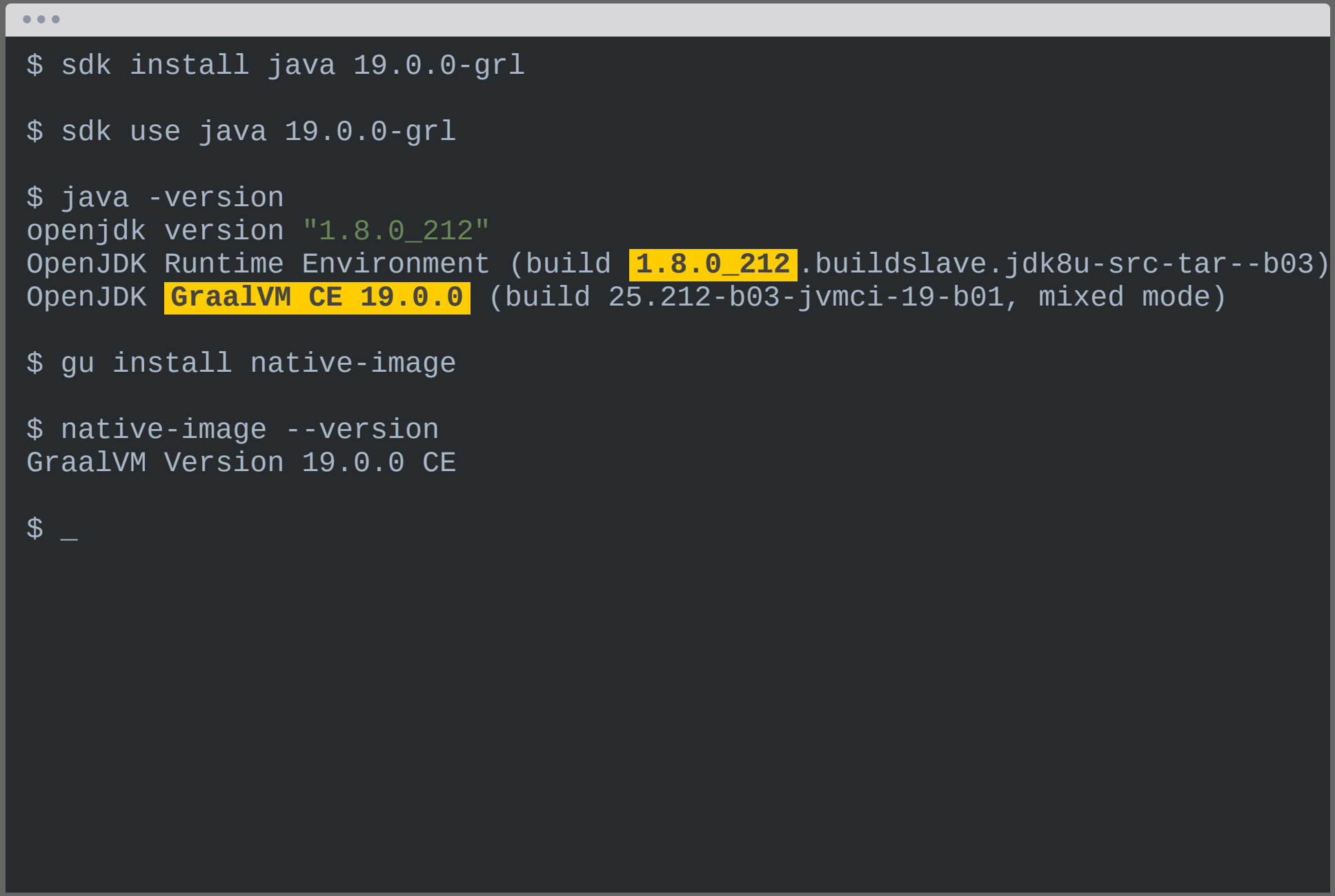
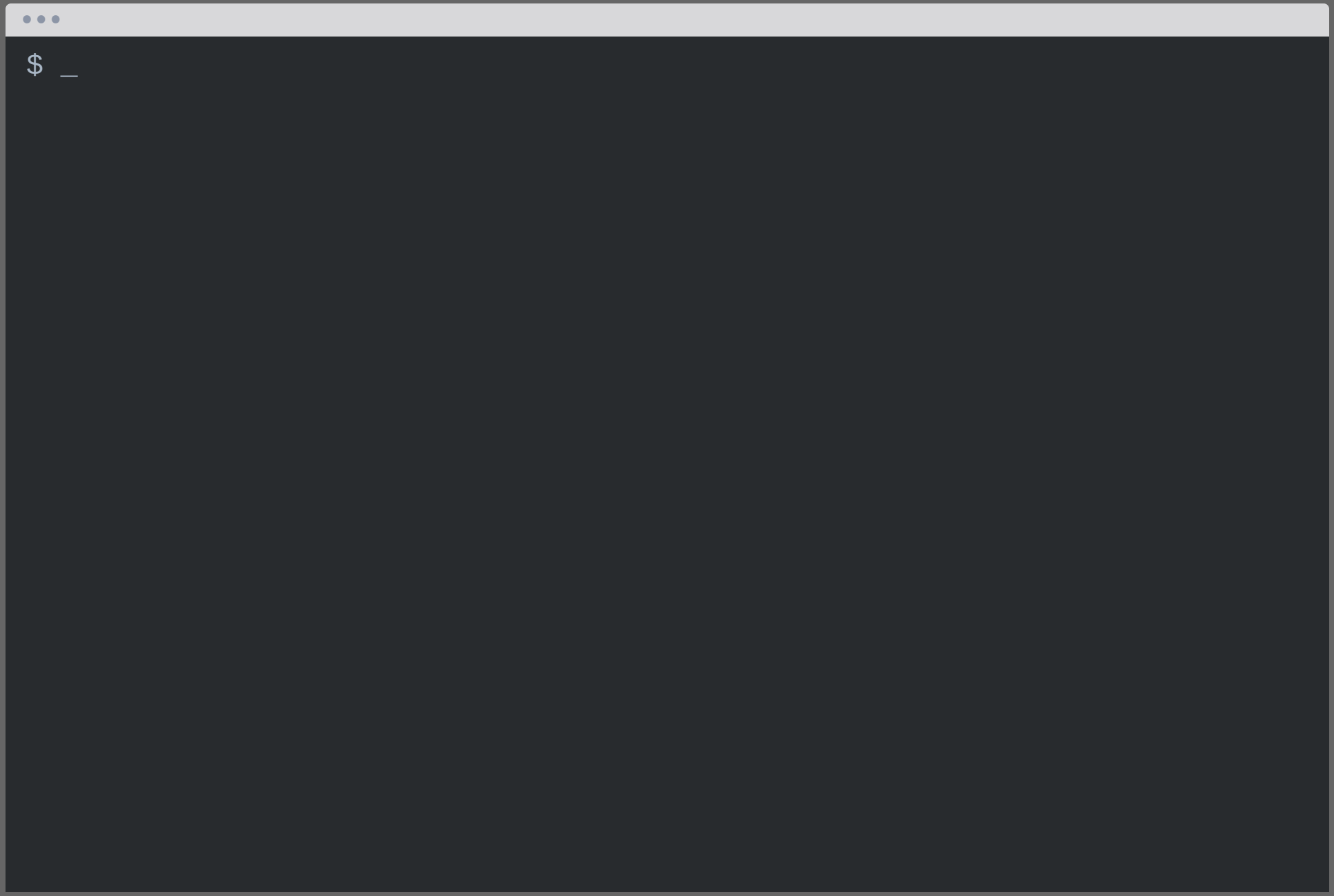
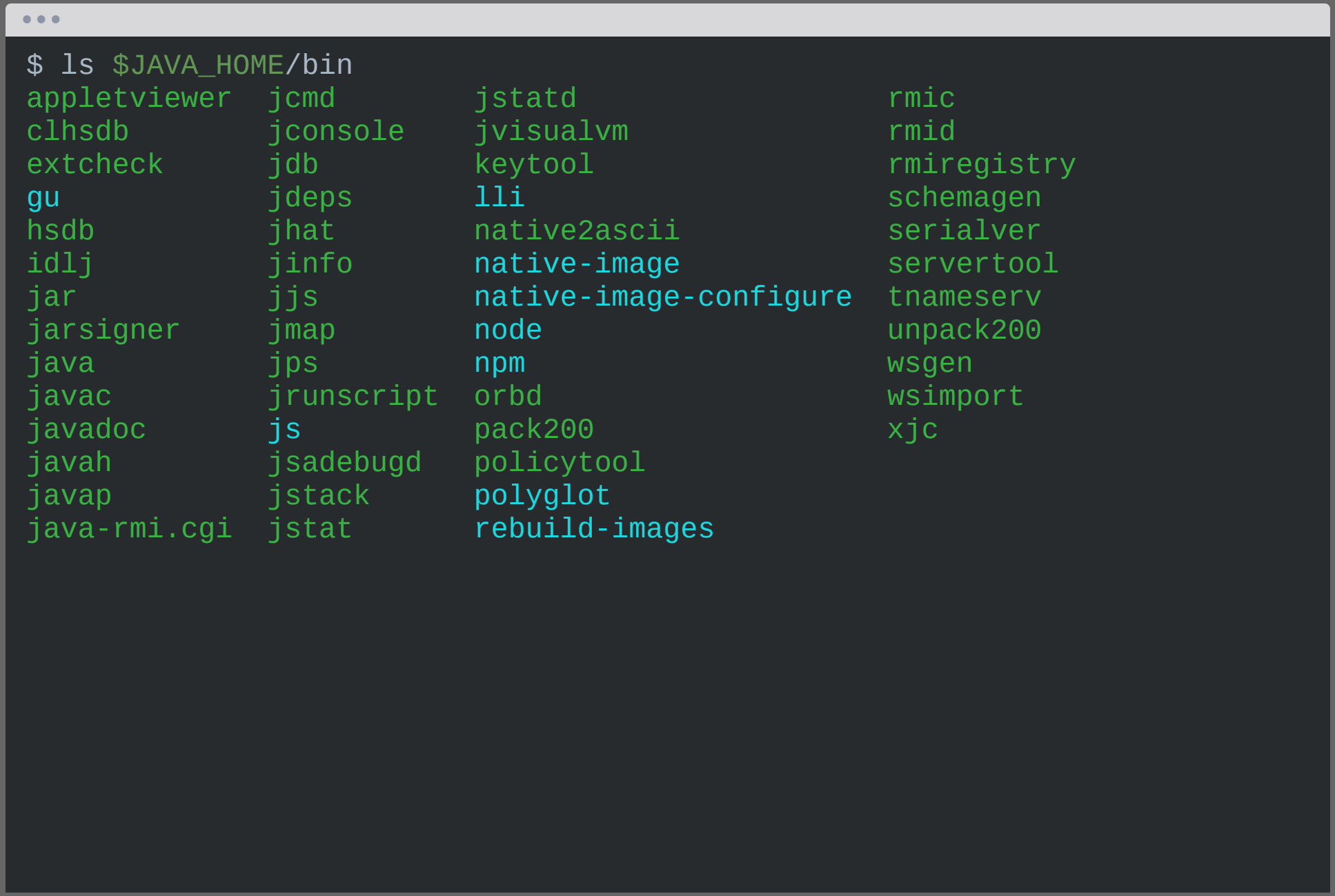
$ _


$ 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
$ _



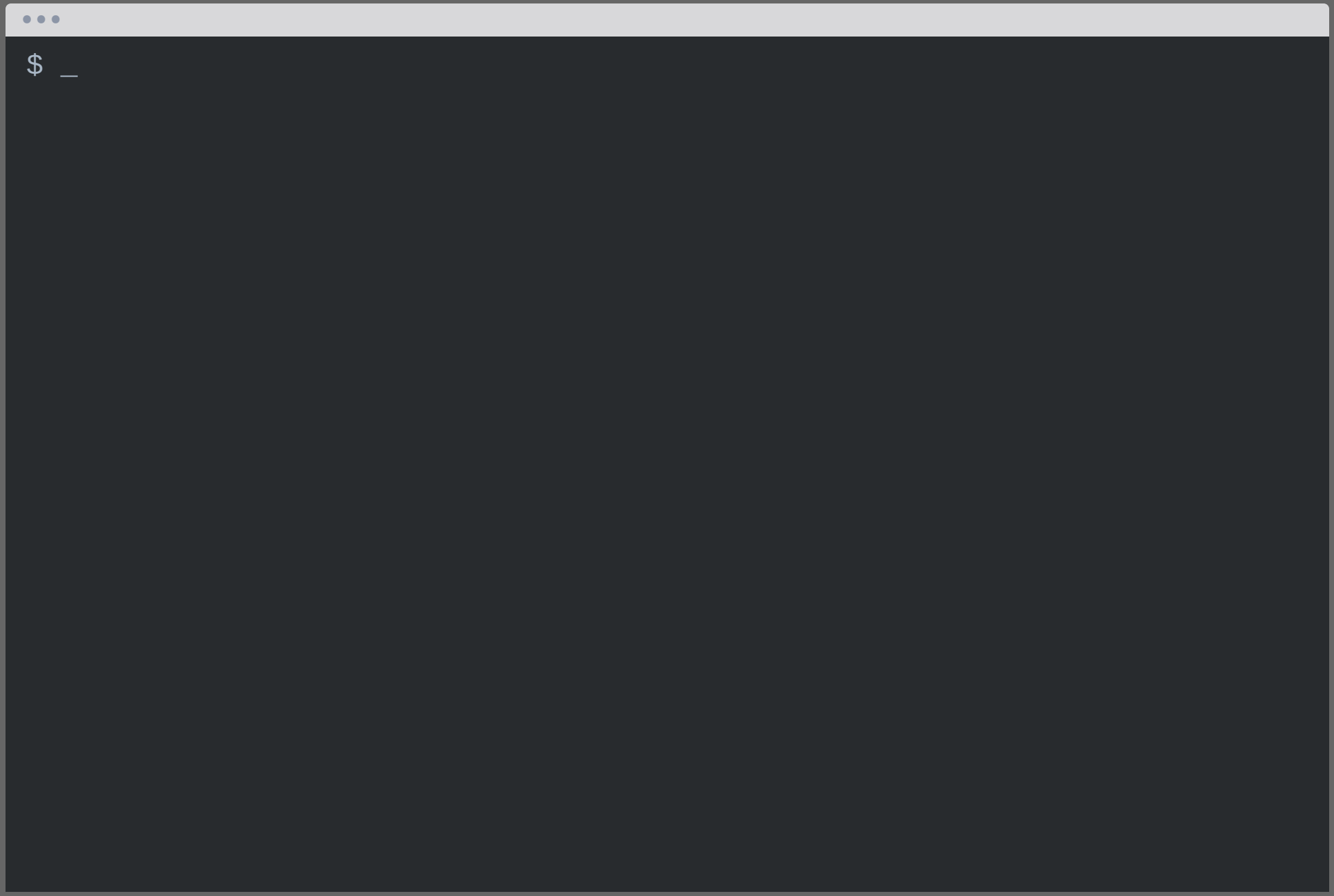
```
$ ls $JAVA_HOME/bin
```


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

Part 2: `native-image`

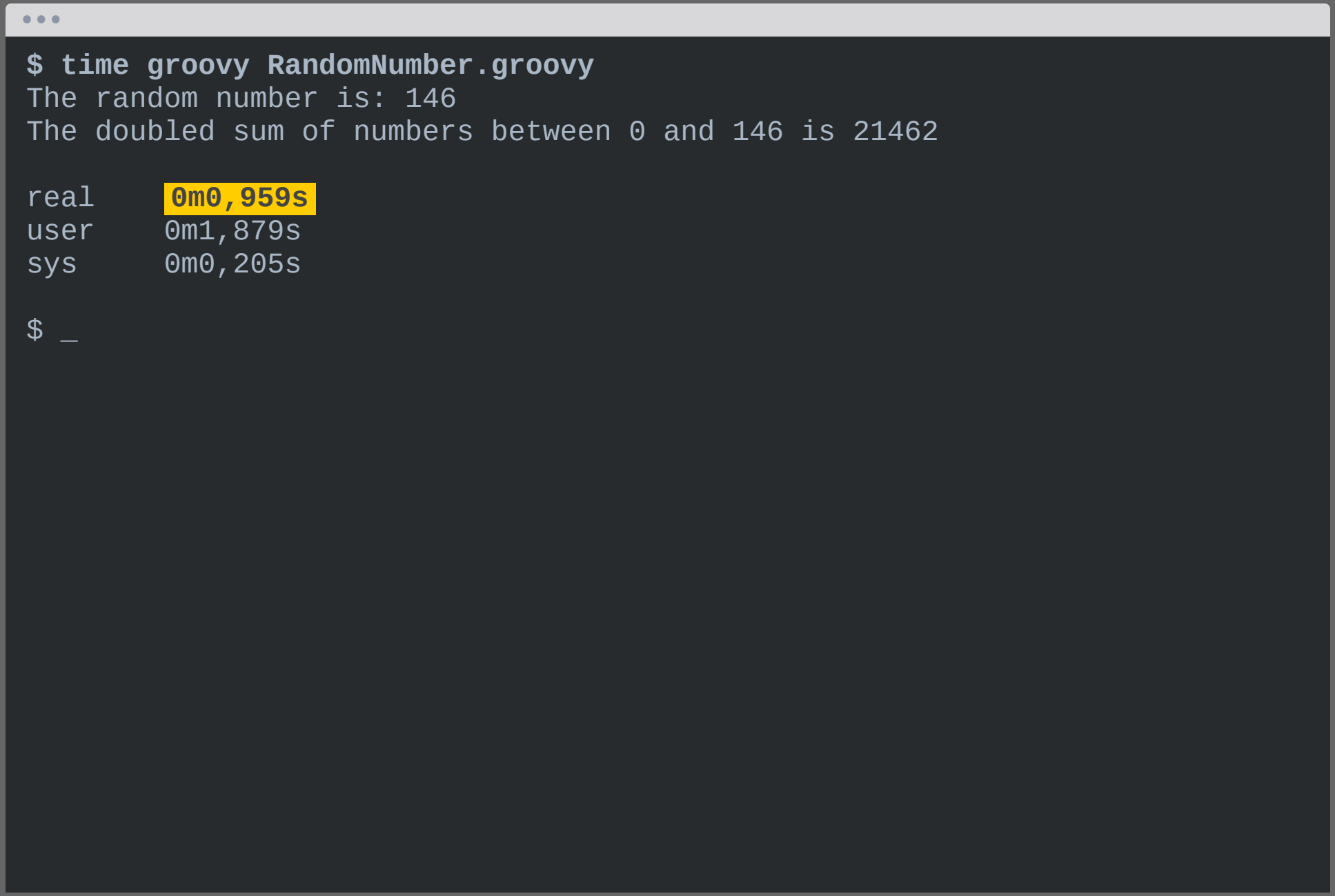
Compiling Groovy program to a native image

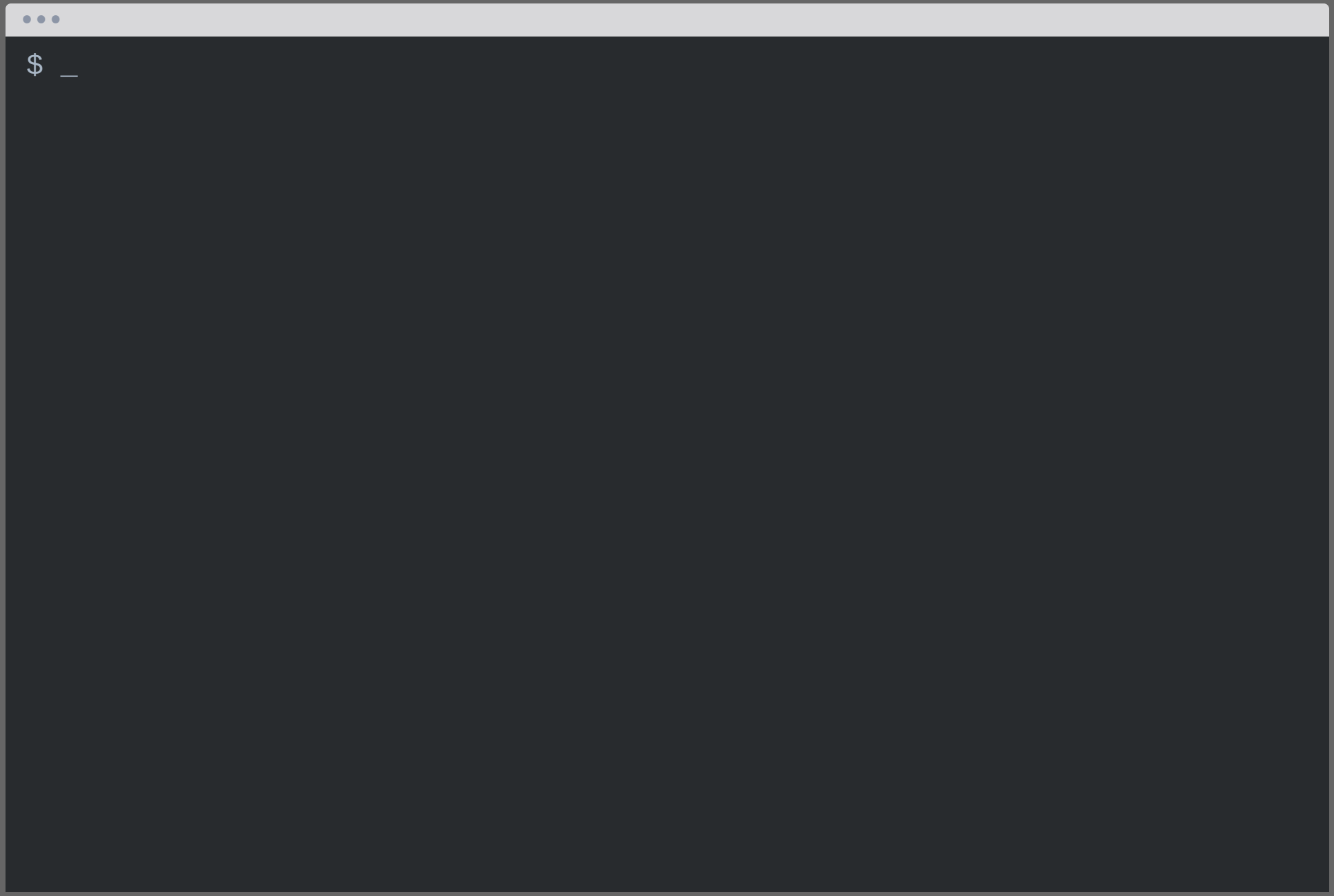
```groovy
// RandomNumber.groovy
import groovy.transform.CompileStatic

@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"
    }
}
```



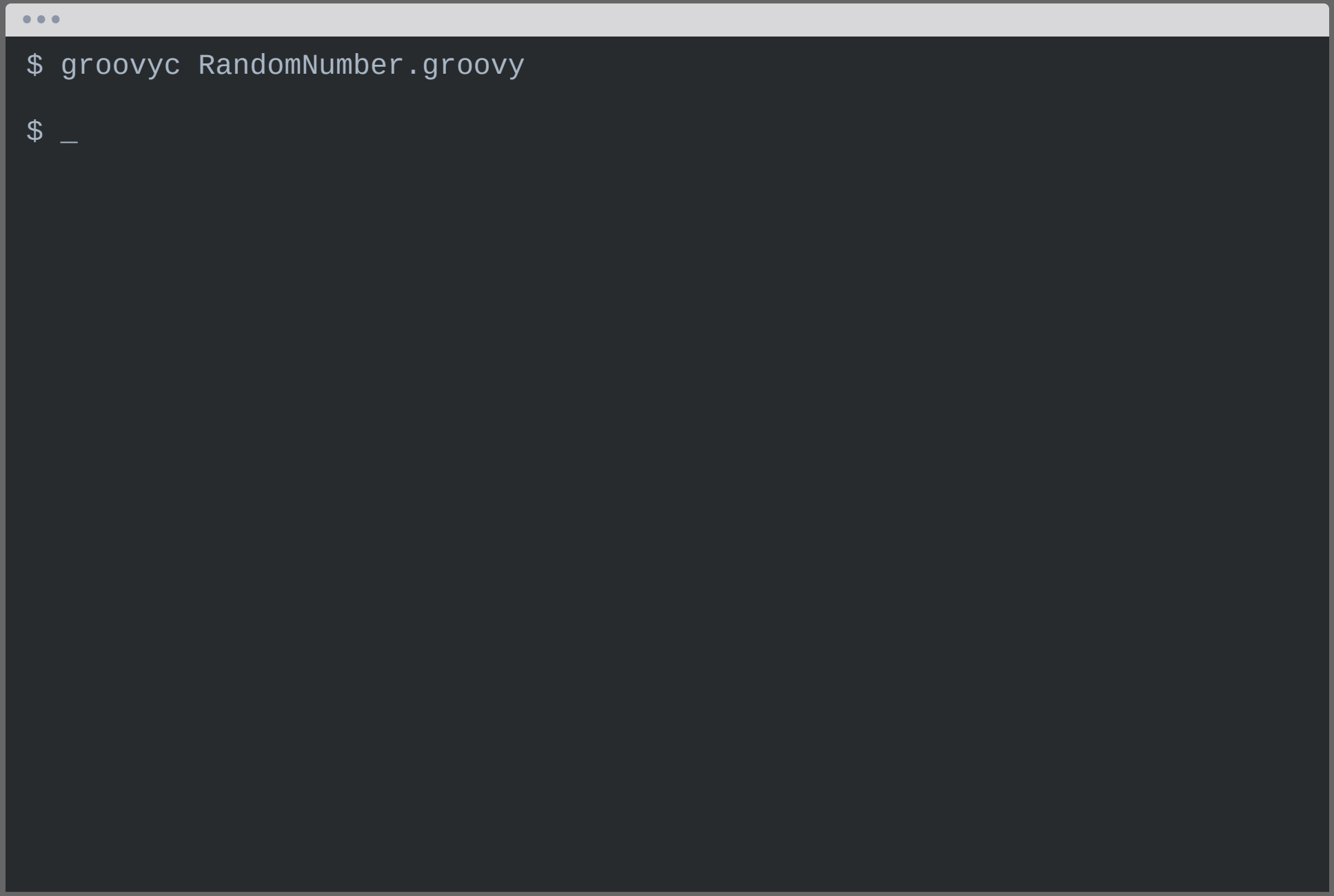
```
$ time groovy RandomNumber.groovy
```

```
$ 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
```

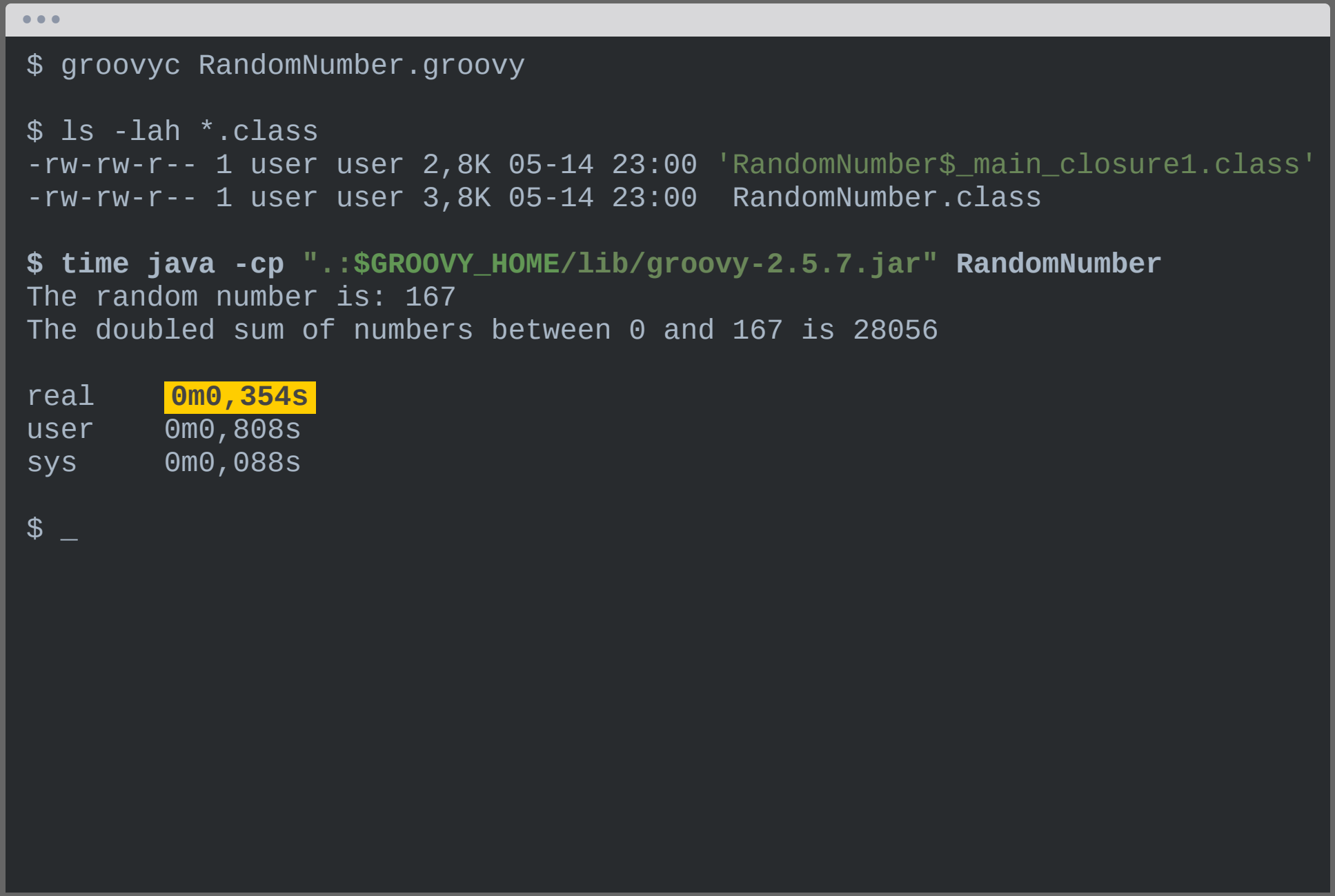

$ groovyc RandomNumber.groovy
$ _

```
$ 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

$ _
```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user 0m0,808s
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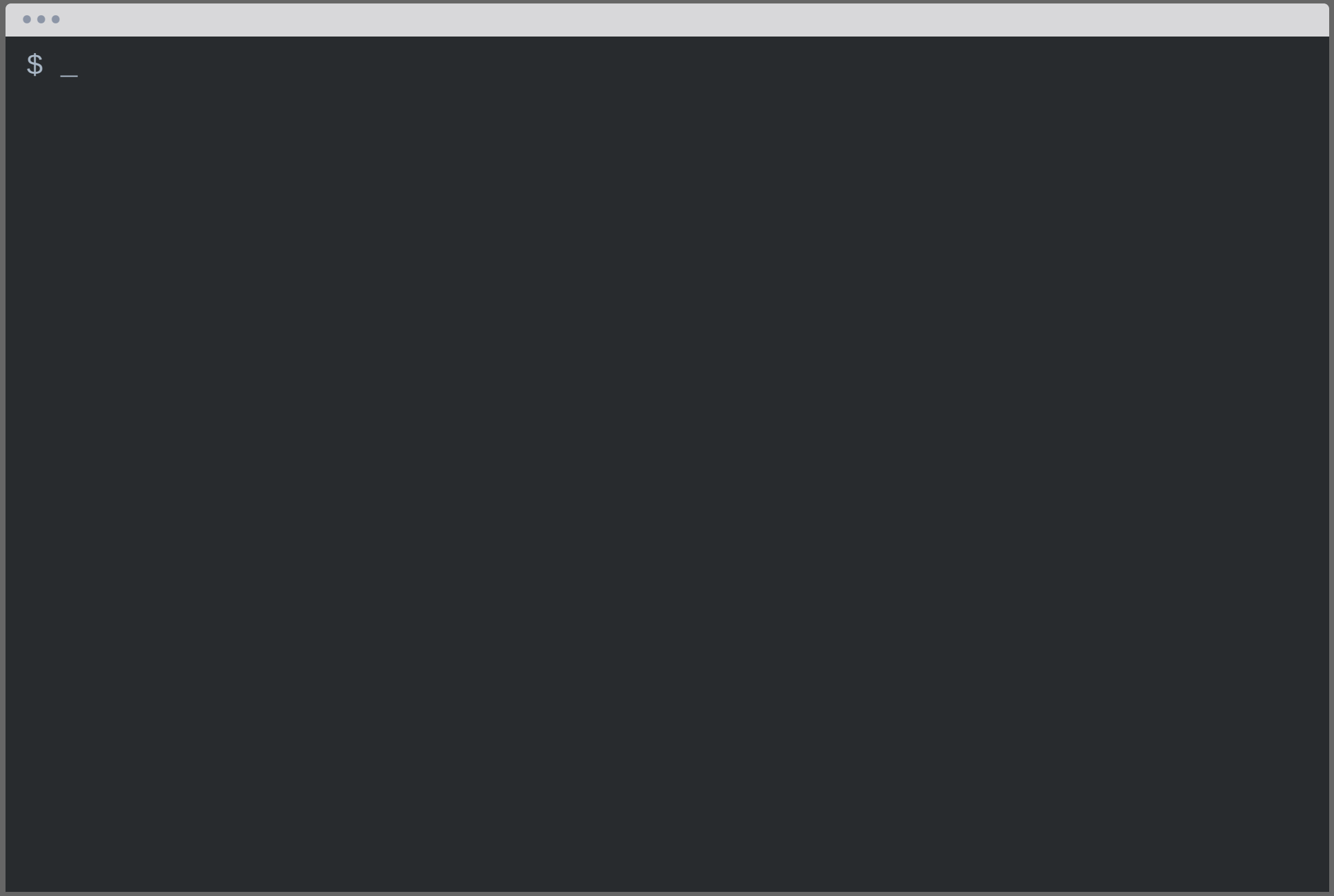
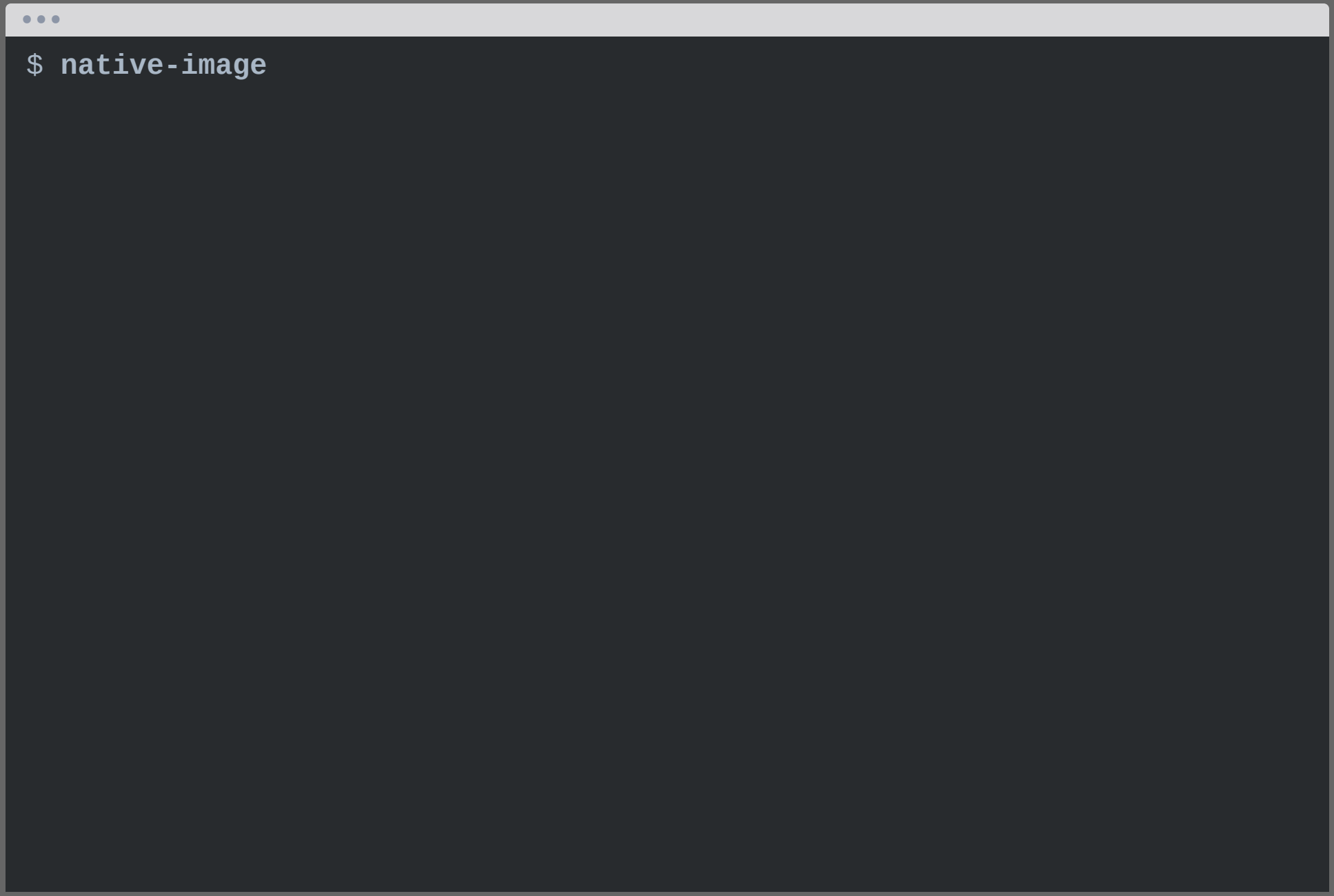
$ _

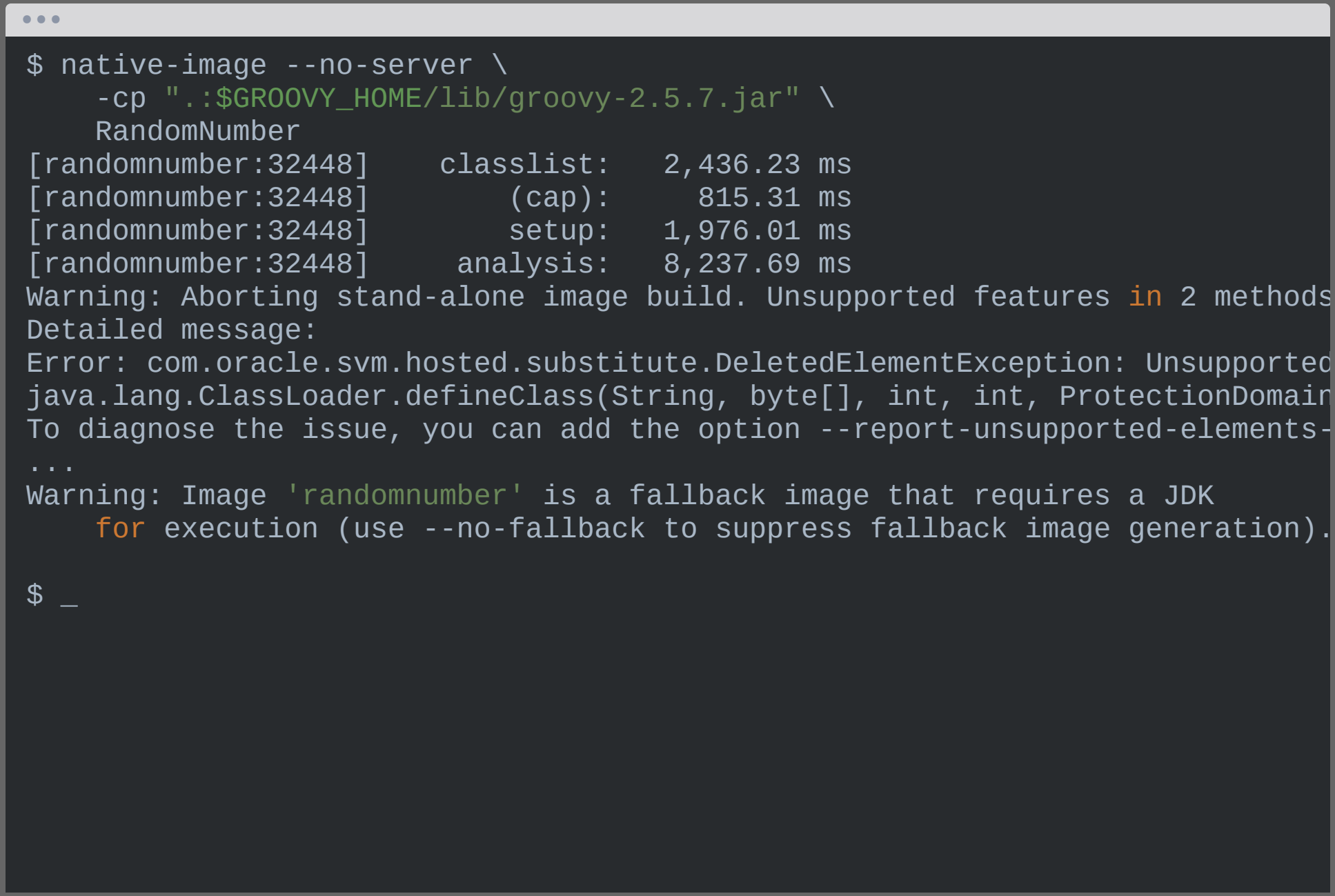


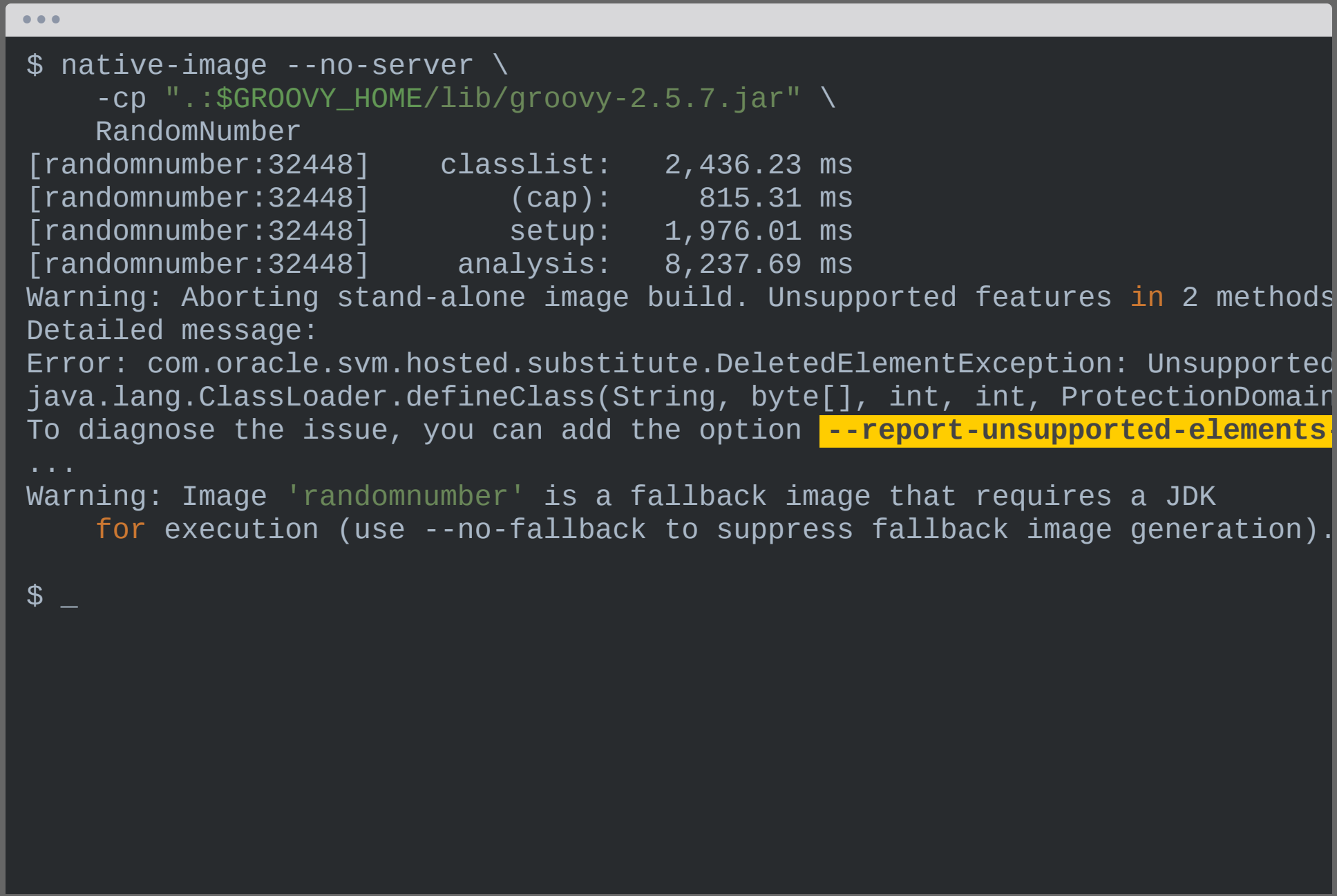

$ native-image

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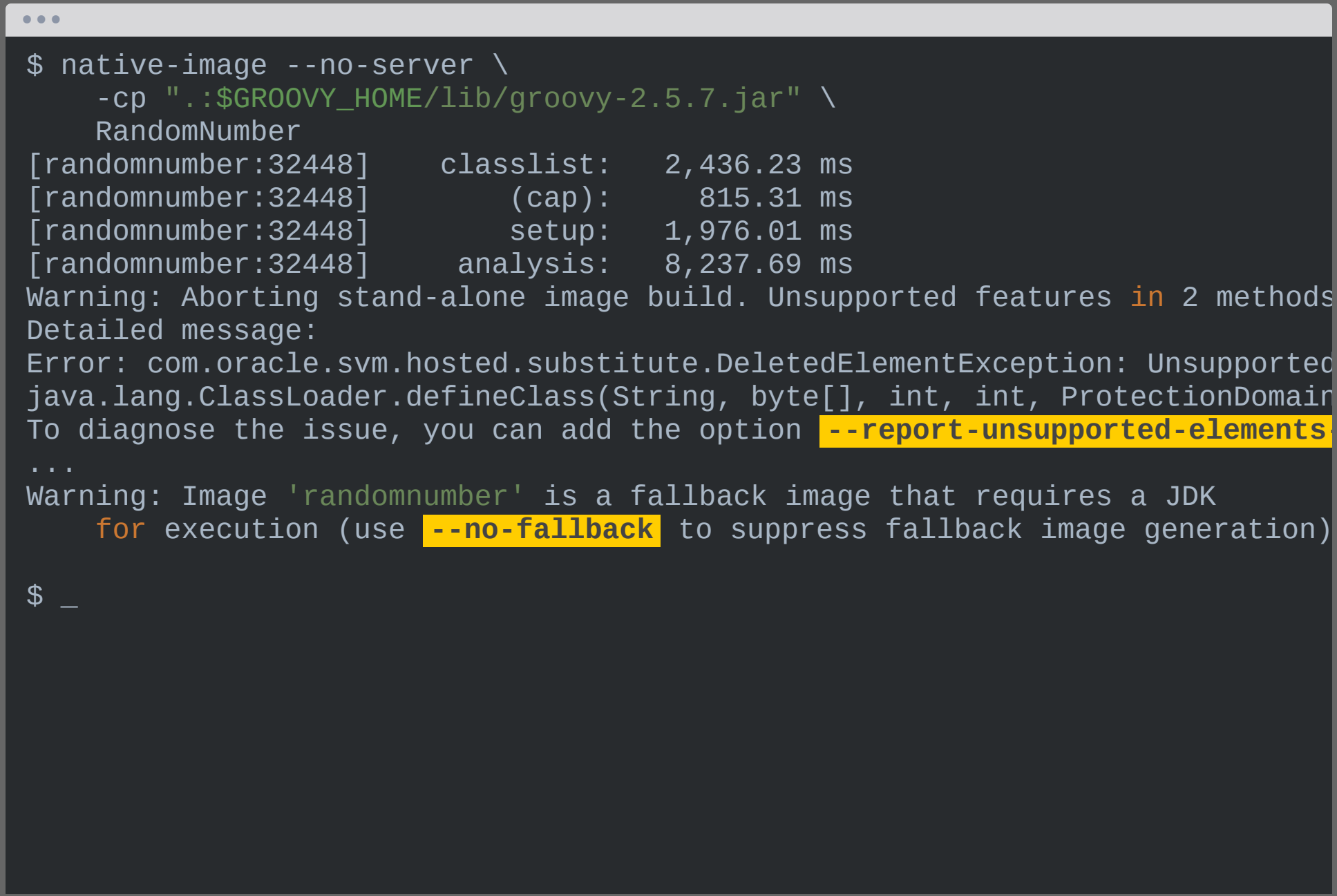
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RandomNumber
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```
$ native-image --no-server \
    -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
    RandomNumber
```

```
$ 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 ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
    RandomNumber
[randomnumber:25925]    classlist:   2,415.95 ms
[randomnumber:25925]     analysis:  33,234.24 ms
Error: Unsupported features in 6 methods
Detailed message:
Error: com.oracle.graal.pointsto.constraints.UnsupportedFeatureException:
Invoke with MethodHandle argument could not be reduced to at most
a single call: java.lang.invoke.MethodHandle.bindTo(Object)
...
Error: type is not available in this platform: org.graalvm.nativeimage.hoste
Trace:  object java.lang.Class[]
        object java.lang.invoke.MethodType
        object java.lang.invoke.MethodType$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" \
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[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
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[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
```

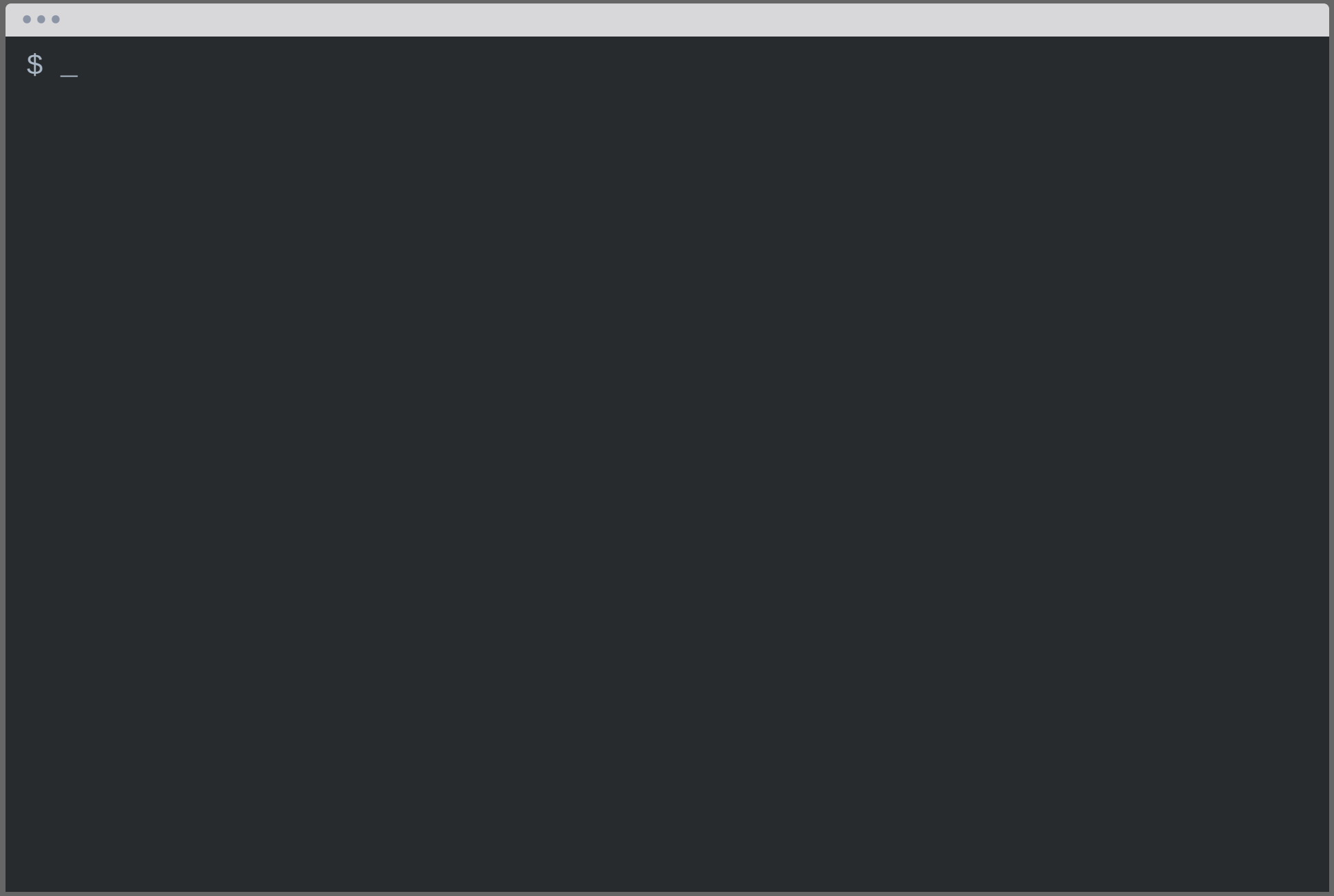
```
$ native-image --no-server \
    --no-fallback \
    --report-unsupported-elements-at-runtime \
    --allow-incomplete-classpath \
    --initialize-at-build-time \
    --initialize-at-run-time=org.codehaus.groovy.control.XStreamUtils,groovy
    -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
    RandomNumber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

```
$ 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

$ _
```

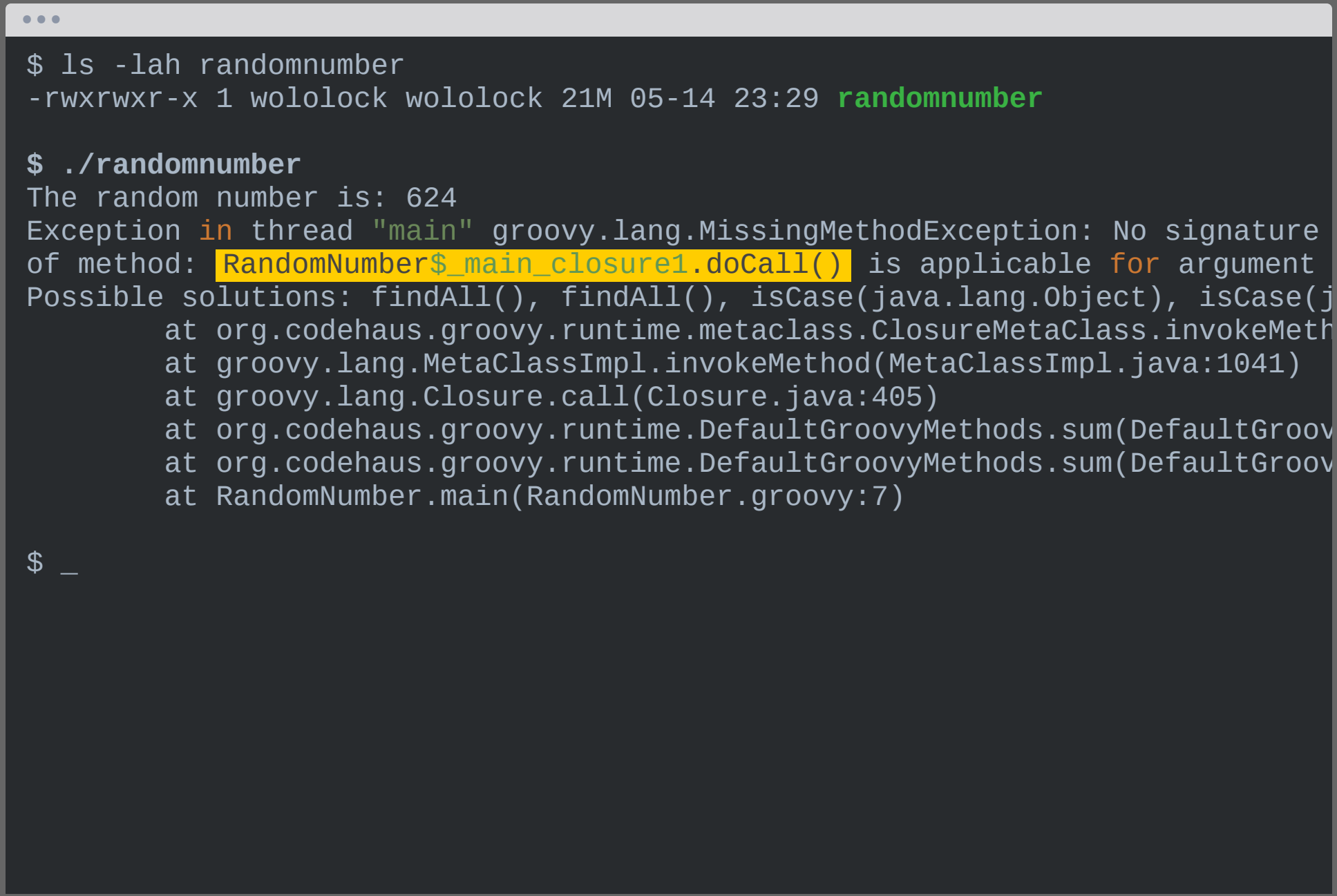
```
$ ls -lah randomnumber
-rwxrwxr-x 1 wololock wololock 21M 05-14 23:29 randomnumber

$ ./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.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)
$ _

```groovy
// 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"
    }
}
```

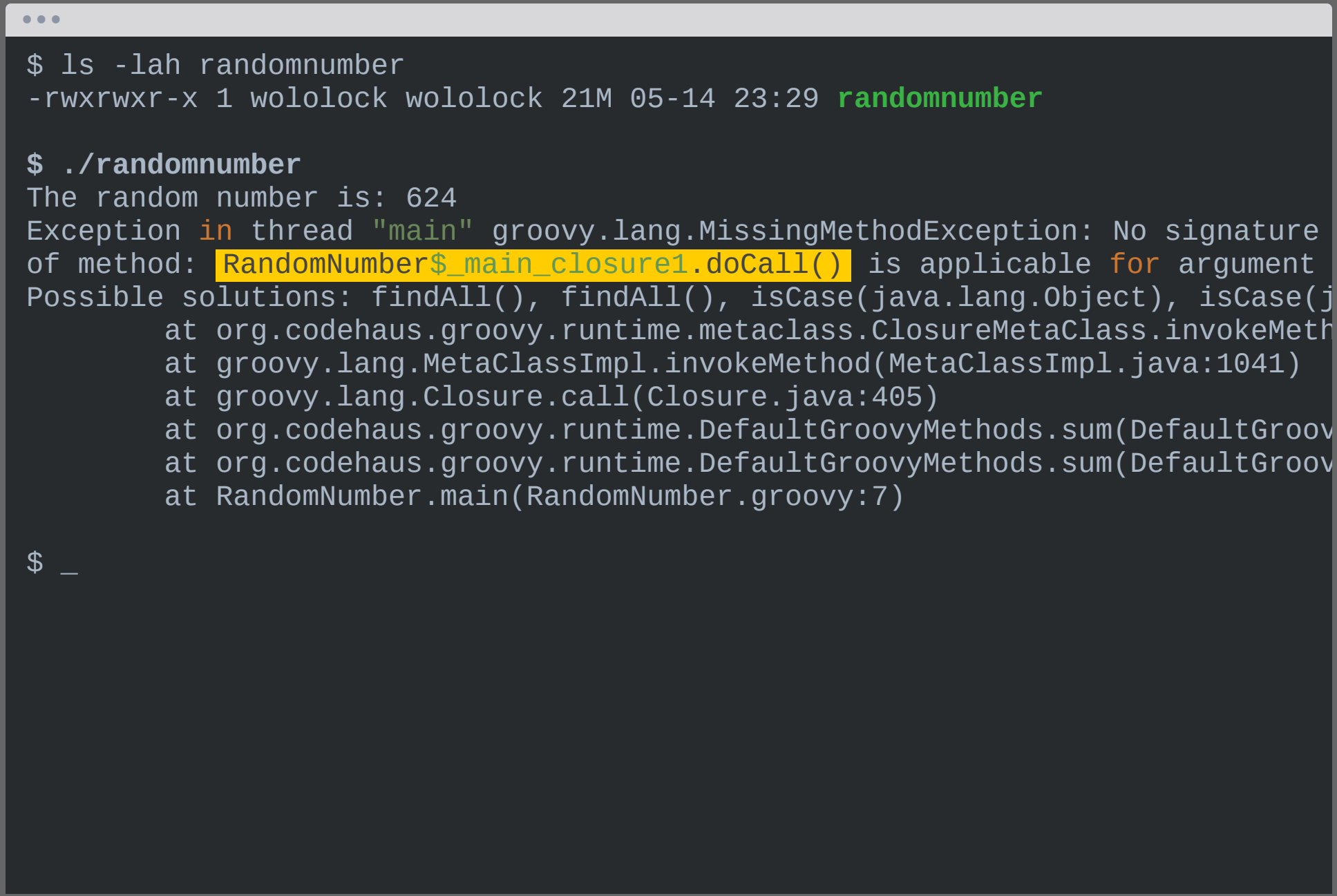
```groovy
// RandomNumber.groovy
import groovy.transform.CompileStatic

@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)
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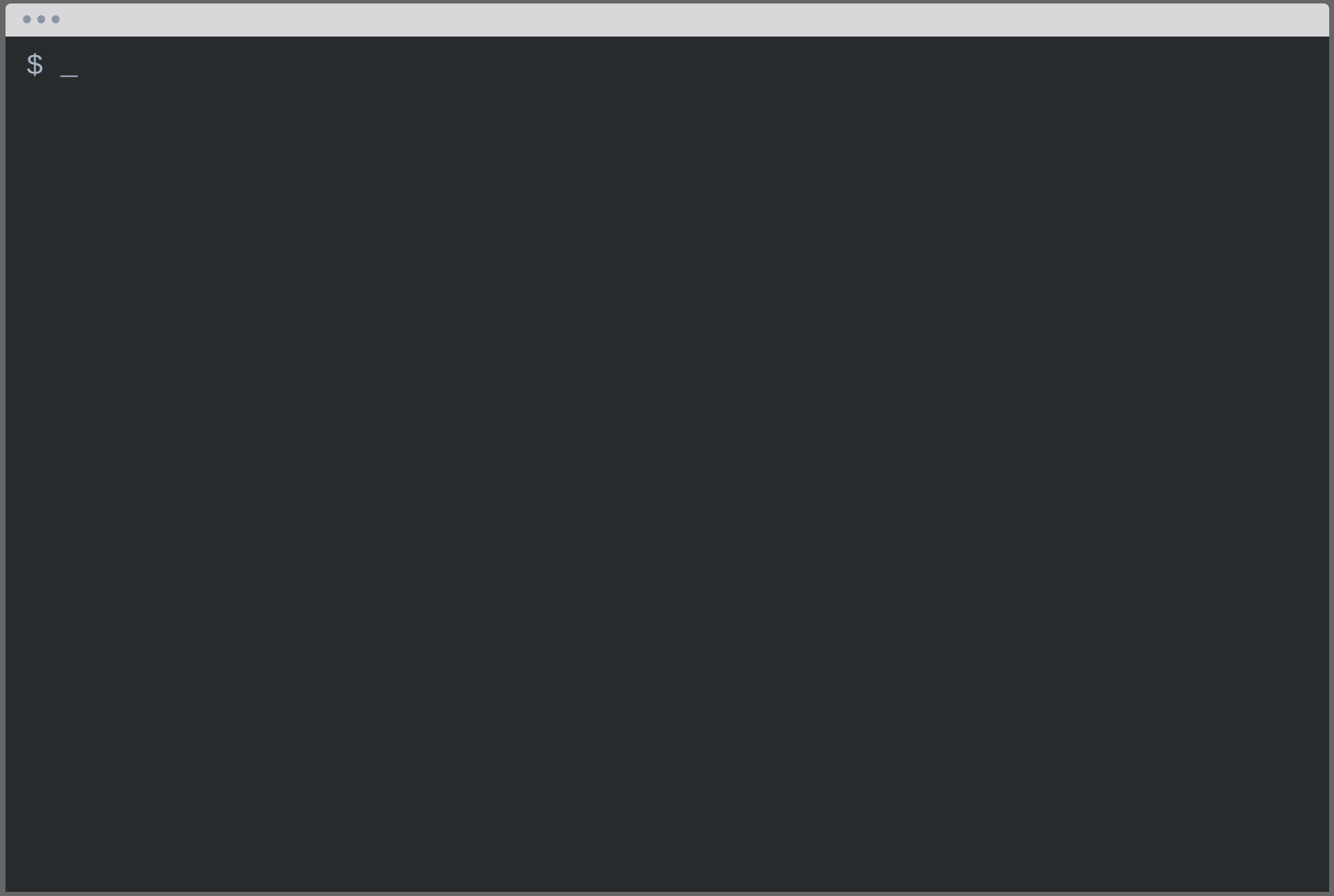
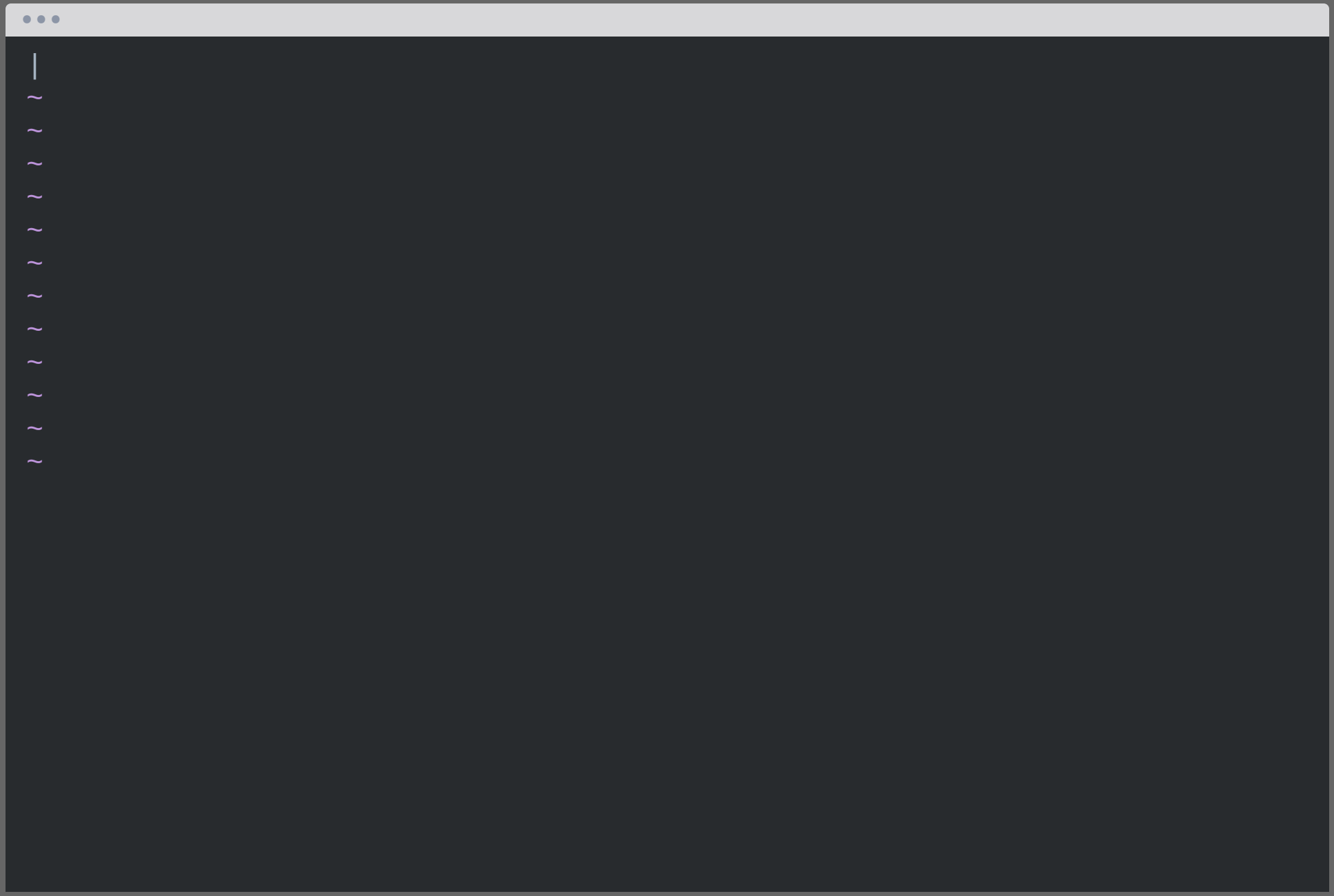
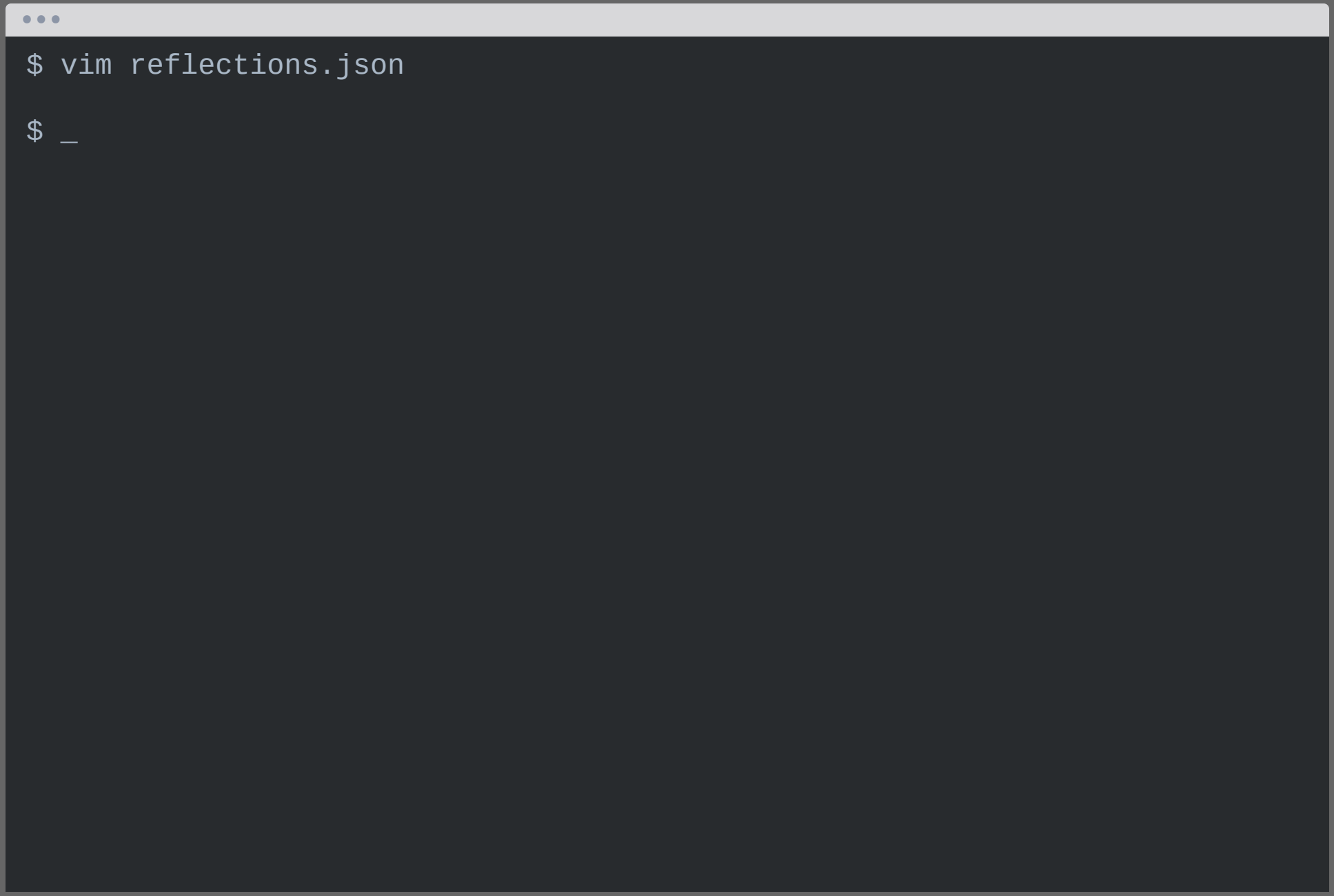
at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroov
at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroov
at RandomNumber.main(RandomNumber.groovy:7)
$ _



```
$ vim reflections.json
```



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

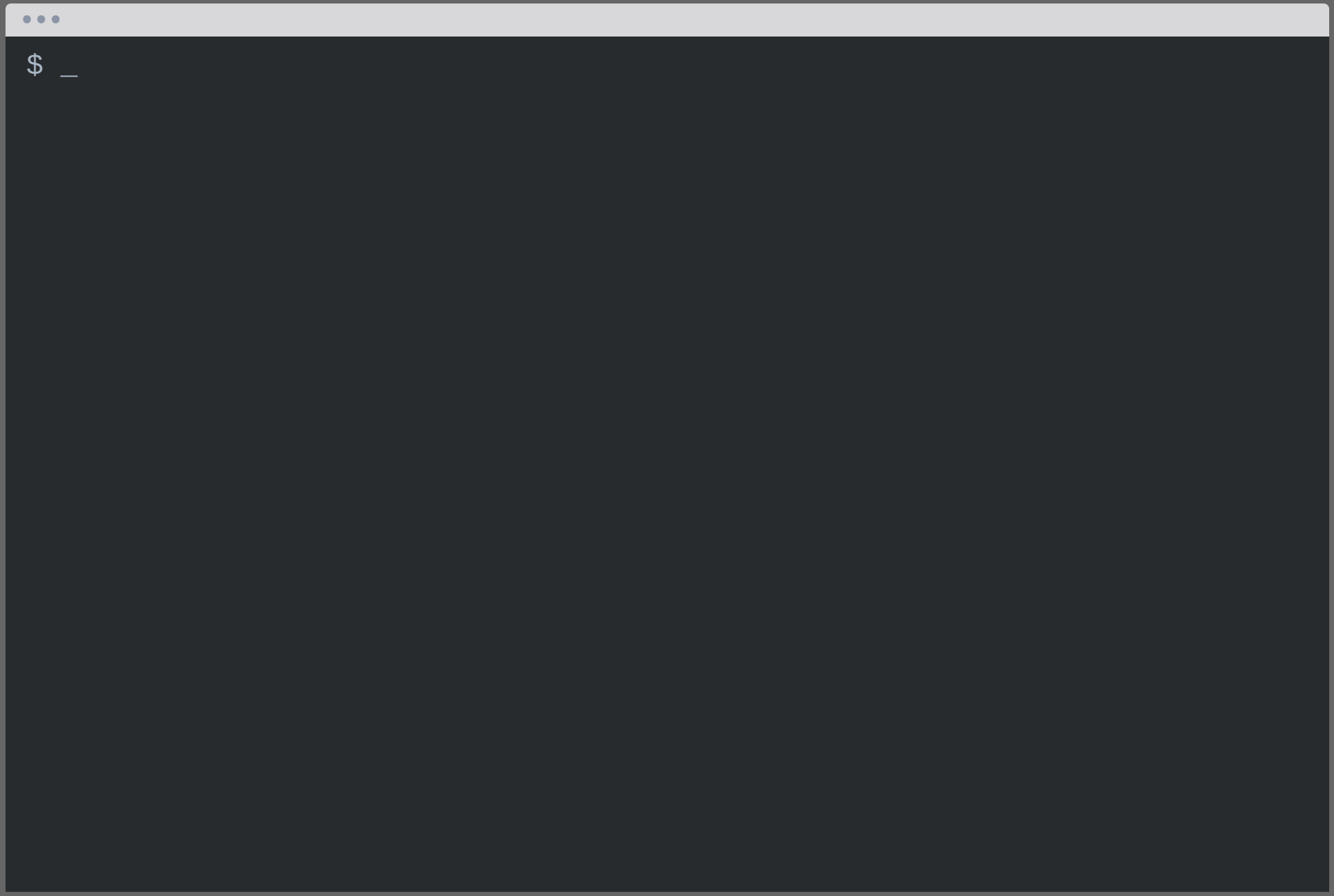

$ vim reflections.json
$ _

```
$ 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
```

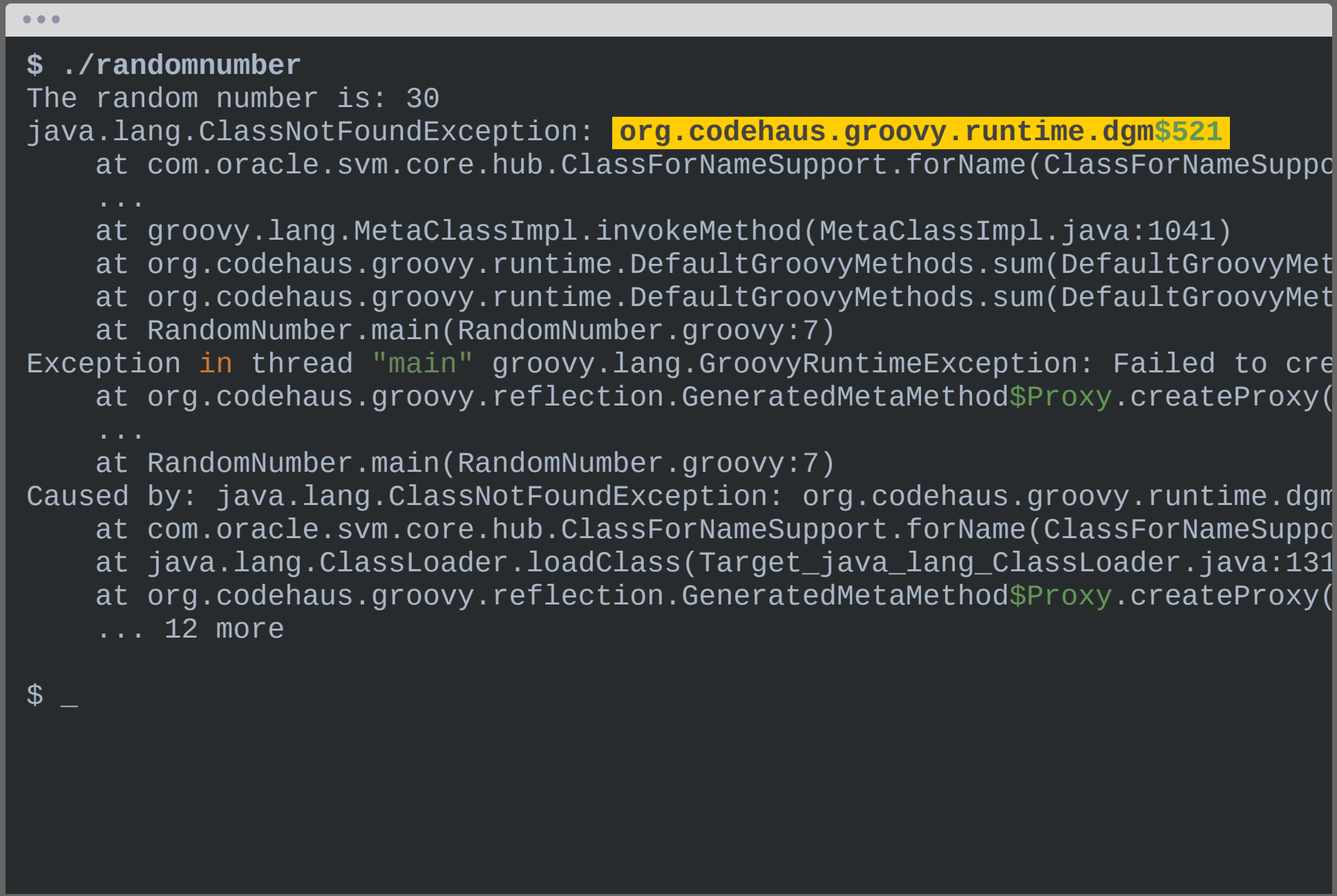
```
$ vim reflections.json

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

$ _
```


$ ./randomnumber
The random number is: 30
java.lang.ClassNotFoundException: org.codehaus.groovy.runtime.dgm$521
at com.oracle.svm.core.hub.ClassForNameSupport.forName(ClassForNameSuppo
...
at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:1041)
at org.codehaus.groovy.runtime.DefaultGroovyMethods.sum(DefaultGroovyMet
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at RandomNumber.main(RandomNumber.groovy:7)
Exception in thread "main" groovy.lang.GroovyRuntimeException: Failed to cre
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...
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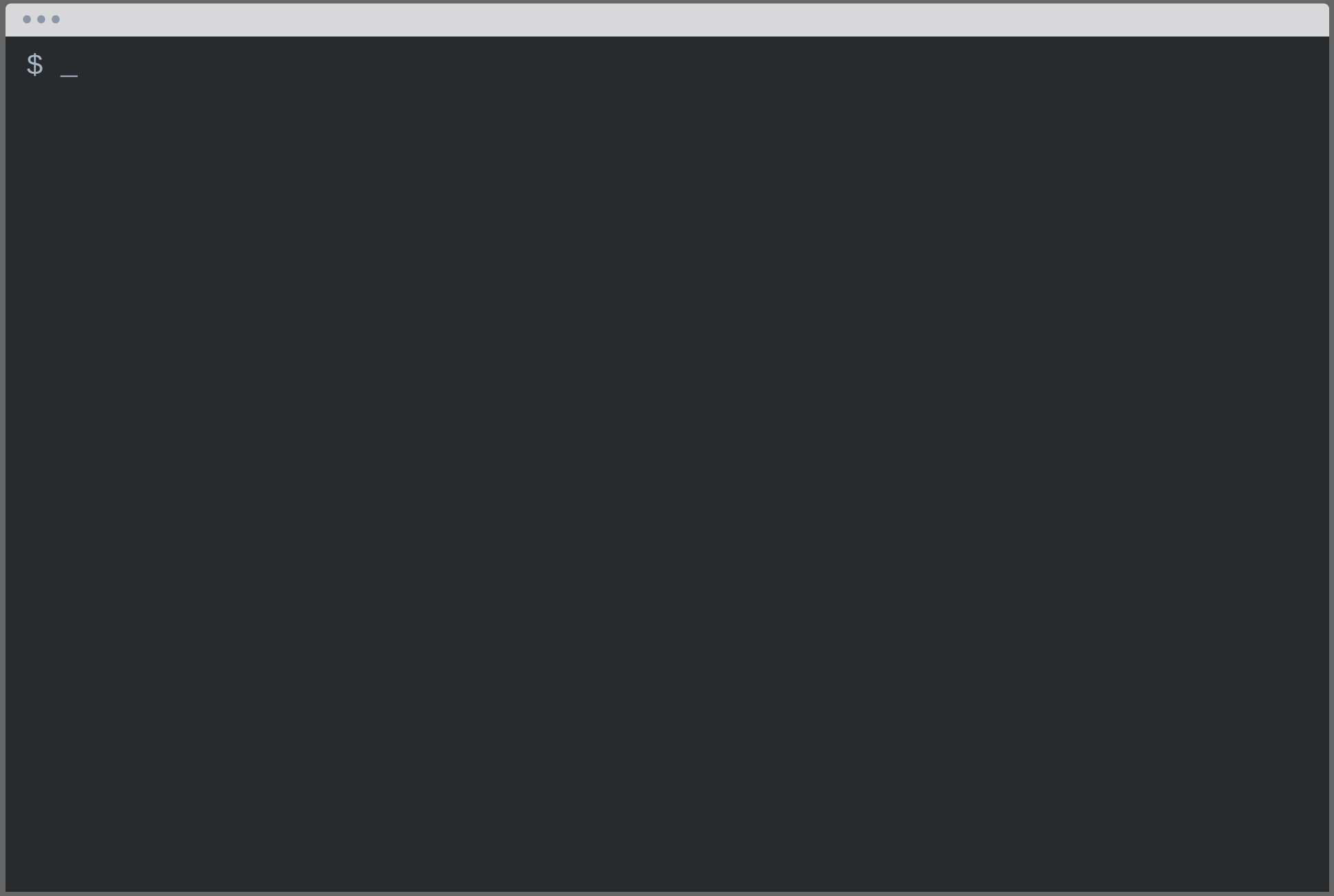
Caused by: java.lang.ClassNotFoundException: org.codehaus.groovy.runtime.dgm
at com.oracle.svm.core.hub.ClassForNameSupport.forName(ClassForNameSuppo
at java.lang.ClassLoader.loadClass(Target_java_lang_ClassLoader.java:131
at org.codehaus.groovy.reflection.GeneratedMetaMethod$Proxy.createProxy(
... 12 more
$ _

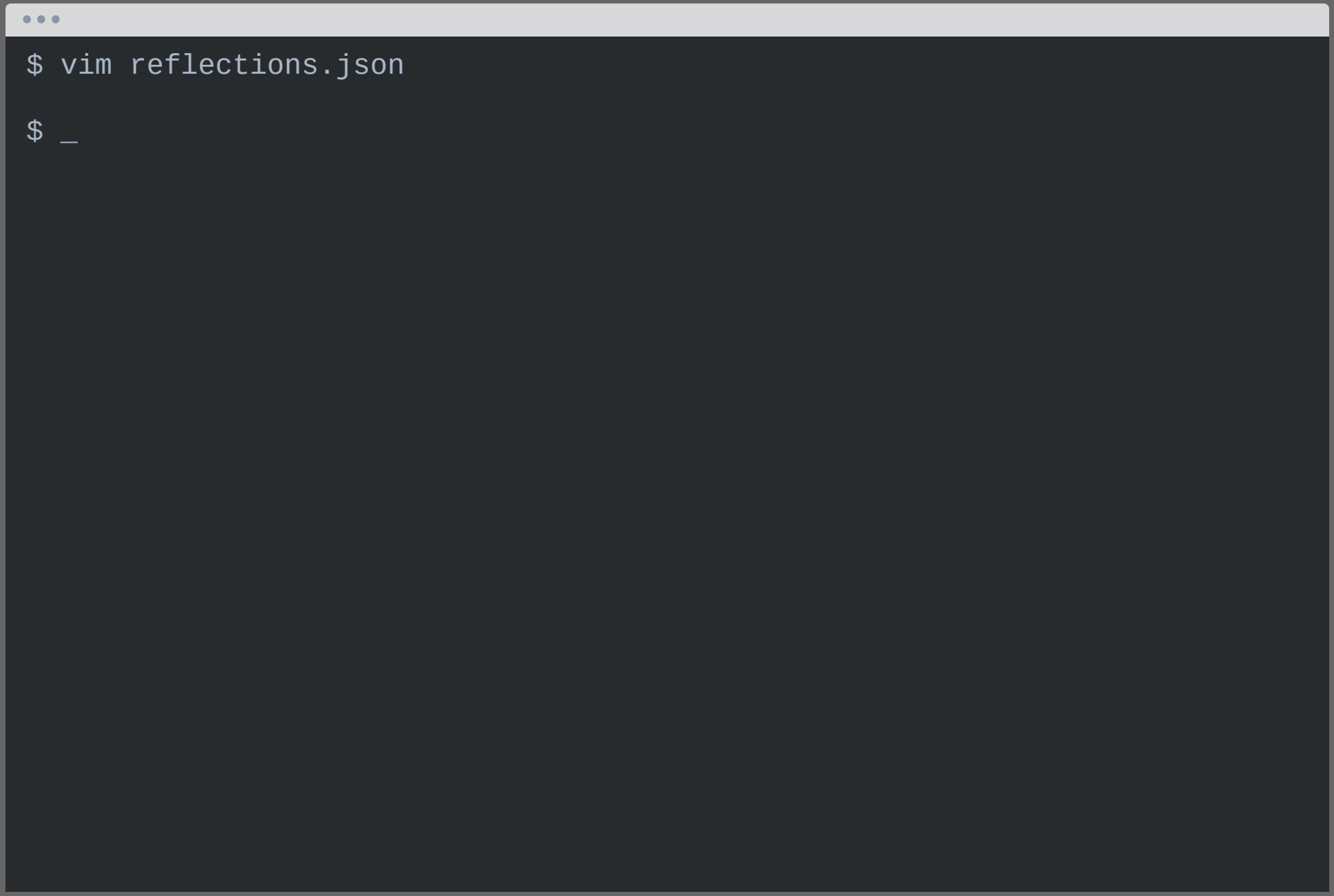


```
$ vim reflections.json
```

```
[
  {
    "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
  }
]
```

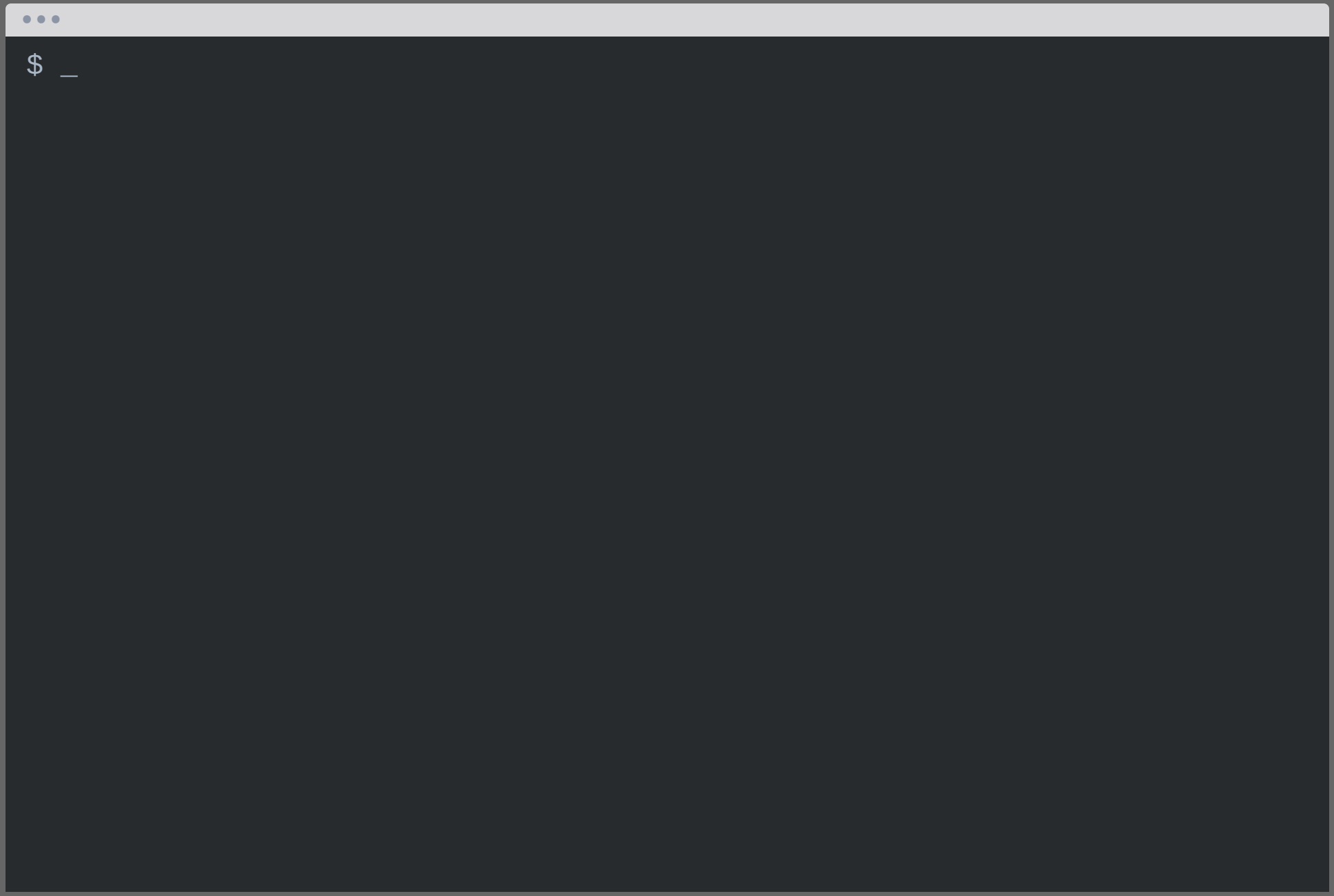
```
[
  {
    "name": "RandomNumber$_main_closure1",
    "allDeclaredConstructors": true,
    "allPublicConstructors": true,
    "allDeclaredMethods": true,
    "allPublicMethods": true
  },{
    "name": "org.codehaus.groovy.runtime.dgm$521",
    "allDeclaredConstructors": true,
    "allPublicConstructors":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

$ _
```

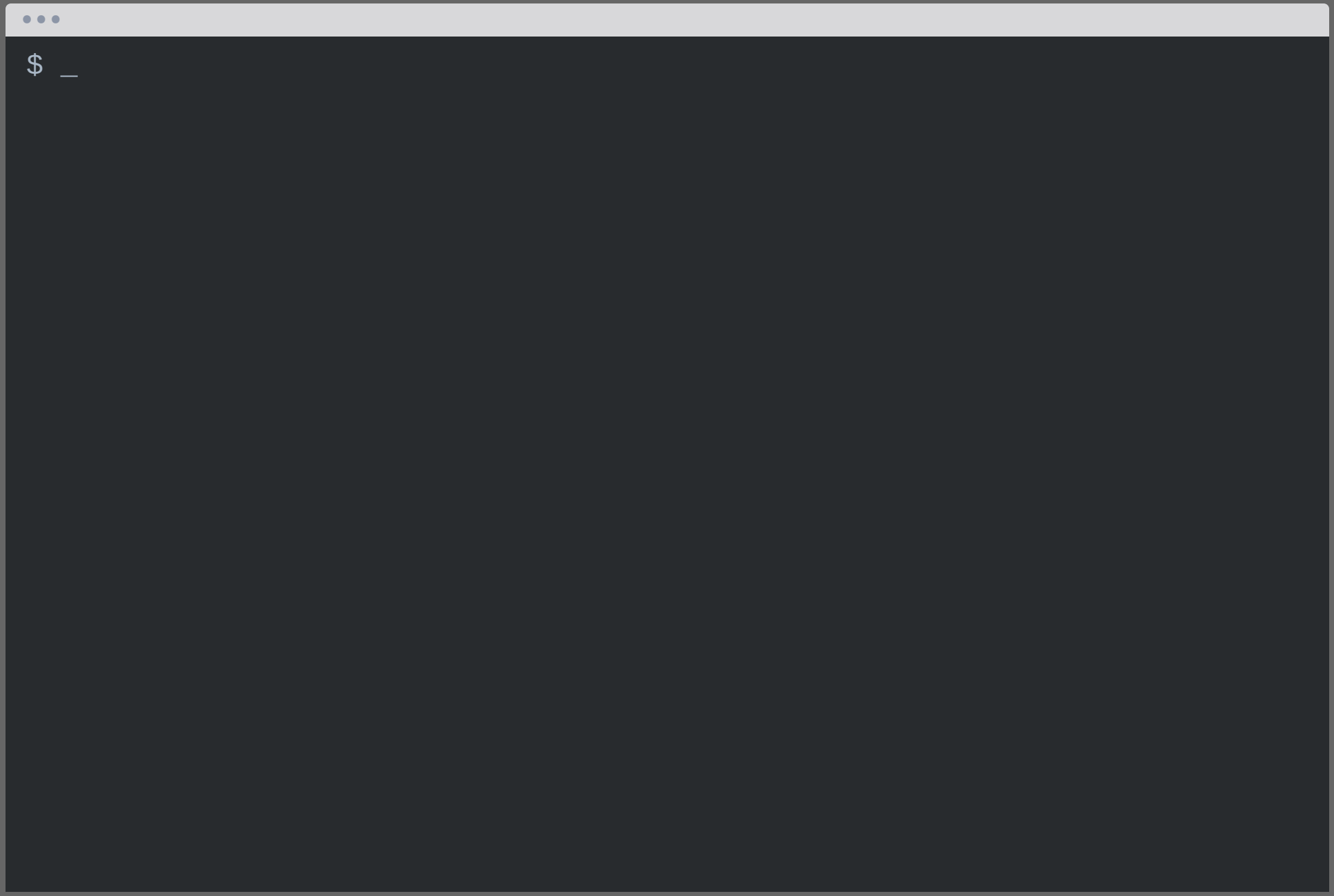
```
$ ./randomnumber
The random number is: 109
The doubled sum of numbers between 0 and 109 is 11990

$ 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

$ _
```

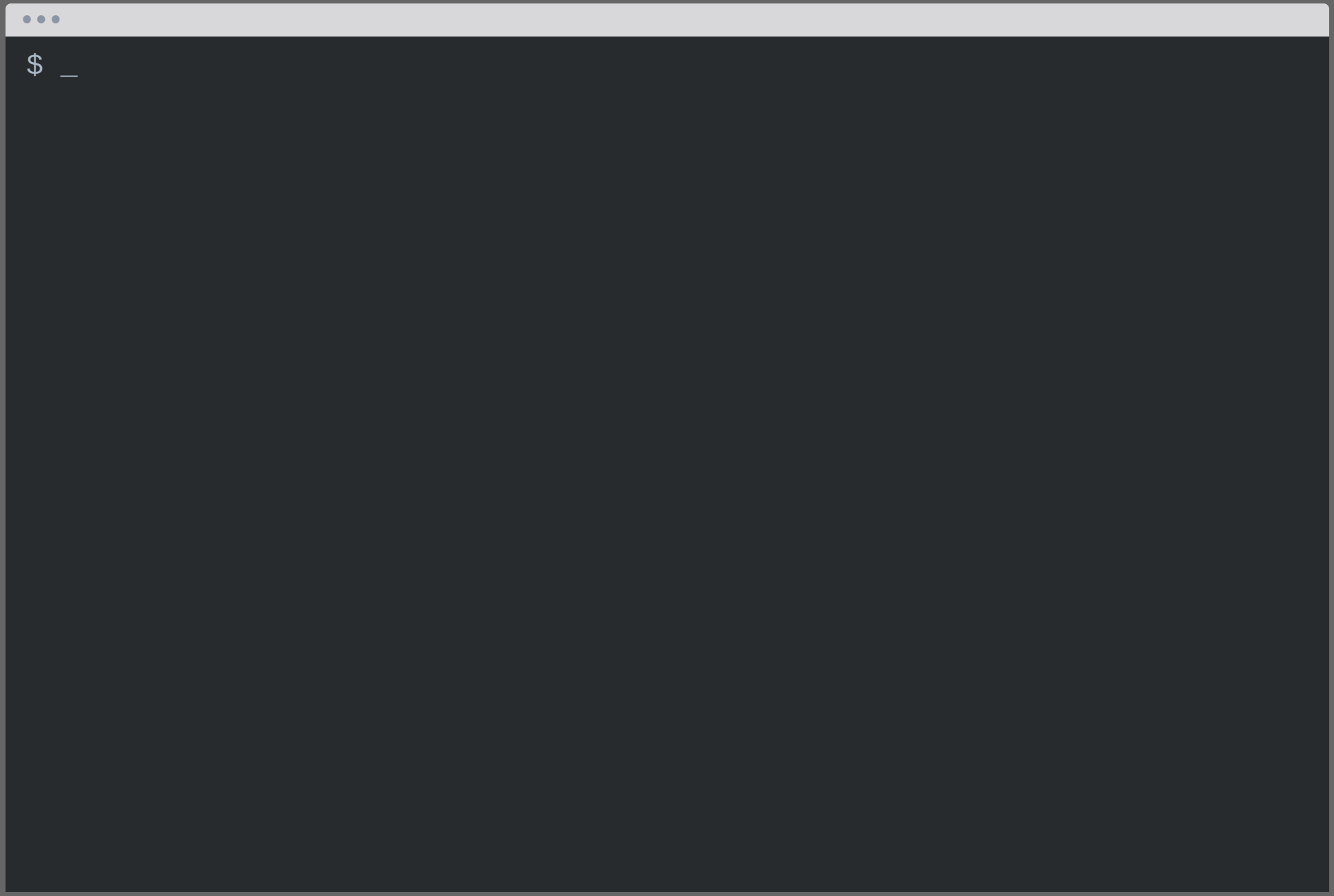
```
$ ./randomnumber
The random number is: 109
The doubled sum of numbers between 0 and 109 is 11990

$ 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

$ _
```

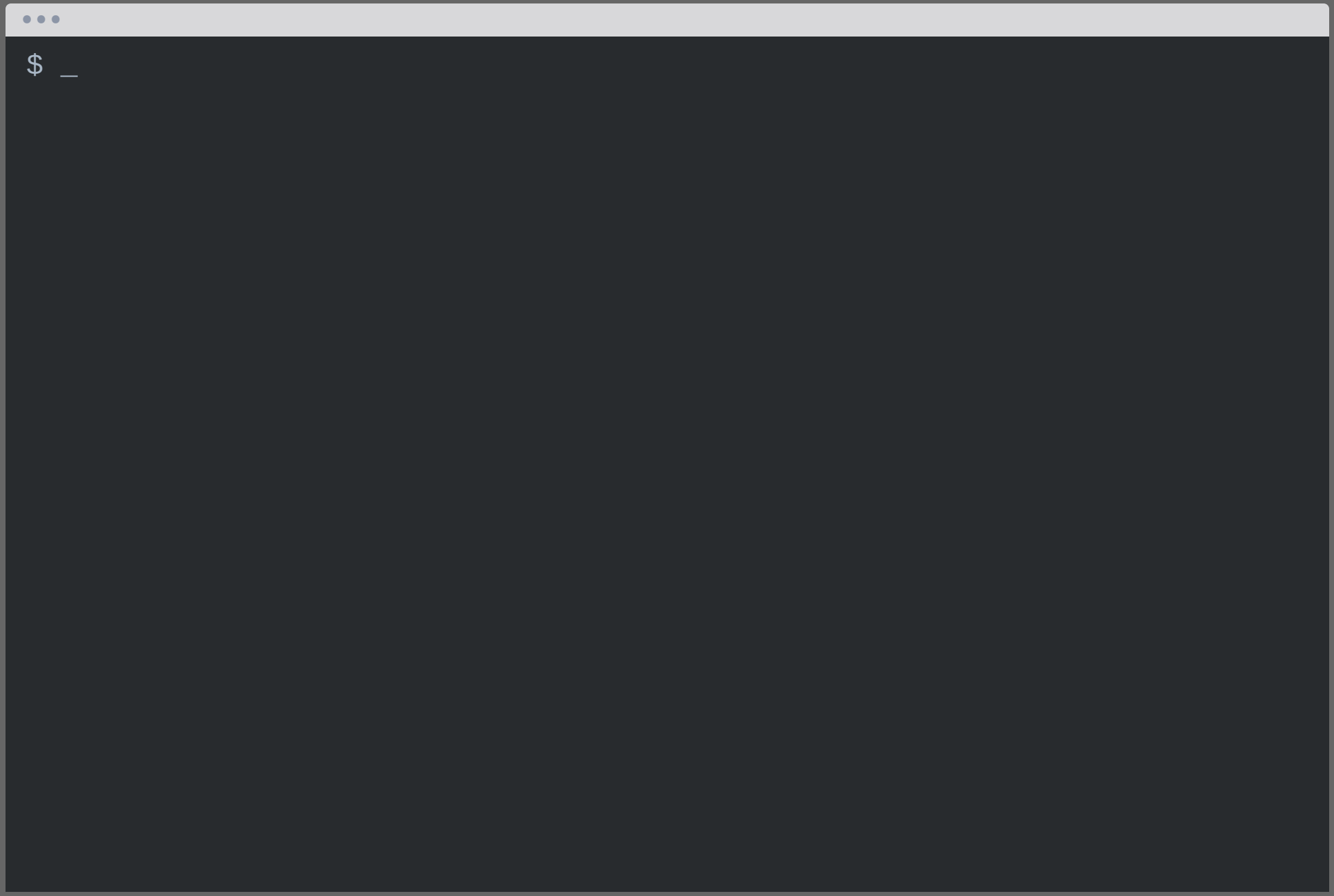
```
$ java -cp ".:$GROOVY_HOME/lib/groovy-2.5.7.jar" \
    -agentlib:native-image-agent=config-output-dir=conf/ \
    RandomNumber
The random number is: 670
The doubled sum of numbers between 0 and 670 is 449570

$ 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     Allow image building with an incomplete
                                   first time, instead of during image buil
  -H:±AllowVMInspection            Enables features that allow the VM to be
  -H:CPUFeatures=...               Comma separated list of CPU features tha
                                   are enabled by default. Other available
                                   SSE4_1, SSE4_2, POPCNT, LZCNT, TSC, TSCI
                                   AVX512PF, AVX512ER, AVX512CD, AVX512BW.
  -H:CStandard="C89"               C standard to use in header files. Possi
  -H:Class=""                      Class containing the default entry point
  -H:ClassInitialization=...       A comma-separated list of classes append
                                   Default: None
  -H:CompilerBackend="lir"         Backend used by the compiler.
  ...
```

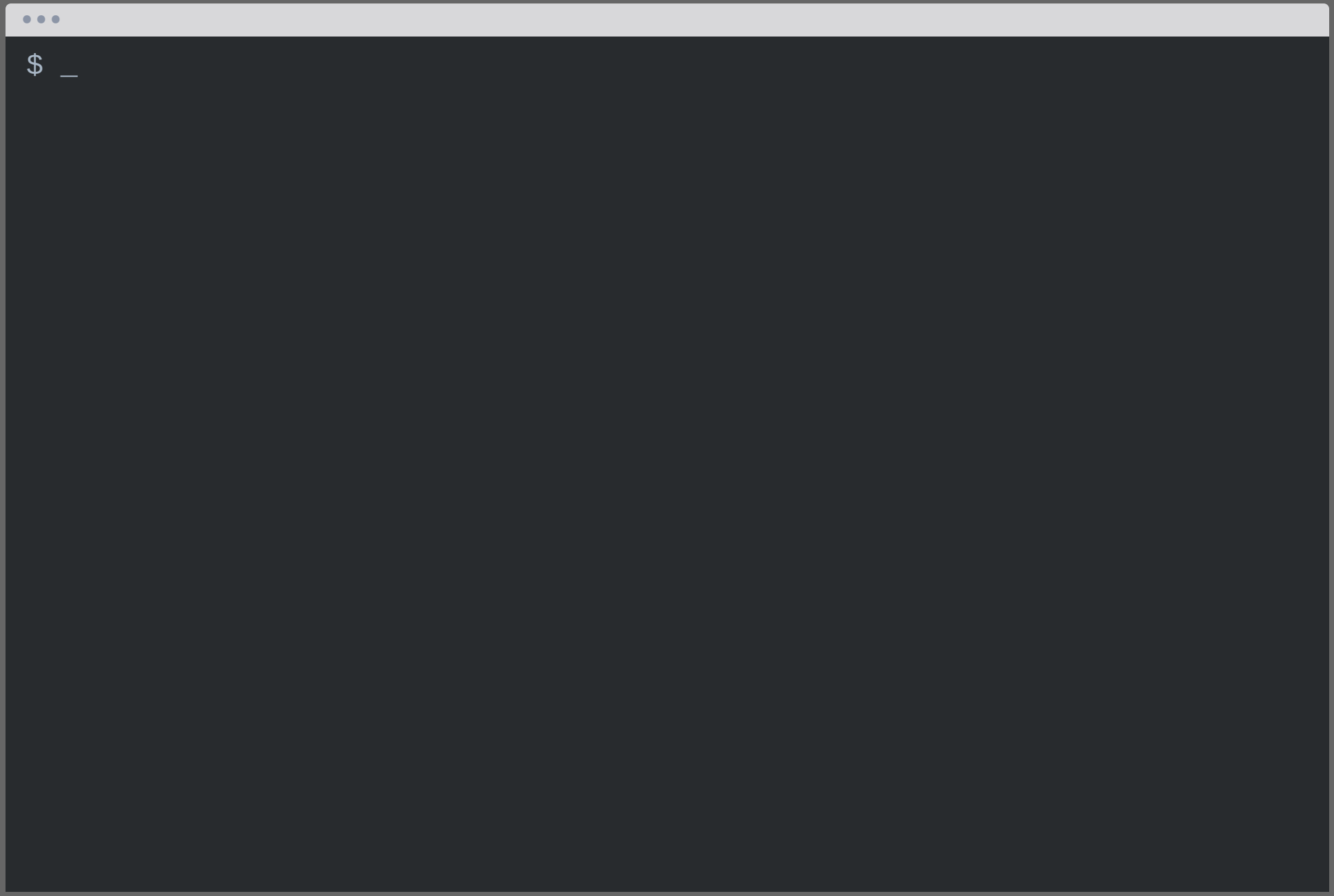
Part 3: benchmark

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!"}%

$ _
```

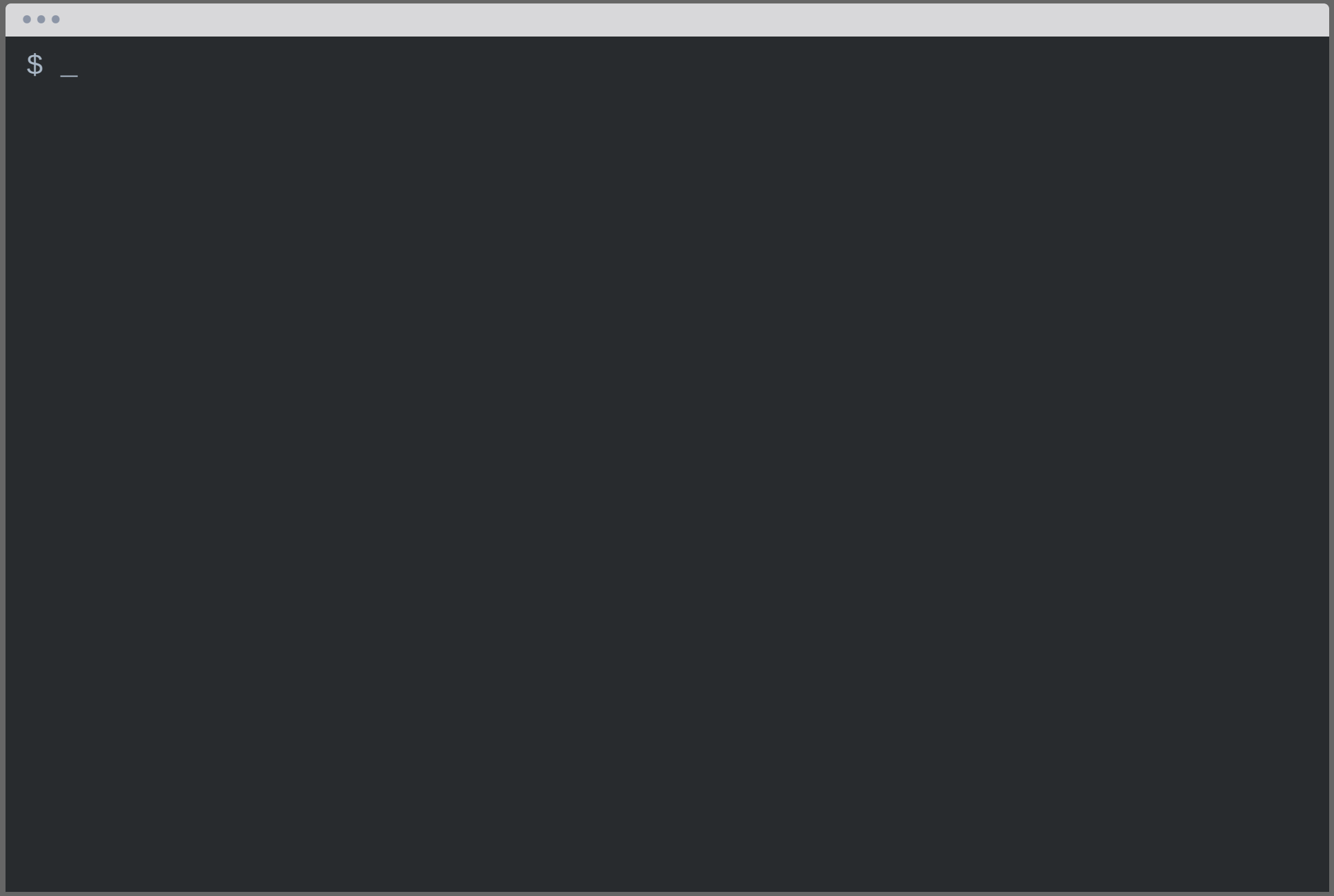
```
$ curl -i localhost:5050
HTTP/1.1 200 OK
content-type: application/json
content-length: 27

{"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/
```

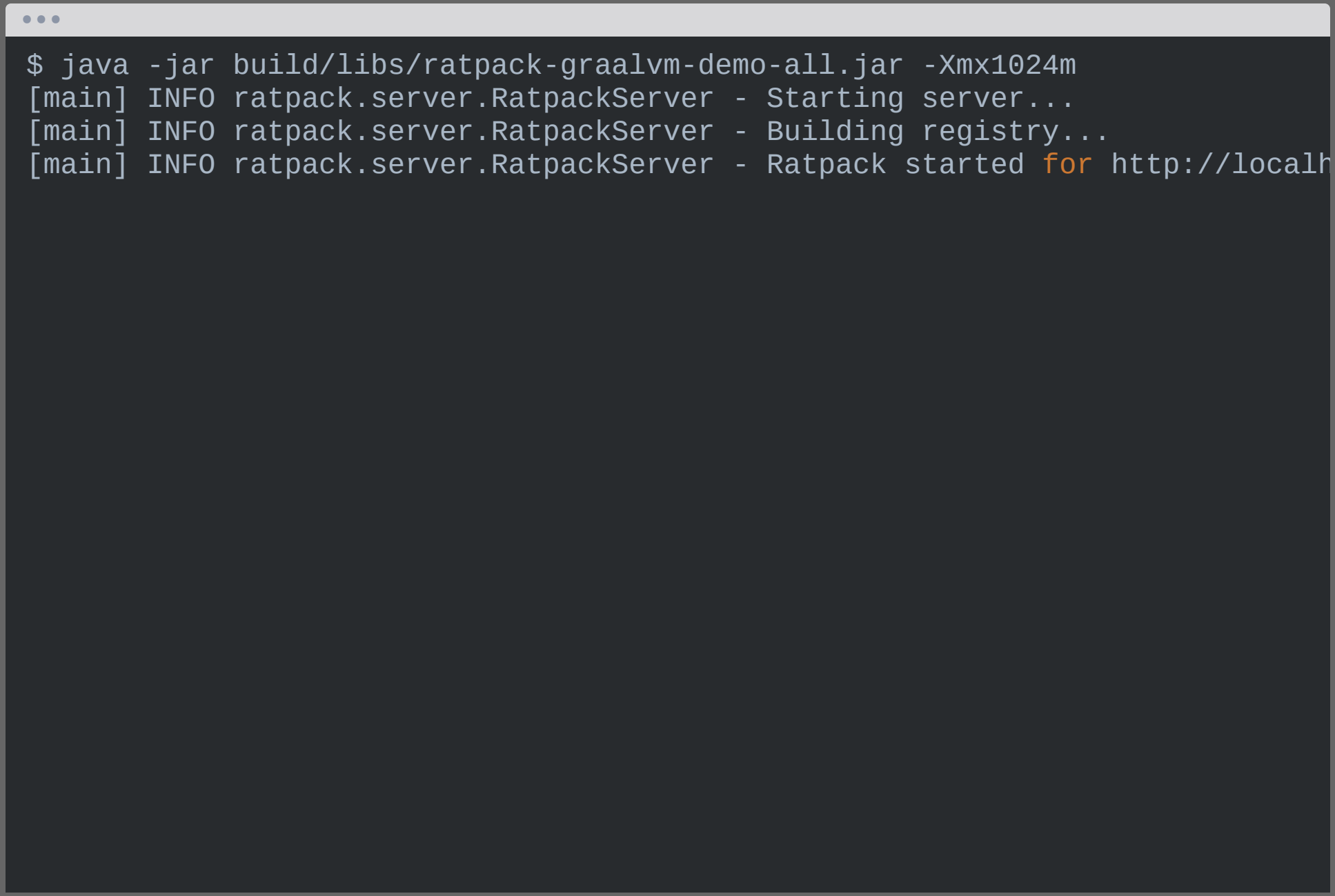
```
$ curl -i localhost:5050
HTTP/1.1 200 OK
content-type: application/json
content-length: 27

{"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/
```

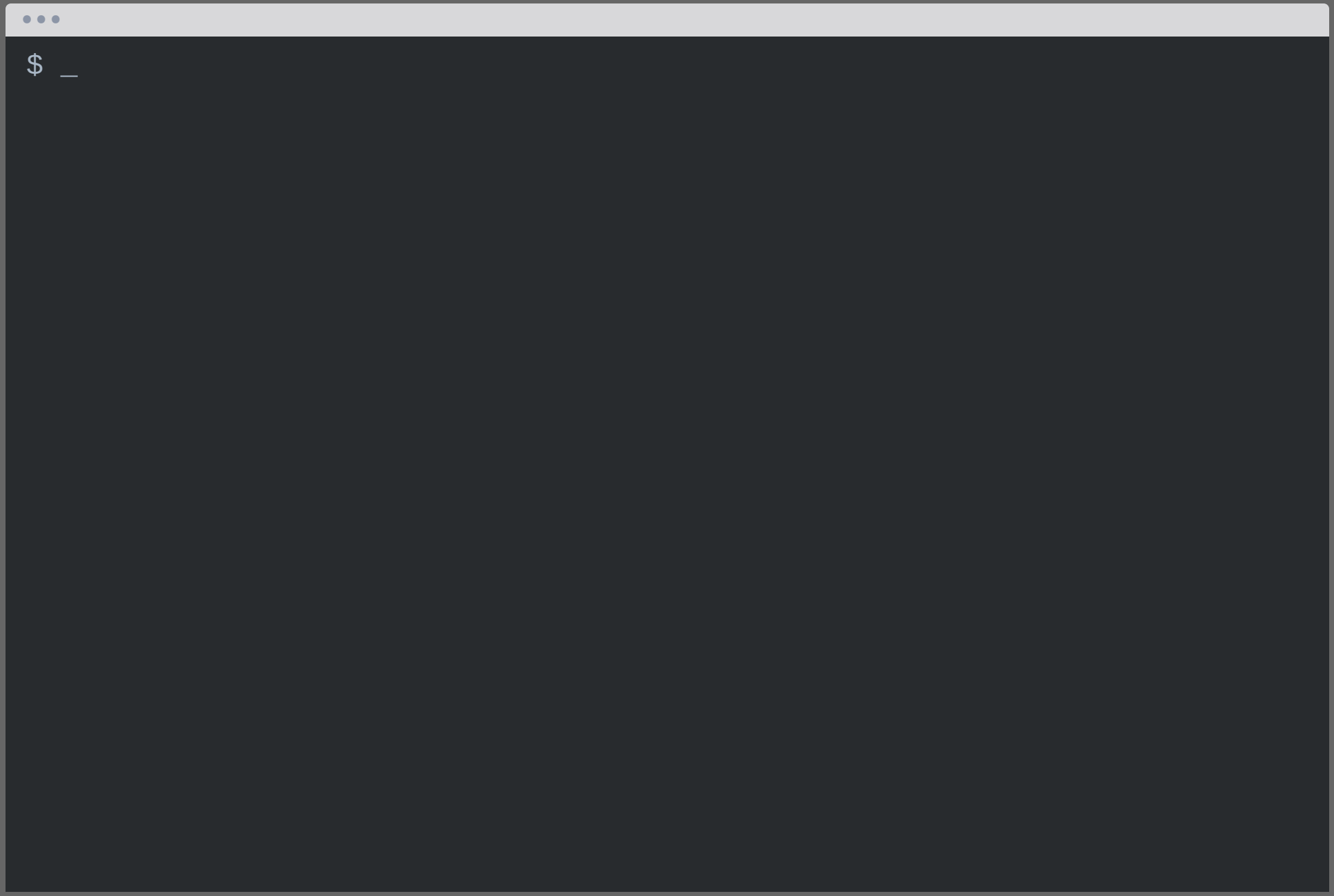
```
$ curl -i localhost:5050
HTTP/1.1 200 OK
content-type: application/json
content-length: 27

{"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://localh



```
$ 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)
```

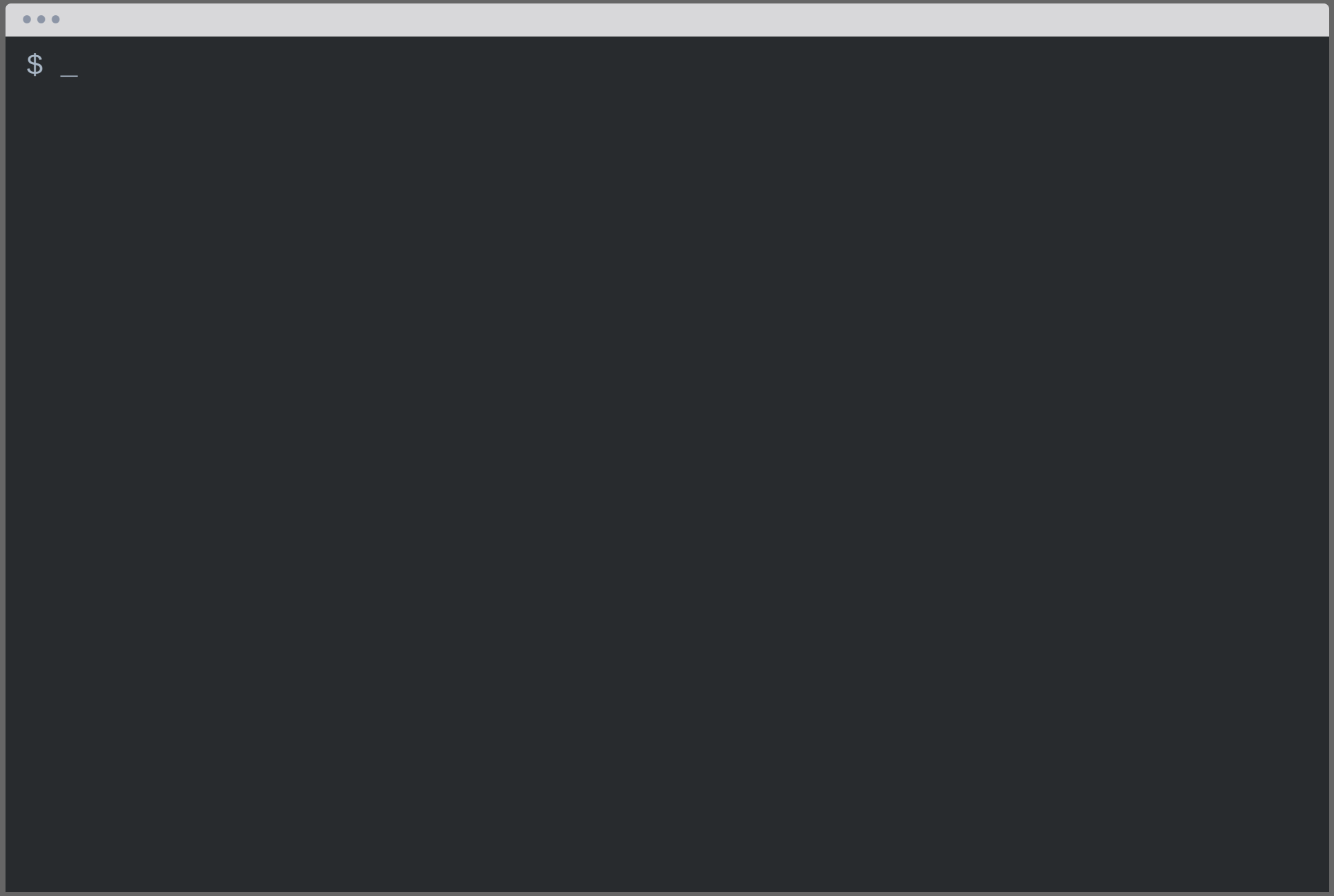
```
$ ab -c 1000 -n 500000 http://localhost:5050/
```

```
$ 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)
```

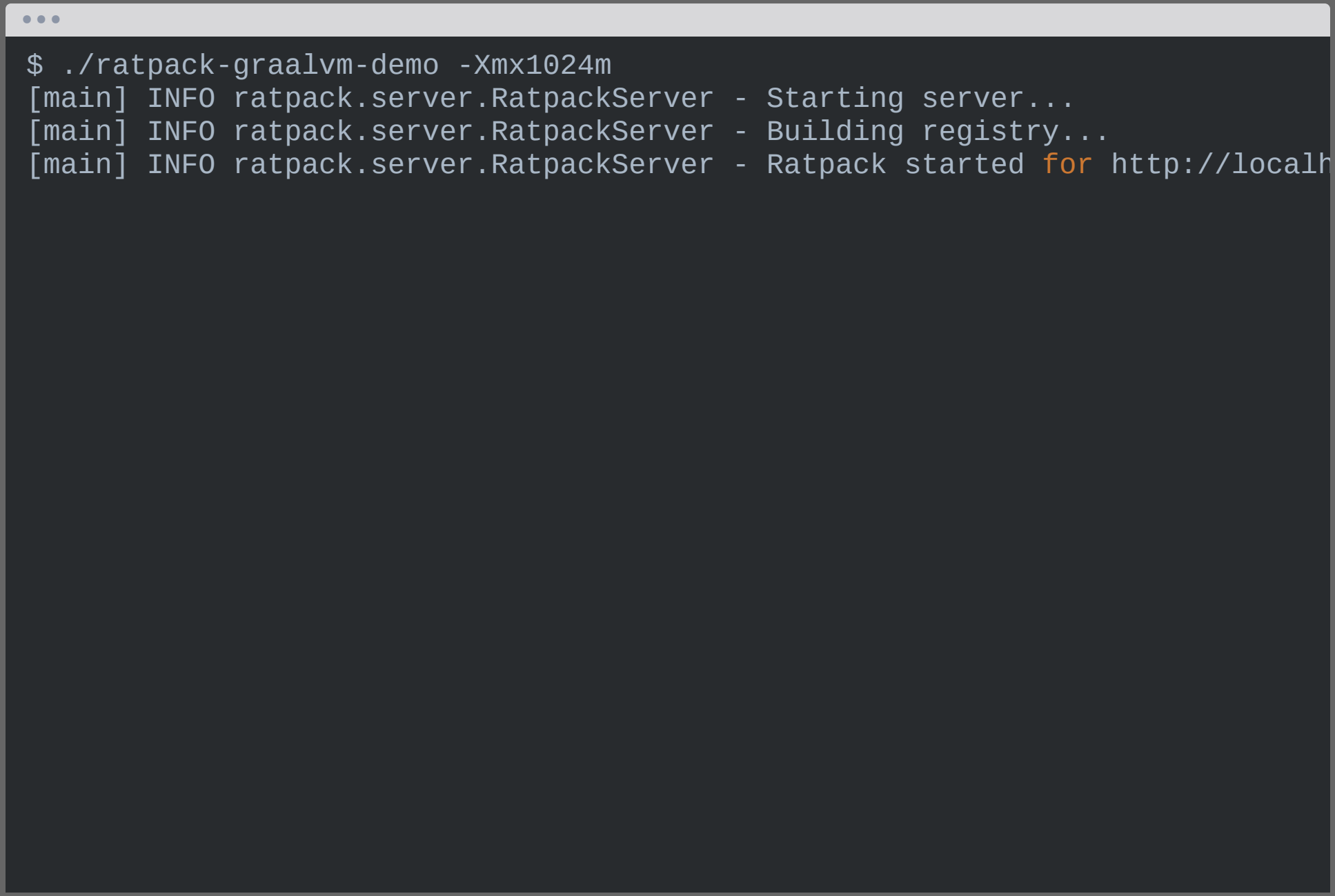
```
$ ab -c 1000 -n 500000 http://localhost:5050/

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

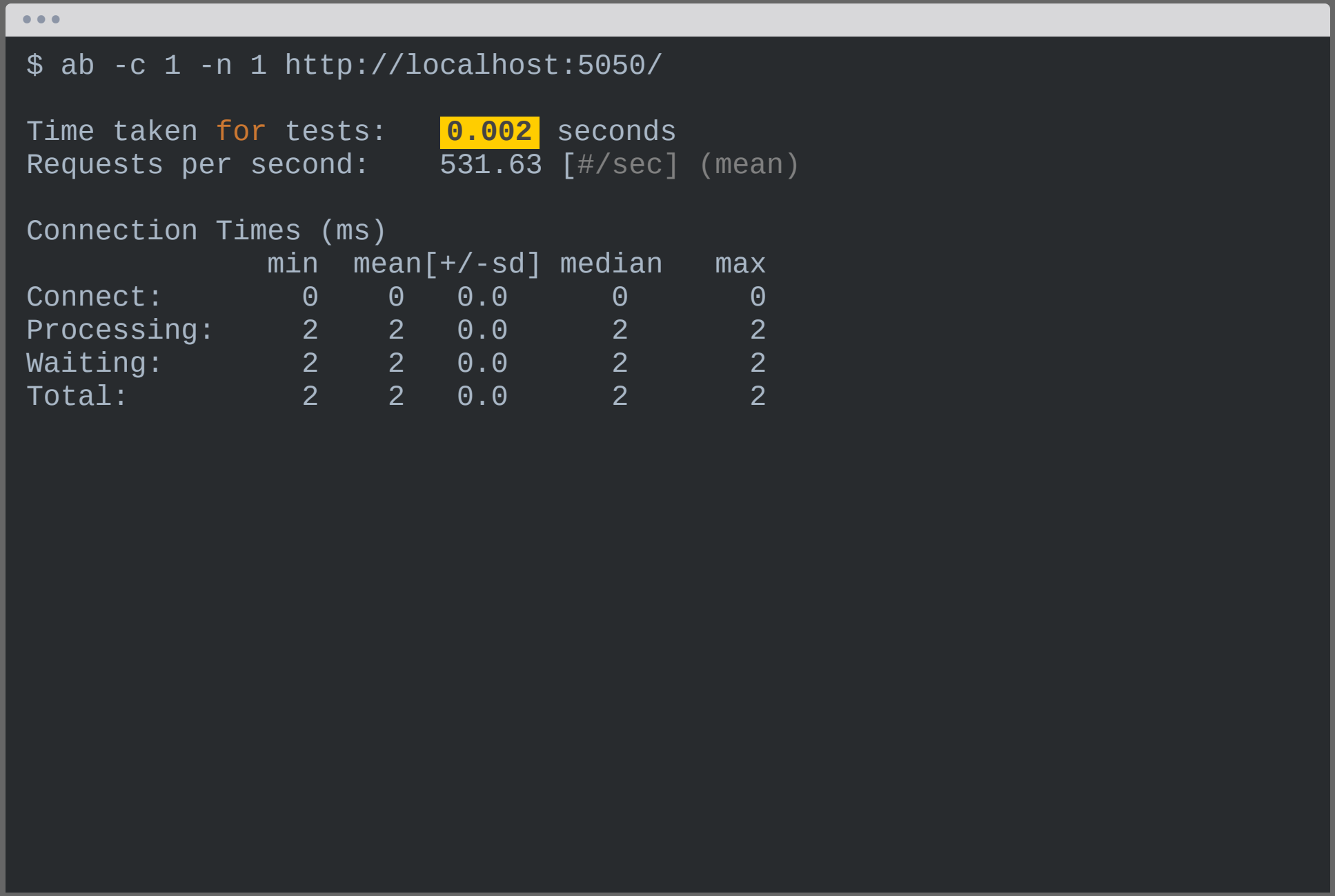


```
$ ./ratpack-graalvm-demo -Xmx1024m
```


$ ./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://localh

```
$ 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)
```

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  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)
```

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

Connection Times (ms)
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Connect:        0   42 183.6     18    3089
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 100%   3109 (longest request)
```
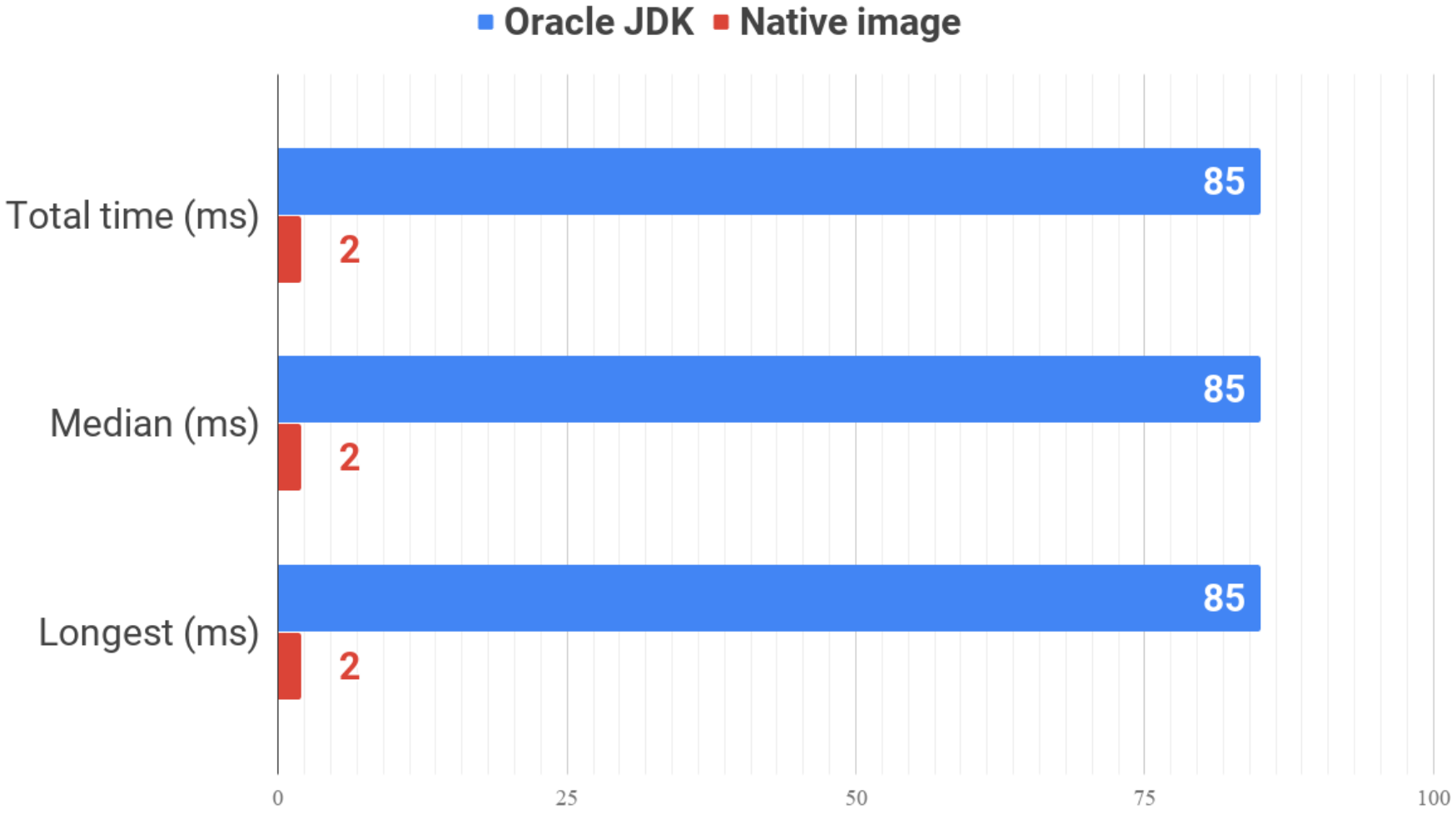
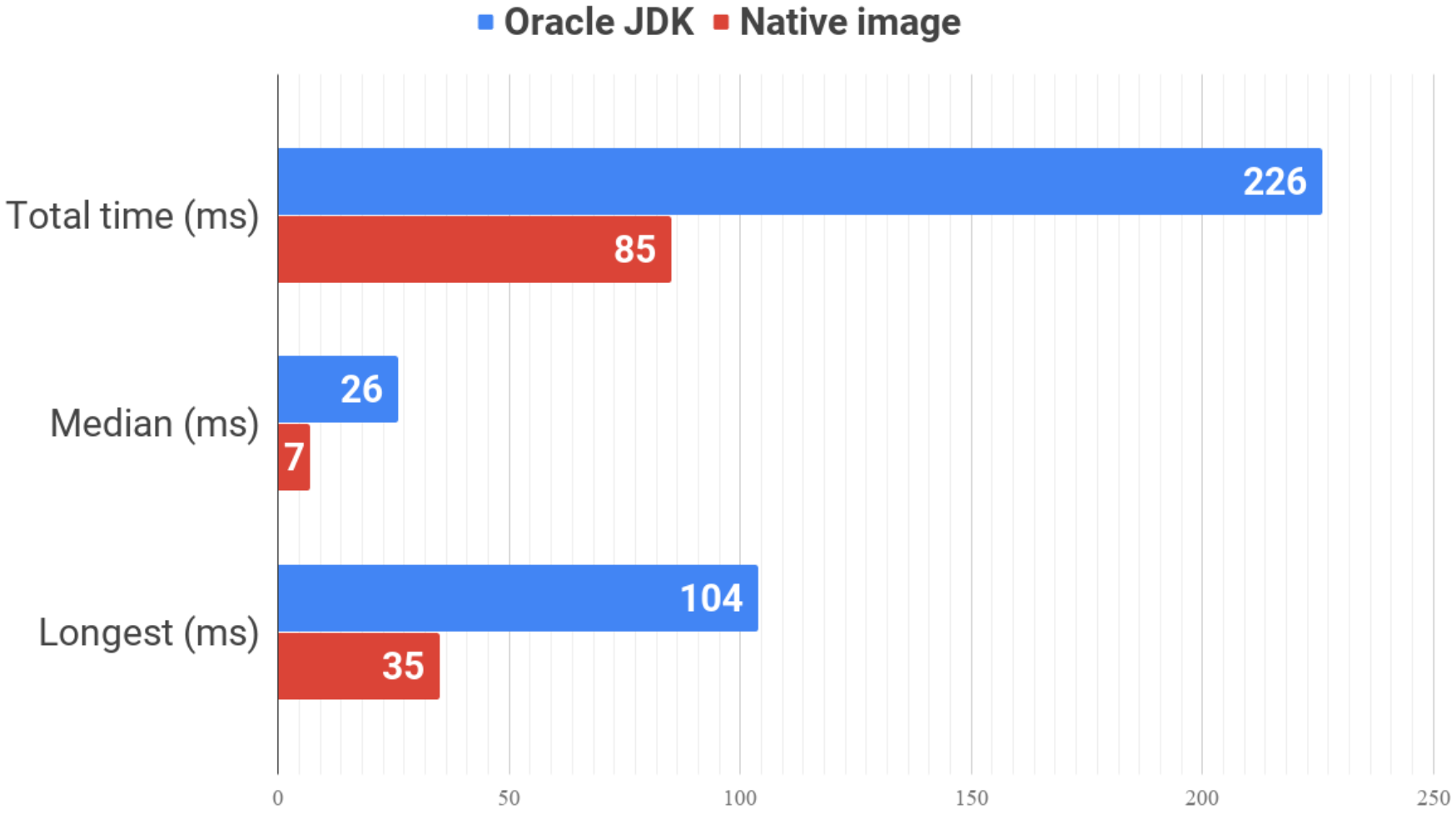
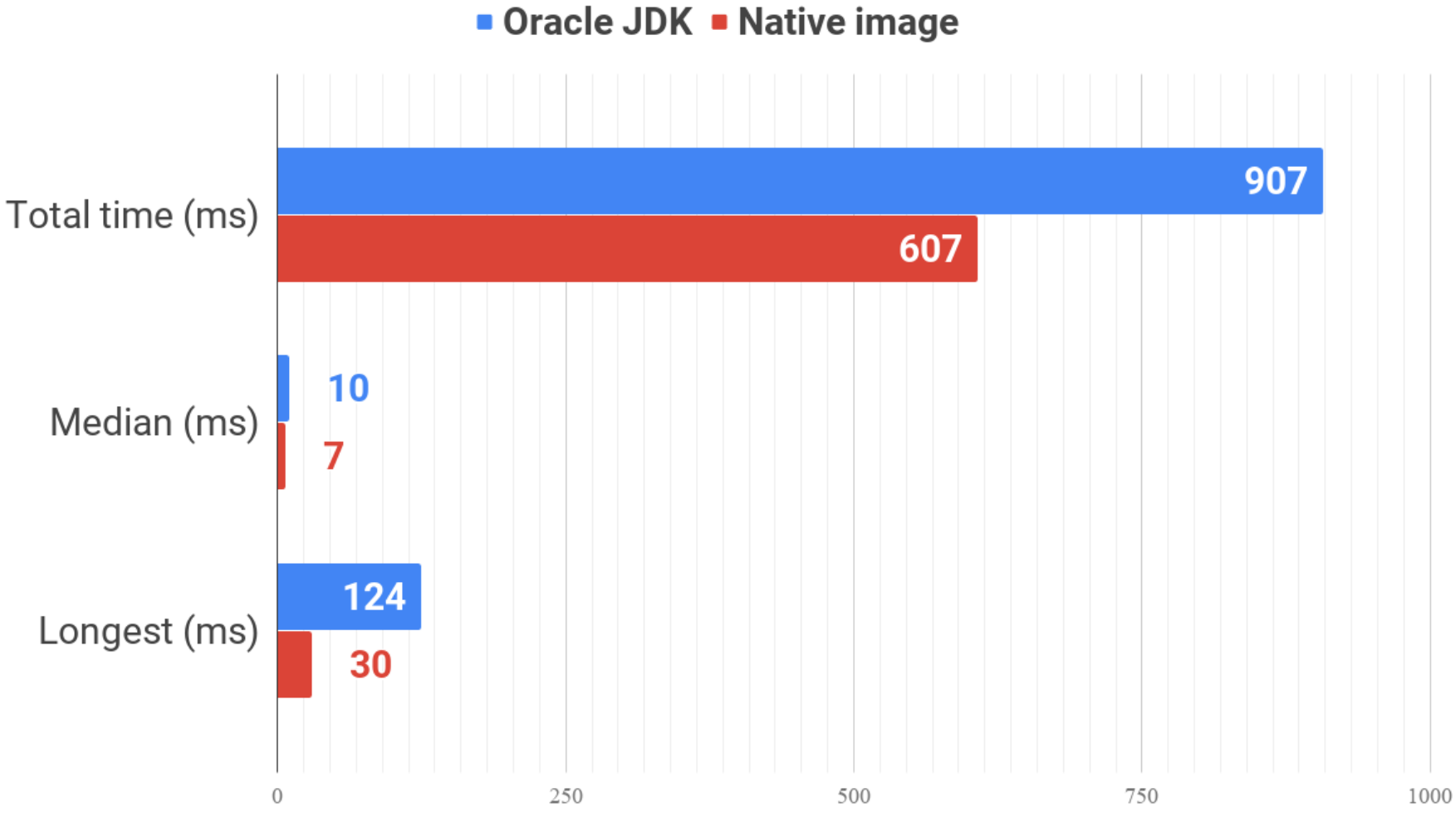

1 req (total: 1)


Oracle JDK
Native image
Total time (ms)
Median (ms)
Longest (ms)
85
2
85
2
85
2
0
25
50
75
100

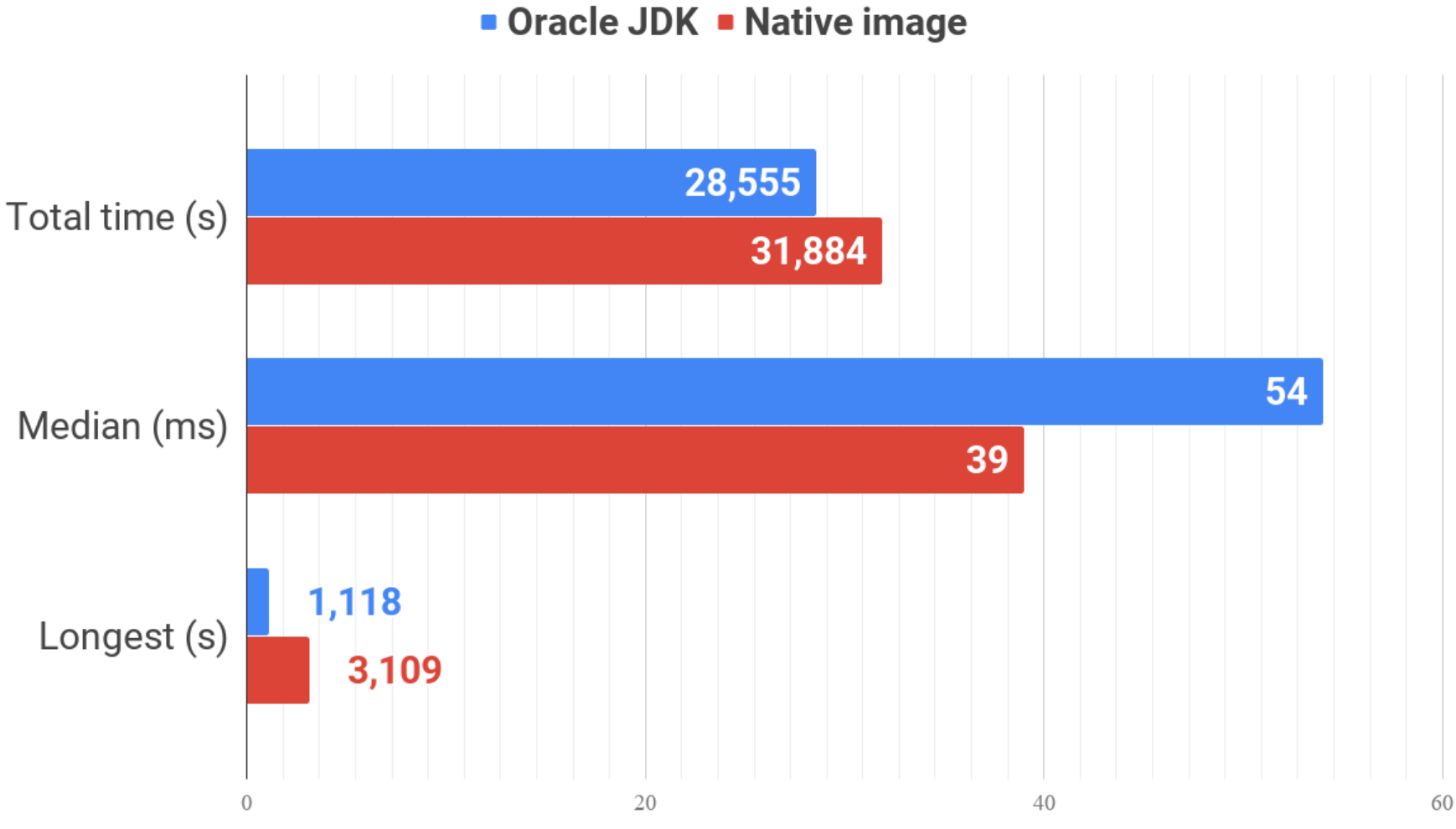
1k conc req (total: 1k)



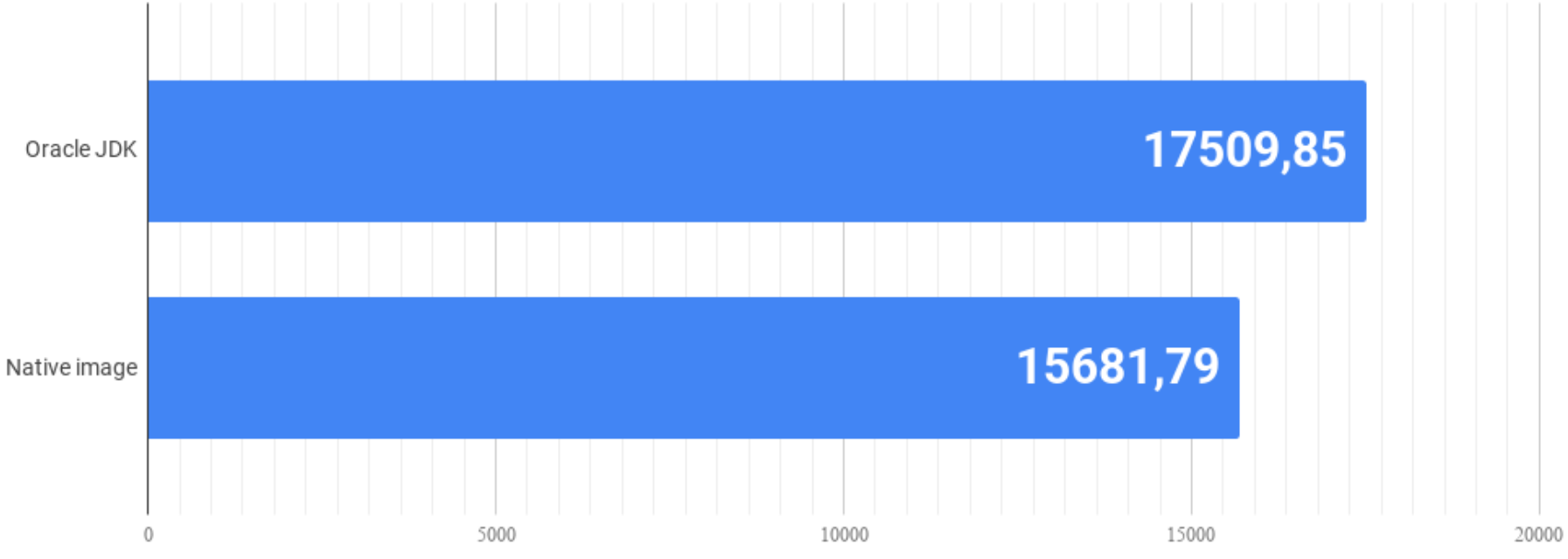
1k conc req (total: 10k)



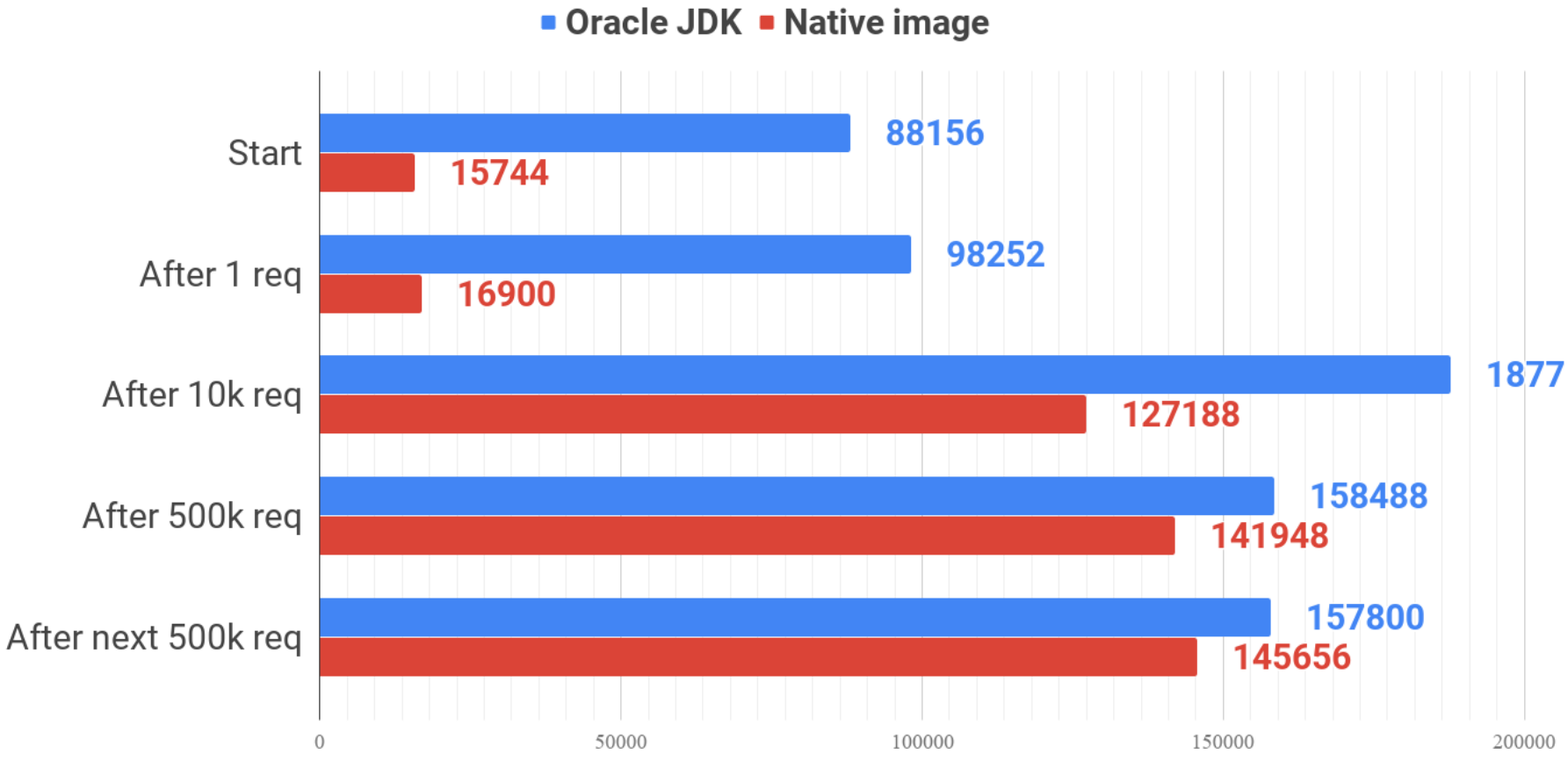
1k conc req (total: 500k)



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



Memory consumption (bytes)



Conclusions

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

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

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

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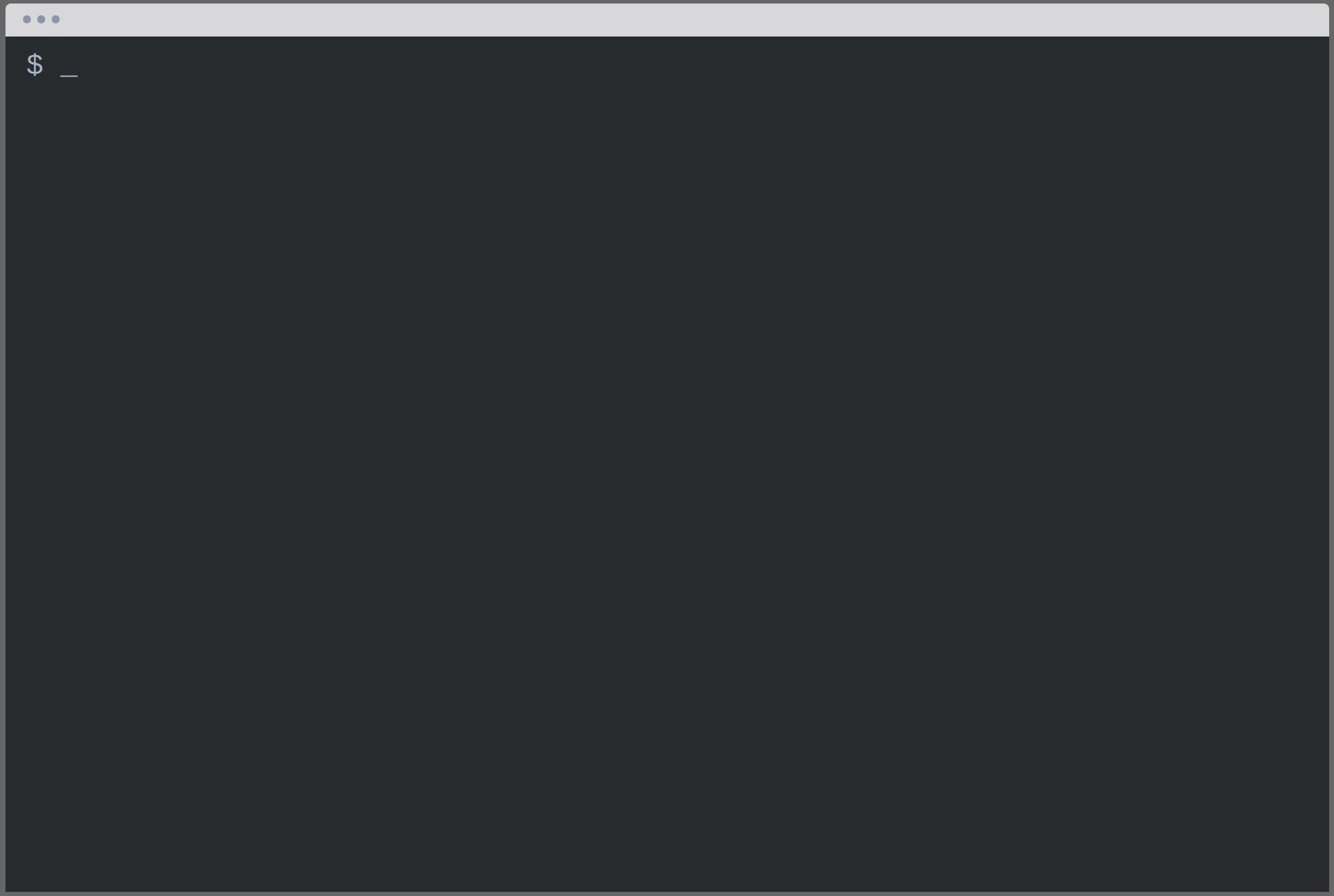
CLI tools, FaaS can benefit from the **native image**.

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! ⚠

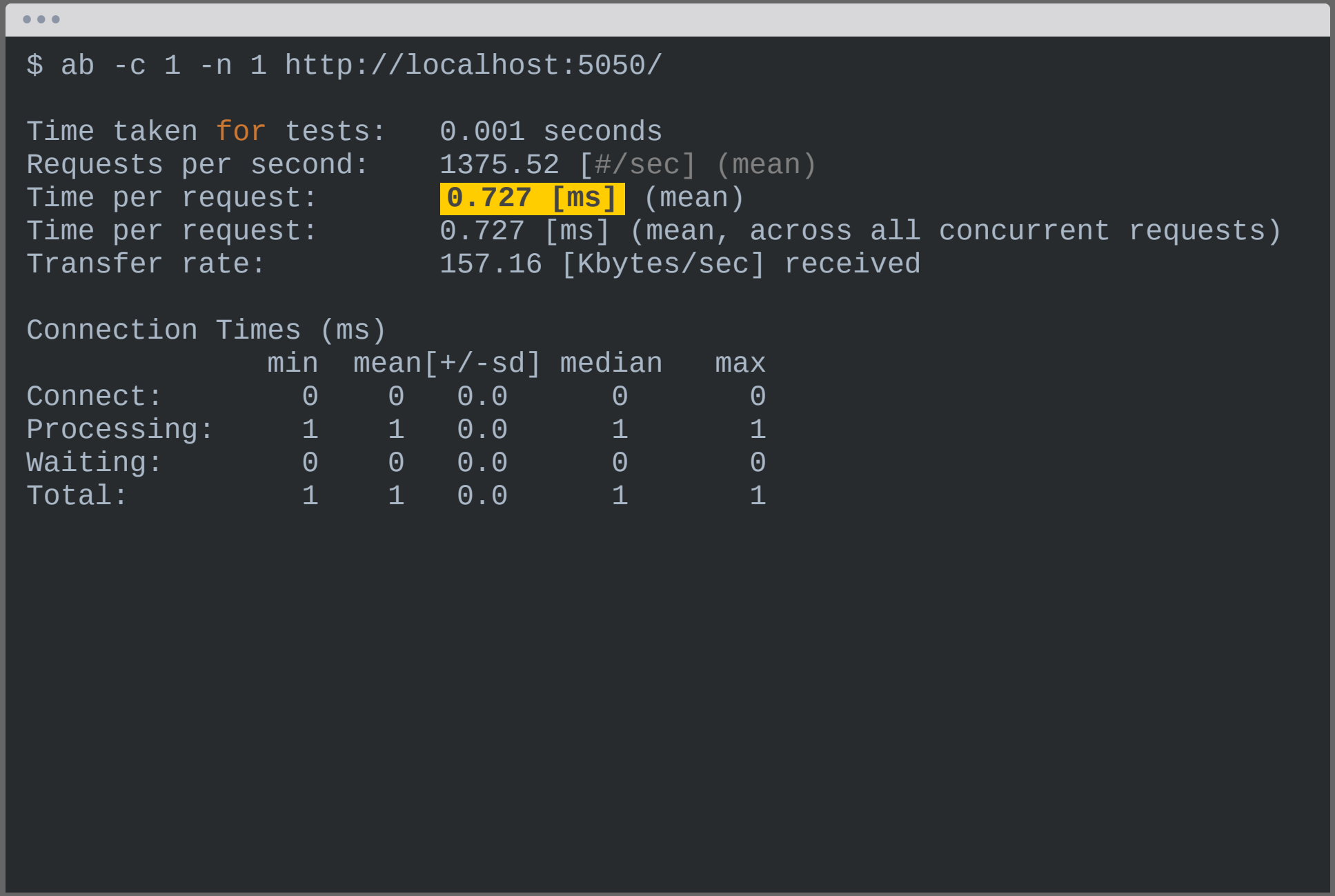


```
$ ab -c 1 -n 1 http://localhost:5050/
```

```
$ 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/

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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