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Adopting Java for the Serverless world

from the perspective of the AWS developer

Vadym Kazulkin, ip.labs, FrOSCon , 21 August 2022

Contact

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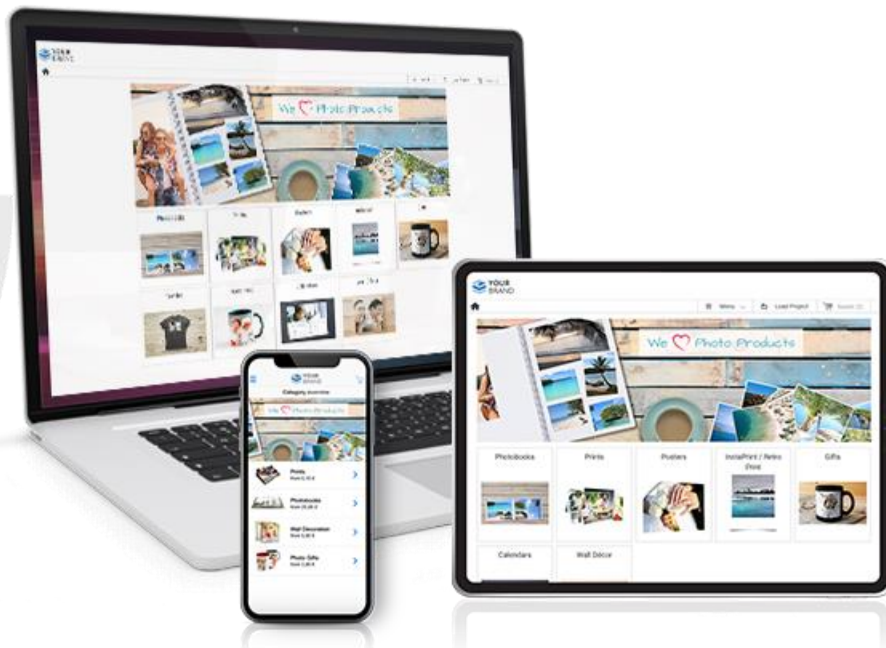


https://www.iplabs.de/

Java popularity

RedMonk Language Rankings

September 2012 - June 2021

1 JavaScript
2 Java
3 PHP
4 Python
5 Ruby
6 C#
7 C++
8 C
9 Objective-C
10 Shell
11 Perl
12 Scala
13 Haskell
14 ASP
15 Assembly
16 ActionScript
17 R
18 Visual Basic
19 CoffeeScript
20 Groovy

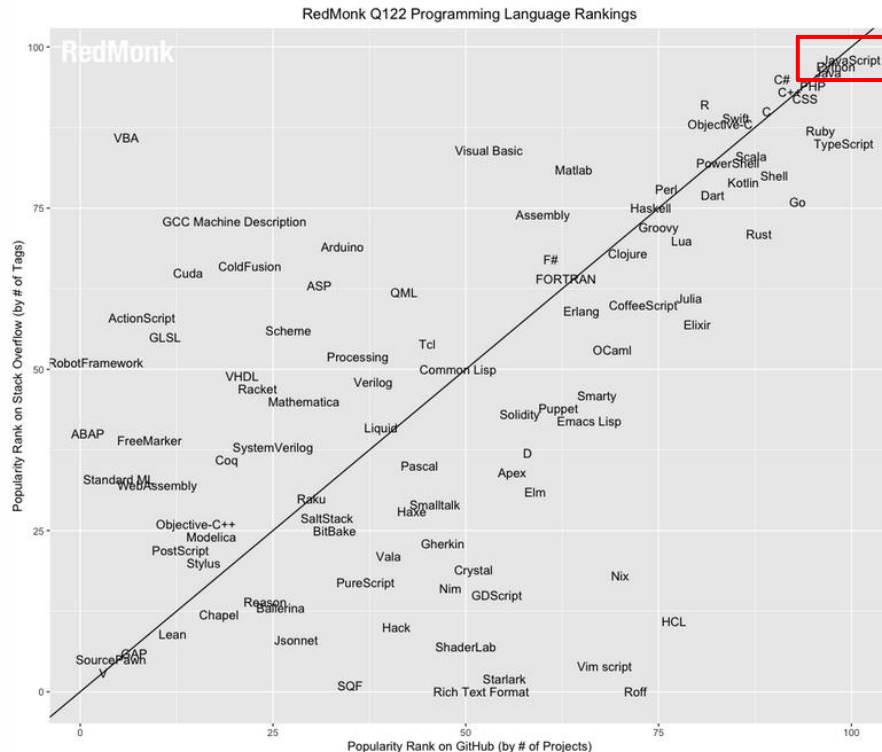
JavaScript 1
Python 2
Java
PHP 4
C# 5
C++
CSS
TypeScript 8
Ruby 9
C 10
Swift 11
R 12
Objective-C 13
Scala 14
Shell
Go 16
PowerShell 17
Kotlin 18
Rust 19
Dart 20

2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

RedMonk

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

Vadym Kazulkin @VKazulkin , ip.labs GmbH



1 JavaScript
2 Python
3 Java
4 PHP
5 CSS

https://redmonk.com/sogrady/2022/03/28/language-rankings-1-22/

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/

Serverless adoption by cloud provider

The State of Serverless 2022
https://www.datadoghq.com/state-of-serverless/

Average Daily Invocations per Lambda Function Index

LAMBDA FUNCTIONS ARE INVOKED 3.5X MORE OFTEN THAN 2 YEARS AGO

Average daily invocations index (Q1 '19 = 100)

500
400
300
200
100
0

Q1 '19 Q2 '19 Q3 '19 Q4 '19 Q1 '20 Q2 '20 Q3 '20 Q4 '20 Q1 '21

Source: Datadog

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

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 Corretto Support for 17 is released, but not currently available for AWS 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

Runtime	Percentage of all functions monitored	Percentage of all invocations monitored
Node.js	52.53%	44.96%
Python	35.84%	21.01%
Java	5.92%	24.39%
.NET Core	3.30%	5.62%
Go	2.05%	3.88%
Ruby	0.22%	0.10%
Custom Runtime	0.15%	0.04%

Percentage of all **functions** monitored

Percentage of all **invocations** monitored

Time frame July-December 2019

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.

Most Popular Runtimes by Distinct Functions

PYTHON IS THE MOST POPULAR LAMBDA RUNTIME

% of Lambda functions: 0%, 10%, 20%, 30%, 40%, 50%, 60%

Runtime: PYTHON, NODE.JS, JAVA, GO, .NET, RUBY, OTHER

Source: Datadog

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

Top languages used in Lambda functions

% of organizations using this language

100%
80%
60%
40%
20%
0%

PYTHON NODE.JS JAVA GO .NET RUBY

Language

Source: Datadog

PYTHON AND NODE.JS ARE THE TWO MOST POPULAR LAMBDA LANGUAGES

The State of Serverless 2022
https://www.datadoghq.com/state-of-serverless/

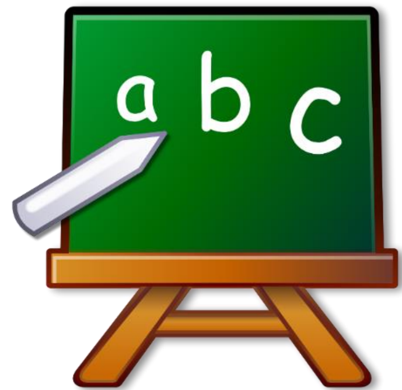
Developers love Java and will be happy to use it for Serverless

```
C:\Windows\system32\cmd.exe
E:\Java>javac First.java

E:\Java>java First
Let's do something using Java technology.

E:\Java>
```

But what are the challenges ?

Serverless with Java challenges

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



AWS Lambda Basics

Creating AWS Lambda with Java 1/3

Basic information

Function name
Enter a name that describes the purpose of your function.
MyFirstJavaFunction
Use only letters, numbers, hyphens, or underscores with no spaces.

Runtime Info
Choose the language to use to write your function. Note that the console code editor supports only Node.js, Python, and Ruby.
Java 11 (Corretto)

Architecture Info
Choose the instruction set architecture you want for your function code.
- x86_64
- arm64

Permissions Info
By default, Lambda will create an execution role with permissions to upload logs to Amazon CloudWatch Logs. You can customize this default role later when adding triggers.

▼ Change default execution role

Execution role
Choose a role that defines the permissions of your function. To create a custom role, go to the IAM console.
- Create a new role with basic Lambda permissions
- Use an existing role
- Create a new role from AWS policy templates

Latest supported
- .NET 6 (C#/PowerShell)
- .NET Core 3.1 (C#/PowerShell)
- Go 1.x
- Java 11 (Corretto)
- Node.js 14.x
- Python 3.9
- Ruby 2.7

Other supported
- Java 8 on Amazon Linux 1
- Java 8 on Amazon Linux 2
- Node.js 12.x

Java 11 (Corretto)

Basic settings

Description

Memory (MB) Info
Your function is allocated CPU proportional to the memory configured.

128 MB

Timeout Info
0 min 3 sec

Full CPU access only approx. at 1.8 GB memory allocated

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

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

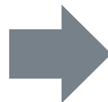
ONE GB

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:

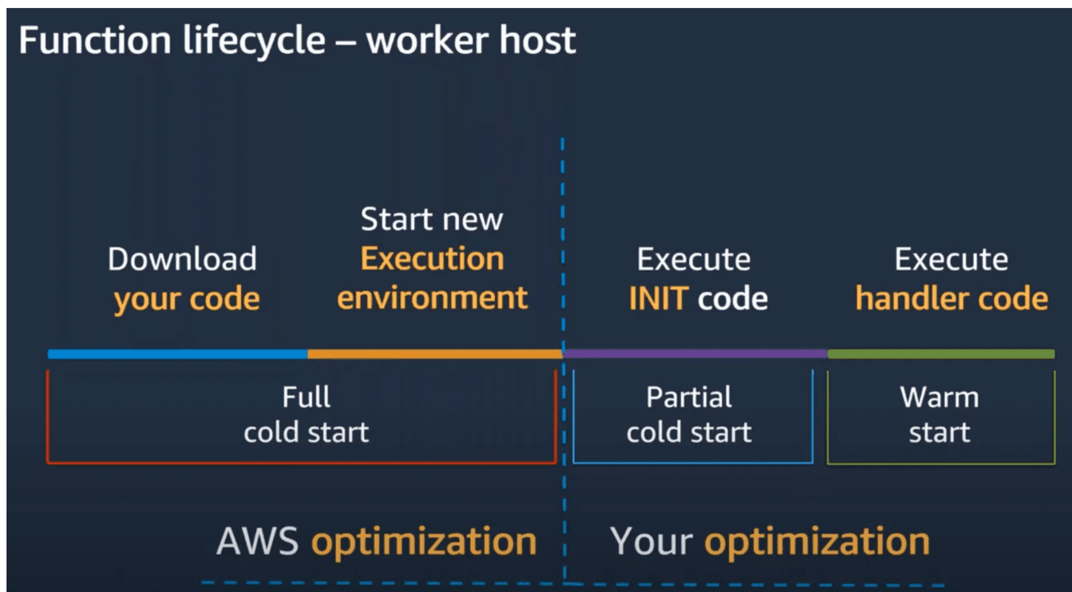
$0.20

GB-Seconds:

$1.67

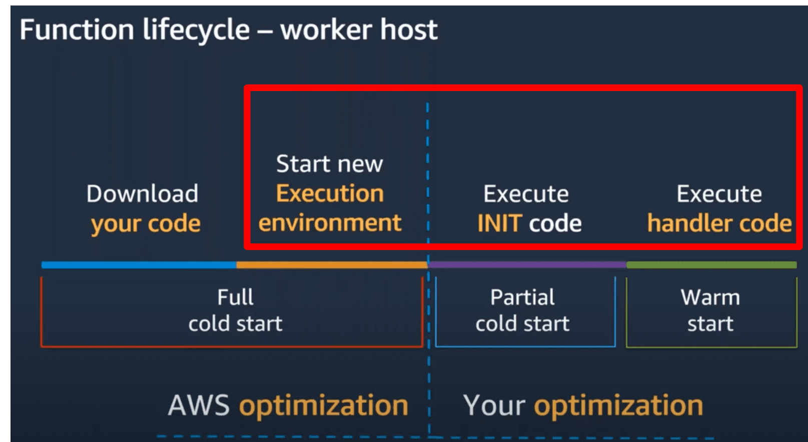
Challenge Number 1 with Java is a big cold-start

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



Basic settings

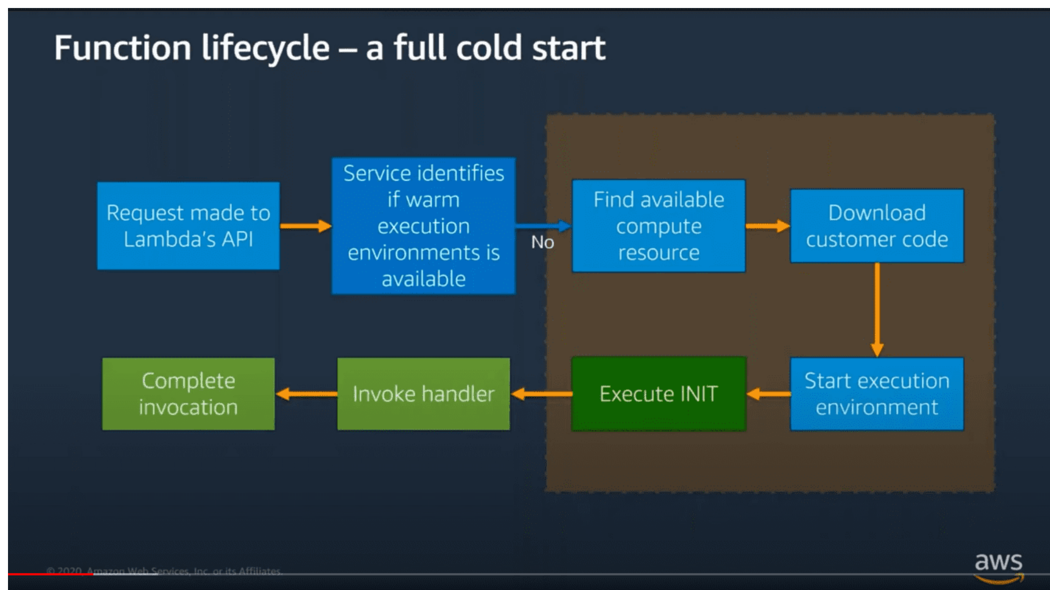
Description

Memory (MB) Info
Your function is allocated CPU proportional to the memory configured.
128 MB

Timeout Info
0 min 3 sec

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
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

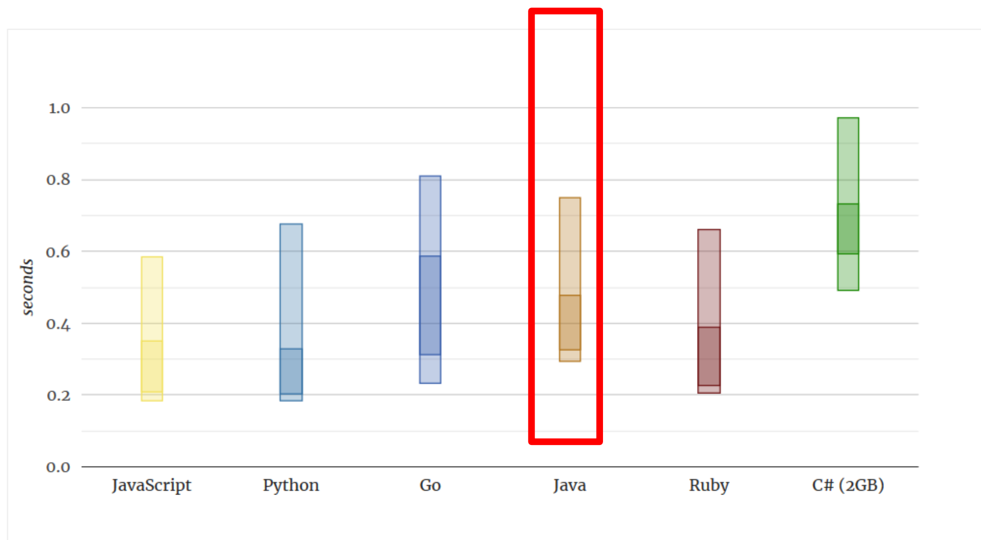
Function lifecycle- a full cold start



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

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)

Latency (ms)
1200
1000
800
600
400
200
0
5/9/20
5/11/20
5/13/20
5/15/20
5/17/20
5/19/20
5/21/20
5/23/20
5/25/20
5/27/20
5/29/20
5/31/20
6/2/20
6/4/20
6/6/20
6/8/20
6/10/20
6/12/20
6/14/20
6/16/20
6/18/20
6/20/20
6/22/20
6/24/20
6/26/20
6/28/20
Date

512 - java11 - large
512 - java11 - small
512 - java8 - large
512 - java8 - largeuberjar
512 - java8 - small
1536 - java11 - large
1536 - java11 - small
1536 - java8 - large
1536 - java8 - small
3008 - java11 - large
3008 - java11 - small
3008 - java8 - large
3008 - java8 - small

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

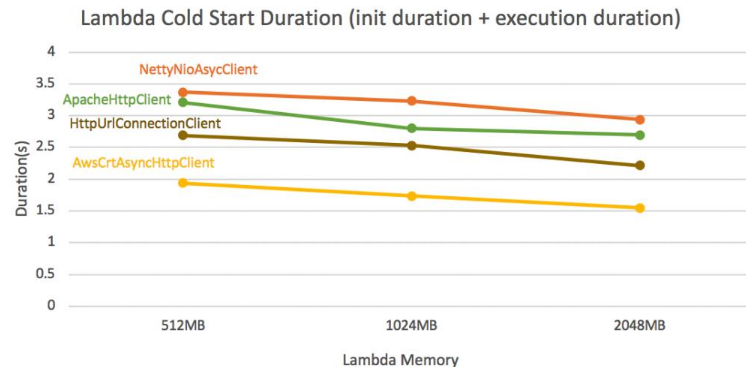
- Below 1 second is best-case cold start duration for very simple Lambda like HelloWorld with no dependencies
- It goes up significantly with more complex scenarios
  - Instantiation outside of the handler method (static instantiation) to communicate with other (AWS) services (i.e. DynamoDB, SNS, SQS,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

Code | Test | Monitor | Configuration | Aliases | Versions

General configuration
Triggers
Permissions
Destinations
Environment variables
Tags

Environment variables (0) Edit

Key | Value

No environment variables
No environment variables associated with this function.
Edit

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

Bash

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

Lambda > Functions > example-with-tiered-comp > Edit environment variables

Edit environment variables

Environment variables

You can define environment variables as key-value pairs that are accessible from your function code. These are useful to store configuration settings without the need to change function code. Learn more

Key: JAVA_TOOL_OPTIONS
Value: -XX:+TieredCompilation -XX:TieredStop
Remove

Add environment variable

▸ Encryption configuration

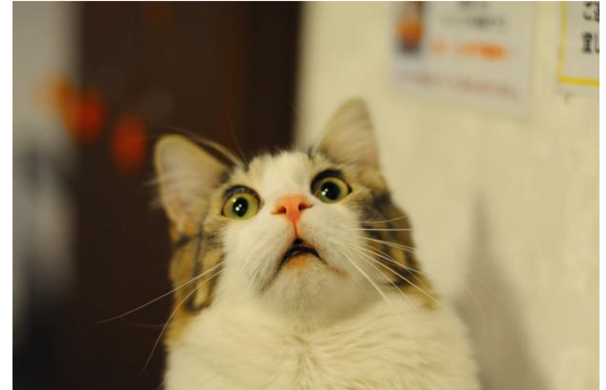
Cancel Save

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



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

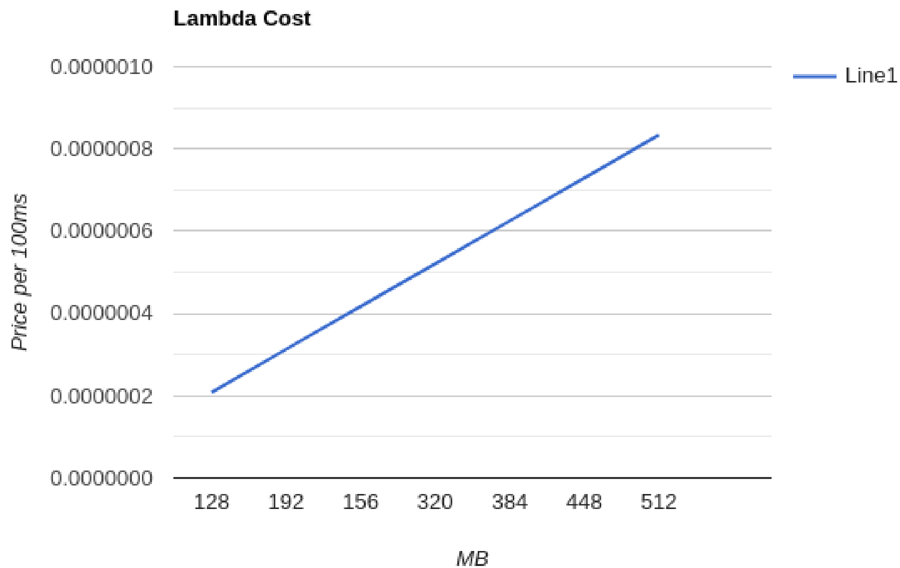
Cost optimization techniques

Cost for Lambda

REQUEST

DURATION

Cost scales linearly with memory



More memory = more expensive?

Basic settings

Description

Memory (MB) Info

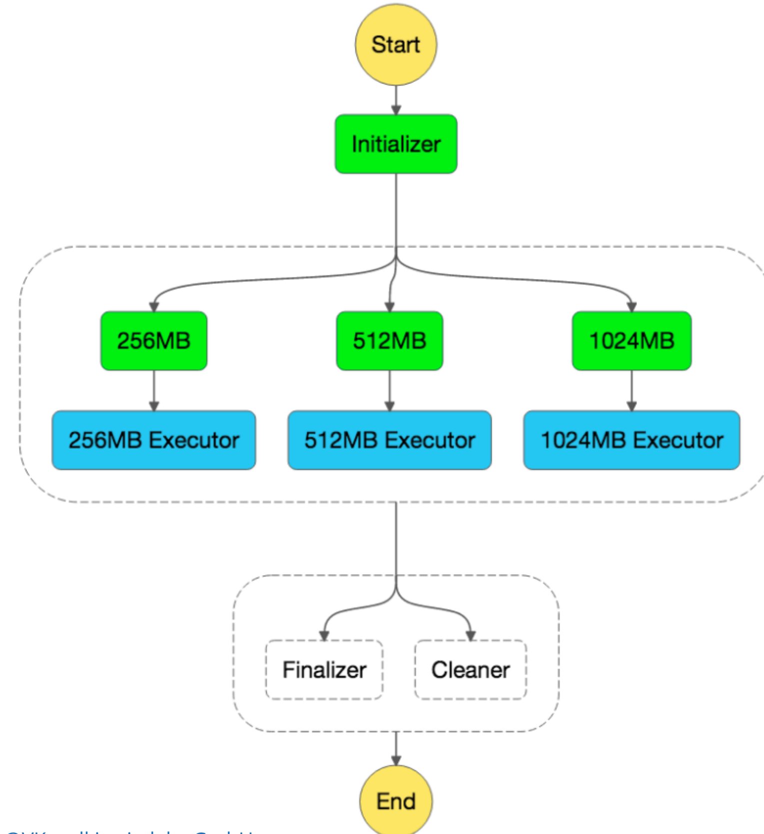
Your function is allocated CPU proportional to the memory configured.

Timeout Info

0 min 3 sec

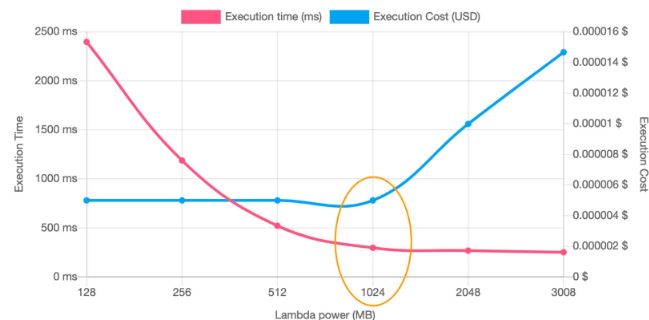
Lambda Power Tuning 1/2

- Executes different settings in parallel
- Outputs the optimal setting



Lambda Power Tuning 2/2

- Executes different settings in parallel
- Outputs the optimal setting



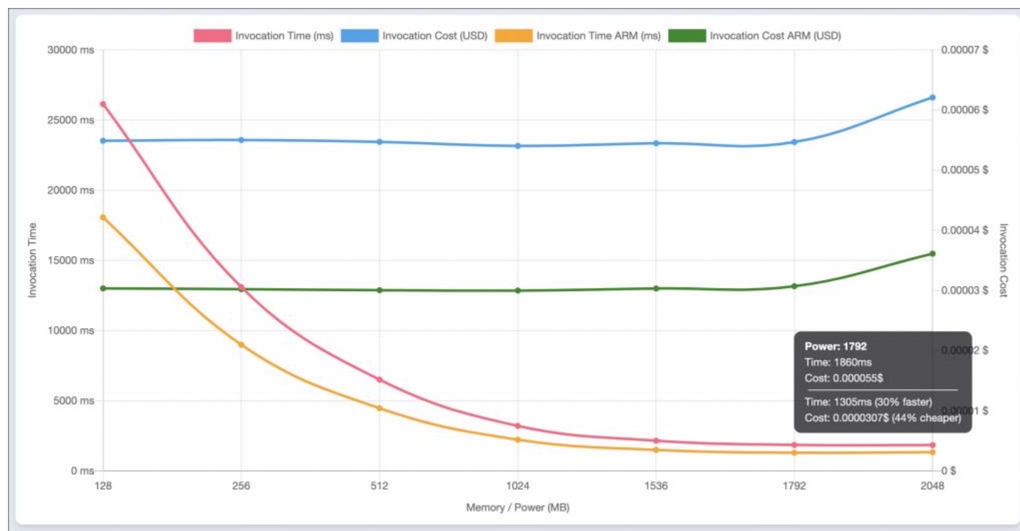


Image: https://github.com/alexcasalboni/aws-lambda-power-tuning
Alex Casalboni: “Deep dive: finding the optimal resources allocation for your Lambda functions“
https://dev.to/aws/deep-dive-finding-the-optimal-resources-allocation-for-your-lambda-functions-35a6

Optimizing AWS Lambda cost and performance using AWS Compute Optimizer

Recommendations for Lambda functions (2) Info

Recommendations for current resources to improve cost and performance.

Action ▼ | View details

Filter by one or more Regions | Memory over-provisioned ▼

Region: US East (N. Virginia) | Clear filters

Function name	Function version	Finding	Finding reason	Current configured memory	Recommended configured memory
lambda-recommendation-test-sleep	$LATEST	Not optimized	Memory over-provisioned	1024 MB	900 MB

AWS Compute Optimizer > Dashboard > Recommendations for Lambda functions > lambda-recommendation-test-sleep details

lambda-recommendation-test-sleep details Info

Open in Lambda Console

Function version: $LATEST

Compare current configured memory with recommended options Info

Consider an alternate memory configuration for the Lambda function.

Options	Configured memory	Cost difference (%)	Used memory (maximum)	Duration (average)	Projected duration (expected)
Current	1024 MB	-	819.0 MB	31333.6 milliseconds	-
Option 1	900 MB	-15.7% ~ -7.1%	-	-	31515.9 milliseconds

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/

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

GraalVM Architecture

node JS

C++ C

Ruby R JS

Sulong (LLVM)

Java Kotlin Scala

Truffle Framework

Graal Compiler

JVM Compiler Interface (JVMCI) JEP 243

Substrate VM

Java HotSpot VM

SubstrateVM

Static Analysis

Ahead-of-Time Compilation

Java Application

JDK

Substrate VM

Machine Code

Image Heap

ELF / MachO Binary

All Java classes from Your application, JDK, and Substrate VM

Reachable methods, fields, and classes

Application running without dependency on JDK and without Java class loading

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.

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

- AWS doesn't provide GraalVM (Native Image) as Java Runtime out of the box
- AWS provides 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

Java™
Scala
Groovy
Kotlin

GraalVM™

JIT

java MyMainClass
OpenJDK™

AOT

native-image MyMainClass
./mymainclass

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

AOT vs JIT

Startup Speed

Peak Throughput

AOT

JIT

Low Memory
Footprint

Reduced Max
Latency

Small Packaging

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

Clients
HTTP API
Lambda function
DynamoDB

	Java	Graalvm	.Net	Go	Rust	Python	NodeJS	Ruby
128MB		1480	11810	1050	844	641	1190	773
256MB	6570	774	5820	661	480	527	769	612
512MB	5180	684	2940	404	304	502	771	677
1024MB	4450	531	1500	299	234	482	656	652
10240MB	2790	501	904	327	219	449	518	649

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 Boot/ Spring Framework : Ongoing work on experimental Spring 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
- The common goals:
  - increase developer productivity
  - May decrease cold start times compared to plain Java solution (with and without the usage of GraalVM Native Image) using various compile-time optimization techniques
    - Currently only available for Micronaut

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

Example function.zip

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

Quarkus

Source: https://quarkus.io/

Quarkus Example with Spring Annotations

```java
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

```xml
<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>
```

```
[INFO] [io.quarkus.deployment.pkg.steps.NativeImageBuildStep] Running Quarkus native-image plugin on GraalVM 22.1.0 Java 17 CE (Java Version 17.0.3+7-jvmci-22.1-b06)
[INFO] [io.quarkus.deployment.pkg.steps.NativeImageBuildRunner] /usr/lib/jvm/graalvm-ce-java17-22.1.0/bin/native-image -J-Dsun.nio.ch.maxUpdateArraySize=100 -J-Djava.util.logging.manager=org.jboss.logmanager.Log
Manager -J-Dio.netty.leakDetection.level=DISABLED -J-Dio.netty.allocator.maxOrder=3 -J-Dvertx.logger-delegate-factory-class-name=io.quarkus.vertx.core.runtime.VertxLogDelegateFactory -J-Dvertx.disableDnsResolver
=true -J-Duser.language=en -J-Dfile.encoding=UTF-8 -H:-ParseOnce -J--add-exports=java.security.jgss/sun.security.krb5=ALL-UNNAMED -J--add-opens=java.base/java.text=ALL-UNNAMED -H:InitialCollectionPolicy=com.orac
le.svm.core.genscavenge.CollectionPolicy\$BySpaceAndTime -H:+JNI -H:+AllowFoldMethods -J-Djava.awt.headless=true -H:FallbackThreshold=0 --link-at-build-time -H:+ReportExceptionStackTraces -H:-AddAllCharsets -H:E
nableURLProtocols=http -H:NativeLinkerOption=-no-pie -H:-UseServiceLoaderFeature -H:+StackTrace quarkus-lambda-1.0.0-SNAPSHOT-runner -jar quarkus-lambda-1.0.0-SNAPSHOT-runner.jar
========================================================================================GraalVM Native Image: Generating 'quarkus-lambda-1.0.0-SNAPSHOT-runner' (executable)...
========================================================================================[1/7] Initializing...
            (18.8s @ 0.25GB) Version info: 'GraalVM 22.1.0 Java 17 CE'
 C compiler: gcc (linux, x86_64, 9.4.0)
 Garbage collector: Serial GC
 3 user-provided feature(s)
  - io.quarkus.runner.AutoFeature
  - io.quarkus.runtime.graal.DisableLoggingAutoFeature
  - io.quarkus.runtime.graal.ResourcesFeature
[2/7] Performing analysis...  [**********]                                         (95.3s @ 2.33GB)  11,273 (90.14%) of 12,506 classes reachable
  16,340 (59.28%) of 27,564 fields reachable
  58,839 (56.99%) of 103,241 methods reachable
     467 classes,   160 fields, and 1,821 methods registered for reflection
      64 classes,    75 fields, and    55 methods registered for JNI access
[3/7] Building universe...                                                          (9.0s @ 2.83GB)[4/7] Parsing methods...      [********]
            (66.7s @ 2.15GB)[5/7] Inlining methods...     [*****]                                          (21.3s @ 1.73GB)[6/7] Compiling methods...    [********]
                            (65.1s @ 3.41GB)[7/7] Creating image...                                                                    (18.1s @ 2.19GB)  22.97MB (44.09%) for code area:
   39,122 compilation units
  23.48MB (45.07%) for image heap:   7,758 classes and 290,542 objects
   5.65MB (10.85%) for other data
  52.09MB in total
```

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;
}

    public APIGatewayProxyResponseEvent handleRequest(APIGatewayProxyRequestEvent request,
                                                      Context context) {
        Pet newPet = new Pet();
        newPet.setId(request.getPathParameters().get("petId"));
        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());
        }
    }
}
```

```yaml
LambdaQuarkusGetPet:
    Type: Api
    Properties:
    RestApiId: !Ref ApiGatewayApi
    Path: /pets/{petId}
    Method: GET
```

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

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

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

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

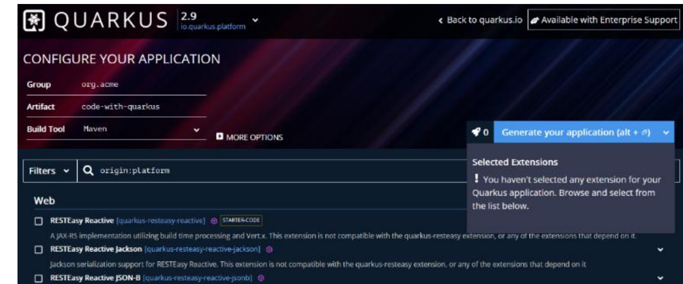
src/main/resources/application.properties

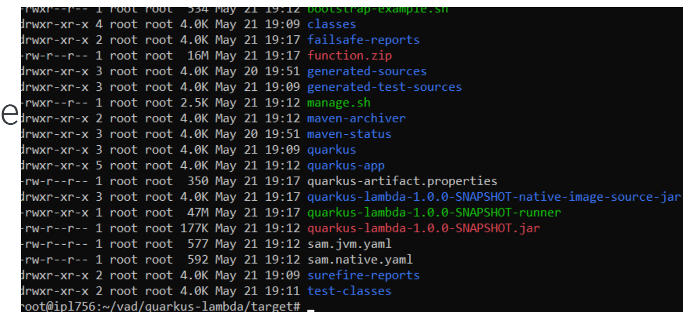
```
quarkus.lambda.handler = petsRequestHandler
quarkus.ssl.native = true
quarkus.native.enable-http-url-handler = true
quarkus.native.native-image-xmx = 6G

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 Function Interface**
- Website (https://code.quarkus.io/)
- CLI for creating the App
  - quarkus create app
  - use **quarkus-amazon-lambda** extension in pom.xml
  - quarkus build --native -Dquarkus.native.container-build=true
- Eclipse MicroProfile compatible
- Funqy for multi cloud solutions





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

- AWS Lambda currently works by implementing its own annotations (very similar to Spring Web) and should potentially work with Spring Web annotations model like **@RestController**, **@RequestMapping**
- Website (https://micronaut.io/launch) or CLI for creating the App
- Custom Validators
- No support for MicroProfile
- Micronaut AOT

MICRONAUT®
LAUNCH

Application Type	Java Version	Name	Base Package
Micronaut Application	17	demo	com.example

Micronaut Version	Language	Build Tool	Test Framework
● 3.4.3	● Java	○ Gradle	● JUnit
○ 3.4.4-SNAPSHOT	○ Groovy	○ Gradle Kotlin	○ Spock
○ 2.5.13	○ Kotlin	● Maven	○ Kotest

FEATURES | DIFF | PREVIEW | GENERATE PROJECT

Included Features (4)

aws-lambda × | aws-lambda-custom-runtime × | spring × | spring-boot ×

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 frameworl assumes that system properties and environment variables won't change, savin 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

Micronaut 3.2.1 | Micronaut 3.2.1+AOT

800ms
600ms
400ms
200ms
0ms

	Micronaut 3.2.1	Micronaut 3.2.1+AOT
Native	133ms	7ms
JVM	723ms	419ms

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.

Announcing
Spring Native Beta!

Quick start

Spring Boot 3 and Spring Framework 6, due in late 2022, will have built-in support for native Java.

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

```xml
<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>
```

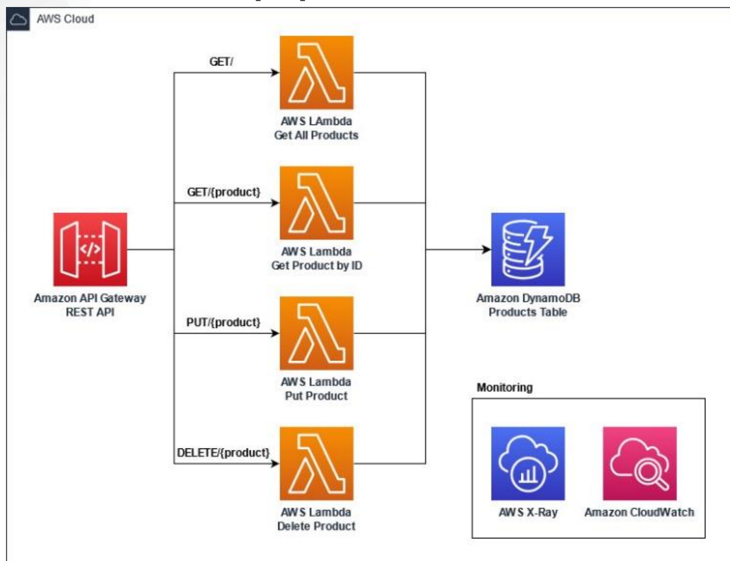
```xml
<dependencies>
	<dependency>
		<groupId>org.springframework.experimental</groupId>
		<artifactId>spring-native</artifactId>
	</dependency>
	<dependency>
		<groupId>org.springframework.cloud</groupId>
		<artifactId>spring-cloud-function-adapter-aws</artifactId>
	</dependency>
	<dependency>
		<groupId>org.springframework.cloud</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

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

https://github.com/aws-samples/serverless-java-frameworks-samples

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

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.

Create function Info

Choose one of the following options to create your function.

- **Author from scratch** — Start with a simple Hello World example.
- **Use a blueprint** — Build a Lambda application from sample code and configuration presets for common use cases.
- **Container image** (selected) — Select a container image to deploy for your function.
- **Browse serverless app repository** — Deploy a sample Lambda application from the AWS Serverless Application Repository.

Basic information

Function name
Enter a name that describes the purpose of your function.
random-letter
Use only letters, numbers, hyphens, or underscores with no spaces.

Container image URI Info
The location of the container image to use for your function.
Enter an Amazon ECR image URI
Requires a valid Amazon ECR image URI

Browse images

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

Lambda Container Image Support

- What about the support of the current Java version for Lambda?
    - Amazon Corretto provides Long Term Support (LTS)
        - Currently only Java 8, Java 11
    - Use Container (Docker) Image with i.e. Java 18

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.

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
  - Building Custom Runtime requires some additional effort
    - i.e. you need to scale CI pipeline to build memory-intensive native image yourself
  - 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 + optionally your favorite framework (Micronaut, Quarkus)
- If you don't want to miss 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 + optionally your favorite framework (Micronaut, Quarkus, Spring Boot 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

- Quarkus
  - https://github.com/aws-samples/aws-quarkus-demo/tree/main/lambda
  - https://quarkus.io/guides/amazon-lambda
- 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

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