Lean Spring Boot

Applications for The Cloud

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Abstract

Lean Spring Boot Applications for The Cloud

With the starters, Spring-Boot offers a functionality that allows you to set up a new software project with little effort and start programming right away. You don't have to worry about the dependencies since the "right" ones are already pre-configured. But how can you, for example, optimize the start-up times and reduce the memory footprint and thus better prepare the application for the cloud?

In this talk, we will go into Spring-Boot features like "spring-context-indexer", classpath exclusions, lazy spring beans, actuator, JMX. In addition, we also look at switching to a different JVM and other tools.

Let's make Spring Boot great again!

Lean Spring Boot

Applications for The Cloud

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⚠️ WARNING:

Numbers shown in is this talk are **not** based on **real data** but **only estimates** and **assumptions** made by the **author** for **educational purposes** only.

Introduction

Patrick Baumgartner

Technical Agile Coach @ 42talents

My focus is on the development of software solutions with humans.

Coaching, Architecture, Development, Reviews, and Training.

Lecturer @ Zürcher Fachhochschule für Angewandte Wissenschaften ZHAW

@patbaumgartner

What is the problem?
Why this talk?

JAVA 😉 & Spring Boot ❤️

Requirements

When Choosing a Cloud

- How many vCPUs per server are required for my application?
- How much RAM do I need?
- How much storage is necessary?
- Which technology stack should I use?

Considerations

Resources

- CPU & RAM not linearly scalable
- Image Size & Network Bandwidth

Scaleability

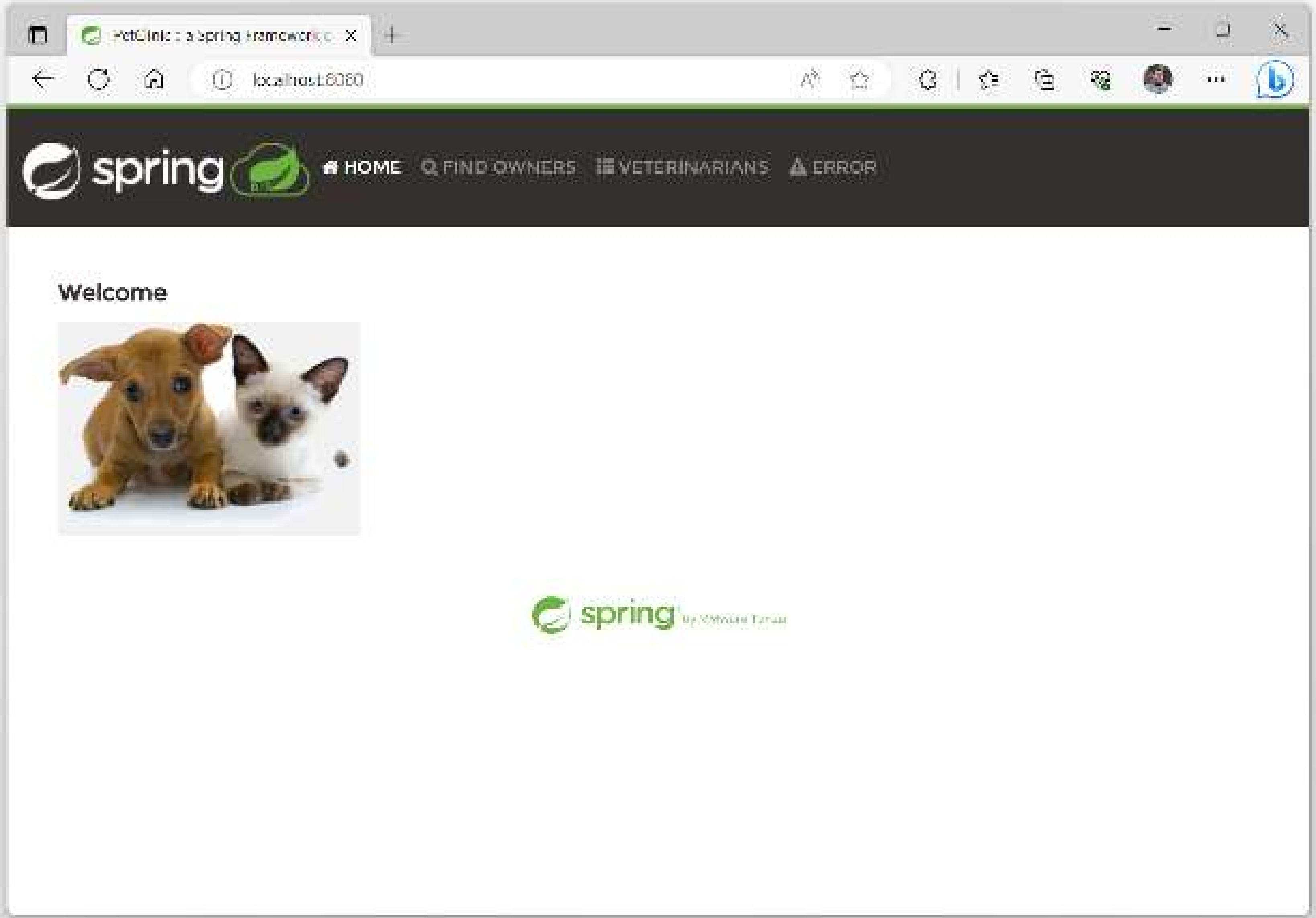
- Fast Startup
- Graceful Shutdown
- Throughput
- Latency

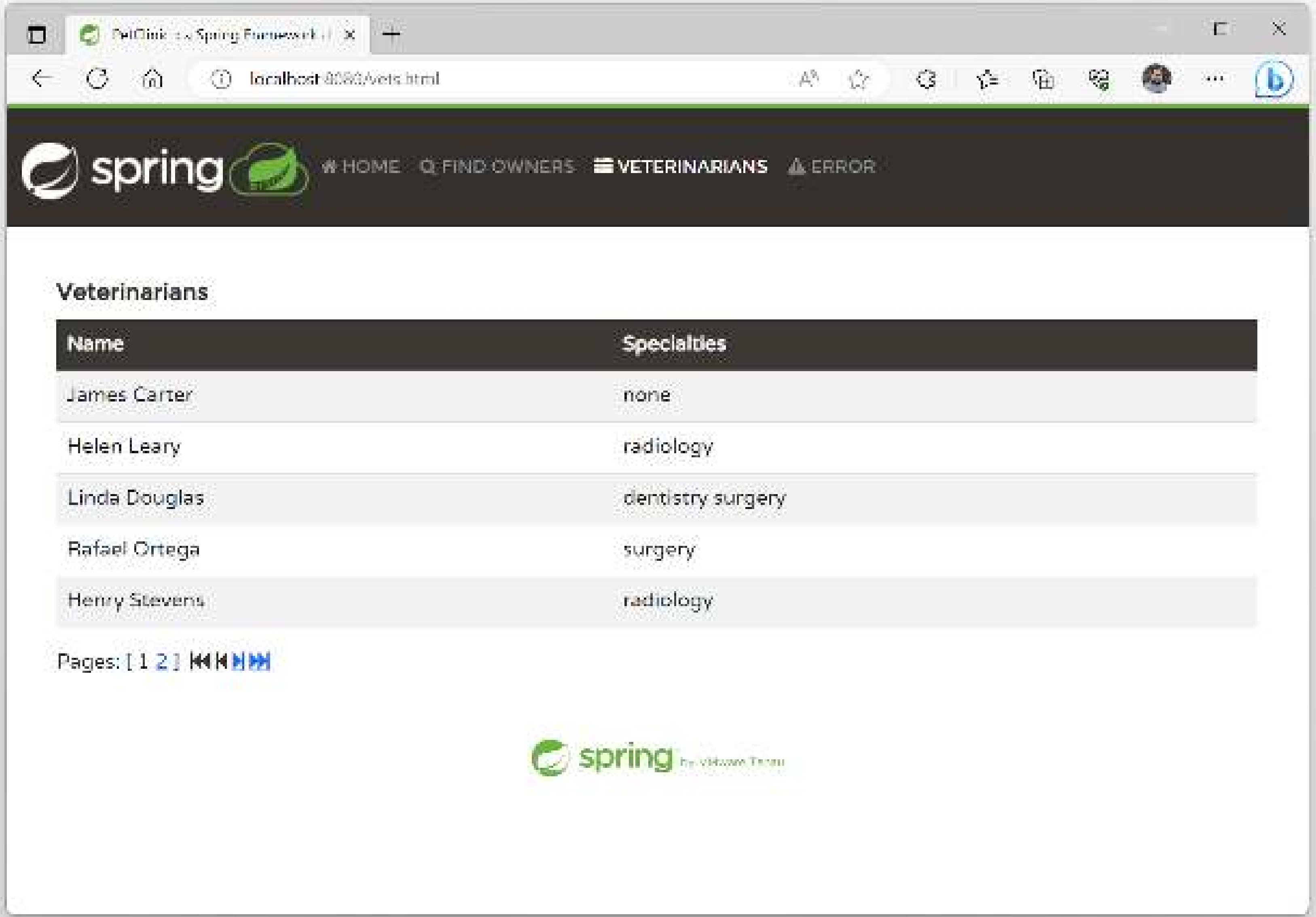
Agenda

Agenda

- Spring PetClinic & Baseline for Comparison
- Java Optimizations
- Spring Boot Optimizations
- Application Optimizations
- Other Runtimes
- Conclusions
- A Few Simple Optimizations Applied (OpenJDK Example)

Spring PetClinic


PetClinic :: a Spring Framework d
localhost:8080
spring
HOME
FIND OWNERS
VETERINARIANS
ERROR
Welcome
spring by VMware Tanzu



Veterinarians

Name	Specialties
James Carter	none
Helen Leary	radiology
Linda Douglas	dentistry surgery
Rafael Ortega	surgery
Henry Stevens	radiology

Pages: [1 2]

Spring Petclinic Community

- spring-framework-petclinic
- spring-petclinic-angular(js)
- spring-petclinic-rest
- spring-petclinic-graphql
- spring-petclinic-microservices
- spring-petclinic-data-jdbc
- spring-petclinic-cloud
- spring-petclinic-mustache
- spring-petclinic-kotlin
- spring-petclinic-reactive
- spring-petclinic-hilla
- spring-petclinic-angularjs
- spring-petclinic-vaadin-flow
- spring-petclinic-reactjs
- spring-petclinic-htmx
- spring-petclinic-istio
- …

Projects on GitHub: https://github.com/spring-petclinic

NO!

The official **Spring PetClinic!** 🐾🏥

Which is based on **Spring Boot**, Caffeine, Thymeleaf, **Spring Data JPA**, H2 and **Spring MVC** ...

Project on GitHub: https://github.com/spring-projects/spring-petclinic

Optimizing Experiments

Baseline

Technology Stack

- OCI Container (Buildpacks)
- Java JDK 17 LTS
- Spring Boot 3.1.4
- DB Migration with SQL Scripts

Examination

- Build Time
- Startup Time
- Resource Usage
- Container Image Size
- Throughput

Buildpacks.io

paketo

buildpacks

Your app,
in your favorite language,
ready to run in the cloud

```
Setting Active Processor Count to 4
Calculating JVM memory based on 16965780K available memory
For more information on this calculation, see https://paketo.io/docs/reference/java-reference/#memory-calculator
Calculated JVM Memory Configuration: -XX:MaxDirectMemorySize=10M -Xmx16335617K -XX:MaxMetaspaceSize=118162K -XX:ReservedCodeCacheSize=240M -Xss1M (Total Memory: 16965780K, Thread Count: 250, Loaded Class Count: 18448, Headroom: 0%)
Enabling Java Native Memory Tracking
Adding 137 container CA certificates to JVM truststore
Spring Cloud Bindings Enabled
Picked up JAVA_TOOL_OPTIONS: -Djava.security.properties=/layers/paketo-buildpacks_bellsoft-liberica/java-security-properties/java-security.properties -XX:+ExitOnOutOfMemoryError
-XX:ActiveProcessorCount=4 -XX:MaxDirectMemorySize=10M -Xmx16335617K -XX:MaxMetaspaceSize=118162K -XX:ReservedCodeCacheSize=240M -Xss1M
-XX:+UnlockDiagnosticVMOptions -XX:NativeMemoryTracking=summary -XX:+PrintNMTStatistics -Dorg.springframework.cloud.bindings.boot.enable=true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 |   |   |   |___  |   | |     |_    |       |   | | |   |   |     |_    ) ) ) )
 |___|   |_______| |___| |_______|_______|___|_|  |__|___|_______|  / / / /
 ==================================================================/_/_/_/

:: Built with Spring Boot :: 3.1.4


2023-08-23T17:17:37.209Z  INFO 1 --- [           main] o.s.s.petclinic.PetClinicApplication     : Starting PetClinicApplication v3.1.4-SNAPSHOT using Java 17.0.8 with PID 1 (/workspace/BOOT-INF/classes started by cnb in /workspace)
2023-08-23T17:17:37.212Z  INFO 1 --- [           main] o.s.s.petclinic.PetClinicApplication     : No active profile set, falling back to 1 default profile: "default"
2023-08-23T17:17:37.927Z  INFO 1 --- [           main] .s.d.r.c.RepositoryConfigurationDelegate : Bootstrapping Spring Data JPA repositories in DEFAULT mode.
2023-08-23T17:17:37.968Z  INFO 1 --- [           main] .s.d.r.c.RepositoryConfigurationDelegate : Finished Spring Data repository scanning in 36 ms. Found 2 JPA repository interfaces.
2023-08-23T17:17:38.379Z  INFO 1 --- [           main] o.s.b.w.embedded.tomcat.TomcatWebServer  : Tomcat initialized with port(s): 8080 (http)
2023-08-23T17:17:38.386Z  INFO 1 --- [           main] o.apache.catalina.core.StandardService   : Starting service [Tomcat]
2023-08-23T17:17:38.386Z  INFO 1 --- [           main] o.apache.catalina.core.StandardEngine    : Starting Servlet engine: [Apache Tomcat/10.1.10]
2023-08-23T17:17:38.445Z  INFO 1 --- [           main] o.a.c.c.C.[Tomcat].[localhost].[/]       : Initializing Spring embedded WebApplicationContext
2023-08-23T17:17:38.447Z  INFO 1 --- [           main] w.s.c.ServletWebServerApplicationContext : Root WebApplicationContext: initialization completed in 1202 ms
2023-08-23T17:17:38.613Z  INFO 1 --- [           main] com.zaxxer.hikari.HikariDataSource       : HikariPool-1 - Starting...
2023-08-23T17:17:38.768Z  INFO 1 --- [           main] com.zaxxer.hikari.pool.HikariPool        : HikariPool-1 - Added connection conn0: url=jdbc:h2:mem:62f6cba7-d5f4-4c9b-8d3b-f66ce0f168e1 user=SA
2023-08-23T17:17:38.770Z  INFO 1 --- [           main] com.zaxxer.hikari.HikariDataSource       : HikariPool-1 - Start completed.
2023-08-23T17:17:38.899Z  INFO 1 --- [           main] o.hibernate.jpa.internal.util.LogHelper  : HHH000204: Processing PersistenceUnitInfo [name: default]
2023-08-23T17:17:38.931Z  INFO 1 --- [           main] org.hibernate.Version                    : HHH000412: Hibernate ORM core version 6.2.5.Final
2023-08-23T17:17:38.933Z  INFO 1 --- [           main] org.hibernate.cfg.Environment            : HHH000406: Using bytecode reflection optimizer
2023-08-23T17:17:39.017Z  INFO 1 --- [           main] o.h.b.i.BytecodeProviderInitiator        : HHH000021: Bytecode provider name : bytebuddy
2023-08-23T17:17:39.107Z  INFO 1 --- [           main] o.s.o.j.p.SpringPersistenceUnitInfo      : No LoadTimeWeaver setup: ignoring JPA class transformer
2023-08-23T17:17:39.330Z  INFO 1 --- [           main] o.h.b.i.BytecodeProviderInitiator        : HHH000021: Bytecode provider name : bytebuddy
2023-08-23T17:17:39.915Z  INFO 1 --- [           main] o.h.e.t.j.p.i.JtaPlatformInitiator       : HHH000490: Using JtaPlatform implementation: [org.hibernate.engine.transaction.jta.platform.internal.NoJtaPlatform]
2023-08-23T17:17:39.917Z  INFO 1 --- [           main] j.LocalContainerEntityManagerFactoryBean : Initialized JPA EntityManagerFactory for persistence unit 'default'
2023-08-23T17:17:40.090Z  INFO 1 --- [           main] o.s.d.j.r.query.QueryEnhancerFactory     : Hibernate is in classpath; If applicable, HQL parser will be used.
2023-08-23T17:17:40.881Z  INFO 1 --- [           main] o.s.b.a.e.web.EndpointLinksResolver      : Exposing 13 endpoint(s) beneath base path '/actuator'
2023-08-23T17:17:40.953Z  INFO 1 --- [           main] o.s.b.w.embedded.tomcat.TomcatWebServer  : Tomcat started on port(s): 8080 (http) with context path ''
2023-08-23T17:17:40.967Z  INFO 1 --- [           main] o.s.s.petclinic.PetClinicApplication     : Started PetClinicApplication in 4.069 seconds (process running for 4.351)
```

1000x Better **than your regular Dockerfile** 📶 **…**

… more secure 🔒 **and maintained by the Buildpacks community.**

See also: https://buildpacks.io/ and https://www.cncf.io/projects/buildpacks/

Startup Reporting

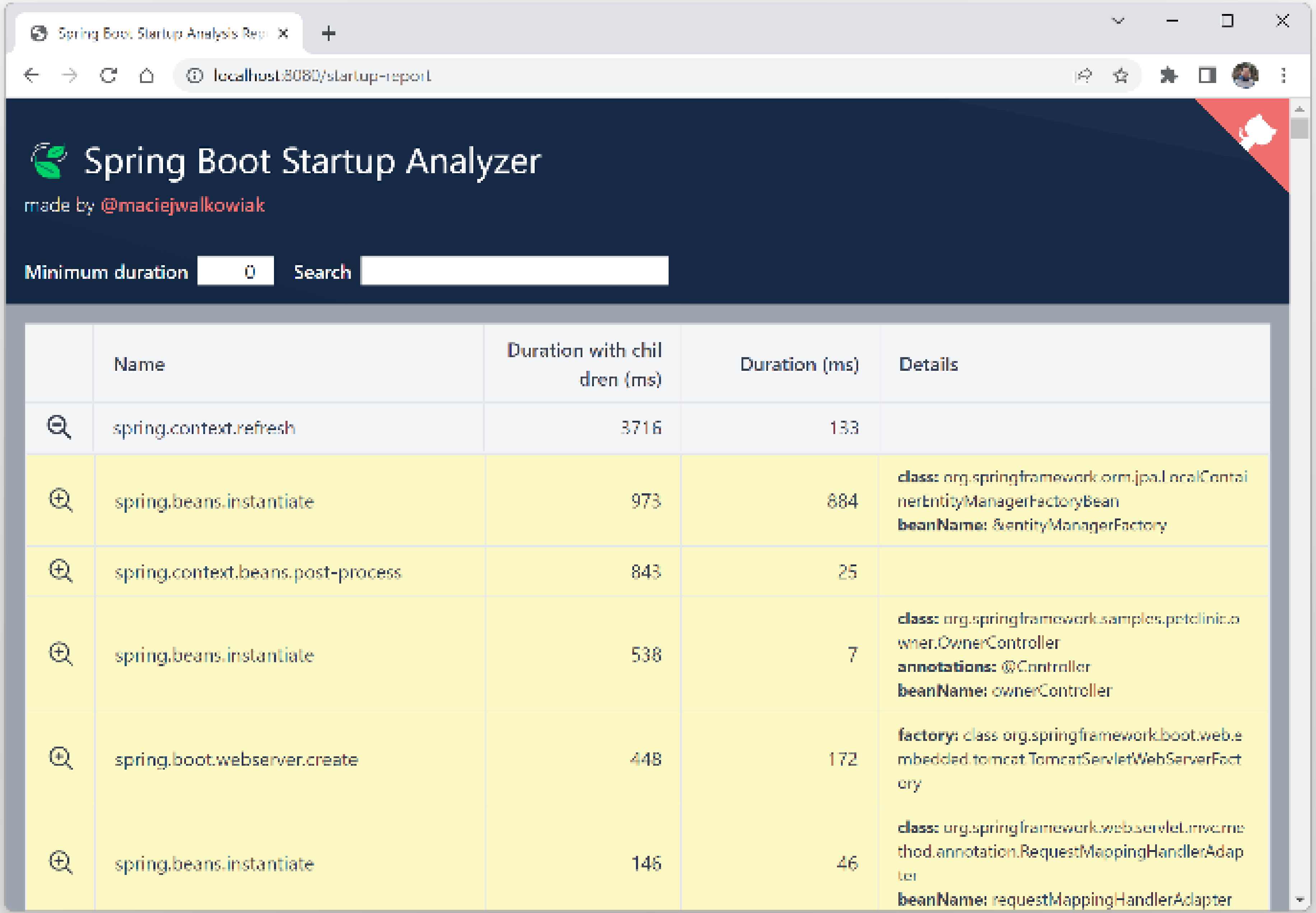
Spring Boot Startup Report

By Maciej Walkowiak

- Startup report available in runtime as an interactive HTML page
- Generating startup reports in integration tests
- Flame chart for timings
- Search by class or an annotation

```
<dependency>
    <groupId>com.maciejwalkowiak.spring</groupId>
    <artifactId>spring-boot-startup-report</artifactId>
    <version>0.2.0</version>
    <optional>true</optional>
</dependency>
```

https://github.com/maciejwalkowiak/spring-boot-startup-report

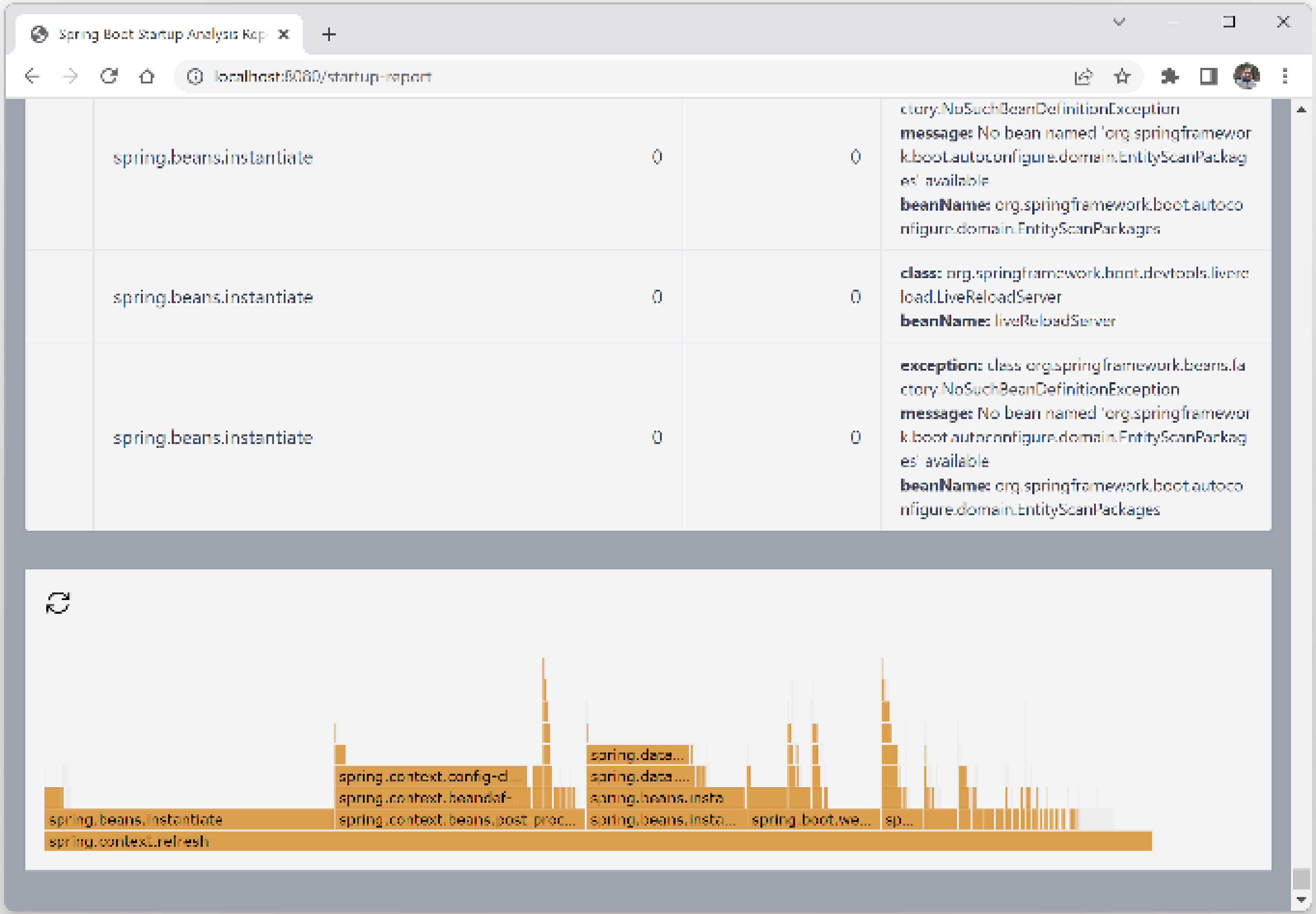


Spring Boot Startup Analyzer

made by @maciejwalkowiak

Minimum duration 0 Search

	Name	Duration with children (ms)	Duration (ms)	Details
	spring.context.refresh	3716	133	
	spring.beans.instantiate	973	884	**class:** org.springframework.orm.jpa.LocalContainerEntityManagerFactoryBean **beanName:** &entityManagerFactory
	spring.context.beans.post-process	843	25	
	spring.beans.instantiate	538	7	**class:** org.springframework.samples.petclinic.owner.OwnerController **annotations:** @Controller **beanName:** ownerController
	spring.boot.webserver.create	448	172	**factory:** class org.springframework.boot.web.embedded.tomcat.TomcatServletWebServerFactory
	spring.beans.instantiate	146	46	**class:** org.springframework.web.servlet.mvc.method.annotation.RequestMappingHandlerAdapter **beanName:** requestMappingHandlerAdapter



Spring Boot Startup Analysis Rep

localhost:8080/startup-report

	spring.beans.instantiate	0	0	ctory.NoSuchBeanDefinitionException **message:** No bean named 'org.springframework.boot.autoconfigure.domain.EntityScanPackages' available **beanName:** org.springframework.boot.autoconfigure.domain.EntityScanPackages
	spring.beans.instantiate	0	0	**class:** org.springframework.boot.devtools.livereload.LiveReloadServer **beanName:** liveReloadServer
	spring.beans.instantiate	0	0	**exception:** class org.springframework.beans.factory.NoSuchBeanDefinitionException **message:** No bean named 'org.springframework.boot.autoconfigure.domain.EntityScanPackages' available **beanName:** org.springframework.boot.autoconfigure.domain.EntityScanPackages

Benchmarks

Benchmarks

- Build
  - Maven build time
  - Artifact / Container Image size
- Startup
  - Startup time
  - Memory usage
- Throughput & Latency
  - wrk2 -t4 -c200 -d60s -R2000 --latency
  - 1 min warmup, 1min measurement
  - Docker container with 4 vCPU and 1 GB RAM

No Optimizing - Baseline

No Optimizing - Baseline JDK 17

- Spring PetClinic (no adjustments)
- Bellsoft Liberica JDK 17.0.8
- Java Memory Calculator

```
sdk use java 17.0.8-librca

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms

No Optimizing - Baseline JDK 21

- Spring PetClinic (JDK 21 adjustments)
- Bellsoft Liberica JDK 21.0.0
- Java Memory Calculator

```
sdk use java 21-librca

mvn -Djava.version=21 spring-boot:build-image \
    -Dspring-boot.build-image.imageName=spring-petclinic:3.1.4-SNAPSHOT-jdk20

docker run -p 8080:8080 -t spring-petclinic:3.1.4-SNAPSHOT-jdk20
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
62s	368MB	3.915s	277MB	1992/s	463MB	30ms	56ms	91ms

-XX:TieredStopAtLevel=1

-XX:TieredStopAtLevel=1

The tiered compilation is enabled by default since Java 8. Unless explicitly specified, the JVM decides which JIT compiler to use based on our CPU. For multi-core processors or 64-bit VMs, the JVM will select C2.

To disable C2 and only use the C1 compiler with no profiling overhead, we can apply the `-XX:TieredStopAtLevel=1` parameter.

```
docker run -p 8080:8080 -e "JAVA_TOOL_OPTIONS=-XX:TieredStopAtLevel=1" \
  -t spring-petclinic:3.1.4-SNAPSHOT
```

It will slow down the JIT later at the expense of the saved startup time!

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
-	-	3.375s	203MB	1441/s	321MB	18340ms	19990ms	21353ms

Lazy Spring Beans

Lazy Spring Beans (1)

Configure lazy initialization across the whole application. A Spring Boot property makes all Beans lazy by default and only initializes them when they are needed. `@Lazy` can be used to override this behavior with e.g. `@Lazy(false)`.

```
docker run -p 8080:8080  \
  -e spring.main.lazy-initialization=true  \
  -e spring.data.jpa.repositories.bootstrap-mode=lazy \
  -t spring-petclinic:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
-	-	2.182s	235MB	1996/s	441MB	35ms	75ms	130ms

Lazy Spring Beans (2)

Pros

- Faster startup useful in cloud environments
- Application startup is a CPU-intensive task. Spreading the load over time

Cons

- The initial requests may take more time
- Class loading issues and misconfigurations unnoticed at startup
- Beans creation errors only be found at the time of loading the bean

No Spring Boot Actuators

No Spring Boot Actuators

Don’t use actuators if you can afford not to. 😊

- No. of Spring Beans
  - Spring Pet Clinic with Actuators: 415
  - Spring Pet Clinic no Actuators: 270 🔥

```
sdk use java 17.0.8-librca

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-no-actuator:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
52.8s	313MB	3.445s	260MB	1996/s	431MB	36ms	62ms	94ms

Fixing Spring Boot Config Location

Fixing Spring Boot Config Location

Fix the location of the Spring Boot config file(s).
Considered in the following order (`application.properties` and `YAML` variants):

- Application properties packaged inside your jar
- Profile-specific application properties packaged inside your jar
- Application properties outside of your packaged jar
- Profile-specific application properties outside of your packaged jar

```
docker run -p 8080:8080 -e spring.config.location=classpath:application.properties \
  -t spring-petclinic:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
-	-	3.931s	292MB	1994/s	454MB	28ms	54ms	103ms

Disabling JMX

Disabling JMX

JMX is `spring.jmx.enabled=false` by default in Spring Boot since 2.2.0 and later. Setting `BPL_JMX_ENABLED=true` and `BPL_JMX_PORT=9999` on the container will add the following arguments to the `java` command.

```
-Djava.rmi.server.hostname=127.0.0.1
-Dcom.sun.management.jmxremote.authenticate=false
-Dcom.sun.management.jmxremote.ssl=false
-Dcom.sun.management.jmxremote.port=9999
-Dcom.sun.management.jmxremote.rmi.port=9999
```

```
docker run -p 8080:8080 -p 9999:9999 \
  -e BPL_JMX_ENABLED=false \
  -e BPL_JMX_PORT=9999 \
  -e spring.jmx.enabled=false \
  -t spring-petclinic:3.1.4-SNAPSHOT
```

I ❤️

Spring Boot 🍃 & Buildpacks

Dependency Cleanup

Dependency Cleanup (2)

DepClean detects and removes all the unused dependencies declared in the `pom.xml` file of a project or imported from its parent. It does not touch the original `pom.xml` file.

```
<plugin>
  <groupId>se.kth.castor</groupId>
  <artifactId>depclean-maven-plugin</artifactId>
  <version>2.0.6</version>
  <executions>
    <execution>
      <goals>
        <goal>depclean</goal>
      </goals>
    </execution>
  </executions>
</plugin>
```

```
mvn se.kth.castor:depclean-maven-plugin:2.0.6:depclean -DfailIfUnusedDirect=true -DignoreScopes=provided,test,runtime,system,import
```

```
[INFO] Starting DepClean dependency analysis
-------------------------------------------------------
 D E P C L E A N   A N A L Y S I S   R E S U L T S
-------------------------------------------------------
USED DIRECT DEPENDENCIES [5]:
        jakarta.xml.bind:jakarta.xml.bind-api:4.0.0:compile (124 KB)
        org.springframework.boot:spring-boot-testcontainers:3.1.4:test (85 KB)
        javax.cache:cache-api:1.1.1:compile (50 KB)
        ...
USED TRANSITIVE DEPENDENCIES [22]:
        org.springframework:spring-core:6.0.10:compile (1 MB)
        org.springframework.boot:spring-boot-autoconfigure:3.1.4:compile (1 MB)
        org.springframework:spring-web:6.0.10:compile (1 MB)
        org.springframework.boot:spring-boot:3.1.4:compile (1 MB)
        org.springframework.data:spring-data-commons:3.1.4:compile (1 MB)
        org.assertj:assertj-core:3.24.2:test (1 MB)
        org.springframework:spring-context:6.0.10:compile (1 MB)
        org.springframework.data:spring-data-jpa:3.1.4:compile (1 MB)
        ...
USED INHERITED DIRECT DEPENDENCIES [0]:
USED INHERITED TRANSITIVE DEPENDENCIES [0]:
POTENTIALLY UNUSED DIRECT DEPENDENCIES [15]:
        com.h2database:h2:2.1.214:runtime (2 MB)
        com.mysql:mysql-connector-j:8.0.33:runtime (2 MB)
        org.webjars.npm:bootstrap:5.2.3:compile (1 MB)
        org.postgresql:postgresql:42.6.0:runtime (1 MB)
        com.github.ben-manes.caffeine:caffeine:3.1.6:compile (734 KB)
        org.webjars.npm:font-awesome:4.7.0:compile (665 KB)
        ...
POTENTIALLY UNUSED TRANSITIVE DEPENDENCIES [87]:
        org.testcontainers:testcontainers:1.18.3:test (11 MB)
        org.hibernate.orm:hibernate-core:6.2.5.Final:compile (10 MB)
        net.bytebuddy:byte-buddy:1.14.5:runtime (3 MB)
        org.apache.tomcat.embed:tomcat-embed-core:10.1.10:compile (3 MB)
        org.aspectj:aspectjweaver:1.9.19:compile (1 MB)
        com.github.docker-java:docker-java-transport-zerodep:3.3.0:test (1 MB)
        net.java.dev.jna:jna:5.12.1:test (1 MB)
        com.fasterxml.jackson.core:jackson-databind:2.15.2:compile (1 MB)
        org.hibernate.validator:hibernate-validator:8.0.0.Final:compile (1 MB)
        org.apache.commons:commons-compress:1.23.0:test (1 MB)
        org.thymeleaf:thymeleaf:3.1.4.RELEASE:compile (915 KB)
        ...
POTENTIALLY UNUSED INHERITED DIRECT DEPENDENCIES [0]:
POTENTIALLY UNUSED INHERITED TRANSITIVE DEPENDENCIES [0]:
[INFO] Analysis done in 0min 8s
```

Dependency Cleanup (2)

But there are some challenges:

- Spring uses reflection to load classes
- Spring Boot uses `META-INF/spring-boot/org.springframework.boot.autoconfigure.AutoConfiguration` to load classes
- Spring Context Indexer uses `META-INF/spring.components`
- Component & Entity Scanning through Classpath Scanning

```
sdk use java 17.0.8-librca

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-depclean:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
65s	307MB	3.299s	244MB	1997/s	415MB	31ms	65ms	104ms

Ahead-of-Time Processing (AOT)

Ahead-of-Time Processing (AOT) (1)

Spring AOT is a process that analyzes your application at build-time and generates an optimized version of it.

As the `BeanFactory` is fully prepared at build-time, conditions are also evaluated.

```xml
<plugin>
    <groupId>org.springframework.boot</groupId>
    <artifactId>spring-boot-maven-plugin</artifactId>
    <executions>
        <execution>
            <id>process-aot</id>
            <goals>
                <goal>process-aot</goal>
            </goals>
        </execution>
    </executions>
</plugin>
```

Ahead-of-Time Processing (AOT) (2)

We are creating a new container image with the AOT-processed application.

```
sdk use java 17.0.8-librca

mvn spring-boot:build-image

docker run -e spring.aot.enabled=true -p 8080:8080 -t spring-petclinic-aot:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
59.6s	317MB	3.916s	283MB	1996/s	447MB	33ms	57ms	82ms

JLink

JLink (1)

Jlink assembles and optimizes a set of modules and their dependencies into a custom runtime image for your application.

```
$ jlink \
  --add-modules java.base, ... \
  --strip-debug \
  --no-man-pages \
  --no-header-files \
  --compress=2 \
  --output /javaruntime
```

```
$ /javaruntime/bin/java HelloWorld
Hello, World!
```

JLink (2)

```xml
<plugin>
  <groupId>org.springframework.boot</groupId>
  <artifactId>spring-boot-maven-plugin</artifactId>
    <configuration>
        <image>
            <env>
                <BP_JVM_JLINK_ENABLED>true</BP_JVM_JLINK_ENABLED>
            </env>
        </image>
    </configuration>
</plugin>
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
68s	249MB	3.944s	281MB	1994/s	451MB	31ms	73ms	116ms

```
sdk use java 17.0.8-

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-jlink:3.1.4-SNAPSHOT
```

JLink (3)

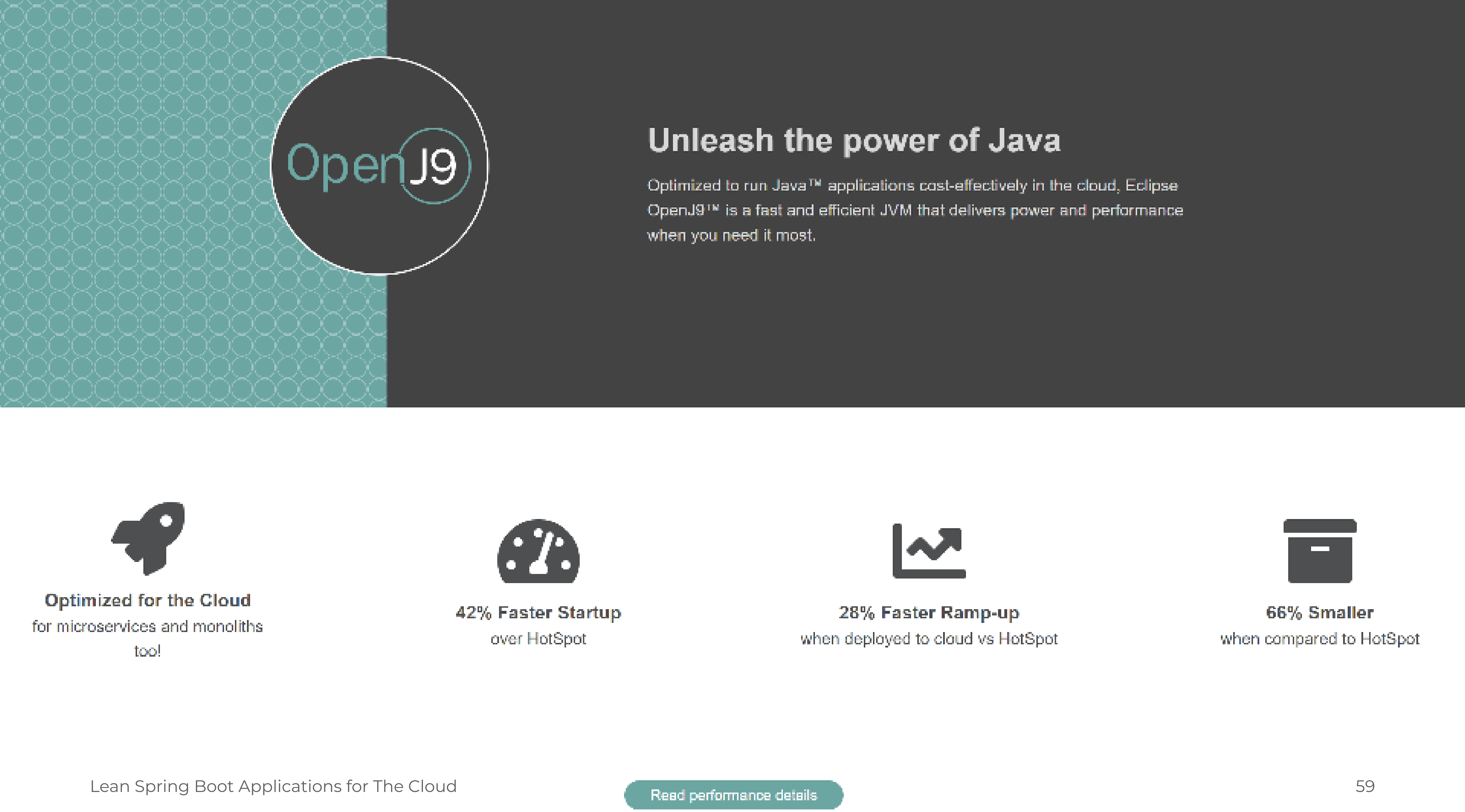
```
<plugin>
  <groupId>org.springframework.boot</groupId>
  <artifactId>spring-boot-maven-plugin</artifactId>
    <configuration>
        <image>
            <env>
                <BP_JVM_JLINK_ENABLED>true</BP_JVM_JLINK_ENABLED>
                <BP_JVM_JLINK_ARGS>--add-modules jdk.management.agent,java.base,java.logging,
                java.xml,jdk.unsupported,java.sql,java.naming,java.desktop,java.management,
                java.security.jgss,java.instrument --compress=2 --no-header-files --no-man-pages
                --strip-debug</BP_JVM_JLINK_ARGS>
            </env>
        </image>
    </configuration>
</plugin>
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
65s	236MB	3.99s	301MB	1996/s	454MB	35ms	78ms	121ms

I ❤️

Spring Boot 🍃 & Buildpacks

Eclipse OpenJ9



Unleash the power of Java

Optimized to run Java™ applications cost-effectively in the cloud, Eclipse OpenJ9™ is a fast and efficient JVM that delivers power and performance when you need it most.

Optimized for the Cloud
for microservices and monoliths too!

42% Faster Startup
over HotSpot

28% Faster Ramp-up
when deployed to cloud vs HotSpot

66% Smaller
when compared to HotSpot

Eclipse OpenJ9

```xml
<plugin>
  <groupId>org.springframework.boot</groupId>
  <artifactId>spring-boot-maven-plugin</artifactId>
  <configuration>
    <image>
        <buildpacks>
            <buildpack>gcr.io/paketo-buildpacks/eclipse-openj9:latest</buildpack>
            <!-- Used to inherit all the other buildpacks -->
            <buildpack>gcr.io/paketo-buildpacks/java:latest</buildpack>
        </buildpacks>
    </image>
  </configuration>
</plugin>
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱ 56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
73s	306MB	6.852s	163MB	1989/s	349MB	46ms	91ms	165ms

```
sdk use java 17.0.8-

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-custom-jvm-openj9:3.1.4-SNAPSHOT
```

Eclipse OpenJ9 Optimized

Eclipse OpenJ9 Optimized Quickstart

`-Xquickstart` causes the JIT compiler to run with a subset of optimizations, which can improve the performance of short-running applications.

Use the `-Xshareclasses` option to enable, disable, or modify class-sharing behavior. Class data sharing is enabled by default for bootstrap classes only, *unless your application is running in a container.*

```
docker run -p 8080:8080 -e "JAVA_TOOL_OPTIONS=-Xshareclasses -Xquickstart" \
  -t spring-petclinic-custom-jvm:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
-	-	5.138s	161MB	1258/s	294MB	23510ms	25330ms	26530ms

Eclipse OpenJ9 Optimized Virtualized

When `-Xtune:virtualized` is used in conjunction with the `-Xshareclasses` option, the JIT compiler is more aggressive with its use of AOT-compiled code compared to setting only `-Xshareclasses`. This action provides additional CPU savings during application start-up and ramp-up, but comes at the expense of an additional small loss in throughput.

```
docker run -p 8080:8080 -e "JAVA_TOOL_OPTIONS=-XX:+IgnoreUnrecognizedVMOptions -XX:+UseContainerSupport -XX:+IdleTuningCompactOnIdle -XX:+IdleTuningGcOnIdle -Xscmx50M -Xshareclasses -Xtune:virtualized" \
  -t spring-petclinic-custom-jvm:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱️56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
-	-	8.632s	190MB	1989/s	342MB	71ms	142ms	235ms

GraalVM

GraalVM

```xml
<plugin>
  <groupId>org.springframework.boot</groupId>
  <artifactId>spring-boot-maven-plugin</artifactId>
  <configuration>
    <image>
        <buildpacks>
            <buildpack>gcr.io/paketo-buildpacks/graalvm:latest</buildpack>
            <!-- Used to inherit all the other buildpacks -->
            <buildpack>gcr.io/paketo-buildpacks/java:latest</buildpack>
        </buildpacks>
    </image>
  </configuration>
</plugin>
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
77.5s	735MB	3.809s	239MB	1996/s	422MB	36ms	62ms	98ms

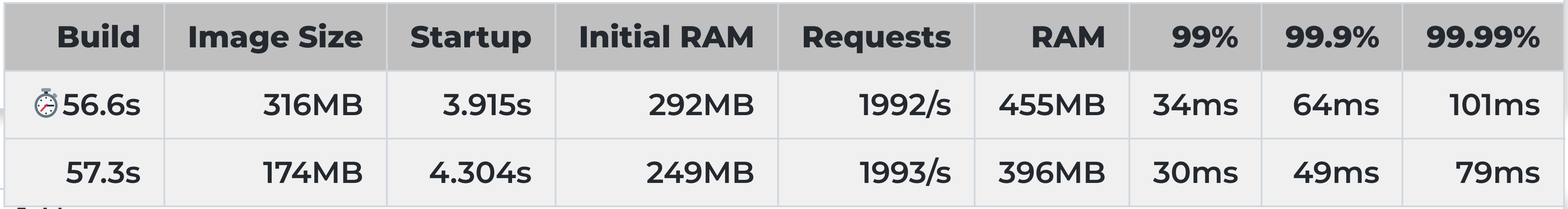
```
sdk use java 17.0.8-

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-custom-jvm-graalvm:3.1.4-SNAPSHOT
```

Other Buildpack Builders

Bellsoft Buildpack Builder

Bellsoft provides an optimized builder for Spring Boot applications. It uses the Bellsoft Alpaquita, Liberica JDK and the musl C library. A glibc version is also available.

```
<plugin>
  <groupId>org.springframework.boot</groupId>
  <artifactId>spring-boot-maven-plugin</artifactId>
  <configuration>
    <image>
      <builder>bellsoft/buildpacks.builder:musl</builder>
    </image>
  </configuration>
</plugin>
```



Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
57.3s	174MB	4.304s	249MB	1993/s	396MB	30ms	49ms	79ms

```
sdk use java 17.0.8-librca

mvn spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-bellsoft-buildpack:3.1.4-SNAPSHOT
```

GraalVM Native Image

GraalVM Native Image

A native image is a technology to build Java code to a standalone executable. This executable includes the application classes, classes from its dependencies, runtime library classes, and statically linked native code from JDK. The JVM is packaged into the native image, so there's no need for any Java Runtime Environment at the target system, but the build artifact is platform-dependent.

```
mvn -Pnative spring-boot:build-image

docker run -p 8080:8080 -t spring-petclinic-native:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱️56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
337s	219MB	0.277s	234MB	1994/s	466MB	114ms	207ms	307ms

CRaC - OpenJDK

CRaC - OpenJDK (1)

CRaC (Checkpoint and Restart in Java) is a feature that allows to checkpoint the state of a Java application and restart it from the checkpointed state.

The application starts within milliseconds!

CRaC - OpenJDK (2)

```
export JAVA_HOME=/opt/openjdk-17-crac+5_linux-x64/
export PATH=$JAVA_HOME/bin:$PATH
```

```
mvn clean verify
```

```
java -XX:CRaCCheckpointTo=crac-files -jar target/spring-petclinic-crac-3.1.4.jar
```

```
jcmd target/spring-petclinic-crac-3.1.4.jar JDK.checkpoint
```

```
java -XX:CRaCRestoreFrom=crac-files
```

CRaC - OpenJDK (3)

CRaC is currently in an experimental state and has the following limitations:

- Works with Spring Boot 3.0 & 3.1
  - Patched Tomcat 10.1.7 is available
- Support for Spring Boot 3.2 is in progress
  - Spring Framework 6.1.0-SNAPSHOT
- Does not work on Windows or on macOS
  - Does not work in Docker containers via WSL (yet)
- But works in VM with Ubuntu 22.04 LTS

Other JVM Vendors have similar features e.g. OpenJ9 with CRIU support.

Virtual Threads

Virtual Threads

A thread is the smallest unit of processing that can be scheduled. It runs concurrently with — and largely independently of — other such units. It's an instance of `java.lang.Thread`. There are two kinds of threads, platform threads and virtual threads.

```
sdk use java 21-librca

mvn spring-boot:build-image

docker run -e spring.threads.virtual.enabled=true \
  -p 8080:8080 -t spring-petclinic-virtual-threads:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱ 56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
62.6s	402MB	4.381s	296MB	1996/s	443MB	20ms	58ms	110ms

Summary

Summary

- No Optimizations with JDK 17 & JDK 20 & JDK 21
- JVM Tuning
- Lazy Spring Beans
- No Spring Boot Actuators
- Fix Spring Boot Config Location
- Disabling JMX
- Dependency Cleanup
- Ahead-of-Time Processing (AOT)
- JLink
- Other JVMs (Eclipse OpenJ9, GraalVM, OpenJDK with CRaC)
- GraalVM Native Image

Conclusions

Conclusions (1)

CPUs

- Your application might not need a full CPU at runtime
- It will need multiple CPUs to start up as quickly as possible (at least 2, 4 are better)
- If you don’t mind a slower startup you could throttle the CPUs down below 4

See: https://spring.io/blog/2018/11/08/spring-boot-in-a-container

Conclusions (2)

Throughput

- Every application is different and has different requirements
- Using proper load testing can help to find the optimal configuration for your application

Conclusions (3)

Other Runtimes

- CRIU Support for OpenJDK and OpenJ9 is promising
- GraalVM Native Image is a great option for Java applications
  - But build times are long
  - The result is different from what you run in your IDE
- Eclipse OpenJ9 is a great option for running apps with less memory
  - But startup times are longer than with HotSpot
- Depending on the distribution, you might get other interesting features
  - Oracle GraalVM Enterprise Edition, Azul Platform Prime, IBM Semeru Runtime, …

Conclusions (4)

Other Ideas

- Using an Obfuscator like ProGuard
- App CDS (Class Data Sharing)
- Importing `AutoConfiguration` classes individually
- Using functional bean definitions
- Spring Context Indexer (removed from Spring Boot 3.2)
- More JVM tuning
- Project Leyden

See also: https://spring.io/blog/2019/01/21/manual-bean-definitions-in-spring-boot

A Few Simple Optimizations Applied

A Few Simple Optimizations Applied (1)

- Dependency Cleanup
  - DB Drivers, Spring Boot Actuator, Jackson, Tomcat Websocket, …
- Bellsoft Buildpack
- JLink
- JVM Parameters (java-memory-calculator)
- Spring AOT
- Lazy Spring Beans
- Fix Spring Boot Config Location

A Few Simple Optimizations Applied (2)

```
sdk use java 17.0.8-librca

mvn spring-boot:build-image

docker run -p 8080:8080 \
  -e spring.aot.enabled=true \
  -e spring.main.lazy-initialization=true \
  -e spring.data.jpa.repositories.bootstrap-mode=lazy \
  -e spring.config.location=classpath:application.properties \
  -t spring-petclinic-optimized:3.1.4-SNAPSHOT
```

Build	Image Size	Startup	Initial RAM	Requests	RAM	99%	99.9%	99.99%
⏱️56.6s	316MB	3.915s	292MB	1992/s	455MB	34ms	64ms	101ms
63s	136MB	1.841s	189MB	1997/s	356MB	27ms	61ms	97ms

Did I miss something? 🧐

Let me/us know! 🙋

... or not! 🙊

Lean Spring Boot

Applications for The Cloud

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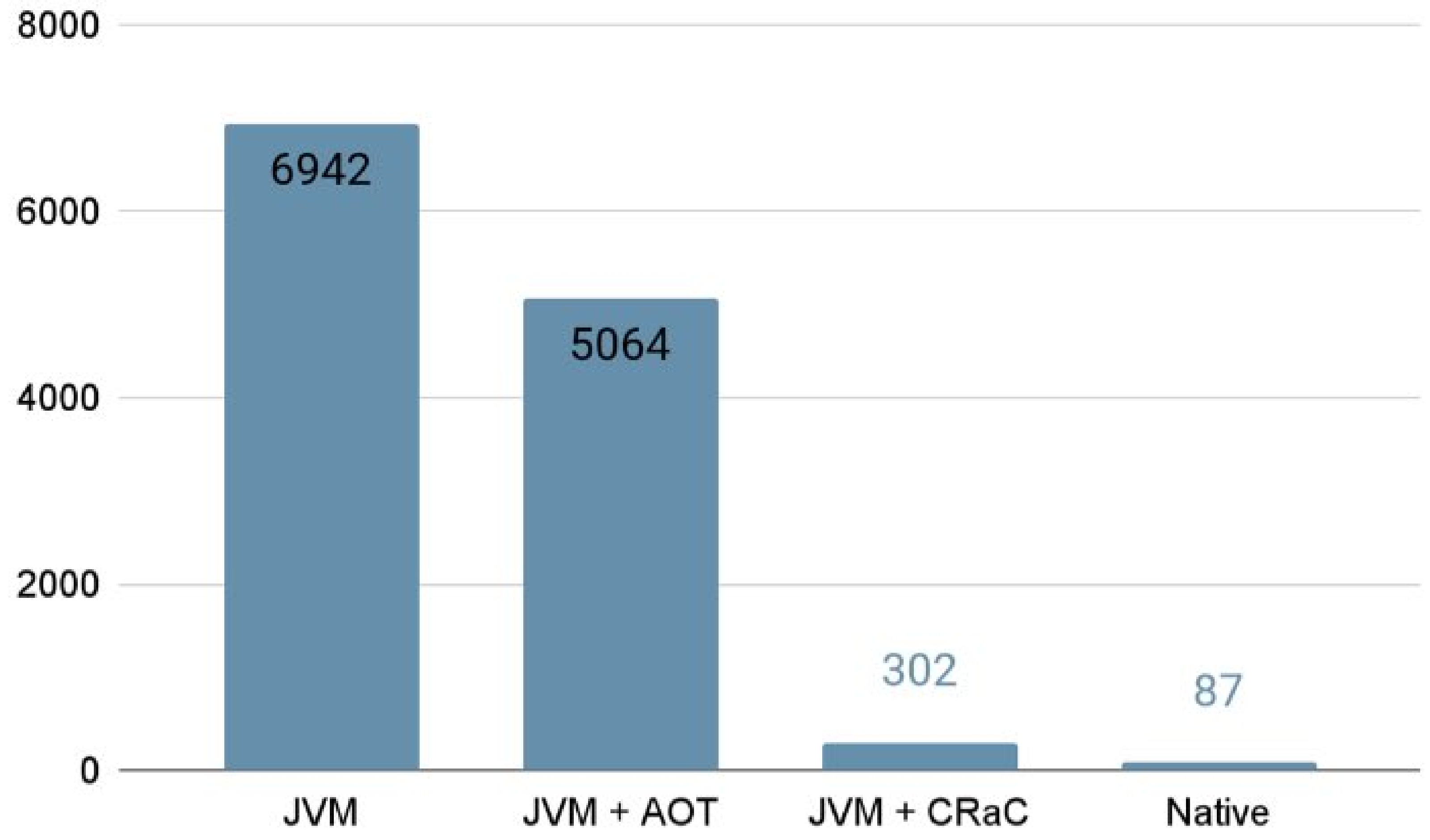
https://github.com/patbaumgartner/lean-spring-boot-applications-for-the-cloud

Container start to application ready (milliseconds)

Webapp on Azure Container Apps with 1 CPU 2G memory



Different tradeoffs

	Instant startup with peak performance	Require upfront deployment and checkpoint storage	Compatibility	Run on low resource devices	Compilation time	Compact packaging	Performance
GraalVM native image	Yes	No	Reachability Metadata	Yes	Slow	Yes	CE / EE
CRaC JVM image	Yes	Yes for now[1]	Regular JVM[2]	No	Fast	JVM + checkpoint image	Regular JVM

[1] Build-time checkpoint could lift this requirement

[2] Can require custom checkpoint handling for specific use cases

https://twitter.com/sdeleuze/status/1659461015719890944