Problem_3

February 21, 2025

```
[ ]: # import the libraries
     import numpy as np
     import torch
     import torchvision
```

```
[ ]: trainingdata = torchvision.datasets.FashionMNIST('./FashionMNIST/
      ↪',train=True,download=True,transform=torchvision.transforms.ToTensor())
     testdata = torchvision.datasets.FashionMNIST('./FashionMNIST/
      ↪',train=False,download=True,transform=torchvision.transforms.ToTensor())
```

```
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-
images-idx3-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-
images-idx3-ubyte.gz to ./FashionMNIST/FashionMNIST/raw/train-images-
idx3-ubyte.gz

100%|      | 26.4M/26.4M [00:02<00:00, 12.6MB/s]

Extracting ./FashionMNIST/FashionMNIST/raw/train-images-idx3-ubyte.gz to
./FashionMNIST/FashionMNIST/raw

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-
labels-idx1-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-
labels-idx1-ubyte.gz to ./FashionMNIST/FashionMNIST/raw/train-labels-
idx1-ubyte.gz

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./FashionMNIST/FashionMNIST/raw

Downloading http://fashion-mnist.s3-website.eu-
central-1.amazonaws.com/t10k-images-idx3-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-
central-1.amazonaws.com/t10k-images-idx3-ubyte.gz to
./FashionMNIST/FashionMNIST/raw/t10k-images-idx3-ubyte.gz

100%|      | 4.42M/4.42M [00:01<00:00, 3.72MB/s]
```

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Extracting ./FashionMNIST/FashionMNIST/raw/t10k-images-idx3-ubyte.gz to
./FashionMNIST/FashionMNIST/raw

Downloading http://fashion-mnist.s3-website.eu-
central-1.amazonaws.com/t10k-labels-idx1-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-
central-1.amazonaws.com/t10k-labels-idx1-ubyte.gz to
./FashionMNIST/FashionMNIST/raw/t10k-labels-idx1-ubyte.gz

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./FashionMNIST/FashionMNIST/raw
```

```
[ ]: print(len(trainingdata))
     print(len(testdata))
```

```
60000
10000
```

```
[ ]: image, label = trainingdata[0]
     print(image.shape, label)
```

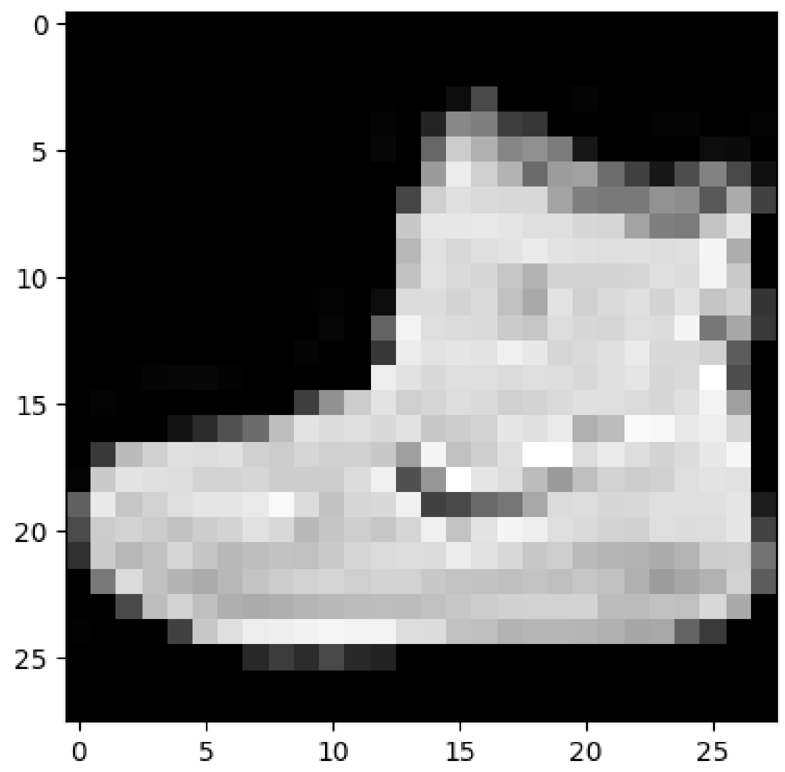
```
torch.Size([1, 28, 28]) 9
```

```
[ ]: print(image.squeeze().shape)
```

```
torch.Size([28, 28])
```

```
[ ]: import matplotlib.pyplot as plt
     %matplotlib inline
     plt.imshow(image.squeeze(), cmap=plt.cm.gray)
```

```
[ ]: <matplotlib.image.AxesImage at 0x7bcceaa85250>
```



[ ]:
```
trainDataLoader = torch.utils.data.
  ↪DataLoader(trainingdata,batch_size=64,shuffle=True)
testDataLoader = torch.utils.data.
  ↪DataLoader(testdata,batch_size=64,shuffle=False)
```

[ ]:
```
print(len(trainDataLoader))
print(len(testDataLoader))
```

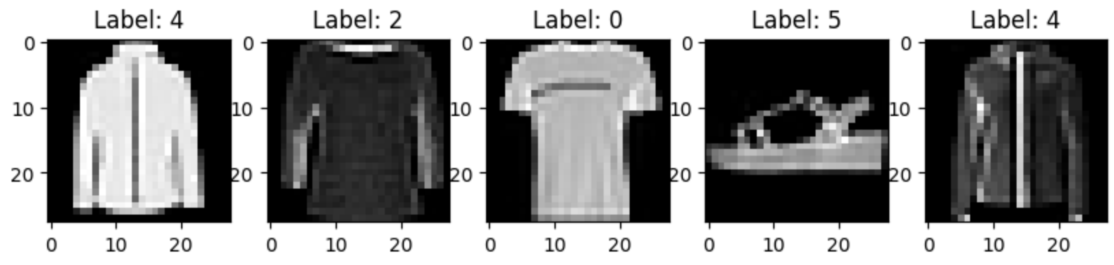
```
938
157
```

[ ]:
```
print(len(trainDataLoader) * 64) # batch_size from above
print(len(testDataLoader) * 64)
```

```
60032
10048
```

[ ]:
```
images, labels = next(iter(trainDataLoader))

plt.figure(figsize=(10,4))
for index in np.arange(0,5):
  plt.subplot(1,5,index+1)
  plt.title(f'Label: {labels[index].item()}')
  plt.imshow(images[index].squeeze(),cmap=plt.cm.gray)
```



[ ]:
```
class FashionMNISTModel(torch.nn.Module):
  def __init__(self):
    super(FashionMNISTModel,self).__init__()
    self.fc1 = torch.nn.Linear(28*28, 256)
    self.fc2 = torch.nn.Linear(256, 128)
    self.fc3 = torch.nn.Linear(128, 64)
    self.fc4 = torch.nn.Linear(64, 10)
    self.relu = torch.nn.ReLU()

  def forward(self, x):
    x = x.view(-1, 28*28)
    x = self.relu(self.fc1(x))
    x = self.relu(self.fc2(x))
    x = self.relu(self.fc3(x))
    x = self.fc4(x)
    return x

model = FashionMNISTModel().cuda() # Step 1: architecture
loss = torch.nn.CrossEntropyLoss() # Step 2: loss
optimizer = torch.optim.SGD(model.parameters(), lr=0.01) # Step 3: training␣
  ↪method
```

[ ]:
```
train_loss_history = []
test_loss_history = []

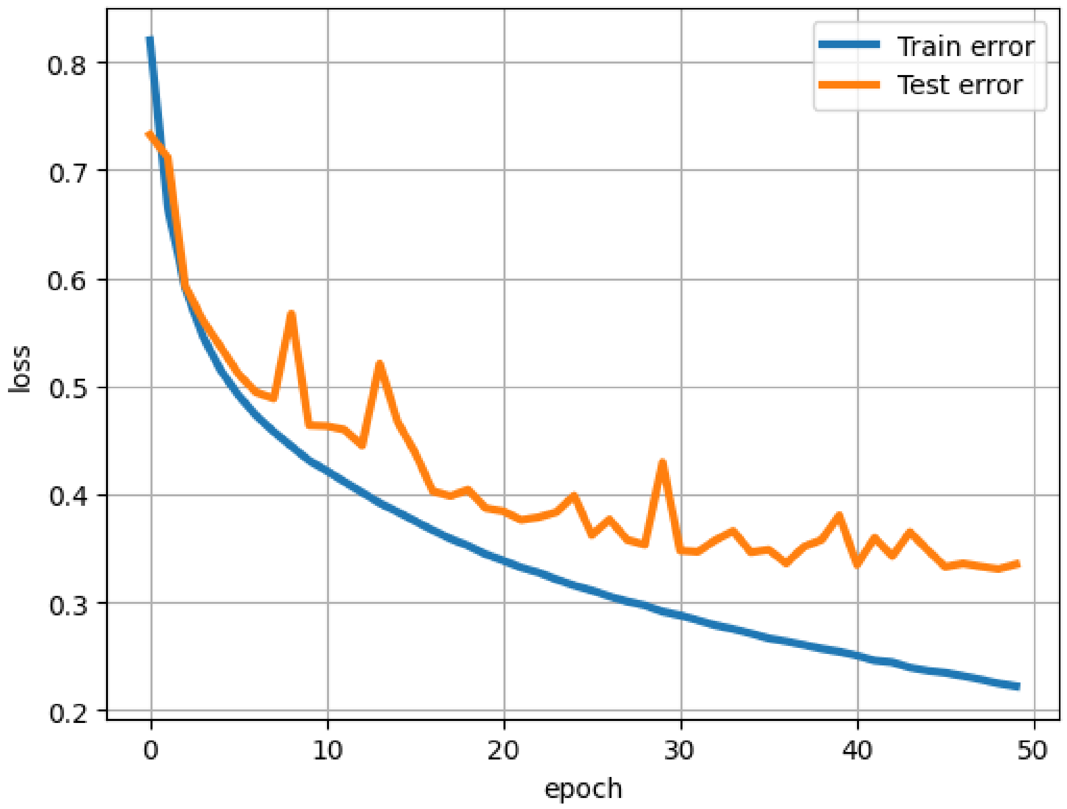
for epoch in range(50):
  train_loss = 0.0
  test_loss = 0.0

  model.train()
  for i, data in enumerate(trainDataLoader):
    images, labels = data
    images = images.cuda()
    labels = labels.cuda()
    optimizer.zero_grad() # zero out any gradient values from the previous␣
↪iteration
    predicted_output = model(images) # forward propagation
    fit = loss(predicted_output, labels)  # calculate our measure of goodness
    fit.backward() # backpropagation
    optimizer.step() # update the weights of our trainable parameters
    train_loss += fit.item()

  model.eval()
  for i, data in enumerate(testDataLoader):
    with torch.no_grad():
      images, labels = data
      images = images.cuda()
      labels = labels.cuda()
      predicted_output = model(images)
      fit = loss(predicted_output, labels)
      test_loss += fit.item()
  train_loss = train_loss / len(trainDataLoader)
  test_loss = test_loss / len(testDataLoader)
  train_loss_history += [train_loss]
  test_loss_history += [test_loss]
  print(f'Epoch {epoch}, Train loss {train_loss}, Test loss {test_loss}')
```

```
Epoch 0, Train loss 0.8200335381572434, Test loss 0.7326804498198686
Epoch 1, Train loss 0.665718307690834, Test loss 0.7116923011412286
Epoch 2, Train loss 0.5906475426228062, Test loss 0.5926861100515742
Epoch 3, Train loss 0.5457974640863028, Test loss 0.5606379247015449
Epoch 4, Train loss 0.5148079536362752, Test loss 0.5363499848705948
Epoch 5, Train loss 0.49167311339299563, Test loss 0.5114035538047742
Epoch 6, Train loss 0.4729746097663064, Test loss 0.4943873890835768
Epoch 7, Train loss 0.4577874707927836, Test loss 0.48849217717055304
Epoch 8, Train loss 0.4445181418297642, Test loss 0.5671002291570044
Epoch 9, Train loss 0.43125458921133075, Test loss 0.4638637961096065
Epoch 10, Train loss 0.4216652001176816, Test loss 0.46319339448099683
Epoch 11, Train loss 0.411558430713377, Test loss 0.4597173428079884
Epoch 12, Train loss 0.401729068665235, Test loss 0.44516734247374684
Epoch 13, Train loss 0.3918211419445111, Test loss 0.5210342504036655
Epoch 14, Train loss 0.383749128746262, Test loss 0.46723415251750094
Epoch 15, Train loss 0.37521459705539856, Test loss 0.4385564943217927
Epoch 16, Train loss 0.3666893032822273, Test loss 0.4028862781205754
Epoch 17, Train loss 0.35885209242291033, Test loss 0.3982689765038764
Epoch 18, Train loss 0.35241075597210986, Test loss 0.40421634219634306
Epoch 19, Train loss 0.3445079951668218, Test loss 0.3870985234618946
Epoch 20, Train loss 0.3386262595764737, Test loss 0.38436001814474724
Epoch 21, Train loss 0.33214848486980647, Test loss 0.3761763641978525
Epoch 22, Train loss 0.32754341848909474, Test loss 0.3787363739150345
Epoch 23, Train loss 0.32119926396431697, Test loss 0.3835079055872692
Epoch 24, Train loss 0.3156572524259594, Test loss 0.39882386765282624
Epoch 25, Train loss 0.31103204473503615, Test loss 0.36221614185791867
Epoch 26, Train loss 0.3055283787217476, Test loss 0.3767634172728107
Epoch 27, Train loss 0.3008508968597917, Test loss 0.3578552864729219
Epoch 28, Train loss 0.29715881352898665, Test loss 0.3533400070325584
Epoch 29, Train loss 0.2914532613573171, Test loss 0.42966997471584634
Epoch 30, Train loss 0.2879214670135777, Test loss 0.3479153208292214
Epoch 31, Train loss 0.28345096788839746, Test loss 0.34679541428377675
Epoch 32, Train loss 0.27875598672547064, Test loss 0.3576511265176117
Epoch 33, Train loss 0.2752353979437463, Test loss 0.36603504855921315
Epoch 34, Train loss 0.27129416232869064, Test loss 0.34637003463165017
Epoch 35, Train loss 0.2666461776727552, Test loss 0.3488483873142558
Epoch 36, Train loss 0.2638548987347688, Test loss 0.33612170483276343
Epoch 37, Train loss 0.2606392344956332, Test loss 0.35152637569388007
Epoch 38, Train loss 0.25712381808488355, Test loss 0.35781701440644115
Epoch 39, Train loss 0.25437884713445647, Test loss 0.3804061690903014
Epoch 40, Train loss 0.2507424075593318, Test loss 0.33481416794335006
Epoch 41, Train loss 0.24622550944307212, Test loss 0.35968598581043776
Epoch 42, Train loss 0.2445218058457888, Test loss 0.3427320975501826
Epoch 43, Train loss 0.2396058153662918, Test loss 0.365043097668013
Epoch 44, Train loss 0.23681550292270398, Test loss 0.34848266802016337
Epoch 45, Train loss 0.23487135837835543, Test loss 0.33279177323458303
Epoch 46, Train loss 0.2317561384941787, Test loss 0.3359520827319212
Epoch 47, Train loss 0.2286240428702028, Test loss 0.3331539783697979
Epoch 48, Train loss 0.22498356889703, Test loss 0.3307615016011675
Epoch 49, Train loss 0.2223383083081703, Test loss 0.3352103267031111
```

[ ]:
```
plt.plot(range(50),train_loss_history,'-',linewidth=3,label='Train error')
plt.plot(range(50),test_loss_history,'-',linewidth=3,label='Test error')
plt.xlabel('epoch')
plt.ylabel('loss')
plt.grid(True)
plt.legend()
plt.show()
```



[ ]:
```
# draw any 3 random image samples from the test dataset, visualize the
# predicted class probabilities for each sample, and comment on what you can␣
↪observe from these plots.

import matplotlib.pyplot as plt
import random

# Select 3 random indices from the test dataset
random_indices = random.sample(range(len(testdata)), 3)

# Get the images and labels for the selected samples
images = [testdata[i][0] for i in random_indices]
labels = [testdata[i][1] for i in random_indices]

device = torch.device("cuda" if torch.cuda.is_available() else "cpu")  #
print(f"Using device: {device}")
model.to(device)

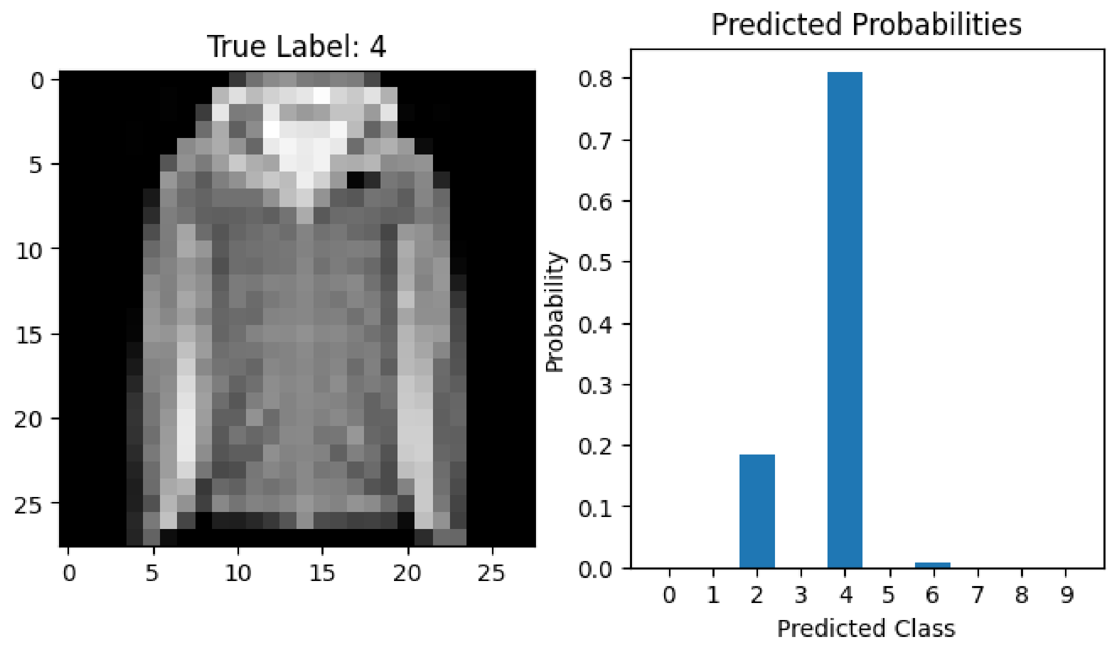
# Get predicted probabilities
model.eval()
with torch.no_grad():
    predicted_probabilities = [
        torch.softmax(model(image.unsqueeze(0).to(device)), dim=1).squeeze()
         for image in images]

# Visualize and comment on predicted probabilities
for i in range(3):
    plt.figure(figsize=(8, 4))
    plt.subplot(1, 2, 1)
    plt.imshow(images[i].squeeze(), cmap=plt.cm.gray)
    plt.title(f"True Label: {labels[i]}")

    plt.subplot(1, 2, 2)
    plt.bar(range(10), predicted_probabilities[i].cpu().numpy())
    plt.xticks(range(10))
    plt.xlabel("Predicted Class")
    plt.ylabel("Probability")
    plt.title(f"Predicted Probabilities")
    plt.show()

    print(f"Observation for sample {i+1}:")
    print(f"The model predicts class {torch.argmax(predicted_probabilities[i])}␣
 ↪with the highest probability.")
    print(f"The true label is {labels[i]}.")
    print("-"*20)
```

```
Using device: cuda
```



```
Observation for sample 1:
The model predicts class 4 with the highest probability.
The true label is 4.
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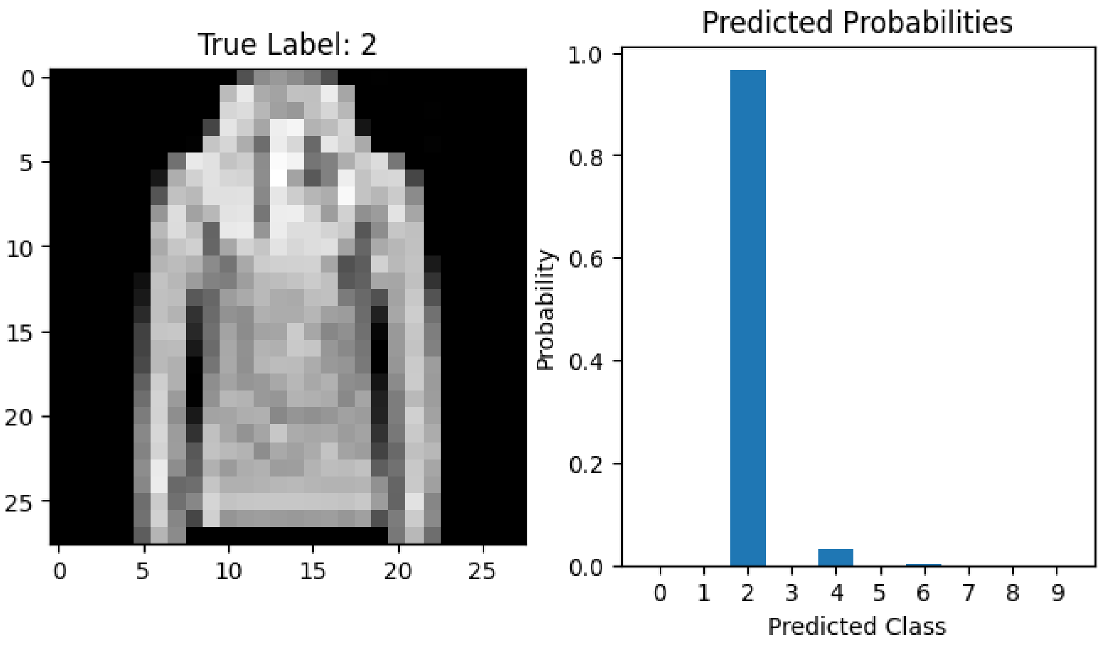
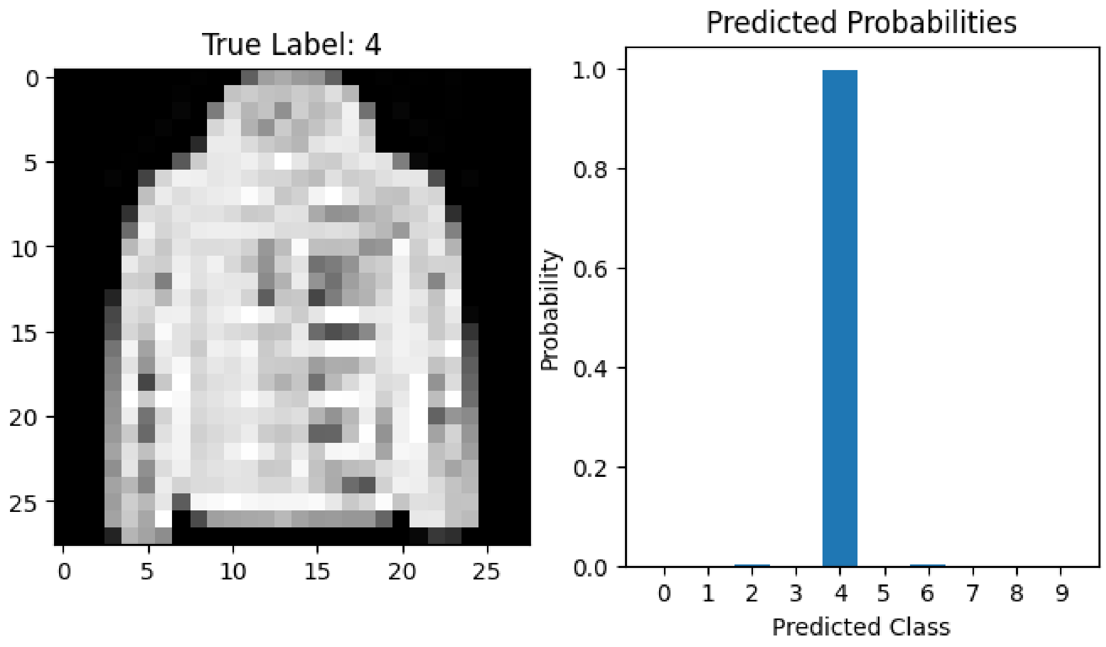
```



```
Observation for sample 2:
The model predicts class 2 with the highest probability.
The true label is 2.
--------------------
```



```
Observation for sample 3:
The model predicts class 4 with the highest probability.
The true label is 4.
--------------------
```

Comment on these plots:

1. The training loss decreases gradually as the epoch increases.
2. From the loss curves, the training loss continues to decrease while the testing loss tends to level off, indicating that the model generalizes well on the test set.
3. On 3 randomly selected test images, we visualized the model's category probability distribution, showing its strong categorization ability.