

Low-Latency Cold Start Optimization for Serverless Machine Learning Inference

MSc Research Project
MSc in Cloud Computing

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Project Submission Sheet
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Programme:	MSc in Cloud Computing
Year:	2025
Module:	MSc Research Project
Supervisor:	Aqeel Kazmi
Submission Due Date:	11/12/2025
Project Title:	Low-Latency Cold Start Optimization for Serverless Machine Learning Inference
Word Count:	1146
Page Count:	12

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Low-Latency Cold Start Optimization for Serverless Machine Learning Inference

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1 Introduction

This guide provides details and steps on how to deploy machine learning models like DistilBERT, ResNet-50 and Random Forest Classifier as serverless functions on AWS, Azure and Google Cloud. The goal is to use to understand cold start behavior of these serverless functions and use the patterns to train logistic regression model and use it as a prewarming service next time before actual user requests comes in to invoke function and avoid cold start. Through this guide, you will know how to setup, generate data, train the model and use the model as a prewarm service.

Github Repo: The source code for this project is available at: <https://github.com/vyomvora/serverless-ml-coldstart>

2 Prerequisites and Environment Setup

2.1 System Dependencies

1. Python 3.9+
2. Windows: Docker Desktop or Linux: install Docker
3. AWS CLI
4. Azure CLI
5. Google Cloud SDK (gcloud)

2.2 Required Libraries

1. Cloud Platform SDK's:
 - boto3==1.28.0
 - azure-storage-blob==12.19.0
 - google-cloud-storage==2.14.0
2. Machine Learning model and Data Collection:
 - scikit-learn==1.3.2

- pandas==2.1.3
- numpy==1.24.3

3. DistilBERT and Resnet-50's frameworks:

- transformers==4.35.0
- torch==2.1.0
- torchvision==0.16.0

4. Common Libraries:

- requests==2.31.0
- Pillow==10.1.0
- python-dotenv==1.0.0

Save this as requirements.txt in your project's root folder.

3 Machine Learning Model Deployment

In this section, we will provide you with the project root to deploy your machine learning on each cloud. AWS Lambda uses Docker as deployment whereas Azure and GCP will have standard zip deployment.

3.1 DistilBERT, Resnet-50 and RandomForest Classifier

The entire setup is same for all three models on AWS Lambda. For Azure and GCP both are same way to setup but it is different than AWS Lambda but same for all the three models.

3.1.1 AWS Lambda, Azure Functions and Google Cloud Run Configuration

1. AWS Lambda Configuration

- Go to aws folder and create 3 files: Dockerfile, lambda_function and requirements.txt
- Create a Docker image with Dockerfile shown in 1 and push the image to AWS ECR.
- Go to AWS Lambda, Create a function and choose deployment type as Container and select image that you pushed to AWS ECR from previous step and launch the function. Services (2025)

2. We are keeping Azure and GCP configuration in same section as the steps are common just the folder structure and deployment command is different.

- Install Azure CLI and gcloud(Google Cloud CLI)
- Azure commands to deploy the function:

- `az functionapp create --resource-group serverless-rg --consumption-plan-location uk-south --runtime python --runtime-version 3.9 --functions-version 4 --name modelname --storage-account coldstartstorage`
- `az functionapp deployment source config-zip --resource-group serverless-rg --name modelname --src modelname.zip` [Retry Microsoft \(2025\)](#)
- GCP commands to deploy the function:
- `gcloud run deploy modelname --source=./modelname --region=us-central1 --allow-unauthenticated --memory=512Mi --timeout=120s --platform=managed` [Cloud \(2025\)](#)

```
FROM public.ecr.aws/lambda/python:3.13

WORKDIR ${LAMBDA_TASK_ROOT}

COPY requirements.txt .
RUN pip install --no-cache-dir -r requirements.txt

COPY lambda_function.py .

CMD ["lambda_function.lambda_handler"]
```

Figure 1: Dockerfile for AWS Lambda

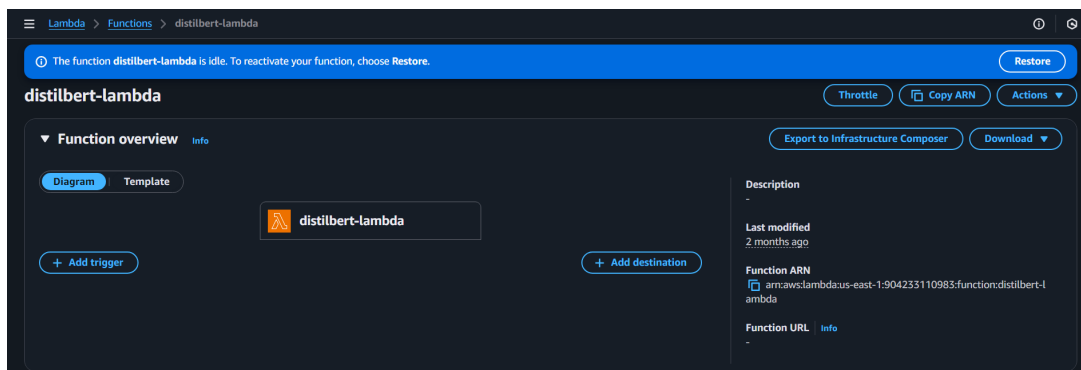


Figure 2: DistilBERT Function on AWS Lambda

4 Data Generation

4.1 Azure VM

1. Create a Azure VM where all the traffic generation scripts will run and download the .pem file.

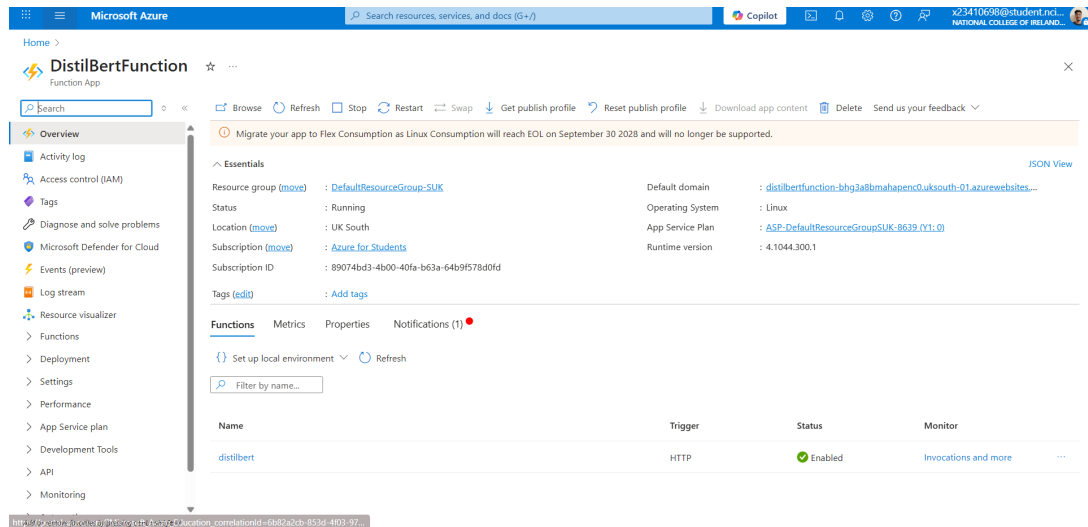


Figure 3: DistilBERT Function on Azure Functions

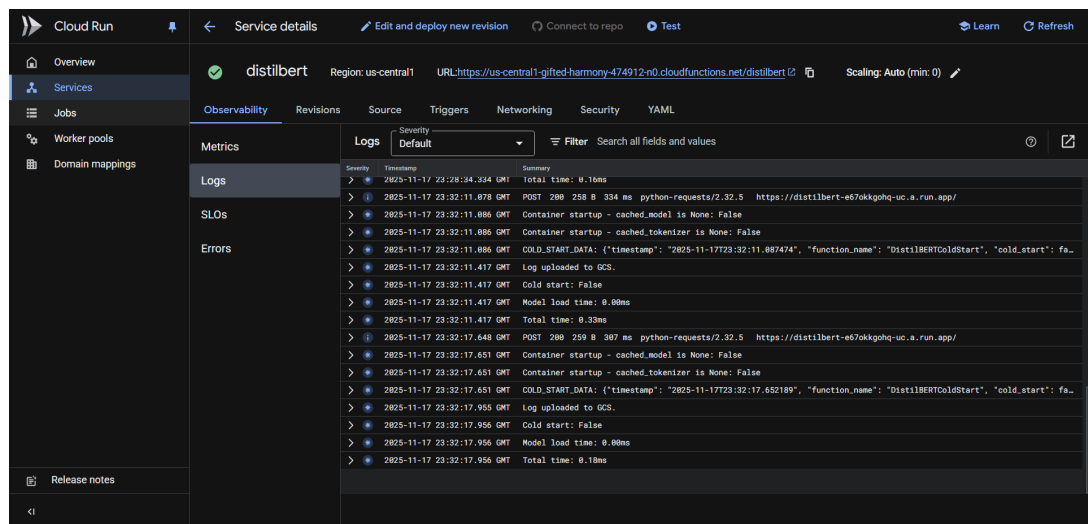


Figure 4: DistilBERT Function on GCP Cloud Run

2. Install python 3.9+ in the VM.
3. Create python environment and install the requirements.txt that is required for running all the python scripts.
4. Copy all the cronjob(traffic generation) file from your local device to Azure's VM using: `sudo scp -i vmkey.pem ./traffic_generation_scripts.py azureuser@20.55.123.10:/home`
5. Install screen on Azure's VM using command `:sudo apt install screen`. It is used for keeping the process running even if you disconnect from the VM

4.2 Traffic Generation Scripts

1. There are three files for traffic generation scripts as shown in 11
2. Make sure they are all copied to the Azure's VM as mentioned in 4.1

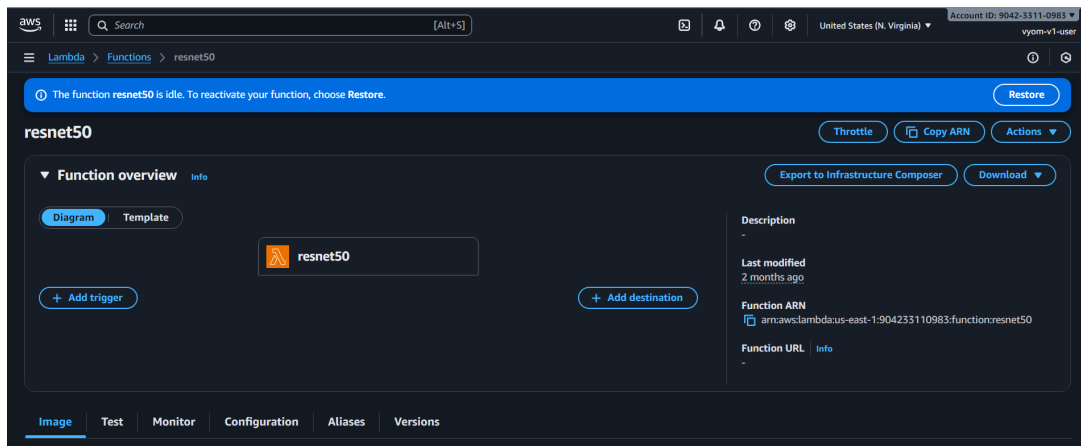


Figure 5: Resnet50 Function on AWS Lambda

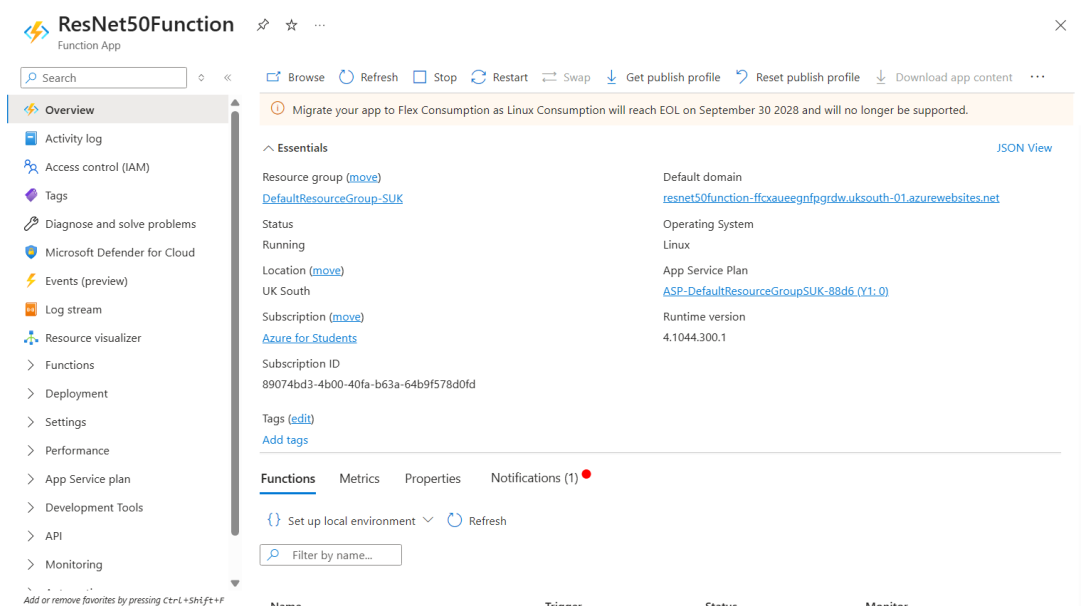


Figure 6: Resnet50 Function on Azure Functions

3. For each platform specific traffic script we follow these steps:
 - screen -S cloud_platform_name
 - python cronjob_lambda.py or cronjob_azure.py or cronjob_gcp.py
 - CTRL + A and press D
4. Now the traffic script will keep on running without any stoppage even if terminal disconnected.
5. Each script will store logs to cloud storages AWS S3 for Lambda, Azure Blob Storage for Azure and Google Cloud Storage for Cloud Run as show in 13 14 15

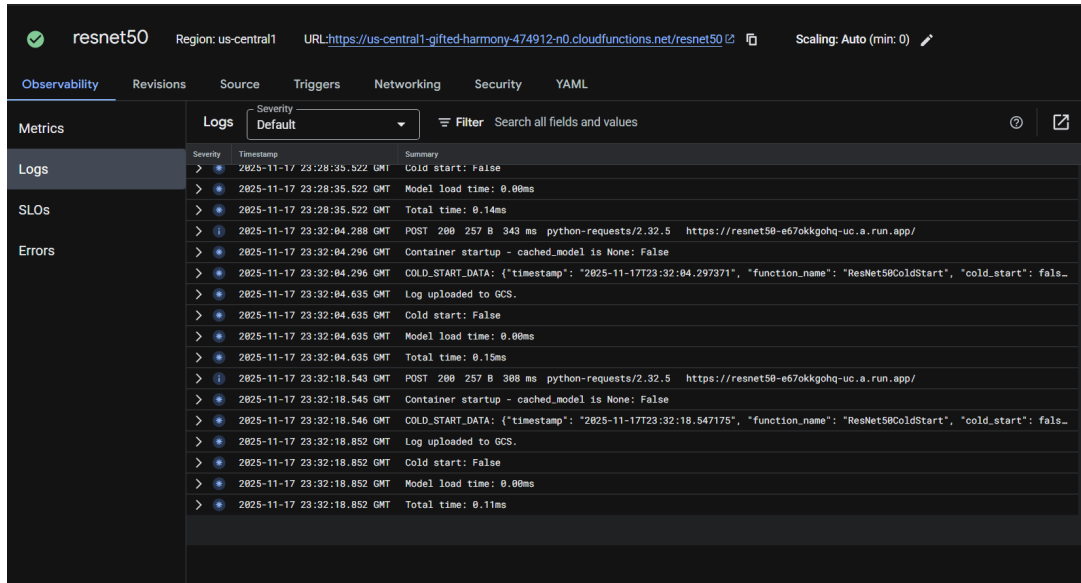


Figure 7: Resnet50 Function on Google Cloud Run

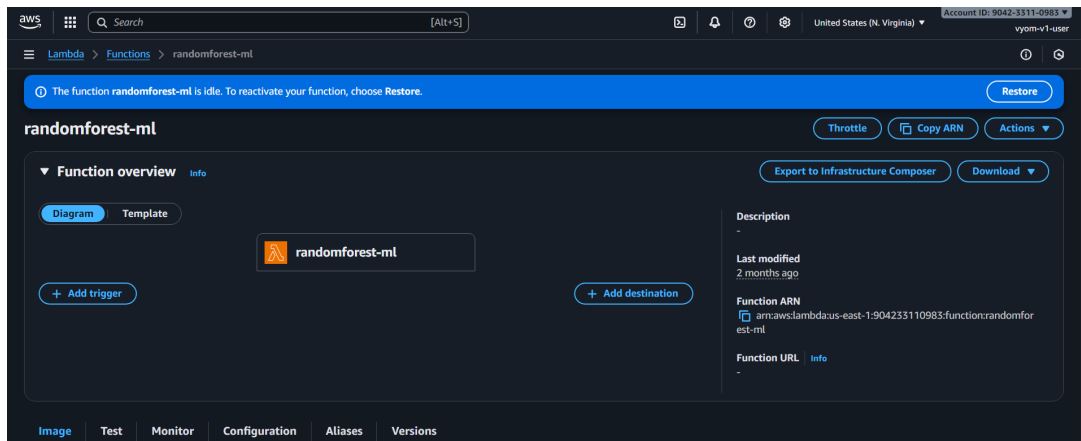


Figure 8: Random Forest Classifier Function on AWS Lambda

5 Model Training Setup

All the feature engineering and model training was done on local device itself. No need of Azure VM for this.

5.1 Transform Training Data

1. Go to folder `extract_feature_from_logs` and there are 3 files for each cloud platform.
2. Just do: `python aws_logs.py` or `azure_logs.py` or `gcp_logs.py`
3. It will save a new transformed csv that can be used further for model training as shown in

5.2 Training Prediction Model

1. Parameters used for training:

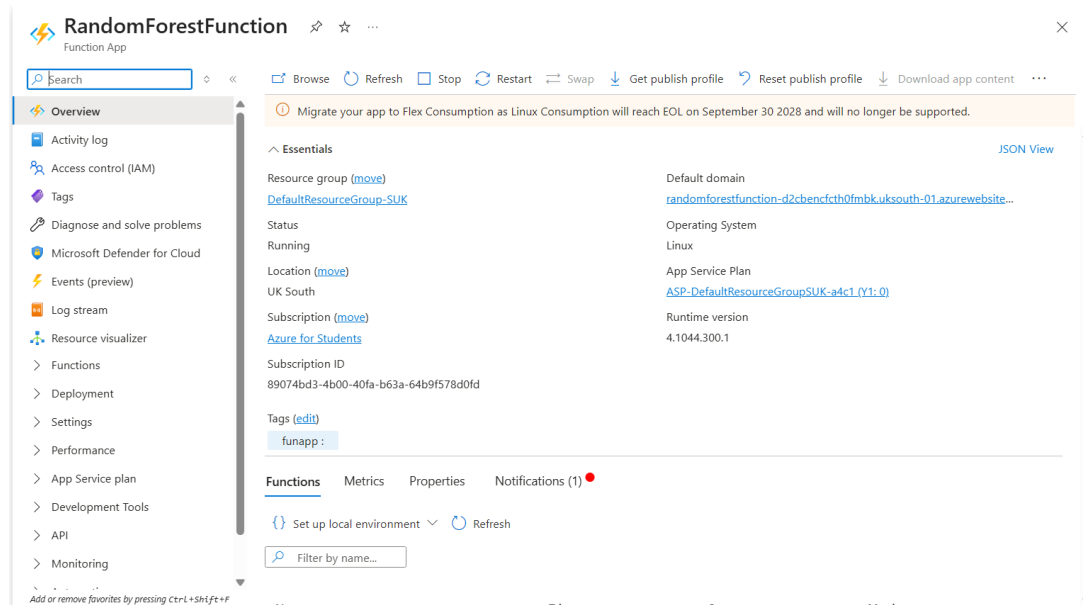


Figure 9: Random Forest Classifier Function on Azure Functions

- Train-test split: 70-30
 - Model: Logistic Regression(max_iter=2000, class_weight='balanced')
 - Threshold: 0.10(10%)
2. Save the model in a directory as lr_model.pkl
 3. Save the model's encoder file as label_encoders.pkl

6 Prediction Service Deployment

6.1 Prediction Service Setup

- We will use the same Azure VM that we used for traffic generation script.
- Copy model pickle and model encoder files from your local device to Azure's VM using `sudo scp -i vmkey.pem lr_model.pkl azureuser@20.55.123.10:/home/azureuser/`

6.2 Baseline traffic script

- Now we need a traffic script on which our prediction service will run against. So we will create a dummy traffic script that invokes function for atleast 30 minutes.
- This traffic script needs to be copied from local device to Azure's VM and this script basically calls all the cloud platform serverless functions in once.
- Create a new screen as shown in section 4.2 and name it "Baseline script"
- Once you are in the screen just do `python baseline_script.py` and keep it running. This script is to send dummy traffic on which model can make decisions to prewarm.

Severity	Timestamp	Summary
INFO	2025-11-17 23:21:08.222 GMT	COLD_START_DATA: {"timestamp": "2025-11-17T23:21:08.223584", "function_name": "RandomForestColdStart", "cold_start": ...}
INFO	2025-11-17 23:21:08.566 GMT	Log uploaded to GCS.
INFO	2025-11-17 23:21:15.282 GMT	POST 200 262 B 367 ms python-requests/2.32.5 https://randomforest-e67okkgohq-uc.a.run.app/
INFO	2025-11-17 23:21:15.285 GMT	COLD_START_DATA: {"timestamp": "2025-11-17T23:21:15.286417", "function_name": "RandomForestColdStart", "cold_start": ...}
INFO	2025-11-17 23:21:15.578 GMT	Log uploaded to GCS.
INFO	2025-11-17 23:25:26.726 GMT	POST 200 261 B 386 ms python-requests/2.32.5 https://randomforest-e67okkgohq-uc.a.run.app/
INFO	2025-11-17 23:25:26.735 GMT	COLD_START_DATA: {"timestamp": "2025-11-17T23:25:26.736382", "function_name": "RandomForestColdStart", "cold_start": ...}
INFO	2025-11-17 23:25:27.039 GMT	Log uploaded to GCS.
INFO	2025-11-17 23:28:32.290 GMT	POST 200 264 B 344 ms python-requests/2.32.5 https://randomforest-e67okkgohq-uc.a.run.app/
INFO	2025-11-17 23:28:32.299 GMT	COLD_START_DATA: {"timestamp": "2025-11-17T23:28:32.300154", "function_name": "RandomForestColdStart", "cold_start": ...}
INFO	2025-11-17 23:28:32.640 GMT	Log uploaded to GCS.
INFO	2025-11-17 23:28:34.575 GMT	POST 200 264 B 356 ms python-requests/2.32.5 https://randomforest-e67okkgohq-uc.a.run.app/
INFO	2025-11-17 23:28:34.578 GMT	COLD_START_DATA: {"timestamp": "2025-11-17T23:28:34.579339", "function_name": "RandomForestColdStart", "cold_start": ...}
INFO	2025-11-17 23:28:34.932 GMT	Log uploaded to GCS.
INFO	2025-11-17 23:32:16.786 GMT	POST 200 265 B 345 ms python-requests/2.32.5 https://randomforest-e67okkgohq-uc.a.run.app/
INFO	2025-11-17 23:32:16.715 GMT	COLD_START_DATA: {"timestamp": "2025-11-17T23:32:16.716873", "function_name": "RandomForestColdStart", "cold_start": ...}
INFO	2025-11-17 23:32:17.058 GMT	Log uploaded to GCS.

Figure 10: Random Forest Classifier Function on Google Cloud Run

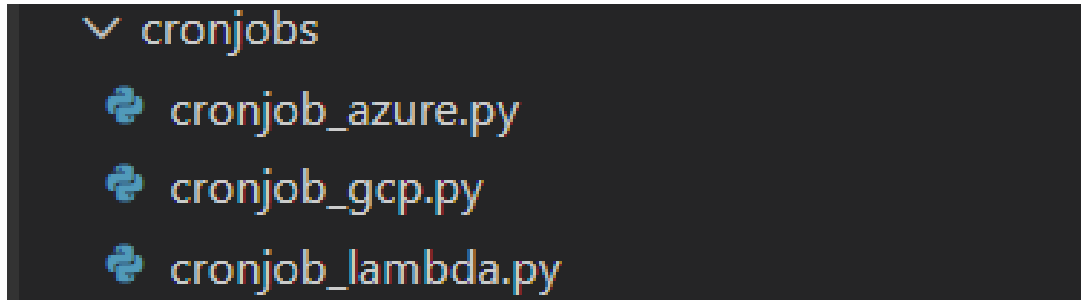


Figure 11: Traffic Generation Scripts for all cloud platforms

6.3 Baseline traffic script

- Now we need a traffic script on which our prediction service will run against. So we will create a dummy traffic script that invokes function for atleast 30 minutes.
- This traffic script needs to be copied from local device to Azure's VM and this script basically calls all the cloud platform serverless functions in once.
- Create a new screen as shown in section 4.2 and name it "baseline"
- Once you are in the screen just do `python baseline_script.py` and keep it running. This script is to send dummy traffic on which model can make decisions to prewarm.
- This script will store logs in the platform specific cloud storage.

6.4 Prewarm Prediction script

- This script uses logistic regression model that we trained earlier to make predictions.
- Copy this script from local device to Azure's VM.
- Create a new screen as shown in section 4.2 and name it "prewarm_prediction"

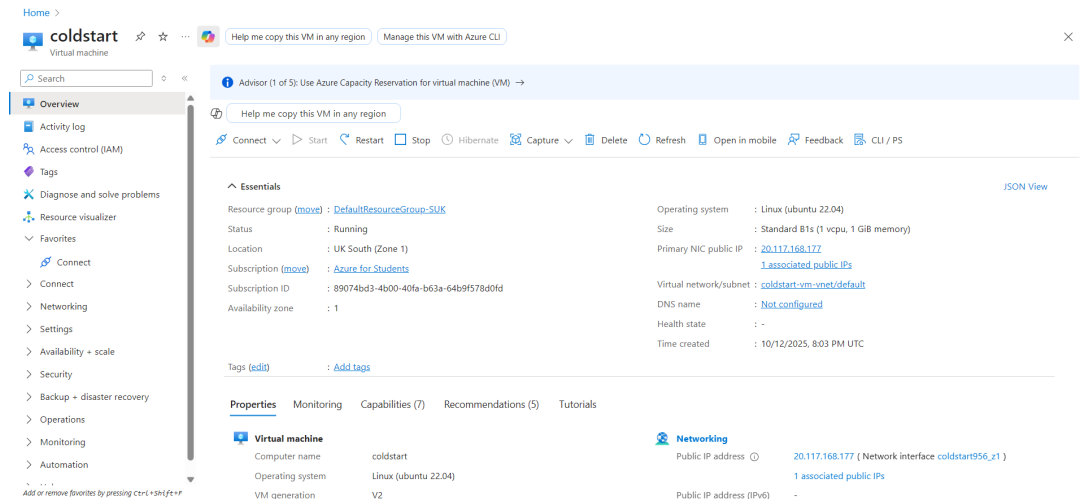


Figure 12: Virtual Machine Created in Azure

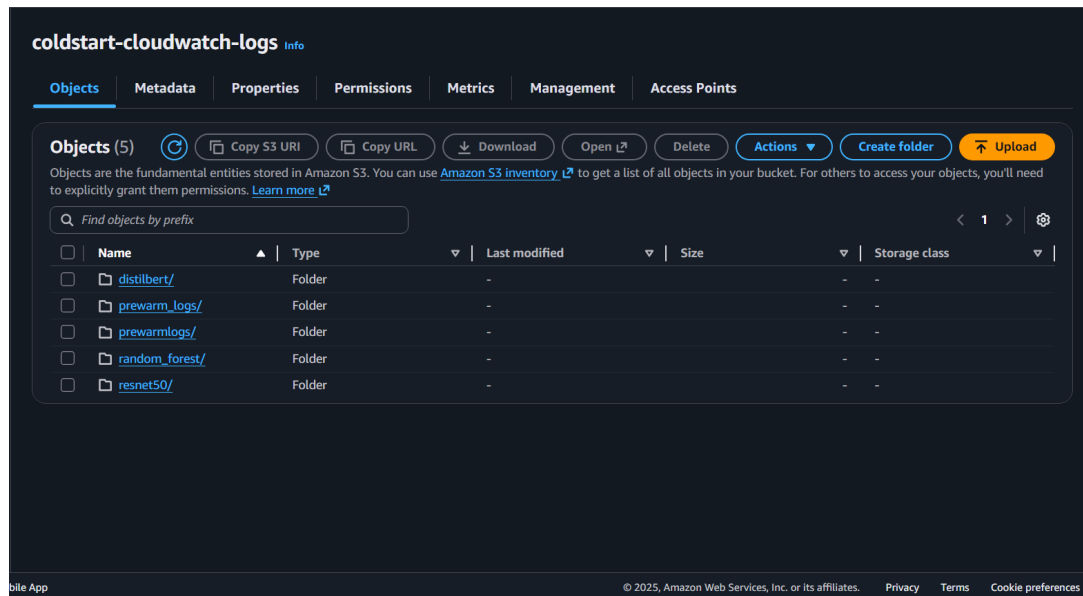


Figure 13: Traffic Script logs in AWS S3

- Once you are in the screen just do `python prewarm_script.py` and keep it running. This script will load model, check logs that were saved by baseline script and makes prewarming decisions
- This script will store decision logs in the platform specific cloud storage which can be used for analysis afterwards.

References

- Cloud, G. (2025). Cloud run documentation, <https://cloud.google.com/run/docs>. Published on 20 September.
- Microsoft (2025). Azure functions documentation, <https://docs.microsoft.com/azure/azure-functions/>. Published on 20 September.

Home > coldstartstorage | Containers >

serverless-logs ...

Container

Search

+ Add Directory ↑ Upload Change access level Refresh Delete Copy Paste Rename Acquire lease Break lease Edit columns

Overview

Diagnose and solve problems

Access Control (IAM)

Settings

serverless-logs

Authentication method: Access key (Switch to Microsoft Entra user account)

Add filter

Search blobs by prefix (case-sensitive)

Only show active blobs

Showing all 71 items

Name	Last modified	Access tier	Blob type	Size	Lease state
coldstart_logs_2025-10-10.jsonl	10/11/2025, 12:30:19 AM	Hot (Inferred)	Block blob	1.36 KiB	Available
coldstart_logs_2025-10-11.jsonl	10/11/2025, 7:00:44 PM	Hot (Inferred)	Block blob	1.64 KiB	Available
coldstart_logs_2025-10-12.jsonl	10/12/2025, 9:16:35 PM	Hot (Inferred)	Block blob	2.73 KiB	Available
coldstart_logs_2025-10-13.jsonl	10/13/2025, 10:30:07 PM	Hot (Inferred)	Block blob	3.01 KiB	Available
coldstart_logs_2025-10-14.jsonl	10/14/2025, 11:00:11 PM	Hot (Inferred)	Block blob	3.02 KiB	Available
coldstart_logs_2025-10-15.jsonl	10/15/2025, 9:00:57 PM	Hot (Inferred)	Block blob	4.09 KiB	Available
coldstart_logs_2025-10-16.jsonl	10/16/2025, 7:30:38 PM	Hot (Inferred)	Block blob	2.46 KiB	Available
coldstart_logs_2025-10-17.jsonl	10/17/2025, 7:30:40 PM	Hot (Inferred)	Block blob	1.93 KiB	Available
coldstart_logs_2025-10-18.jsonl	10/18/2025, 11:00:17 PM	Hot (Inferred)	Block blob	2.73 KiB	Available
coldstart_logs_2025-10-19.jsonl	10/19/2025, 12:30:48 PM	Hot (Inferred)	Block blob	1.9 KiB	Available
coldstart_logs_2025-10-29.jsonl	10/29/2025, 11:59:52 PM	Hot (Inferred)	Block blob	15.46 KiB	Available

Add or remove favorites by pressing Ctrl+Shift+F

Figure 14: Traffic Script logs in Azure Blob Storage

Cloud Storage

Bucket details

Go to path Refresh

Overview Buckets Monitoring Settings Storage Intelligence Insights datasets Configuration Marketplace Release notes

Objects Configuration Permissions Protection Lifecycle Observability New Inventory Reports Operations

Buckets > serverless-logs

Create folder Upload Transfer data Other services Learn

Sort and filter Filter Filter objects and folders Show Live objects only

Object sorting and filtering can make the Storage browser slower. For faster performance, select Filter by name prefix only from the filtering menu. Dismiss

Name	Size	Type	Created	Storage class	Last modified	Public access
gcp_distilbert_logs_2025-10-12.js	2.5 KB	application/jsonl	13 Oct 2025, 00:02:20	Standard	13 Oct 2025, 00:02:20	Not public
gcp_distilbert_logs_2025-10-13.js	4.6 KB	application/jsonl	13 Oct 2025, 23:32:25	Standard	13 Oct 2025, 23:32:25	Not public
gcp_distilbert_logs_2025-10-14.js	4.6 KB	application/jsonl	14 Oct 2025, 21:31:44	Standard	14 Oct 2025, 21:31:44	Not public
gcp_distilbert_logs_2025-10-15.js	5.7 KB	application/jsonl	15 Oct 2025, 21:32:16	Standard	15 Oct 2025, 21:32:16	Not public
gcp_distilbert_logs_2025-10-16.js	5.3 KB	application/jsonl	16 Oct 2025, 22:02:34	Standard	16 Oct 2025, 22:02:34	Not public
gcp_distilbert_logs_2025-10-17.js	5.7 KB	application/jsonl	18 Oct 2025, 00:02:11	Standard	18 Oct 2025, 00:02:11	Not public
gcp_distilbert_logs_2025-10-18.js	2.1 KB	application/jsonl	18 Oct 2025, 23:31:56	Standard	18 Oct 2025, 23:31:56	Not public
gcp_distilbert_logs_2025-10-19.js	3.6 KB	application/jsonl	19 Oct 2025, 14:01:34	Standard	19 Oct 2025, 14:01:34	Not public
gcp_distilbert_logs_2025-10-29.js	20.3 KB	application/jsonl	29 Oct 2025, 23:55:59	Standard	29 Oct 2025, 23:55:59	Not public
gcp_distilbert_logs_2025-10-30.js	181.7 KB	application/jsonl	30 Oct 2025, 23:58:58	Standard	30 Oct 2025, 23:58:58	Not public
gcp_distilbert_logs_2025-10-31.js	176 KB	application/jsonl	31 Oct 2025, 23:58:40	Standard	31 Oct 2025, 23:58:40	Not public
gcp_distilbert_logs_2025-11-01.js	170.4 KB	application/jsonl	1 Nov 2025, 23:58:52	Standard	1 Nov 2025, 23:58:52	Not public
gcp_distilbert_logs_2025-11-02.js	145.5 KB	application/jsonl	2 Nov 2025, 23:41:09	Standard	2 Nov 2025, 23:41:09	Not public
gcp_distilbert_logs_2025-11-03.js	108.8 KB	application/jsonl	3 Nov 2025, 16:29:22	Standard	3 Nov 2025, 16:29:22	Not public
gcp_distilbert_logs_2025-11-04.js	40.6 KB	application/jsonl	10 Nov 2025, 23:46:27	Standard	10 Nov 2025, 23:46:27	Not public

Figure 15: Traffic Script logs in GCP Cloud Storage

Services, A. W. (2025). Aws lambda documentation, <https://docs.aws.amazon.com/lambda>.

```
Command Prompt
(coldstart) E:\coldstart_ml\extract_features_from_logs>python azure_logs.py
LOADING AZURE DATA FROM BLOB STORAGE
Files in Azure Blob Storage:
Found 71 JSONL files:
- coldstart_logs_2025-10-10.jsonl
- coldstart_logs_2025-10-11.jsonl
- coldstart_logs_2025-10-12.jsonl
- coldstart_logs_2025-10-13.jsonl
- coldstart_logs_2025-10-14.jsonl
- coldstart_logs_2025-10-15.jsonl
- coldstart_logs_2025-10-16.jsonl
- coldstart_logs_2025-10-17.jsonl
- coldstart_logs_2025-10-18.jsonl
- coldstart_logs_2025-10-19.jsonl
- coldstart_logs_2025-10-29.jsonl
- coldstart_logs_2025-10-30.jsonl
- coldstart_logs_2025-10-31.jsonl
- coldstart_logs_2025-11-01.jsonl
- coldstart_logs_2025-11-02.jsonl
- coldstart_logs_2025-11-03.jsonl
- coldstart_logs_2025-11-10.jsonl
- coldstart_logs_2025-11-11.jsonl
- coldstart_logs_2025-11-12.jsonl
- coldstart_logs_2025-11-13.jsonl
- coldstart_logs_2025-11-14.jsonl
- coldstart_logs_2025-11-15.jsonl
- coldstart_logs_2025-11-16.jsonl
- coldstart_logs_2025-11-17.jsonl
- distilbert_coldstart_logs_2025-10-10.jsonl
- distilbert_coldstart_logs_2025-10-12.jsonl
- distilbert_coldstart_logs_2025-10-13.jsonl
- distilbert_coldstart_logs_2025-10-14.jsonl
- distilbert_coldstart_logs_2025-10-15.jsonl
- distilbert_coldstart_logs_2025-10-16.jsonl
- distilbert_coldstart_logs_2025-10-17.jsonl
- distilbert_coldstart_logs_2025-10-18.jsonl
- distilbert_coldstart_logs_2025-10-19.jsonl
- distilbert_coldstart_logs_2025-10-29.jsonl
- distilbert_coldstart_logs_2025-10-30.jsonl
- distilbert_coldstart_logs_2025-10-31.jsonl
- distilbert_coldstart_logs_2025-11-01.jsonl
- distilbert_coldstart_logs_2025-11-02.jsonl
- distilbert_coldstart_logs_2025-11-03.jsonl
```

Figure 16: Downloading and Transforming Logs

```
Python
# splitting the dataset
print("Splitting data into train and test")
X_train, X_test, y_train, y_test = train_test_split(
    X, y, test_size=0.2, random_state=42, stratify=y
)

# Logistic Regression model
model = LogisticRegression(max_iter=2000, class_weight='balanced', random_state=42)

# Train the model on the training data
print("Training Logistic Regression...")
model.fit(X_train, y_train)

# Make predictions on the test data
y_pred = model.predict(X_test)

accuracy = accuracy_score(y_test, y_pred)

# Display the results
print(f"Logistic Regression Results")
print(f"Accuracy: {accuracy * 100:.1f}%")

[e] ✓ 0.4s Python

Splitting data into train and test
Training Logistic Regression...
Logistic Regression Results
Accuracy: 66.0%
e:\coldstart_ml\coldstart\lib\site-packages\sklearn\linear_model\logistic.py:473: ConvergenceWarning: lbfgs failed to converge after 2000 iterations
STOP: TOTAL NO. OF ITERATIONS REACHED LIMIT

Increase the number of iterations to improve the convergence (max_iter=2000).
You might also want to scale the data as shown in:
https://scikit-learn.org/stable/modules/preprocessing.html
Please also refer to the documentation for alternative solver options:
https://scikit-learn.org/stable/modules/linear_model.html#logistic-regression
n_iter_i = check_optimize_result(
```

Figure 17: Logistic Regression Training

