MLOps: Major Assignment

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GitHub Repo: Major Assignment

Step-by-Step Breakdown

- Pre-requisite for Step 1:
    - Create local project structure

```
(base) PS D:\Projects\Study_Assignments\ML_OPS> mkdir mlops-linear-regression


    Directory: D:\Projects\Study_Assignments\ML_OPS


Mode                 LastWriteTime         Length Name
----                 -------------         ------ ----
d-----         7/30/2025  11:15 PM                mlops-linear-regression


(base) PS D:\Projects\Study_Assignments\ML_OPS> cd .\mlops-linear-regression\
```

```
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> mkdir src, tests, .github, .github/workflows


    Directory: D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression
```

```
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> New-Item -Path README.md -ItemType File
>> New-Item -Path .gitignore -ItemType File
>> New-Item -Path requirements.txt -ItemType File
>> New-Item -Path src/train.py -ItemType File -Force
>> New-Item -Path src/quantize.py -ItemType File -Force
>> New-Item -Path src/predict.py -ItemType File -Force
>> New-Item -Path src/utils.py -ItemType File -Force
>> New-Item -Path tests/test_train.py -ItemType File -Force
>> New-Item -Path .github/workflows/ci.yml -ItemType File -Force
```

Step 1: Repository Setup

- Initialize repo with:
    - README.md

- .gitignore
- requirements.txt

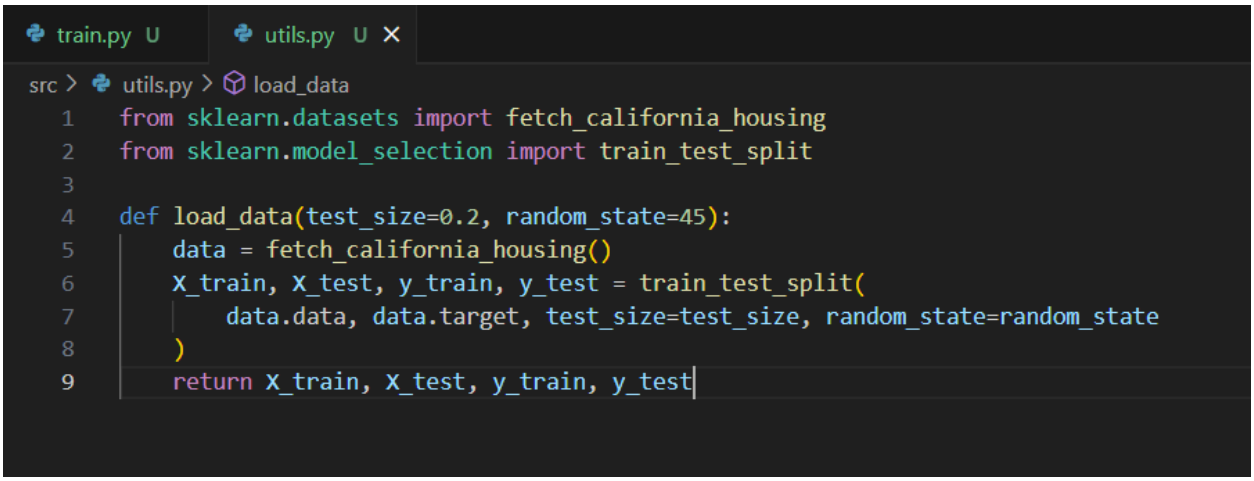
```
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git init
Initialized empty Git repository in D:/Projects/Study_Assignments/ML_OPS/mlops-linear-regression/.git/
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> echo "# mlops-linear-regression" > README.md
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> echo "__pycache__/\n*.pyc\n*.pkl\n*.joblib\n.env/\n.env" > .gitignore
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> echo "scikit-learn/\njoblib/\n" > requirements.txt
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git add README.md, requirements.txt, .gitignore
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git commit -m "Step 1: Repository setup"
[master (root-commit) e85df81] Step 1: Repository setup
 3 files changed, 0 insertions(+), 0 deletions(-)
 create mode 100644 .gitignore
 create mode 100644 README.md
 create mode 100644 requirements.txt
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git remote add origin https://github.com/git-commit-acc/mlops-linear-regression.git
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git branch -M main
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git push -u origin main
Enumerating objects: 5, done.
Counting objects: 100% (5/5), done.
Delta compression using up to 20 threads
Compressing objects: 100% (5/5), done.
Writing objects: 100% (5/5), 474 bytes | 474.00 KiB/s, done.
Total 5 (delta 0), reused 0 (delta 0), pack-reused 0 (from 0)
To https://github.com/git-commit-acc/mlops-linear-regression.git
 * [new branch]      main -> main
branch 'main' set up to track 'origin/main'.
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression>
```

- Pre-requisite for Step 2:
  - Create a conda virtual environment locally
  - Install the dependencies (requirements.txt)

```
(base) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> conda create -n mlops-linear-regression
Retrieving notices: ...working... done
Channels:
 - defaults
Platform: win-64
Collecting package metadata (repodata.json): done
Solving environment: done

## Package Plan ##

  environment location: C:\Users\ajink\anaconda3\envs\mlops-linear-regression



Proceed ([y]/n)? y

Preparing transaction: done
Verifying transaction: done
Executing transaction: done
#
# To activate this environment, use
#
#     $ conda activate mlops-linear-regression
#
# To deactivate an active environment, use
#
#     $ conda deactivate

(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> pip install -r .\requirements.txt
Requirement already satisfied: scikit-learn in c:\users\ajink\appdata\local\programs\python\python313\lib\site-packages (from -r
Requirement already satisfied: numpy in c:\users\ajink\appdata\local\programs\python\python313\lib\site-packages (from -r .\requ
Requirement already satisfied: joblib in c:\users\ajink\appdata\local\programs\python\python313\lib\site-packages (from -r .\req
Collecting pytest (from -r .\requirements.txt (line 4))
```

Step 2: Model Training (src/train.py)

• Load dataset.



• Train LinearRegression model.

• Print R2 score and loss.

• Save model using joblib.

train.py U utils.py U

src > train.py > ...

```python
from sklearn.datasets import fetch_california_housing
from sklearn.linear_model import LinearRegression
from sklearn.model_selection import train_test_split
from sklearn.metrics import mean_squared_error, r2_score
import joblib
import numpy as np
import sys, os
sys.path.append(os.path.dirname(__file__))
from utils import load_data

def main():
    X_train, X_test, y_train, y_test = load_data()

    model = LinearRegression()
    model.fit(X_train, y_train)

    preds = model.predict(X_test)
    r2 = r2_score(y_test, preds)
    mse = mean_squared_error(y_test, preds)

    print(f"R2 Score: {r2:.4f}")
    print(f"MSE: {mse:.4f}")

    joblib.dump(model, "src/trained_model.joblib")

if __name__ == "__main__":
    main()
```

- Test the code by running locally:

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> python .\src\train.py
R2 Score: 0.5758
MSE: 0.5559
```

- Commit changes to main branch:

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git add src/train.py, src/utils.py, requirements.txt
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git commit -m "Step 2: Model Training done"
[main 5c4ff4c] Step 2: Model Training done
 3 files changed, 36 insertions(+)
 create mode 100644 src/train.py
 create mode 100644 src/utils.py
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> git push origin main
Enumerating objects: 8, done.
Counting objects: 100% (8/8), done.
Delta compression using up to 20 threads
Compressing objects: 100% (6/6), done.
Writing objects: 100% (6/6), 1.03 KiB | 1.03 MiB/s, done.
Total 6 (delta 0), reused 0 (delta 0), pack-reused 0 (from 0)
To https://github.com/git-commit-acc/mlops-linear-regression.git
   e85df81..5c4ff4c  main -> main
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression>
```

Step 3: Testing Pipeline (tests/test train.py)

- Unit test dataset loading.
- Validate model creation (LinearRegression instance).
- Check if model was trained (e.g., coef exists).
- Ensure R2 score exceeds minimum threshold.

test_train.py U

tests > test_train.py > ...

```python
import sys, os
sys.path.append(os.path.abspath(os.path.join(os.path.dirname(__file__), '..')))
from src.utils import load_data
from sklearn.linear_model import LinearRegression
from sklearn.metrics import r2_score

def test_data_loading():
    X_train, X_test, y_train, y_test = load_data()
    assert X_train.shape[0] > 0
    assert X_test.shape[0] > 0

def test_model_creation():
    model = LinearRegression()
    assert isinstance(model, LinearRegression)

def test_model_training():
    X_train, X_test, y_train, y_test = load_data()
    model = LinearRegression()
    model.fit(X_train, y_train)
    assert hasattr(model, 'coef_')
    preds = model.predict(X_test)
    r2 = r2_score(y_test, preds)
    assert r2 > 0.5

```

- Test locally if these testcases work:

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> pytest tests/
============================= test session starts ==============================
platform win32 -- Python 3.13.0, pytest-8.4.1, pluggy-1.6.0
rootdir: D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression
plugins: dash-3.0.3
collected 3 items

tests\test_train.py ...                                                  [100%]

============================== 3 passed in 0.98s ==============================
```

Step 4: Manual Quantization (src/quantize.py)

- Load trained model.
- Extract coef and intercept .
- Save raw parameters (unquant params.joblib).
- Manually quantize them to unsigned 8-bit integers.
- Save quantized parameters (quant params.joblib).
- Perform inference with the de-quantized weights.

src > quantize.py > symmetric_quantize_int8

```python
import joblib
import numpy as np
import sys, os
sys.path.append(os.path.dirname(__file__))
from utils import load_data
from sklearn.metrics import r2_score, mean_squared_error

def symmetric_quantize_int8(arr):
    qmin, qmax = -128, 127

    max_abs = np.max(np.abs(arr))
    if max_abs == 0:
        scale = 1.0
        quantized = np.zeros_like(arr, dtype=np.int8)
    else:
        scale = max_abs / qmax
        quantized = np.clip(np.round(arr / scale), qmin, qmax).astype(np.int8)

    return quantized, scale

def symmetric_dequantize_int8(quantized, scale):
    return quantized.astype(np.float32) * scale
```

src > quantize.py > get_size_in_kb

```python
def symmetric_quantize_int16(arr):
    qmin, qmax = -32768, 32767

    max_abs = np.max(np.abs(arr))
    if max_abs == 0:
        scale = 1.0
        quantized = np.zeros_like(arr, dtype=np.int16)
    else:
        scale = max_abs / qmax
        quantized = np.clip(np.round(arr / scale), qmin, qmax).astype(np.int16)

    return quantized, scale

def symmetric_dequantize_int16(quantized, scale):
    return quantized.astype(np.float32) * scale

def get_size_in_kb(filepath):
    size_bytes = os.path.getsize(filepath)
    return round(size_bytes / 1024, 4)
```

src > quantize.py > symmetric_quantize_int8

```python
def main():
    model = joblib.load("src/trained_model.joblib")
    coef = model.coef_
    intercept = np.atleast_1d(model.intercept_)

    joblib.dump({'coef_': coef, 'intercept_': intercept}, "src/unquant_params.joblib")

    X_train, X_test, y_train, y_test = load_data()

    # Evaluate original model
    orig_preds = np.dot(X_test, coef) + intercept[0]
    orig_r2 = r2_score(y_test, orig_preds)
    orig_mse = mean_squared_error(y_test, orig_preds)

    # Quantize model int8 parameters symmetrically
    q_coef_int8, coef_scale_int8 = symmetric_quantize_int8(coef)
    q_intercept_int8, int_scale_int8 = symmetric_quantize_int8(intercept)

    # Quantize model int16 parameters symmetrically
    q_coef_int16, coef_scale_int16 = symmetric_quantize_int16(coef)
    q_intercept_int16, int_scale_int16 = symmetric_quantize_int16(intercept)

    joblib.dump({
        'q_coef': q_coef_int8,
        'coef_scale': coef_scale_int8,
        'q_intercept': q_intercept_int8,
        'int_scale': int_scale_int8,
    }, "src/quant_params_int8.joblib")

    joblib.dump({
        'q_coef': q_coef_int16,
        'coef_scale': coef_scale_int16,
        'q_intercept': q_intercept_int16,
        'int_scale': int_scale_int16,
    }, "src/quant_params_int16.joblib")
```

```python
src > quantize.py > get_size_in_kb
def main():

    # Paths to the saved models
    original_model = "src/trained_model.joblib"
    int8_model = "src/quant_params_int8.joblib"
    int16_model = "src/quant_params_int16.joblib"

    # Dequantize
    dq_coef_int8 = symmetric_dequantize_int8(q_coef_int8, coef_scale_int8)
    dq_intercept_int8 = symmetric_dequantize_int8(q_intercept_int8, int_scale_int8).item()

    dq_coef_int16 = symmetric_dequantize_int16(q_coef_int16, coef_scale_int16)
    dq_intercept_int16 = symmetric_dequantize_int16(q_intercept_int16, int_scale_int16).item()

    # Debug
    # print("\nSample coefficient comparison:")
    # print(f"Original coef[:5]:    {coef[:5]}")
    # print(f"Quantized 8 bit coef[:5]:   {q_coef_int8[:5]}")
    # print(f"Dequantized 8 bit coef[:5]: {dq_coef_int8[:5]}\n")
    # print(f"Quantized 16 bit coef[:5]:   {q_coef_int16[:5]}")
    # print(f"Dequantized 16 bit coef[:5]: {dq_coef_int16[:5]}\n")

    # Evaluate quantized model
    preds_int8 = np.dot(X_test, dq_coef_int8) + dq_intercept_int8
    r2_int8 = r2_score(y_test, preds_int8)
    mse_int8 = mean_squared_error(y_test, preds_int8)

    preds_int16 = np.dot(X_test, dq_coef_int16) + dq_intercept_int16
    r2_int16 = r2_score(y_test, preds_int16)
    mse_int16 = mean_squared_error(y_test, preds_int16)

    print(f"\n" + "="*50)
    print(f"RESULTS:")
    print(f"Original Model R2: {orig_r2:.4f}, MSE: {orig_mse:.4f}, Size:  {get_size_in_kb(original_model)} KB")
    print(f"Quantized Model 8 bit R2: {r2_int8:.4f}, MSE: {mse_int8:.4f}, Size:  {get_size_in_kb(int8_model)} KB")
    print(f"Quantized Model 16 bit R2: {r2_int16:.4f}, MSE: {mse_int16:.4f}, Size:  {get_size_in_kb(int16_model)} KB")
    print(f"\n" + "="*50)

if __name__ == "__main__":
    main()
```

- Test locally to check the code:

```
================================================
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> python .\src\quantize.py

==================================================
RESULTS:
Original Model R2: 0.5758, MSE: 0.5559, Size:  0.6807 KB
Quantized Model 8 bit R2: 0.5566, MSE: 0.5810, Size:  0.4482 KB
Quantized Model 16 bit R2: 0.5758, MSE: 0.5559, Size:  0.4492 KB

==================================================
```

Further Explanation on Quantization:

- 8 bit quantization was giving negative R^2 scores before (-0.1799).

```python
#Original Logic used for Quantization:

def min_max_quantize(arr):
    arr_min, arr_max = arr.min(), arr.max()
```

```
    if arr_max == arr_min:
        quantized = np.full(arr.shape, 127, dtype=np.uint8)
        return quantized, arr_min, arr_max

    # Normal quantization
    quantized = ((arr - arr_min) / (arr_max - arr_min) *
255).round().astype(np.uint8)
    return quantized, arr_min, arr_max

def dequantize(quantized, arr_min, arr_max):

    if arr_max == arr_min:
        return np.full(quantized.shape, arr_min, dtype=np.float32)

    # Normal dequantization
    return quantized.astype(np.float32) / 255 * (arr_max - arr_min) + arr_min
```

Output:

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> python .\src\quantize.py

================================================
RESULTS:
Original Model - R2: 0.575788, MSE: 0.555892
Quantized Model - R2: -0.1799, MSE: 1.5462

================================================
```

- Original code failed when all values were the same. I fixed it to avoid division by zero.
- I used symmetric quantization to support both positive and negative values.
- After the code change, 8 bit quantization gave a much better R^2 than the original quantization logic (0.5566). But it is still lower than the original model R^2 value (0.5758 > 0.5566)
- Tested the quantization by switching to 16 bit for a wider range than 8 bit.
- 16 bit quantization kept values closer to original and gave better R^2 value (0.5758)

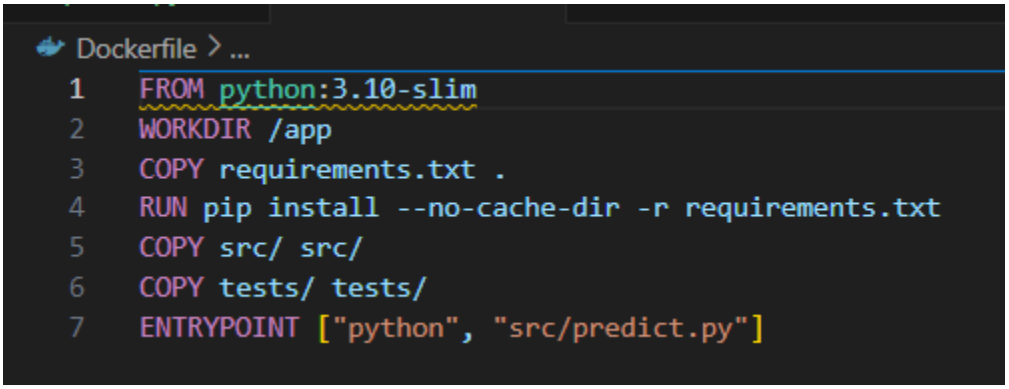
Step 5: Dockerization

Create a Dockerfile that:

• Installs dependencies

• Includes predict.py for model verification

Job Name	Description	Depends On
test_suite	Runs pytest. Must pass before others execute.	None
train_and_quantize	Trains model, runs quantization, uploads artifacts	test_suite
build_and_test_container	Builds Docker image, runs container (must execute predict.py successfully)	train_and_quantize



src/predict.py:

- Load trained model
- Run prediction on test set
- Print sample outputs

predict.py U Dockerfile 1, U

src > predict.py > ...

```python
import joblib
import sys, os
sys.path.append(os.path.dirname(__file__))
from utils import load_data

def main():
    _, X_test, _, y_test = load_data()
    model = joblib.load("src/trained_model.joblib")
    preds = model.predict(X_test)
    print("Sample predictions:", preds[:5])
    print("Corresponding ground truths:", y_test[:5])

if __name__ == "__main__":
    main()
```

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> python .\src\predict.py
Sample predictions: [0.71912284 1.76401657 2.70965883 2.83892593 2.60465725]
Corresponding ground truths: [0.477   0.458   5.00001 2.186   2.78   ]
```

- Test locally by building Docker image:

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> docker build -t mlops-lr-demo:latest .
[+] Building 30.5s (11/11) FINISHED                                                                                  docker:desktop-linux
 => [internal] load build definition from Dockerfile                                                                                 0.0s
 => => transferring dockerfile: 228B                                                                                                 0.0s
 => [internal] load metadata for docker.io/library/python:3.10-slim                                                                  0.5s
 => [internal] load .dockerignore                                                                                                    0.0s
 => => transferring context: 2B                                                                                                      0.0s
 => [1/6] FROM docker.io/library/python:3.10-slim@sha256:81f1cdb3770d54ecfdbddcc52c2125fce674c14a1d976dfd8f65dc0734f9c3c5            0.0s
 => => resolve docker.io/library/python:3.10-slim@sha256:81f1cdb3770d54ecfdbddcc52c2125fce674c14a1d976dfd8f65dc0734f9c3c5            0.0s
 => [internal] load build context                                                                                                    0.0s
 => => transferring context: 12.41kB                                                                                                 0.0s
 => CACHED [2/6] WORKDIR /app                                                                                                        0.0s
 => [3/6] COPY requirements.txt .                                                                                                    0.0s
 => [4/6] RUN pip install --no-cache-dir -r requirements.txt                                                                        20.2s
 => [5/6] COPY src/ src/                                                                                                             0.0s
 => [6/6] COPY tests/ tests/                                                                                                         0.0s
 => exporting to image                                                                                                               9.4s
 => => exporting layers                                                                                                              8.0s
 => => exporting manifest sha256:b183e328fcd9bdaa6b2f356fb2438c4846b1ef2e9e4e92db89107148beafcd4e                                     0.0s
 => => exporting config sha256:988919e81aa4f07a29881ad7ec8ea7c75750b020926d6faef4853a7e5a07aa45                                      0.0s
 => => exporting attestation manifest sha256:8ca0d430fe45e2a711209b8de2729289289c8428087f42f7ab1685ee045d37e6                        0.0s
 => => exporting manifest list sha256:fbc547650e3aeb1a2c7a0a7b74d8fb29c3bdabeb37d32bed2f8ea12a2150e310                               0.0s
 => => naming to docker.io/library/mlops-lr-demo:latest                                                                              0.0s
 => => unpacking to docker.io/library/mlops-lr-demo:latest                                                                           1.4s

What's next:
    View a summary of image vulnerabilities and recommendations → docker scout quickview
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression>
```

```
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression> docker run mlops-lr-demo:latest
Sample predictions: [0.71912284 1.76401657 2.70965883 2.83892593 2.60465725]
Corresponding ground truths: [0.477   0.458   5.00001 2.186   2.78   ]
(mlops-linear-regression) PS D:\Projects\Study_Assignments\ML_OPS\mlops-linear-regression>
```

Step 6: CI/CD Workflow (.github/workflows/ci.yml)

Run on every push to main.

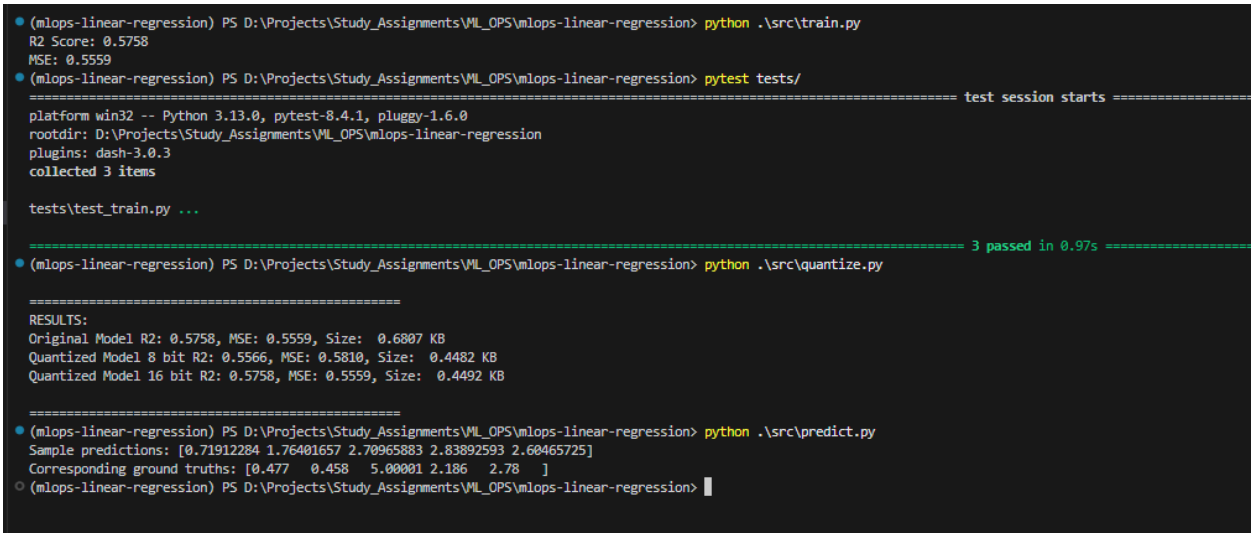
Define 3 jobs:

.github > workflows > ci.yml

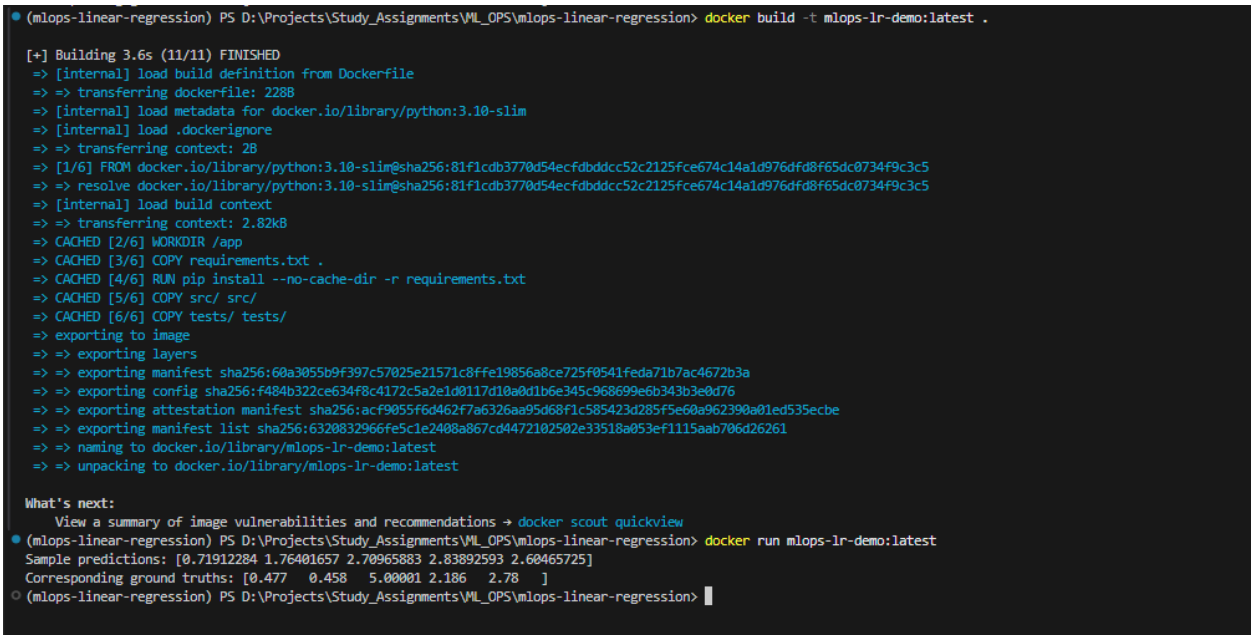
```yaml
name: MLOps Workflow

on:
  push:
    branches: [main]

jobs:
  test-suite:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v4
      - uses: actions/setup-python@v5
        with:
          python-version: '3.10'
      - run: pip install -r requirements.txt
      - run: pytest tests/

  train-and-quantize:
    needs: test-suite
    runs-on: ubuntu-latest

    steps:
      - uses: actions/checkout@v4
      - uses: actions/setup-python@v5
        with:
          python-version: '3.10'

      - name: Install dependencies
        run: pip install -r requirements.txt

      - name: Train original model
        run: python src/train.py

      - name: Run quantization (symmetric int16)
        run: python src/quantize.py

      - name: Upload artifacts
        uses: actions/upload-artifact@v4
        with:
          name: model
          path: |
            src/trained_model.joblib
            src/quant_params_int16.joblib

  build-and-test-container:
    needs: train-and-quantize
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v4
      - run: docker build -t mlops-lr-demo .
      - run: docker run mlops-lr-demo
```

Outputs

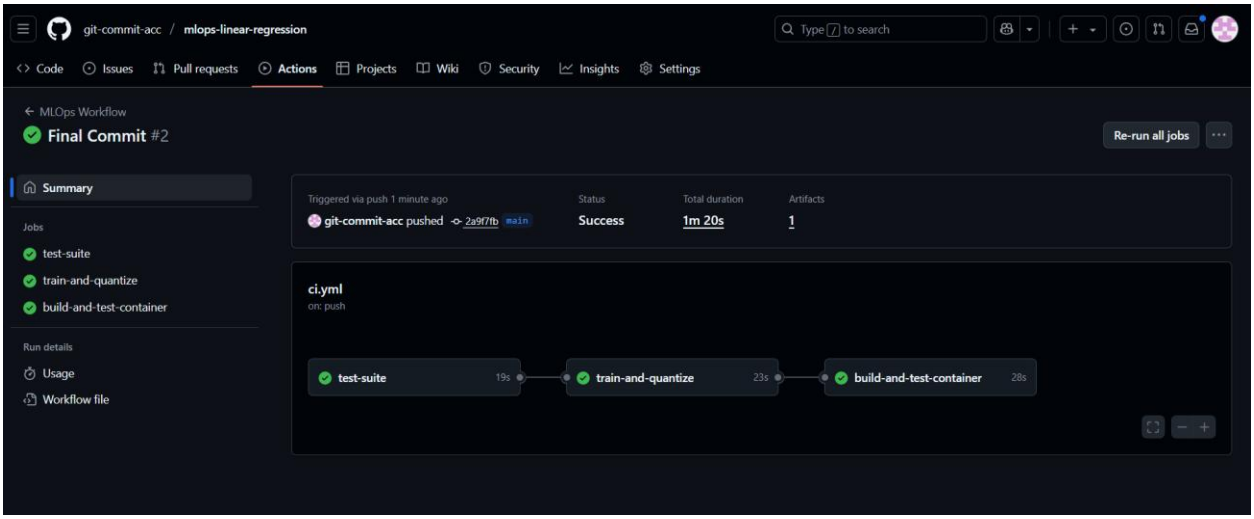
- Execution in local environment:



- Docker containerization:



- Github Actions:



- Tabular comparison of all models:

Model	R^2 value	MSE	Model Size
Original Model	0.5758	0.5559	0.6807 KB
8 bit Quantized (before fix)	-0.1799	1.5462	-
8 bit Quantized (after fix)	0.5566	0.5810	0.4482 KB
16 bit Quantized	0.5758	0.5559	0.4492 KB

Note: Uploading docker image to Docker hub was not mentioned in the Assignment guidelines. Hence, I have not implemented any logic to upload the Docker image to Docker hub.