Adopting Java for the Serverless world

from the perspective of the AWS developer

Vadym Kazulkin, ip.labs, JUG Darmstadt , 19 Mai 2022

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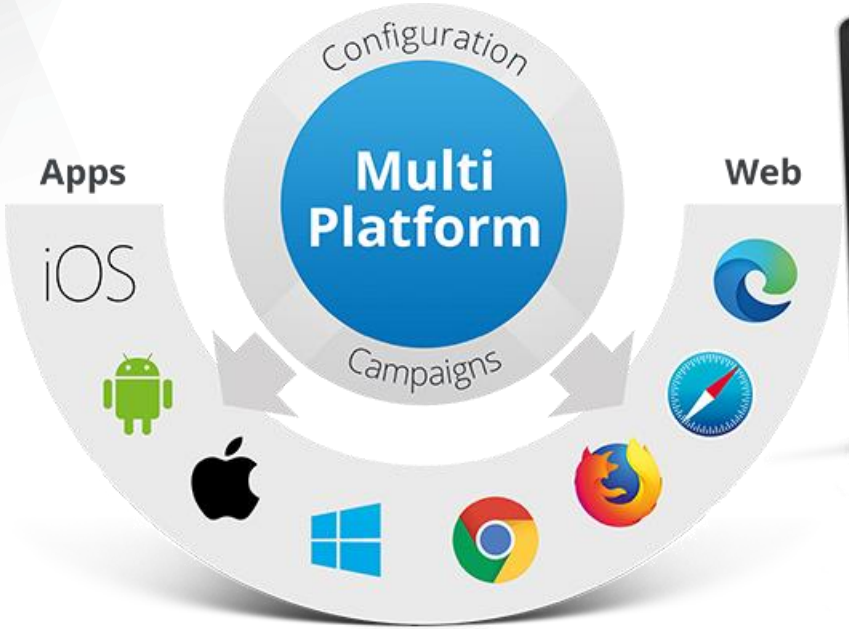
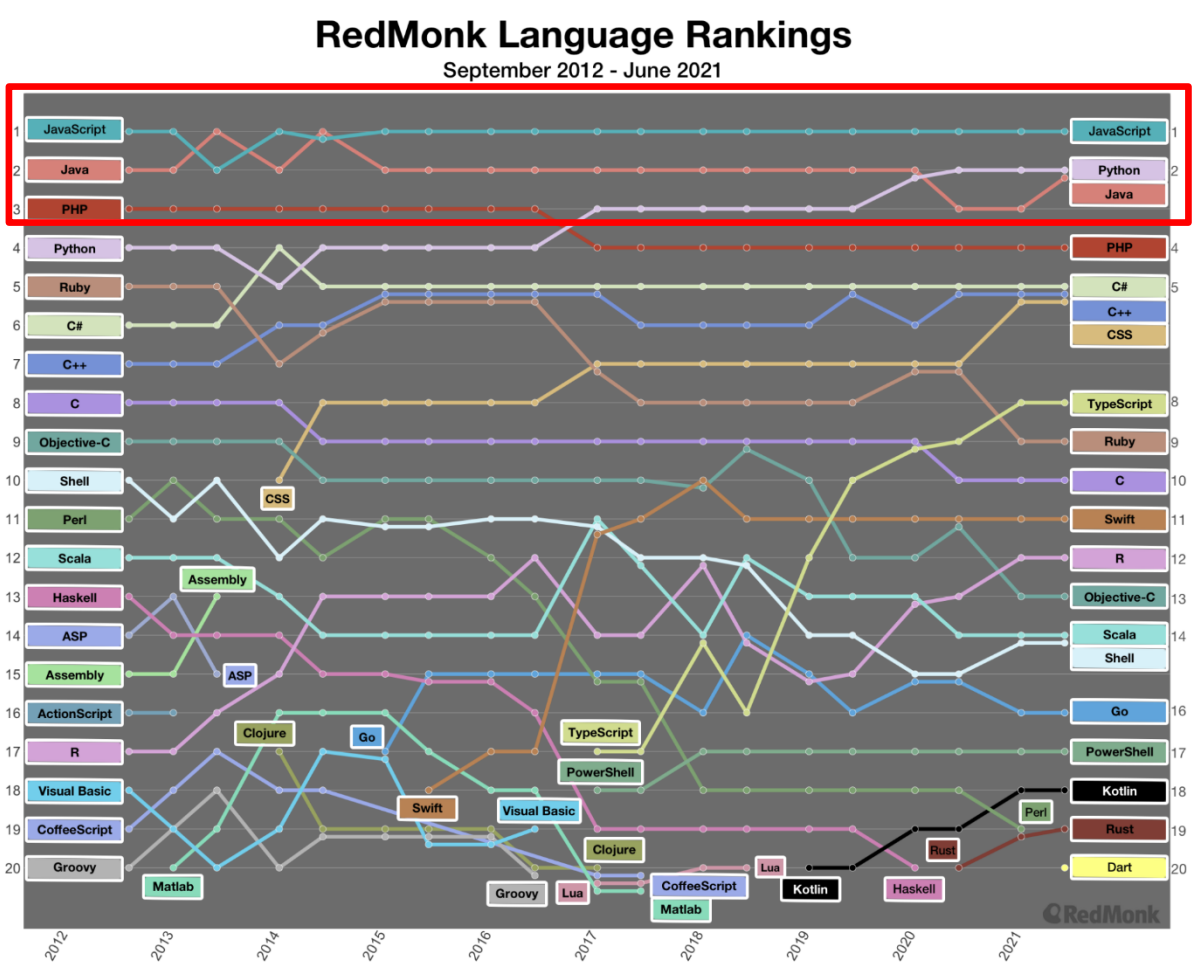


https://www.iplabs.de/

Java popularity

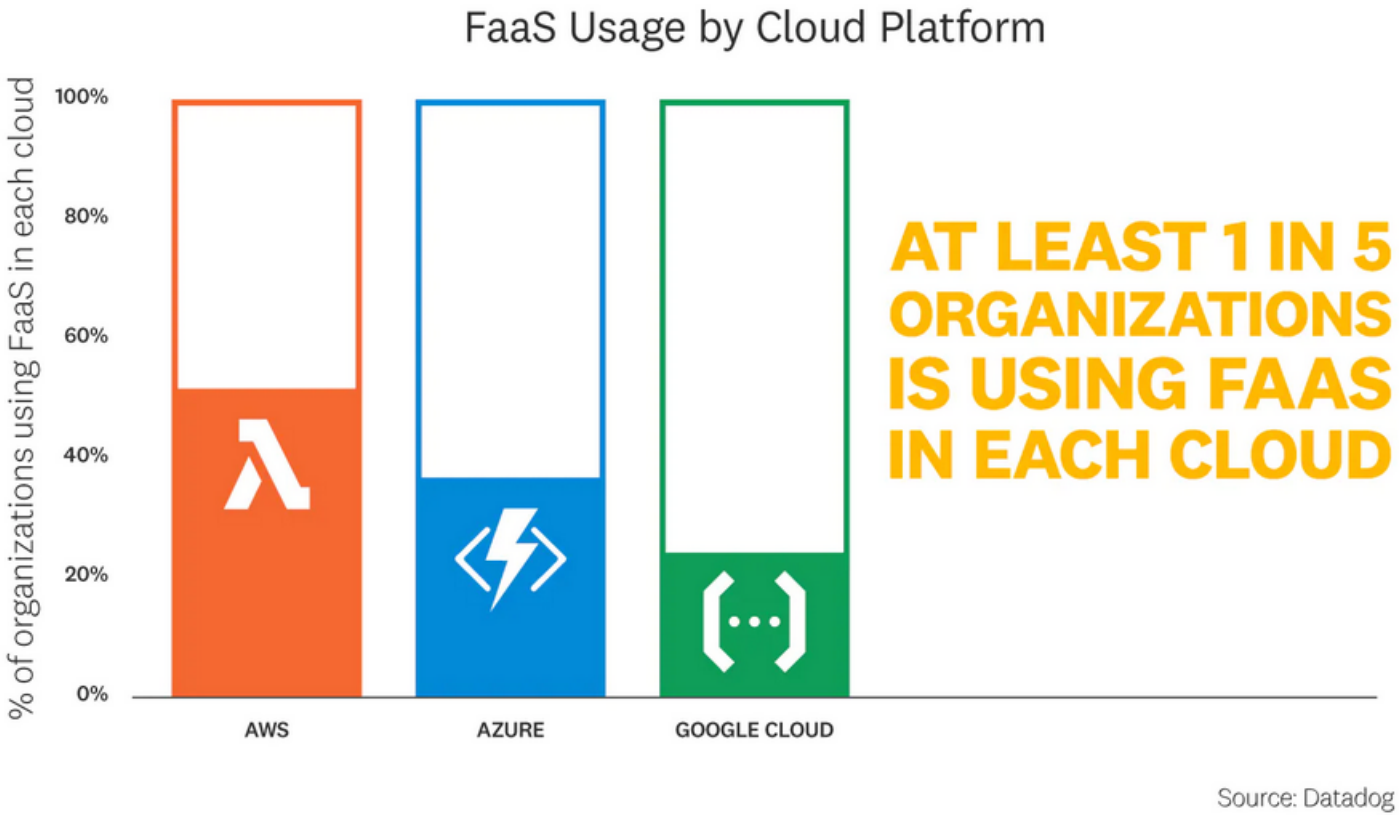


https://redmonk.com/rstephens/2021/08/05/top-20-june-2021/

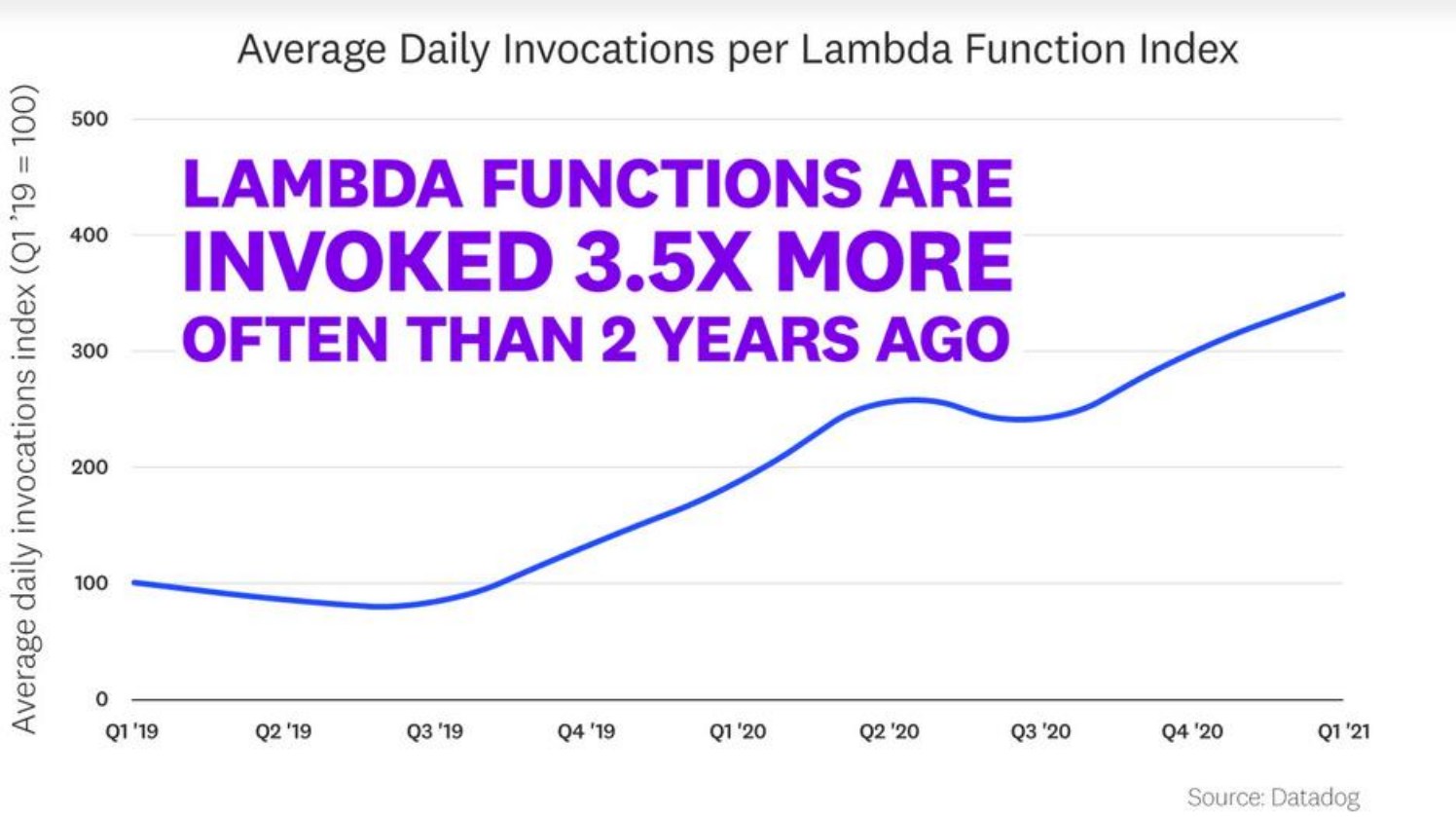
AWS and Serverless

Source: Gartner (July 2021)

2020 Magic Quadrant for Cloud Infrastructure & Platform Services
https://pages.awscloud.com/GLOBAL-multi-DL-gartner-mq-cips-2020-learn.html?pg=LWIAWS
https://aws.amazon.com/de/resources/analyst-reports/gartner-mq-cips-2021/



The State of Serverless 2021
https://www.datadoghq.com/state-of-serverless/



The State of Serverless 2021
https://www.datadoghq.com/state-of-serverless/

Life of the Java Serverless developer on AWS

AWS Java Versions Support

- Java 8
  - With extended long-term support
- Java 11 (since 2019)
- Only Long Term Support (LTS) by AWS
- Current LTS Java version is Java 17
  - Amazon Corrett Support for 17 is released, but not currently available for Lambda

Amazon Corretto

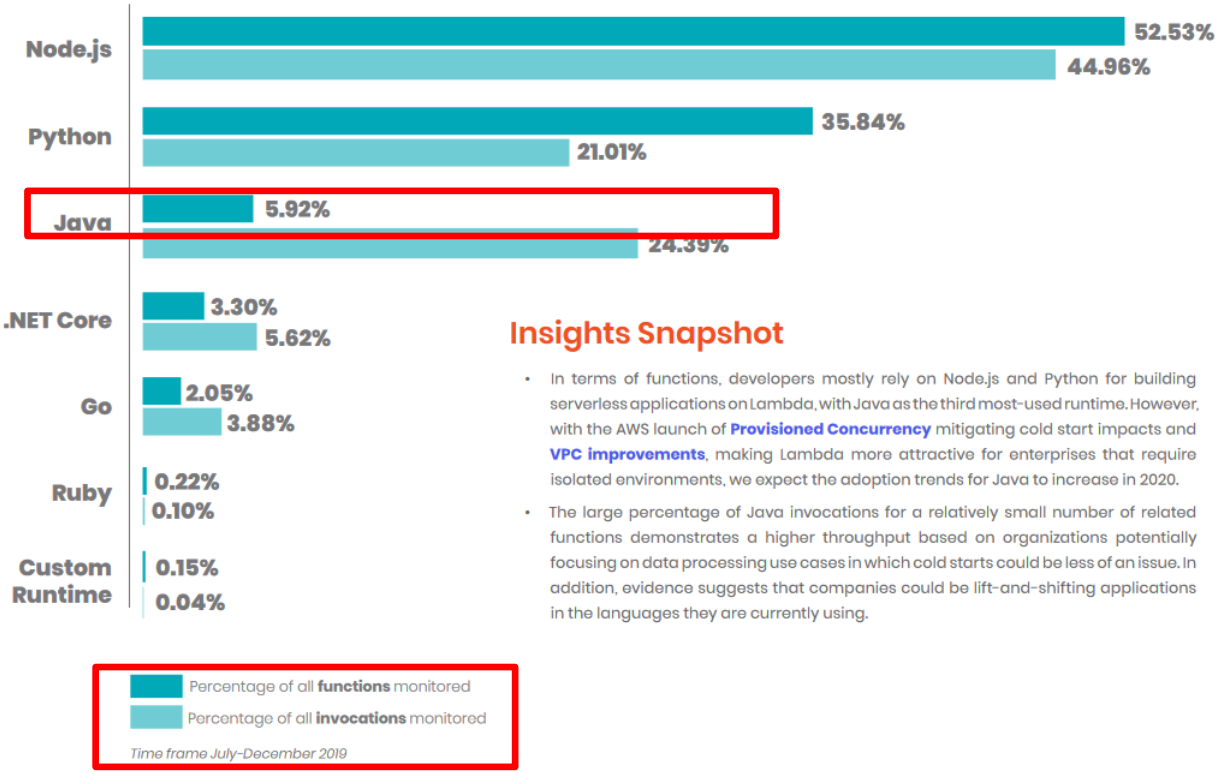
No-cost, multiplatform, production-ready distribution of OpenJDK

Amazon Corretto is a no-cost, multiplatform, production-ready distribution of the Open Java Development Kit (OpenJDK). Corretto comes with long-term support that will include performance enhancements and security fixes. Amazon runs Corretto internally on thousands of production services and Corretto is certified as compatible with the Java SE standard. With Corretto, you can develop and run Java applications on popular operating systems, including Linux, Windows, and macOS.

Java ist very fast and mature programming language…

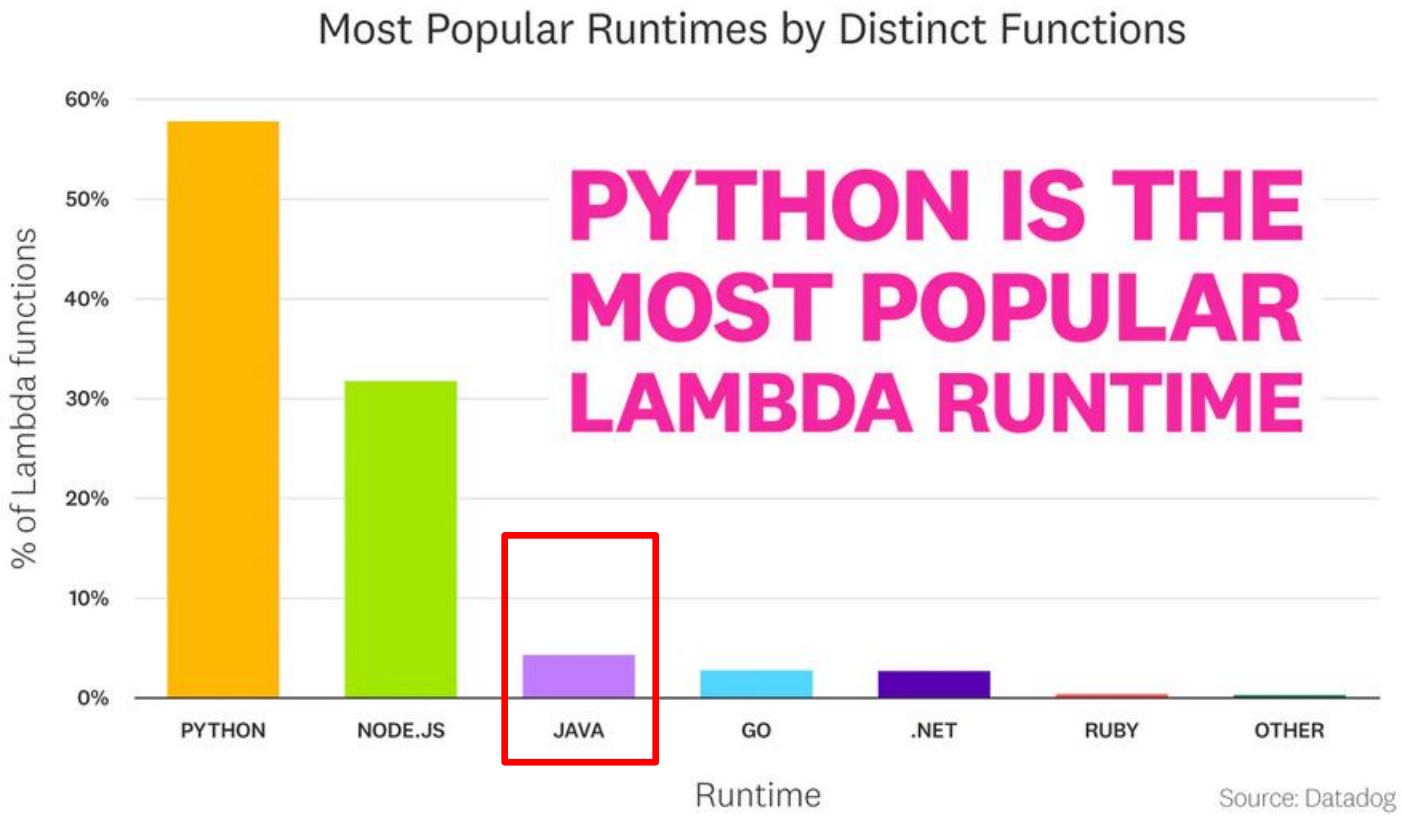
… but Serverless adoption of Java looks like this

Lambda Adoption by Runtime



Insights Snapshot

- In terms of functions, developers mostly rely on Node.js and Python for building serverless applications on Lambda, with Java as the third most-used runtime. However, with the AWS launch of **Provisioned Concurrency** mitigating cold start impacts and **VPC improvements**, making Lambda more attractive for enterprises that require isolated environments, we expect the adoption trends for Java to increase in 2020.
- The large percentage of Java invocations for a relatively small number of related functions demonstrates a higher throughput based on organizations potentially focusing on data processing use cases in which cold starts could be less of an issue. In addition, evidence suggests that companies could be lift-and-shifting applications in the languages they are currently using.



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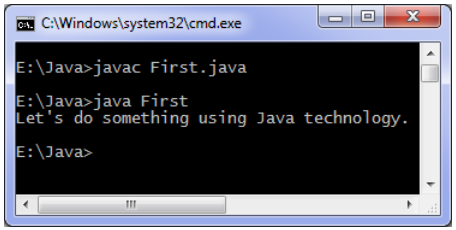
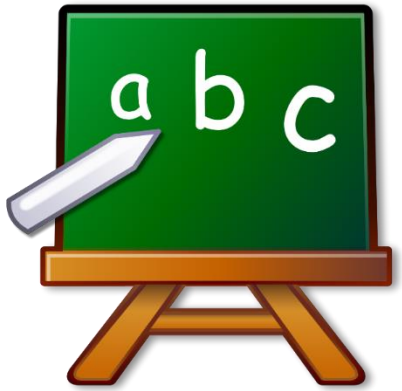


Developers love Java and will be happy to use it for Serverless

But what are the challenges ?

Serverless with Java challenges

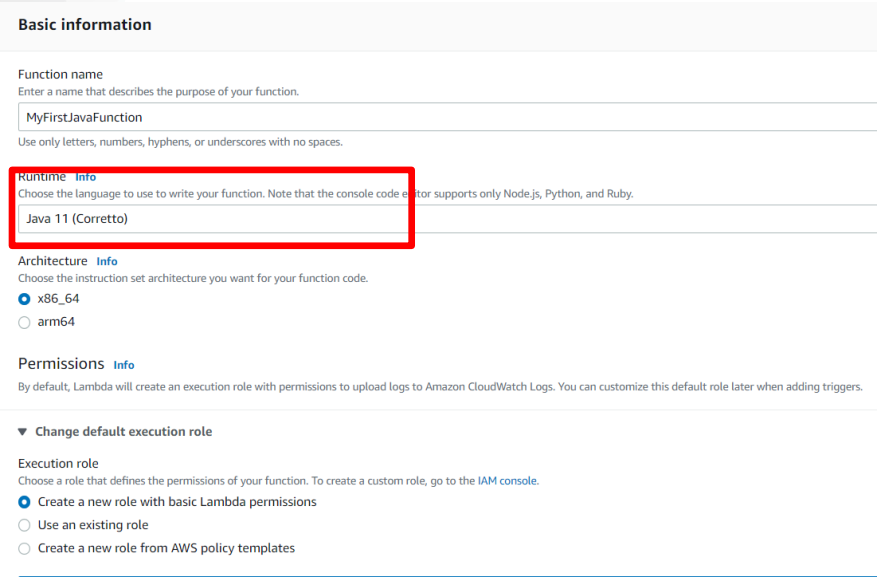
- “cold start” times (latencies)
- memory footprint (high cost in AWS)

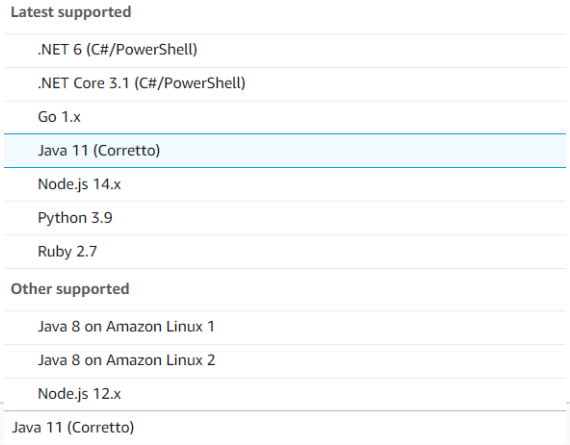


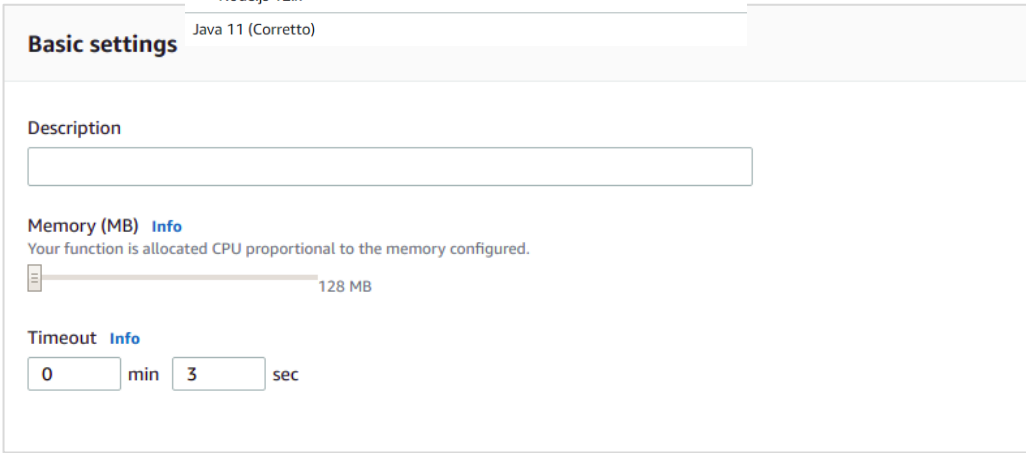
AWS Lambda Basics

Vadym Kazulkin @VKazulkin , ip.labs GmbH

Creating AWS Lambda with Java 1/3







Source https://blog.runscope.com/posts/how-to-write-your-first-aws-lambda-function

Creating AWS Lambda with Java 2/3

```java
import javax.inject.Inject;

import org.slf4j.Logger;
import org.slf4j.LoggerFactory;

import com.amazonaws.services.lambda.runtime.Context;
import com.amazonaws.services.lambda.runtime.RequestHandler;


public class MonthlyInvoiceGeneratorFunction
implements RequestHandler<MonthlyInvoiceRequest, MonthlyInvoiceResponse> {

    private static final Logger LOG = LoggerFactory.getLogger(MonthlyInvoiceGeneratorFunction.class);

    @Inject
    private MonthlyInvoiceGeneratorService monthlyInvoiceGeneratorService;

    @Override
    public MonthlyInvoiceResponse handleRequest(MonthlyInvoiceRequest monthlyInvoiceRequest,
            final Context context) {

        if (LOG.isDebugEnabled()) {
            LOG.debug("request: {}", monthlyInvoiceRequest);
        }
        return this.monthlyInvoiceGeneratorService.generateInvoice(monthlyInvoiceRequest);
    }

}
```

```java
import java.util.function.Function;

import org.slf4j.Logger;
import org.slf4j.LoggerFactory;
import org.springframework.beans.factory.annotation.Autowired;


public class MonthlyInvoiceGeneratorFunction
    implements Function<MonthlyInvoiceRequest, MonthlyInvoiceResponse> {

    private static final Logger LOG = LoggerFactory.getLogger(MonthlyInvoiceGeneratorFunction.class);

    @Autowired
    private MonthlyInvoiceGeneratorService monthlyInvoiceGeneratorService;

    @Override
    public MonthlyInvoiceResponse apply(MonthlyInvoiceRequest monthlyInvoiceRequest) {

        if (LOG.isDebugEnabled()) {
            LOG.debug("request: {}", monthlyInvoiceRequest);
        }
        return this.monthlyInvoiceGeneratorService.generateInvoice(monthlyInvoiceRequest);
    }
}
```

Creating AWS Lambda with Java 3/3

AWS Lambda context object in Java

PDF | Kindle | RSS

When Lambda runs your function, it passes a context object to the handler. This object provides methods and properties that provide information about the invocation, function, and execution environment.

Context methods

- `getRemainingTimeInMillis()` – Returns the number of milliseconds left before the execution times out.
- `getFunctionName()` – Returns the name of the Lambda function.
- `getFunctionVersion()` – Returns the version of the function.
- `getInvokedFunctionArn()` – Returns the Amazon Resource Name (ARN) that's used to invoke the function. Indicates if the invoker specified a version number or alias.
- `getMemoryLimitInMB()` – Returns the amount of memory that's allocated for the function.
- `getAwsRequestId()` – Returns the identifier of the invocation request.
- `getLogGroupName()` – Returns the log group for the function.
- `getLogStreamName()` – Returns the log stream for the function instance.
- `getIdentity()` – (mobile apps) Returns information about the Amazon Cognito identity that authorized the request.
- `getClientContext()` – (mobile apps) Returns the client context that's provided to Lambda by the client application.
- `getLogger()` – Returns the logger object for the function.

AWS Lambda Price Model

Vadym Kazulkin @VKazulkin , ip.labs GmbH

Cost for Lambda

REQUEST

DURATION

Request Tier

$ 0.20

Per 1 Mio Requests

Duration Tier

$ 0.00001667 (x86)
$ 0.00001333 (Arm)

Per GB-Second

GB-Second

ONE SECOND

ONE GB

Example

- 1 Mio requests
- Lambda x86 with 512MiB
- Each lambda takes 200ms

0.5 GiB * 0.2 sec * 1 Mio

= 100 000 GB-Seconds

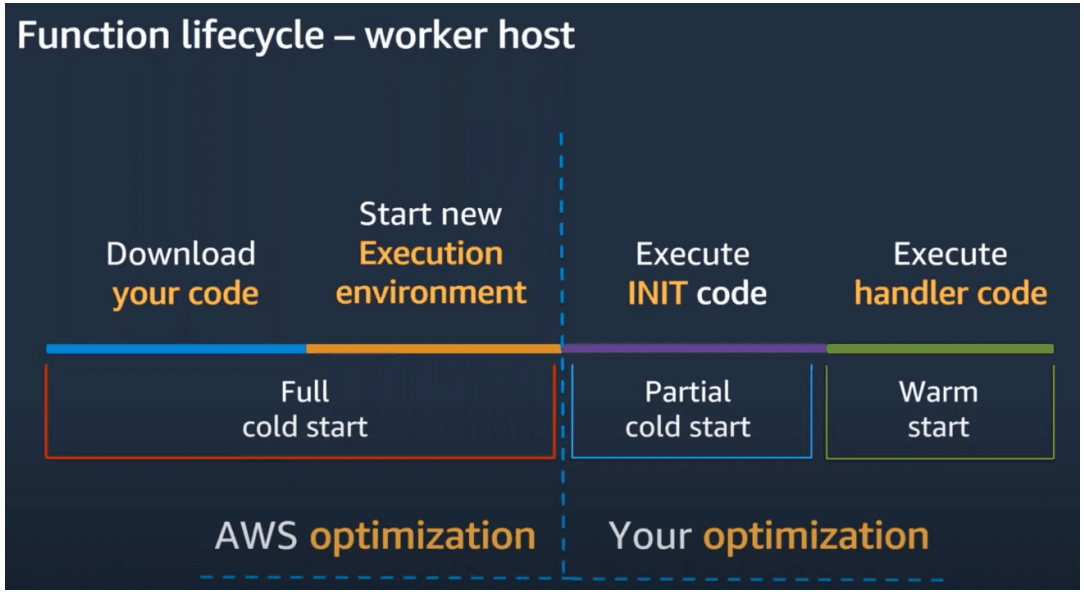
Requests:
$0.20

GB-Seconds:
$1.67

Challenge Number 1 with Java is a

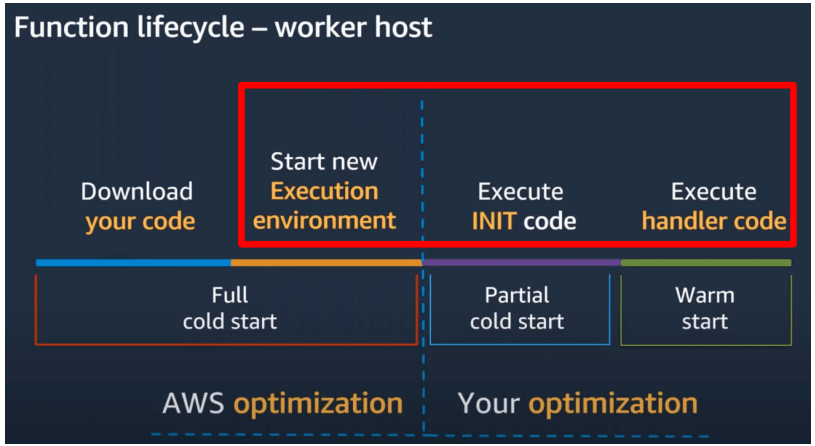
big cold-start

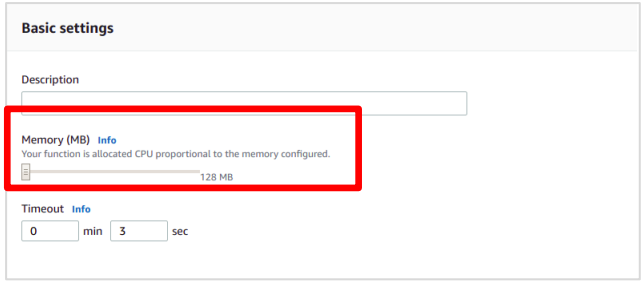
Cold Start



Sources: Ajay Nair „Become a Serverless Black Belt” https://www.youtube.com/watch?v=oQFORsso2go
Tomasz Łakomy "Notes from Optimizing Lambda Performance for Your Serverless Applications“ https://tlakomy.com/optimizing-lambda-performance-for-serverless-applications

- Start Firecracker VM
- AWS Lambda starts the JVM
- Java runtime loads and initializes handler class
  - Static initializer block of the handler class is executed
  - Init-phase has full CPU access up to 10 seconds *for free* *for the managed execution environments*
- Lambda calls the handler method
  - Full CPU access only approx. at 1.8 GB “assigned” memory to the function





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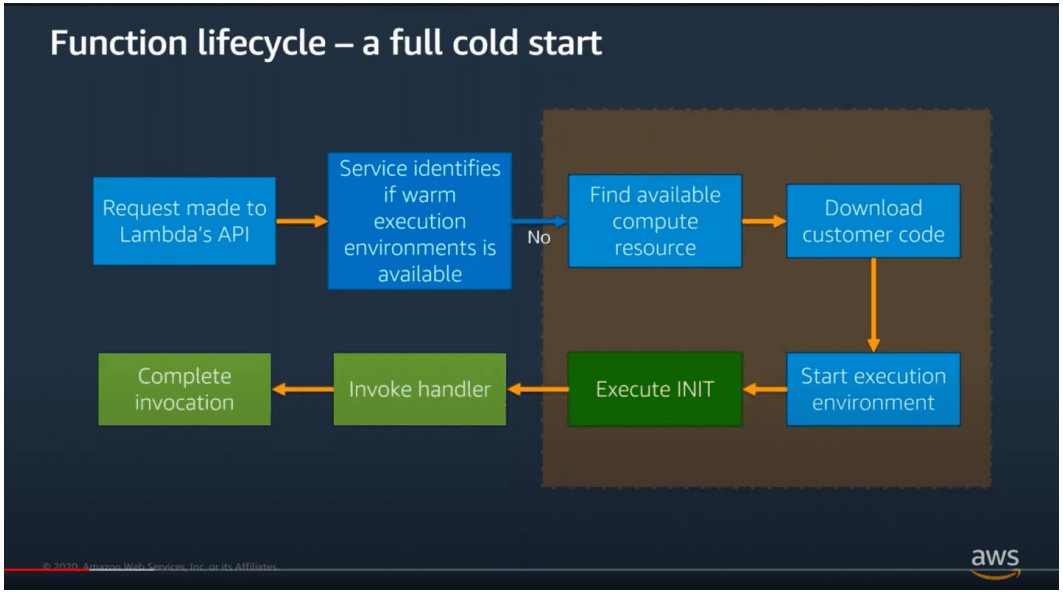
Michael Hart: „Shave 99.93% off your Lambda bill with this one weird trick“ https://hichaelmart.medium.com/shave-99-93-off-your-lambda-bill-with-this-one-weird-trick-33c0acebb2ea

Function lifecycle- a full cold start



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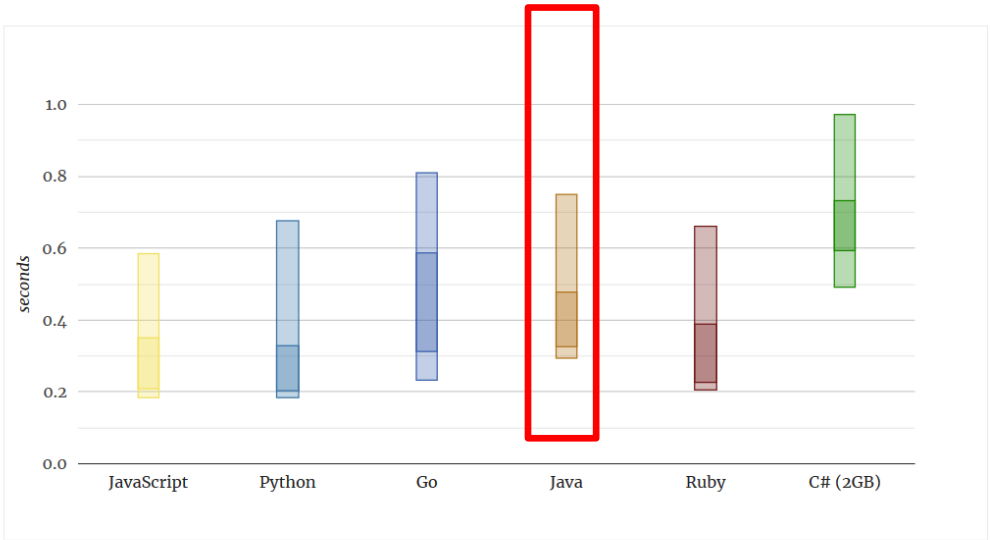
Tomasz Łakomy "Notes from Optimizing Lambda Performance for Your Serverless Applications" https://tlakomy.com/optimizing-lambda-performance-for-serverless-applications

AWS Lambda cold start duration per programming language

The following chart shows the typical range of cold starts in AWS Lambda, broken down per language. The darker ranges are the most common 67% of durations, and lighter ranges include 95%.



Typical cold start durations per language

Source: Mikhail Shilkov: „AWS Lambda: Cold Start Duration per Language. 2020 edition" https://mikhail.io/serverless/coldstarts/aws/languages/

Cold start duration with Java

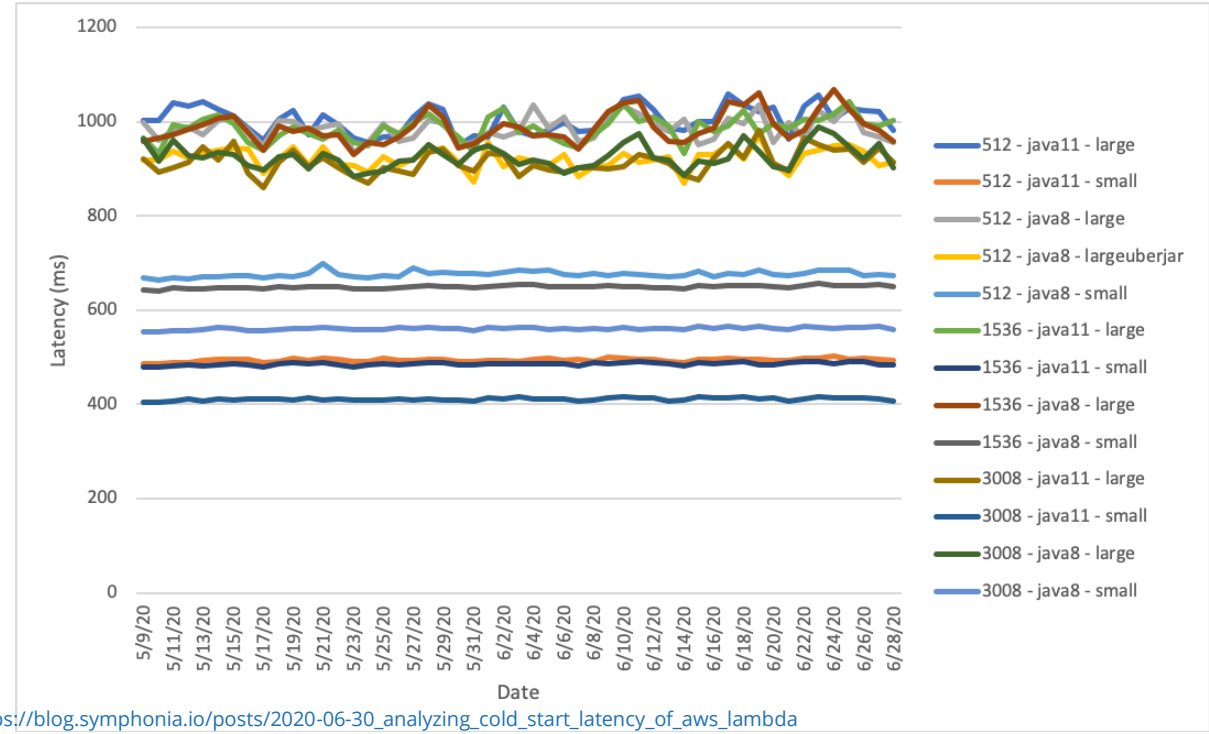
- Below 1 second is best-case cold start duration for very simple Lambda like HelloWorld with no dependencies
- It goes up significantly with more complex scenarios
  - Instantiation outside of the handler method (static initializer block) to communicate with other (AWS) services (e.g. DynamoDB, SNS, SQS, 3rd party)
- Artifact size

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O'Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts" https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/

AWS Lambda cold starts by memory size, runtime and artifact size

Artifact Size:

- Small zip (1KB)
- Large zip (48MB)
- Large uberjar (53MB)



Source: Mike Roberts "Analyzing Cold Start latency of AWS Lambda" https://blog.symphonia.io/posts/2020-06-30_analyzing_cold_start_latency_of_aws_lambda

Cold start duration with Java

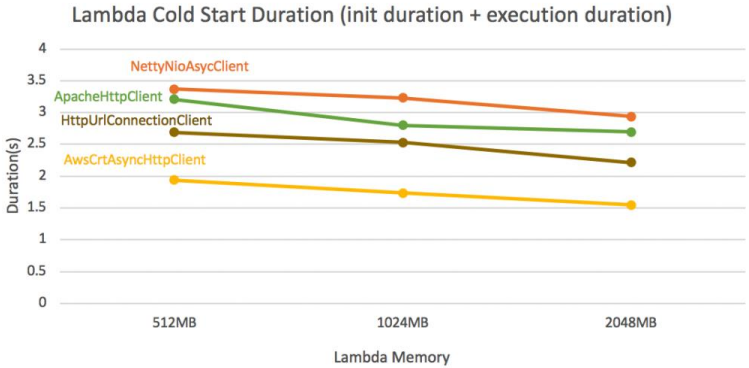
- Below 1 second is best-case cold start duration for very simple Lambda like HelloWorld with no dependencies
- It goes up significantly with more complex scenarios
  - Instantiation outside of the handler method (static instantiation) to communicate with other (AWS) services (i.e. DynamoDB, SNS, SQS, 3rd party)
- Artifact size
- To minimize the cold start time apply best practices from this talk
  - Worst-case cold starts can be higher than 10 and even 20 seconds

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O'Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts" https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/

Best Practices and Recommendations

- Switch to the AWS SDK 2.0 for Java
  - Lower footprint and more modular
  - Allows to configure HTTP Client of your choice (i.e. Java own Basic HTTP Client or *newly introduced AWS Common Runtime async HTTP Client*)

```
S3AsyncClient.builder()
.httpClientBuilder(AwsCrtAsyncHttpClient.builder()
.maxConcurrency(50))
.build();
```



Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Zoe Wang: „Introducing AWS Common Runtime HTTP Client in the AWS SDK for Java 2.x"
https://aws.amazon.com/de/blogs/developer/introducing-aws-common-runtime-http-client-in-the-aws-sdk-for-java-2-x/

Best Practices and Recommendations

- Less (dependencies, classes) is more
  - Include only required dependencies (e.g. not the whole AWS SDK 2.0 for Java, but the dependencies to the clients to be used in Lambda)
  - Exclude dependencies, which you don't need at runtime e.g. test frameworks like Junit

```
<dependency>
    <groupId>software.amazon.awssdk</groupId>
    <artifactId>bom</artifactId>
    <version>2.10.86</version>
    <type>pom</type>
    <scope>import</scope>
</dependency>
```

```
<dependency>
    <groupId>software.amazon.awssdk</groupId>
    <artifactId>dynamodb</artifactId>
    <version>2.10.86</version>
</dependency>
```

```
<dependency>
    <groupId>org.junit.jupiter</groupId>
    <artifactId>junit-jupiter-api</artifactId>
    <version>5.4.2</version>
    <scope>test</scope>
</dependency>
```

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O'Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts" https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/
https://github.com/awsdocs/aws-doc-sdk-examples/tree/master/javav2

Best Practices and Recommendations

- Initialize dependencies during initialization phase
  - Use static initialization in the handler class, instead of in the handler method (e.g. handleRequest) *to take the advantage of the access to the full CPU core for max 10 seconds*
  - In case of DynamoDB client put the following code outside of the handler method:

```
AmazonDynamoDB client = AmazonDynamoDBClientBuilder.standard()...build();
DynamoDB dynamoDB = new DynamoDB(client);
```

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O'Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts" https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/

Best Practices and Recommendations

Provide all known values (for building clients i.e. DynamoDB client) to avoid auto-discovery

- credential provider, region, endpoint

```
AmazonDynamoDB client = AmazonDynamoDBClientBuilder.standard()
.withRegion(Regions.US_WEST_2)
.withCredentials(new ProfileCredentialsProvider("myProfile"))

.build();
```

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O'Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts" https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/

Best Practices and Recommendations

- Prime dependencies during initialization phase
  - „Fake“ the calls to pre-initalize „some other expensive stuff“
  - In case of DynamoDB client put the following code outside of the handler method to pre-initialize the Jackson Marshaller:

```
AmazonDynamoDB client = AmazonDynamoDBClientBuilder.standard()...build();
DynamoDB dynamoDB = new DynamoDB(client);

Table table = dynamoDB.getTable(„mytable");

Item item = table.getItem("Id", 210);
```

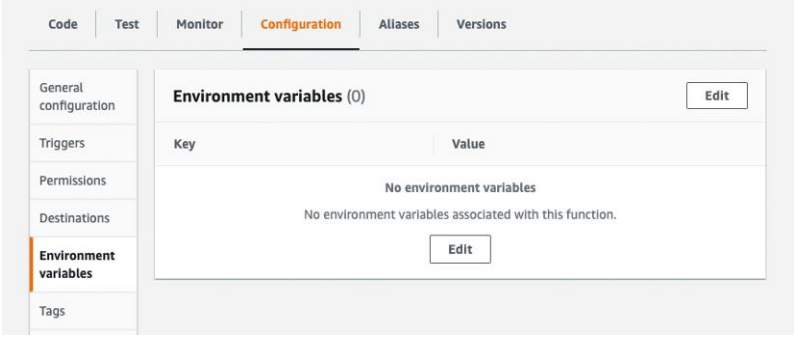
getItem() call forces Jackson Marshallers to initialize

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O'Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts" https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/

Best Practices and Recommendations Using Tiered Compilation

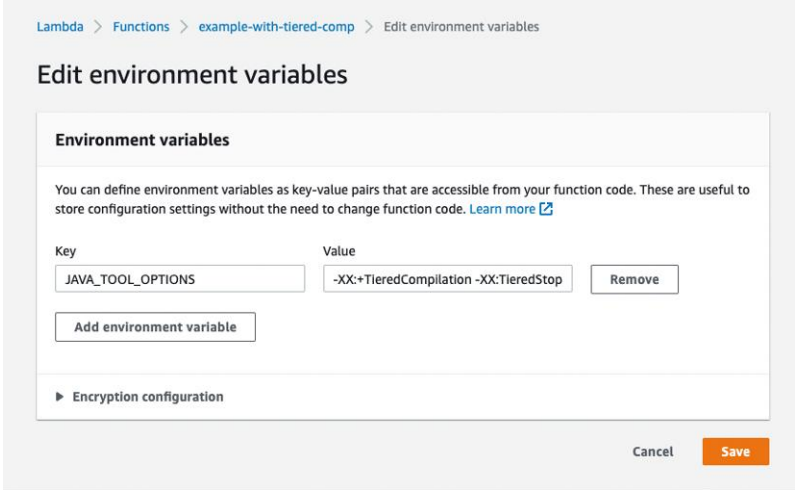
- Achieve **up to 60%** faster startup times can use **level 1** compilation with little risk of reducing warm start performance

Level 4 - C2
Level 3 - C1 w/ full profiling
Level 2 - C1 w/ basic profiling
Level 1 - C1 w/o profiling
Level 0 - Interpreter



Choose **Add environment variable**. Add the following:

```
Bash
  - Key: JAVA_TOOL_OPTIONS
  - Value: -XX:+TieredCompilation -XX:TieredStopAtLevel=1
```

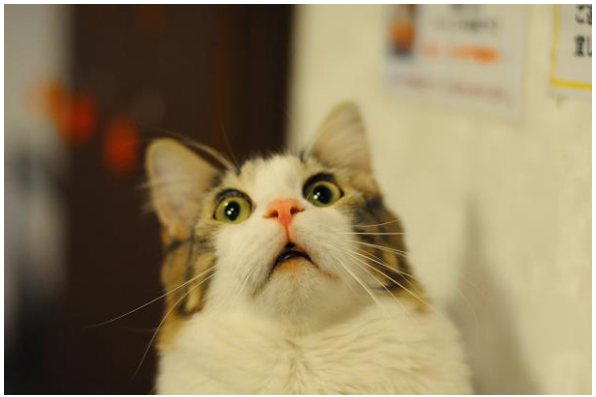


Mark Sailes: "Optimizing AWS Lambda function performance for Java"
https://aws.amazon.com/de/blogs/compute/optimizing-aws-lambda-function-performance-for-java/

Best Practices and Recommendations

Avoid:

- reflection
- runtime byte code generation
- runtime generated proxies
- dynamic class loading



spring Guice

Use DI Frameworks which aren‘t reflection-based

Source: Stefano Buliani : "Best practices for AWS Lambda and Java„ https://www.youtube.com/watch?v=ddg1u5HLwg8
Sean O‘Toole „AWS Lambda Java Tutorial: Best Practices to Lower Cold Starts” https://www.capitalone.com/tech/cloud/aws-lambda-java-tutorial-reduce-cold-starts/

Best Practices and Recommendations

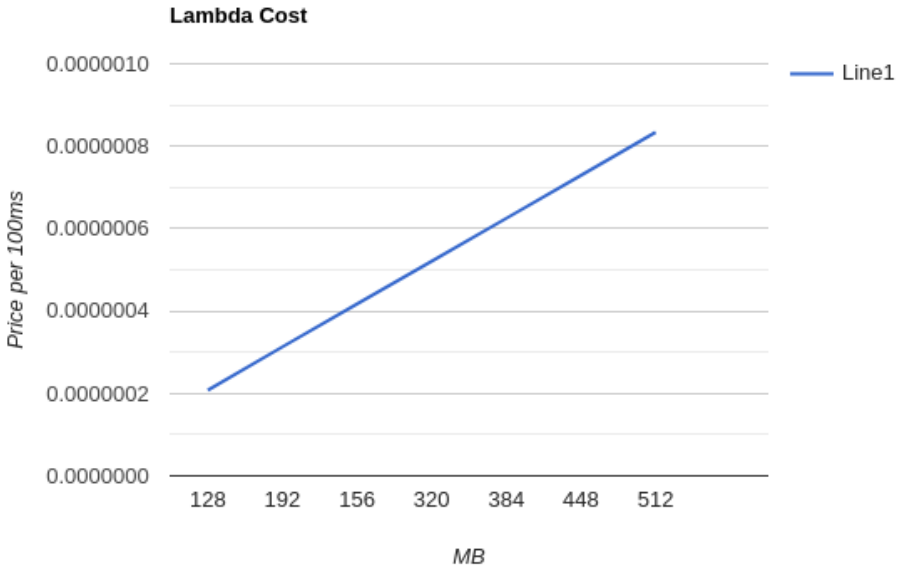
Cost optimization techniques

Cost for Lambda

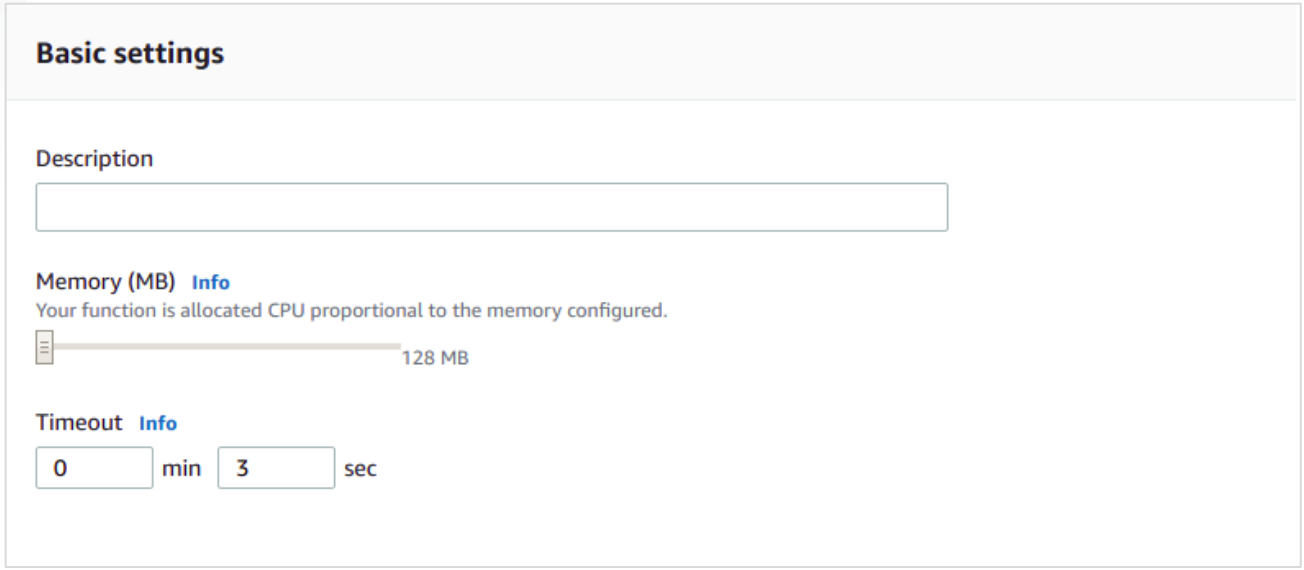
REQUEST

DURATION

Cost scales linearly with memory

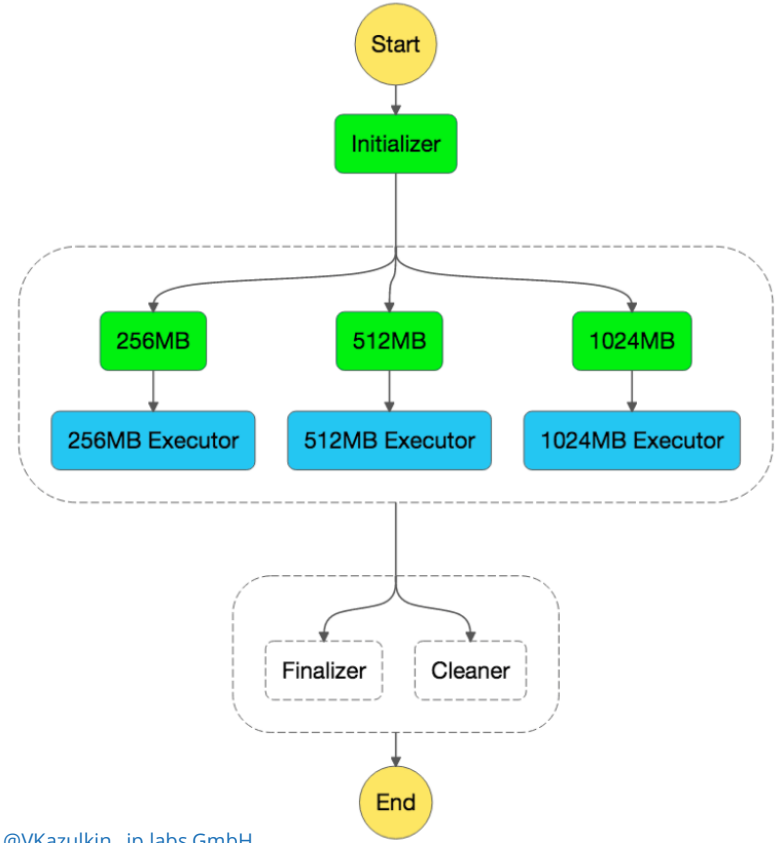


More memory = more expensive?



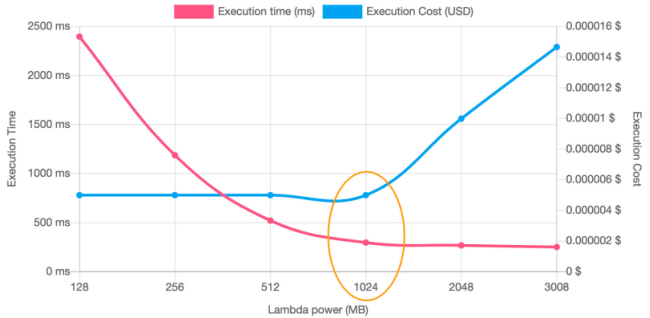
Lambda Power Tuning 1/2

- Executes different settings in parallel
- Outputs the optimal setting



Lambda Power Tuning 2/2

- Executes different settings in parallel
- Outputs the optimal setting



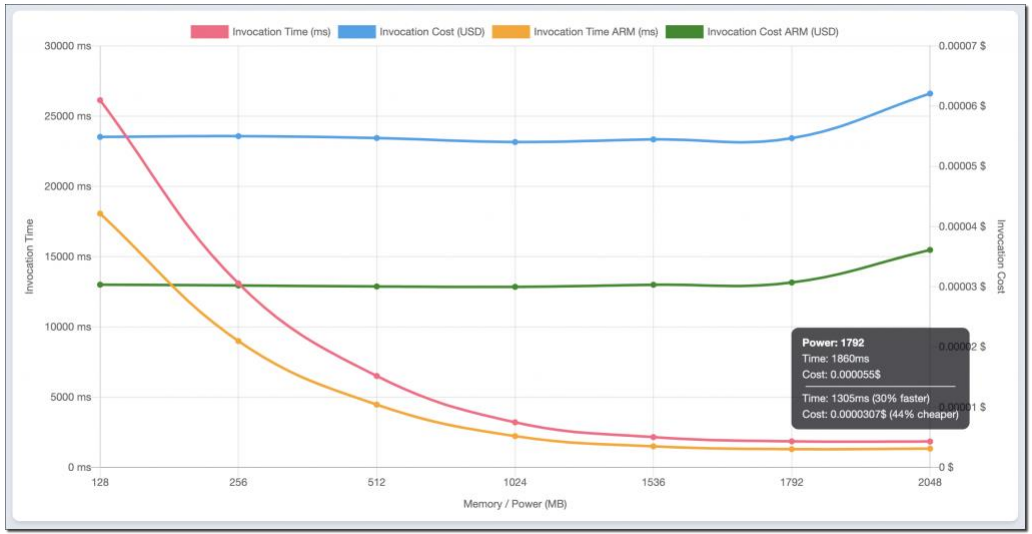
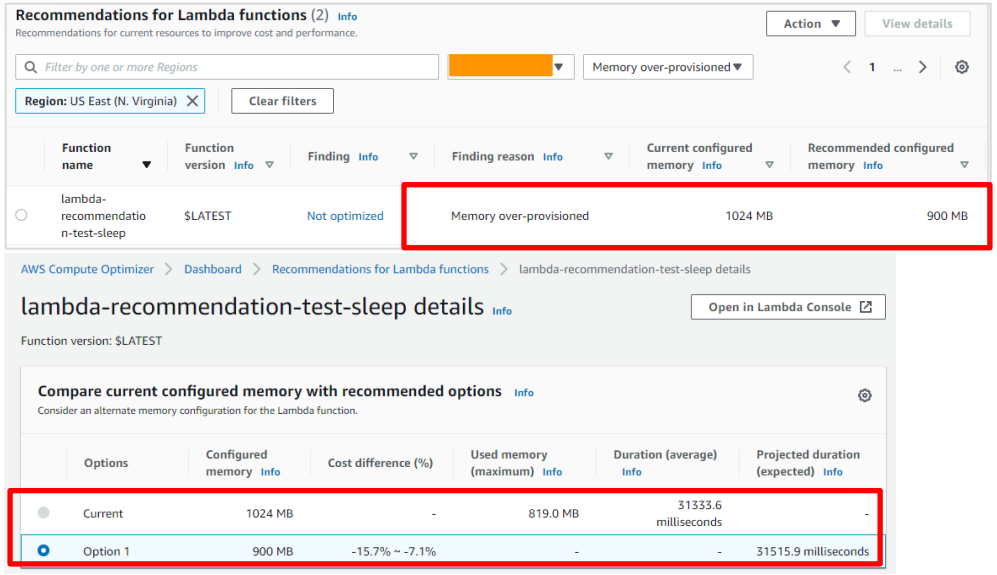


Image: https://github.com/alexcasalboni/aws-lambda-power-tuning
Alex Casalboni: "Deep dive: finding the optimal resources allocation for your Lambda functions"
https://dev.to/aws/deep-dive-finding-the-optimal-resources-allocation-for-your-lambda-functions-35a6

Optimizing AWS Lambda cost and performance using AWS Compute Optimizer



Bash

```
$ aws compute-optimizer \
  get-lambda-function-recommendations \
  --function-arns arn:aws:lambda:us-east-1:123456789012:function:lambda-recommendation-test-sleep
```

JSON


```
{
    "lambdaFunctionRecommendations": [
        {
            "utilizationMetrics": [
                {
                    "name": "Duration",
                    "value": 31333.63587049883,
                    "statistic": "Average"
                },
                {
                    "name": "Duration",
                    "value": 32522.04,
                    "statistic": "Maximum"
                },
                {
                    "name": "Memory",
                    "value": 817.67049838188,
                    "statistic": "Average"
```


Source: Chad Schmutzer „Optimizing AWS Lambda cost and performance using AWS Compute Optimizer"
https://aws.amazon.com/de/blogs/compute/optimizing-aws-lambda-cost-and-performance-using-aws-compute-optimizer/

AWS Lambda Java Libs

driverpt Use JUnit 5 Parameterized Test (#319) — ✓ 2448acc 6 days ago — 180 commits

.github	Stage events 3.11.0, sdk-transformer 3.0.7, and tests 1.1.1 (#280)	5 months ago
aws-lambda-java-core	minor: Use full month name in RELEASE.CHANGELOG.md files	2 years ago
aws-lambda-java-events-sdk-transfor...	Assert on AttributeValue List type to ensure consistency when empty a...	2 months ago
aws-lambda-java-events	fix: add support for ARM based platforms (#300)	3 months ago
aws-lambda-java-log4j2	Update log4j-core and log4j-api dependencies to 2.17.1 (#299)	3 months ago
aws-lambda-java-runtime-interface-c...	fix: add support for ARM based platforms (#300)	3 months ago
aws-lambda-java-serialization	Use JUnit 5 Parameterized Test (#319)	6 days ago
aws-lambda-java-tests	fix: add support for ARM based platforms (#300)	3 months ago
git-config/hooks	Initial Java RIC Implementation (#190)	17 months ago
samples/kinesis-firehose-event-handl...	Stage events 3.11.0, sdk-transformer 3.0.7, and tests 1.1.1 (#280)	5 months ago
.gitignore	Initial Java RIC Implementation (#190)	17 months ago
CODE_OF_CONDUCT.md	Adding standard files	4 years ago
CONTRIBUTING.md	Adding standard files	4 years ago
LICENSE	Initial commit	7 years ago
README.md	Bump events-sdk-transformer to 3.1.0	2 months ago

Official mirror for interface definitions and helper classes for Java code running on the AWS Lambda platform.

aws.amazon.com/lambda/

Readme
Apache-2.0 License
Code of conduct
397 stars
58 watching
185 forks

Releases

No releases published

Packages

No packages published

Contributors 50

https://github.com/aws/aws-lambda-java-libs

Cost optimization

- Java is well optimized for long running server applications
  - High startup times
  - High memory utilization

Even with all optimization applied we'll be left with seconds of the colds starts and high memory utilization

GraalVM enters the scene

GraalVM

GraalVM

Goals:

Low footprint ahead-of-time mode for JVM-based languages

High performance for all languages

Convenient language interoperability and polyglot tooling

Source: „Everything you need to know about GraalVM by Oleg Šelajev & Thomas Wuerthinger" https://www.youtube.com/watch?v=ANN9rxYo5Hg

Community Edition

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

DOWNLOAD FROM GITHUB

LICENSE

- Open Source Licenses
- Free for development and production use

BENEFITS

- Open-source license
- Free community support via public channels
- Presence of all enterprise components
- Bug fixes and enhancements

Enterprise Edition

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

DOWNLOAD FROM OTN

LICENSE

- Oracle Master License Agreement
- Free for evaluation and non-production use
- Contact us for commercial use and support options

BENEFITS

- Faster performance and smaller footprint
- Enhanced security features
- Managed capabilities for native code
- Premier 24x7x365 support via MOS

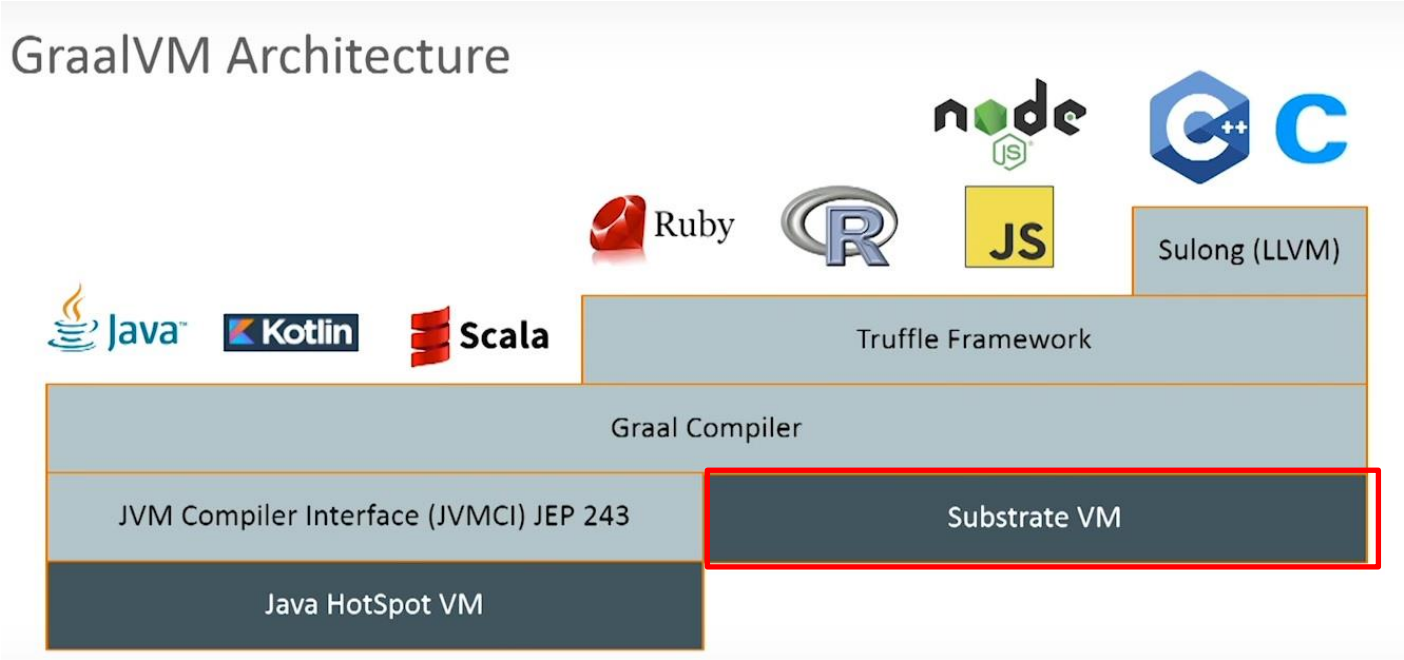
Available Distributions

GraalVM is available as **GraalVM Enterprise** and **GraalVM Community** editions and includes support for Java 11 and Java 17. GraalVM Enterprise is based on Oracle JDK while GraalVM Community is based on OpenJDK.

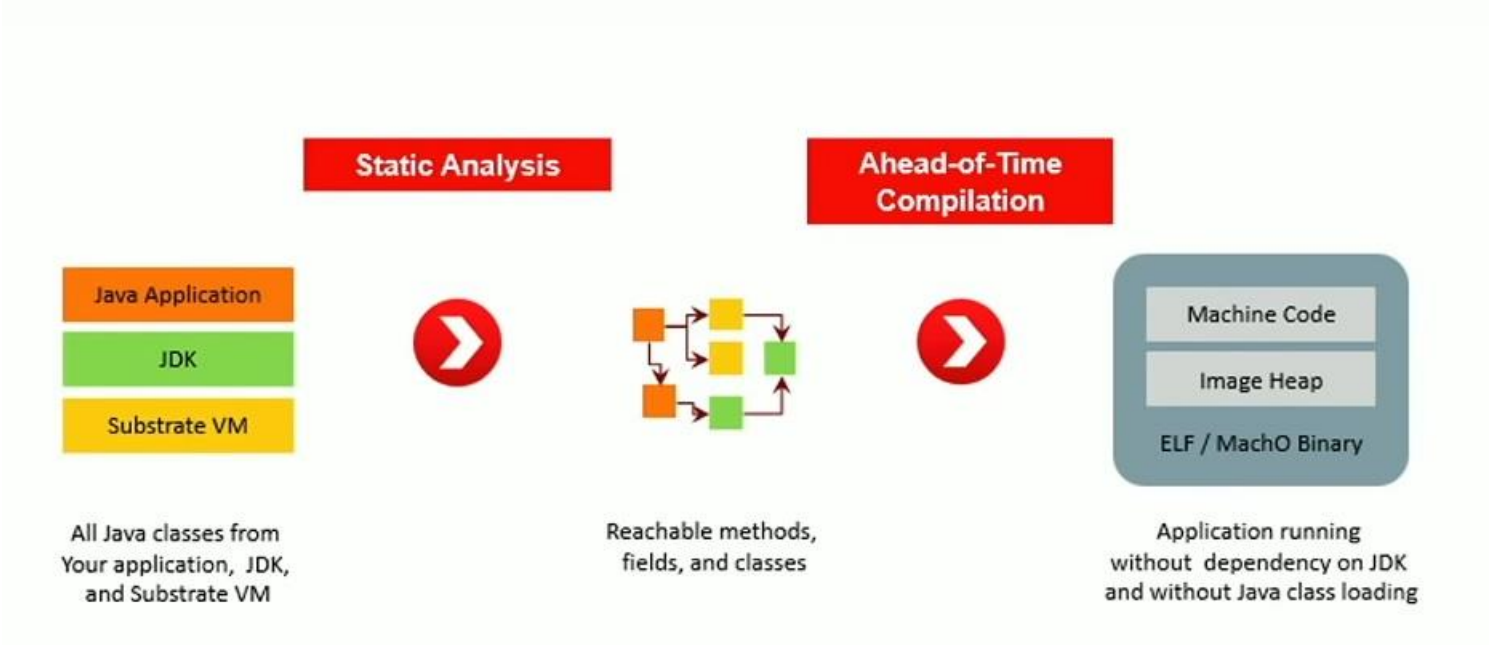
GraalVM is available for Linux and macOS on x86 64-bit and ARM 64-bit systems, and for Windows on x86 64-bit systems. Depending on the platform, the distributions are shipped as *.tar.gz* or *.zip* archives. See the Getting Started guide for installation instructions.

Source: https://www.graalvm.org/22.1/docs/introduction/#available-distributions

GraalVM Architecture



SubstrateVM



Source: Oleg Šelajev, Thomas Wuerthinger, Oracle: “Deep dive into using GraalVM for Java and JavaScript”
https://www.youtube.com/watch?v=a-XEZobXspo

GraalVM on SubstrateVM
A game changer for Java & Serverless?

Java Function compiled into a **native executable** using **GraalVM on SubstrateVM** reduces

- “cold start” times
- memory footprint

by order of magnitude compared to running on JVM.

GraalVM on SubstrateVM
A game changer for Java & Serverless?

Current challenges with **native executable** using **GraalVM :**

- Most Cloud Providers (AWS) doesn't provide GraalVM as Java Runtime out of the box, only Open JDK (i.e. AWS provides Corretto)

- Some Cloud Providers (e.g. AWS) provide Custom Runtime Option

Custom Lambda Runtimes

Custom AWS Lambda runtimes

You can implement an AWS Lambda runtime in any programming language. A runtime is a program that runs a Lambda function's handler method when the function is invoked. You can include a runtime in your function's deployment package in the form of an executable file named `bootstrap`.

A runtime is responsible for running the function's setup code, reading the handler name from an environment variable, and reading invocation events from the Lambda runtime API. The runtime passes the event data to the function handler, and posts the response from the handler back to Lambda.

Your custom runtime runs in the standard Lambda execution environment. It can be a shell script, a script in a language that's included in Amazon Linux, or a binary executable file that's compiled in Amazon Linux.

To get started with custom runtimes, see Tutorial – Publishing a custom runtime. You can also explore a custom runtime implemented in C++ at awslabs/aws-lambda-cpp on GitHub.

Topics

- Using a custom runtime
- Building a custom runtime

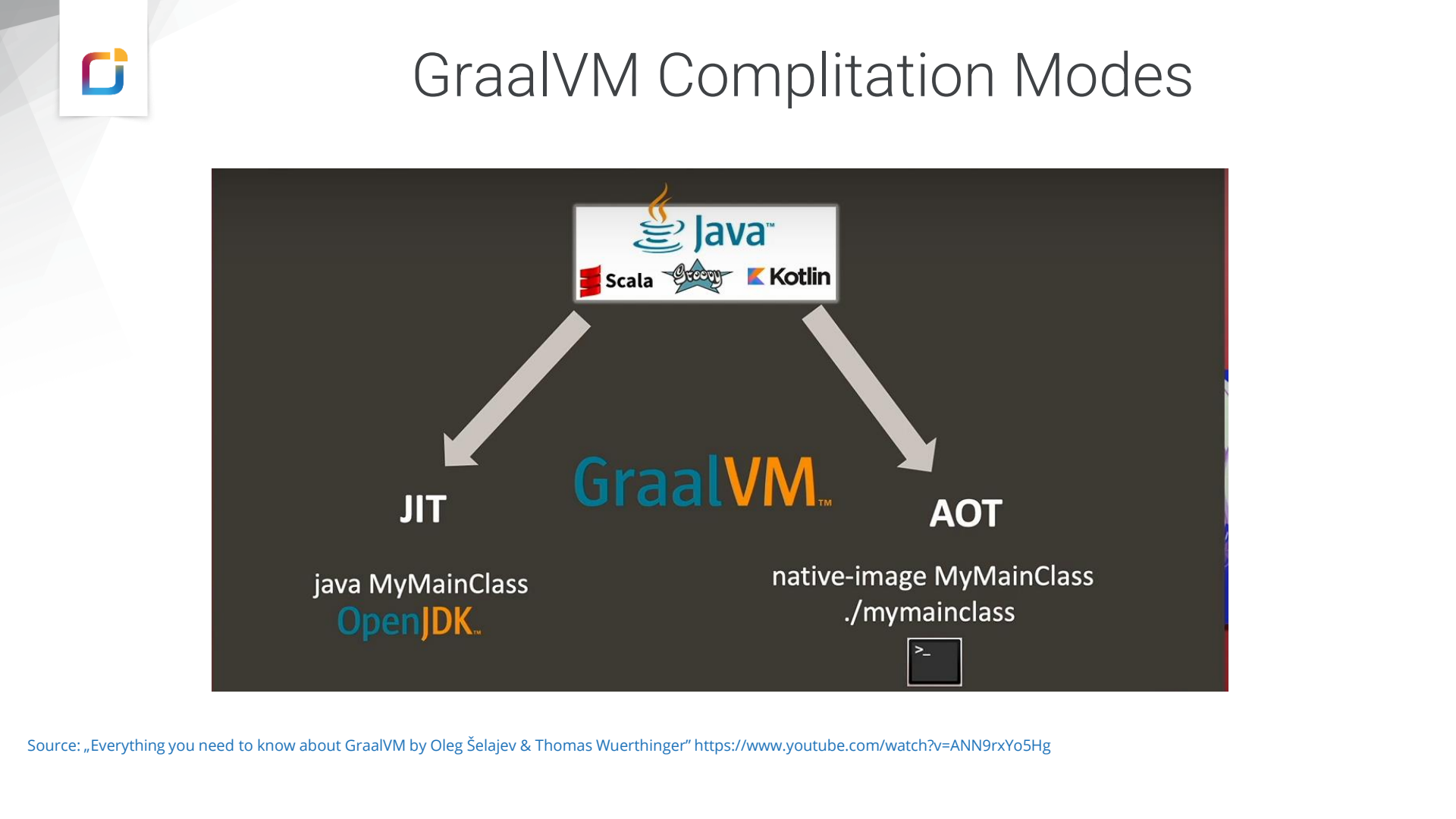
Using a custom runtime

To use a custom runtime, set your function's runtime to `provided`. The runtime can be included in your function's deployment package, or in a layer.

Example function.zip

```
.
├── bootstrap
├── function.sh
```

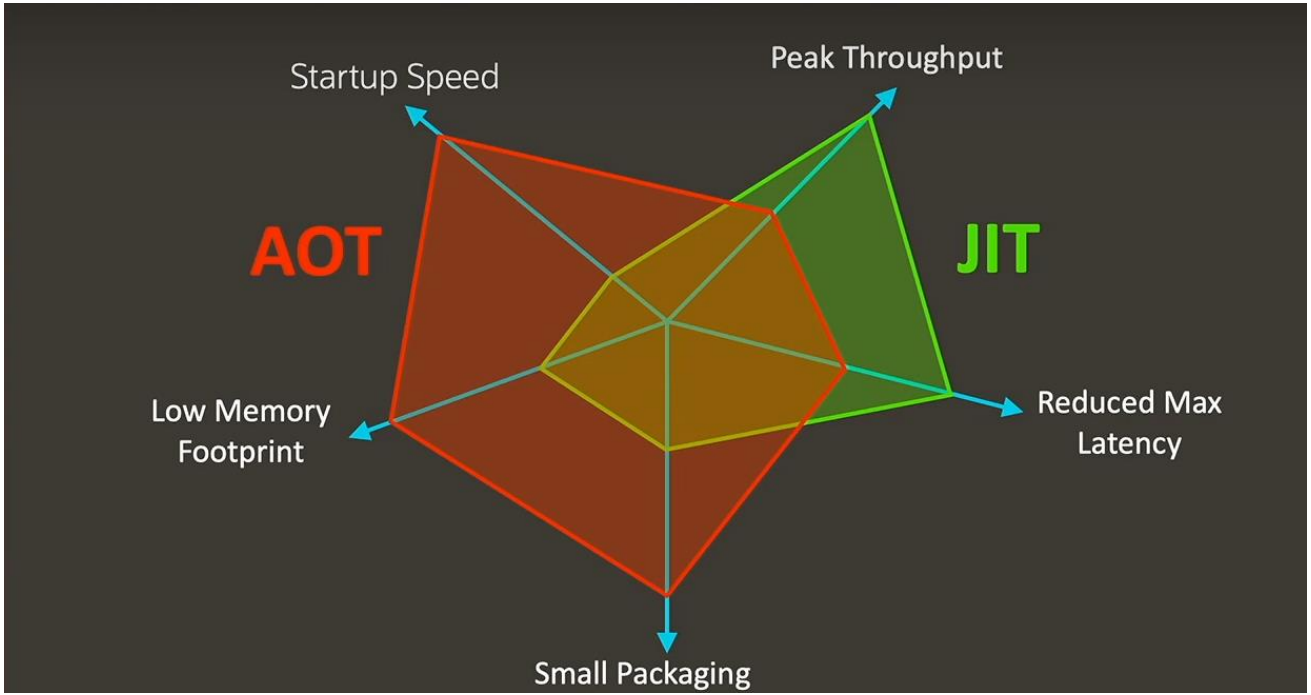
If there's a file named `bootstrap` in your deployment package, Lambda executes that file. If not, Lambda looks for a runtime in the function's layers. If the bootstrap file isn't found or isn't executable, your function returns an error upon invocation.



GraalVM Complitation Modes

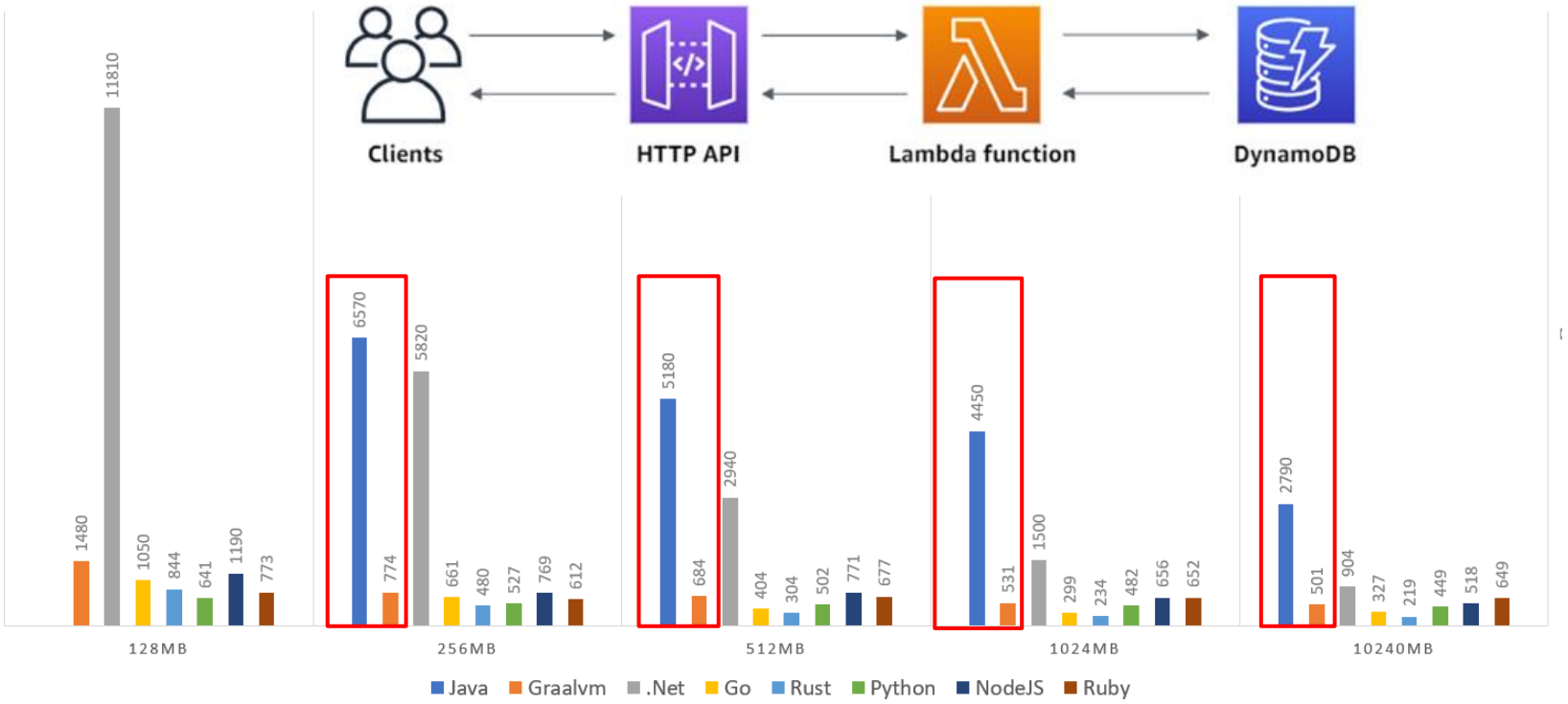
Source: „Everything you need to know about GraalVM by Oleg Šelajev & Thomas Wuerthinger" https://www.youtube.com/watch?v=ANN9rxYo5Hg

AOT vs JIT



Source: „Everything you need to know about GraalVM by Oleg Šelajev & Thomas Wuerthinger" https://www.youtube.com/watch?v=ANN9rxYo5Hg

GraalVM Native Cold Start 2021



Source: Aleksandr Filichkin: "AWS Lambda battle 2021: performance comparison for all languages (cold and warm start)"
https://filia-aleks.medium.com/aws-lambda-battle-2021-performance-comparison-for-all-languages-c1b441005fd1

Support of GraalVM native images in Frameworks

Spring Framework: GraalVM native image support in Beta without requiring additional configuration

Spring Boot: Ongoing work on experimental Spring Graal Native project.

Quarkus: a Kubernetes Native Java framework developed by Red Hat tailored for GraalVM and HotSpot, crafted from best-of-breed Java libraries and standards.

Micronaut: a modern, JVM-based, full-stack framework for building modular, easily testable microservice and serverless applications.

Common principles for all frameworks

- Rely on as little reflection as possible
- Avoid runtime byte code generation, runtime generated proxies and dynamic class loading as much as possible
- Process annotations at compile time
- Compatible with Spring‘s annotations
- The common goals:
  - increase developer productivity
  - speed up start up times and decrease memory usage for **Microservice and Serverless Java applications**
    - *with and without usage of GraalVM and native image*

Steps to deploy to AWS

- Installation prerequisites
  - Framework of your choice (Micronaut, Quarkus, Spring Native)
  - GraalVM and Native Image
  - Apache Maven or Gradle
  - AWS CLI and AWS SAM CLI (or SAM local for local testing)
- Build Linux executable of your application with GraalVM native-image
  - Use Maven or Gradle plugin
- Deploy Linux executable as AWS Lambda Custom Runtime
  - Function.zip with bootstrap Linux executable

Quarkus

Source: https://quarkus.io/

Quarkus Example with Spring Annotations

```
import org.springframework.beans.factory.annotation.Autowired;
import org.springframework.web.bind.annotation.*;


@RestController
public class PetsController {

    private PetData petData;

    @Autowired
    public PetsController(PetData data) {
        petData = data;
    }

    @RequestMapping(path = "/pets", method = RequestMethod.POST)
    public Pet createPet(@RequestBody Pet newPet) {
        if (newPet.getName() == null || newPet.getBreed() == null) {
            return null;
        }

        Pet dbPet = newPet;
        dbPet.setId(UUID.randomUUID().toString());
        return dbPet;
    }

    @RequestMapping(path = "/pets/{petId}", method = RequestMethod.GET)
    public Pet getPet(@RequestParam("petId") String petId) {
        Pet newPet = new Pet();
        newPet.setId(UUID.randomUUID().toString());
        newPet.setBreed(petData.getRandomBreed());
        newPet.setDateOfBirth(petData.getRandomDoB());
        newPet.setName(petData.getRandomName());
        return newPet;
    }

}

    @RequestMapping(path = "/pets", method = RequestMethod.GET)
    public Pet[] listPets(@RequestParam("limit") Optional<Integer> limit) {
        int queryLimit = 10;
```

Source: https://github.com/awslabs/aws-serverless-java-container/tree/master/samples/quarkus/pet-store

Build GraalVM Native Image with Quarkus

```
<profile>
    <id>native</id>
    <activation>
        <property>
            <name>native</name>
        </property>
    </activation>
    <build>
        <plugins>
            <plugin>
                <groupId>io.quarkus</groupId>
                <artifactId>quarkus-maven-plugin</artifactId>
                <version>${quarkus.version}</version>
                <executions>
                    <execution>
                        <goals>
                            <goal>native-image</goal>
                        </goals>
                        <configuration>
                            <enableHttpUrlHandler>true</enableHttpUrlHandler>
                        </configuration>
                    </execution>
                </executions>
            </plugin>
        </plugins>
    </build>
</profile>
```

mvn –Pnative package
and optionally
-Dquarkus.native.container-build=true

```
<plugin>
    <groupId>org.apache.maven.plugins</groupId>
    <artifactId>maven-assembly-plugin</artifactId>
    <version>3.1.0</version>
    <executions>
        <execution>
            <id>zip-assembly</id>
            <phase>package</phase>
            <goals>
                <goal>single</goal>
            </goals>
            <configuration>
                <finalName>function</finalName>
                <descriptors>
                    <descriptor>src/assembly/zip.xml</descriptor>
                </descriptors>
                <attach>false</attach>
                <appendAssemblyId>false</appendAssemblyId>
            </configuration>
        </execution>
    </executions>
</plugin>
```

Build GraalVM Native Image with Quarkus

```
<dependencies>
    <dependency>
        <groupId>io.quarkus</groupId>
        <artifactId>quarkus-resteasy</artifactId>
    </dependency>
    <dependency>
        <groupId>io.quarkus</groupId>
        <artifactId>quarkus-amazon-lambda-http</artifactId>
    </dependency>
    <dependency>
        <groupId>io.quarkus</groupId>
        <artifactId>quarkus-spring-web</artifactId>
    </dependency>
    <dependency>
        <groupId>io.quarkus</groupId>
        <artifactId>quarkus-junit5</artifactId>
        <scope>test</scope>
    </dependency>
    <dependency>
        <groupId>io.rest-assured</groupId>
        <artifactId>rest-assured</artifactId>
        <scope>test</scope>
    </dependency>
</dependencies>
```

AWS Lambda Deployment of Custom Runtime with SAM

```yaml
Resources:
  PetStoreNativeFunction:
    Type: AWS::Serverless::Function
    Properties:
      Handler: not.used.in.provided.runtime
      Runtime: provided
      CodeUri: target/function.zip
      MemorySize: 128
      Policies: AWSLambdaBasicExecutionRole
      Tracing: Active
      Timeout: 15
      Environment:
        Variables:
          DISABLE_SIGNAL_HANDLERS: true
      Events:
        GetResource:
          Type: Api
          Properties:
            Path: /{proxy+}
            Method: any

Outputs:
  PetStoreNativeApi:
    Description: URL for application
    Value: !Sub 'https://${ServerlessRestApi}.execute-api
      .${AWS::Region}.amazonaws.com/Prod/'
    Export:
      Name: PetStoreNativeApi
```

Local testing:

sam local start-api -t sam.native.yaml

curl localhost:3000/{yourURI}

Cloud deployment:

sam deploy -g -t sam.native.yaml

curl https://xxxxxxxxxx.execute-api.xx-xxxx-1.amazonaws.com/Prod/pets/5

Source: https://github.com/awslabs/aws-serverless-java-container/tree/master/samples/micronaut/pet-store

Quarkus Example with Quarkus Annotations

```java
import com.amazonaws.services.lambda.runtime.Context;
import com.amazonaws.services.lambda.runtime.RequestHandler;
import com.amazonaws.services.lambda.runtime.events.APIGatewayProxyRequestEvent;
import com.amazonaws.services.lambda.runtime.events.APIGatewayProxyResponseEvent;
import software.amazon.awssdk.http.HttpStatusCode;

import javax.inject.Inject;
import javax.inject.Named;

@Named("petsRequestHandler")
public class PetsRequestHandler implements RequestHandler<APIGatewayProxyRequestEvent,
                                                          APIGatewayProxyResponseEvent> {

    private PetData petData;
    private ObjectMapper objectMapper = new ObjectMapper();


    @Inject
    public PetsRequestHandler(PetData data) {
        petData = data;
    }

    @Override
    public APIGatewayProxyResponseEvent handleRequest(APIGatewayProxyRequestEvent request,
                                                      Context context) {
        Pet newPet = new Pet();
        newPet.setId(UUID.randomUUID().toString());
        newPet.setBreed(petData.getRandomBreed());
        newPet.setDateOfBirth(petData.getRandomDoB());
        newPet.setName(petData.getRandomName());

        try {
        return new APIGatewayProxyResponseEvent()
        .withStatusCode(HttpStatusCode.OK)
        .withBody(objectMapper.writeValueAsString(newPet.toString()));
        } catch (Exception je) {
          return new APIGatewayProxyResponseEvent()
         .withStatusCode(HttpStatusCode.INTERNAL_SERVER_ERROR)
          .withBody("Internal Server Error :: " + je.getMessage());
         }
    }
}
```

```java
import javax.enterprise.context.ApplicationScoped;

@ApplicationScoped
public class PetData {
  .......
}
```

```java
import io.quarkus.runtime.annotations.RegisterForReflection;

@RegisterForReflection
public class Pet {
  .......
}
```

main/resources/application.properties

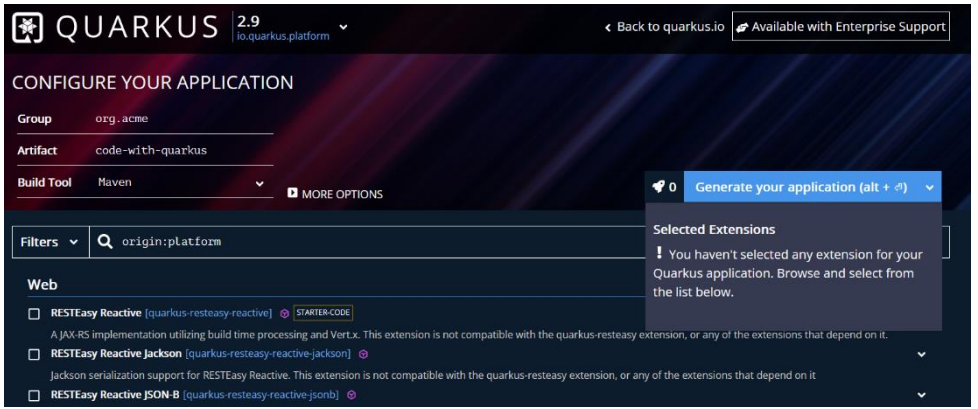
```
quarkus.lambda.handler = petsRequestHandler
quarkus.ssl.native = true
quarkus.native.enable-http-url-handler = true
quarkus.native.native-image-xmx = 6G

quarkus.native.container-build=true
quarkus.native.container-runtime=docker
quarkus.native.builder-image=quay.io/quarkus/ubi-quarkus
    -native-image:19.2.1
```

Source: https://github.com/awslabs/aws-serverless-java-container/tree/master/samples/quarkus/pet-store

Quarkus Additional Features

- AWS Lambda currently works by implementing com.amazonaws.services.lambda.runtime.**RequestHandler** interface or by using Spring Web Annotations model like **@RestController**, **@RequestMapping**
  - Doesn't support Lambda function implementing **Java 8 Functional Interface**
- Website (https://code.quarkus.io/)

  or CLI for creating the App
- Eclipse MicroProfile compatible
- Funqy for multi cloud solutions



Quarkus-Fanqy AWS Serverless Support

- AWS Lambda
- AWS API Gateway

QUARKUS - FUNQY

Quarkus Funqy is part of Quarkus's serverless strategy and aims to provide a portable Java API to write functions deployable to various FaaS environments like AWS Lambda, Azure Functions, Knative, and Knative Events (Cloud Events). It is also usable as a standalone service.

Because Funqy is an abstraction that spans multiple different cloud/function providers and protocols it has to be a very simple API and thus, might not have all the features you are used to in other remoting abstractions. A nice side effect though is that Funqy is as optimized and as small as possible. This means that because Funqy sacrifices a little bit on flexibility, you'll get a framework that has little to no overhead.

Source: https://quarkus.io/guides/funqy-amazon-lambda-http

Micronaut Framework

Source: https://micronaut.io/

Micronaut Example

```
package example.micronaut;

import io.micronaut.http.annotation.Controller;
import io.micronaut.http.annotation.Get;
import io.micronaut.http.annotation.Post;

@Controller("/book")
public class BookController {

    @Post("/saveBook/{name}/{isbn}")
    public Book save(String name, int isbn) {
        Book book = new Book();
        book.setName(name);
        book.setIsbn(isbn);
        return book;
    }

    @Get ("/getBook/{isbn}")
    public Book get(int isbn) {
        Book book = new Book ();
        book.setName("New Vadym's book");
        book.setIsbn(isbn);
        return book;
    }
}
```

Build GraalVM Native Image with Quarkus

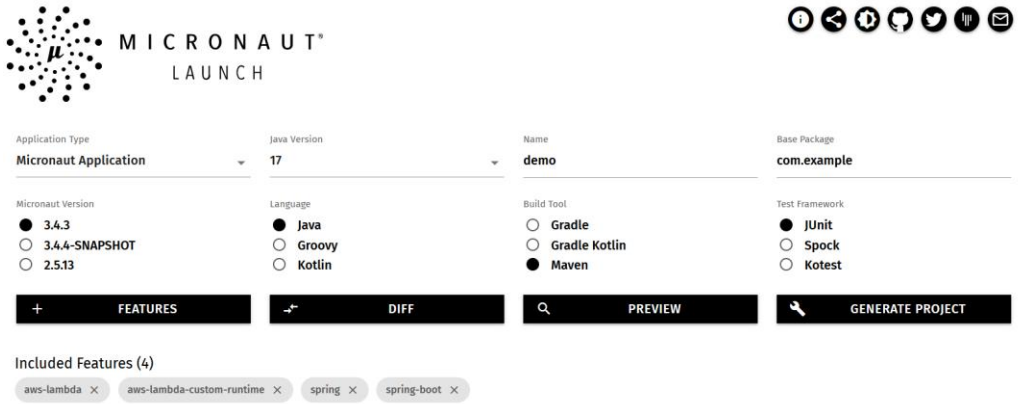
```
<dependencies>
  <dependency>
    <groupId>io.micronaut</groupId>
    <artifactId>micronaut-inject</artifactId>
    <scope>compile</scope>
  </dependency>
  <dependency>
    <groupId>io.micronaut</groupId>
    <artifactId>micronaut-validation</artifactId>
    <scope>compile</scope>
  </dependency>
  <dependency>
    <groupId>io.micronaut.aws</groupId>
    <artifactId>micronaut-function-aws-api-proxy</artifactId>
    <scope>compile</scope>
  </dependency>
  <dependency>
    <groupId>io.micronaut.aws</groupId>
    <artifactId>micronaut-function-aws-custom-runtime</artifactId>
    <scope>compile</scope>
  </dependency>
  <dependency>
    <groupId>io.micronaut.aws</groupId>
    <artifactId>micronaut-function-aws-api-proxy-test</artifactId>
    <scope>test</scope>
  </dependency>
```

./mvnw package -Dpackaging=native-image
-Dmicronaut.runtime=lambda

Packaging can also have docker or
docker-native value

Micronaut Additional Features

- Website (https://micronaut.io/launch) or CLI for creating the App
- Custom Validators
- No MicroProfile standard
- Micronaut AOT



Micronaut® AOT: build-time optimizations for Micronaut applications

Micronaut AOT is an extension to the Micronaut Framework which is the foundation to many optimizations that can be implemented at build time but weren't possible solely with annotation processing.

By effectively analyzing the deployment environment, AOT is capable of reducing startup times or distribution size for both native and JVM deliverables.

./mvnw package -Dpackaging=native-image
-Dmicronaut.runtime=lambda -Dmicronaut.aot.enabled=true

Packaging can also have docker or docker-native value

Source: "Introducing Micronaut® AOT: build-time optimizations for your Micronaut applications"
https://medium.com/graalvm/introducing-micronaut-aot-build-time-optimizations-for-your-micronaut-applications-68b8f1302c5
https://micronaut-projects.github.io/micronaut-maven-plugin/latest/examples/aot.html

Micronaut® AOT: build-time optimizations for Micronaut applications

- **optimize service loading** by pre-scanning the list of available services and implementing a loading strategy that's fully parallel in the JVM and serial in GraalVM native executables (because classloading is effectively free in native executables)

- **convert YAML configuration to Java configuration** to make apps startup faster, while reducing the final binary size because YAML parsing is no longer necessary

- **cache the environment** so that once the application is started, the framework assumes that system properties and environment variables won't change, saving time when performing lookups

- **precompute bean requirements** to eliminate beans whose requirements won't be met at runtime (this can happen if you have transitive dependencies bringing beans that you don't use, for example)

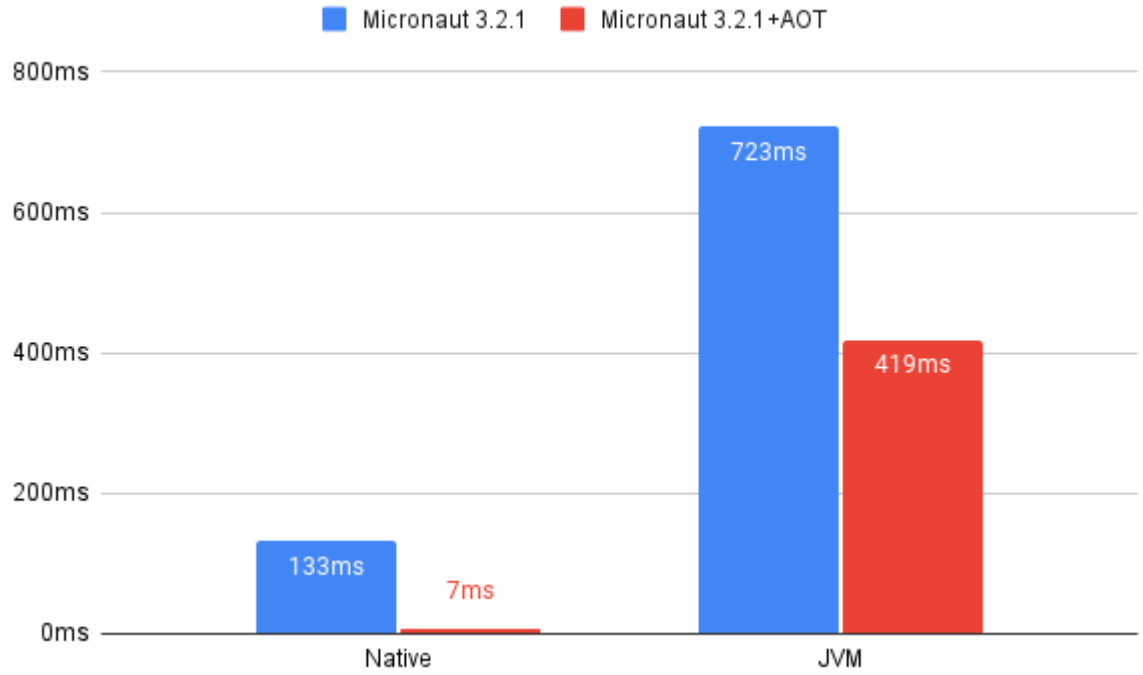
- **deduce the environment at build time**, which is the major optimization we used in the example above

- **precompute some expensive operations,** like converting environment variable names to Micronaut configuration properties

- **optimize classloading** by avoiding lookup for classes that we know are not on classpath

Source: "Introducing Micronaut® AOT: build-time optimizations for your Micronaut applications"
https://medium.com/graalvm/introducing-micronaut-aot-build-time-optimizations-for-your-micronaut-applications-68b8f1302c5

Micronaut® AOT: build-time optimizations for Micronaut applications



Source: "Introducing Micronaut® AOT: build-time optimizations for your Micronaut applications"
https://medium.com/graalvm/introducing-micronaut-aot-build-time-optimizations-for-your-micronaut-applications-68b8f1302c5

Spring (Boot) Framework

Source: https://spring.io/

Spring GraalVM Native Project

build failing documentation

Spring Native provides beta support for compiling Spring applications to native executables using GraalVM native-image compiler, in order to provide a native deployment option typically designed to be packaged in lightweight containers. In practice, the target is to support your Spring Boot application , almost unmodified, on this new platform.

Watch the video and read the blog post of Spring Native Beta announcement to learn more.

Quick start

Source: https://github.com/spring-projects-experimental/spring-native

Spring Native Example

```java
@SpringBootApplication
public class SpringBootNativeApp {

  public static void main(String[] args) {
    SpringApplication.run(SpringBootNativeApp.class, args);
  }

  @Bean
  public GetBookByIdFunction getBookById() {
    return new GetBookByIdFunction();
  }
```

```yaml
GetBookByIdFunction:
  Type: AWS::Serverless::Function
  Properties:
    Environment:
      Variables:
        DEFAULT_HANDLER: getBookById
    Events:
      GetRequestById:
        Type: Api
        Properties:
          RestApiId: !Ref MyApi
          Path: /book/{id}
          Method: get
```

```java
import com.amazonaws.services.lambda.runtime.events.APIGatewayProxyRequestEvent;
import com.amazonaws.services.lambda.runtime.events.APIGatewayProxyResponseEvent;

import java.util.function.Function;

@Component
public class GetBookByIdFunction implements Function<APIGatewayProxyRequestEvent,
                                                     APIGatewayProxyResponseEvent> {

  @Override
  public APIGatewayProxyResponseEvent apply(APIGatewayProxyRequestEvent requestEvent) {
    String id = requestEvent.getPathParameters().get("id");

    return new APIGatewayProxyResponseEvent()
      .withStatusCode(HttpStatusCode.OK)
      .withBody(objectMapper.writeValueAsString("book with id "+id+
      "found and has title "+" Vadym"));
    } catch (Exception je) {
    return new APIGatewayProxyResponseEvent()
      .withStatusCode(HttpStatusCode.INTERNAL_SERVER_ERROR)
      .withBody("Internal Server Error :: " + je.getMessage());
    }
  }
```

curl https://xxxxxxxxxx.execute-api.xx-xxxx-1.amazonaws.com/prod/book/5

Source: https://github.com/spring-projects-experimental/spring-native/tree/main/samples/cloud-function-aws

Build GraalVM Native Image with Spring

mvn –Pnative package

```
<profiles>
    <profile>
        <id>native</id>
        <build>
            <plugins>
                <plugin>
                    <artifactId>maven-assembly-plugin</artifactId>
                    <executions>
                        <execution>
                            <id>native-zip</id>
                            <phase>package</phase>
                            <goals>
                                <goal>single</goal>
                            </goals>
                            <inherited>false</inherited>
                        </execution>
                    </executions>
                    <configuration>
                        <descriptors>
                            <descriptor>src/assembly/native.xml</descriptor>
                        </descriptors>
                    </configuration>
                </plugin>
            </plugins>
        </build>
    </profile>
</profiles>
```

```
<dependencies>
    <dependency>
        <groupId>org.springframework.experimental</groupId>
        <artifactId>spring-native</artifactId>
    </dependency>
    <dependency>
        <groupId>org.springframework.cloud</groupId>
        <artifactId>spring-cloud-function-adapter-aws</artifactId>
    </dependency>
    <dependency>
        <groupId>org.springframework.cloud</groupId>
        <artifactId>spring-cloud-function-web</artifactId>
    </dependency>
    <dependency>
        <groupId>org.springframework</groupId>
        <artifactId>spring-web</artifactId>
    </dependency>
    <dependency>
        <groupId>org.springframework.boot</groupId>
        <artifactId>spring-boot-starter-web</artifactId>
    </dependency>
    <dependency>
        <groupId>org.springframework.boot</groupId>
        <artifactId>spring-boot-starter-test</artifactId>
        <scope>test</scope>
    </dependency>
</dependencies>
```

Source: https://github.com/spring-projects-experimental/spring-native/tree/main/samples/cloud-function-aws

Spring Native

- AWS Lambda currently only works by implementing **Java 8 Functional Interface**
  - Doesn‘t support Lambda function implementing com.amazonaws.services.lambda.runtime.**RequestHandler** interface
  - Doesn‘t support Spring Web Annotations model like **@RestController**, **@RequestMapping**, which Quarkus and Micronaut do

Framework Comparison

- Project Initializer
- Programming Model
- Database Access Model Support
- Testing Support
- Standards Support (i.e. MicroProfile)

Source: „Battle Of The Microservice Frameworks: Micronaut versus Quarkus edition! by Michel Schudel“ https://www.youtube.com/watch?v=hnEXOqcNXPs
„Micronaut 2.0 vs Quarkus 1.3.1 vs Spring Boot 2.3 Performance on JDK 14“ https://www.youtube.com/watch?v=rJFgdFIs_k8
„Java EE, Jakarta EE, MicroProfile, or Maybe All of Them” https://www.eclipse.org/community/eclipse_newsletter/2019/february/Jakarta_Micro_All.php

Plain Java vs GraalVM Native Image

- Plain Java
  - Application Size
  - (Cold) Start Time
  - Request/Invocation duration
  - Memory Consumption
- GraalVM Native Image
  - Build time
    - GraalVM Native Image compilation time with Plain Java vs Framework
  - Native Image Size
    - with Plain Java vs Framework
  - (Cold) Startup Time
  - Request/Invocation duration
  - Memory Consumption

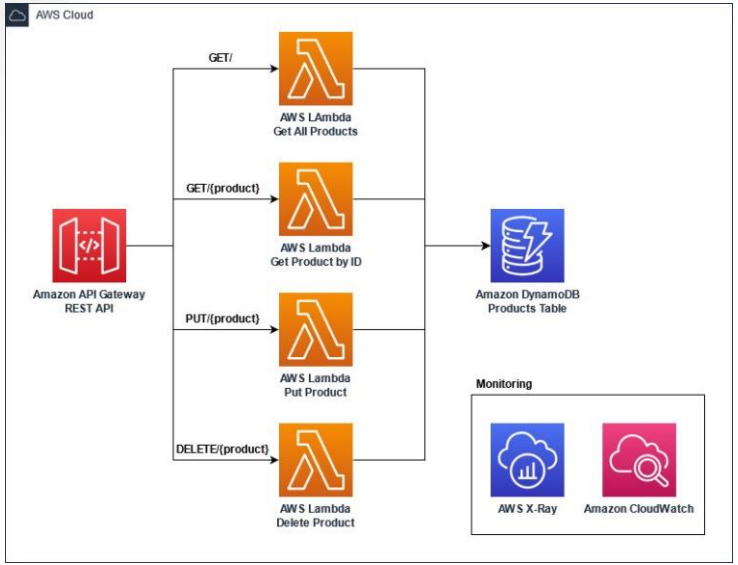
Source: „Battle Of The Microservice Frameworks: Micronaut versus Quarkus edition! by Michel Schudel“ https://www.youtube.com/watch?v=hnEXOqcNXPs
„Micronaut 2.0 vs Quarkus 1.3.1 vs Spring Boot 2.3 Performance on JDK 14“ https://www.youtube.com/watch?v=rJFgdFIs_k8

Plain Java + GraalVM vs Quarkus + GraalVM

Criteria	Plain Java+GraalVM	Quarkus+GraalVM
Jar size	8.8mb	29mb
Native binary size	55mb	62mb
Compilation time	3m 1s	3m 50s
Cold start 128mb	1.073sec	1.65sec
Cold start 256mb	0.883sec	1.2sec
Cold start 512mb	0.62sec	0.913sec
Warm state 128mb	14ms	130ms
Warm state 256mb	14ms	60ms
Warm state 512mb	14ms	41ms

https://filia-aleks.medium.com/aws-lambda-graalvm-native-quarkus-vs-plain-java-90176eff515d

Lambda demo with common Java application frameworks



Artillery is used to make **100 requests / second for 10 minutes to our API endpoints.**

Results from Managed Java Runtime

	Cold Start (ms)				Warm Start (ms)			
	p50	p90	p99	max	p50	p90	p99	max
Micronaut	8505.57	8977.26	9685.76	10512.48	**9.38**	**14.86**	**40.39**	553.75
Quarkus	**6384.45**	**6671.49**	**7055.55**	**8303.17**	10.41	19.07	48.45	**317.69**
Spring Boot	12673.61	13098.60	13497.31	14118.06	10.99	21.75	75.00	419.90

Results from GraalVM Native images running in custom runtime

	Cold Start (ms)				Warm Start (ms)			
	p50	p90	p99	max	p50	p90	p99	max
Micronaut	604.16	659.02	700.45	893.70	**6.30**	**8.00**	**15.88**	**69.9**
Quarkus	**437.45**	**475.76**	**519.50**	**528.03**	7.45	12.60	21.32	93.45
Spring Boot	620.66	684.53	721.77	751.98	9.10	14.22	23.61	259.16

Lambda Container Image Support

AWS News Blog

New for AWS Lambda – Container Image Support

by Danilo Poccia | on 01 DEC 2020 | in Announcements, AWS Lambda, AWS Re:Invent, Compute, Containers, Serverless | Permalink | Share

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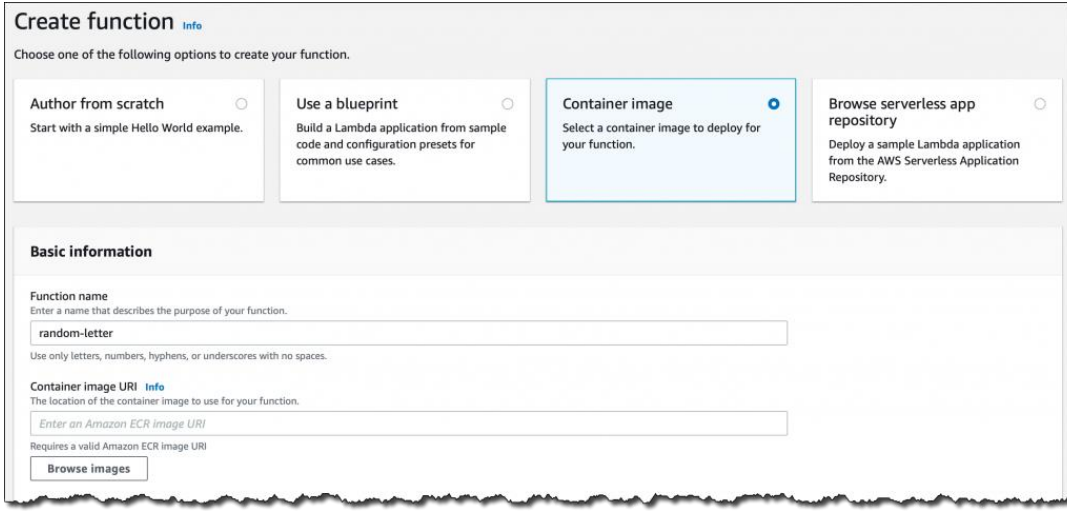
Voiced by Amazon Polly

With AWS Lambda, you upload your code and run it without thinking about servers. Many customers enjoy the way this works, but if you've invested in container tooling for your development workflows, it's not easy to use the same approach to build applications using Lambda.

To help you with that, you can now package and deploy Lambda functions as **container images** of up to **10 GB** in size. In this way, you can also easily build and deploy larger workloads that rely on sizable dependencies, such as machine learning or data intensive workloads. Just like functions packaged as ZIP archives, functions deployed as container images benefit from the same operational simplicity, automatic scaling, high availability, and native integrations with many services.

We are providing **base images** for all the supported Lambda runtimes (Python, Node.js, Java, .NET, Go, Ruby) so that you can easily add your code and dependencies. We also have base images for custom runtimes based on Amazon Linux that you can extend to include your own runtime implementing the Lambda Runtime API.



Source: „https://aws.amazon.com/de/blogs/aws/new-for-aws-lambda-container-image-support/

Lambda Container Image Support Use Cases:

- What about the support of the current Java version?
  - Only Long Term Support (LTS) by AWS
    - Java 8, Java 11, Java 17 (not for Lambda)
  - Use Container (Docker) Image with i.e. Java 18

Source: https://aws.amazon.com/de/corretto/

Lambda Container Image Support with Java 18

1. Download the desired Java version and copy the local application code to the Docker environment and build it with Maven:

```
FROM amazonlinux:2

...

# Update packages and install Amazon Corretto 18, Maven and Zip
RUN yum -y update
RUN yum install -y java-18-amazon-corretto-devel maven zip

...

# Copy the software folder to the image and build the function
COPY software software
WORKDIR /software/example-function
RUN mvn clean package
```

2. This step results in an uber-jar (function.jar) that you can use as an input argument for jdeps. The output is a file containing all the Java modules that the function depends on:

```
RUN jdeps -q \
    --ignore-missing-deps \
    --multi-release 18 \
    --print-module-deps \
    target/function.jar > jre-deps.info
```

3. Create an optimized Java runtime based on those application modules with jlink. Remove unnecessary information from the runtime, for example header files or man-pages:

```
RUN jlink --verbose \
    --compress 2 \
    --strip-java-debug-attributes \
    --no-header-files \
    --no-man-pages \
    --output /jre18-slim \
    --add-modules $(cat jre-deps.info)
```

4. This creates your own custom Java 18 runtime in the /jre18-slim folder. You can apply additional optimization techniques such as Class-Data-Sharing (CDS) to generate a classes.jsa file to accelerate the class loading time of the JVM.

```
RUN /jre18-slim/bin/java -Xshare:dump
```

https://aws.amazon.com/de/blogs/compute/build-a-custom-java-runtime-for-aws-lambda//

Conclusion

- GraalVM and Frameworks are really powerful with a lot of potential
- GraalVM Native Image improves cold starts and memory footprint significally
- GraalVM Native Image is currently not without challenges
  - AWS Lambda Custom Runtime requires Linux executable only
  - Managing Custom Runtime requires some additional effort
  - Build time is a factor
  - You pay for the init-phase of the function packaged as AWS Lambda Custom Runtime
    - Init-phase is free for the managed runtimes like Java 8 and Java 11 (Corretto)

Personal Recommendations (highly opinionated)

- By default start with **plain managed** Java Long Term Support Version with Amazon Corretto 11
- If you don‘t want to miss 3 years of innovation and use the newest Java Version?
  - Use Lambda Docker Container Image Support
- If your function needs constantly low response times for the known period of time ?
  - Use Provisioned Concurrency additionally
- If your function needs constantly low response time and low cost is a requirement?
  - Use GraalVM Native Image and optionally with your favorite framework (Micronaut, Quarkus, Spring Boot GraalVM Native) and AWS Lambda Custom Runtime
- The usage of the frameworks (Micronaut, Quarkus, Spring Boot GraalVM Native) may improve your productivity but may add up additional costs (longer build time, larger cold starts)

Try it yourselves

- Micronaut
  - https://github.com/micronaut-guides/micronaut-function-aws-lambda
- Spring Native
  - https://github.com/spring-projects-experimental/spring-native/tree/main/samples/cloud-function-aws
- Misc examples with all frameworks
  - https://github.com/awslabs/aws-serverless-java-container/tree/master/samples

What about Project Helidon?

helidon.io

Helidon is a collection of Java libraries for writing microservices
that run on a fast web core powered by Netty.

GraalVM

GraalVM native-image support in both Helidon SE and Helidon MP

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