HUCENROTIA LAB

Machine Learning

LABORATORY: Gradient Descent In Class

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Objectives:

- Understand and implement Stochastic Gradient Descent (SGD) using one sample at a time (Algorithm 7.1).
- Apply the sigmoid activation function to perform binary classification.
- Learn how to update model weights manually using the gradient of the loss function.
- Practice using NumPy for mathematical operations on real MNIST data.
- Evaluate classification results using accuracy and misclassified samples visualization.

Part 1. Instruction

- In this assignment, you will implement Stochastic Gradient Descent (SGD) from scratch using Algorithm 7.1 provided in class.
- The task is to build a binary classifier to distinguish whether an MNIST image corresponds to a target digit or not (e.g., "Is this a 0 or not?").
- You will complete the code template provided in the in-class assignment.
- The classifier will use the sigmoid function for binary probability output. Use only NumPy for all computations. Do not use libraries like scikit-learn or PyTorch.
- Evaluate your results using the printed accuracy and a visualization of misclassified samples.

Part 2. Arithmetic Instructions.

Algorithm 7.1: Stochastic gradient descent

Input: Training set of data points indexed by $n \in \{1, \ldots, N\}$
Error function per data point $E_n(\mathbf{w})$
Learning rate parameter η
Initial weight vector $\mathbf{w}$

Output: Final weight vector $\mathbf{w}$

$n \leftarrow 1$

repeat

  $\mathbf{w} \leftarrow \mathbf{w} - \eta \nabla E_n(\mathbf{w})$ `// update weight vector`

  $n \leftarrow n + 1 (\text{mod } N)$ `// iterate over data`

until convergence

return $\mathbf{w}$

Part 3. Code Template.

Step	Procedure

1	#Load Dataset
	`import struct`
	`import numpy as np`
	`import matplotlib.pyplot as plt`
	
	`# ==========Load IDX Files ==========`
	`def load_images(filename):`
	`  with open(filename, 'rb') as f:`
	`  _, num, rows, cols = struct.unpack(">IIII", f.read(16))`
	`  images=np.frombuffer(f.read(), dtype=np.uint8)`
	`  images = images[:(len(images)//(rows * cols)) * rows * cols]`
	`  return images.reshape(-1, rows * cols).astype(np.float32) / 255.0`
	
	`def load_labels(filename):`
	`  with open(filename, 'rb') as f:`
	`  _, num = struct.unpack(">II", f.read(8))`
	`  labels = np.frombuffer(f.read(), dtype=np.uint8)`
	`  return labels[:num]`

2	`# ========== 1. Sigmoid Function ==========`
	`def sigmoid(z):`
	`  # TODO: Implement sigmoid function`
	`  pass`
	
	`# ========== 2. SGD: Algorithm 7.1 ==========`
	`def sgd_logistic(X, y, eta, max_iters):`
	
	`  pass`

3	`# ==========Show Misclassified Samples ==========`
	`def show_misclassified(X, true_labels, pred_labels, max_show=10):`
	`  mis_idx = np.where(true_labels != pred_labels)[0][:max_show]`
	`  plt.figure(figsize=(10, 2))`
	`  for i, idx in enumerate(mis_idx):`
	`  plt.subplot(1, len(mis_idx), i + 1)`
	`  plt.imshow(X[idx, 1:].reshape(28, 28), cmap='gray')`
	`  plt.axis('off')`
	`  plt.title(f"T:{true_labels[idx]} P:{pred_labels[idx]}")`
	`  plt.suptitle("Misclassified Samples")`
	`  plt.show()`

4	`# ========== 3. Main ==========`
	`if __name__ == "__main__":`
	`  # === Load Data ===`
	`  X_train = load_images("train-images.idx3-ubyte__")`
	`  y_train = load_labels("train-labels.idx1-ubyte__")`
	`  X_test = load_images("t10k-images.idx3-ubyte__")`
	`  y_test = load_labels("t10k-labels.idx1-ubyte__")`

```
    # === Choose binary classification target digit ===
    TARGET_DIGIT = 0   # TODO: Fill in (0 to 9)

    y_train_bin = np.where(y_train == TARGET_DIGIT, 1, 0)
    y_test_bin = np.where(y_test == TARGET_DIGIT, 1, 0)

    # === Add bias term ===
    X_train   =   np.hstack([np.ones((X_train.shape[0],   1)),
X_train])
    X_test    =    np.hstack([np.ones((X_test.shape[0],    1)),
X_test])

    # === Set parameters ===
    #eta = _____            # TODO: Learning rate
    #max_iters = _____      # TODO: Number of SGD iterations

    # === Train ===
    #w = sgd_logistic(X_train, y_train_bin, eta, max_iters)

    # === Predict ===
    #pred_probs = ____
    #preds = (pred_probs >= 0.5).astype(int)

    # === Evaluate ===
    #accuracy = np.mean(preds == y_test_bin)
    #print(f"Accuracy: {accuracy:.4f}")

    # === Show Misclassified Samples ===
    #show_misclassified(X_test, y_test_bin, preds)
```

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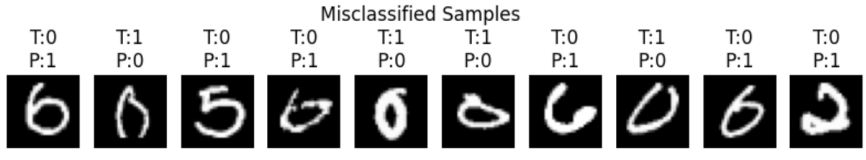
```
#Example Output:
```

```
[INFO] Header: 60000 images, 28x28
[INFO] Loading 60000 images based on file size
[INFO] Loading 60000 labels based on file size
[INFO] Header: 10000 images, 28x28
[INFO] Loading 10000 images based on file size
[INFO] Loading 10000 labels based on file size

[INFO] Binary classification: '0' vs not-0

Test Accuracy (is 0 or not): 0.9927
```



Grading Assignment & Submission (30% Max)

Implementation:

1. (15%) Implement the Stochastic Gradient Descent (SGD) algorithm based on Algorithm 7.1.
2. (10%) The model runs successfully without errors, Trains using the provided MNIST dataset, and output the test accuracy.
3. (5%) Set the class of binary classification to the last digit of your student ID. (e.g., if your ID ends in 7, use the class '7'). Displays at least 5 misclassified test images along with their true (T:) and predicted (P:) labels, as shown in the "Example Output" in the last pages of this document.

Submission :

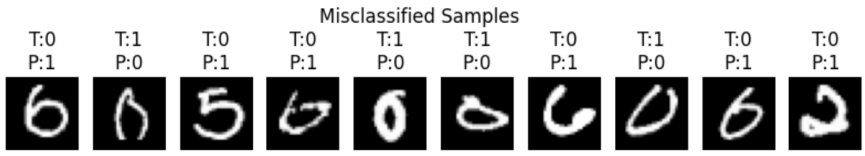
1. Report: Answer all conceptual questions. Include screenshots of your results in the last pages of this PDF File.
2. Code: Submit your complete Python script in either .py or .ipynb format.
3. Upload both your report and code to the E3 system (**Labs4 In Class Assignment**). Name your files correctly:
    a. Report: StudentID_Lab4_InClass.pdf
    b. Code: StudentID_Lab4_ InClass.py or StudentID_Lab4_InClass.ipynb
4. Deadline: 16:20 PM
5. Plagiarism is **strictly prohibited**. Submitting copied work from other students will result in penalties.

Example Output (Just for reference):

```
[INFO] Header: 60000 images, 28x28
[INFO] Loading 60000 images based on file size
[INFO] Loading 60000 labels based on file size
[INFO] Header: 10000 images, 28x28
[INFO] Loading 10000 images based on file size
[INFO] Loading 10000 labels based on file size

[INFO] Binary classification: '0' vs not-0

Test Accuracy (is 0 or not): 0.9927
```



Code Results and Answer:

```
Binary Classification Target Digit: 3
Accuracy: 0.9777
```