# Operationalizing an AWS ML Project

## Dog Breed Image Classification using AWS SageMaker and PyTorch

In this project, several important tools and features of AWS are used to adjust, improve, configure, and prepare a ML model for production deployment. The project contains code that trains and deploys an image classification model on AWS Sagemaker.

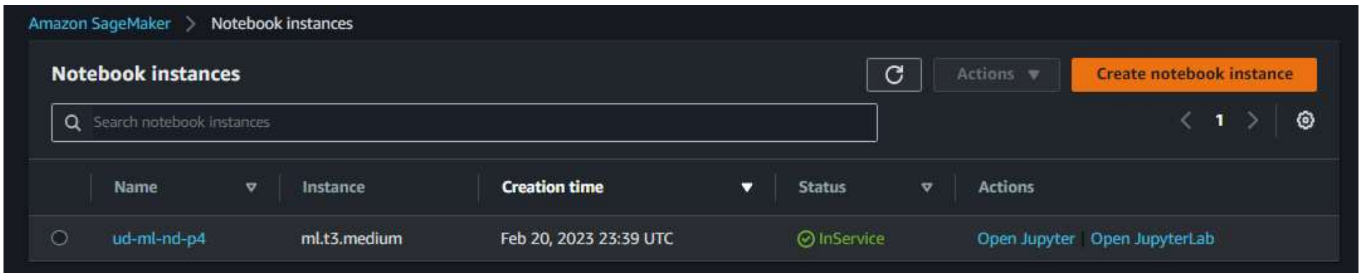
The project is performed following the next steps:

Step 1: Training and deployment on AWS Sagemaker.
Step 2: Training using EC2.
Step 3: Lambda function setup for inference.
Step 4: Lambda security setup and testing.
Step 5: Lambda concurrency setup and endpoint auto-scaling.

## Step 1: Training and deployment on AWS Sagemaker

The training process is performed using a Notebook instance on Sagemaker. A small instance type such as `ml.t3.medium` (2 vCPU and 6 GiB of memory) is selected for the project, since this meets the requirements for running the `train_and_deploy-solution.ipynb` notebook at the lowest cost of $ 0.05 per hour.

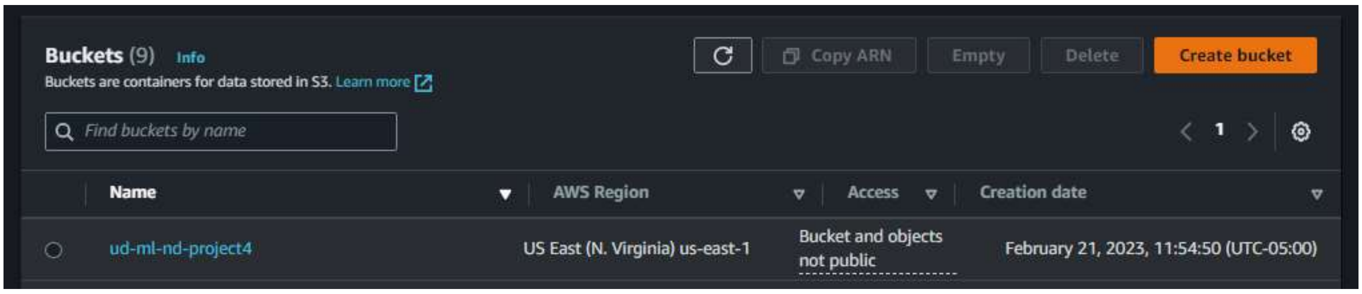
The following image shows the notebook instance created:


Amazon SageMaker > Notebook instances

Notebook instances

| Name | Instance | Creation time | Status | Actions |
|---|---|---|---|---|
| ud-ml-nd-p4 | ml.t3.medium | Feb 20, 2023 23:39 UTC | InService | Open Jupyter \| Open JupyterLab |

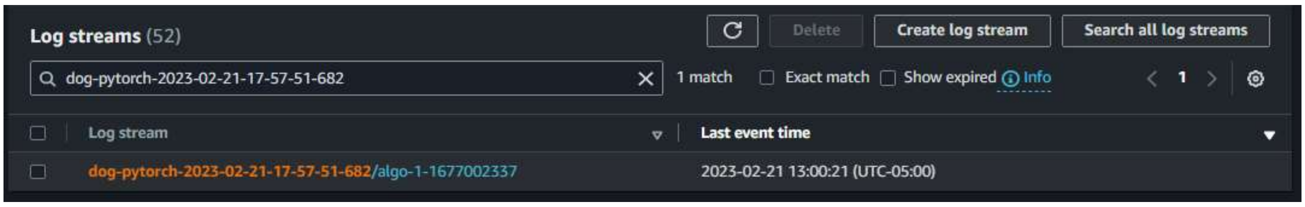
A S3 bucket is set up in order to storage the training data:


Buckets (9) Info
Buckets are containers for data stored in S3. Learn more

| Name | AWS Region | Access | Creation date |
|---|---|---|---|
| ud-ml-nd-project4 | US East (N. Virginia) us-east-1 | Bucket and objects not public | February 21, 2023, 11:54:50 (UTC-05:00) |

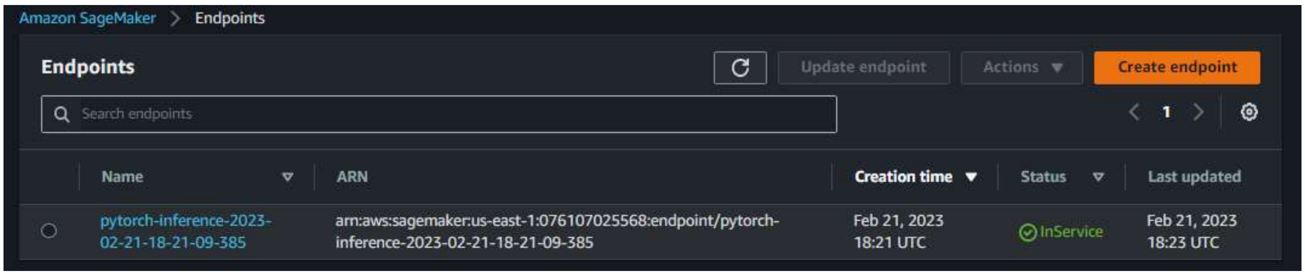
The model is trained on both single and multiple instances using a `ml.g4dn.xlarge` instance type. For practical purposes, the training halts at the first epoch. Then, the models from single instance and multiple instance training jobs are deployed, as follows:

- Single-instance training:


Log streams (52)

dog-pytorch-2023-02-21-17-57-51-682 — 1 match

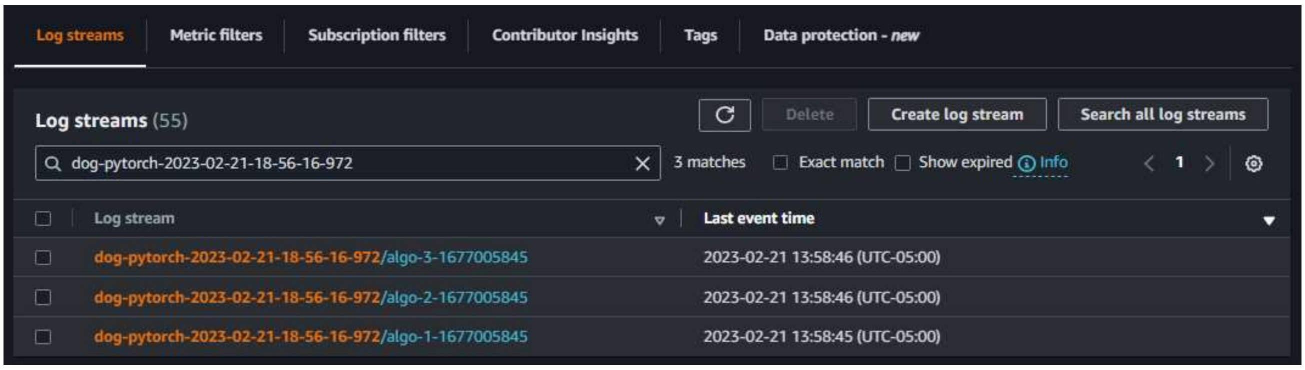
| Log stream | Last event time |
|---|---|
| dog-pytorch-2023-02-21-17-57-51-682/algo-1-1677002337 | 2023-02-21 13:00:21 (UTC-05:00) |


Amazon SageMaker > Endpoints

Endpoints

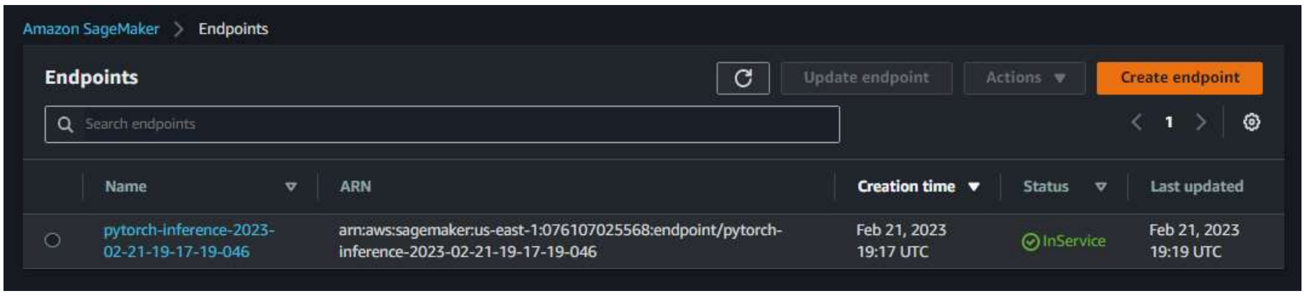
| Name | ARN | Creation time | Status | Last updated |
|---|---|---|---|---|
| pytorch-inference-2023-02-21-18-21-09-385 | arn:aws:sagemaker:us-east-1:076107025568:endpoint/pytorch-inference-2023-02-21-18-21-09-385 | Feb 21, 2023 18:21 UTC | InService | Feb 21, 2023 18:23 UTC |

- Multi-instance training:


Log streams (55)

dog-pytorch-2023-02-21-18-56-16-972 — 3 matches

| Log stream | Last event time |
|---|---|
| dog-pytorch-2023-02-21-18-56-16-972/algo-3-1677005845 | 2023-02-21 13:58:46 (UTC-05:00) |
| dog-pytorch-2023-02-21-18-56-16-972/algo-2-1677005845 | 2023-02-21 13:58:46 (UTC-05:00) |
| dog-pytorch-2023-02-21-18-56-16-972/algo-1-1677005845 | 2023-02-21 13:58:45 (UTC-05:00) |


Amazon SageMaker > Endpoints

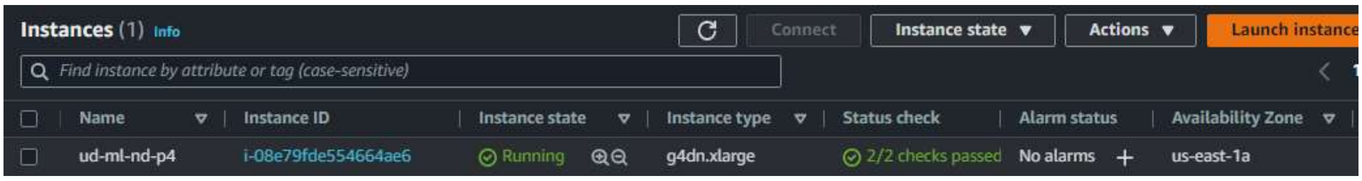
Endpoints

| Name | ARN | Creation time | Status | Last updated |
|---|---|---|---|---|
| pytorch-inference-2023-02-21-19-17-19-046 | arn:aws:sagemaker:us-east-1:076107025568:endpoint/pytorch-inference-2023-02-21-19-17-19-046 | Feb 21, 2023 19:17 UTC | InService | Feb 21, 2023 19:19 UTC |

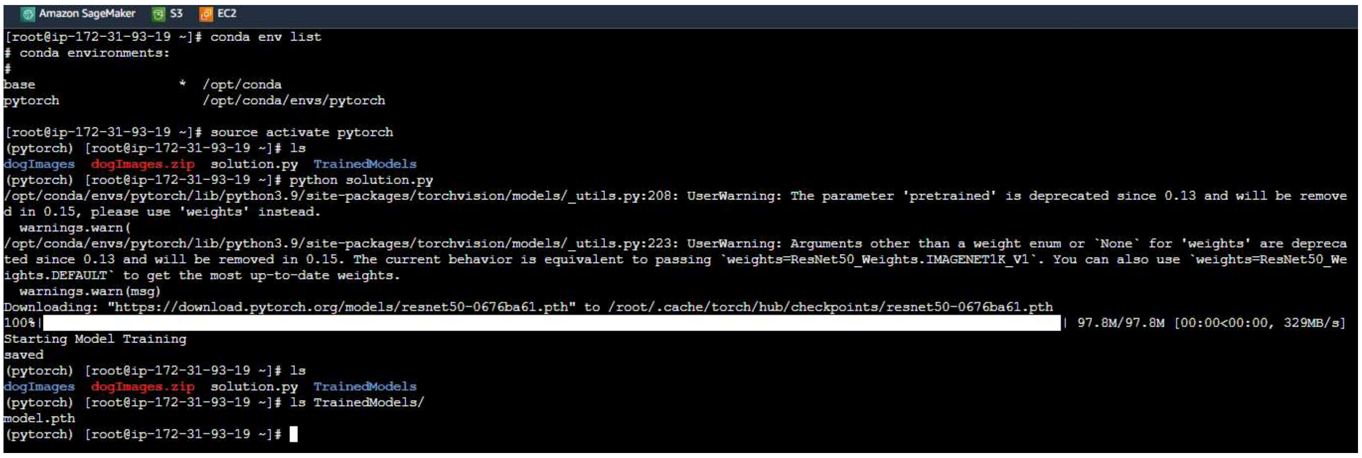
## Step 2: Training on EC2

An alternative for training a model is using an EC2 instance instead of Sagemaker. In this scenario, a script adapted from the notebook is necessary. The instance type chosen for training the model on EC2 is the same `ml.g4dn.xlarge` , since it meets the computing requeriments at a lower cost for processing and training. As said before, for practical purposes, the training will halt at the first epoch.

The following images shows the EC2 instance and the terminal running the `ec2train1.py` script for training the model.


Instances (1)

| Name | Instance ID | Instance state | Instance type | Status check | Alarm status | Availability Zone |
|---|---|---|---|---|---|---|
| ud-ml-nd-p4 | i-08e79fde554664ae6 | Running | g4dn.xlarge | 2/2 checks passed | No alarms | us-east-1a |



```
[root@ip-172-31-93-19 ~]# conda env list
# conda environments:
#
base                  *  /opt/conda
pytorch                  /opt/conda/envs/pytorch

[root@ip-172-31-93-19 ~]# source activate pytorch
(pytorch) [root@ip-172-31-93-19 ~]# ls
dogImages  dogImages.zip  solution.py  TrainedModels
(pytorch) [root@ip-172-31-93-19 ~]# python solution.py
/opt/conda/envs/pytorch/lib/python3.9/site-packages/torchvision/models/_utils.py:208: UserWarning: The parameter 'pretrained' is deprecated since 0.13 and will be remove
d in 0.15, please use 'weights' instead.
  warnings.warn(
/opt/conda/envs/pytorch/lib/python3.9/site-packages/torchvision/models/_utils.py:223: UserWarning: Arguments other than a weight enum or `None` for 'weights' are depreca
ted since 0.13 and will be removed in 0.15. The current behavior is equivalent to passing `weights=ResNet50_Weights.IMAGENET1K_V1`. You can also use `weights=ResNet50_We
ights.DEFAULT` to get the most up-to-date weights.
  warnings.warn(msg)
Downloading: "https://download.pytorch.org/models/resnet50-0676ba61.pth" to /root/.cache/torch/hub/checkpoints/resnet50-0676ba61.pth
100%|██████████████████████████████████████████████████| 97.8M/97.8M [00:00<00:00, 329MB/s]
Starting Model Training
saved
(pytorch) [root@ip-172-31-93-19 ~]# ls
dogImages  dogImages.zip  solution.py  TrainedModels
(pytorch) [root@ip-172-31-93-19 ~]# ls TrainedModels/
model.pth
(pytorch) [root@ip-172-31-93-19 ~]# 
```

## Step 3: Lambda function setup

After training and deploying the model, setting up a Lambda function, using the `lamdafunction.py` script, is an important task as this enables the model to be accessed by API's and other programs.

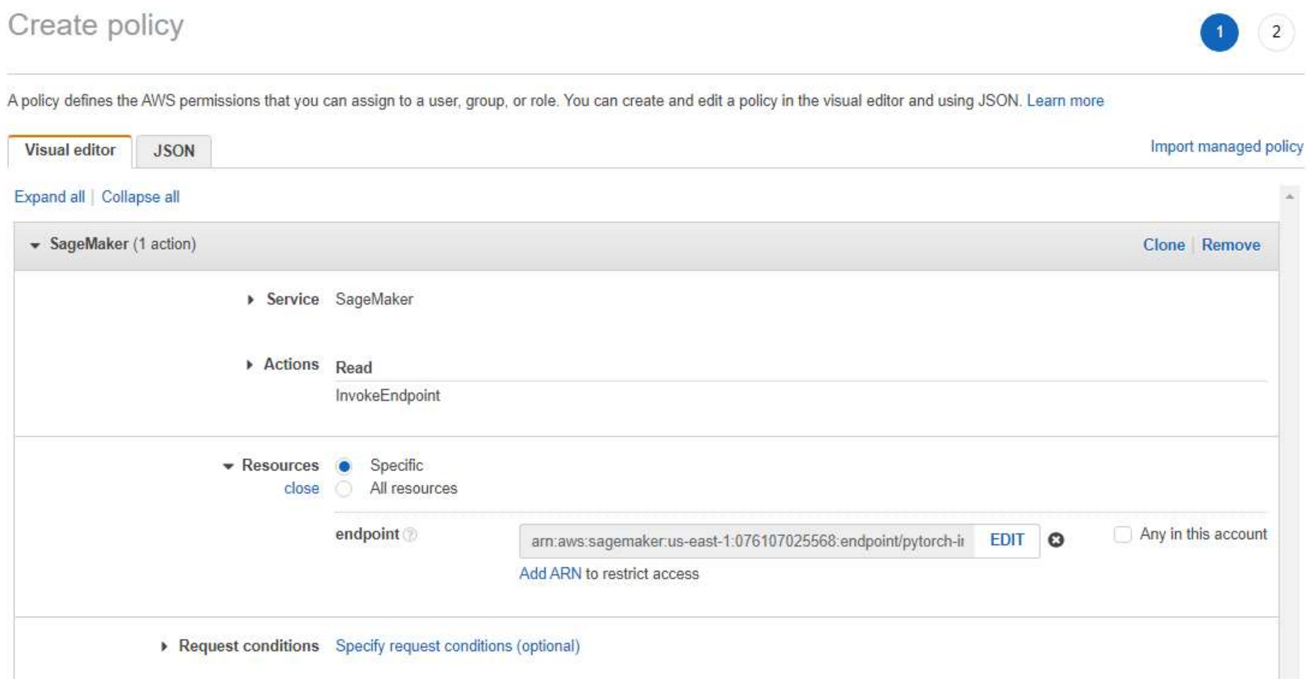
## Step 4: Lambda security setup and testing

Once the Lambda function is configured, it will return an error when performing a request test to invoke the Sagemaker deployed endpoint. This error is returned since the Lambda function role has no permissions to access the endpoint.

When choosing a proper policy to resolve the security issue, it is necessary to evaluate some vulnerabilities such as the following:

- Setting up a “FullAccess” policy without restrictions is a vulnerability that can be exploited by external elements, such as cybercriminals, in case of an unauthorized access to the Lambda Function.
- Roles that are old or inactive pose a security risk that can compromise a Lambda Function, hence they should be identified and removed.
- Roles with policies for Lambda functions that are no longer in use are also a potential risk of unauthorized access and they should be revoked and deleted.

For this project, a suitable policy that limits access to invoke a specific Sagemaker endpoint is created and attached to the Lambda role using the IAM interface, as follows:



Create policy

A policy defines the AWS permissions that you can assign to a user, group, or role. You can create and edit a policy in the visual editor and using JSON. Learn more

SageMaker (1 action)

Service: SageMaker

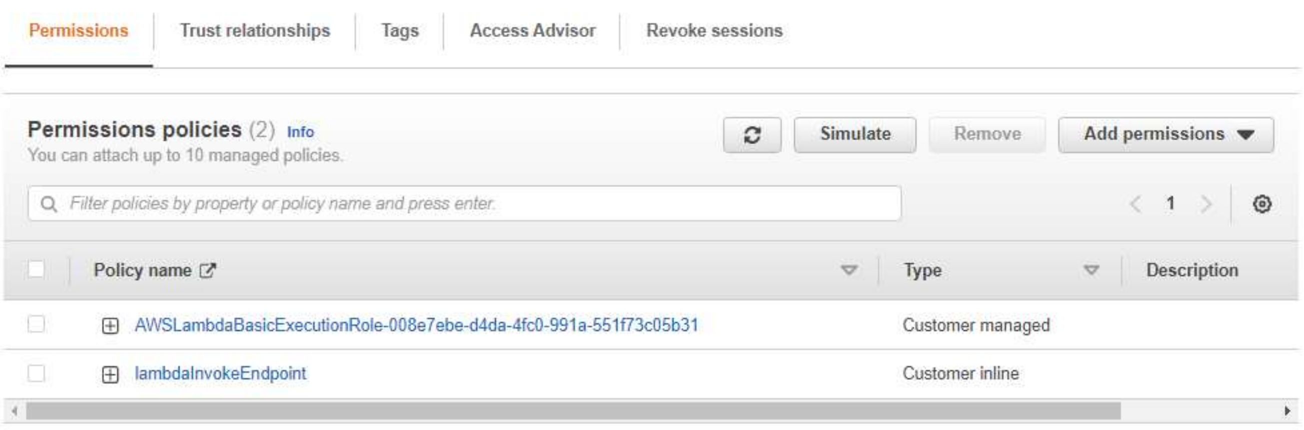
Actions: Read
InvokeEndpoint

Resources: [✓ Specific] All resources

endpoint: arn:aws:sagemaker:us-east-1:076107025568:endpoint/pytorch-i

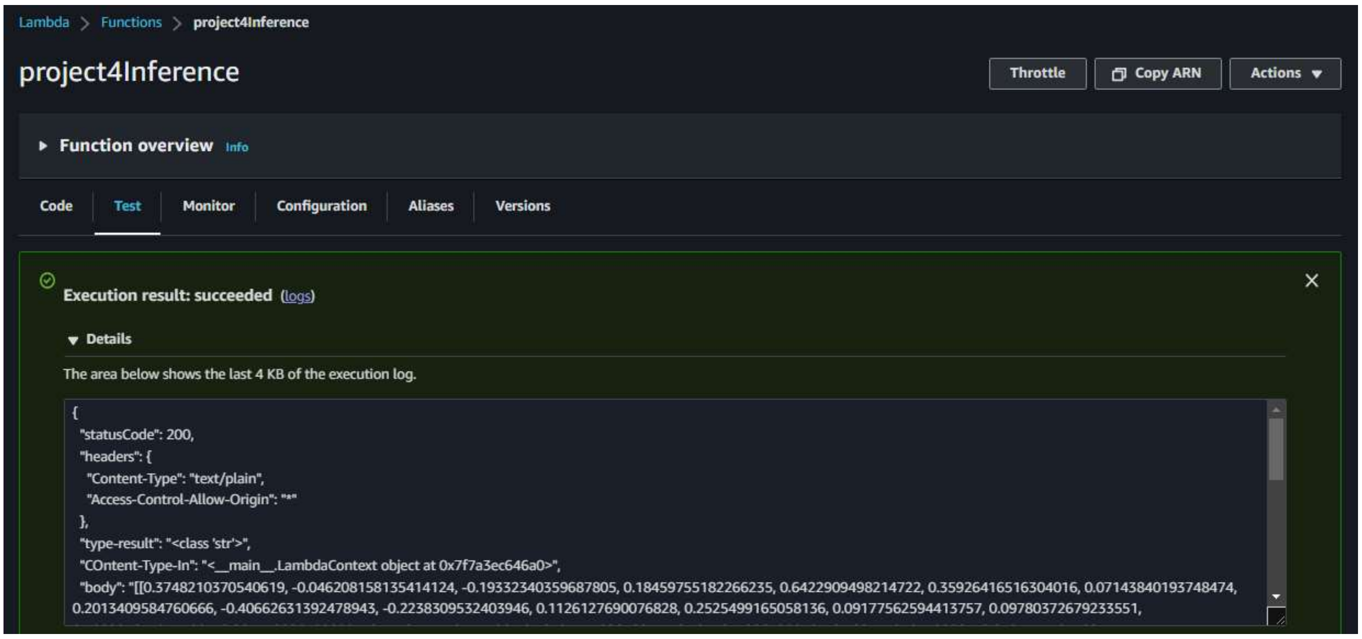
Any in this account

Request conditions: Specify request conditions (optional)


Permissions
Trust relationships
Tags
Access Advisor
Revoke sessions
Permissions policies (2) Info
You can attach up to 10 managed policies.
Simulate
Remove
Add permissions
Filter policies by property or policy name and press enter.
1

| Policy name | Type | Description |
|---|---|---|
| AWSLambdaBasicExecutionRole-008e7ebe-d4da-4fc0-991a-551f73c05b31 | Customer managed | |
| lambdaInvokeEndpoint | Customer inline | |

The results of a successful invoking test performed on the Lambda function are shown below:



Execution result: succeeded (logs)

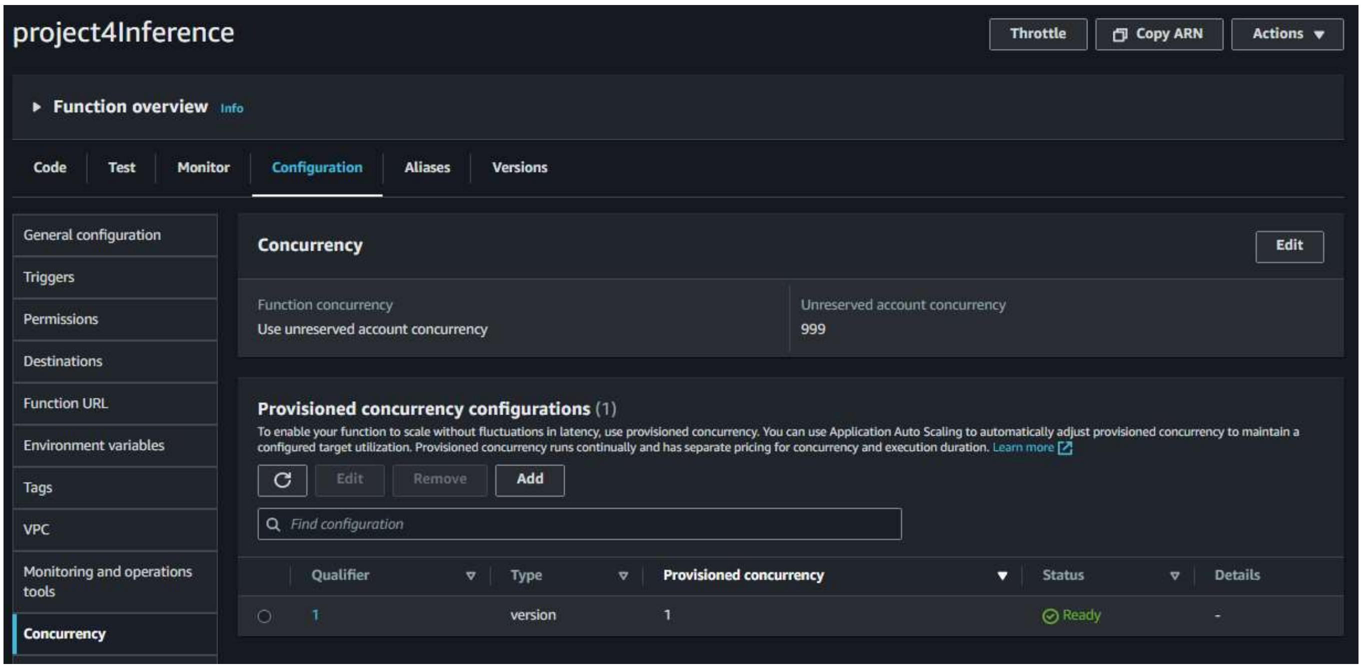
Details

The area below shows the last 4 KB of the execution log.

```
{
 "statusCode": 200,
 "headers": {
  "Content-Type": "text/plain",
  "Access-Control-Allow-Origin": "*"
 },
 "type-result": "<class 'str'>",
 "COntent-Type-In": "<__main__.LambdaContext object at 0x7f7a3ec646a0>",
 "body": "[[0.3748210370540619, -0.046208158135414124, -0.19332340359687805, 0.18459755182266235, 0.6422909498214722, 0.35926416516304016, 0.07143840193748474,
0.2013409584760666, -0.40662631392478943, -0.2238309532403946, 0.1126127690076828, 0.2525499165058136, 0.09177562594413757, 0.09780372679233551,
{
  "statusCode": 200,
  "headers": {
    "Content-Type": "text/plain",
    "Access-Control-Allow-Origin": "*"
  },
  "type-result": "<class 'str'>",
  "COntent-Type-In": "<__main__.LambdaContext object at 0x7f7a3ec646a0>",
  "body": "[[0.3748210370540619, -0.046208158135414124, -0.19332340359687805, 0.
18459755182266235, 0.6422909498214722, 0.35926416516304016, 0.07143840193748474,
0.2013409584760666, -0.40662631392478943, -0.2238309532403946, 0.112612769007682
8, 0.252549916505813 6, 0.09177562594413757, 0.09780372679233551, 0.5082946419715
881, 0.2655788064002991, 0.3439544439315796, -0.4079475402832031, -0.18330448865
890503, 0.4885449707508087, 0.2703157365322113, 0.15254491567611694, 0.457885950
8037567, 0.4886816740036011, -0.2267102301120758, 0.06121187284588814, 0.0862066
1497116089, -0.07932054996490479, 0.49667492508888245, 0.3141535520553589, 0.076
74485445022583, 0.1663159877061844, -0.25284793972969055, 0.21378761529922485,
0.2513206005096 4355, 0.561052620410919 2, 0.18995662033557892, 0.136289477348327 6
4, 0.1684465855360031, -0.15521439909934998, 0.4581757187843323, 0.1620015799999
237, 0.30257973074913025, 0.09637795388698578, 0.04541651904582977, 0.1521347463
130951, -0.08743750303983688, 0.04993806779384613, -0.20915032923221588, -0.2128
4787356853485, -0.02543587237596512, 0.1883545070886612, -0.30492720007896423,
0.18603497743606567, -0.2546696066856384, 0.1975076049566269, 0.455602020025253
3, 0.16756783425807953, 0.12390435487031937, -0.1146358922123909, 0.110598199069
49997, -0.11682835221290588, 0.0710432380437851, -0.4874916970729828, 0.05493775
010108948, -0.4273858070373535, -0.10279837250709534, 0.12126364558935165, 0.295
50567269325256, 0.18309897184371948, 0.06595314294099808, -0.025738196447491646,
-0.30459538102149963, 0.014923303388 05914, -0.15622296929359436, 0.1888063699007
0343, -0.2251722812652588, -0.2873472273349762, 0.1890975534915924, -0.003290688
619017601, -0.10139472037553787, 0.29221588373184204, 0.055993661284446716, 0.10
98623126745224, -0.1766642928123474, 0.08243223279714584, 0.3377177119255066, 0.
06499467045068741, 0.24551309645175934, 0.3099081516265869, -0.0449225306510925
3, -0.2474137842655182, -0.5685271620750427, -0.3114491403102875, -0.39963656663
894653, -0.33272674679756165, -0.08196931332349777, -0.1892833411693573, -0.0922
6399660110474, -0.4018873870372772, -0.06535250693559647, -0.4086303412914276, -
0.07361125200986862, -0.020849514752626 42, -0.508001446723938, -0.1040288507938 3
85, -0.4590185582637787, -0.9188807606697083, -0.010974306613206863, -0.46872627
73513794, -0.05386451259255409, 0.1874505877494812, -0.014306633733212948, -0.31
30384385585785, 0.3803076446056366, -0.5665944814682007, -0.14233903586864471, -
0.19892369210720062, -0.6708981990814209, -0.24014577269554138, -0.7050748467445
374, -0.48393329977989197, -0.05161240696907043 5, -0.2619426250457763 7, -0.48059
3204498291, -0.6064732670783997, 0.018597776070237 16, -0.3616325557231903, 0.152
866393327713, 0.26529568433761597, -0.5362987518310547, -0.5450462102890015, -0.
34911587834358215]]"
}
```

## Step 5: Lambda concurrency setup and endpoint auto-scaling

In order to prepare a Lambda function to respond to high traffic demand with low latency, i.e multiple invocations at once, provisioned concurrency can be set up. The price depends on the amount of memory is allocated to the function and the amount of concurrency. For the purposes of this project, a small amout of concurrency is set up, as follows:



**Concurrency**

Function concurrency
Use unreserved account concurrency

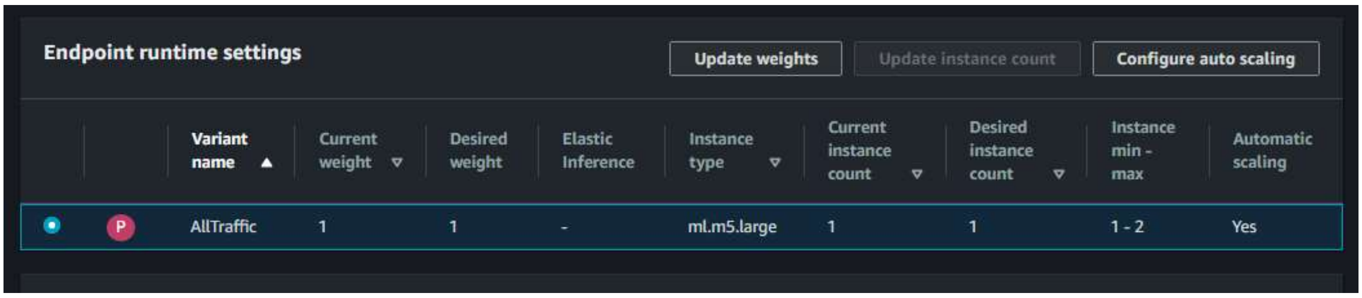
Unreserved account concurrency
999

**Provisioned concurrency configurations** (1)

To enable your function to scale without fluctuations in latency, use provisioned concurrency. You can use Application Auto Scaling to automatically adjust provisioned concurrency to maintain a configured target utilization. Provisioned concurrency runs continually and has separate pricing for concurrency and execution duration. Learn more

| | Qualifier | Type | Provisioned concurrency | Status | Details |
|---|---|---|---|---|---|
| ○ | 1 | version | 1 | Ready | - |

Finally, like Lambda functions use concurrency to respond to multiple requests at the same time, Sagemaker endpoints require automatic scaling to perform in a similar scenario. For this project, the auto-scaling setup with a maximun of 2 instances is shown in the following image:



**Endpoint runtime settings**

| | | Variant name | Current weight | Desired weight | Elastic Inference | Instance type | Current instance count | Desired instance count | Instance min - max | Automatic scaling |
|---|---|---|---|---|---|---|---|---|---|---|
| ● | P | AllTraffic | 1 | 1 | - | ml.m5.large | 1 | 1 | 1 - 2 | Yes |