

# 5241\_Project

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## 1 Stat 5241 Statistical Machine Learning Final Project

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## 2 I. BackGround

The MNIST database of handwritten digits is one of the most commonly used dataset for training various image processing systems and machine learning algorithms. MNIST has a training set of 60,000 examples, and a test set of 10,000 examples. It is a good database for people who want to try learning techniques and pattern recognition methods on real-world data while spending minimal efforts on preprocessing and formatting. MNIST is a subset of a larger set available from NIST. The digits have been size-normalized and centered in a fixed-size image. The original black and white (bilevel) images from NIST were size normalized. The resulting images contain grey levels as a result of the anti-aliasing technique used by the normalization algorithm. The images were centered in a  $28 \times 28$  image by computing the center of mass of the pixels, and translating the image so as to position this point at the center of the  $28 \times 28$  field.

## 3 II. Data Processing

```
[47]: # Import Required Packages
import time
import pandas as pd
from torchvision.datasets import MNIST
import matplotlib.pyplot as plt
import numpy as np
from pylab import *
from sklearn import preprocessing
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import AdaBoostClassifier
from sklearn.tree import DecisionTreeClassifier
from sklearn.svm import SVC
from sklearn.naive_bayes import GaussianNB
import torch
import torch.nn as nn
import torch.optim as optim
import torch.nn.functional as F
import torchvision.transforms as transforms
```

```
from torch.utils.data import DataLoader
from torch.utils.data import BatchSampler
```

```
[ ]: # Data download and preprocessing
```

```
DOWNLOAD_MNIST = True # If already download , set as False
train_data = MNIST(
    root='../data/mnist/',
    train=True , # this is training data
    #transform=torchvision.transforms.ToTensor (),
    download=DOWNLOAD_MNIST ,
)

test_data = MNIST(root='../data/ mnist/', train=False, download=DOWNLOAD_MNIST)

# change the features to numpy
X_train = train_data.train_data.numpy()
X_test = test_data.test_data.numpy ()

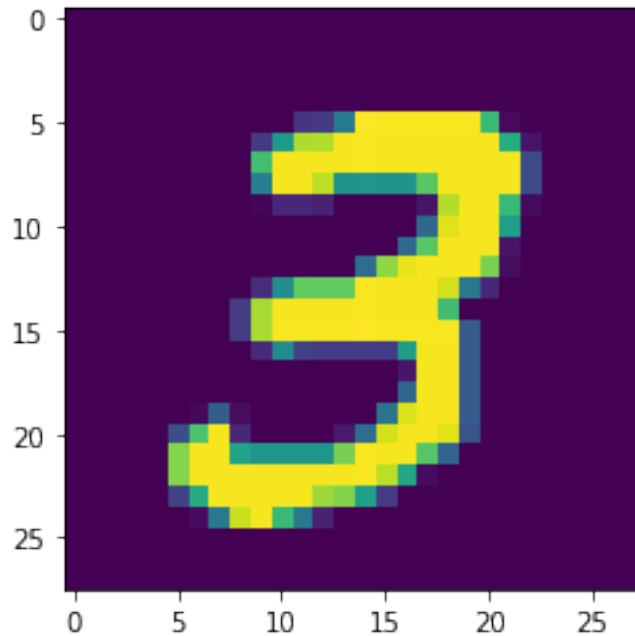
# change the labels to numpy
Y_train = train_data.train_labels.numpy()
Y_test = test_data.test_labels.numpy ()
```

```
/usr/local/lib/python3.7/dist-packages/torchvision/datasets/mnist.py:75:
UserWarning: train_data has been renamed data
  warnings.warn("train_data has been renamed data")
/usr/local/lib/python3.7/dist-packages/torchvision/datasets/mnist.py:80:
UserWarning: test_data has been renamed data
  warnings.warn("test_data has been renamed data")
/usr/local/lib/python3.7/dist-packages/torchvision/datasets/mnist.py:65:
UserWarning: train_labels has been renamed targets
  warnings.warn("train_labels has been renamed targets")
/usr/local/lib/python3.7/dist-packages/torchvision/datasets/mnist.py:70:
UserWarning: test_labels has been renamed targets
  warnings.warn("test_labels has been renamed targets")
```

### 3.1 1.(a)

```
[ ]: # Plot The Feature Parameters
imshow(X_train[7]);

# Return the Output
print(Y_train[7])
```



From above image, we can see the number is '3' which matches the label in Y\_train.

### 3.2 1.(b)

```
[ ]: # Check Dimensions
      [shape(X_test),shape(X_train)]
```

```
[ ]: [(10000, 28, 28), (60000, 28, 28)]
```

```
[ ]: # Data Reshape
      X_train = X_train.reshape(-1,28*28)
      X_test = X_test.reshape(-1, 28*28)
```

```
[ ]: # Data Normalization
      X_train = preprocessing.normalize(X_train)
      X_test = preprocessing.normalize(X_test)
```

### 3.3 1.(c)

```
[ ]: # One Hot Encoding
      onehot = preprocessing.OneHotEncoder(sparse = False)
      onehot.fit(Y_train.reshape(-1,1))
      Y_train_oh = onehot.transform(Y_train.reshape(-1,1))
      Y_test_oh = onehot.transform(Y_test.reshape(-1,1))
```

One hot embedding transfer every labels to 1\*N matrix containing only 0 and 1. In this way, each label can be treated equally by machine learning algorithm, which is difficult to be achieved by using numerical values to represent classes.

## 4 III. Before Deep Learning

### 4.1 2.(a)

```
[ ]: # KNN Training With K = 3
KNN = KNeighborsClassifier(n_neighbors=3).fit(X_train, Y_train_oh)

[ ]: 1 - KNN.score(X_test, Y_test_oh)

[ ]: 0.027299999999999999

[ ]: # AdaBoost Training
ada = AdaBoostClassifier(base_estimator=DecisionTreeClassifier(max_depth=20),
↪n_estimators=30).fit(X_train, Y_train)

[ ]: 1 - ada.score(X_test, Y_test)

[ ]: 0.037200000000000001

[ ]: dt = DecisionTreeClassifier(max_depth = 20).fit(X_train, Y_train)

[ ]: 1 - dt.score(X_test, Y_test)

[ ]: 0.112800000000000001

[ ]: # SVM with Gaussian Kernel
svm = SVC().fit(X_train, Y_train)

[ ]: 1 - svm.score(X_test, Y_test)

[ ]: 0.0189000000000000028
```

From above, we can see that the test errors of all three algorithms are different from the given result.

KNN: 2.73% Test Error vs. 5% Desired Test Error

AdaBoost.M1: 3.72% Test Error vs. 4.05% Desired Test Error

Decision Tree: 11.3% Test Error vs. 4.05% Desired Test Error

SVM with Gaussian Kernel: 1.9% Test Error vs. 1.4% Test Error

It can be caused by multiple reasons:

1. The data we used above may be different from the data authors used;
2. The preprocessing procedures are different (We have done normalization in Part1);
3. The hyperparameters for the four algorithms may be different (KNN with  $K = 3$ , AdaBoost & Decision Tree with maximum

depth = 20, SVM with  $C = 1$ );

4. The train test split method applied on the dataset may be different.

## 4.2 2.(b)

```
[ ]: #SVM with Gaussian Kernel
svm1 = SVC(C = 2).fit(X_train, Y_train)
1 - svm1.score(X_test, Y_test)
```

```
[ ]: 0.0158000000000000036
```

From above, we can see that the testing error for SVM with Gaussian Kernel with  $C = 2$  is 1.5%, which is lower than the test errors of all classifiers in part (a).

## 5 IV. Deep Learning

```
[ ]: # Define Required Plot Function
def loss_plot(train,test):
    index = []
    train_set = []
    test_set = []
    for i in range(len(train)):
        index.append(i+1)
        train_set.append(train[i][0])
        test_set.append(test[i][0])
    plt.plot(index, train_set, label = "Train")
    plt.plot(index, test_set, label = "Test")
    plt.legend()
    plt.xlabel("Number of Iterations")
    plt.ylabel("Loss Function")
    plt.title("Loss vs. Epochs Plot")

def error_plot(train,test):
    index = []
    train_set = []
    test_set = []
    for i in range(len(train)):
        index.append(i+1)
        train_set.append(1 - train[i][1])
        test_set.append(1 - test[i][1])
    plt.plot(index, train_set, label = "Train")
    plt.plot(index, test_set, label = "Test")
    plt.legend()
    plt.xlabel("Number of Iterations")
    plt.ylabel("Classification Error")
    plt.title("Classification Error vs. Epochs Plot")
```

```
[ ]: # Use Better-performance GPU If Available
device = 'cuda' if torch.cuda.is_available() else 'cpu'
print('Using {} device'.format(device))
```

Using cuda device

```
[ ]: # Data Type Transformation & Normalization
transform = transforms.Compose(
    [transforms.ToTensor(),
     transforms.Normalize((0.5,), (0.5,))])

# Read Data
train_data = MNIST(root='../data/mnist/', train=True, download=True, transform=
    ↳ transform)

test_data = MNIST(root='../data/ mnist/', train=False, download=True, transform=
    ↳ transform)
```

Downloading <http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz>  
 Downloading <http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz> to  
 ../data/mnist/MNIST/raw/train-images-idx3-ubyte.gz

0%| | 0/9912422 [00:00<?, ?it/s]

Extracting ../data/mnist/MNIST/raw/train-images-idx3-ubyte.gz to  
 ../data/mnist/MNIST/raw

Downloading <http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz>  
 Downloading <http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz> to  
 ../data/mnist/MNIST/raw/train-labels-idx1-ubyte.gz

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 ../data/mnist/MNIST/raw

Downloading <http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz>  
 Downloading <http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz> to  
 ../data/mnist/MNIST/raw/t10k-images-idx3-ubyte.gz

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 ../data/mnist/MNIST/raw

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 Downloading <http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz> to  
 ../data/mnist/MNIST/raw/t10k-labels-idx1-ubyte.gz

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```

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../data/mnist/MNIST/raw

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Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz to
../data/ mnist/MNIST/raw/train-images-idx3-ubyte.gz

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Extracting ../data/ mnist/MNIST/raw/train-images-idx3-ubyte.gz to ../data/
mnist/MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz to
../data/ mnist/MNIST/raw/train-labels-idx1-ubyte.gz

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mnist/MNIST/raw

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Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz to
../data/ mnist/MNIST/raw/t10k-images-idx3-ubyte.gz

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mnist/MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz to
../data/ mnist/MNIST/raw/t10k-labels-idx1-ubyte.gz

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Extracting ../data/ mnist/MNIST/raw/t10k-labels-idx1-ubyte.gz to ../data/
mnist/MNIST/raw

```

## 5.1 3.(a) & (b)

```

[ ]: # Create a Fully Connected Neural Network With Linear Layer
class ANN(nn.Module):
    def __init__(self, input_size, num_classes):
        super(ANN, self).__init__()
        self.flatten = nn.Flatten()
        # 100 Hidden Neurons
        self.layer1 = nn.Linear(input_size, 100)
        # 10 Output Classes
        self.layer2 = nn.Linear(100, num_classes)

```

```

def forward(self, x):
    x = self.flatten(x)
    # Sigmoid As Activation Function
    x = torch.sigmoid(self.layer1(x))
    x = self.layer2(x)
    return x

```

```

[ ]: # Two Functions Below can be Utilized From Part 3 to Part 5
# Define Training Process
def train_loop(dataloader, model, loss_fn, optimizer):
    running_loss, correct = 0, 0
    size = len(dataloader.dataset)
    for batch, (X, y) in enumerate(dataloader):
        # Compute prediction and loss
        pred = model(X)
        loss = loss_fn(pred, y)
        running_loss += loss.item() * X.size(0)
        correct += (pred.argmax(1) == y).type(torch.float).sum().item()
        # Backpropagation
        optimizer.zero_grad()
        loss.backward()
        optimizer.step()
    running_loss = running_loss / size
    correct /= size
    print('Training loss: {}'.format(running_loss))
    print('Training accuracy: {}'.format(correct))
    return running_loss, correct

# Define Test Loss And Accuracy Calculation
def test_loop(dataloader, model, loss_fn):
    size = len(dataloader.dataset)
    num_batches = len(dataloader)
    test_loss, correct = 0, 0

    with torch.no_grad():
        for X, y in dataloader:
            pred = model(X)
            test_loss += loss_fn(pred, y).item()
            correct += (pred.argmax(1) == y).type(torch.float).sum().item()

    test_loss /= num_batches
    correct /= size
    print('Testing loss: {}'.format(test_loss))
    print('Testing accuracy: {}'.format(correct))
    return test_loss, correct

```



### 5.1.1 Seed 1

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
model1 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model1.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    # Record Errors and Accuracy For Each Epoch
    train_loss_record.append(train_loop(train_loader,model1,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model1,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 0.6297853591203689
Training accuracy: 0.8404333333333334
Testing loss: 0.3246687440925343
Testing accuracy: 0.9099
Epoch 2
```

```
-----
Training loss: 0.3062173386176427
Training accuracy: 0.90985
Testing loss: 0.2625952813845531
Testing accuracy: 0.9232
```

Epoch 3

-----  
Training loss: 0.2574633126338323  
Training accuracy: 0.9253666666666667  
Testing loss: 0.2444920286441305  
Testing accuracy: 0.9279  
Epoch 4

-----  
Training loss: 0.22505092318455377  
Training accuracy: 0.9355166666666667  
Testing loss: 0.20499181634135497  
Testing accuracy: 0.9398  
Epoch 5

-----  
Training loss: 0.19978262469768523  
Training accuracy: 0.9427833333333333  
Testing loss: 0.19584464236714277  
Testing accuracy: 0.9426  
Epoch 6

-----  
Training loss: 0.18053489449024201  
Training accuracy: 0.9485166666666667  
Testing loss: 0.1671521149243519  
Testing accuracy: 0.9514  
Epoch 7

-----  
Training loss: 0.1641195891737938  
Training accuracy: 0.9527666666666667  
Testing loss: 0.15931019438489988  
Testing accuracy: 0.9519  
Epoch 8

-----  
Training loss: 0.1507589489340782  
Training accuracy: 0.9571666666666667  
Testing loss: 0.15489076075565283  
Testing accuracy: 0.9526  
Epoch 9

-----  
Training loss: 0.1394127394636472  
Training accuracy: 0.9600666666666666  
Testing loss: 0.13896149655531168  
Testing accuracy: 0.9587  
Epoch 10

-----  
Training loss: 0.13002917232116062  
Training accuracy: 0.9628833333333333  
Testing loss: 0.1283430814814226  
Testing accuracy: 0.9618

Epoch 11

-----  
Training loss: 0.12137663384079933  
Training accuracy: 0.9657333333333333  
Testing loss: 0.12744171681345268  
Testing accuracy: 0.9606  
Epoch 12

-----  
Training loss: 0.11405603938698769  
Training accuracy: 0.9678666666666667  
Testing loss: 0.1191791052912261  
Testing accuracy: 0.9648  
Epoch 13

-----  
Training loss: 0.1072008634964625  
Training accuracy: 0.9695166666666667  
Testing loss: 0.11367190620939063  
Testing accuracy: 0.9664  
Epoch 14

-----  
Training loss: 0.1020251943786939  
Training accuracy: 0.9715166666666667  
Testing loss: 0.10837410675112609  
Testing accuracy: 0.9674  
Epoch 15

-----  
Training loss: 0.09654787136564652  
Training accuracy: 0.9732166666666666  
Testing loss: 0.10345087648861727  
Testing accuracy: 0.9668  
Epoch 16

-----  
Training loss: 0.0917738558769226  
Training accuracy: 0.9743333333333334  
Testing loss: 0.10430020706099309  
Testing accuracy: 0.9675  
Epoch 17

-----  
Training loss: 0.08744012594322363  
Training accuracy: 0.97565  
Testing loss: 0.09950410514761499  
Testing accuracy: 0.9696  
Epoch 18

-----  
Training loss: 0.08369460960129897  
Training accuracy: 0.9767666666666667  
Testing loss: 0.10059487138679073  
Testing accuracy: 0.9692

Epoch 19

-----  
Training loss: 0.08013563364595175  
Training accuracy: 0.97835  
Testing loss: 0.09316612231384987  
Testing accuracy: 0.9702  
Epoch 20

-----  
Training loss: 0.07659215114911397  
Training accuracy: 0.9789833333333333  
Testing loss: 0.09520878807706817  
Testing accuracy: 0.9699  
Epoch 21

-----  
Training loss: 0.07356261316239834  
Training accuracy: 0.9792  
Testing loss: 0.09566314121008299  
Testing accuracy: 0.97  
Epoch 22

-----  
Training loss: 0.07069756077229977  
Training accuracy: 0.9808833333333333  
Testing loss: 0.09185979292271243  
Testing accuracy: 0.9725  
Epoch 23

-----  
Training loss: 0.06789225129336118  
Training accuracy: 0.9813333333333333  
Testing loss: 0.08959225422827302  
Testing accuracy: 0.9724  
Epoch 24

-----  
Training loss: 0.06540948421756426  
Training accuracy: 0.9821333333333333  
Testing loss: 0.08715340098259365  
Testing accuracy: 0.9732  
Epoch 25

-----  
Training loss: 0.0631390792225798  
Training accuracy: 0.9829333333333333  
Testing loss: 0.08407263693275155  
Testing accuracy: 0.9725  
Epoch 26

-----  
Training loss: 0.06067306455473105  
Training accuracy: 0.9835166666666667  
Testing loss: 0.08376484116907143  
Testing accuracy: 0.9731

Epoch 27

-----  
Training loss: 0.05861800416757663  
Training accuracy: 0.9840666666666666  
Testing loss: 0.08271520888539637  
Testing accuracy: 0.9738  
Epoch 28

-----  
Training loss: 0.05648891526013613  
Training accuracy: 0.98525  
Testing loss: 0.08755451794951015  
Testing accuracy: 0.9704  
Epoch 29

-----  
Training loss: 0.05469670623143514  
Training accuracy: 0.9853333333333333  
Testing loss: 0.0830236835773014  
Testing accuracy: 0.9737  
Epoch 30

-----  
Training loss: 0.053051174869636696  
Training accuracy: 0.98615  
Testing loss: 0.08427860329200508  
Testing accuracy: 0.9744  
Epoch 31

-----  
Training loss: 0.051173818831642466  
Training accuracy: 0.98675  
Testing loss: 0.08113522220189405  
Testing accuracy: 0.974  
Epoch 32

-----  
Training loss: 0.04986626948664586  
Training accuracy: 0.9872333333333333  
Testing loss: 0.0796349972462768  
Testing accuracy: 0.9749  
Epoch 33

-----  
Training loss: 0.047968516080578165  
Training accuracy: 0.988  
Training loss: 0.046461095530291395  
Training accuracy: 0.98795  
Testing loss: 0.08864543935473843  
Testing accuracy: 0.9725  
Epoch 35

-----  
Training loss: 0.04507692126383384  
Training accuracy: 0.9886666666666667

```
Testing loss: 0.0842148039822176
Testing accuracy: 0.9736
Epoch 36
-----
Training loss: 0.043707173978288966
Training accuracy: 0.98935
Testing loss: 0.07819860157776315
Testing accuracy: 0.9749
Epoch 37
-----
Training loss: 0.04235785040507714
Training accuracy: 0.9895833333333334
Testing loss: 0.07933978553102085
Testing accuracy: 0.9747
Epoch 38
-----
Training loss: 0.04118003966162602
Training accuracy: 0.9901
Testing loss: 0.07513726667566284
Testing accuracy: 0.9762
Epoch 39
-----
Training loss: 0.039829939324160415
Training accuracy: 0.9904
Testing loss: 0.07611486022686882
Testing accuracy: 0.9764
Epoch 40
-----
Training loss: 0.03881696707010269
Training accuracy: 0.9908
Testing loss: 0.07677703594883821
Testing accuracy: 0.9753
Epoch 41
-----
Training loss: 0.03797004208564758
Training accuracy: 0.99115
Testing loss: 0.07616835603620975
Testing accuracy: 0.9756
Epoch 42
-----
Training loss: 0.03639861912354827
Training accuracy: 0.9915833333333334
Testing loss: 0.07413552147425284
Testing accuracy: 0.976
Epoch 43
-----
Training loss: 0.035527695972969134
Training accuracy: 0.992
```

```

Testing loss: 0.07426353560013187
Testing accuracy: 0.9757
Epoch 44
-----
Training loss: 0.03461810613026221
Training accuracy: 0.9925
Testing loss: 0.07312003684609797
Testing accuracy: 0.9769
Epoch 45
-----
Training loss: 0.03359621330748002
Training accuracy: 0.9923666666666666
Testing loss: 0.07761707992714112
Testing accuracy: 0.9757
Epoch 46
-----
Training loss: 0.03276621801704168
Training accuracy: 0.9928166666666667
Testing loss: 0.07296595740084579
Testing accuracy: 0.9773
Epoch 47
-----
Training loss: 0.031750089348852636
Training accuracy: 0.99345
Testing loss: 0.07499310941358281
Testing accuracy: 0.9744
Epoch 48
-----
Training loss: 0.031092664072165887
Training accuracy: 0.9934833333333334
Testing loss: 0.07364840640028002
Testing accuracy: 0.9764
Epoch 49
-----
Training loss: 0.030156250004470347
Training accuracy: 0.9937
Testing loss: 0.07503982146929024
Testing accuracy: 0.9758
Epoch 50
-----
Training loss: 0.029338899896045528
Training accuracy: 0.99385
Testing loss: 0.07201561965285593
Testing accuracy: 0.9773
Epoch 51
-----
Training loss: 0.028584230779111385
Training accuracy: 0.99405

```

```
Testing loss: 0.07436138840694763
Testing accuracy: 0.9759
Epoch 52
-----
Training loss: 0.027678367530554533
Training accuracy: 0.9944333333333333
Testing loss: 0.07151810725065316
Testing accuracy: 0.9778
Epoch 53
-----
Training loss: 0.026981148327142
Training accuracy: 0.9949
Testing loss: 0.0726002849702231
Testing accuracy: 0.9767
Epoch 54
-----
Training loss: 0.026254749822616576
Training accuracy: 0.9950333333333333
Testing loss: 0.07293168999622487
Testing accuracy: 0.9777
Epoch 55
-----
Training loss: 0.02554147374071181
Training accuracy: 0.9952166666666666
Testing loss: 0.07095962380812426
Testing accuracy: 0.9767
Epoch 56
-----
Training loss: 0.024965715322146812
Training accuracy: 0.9955833333333334
Testing loss: 0.07225324779861625
Testing accuracy: 0.9774
Epoch 57
-----
Training loss: 0.02434097584610184
Training accuracy: 0.9956
Testing loss: 0.07494348648840644
Testing accuracy: 0.9752
Epoch 58
-----
Training loss: 0.02378548802062869
Training accuracy: 0.9958333333333333
Testing loss: 0.0726675170734762
Testing accuracy: 0.9774
Epoch 59
-----
Training loss: 0.023214865994205077
Training accuracy: 0.9961333333333333
```



```
Testing loss: 0.07319938904564281
Testing accuracy: 0.9769
Epoch 60
-----
Training loss: 0.022520517407606046
Training accuracy: 0.9962833333333333
Testing loss: 0.07305599168791276
Testing accuracy: 0.9775
Epoch 61
-----
Training loss: 0.02193612810410559
Training accuracy: 0.9965833333333334
Testing loss: 0.07049293401146865
Testing accuracy: 0.978
Epoch 62
-----
Training loss: 0.021486812064424158
Training accuracy: 0.99685
Testing loss: 0.07142370346945467
Testing accuracy: 0.9785
Epoch 63
-----
Training loss: 0.02100057579179605
Training accuracy: 0.9965
Testing loss: 0.07135517975896787
Testing accuracy: 0.9778
Epoch 64
-----
Training loss: 0.020411186934138337
Training accuracy: 0.9968
Testing loss: 0.07075866016375411
Testing accuracy: 0.9776
Epoch 65
-----
Training loss: 0.020128379082183043
Training accuracy: 0.9971333333333333
Testing loss: 0.07451339981927993
Testing accuracy: 0.9763
Epoch 66
-----
Training loss: 0.01966030284973482
Training accuracy: 0.9970166666666667
Testing loss: 0.07189591975354702
Testing accuracy: 0.9782
Epoch 67
-----
Training loss: 0.019257570180669425
Training accuracy: 0.99705
```

```

Testing loss: 0.07320132677051815
Testing accuracy: 0.9777
Epoch 68
-----
Training loss: 0.018688038597255947
Training accuracy: 0.9972833333333333
Testing loss: 0.07094505739214409
Testing accuracy: 0.9773
Epoch 69
-----
Training loss: 0.018201764854664605
Training accuracy: 0.9973666666666666
Testing loss: 0.07207143405796426
Testing accuracy: 0.9781
Epoch 70
-----
Training loss: 0.01780897956552605
Training accuracy: 0.99775
Testing loss: 0.07372030940879683
Testing accuracy: 0.9775
Epoch 71
-----
Training loss: 0.017511391474182406
Training accuracy: 0.99775
Testing loss: 0.07172968036756157
Testing accuracy: 0.9781
Epoch 72
-----
Training loss: 0.017020372746139763
Training accuracy: 0.9978333333333333
Testing loss: 0.07178629979574282
Testing accuracy: 0.978
Epoch 73
-----
Training loss: 0.016644504422321914
Training accuracy: 0.9979333333333333
Testing loss: 0.07162606316784717
Testing accuracy: 0.9775
Epoch 74
-----
Training loss: 0.016193062488983074
Training accuracy: 0.9980166666666667
Testing loss: 0.07213941167529886
Testing accuracy: 0.9773
Epoch 75
-----
Training loss: 0.015884743539616466
Training accuracy: 0.9981

```

Testing loss: 0.07176737414500943  
Testing accuracy: 0.9772  
Epoch 76  
-----  
Training loss: 0.015601818679024776  
Training accuracy: 0.9981333333333333  
Testing loss: 0.07085743356662191  
Testing accuracy: 0.9776  
Epoch 77  
-----  
Training loss: 0.015212223796049754  
Training accuracy: 0.9983666666666666  
Testing loss: 0.0710227491176883  
Testing accuracy: 0.9771  
Epoch 78  
-----  
Training loss: 0.014928027247885863  
Training accuracy: 0.9982166666666666  
Testing loss: 0.07231175029430847  
Testing accuracy: 0.9772  
Epoch 79  
-----  
Training loss: 0.014671817204977075  
Training accuracy: 0.9983  
Testing loss: 0.07110384474716085  
Testing accuracy: 0.9776  
Epoch 80  
-----  
Training loss: 0.01429324615088602  
Training accuracy: 0.9983833333333333  
Testing loss: 0.07236953653323992  
Testing accuracy: 0.9776  
Epoch 81  
-----  
Training loss: 0.013976049508651098  
Training accuracy: 0.9986  
Testing loss: 0.07208935891286986  
Testing accuracy: 0.9769  
Epoch 82  
-----  
Training loss: 0.01376391908278068  
Training accuracy: 0.9986666666666667  
Testing loss: 0.06988278976018736  
Testing accuracy: 0.9784  
Epoch 83  
-----  
Training loss: 0.013468942063053449  
Training accuracy: 0.9986333333333334

```
Testing loss: 0.07142065925476183
Testing accuracy: 0.9776
Epoch 84
-----
Training loss: 0.013190534527848165
Training accuracy: 0.9988666666666667
Testing loss: 0.07248787209836494
Testing accuracy: 0.9779
Epoch 85
-----
Training loss: 0.012952483443791667
Training accuracy: 0.99885
Testing loss: 0.07120354207244459
Testing accuracy: 0.978
Epoch 86
-----
Training loss: 0.012685294490059217
Training accuracy: 0.9989
Testing loss: 0.08222644323346674
Testing accuracy: 0.9748
Epoch 87
-----
Training loss: 0.012507170622174938
Training accuracy: 0.9989333333333333
Testing loss: 0.07081349479675197
Testing accuracy: 0.9779
Epoch 88
-----
Training loss: 0.012252864164859056
Training accuracy: 0.9989333333333333
Testing loss: 0.07060918012028856
Testing accuracy: 0.9774
Epoch 89
-----
Training loss: 0.011919612067565323
Training accuracy: 0.9990166666666667
Testing loss: 0.07106435046810064
Testing accuracy: 0.9777
Epoch 90
-----
Training loss: 0.01170339570964376
Training accuracy: 0.9990833333333333
Testing loss: 0.07112922781342819
Testing accuracy: 0.9779
Epoch 91
-----
Training loss: 0.01152373623351256
Training accuracy: 0.99905
```

```
Testing loss: 0.07269519032127443
Testing accuracy: 0.9774
Epoch 92
-----
Training loss: 0.011333768441403906
Training accuracy: 0.9991166666666667
Testing loss: 0.0719588083047479
Testing accuracy: 0.9779
Epoch 93
-----
Training loss: 0.011116684358318647
Training accuracy: 0.9991833333333333
Testing loss: 0.07122379369369358
Testing accuracy: 0.9779
Epoch 94
-----
Training loss: 0.010824340550166865
Training accuracy: 0.9993166666666666
Testing loss: 0.0715775265637192
Testing accuracy: 0.9776
Epoch 95
-----
Training loss: 0.010667340270802378
Training accuracy: 0.9992666666666666
Testing loss: 0.0709852965906037
Testing accuracy: 0.9783
Epoch 96
-----
Training loss: 0.010527977102001509
Training accuracy: 0.9993333333333333
Testing loss: 0.07165163715375931
Testing accuracy: 0.9781
Epoch 97
-----
Training loss: 0.010351135115946333
Training accuracy: 0.9993166666666666
Testing loss: 0.07155821601130591
Testing accuracy: 0.9783
Epoch 98
-----
Training loss: 0.01011565810777247
Training accuracy: 0.9993166666666666
Testing loss: 0.07341599064007116
Testing accuracy: 0.9783
Epoch 99
-----
Training loss: 0.010021183140327534
Training accuracy: 0.9994333333333333
```

```
Testing loss: 0.0728024453225777
Testing accuracy: 0.9775
Epoch 100
-----
Training loss: 0.009790361591676872
Training accuracy: 0.9994666666666666
Testing loss: 0.07162054529291975
Testing accuracy: 0.9778
Epoch 101
-----
Training loss: 0.00963975324543814
Training accuracy: 0.9994666666666666
Testing loss: 0.07150967063376336
Testing accuracy: 0.9779
Epoch 102
-----
Training loss: 0.009441808728749553
Training accuracy: 0.99955
Testing loss: 0.07154451010550023
Testing accuracy: 0.9782
Epoch 103
-----
Training loss: 0.00929507545704643
Training accuracy: 0.9995333333333334
Testing loss: 0.0721801087470832
Testing accuracy: 0.9783
Epoch 104
-----
Training loss: 0.009162861742451787
Training accuracy: 0.9995166666666667
Testing loss: 0.07226430446022208
Testing accuracy: 0.9781
Epoch 105
-----
Training loss: 0.009027468014198044
Training accuracy: 0.99965
Testing loss: 0.077288128911654
Testing accuracy: 0.9779
Epoch 106
-----
Training loss: 0.008841111483300726
Training accuracy: 0.9996166666666667
Testing loss: 0.07281086186264422
Testing accuracy: 0.9776
Epoch 107
-----
Training loss: 0.008731287605439623
Training accuracy: 0.9996333333333334
```

```

Testing loss: 0.07308963662425685
Testing accuracy: 0.9774
Epoch 108
-----
Training loss: 0.008564934982111057
Training accuracy: 0.9996333333333334
Testing loss: 0.07116222299582023
Testing accuracy: 0.9779
Epoch 109
-----
Training loss: 0.008403215462900699
Training accuracy: 0.9996833333333334
Testing loss: 0.07414288942592373
Testing accuracy: 0.9778
Epoch 110
-----
Training loss: 0.008344238369725645
Training accuracy: 0.9996166666666667
Testing loss: 0.07334809948743623
Testing accuracy: 0.9778
Epoch 111
-----
Training loss: 0.008233000619523227
Training accuracy: 0.99965
Testing loss: 0.07408256085525018
Testing accuracy: 0.9778
Epoch 112
-----
Training loss: 0.008103546246513724
Training accuracy: 0.9996333333333334
Testing loss: 0.07179820765578039
Testing accuracy: 0.9787
Epoch 113
-----
Training loss: 0.007933155863111219
Training accuracy: 0.9997333333333334
Testing loss: 0.07334430879100588
Testing accuracy: 0.9779
Epoch 114
-----
Training loss: 0.007776250189604859
Training accuracy: 0.9997833333333334
Testing loss: 0.07228379110823487
Testing accuracy: 0.9773
Epoch 115
-----
Training loss: 0.007683965455802778
Training accuracy: 0.99975

```

```

Testing loss: 0.07264305707059836
Testing accuracy: 0.9778
Epoch 116
-----
Training loss: 0.0075929490795048574
Training accuracy: 0.9997
Testing loss: 0.07348541446863585
Testing accuracy: 0.9781
Epoch 117
-----
Training loss: 0.007477357934042811
Training accuracy: 0.9997833333333334
Testing loss: 0.07304900613313861
Testing accuracy: 0.9776
Epoch 118
-----
Training loss: 0.007397994754649698
Training accuracy: 0.9997833333333334
Testing loss: 0.0749621954983824
Testing accuracy: 0.9777
Epoch 119
-----
Training loss: 0.007309283566102385
Training accuracy: 0.9998
Testing loss: 0.07395093274898945
Testing accuracy: 0.9782
Epoch 120
-----
Training loss: 0.007169516205042601
Training accuracy: 0.9998166666666667
Testing loss: 0.07327717470426326
Testing accuracy: 0.9782
Epoch 121
-----
Training loss: 0.00707680729944259
Training accuracy: 0.9997833333333334
Testing loss: 0.07276607992774124
Testing accuracy: 0.9781
Epoch 122
-----
Training loss: 0.006977961366530508
Training accuracy: 0.9998166666666667
Testing loss: 0.07262240058967137
Testing accuracy: 0.9779
Epoch 123
-----
Training loss: 0.006874063401296735
Training accuracy: 0.99985

```



```
Testing loss: 0.07256052143587048
Testing accuracy: 0.978
Epoch 124
-----
Training loss: 0.006775192267509798
Training accuracy: 0.9998166666666667
Testing loss: 0.07368610912910217
Testing accuracy: 0.9778
Epoch 125
-----
Training loss: 0.00670345927135398
Training accuracy: 0.99985
Testing loss: 0.07327827268315681
Testing accuracy: 0.9786
Epoch 126
-----
Training loss: 0.006582161154411733
Training accuracy: 0.9998833333333333
Testing loss: 0.07441933297739026
Testing accuracy: 0.9778
Epoch 127
-----
Training loss: 0.006525548467971385
Training accuracy: 0.9998666666666667
Testing loss: 0.07436018859356594
Testing accuracy: 0.9787
Epoch 128
-----
Training loss: 0.006423189918293307
Training accuracy: 0.9999
Testing loss: 0.07367654806032635
Testing accuracy: 0.979
Epoch 129
-----
Training loss: 0.006350422220149388
Training accuracy: 0.9999
Testing loss: 0.07465599644869851
Testing accuracy: 0.9784
Epoch 130
-----
Training loss: 0.00628829968875895
Training accuracy: 0.9998666666666667
Testing loss: 0.07318416922123343
Testing accuracy: 0.978
Epoch 131
-----
Training loss: 0.006166386165904502
Training accuracy: 0.9999
```

```

Testing loss: 0.07320305664881258
Testing accuracy: 0.9783
Epoch 132
-----
Training loss: 0.00611786962999031
Training accuracy: 0.9999166666666667
Testing loss: 0.07342421572216472
Testing accuracy: 0.9781
Epoch 133
-----
Training loss: 0.006049480984173715
Training accuracy: 0.9999166666666667
Testing loss: 0.07306367310118464
Testing accuracy: 0.9787
Epoch 134
-----
Training loss: 0.0059489312998640045
Training accuracy: 0.9999166666666667
Testing loss: 0.07319982670793299
Testing accuracy: 0.9782
Epoch 135
-----
Training loss: 0.0059141443810425695
Training accuracy: 0.9999166666666667
Testing loss: 0.0729787292041976
Testing accuracy: 0.9784
Epoch 136
-----
Training loss: 0.005802631357374291
Training accuracy: 0.99995
Testing loss: 0.07361874170230619
Testing accuracy: 0.9782
Epoch 137
-----
Training loss: 0.005762359465037783
Training accuracy: 0.9999333333333333
Testing loss: 0.07299416413334951
Testing accuracy: 0.9779
Epoch 138
-----
Training loss: 0.005658813695547481
Training accuracy: 0.99995
Testing loss: 0.07443759049074636
Testing accuracy: 0.9782
Epoch 139
-----
Training loss: 0.00559600533961008
Training accuracy: 0.9999333333333333

```

```

Testing loss: 0.07415752150385291
Testing accuracy: 0.9779
Epoch 140
-----
Training loss: 0.005572710842639208
Training accuracy: 0.9999666666666667
Testing loss: 0.0739445144082212
Testing accuracy: 0.9778
Epoch 141
-----
Training loss: 0.005484755314514041
Training accuracy: 0.9999666666666667
Testing loss: 0.07464323552461803
Testing accuracy: 0.9777
Epoch 142
-----
Training loss: 0.005418757839314639
Training accuracy: 0.99995
Testing loss: 0.07440182780565184
Testing accuracy: 0.9784
Epoch 143
-----
Training loss: 0.005340753162155549
Training accuracy: 0.9999666666666667
Testing loss: 0.07395686023604647
Testing accuracy: 0.9775
Epoch 144
-----
Training loss: 0.005314431510058542
Training accuracy: 0.9999
Testing loss: 0.07422283398444249
Testing accuracy: 0.9783
Epoch 145
-----
Training loss: 0.005264033389805506
Training accuracy: 0.99995
Testing loss: 0.07428817593071396
Testing accuracy: 0.9781
Epoch 146
-----
Training loss: 0.00518930071350187
Training accuracy: 0.99995
Testing loss: 0.07460421853799634
Testing accuracy: 0.9778
Epoch 147
-----
Training loss: 0.005133134151125948
Training accuracy: 0.99995

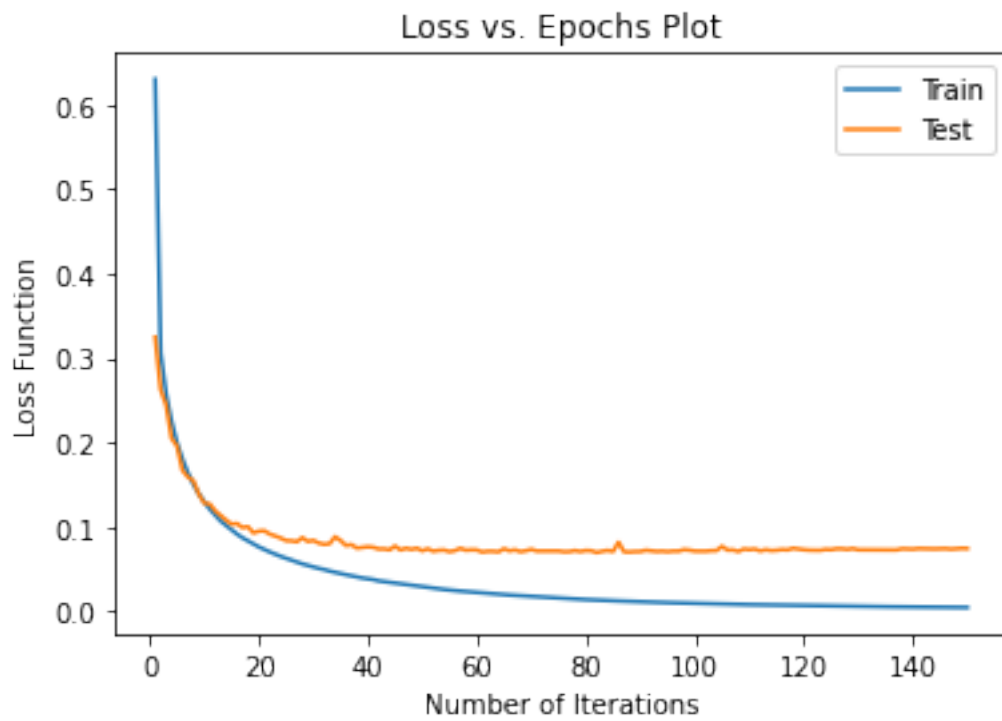
```

```

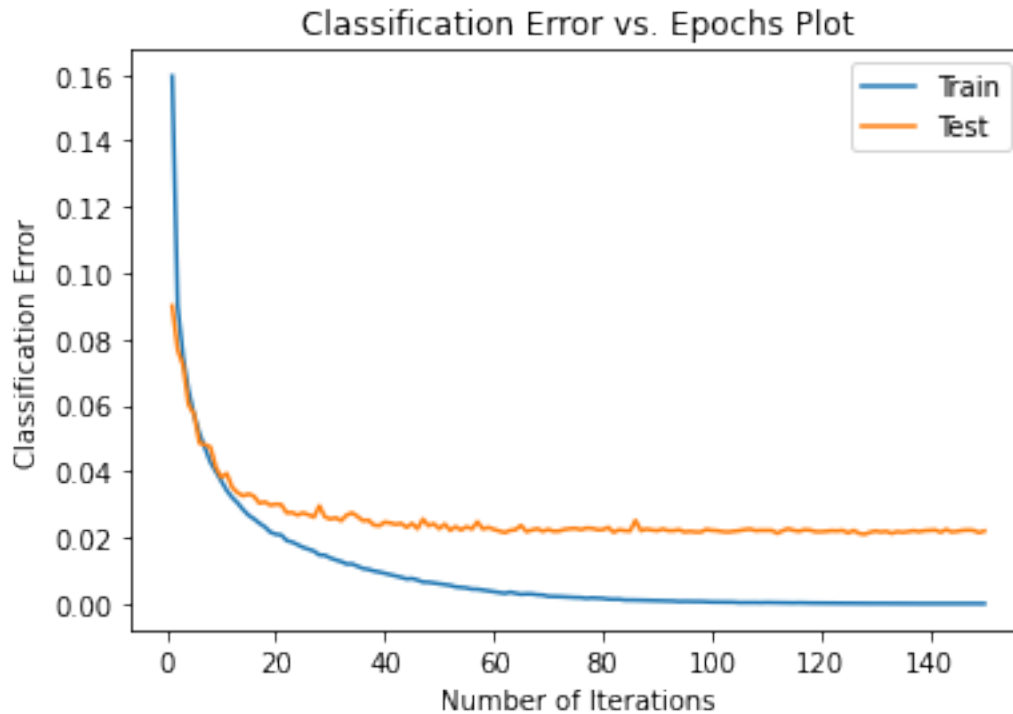
Testing loss: 0.07397771903734868
Testing accuracy: 0.9777
Epoch 148
-----
Training loss: 0.005080946041705708
Training accuracy: 0.9999333333333333
Testing loss: 0.07453322259021128
Testing accuracy: 0.9778
Epoch 149
-----
Training loss: 0.005022281877137721
Training accuracy: 0.99995
Testing loss: 0.07490387789580295
Testing accuracy: 0.9785
Epoch 150
-----
Training loss: 0.004958816983861228
Training accuracy: 0.9999666666666667
Testing loss: 0.0746828461666317
Testing accuracy: 0.978
Done
Total Time Consumed: 1601.9314296245575

```

```
[ ]: # Plot the Cross Entropy Loss
loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: # Plot Classification Error
error_plot(train_loss_record, test_loss_record)
```



### 5.1.2 Seed 2

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
model2 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model2.parameters(), lr = learning_rate)
```

```
[ ]: # Set Seed
torch.manual_seed(2)

# Data Loading
```

```

train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model2,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model2,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.6285737864812215
Training accuracy: 0.83575
Testing loss: 0.32961231640949373
Testing accuracy: 0.9084
Epoch 2

```

```

-----
Training loss: 0.3063160417238871
Training accuracy: 0.9112166666666667
Testing loss: 0.27231808049473794
Testing accuracy: 0.9221
Epoch 3

```

```

-----
Training loss: 0.2572185028076172
Training accuracy: 0.9245666666666666
Testing loss: 0.2324833566690706
Testing accuracy: 0.9329
Epoch 4

```

```

-----
Training loss: 0.22372442430655162
Training accuracy: 0.9354666666666667
Testing loss: 0.213163637336652
Testing accuracy: 0.937
Epoch 5

```

```

-----
Training loss: 0.19896439953446388
Training accuracy: 0.9425833333333333
Testing loss: 0.18708855639787236
Testing accuracy: 0.945

```

Epoch 6

-----  
Training loss: 0.17874435766935348  
Training accuracy: 0.9482  
Testing loss: 0.17481042874182107  
Testing accuracy: 0.9477  
Epoch 7

-----  
Training loss: 0.16321579337716102  
Training accuracy: 0.95305  
Testing loss: 0.16185499020632665  
Testing accuracy: 0.9518  
Epoch 8

-----  
Training loss: 0.14929702023267746  
Training accuracy: 0.9571666666666667  
Testing loss: 0.14733545600798478  
Testing accuracy: 0.9562  
Epoch 9

-----  
Training loss: 0.13792286259134612  
Training accuracy: 0.9602666666666667  
Testing loss: 0.14400177406277626  
Testing accuracy: 0.9583  
Epoch 10

-----  
Training loss: 0.12857665564815204  
Training accuracy: 0.9634166666666667  
Testing loss: 0.1383635588702123  
Testing accuracy: 0.9585  
Epoch 11

-----  
Training loss: 0.12060605541467667  
Training accuracy: 0.96595  
Testing loss: 0.12800939974321682  
Testing accuracy: 0.9617  
Epoch 12

-----  
Training loss: 0.11302766028443972  
Training accuracy: 0.96805  
Testing loss: 0.12273031986870203  
Testing accuracy: 0.9621  
Epoch 13

-----  
Training loss: 0.1063709796855847  
Training accuracy: 0.9699166666666666  
Testing loss: 0.11911342778260921  
Testing accuracy: 0.9623

Epoch 14

-----  
Training loss: 0.10067304199635982  
Training accuracy: 0.9721666666666666  
Testing loss: 0.11402667341101322  
Testing accuracy: 0.966  
Epoch 15

-----  
Training loss: 0.09564102665583292  
Training accuracy: 0.97355  
Testing loss: 0.10910229574722849  
Testing accuracy: 0.966  
Epoch 16

-----  
Training loss: 0.09108620736499627  
Training accuracy: 0.9743833333333334  
Testing loss: 0.10183491973669097  
Testing accuracy: 0.9689  
Epoch 17

-----  
Training loss: 0.08663212414880593  
Training accuracy: 0.9762666666666666  
Testing loss: 0.09818576008176348  
Testing accuracy: 0.9689  
Epoch 18

-----  
Training loss: 0.08280838174521923  
Training accuracy: 0.9772666666666666  
Testing loss: 0.10006814992209528  
Testing accuracy: 0.9688  
Epoch 19

-----  
Training loss: 0.07912849098543326  
Training accuracy: 0.9785  
Testing loss: 0.0952982705525437  
Testing accuracy: 0.9701  
Epoch 20

-----  
Training loss: 0.07598581587274869  
Training accuracy: 0.9798833333333333  
Testing loss: 0.09374547057494426  
Testing accuracy: 0.9703  
Epoch 21

-----  
Training loss: 0.07281562159260115  
Training accuracy: 0.9803  
Testing loss: 0.09506330573278818  
Testing accuracy: 0.9694



Epoch 22

-----  
Training loss: 0.07039664616982143  
Training accuracy: 0.9812  
Testing loss: 0.08870596385851598  
Testing accuracy: 0.9725  
Epoch 23

-----  
Training loss: 0.0673826634923617  
Training accuracy: 0.982  
Testing loss: 0.09200298147584507  
Testing accuracy: 0.9718  
Epoch 24

-----  
Training loss: 0.06474385134279728  
Training accuracy: 0.9830166666666666  
Testing loss: 0.09549033058107279  
Testing accuracy: 0.9706  
Epoch 25

-----  
Training loss: 0.062350328982373075  
Training accuracy: 0.9834666666666667  
Testing loss: 0.08669588596791408  
Testing accuracy: 0.9729  
Epoch 26

-----  
Training loss: 0.06044917049904664  
Training accuracy: 0.9840666666666666  
Testing loss: 0.0846662170959601  
Testing accuracy: 0.9748  
Epoch 27

-----  
Training loss: 0.058516134481628734  
Training accuracy: 0.9846166666666667  
Testing loss: 0.08359660542789538  
Testing accuracy: 0.9742  
Epoch 28

-----  
Training loss: 0.05614734697639942  
Training accuracy: 0.9857333333333334  
Testing loss: 0.08684591945426859  
Testing accuracy: 0.9732  
Epoch 29

-----  
Training loss: 0.05397357148180405  
Training accuracy: 0.9864  
Testing loss: 0.0858289288463676  
Testing accuracy: 0.974

Epoch 30

-----  
Training loss: 0.052699432454506555  
Training accuracy: 0.9866333333333334  
Testing loss: 0.08090503659443396  
Testing accuracy: 0.9751  
Epoch 31

-----  
Training loss: 0.05097889289905628  
Training accuracy: 0.98695  
Testing loss: 0.08258887658571931  
Testing accuracy: 0.9746  
Epoch 32

-----  
Training loss: 0.04936678807189067  
Training accuracy: 0.9875833333333334  
Testing loss: 0.07852093629823749  
Testing accuracy: 0.9762  
Epoch 33

-----  
Training loss: 0.04756866630216439  
Training accuracy: 0.9883833333333333  
Testing loss: 0.08103696985917676  
Testing accuracy: 0.9747  
Epoch 34

-----  
Training loss: 0.046292624588807424  
Training accuracy: 0.9884666666666667  
Testing loss: 0.08065716871268051  
Testing accuracy: 0.9748  
Epoch 35

-----  
Training loss: 0.044669565804799395  
Training accuracy: 0.9894166666666667  
Testing loss: 0.0797494895590149  
Testing accuracy: 0.9753  
Epoch 36

-----  
Training loss: 0.043538772259652615  
Training accuracy: 0.9893333333333333  
Testing loss: 0.08051223326830348  
Testing accuracy: 0.9747  
Epoch 37

-----  
Training loss: 0.04217227722207705  
Training accuracy: 0.9898666666666667  
Testing loss: 0.07997253241764891  
Testing accuracy: 0.9746

Epoch 38

-----  
Training loss: 0.040922468990584215  
Training accuracy: 0.99035  
Testing loss: 0.07536138750161904  
Testing accuracy: 0.9766  
Epoch 39

-----  
Training loss: 0.03966042507936557  
Training accuracy: 0.9907  
Testing loss: 0.0755780126104594  
Testing accuracy: 0.9763  
Epoch 40

-----  
Training loss: 0.0384651448123157  
Training accuracy: 0.9910833333333333  
Testing loss: 0.07517498821334521  
Testing accuracy: 0.9758  
Epoch 41

-----  
Training loss: 0.03706449047997594  
Training accuracy: 0.99155  
Testing loss: 0.07484517952984875  
Testing accuracy: 0.9752  
Epoch 42

-----  
Training loss: 0.03652799854079882  
Training accuracy: 0.9915333333333334  
Testing loss: 0.07627489392283805  
Testing accuracy: 0.9756  
Epoch 43

-----  
Training loss: 0.03536047281300028  
Training accuracy: 0.9922  
Testing loss: 0.07423839315914424  
Testing accuracy: 0.9775  
Epoch 44

-----  
Training loss: 0.034284380360444386  
Training accuracy: 0.9921166666666666  
Testing loss: 0.07543945230341925  
Testing accuracy: 0.9763  
Epoch 45

-----  
Training loss: 0.03344295054549972  
Training accuracy: 0.9925166666666667  
Testing loss: 0.07478219448962505  
Testing accuracy: 0.978

Epoch 46

-----  
Training loss: 0.032385329402734836  
Training accuracy: 0.9929  
Testing loss: 0.07399546490555071  
Testing accuracy: 0.9767  
Epoch 47

-----  
Training loss: 0.03171028299132983  
Training accuracy: 0.9932666666666666  
Testing loss: 0.0728692296524621  
Testing accuracy: 0.9771  
Epoch 48

-----  
Training loss: 0.03063012059678634  
Training accuracy: 0.9938833333333333  
Testing loss: 0.07323242044580543  
Testing accuracy: 0.9779  
Epoch 49

-----  
Training loss: 0.029844400102396806  
Training accuracy: 0.9941166666666666  
Testing loss: 0.07285529068688963  
Testing accuracy: 0.9775  
Epoch 50

-----  
Training loss: 0.029017367253204186  
Training accuracy: 0.9943  
Testing loss: 0.07111878374555877  
Testing accuracy: 0.9775  
Epoch 51

-----  
Training loss: 0.028350655814260245  
Training accuracy: 0.99435  
Testing loss: 0.0731133839358712  
Testing accuracy: 0.9765  
Epoch 52

-----  
Training loss: 0.02748472862392664  
Training accuracy: 0.9945833333333334  
Testing loss: 0.07165209031189276  
Testing accuracy: 0.978  
Epoch 53

-----  
Training loss: 0.026821382365872462  
Training accuracy: 0.9951  
Testing loss: 0.07084982610006585  
Testing accuracy: 0.9771

Epoch 54

-----  
Training loss: 0.02600472120543321  
Training accuracy: 0.9951  
Testing loss: 0.07262420779461884  
Testing accuracy: 0.9775  
Epoch 55

-----  
Training loss: 0.025504957345376413  
Training accuracy: 0.9952833333333333  
Testing loss: 0.0724742919455763  
Testing accuracy: 0.9779  
Epoch 56

-----  
Training loss: 0.02492121780787905  
Training accuracy: 0.99555  
Testing loss: 0.07182846290717838  
Testing accuracy: 0.977  
Epoch 57

-----  
Training loss: 0.024190044724196197  
Training accuracy: 0.9956333333333334  
Testing loss: 0.0719371075581783  
Testing accuracy: 0.9774  
Epoch 58

-----  
Training loss: 0.023410038677106303  
Training accuracy: 0.9957333333333334  
Testing loss: 0.07369127184461066  
Testing accuracy: 0.978  
Epoch 59

-----  
Training loss: 0.023063867766658464  
Training accuracy: 0.9958333333333333  
Testing loss: 0.07074678389082668  
Testing accuracy: 0.9783  
Epoch 60

-----  
Training loss: 0.022517660277709364  
Training accuracy: 0.9962  
Testing loss: 0.07080679523883163  
Testing accuracy: 0.9776  
Epoch 61

-----  
Training loss: 0.021901406099026403  
Training accuracy: 0.9966  
Testing loss: 0.07054259636955466  
Testing accuracy: 0.9769

Epoch 62

-----  
Training loss: 0.021224073892335098  
Training accuracy: 0.9968  
Testing loss: 0.07048016584146127  
Testing accuracy: 0.9784  
Epoch 63

-----  
Training loss: 0.02079878752330939  
Training accuracy: 0.9968666666666667  
Testing loss: 0.07155777899115376  
Testing accuracy: 0.9789  
Epoch 64

-----  
Training loss: 0.02037790816401442  
Training accuracy: 0.99695  
Testing loss: 0.0720597638831634  
Testing accuracy: 0.9781  
Epoch 65

-----  
Training loss: 0.019858692616348466  
Training accuracy: 0.997  
Testing loss: 0.07050493249823903  
Testing accuracy: 0.9776  
Epoch 66

-----  
Training loss: 0.019458655671402814  
Training accuracy: 0.9972833333333333  
Testing loss: 0.07134088930513734  
Testing accuracy: 0.978  
Epoch 67

-----  
Training loss: 0.01891411584019661  
Training accuracy: 0.9975166666666667  
Testing loss: 0.06926360442214141  
Testing accuracy: 0.9783  
Epoch 68

-----  
Training loss: 0.018574561191598574  
Training accuracy: 0.9974666666666666  
Testing loss: 0.07011159170407114  
Testing accuracy: 0.9777  
Epoch 69

-----  
Training loss: 0.018147481560334563  
Training accuracy: 0.9978  
Testing loss: 0.07064934947029658  
Testing accuracy: 0.9773

Epoch 70

-----  
Training loss: 0.017625377865508197  
Training accuracy: 0.9978833333333333  
Testing loss: 0.0693455598128746  
Testing accuracy: 0.978  
Epoch 71

-----  
Training loss: 0.017272138194491467  
Training accuracy: 0.99795  
Testing loss: 0.06878831911132119  
Testing accuracy: 0.9778  
Epoch 72

-----  
Training loss: 0.016888884529968104  
Training accuracy: 0.9978666666666667  
Testing loss: 0.06931560491448992  
Testing accuracy: 0.9785  
Epoch 73

-----  
Training loss: 0.016369452432667214  
Training accuracy: 0.99825  
Testing loss: 0.06941786855696493  
Testing accuracy: 0.9784  
Epoch 74

-----  
Training loss: 0.016128405962139367  
Training accuracy: 0.9980833333333333  
Testing loss: 0.07123871210511702  
Testing accuracy: 0.9782  
Epoch 75

-----  
Training loss: 0.015839252349237602  
Training accuracy: 0.9982666666666666  
Testing loss: 0.06944474098450582  
Testing accuracy: 0.9782  
Epoch 76

-----  
Training loss: 0.015499269999191165  
Training accuracy: 0.9983166666666666  
Testing loss: 0.07014742957362846  
Testing accuracy: 0.9782  
Epoch 77

-----  
Training loss: 0.01510689558237791  
Training accuracy: 0.9983833333333333  
Testing loss: 0.06888232171271519  
Testing accuracy: 0.9783

Epoch 78

-----  
Training loss: 0.014740027582769592  
Training accuracy: 0.9985  
Testing loss: 0.06992842151878319  
Testing accuracy: 0.9788  
Epoch 79

-----  
Training loss: 0.014426636022080977  
Training accuracy: 0.9986333333333334  
Testing loss: 0.0683390339984778  
Testing accuracy: 0.9781  
Epoch 80

-----  
Training loss: 0.014130361816535394  
Training accuracy: 0.9986  
Testing loss: 0.06805566791445017  
Testing accuracy: 0.9785  
Epoch 81

-----  
Training loss: 0.013952048848569393  
Training accuracy: 0.9986666666666667  
Testing loss: 0.0698901778739539  
Testing accuracy: 0.9779  
Epoch 82

-----  
Training loss: 0.013566068100060025  
Training accuracy: 0.9987833333333334  
Testing loss: 0.06975118960750698  
Testing accuracy: 0.9789  
Epoch 83

-----  
Training loss: 0.013306680979082981  
Training accuracy: 0.9988833333333333  
Testing loss: 0.06954389934837343  
Testing accuracy: 0.9777  
Epoch 84

-----  
Training loss: 0.013040064274830123  
Training accuracy: 0.99885  
Testing loss: 0.07228709062246998  
Testing accuracy: 0.9784  
Epoch 85

-----  
Training loss: 0.012776017658784986  
Training accuracy: 0.9989666666666667  
Testing loss: 0.07041131625037972  
Testing accuracy: 0.9781



Epoch 86

-----  
Training loss: 0.012613022963268062  
Training accuracy: 0.9989833333333333  
Testing loss: 0.06862930403236348  
Testing accuracy: 0.9786  
Epoch 87

-----  
Training loss: 0.01233464538268745  
Training accuracy: 0.999  
Testing loss: 0.07145792927598925  
Testing accuracy: 0.9775  
Epoch 88

-----  
Training loss: 0.01211918520014733  
Training accuracy: 0.9992333333333333  
Testing loss: 0.07048930798265728  
Testing accuracy: 0.9785  
Epoch 89

-----  
Training loss: 0.011856670990337928  
Training accuracy: 0.9990333333333333  
Testing loss: 0.06927486519317386  
Testing accuracy: 0.9785  
Epoch 90

-----  
Training loss: 0.011586245795711875  
Training accuracy: 0.99915  
Testing loss: 0.07125501230857365  
Testing accuracy: 0.9778  
Epoch 91

-----  
Training loss: 0.011476010885089635  
Training accuracy: 0.9991166666666667  
Testing loss: 0.0695785690012987  
Testing accuracy: 0.9783  
Epoch 92

-----  
Training loss: 0.0112040687824289  
Training accuracy: 0.9992666666666666  
Testing loss: 0.07012675439932971  
Testing accuracy: 0.9774  
Epoch 93

-----  
Training loss: 0.011040718500937024  
Training accuracy: 0.9992166666666666  
Testing loss: 0.06893600209706588  
Testing accuracy: 0.9779

Epoch 94

-----  
Training loss: 0.010813711636513472  
Training accuracy: 0.9992833333333333  
Testing loss: 0.07048800653462138  
Testing accuracy: 0.9773  
Epoch 95

-----  
Training loss: 0.010593337108939886  
Training accuracy: 0.9993  
Testing loss: 0.06900906784290886  
Testing accuracy: 0.9785  
Epoch 96

-----  
Training loss: 0.010478690005963047  
Training accuracy: 0.9994666666666666  
Testing loss: 0.07104739601053535  
Testing accuracy: 0.9783  
Epoch 97

-----  
Training loss: 0.010253140546008944  
Training accuracy: 0.9993833333333333  
Testing loss: 0.06869717471443923  
Testing accuracy: 0.9789  
Epoch 98

-----  
Training loss: 0.010103578436002136  
Training accuracy: 0.9995166666666667  
Testing loss: 0.07026958312827405  
Testing accuracy: 0.9785  
Epoch 99

-----  
Training loss: 0.009970391543333729  
Training accuracy: 0.9994666666666666  
Testing loss: 0.07013732269050399  
Testing accuracy: 0.9786  
Epoch 100

-----  
Training loss: 0.009760910403790573  
Training accuracy: 0.9994333333333333  
Testing loss: 0.06954525340464156  
Testing accuracy: 0.9783  
Epoch 101

-----  
Training loss: 0.009578232794255018  
Training accuracy: 0.9995833333333334  
Testing loss: 0.0696278307156839  
Testing accuracy: 0.979

```

Epoch 102
-----
Training loss: 0.009384585250231127
Training accuracy: 0.9994666666666666
Testing loss: 0.0699971006014592
Testing accuracy: 0.9781
Epoch 103
-----
Training loss: 0.009223992248997092
Training accuracy: 0.9996
Testing loss: 0.07067755187402262
Testing accuracy: 0.9782
Epoch 104
-----
Training loss: 0.00911659574881196
Training accuracy: 0.9995333333333334
Testing loss: 0.07007397873998934
Testing accuracy: 0.9783
Epoch 105
-----
Training loss: 0.008927542265752951
Training accuracy: 0.9994833333333333
Testing loss: 0.07201112068783207
Testing accuracy: 0.977
Epoch 106
-----
Training loss: 0.008769504489998022
Training accuracy: 0.9996666666666667
Testing loss: 0.07052863588716811
Testing accuracy: 0.9789
Epoch 107
-----
Training loss: 0.008660392072796822
Training accuracy: 0.9995833333333334
Testing loss: 0.07111143386940573
Testing accuracy: 0.978
Epoch 108
-----
Training loss: 0.008524384977854788
Training accuracy: 0.9995833333333334
Testing loss: 0.06964733072254024
Testing accuracy: 0.9782
Epoch 109
-----
Training loss: 0.008387267971597612
Training accuracy: 0.9996833333333334
Testing loss: 0.06997644660955853
Testing accuracy: 0.9792

```

```

Epoch 110
-----
Training loss: 0.0082765281703944
Training accuracy: 0.9997
Testing loss: 0.06977354667659635
Testing accuracy: 0.9784
Epoch 111
-----
Training loss: 0.008083740041032433
Training accuracy: 0.99965
Testing loss: 0.07072616255231154
Testing accuracy: 0.9787
Epoch 112
-----
Training loss: 0.008021164187292257
Training accuracy: 0.9996
Testing loss: 0.0709026340539063
Testing accuracy: 0.9783
Epoch 113
-----
Training loss: 0.007922016961500048
Training accuracy: 0.9996833333333334
Testing loss: 0.07070624644743503
Testing accuracy: 0.9781
Epoch 114
-----
Training loss: 0.007755282561046382
Training accuracy: 0.9997166666666667
Testing loss: 0.0713885058263305
Testing accuracy: 0.978
Epoch 115
-----
Training loss: 0.007671378144497673
Training accuracy: 0.9998
Testing loss: 0.07075711079149442
Testing accuracy: 0.9786
Epoch 116
-----
Training loss: 0.007523581637628377
Training accuracy: 0.99975
Testing loss: 0.07050679365445854
Testing accuracy: 0.9787
Epoch 117
-----
Training loss: 0.007420406123126546
Training accuracy: 0.9997833333333334
Testing loss: 0.07102111613030908
Testing accuracy: 0.9787

```

Epoch 118

-----  
Training loss: 0.00729600171217074  
Training accuracy: 0.9997833333333334  
Testing loss: 0.07024849193418327  
Testing accuracy: 0.9782  
Epoch 119

-----  
Training loss: 0.007272973755126198  
Training accuracy: 0.9997333333333334  
Testing loss: 0.07100545756584092  
Testing accuracy: 0.9787  
Epoch 120

-----  
Training loss: 0.007109032184506456  
Training accuracy: 0.9997333333333334  
Testing loss: 0.07136469958020096  
Testing accuracy: 0.9788  
Epoch 121

-----  
Training loss: 0.006995657336463531  
Training accuracy: 0.99975  
Testing loss: 0.0719680789751327  
Testing accuracy: 0.9779  
Epoch 122

-----  
Training loss: 0.00694011008789142  
Training accuracy: 0.99985  
Testing loss: 0.07186261094234599  
Testing accuracy: 0.978  
Epoch 123

-----  
Training loss: 0.006820521535289784  
Training accuracy: 0.99985  
Testing loss: 0.07162014755367  
Testing accuracy: 0.9784  
Epoch 124

-----  
Training loss: 0.0067141029134392734  
Training accuracy: 0.9998333333333334  
Testing loss: 0.06961750296377547  
Testing accuracy: 0.9786  
Epoch 125

-----  
Training loss: 0.0066062401067465545  
Training accuracy: 0.99985  
Testing loss: 0.0707587892648239  
Testing accuracy: 0.9787

Epoch 126

-----  
Training loss: 0.006592560765985399  
Training accuracy: 0.9998  
Testing loss: 0.07086762090830524  
Testing accuracy: 0.9789  
Epoch 127

-----  
Training loss: 0.006461424162859718  
Training accuracy: 0.9998666666666667  
Testing loss: 0.07032578787321497  
Testing accuracy: 0.9785  
Epoch 128

-----  
Training loss: 0.006357644504184524  
Training accuracy: 0.99985  
Testing loss: 0.0705882140092706  
Testing accuracy: 0.9782  
Epoch 129

-----  
Training loss: 0.006275771504330139  
Training accuracy: 0.9998333333333334  
Testing loss: 0.07143081718711716  
Testing accuracy: 0.9787  
Epoch 130

-----  
Training loss: 0.0061663444755909345  
Training accuracy: 0.9999166666666667  
Testing loss: 0.07335884188921754  
Testing accuracy: 0.9788  
Epoch 131

-----  
Training loss: 0.00611242791833356  
Training accuracy: 0.9998833333333333  
Testing loss: 0.07196681888493751  
Testing accuracy: 0.9784  
Epoch 132

-----  
Training loss: 0.006063170499106248  
Training accuracy: 0.9998166666666667  
Testing loss: 0.07131683373687327  
Testing accuracy: 0.9785  
Epoch 133

-----  
Training loss: 0.005981755514194568  
Training accuracy: 0.99985  
Testing loss: 0.07097447527628867  
Testing accuracy: 0.9785

Epoch 134

-----  
Training loss: 0.005872012414100269  
Training accuracy: 0.9999  
Testing loss: 0.07187847006297819  
Testing accuracy: 0.9789  
Epoch 135

-----  
Training loss: 0.005779711404318611  
Training accuracy: 0.9999333333333333  
Testing loss: 0.07102199931329436  
Testing accuracy: 0.9788  
Epoch 136

-----  
Training loss: 0.0057462278053164485  
Training accuracy: 0.9999166666666667  
Testing loss: 0.07088746221374222  
Testing accuracy: 0.9789  
Epoch 137

-----  
Training loss: 0.0056932310117408635  
Training accuracy: 0.9998833333333333  
Testing loss: 0.07111810744668885  
Testing accuracy: 0.9783  
Epoch 138

-----  
Training loss: 0.00558333683591336  
Training accuracy: 0.9999166666666667  
Testing loss: 0.07147144534399698  
Testing accuracy: 0.9788  
Epoch 139

-----  
Training loss: 0.0055607405841040115  
Training accuracy: 0.9999  
Testing loss: 0.07351801619096808  
Testing accuracy: 0.9789  
Epoch 140

-----  
Training loss: 0.005460160657266776  
Training accuracy: 0.9999  
Testing loss: 0.07251084171336405  
Testing accuracy: 0.9779  
Epoch 141

-----  
Training loss: 0.005430121879310658  
Training accuracy: 0.9999166666666667  
Testing loss: 0.0721590933864521  
Testing accuracy: 0.9789

Epoch 142

-----  
Training loss: 0.005368005811050534

Training accuracy: 0.99995

Testing loss: 0.07184624481852801

Testing accuracy: 0.9786

Epoch 143

-----  
Training loss: 0.0052898148921628795

Training accuracy: 0.9999166666666667

Testing loss: 0.07239202052580228

Testing accuracy: 0.9783

Epoch 144

-----  
Training loss: 0.0052218262430280445

Training accuracy: 0.99995

Testing loss: 0.07234039850188953

Testing accuracy: 0.9782

Epoch 145

-----  
Training loss: 0.005169558666211864

Training accuracy: 0.9999166666666667

Testing loss: 0.07168586572237716

Testing accuracy: 0.9789

Epoch 146

-----  
Training loss: 0.005110908136082192

Training accuracy: 0.9999333333333333

Testing loss: 0.07252142007483442

Testing accuracy: 0.9783

Epoch 147

-----  
Training loss: 0.00505019114324823

Training accuracy: 0.9999666666666667

Testing loss: 0.07267697652502306

Testing accuracy: 0.9789

Epoch 148

-----  
Training loss: 0.00500572161624829

Training accuracy: 0.99995

Testing loss: 0.07158106663483077

Testing accuracy: 0.9782

Epoch 149

-----  
Training loss: 0.004945086924203982

Training accuracy: 0.9999666666666667

Testing loss: 0.07252243770416944

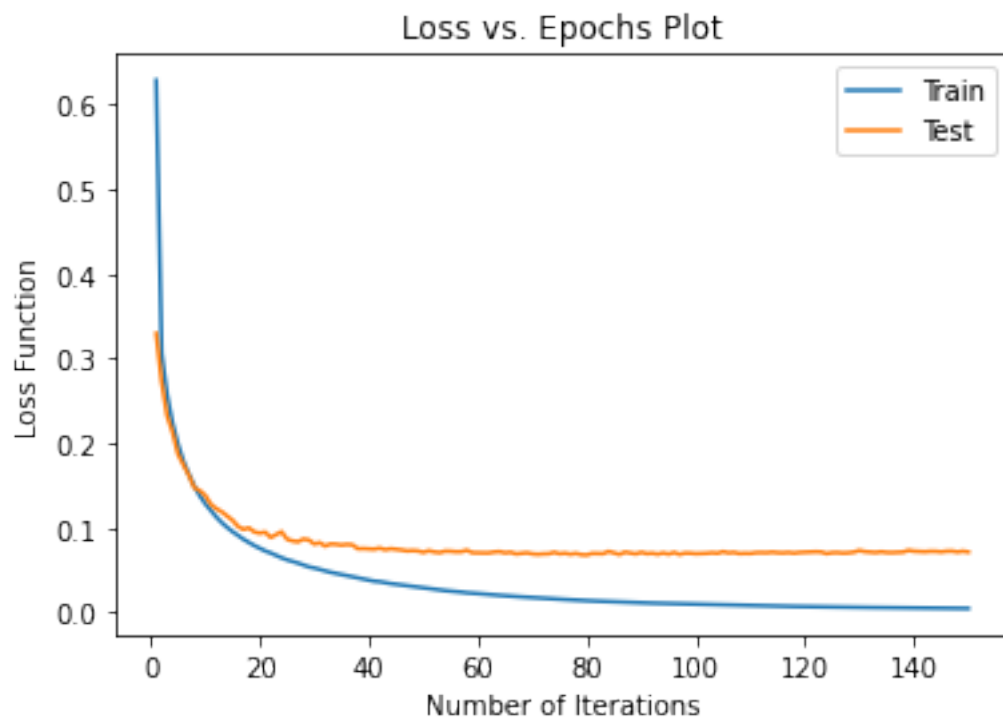
Testing accuracy: 0.9789



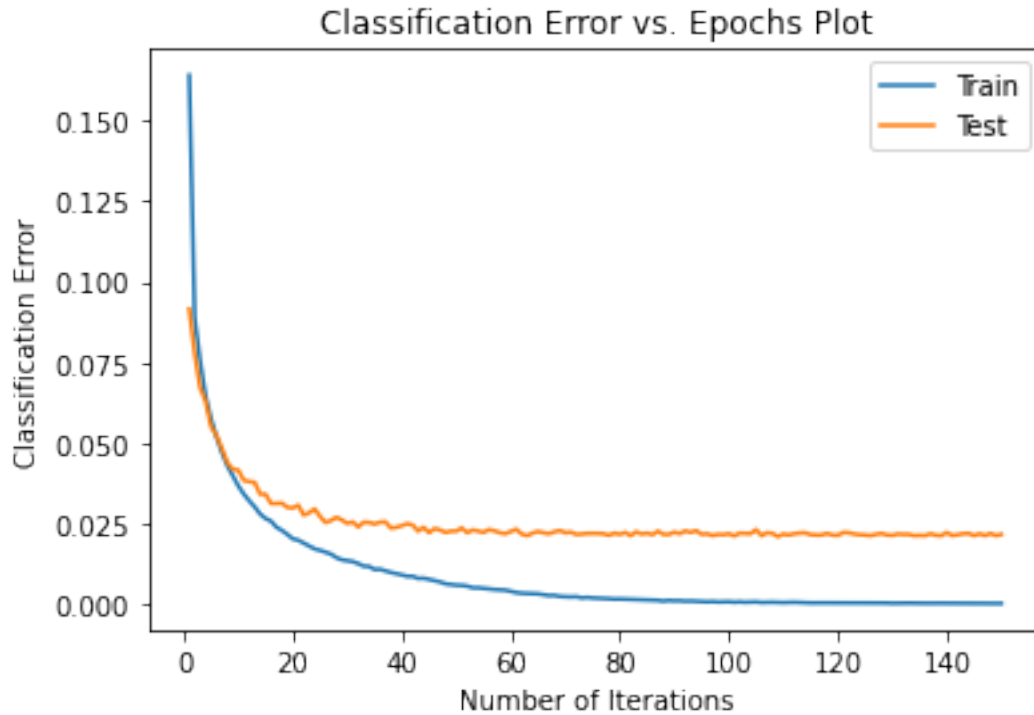
Epoch 150

-----  
Training loss: 0.004887553844818224  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0715633766394951  
Testing accuracy: 0.9785  
Done  
Total Time Consumed: 1583.0511856079102

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.1.3 Seed 3

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
model3 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model3.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(3)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model3,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model3,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.6275367340485255
Training accuracy: 0.8404666666666667
Testing loss: 0.31873518200057327
Testing accuracy: 0.9077

```

Epoch 2

```

-----
Training loss: 0.30368664303620657
Training accuracy: 0.9121166666666667
Testing loss: 0.2614467456747013
Testing accuracy: 0.925

```

Epoch 3

```

-----
Training loss: 0.2540707253257434
Training accuracy: 0.92645
Testing loss: 0.2231266686728426
Testing accuracy: 0.9374

```

Epoch 4

```

-----
Training loss: 0.2208526145418485
Training accuracy: 0.9356666666666666
Testing loss: 0.204401060369364
Testing accuracy: 0.9401

```

Epoch 5

```

-----
Training loss: 0.1954198545495669
Training accuracy: 0.94395
Testing loss: 0.18842660322500643
Testing accuracy: 0.9439

```

Epoch 6

```

-----
Training loss: 0.1762587542394797
Training accuracy: 0.9491166666666667
Testing loss: 0.17103185219939349

```

```

Testing accuracy: 0.9509
Epoch 7
-----
Training loss: 0.16024779278635978
Training accuracy: 0.9545333333333333
Testing loss: 0.15526719262028577
Testing accuracy: 0.9528
Epoch 8
-----
Training loss: 0.14727833667198817
Training accuracy: 0.95755
Testing loss: 0.15157935191776342
Testing accuracy: 0.9555
Epoch 9
-----
Training loss: 0.13643245441913604
Training accuracy: 0.9606
Testing loss: 0.14144150390746488
Testing accuracy: 0.9584
Epoch 10
-----
Training loss: 0.12682265507976215
Training accuracy: 0.9640666666666666
Testing loss: 0.12876840706938392
Testing accuracy: 0.9619
Epoch 11
-----
Training loss: 0.11896932044525942
Training accuracy: 0.9662833333333334
Testing loss: 0.12277976463839507
Testing accuracy: 0.9638
Epoch 12
-----
Training loss: 0.111782214007775
Training accuracy: 0.96855
Testing loss: 0.12480809252448143
Testing accuracy: 0.9629
Epoch 13
-----
Training loss: 0.10530120868484179
Training accuracy: 0.9706
Testing loss: 0.11190139779904086
Testing accuracy: 0.9657
Epoch 14
-----
Training loss: 0.09978745585530996
Training accuracy: 0.9719
Testing loss: 0.10828061266594631

```

```

Testing accuracy: 0.9674
Epoch 15
-----
Training loss: 0.0942854739189148
Training accuracy: 0.9740166666666666
Testing loss: 0.11031654398817166
Testing accuracy: 0.967
Epoch 16
-----
Training loss: 0.08993456039925417
Training accuracy: 0.9752
Testing loss: 0.10257775677000261
Testing accuracy: 0.9687
Epoch 17
-----
Training loss: 0.08593676565786203
Training accuracy: 0.9764833333333334
Testing loss: 0.1028845489060708
Testing accuracy: 0.9695
Epoch 18
-----
Training loss: 0.08185095246930917
Training accuracy: 0.9770166666666666
Testing loss: 0.09746892605522636
Testing accuracy: 0.9704
Epoch 19
-----
Training loss: 0.0782573554644982
Training accuracy: 0.97895
Testing loss: 0.09587781016186923
Testing accuracy: 0.9717
Epoch 20
-----
Training loss: 0.07462226511836052
Training accuracy: 0.9794166666666667
Testing loss: 0.09456036916109407
Testing accuracy: 0.971
Epoch 21
-----
Training loss: 0.07181349197725455
Training accuracy: 0.9811166666666666
Testing loss: 0.09049826426206121
Testing accuracy: 0.9728
Epoch 22
-----
Training loss: 0.06899559718767802
Training accuracy: 0.9814333333333334
Testing loss: 0.08829601351053092

```

```

Testing accuracy: 0.9728
Epoch 23
-----
Training loss: 0.06617770145237446
Training accuracy: 0.9823333333333333
Testing loss: 0.09049276499208181
Testing accuracy: 0.9719
Epoch 24
-----
Training loss: 0.06371375483771165
Training accuracy: 0.9831666666666666
Testing loss: 0.08881322258288503
Testing accuracy: 0.9722
Epoch 25
-----
Training loss: 0.061650203086932504
Training accuracy: 0.9836833333333334
Testing loss: 0.08633669272397354
Testing accuracy: 0.9728
Epoch 26
-----
Training loss: 0.05918489856322606
Training accuracy: 0.9847166666666667
Testing loss: 0.0829430540406685
Testing accuracy: 0.9734
Epoch 27
-----
Training loss: 0.05714081796556711
Training accuracy: 0.9845666666666667
Testing loss: 0.0821008131762219
Testing accuracy: 0.9739
Epoch 28
-----
Training loss: 0.055021160699923834
Training accuracy: 0.9855666666666667
Testing loss: 0.08799857798679049
Testing accuracy: 0.9726
Epoch 29
-----
Training loss: 0.053074295047918954
Training accuracy: 0.9862
Testing loss: 0.08135027376116272
Testing accuracy: 0.9742
Epoch 30
-----
Training loss: 0.051417985042432945
Training accuracy: 0.9864666666666667
Testing loss: 0.08137461055473537

```

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Testing accuracy: 0.9746
Epoch 31
-----
Training loss: 0.0500180477514863
Training accuracy: 0.9871833333333333
Testing loss: 0.07933720949574545
Testing accuracy: 0.9744
Epoch 32
-----
Training loss: 0.04809190270503362
Training accuracy: 0.9876166666666667
Testing loss: 0.08111001569540448
Testing accuracy: 0.9742
Epoch 33
-----
Training loss: 0.04683415345698595
Training accuracy: 0.9880666666666666
Testing loss: 0.07708574568105352
Testing accuracy: 0.9748
Epoch 34
-----
Training loss: 0.045315490853538115
Training accuracy: 0.98885
Testing loss: 0.07858992262986625
Testing accuracy: 0.975
Epoch 35
-----
Training loss: 0.04388830802738666
Training accuracy: 0.9890833333333333
Testing loss: 0.0762163401510163
Testing accuracy: 0.9761
Epoch 36
-----
Training loss: 0.04274295291999976
Training accuracy: 0.9892833333333333
Testing loss: 0.07765708707130639
Testing accuracy: 0.9749
Epoch 37
-----
Training loss: 0.041252287851274015
Training accuracy: 0.9900833333333333
Testing loss: 0.07511397900214051
Testing accuracy: 0.9767
Epoch 38
-----
Training loss: 0.03989140367756287
Training accuracy: 0.9904666666666667
Testing loss: 0.07551812710370986

```

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Testing accuracy: 0.9752
Epoch 39
-----
Training loss: 0.038684180541833244
Training accuracy: 0.9910666666666667
Testing loss: 0.0756313175876524
Testing accuracy: 0.976
Epoch 40
-----
Training loss: 0.03771085589875778
Training accuracy: 0.9912666666666666
Testing loss: 0.07279714041947132
Testing accuracy: 0.9764
Epoch 41
-----
Training loss: 0.036520105231553315
Training accuracy: 0.9914833333333334
Testing loss: 0.07148532516317098
Testing accuracy: 0.9763
Epoch 42
-----
Training loss: 0.03560646816889445
Training accuracy: 0.9920666666666667
Testing loss: 0.07274069497954978
Testing accuracy: 0.9761
Epoch 43
-----
Training loss: 0.0346537276558578
Training accuracy: 0.9923
Testing loss: 0.07603640376833404
Testing accuracy: 0.9767
Epoch 44
-----
Training loss: 0.0337782984038194
Training accuracy: 0.9927
Testing loss: 0.07046213663022989
Testing accuracy: 0.9754
Epoch 45
-----
Training loss: 0.03274185493861635
Training accuracy: 0.9930166666666667
Testing loss: 0.07033242194492156
Testing accuracy: 0.977
Epoch 46
-----
Training loss: 0.03157231645608942
Training accuracy: 0.99315
Testing loss: 0.06991754009560415

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Testing accuracy: 0.9767
Epoch 47
-----
Training loss: 0.030783155868699154
Training accuracy: 0.9935166666666667
Testing loss: 0.07021525538983239
Testing accuracy: 0.9762
Epoch 48
-----
Training loss: 0.029967002315819263
Training accuracy: 0.9936833333333334
Testing loss: 0.07197846718737559
Testing accuracy: 0.9784
Epoch 49
-----
Training loss: 0.029228671885778507
Training accuracy: 0.9937333333333334
Testing loss: 0.07147527931281811
Testing accuracy: 0.976
Epoch 50
-----
Training loss: 0.028367103807628156
Training accuracy: 0.9942333333333333
Testing loss: 0.06936667567700337
Testing accuracy: 0.978
Epoch 51
-----
Training loss: 0.027772560347865027
Training accuracy: 0.9942333333333333
Testing loss: 0.06922125358098916
Testing accuracy: 0.977
Epoch 52
-----
Training loss: 0.027065002104143303
Training accuracy: 0.99445
Testing loss: 0.07129421511036195
Testing accuracy: 0.9768
Epoch 53
-----
Training loss: 0.026505202445636193
Training accuracy: 0.9947666666666667
Testing loss: 0.06859253431747483
Testing accuracy: 0.9783
Epoch 54
-----
Training loss: 0.025677907004207374
Training accuracy: 0.9952333333333333
Testing loss: 0.0694744216565897

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Testing accuracy: 0.9771
Epoch 55
-----
Training loss: 0.024986695134888093
Training accuracy: 0.9951833333333333
Testing loss: 0.07319811033826487
Testing accuracy: 0.9766
Epoch 56
-----
Training loss: 0.024557592351486284
Training accuracy: 0.9954
Testing loss: 0.06861772104077468
Testing accuracy: 0.9781
Epoch 57
-----
Training loss: 0.023793080788354078
Training accuracy: 0.9959
Testing loss: 0.06955963837955693
Testing accuracy: 0.9778
Epoch 58
-----
Training loss: 0.023262163226306438
Training accuracy: 0.9959166666666667
Testing loss: 0.06701854997830596
Testing accuracy: 0.9776
Epoch 59
-----
Training loss: 0.022600145374486843
Training accuracy: 0.99615
Testing loss: 0.06751230588200603
Testing accuracy: 0.9768
Epoch 60
-----
Training loss: 0.022032274090250333
Training accuracy: 0.9962666666666666
Testing loss: 0.06652936049304001
Testing accuracy: 0.9789
Epoch 61
-----
Training loss: 0.021529015805820624
Training accuracy: 0.9966666666666667
Testing loss: 0.06857264060883006
Testing accuracy: 0.9776
Epoch 62
-----
Training loss: 0.021005663094917932
Training accuracy: 0.9966666666666667
Testing loss: 0.06640882580985974

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Testing accuracy: 0.9782
Epoch 63
-----
Training loss: 0.020486056916415692
Training accuracy: 0.99695
Testing loss: 0.06616809839459883
Testing accuracy: 0.9778
Epoch 64
-----
Training loss: 0.02003237365707755
Training accuracy: 0.9971833333333333
Testing loss: 0.06841970302140826
Testing accuracy: 0.9771
Epoch 65
-----
Training loss: 0.019595460744698843
Training accuracy: 0.9971
Testing loss: 0.06746176860419809
Testing accuracy: 0.9782
Epoch 66
-----
Training loss: 0.01917766130976379
Training accuracy: 0.9970333333333333
Testing loss: 0.06751955751994043
Testing accuracy: 0.9779
Epoch 67
-----
Training loss: 0.01870550022597114
Training accuracy: 0.9971666666666666
Testing loss: 0.06627464225325899
Testing accuracy: 0.9785
Epoch 68
-----
Training loss: 0.018272141293932995
Training accuracy: 0.9974166666666666
Testing loss: 0.0675431877451765
Testing accuracy: 0.9785
Epoch 69
-----
Training loss: 0.017755002839118243
Training accuracy: 0.9975333333333334
Testing loss: 0.0686662708806574
Testing accuracy: 0.9788
Epoch 70
-----
Training loss: 0.017502071712786952
Training accuracy: 0.99775
Testing loss: 0.06649005213888824

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Testing accuracy: 0.9777
Epoch 71
-----
Training loss: 0.01693582007996738
Training accuracy: 0.9977833333333334
Testing loss: 0.0677060250631848
Testing accuracy: 0.9781
Epoch 72
-----
Training loss: 0.01662129197580119
Training accuracy: 0.99785
Testing loss: 0.06691841514051483
Testing accuracy: 0.9773
Epoch 73
-----
Training loss: 0.016287422442560394
Training accuracy: 0.9979333333333333
Testing loss: 0.06621149028532776
Testing accuracy: 0.9776
Epoch 74
-----
Training loss: 0.015871902196854352
Training accuracy: 0.998
Testing loss: 0.06590152313564993
Testing accuracy: 0.9783
Epoch 75
-----
Training loss: 0.015530831128855546
Training accuracy: 0.9982166666666666
Testing loss: 0.06939897883926655
Testing accuracy: 0.9768
Epoch 76
-----
Training loss: 0.01511548680315415
Training accuracy: 0.9984
Testing loss: 0.06662002095217064
Testing accuracy: 0.979
Epoch 77
-----
Training loss: 0.014855145304650067
Training accuracy: 0.9984333333333333
Testing loss: 0.06674515939344337
Testing accuracy: 0.979
Epoch 78
-----
Training loss: 0.014582004954417546
Training accuracy: 0.9984666666666666
Testing loss: 0.06699846020698025

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```
Testing accuracy: 0.9782
Epoch 79
-----
Training loss: 0.014217464092125496
Training accuracy: 0.9986
Testing loss: 0.06632972238911612
Testing accuracy: 0.9789
Epoch 80
-----
Training loss: 0.013916923571377993
Training accuracy: 0.99855
Testing loss: 0.06754430240186252
Testing accuracy: 0.979
Epoch 81
-----
Training loss: 0.013715354813635349
Training accuracy: 0.9986
Testing loss: 0.06578824387723876
Testing accuracy: 0.9783
Epoch 82
-----
Training loss: 0.013348185764749845
Training accuracy: 0.9987333333333334
Testing loss: 0.06570784154994662
Testing accuracy: 0.978
Epoch 83
-----
Training loss: 0.013251747742543618
Training accuracy: 0.9986166666666667
Testing loss: 0.06754478927224186
Testing accuracy: 0.9777
Epoch 84
-----
Training loss: 0.012856205236290892
Training accuracy: 0.9988333333333334
Testing loss: 0.06647440274750256
Testing accuracy: 0.978
Epoch 85
-----
Training loss: 0.012611471964232623
Training accuracy: 0.9989333333333333
Testing loss: 0.06681760451548797
Testing accuracy: 0.978
Epoch 86
-----
Training loss: 0.012359419260919094
Training accuracy: 0.99895
Testing loss: 0.0694794254585104
```

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Testing accuracy: 0.9789
Epoch 87
-----
Training loss: 0.012097188882529735
Training accuracy: 0.9990666666666667
Testing loss: 0.06667187927397573
Testing accuracy: 0.9785
Epoch 88
-----
Training loss: 0.011903317673380176
Training accuracy: 0.9990333333333333
Testing loss: 0.06657945225756781
Testing accuracy: 0.9783
Epoch 89
-----
Training loss: 0.011649147492647172
Training accuracy: 0.9990666666666667
Testing loss: 0.06636008166464841
Testing accuracy: 0.9781
Epoch 90
-----
Training loss: 0.011456425436834495
Training accuracy: 0.9988666666666667
Testing loss: 0.06785292562562972
Testing accuracy: 0.978
Epoch 91
-----
Training loss: 0.011192469649513563
Training accuracy: 0.99915
Testing loss: 0.06747207960045665
Testing accuracy: 0.9788
Epoch 92
-----
Training loss: 0.011044802893636128
Training accuracy: 0.99915
Testing loss: 0.06744671996481194
Testing accuracy: 0.9779
Epoch 93
-----
Training loss: 0.010840485639994343
Training accuracy: 0.9992166666666666
Testing loss: 0.0671683938278087
Testing accuracy: 0.9784
Epoch 94
-----
Training loss: 0.010596184030920268
Training accuracy: 0.99915
Testing loss: 0.06669250408214944

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```
Testing accuracy: 0.9781
Epoch 95
-----
Training loss: 0.010374406091372171
Training accuracy: 0.9992
Testing loss: 0.06597629513081377
Testing accuracy: 0.9789
Epoch 96
-----
Training loss: 0.010247700773303708
Training accuracy: 0.9992666666666666
Testing loss: 0.06655277322034595
Testing accuracy: 0.9781
Epoch 97
-----
Training loss: 0.01007267892671128
Training accuracy: 0.9993
Testing loss: 0.0665968900329914
Testing accuracy: 0.9781
Epoch 98
-----
Training loss: 0.009933370936041077
Training accuracy: 0.9993666666666666
Testing loss: 0.06751111731864512
Testing accuracy: 0.9782
Epoch 99
-----
Training loss: 0.00967129841732482
Training accuracy: 0.9993833333333333
Testing loss: 0.06700614463852327
Testing accuracy: 0.9786
Epoch 100
-----
Training loss: 0.009528387374182542
Training accuracy: 0.9994333333333333
Testing loss: 0.06684006905408611
Testing accuracy: 0.9793
Epoch 101
-----
Training loss: 0.009376796913395326
Training accuracy: 0.9994
Testing loss: 0.06945426193226105
Testing accuracy: 0.978
Epoch 102
-----
Training loss: 0.009236561176305016
Training accuracy: 0.9994833333333333
Testing loss: 0.06707561321135397
```

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Testing accuracy: 0.9788
Epoch 103
-----
Training loss: 0.009069289871926109
Training accuracy: 0.9995
Testing loss: 0.0676279718814133
Testing accuracy: 0.9781
Epoch 104
-----
Training loss: 0.008924622145698717
Training accuracy: 0.99945
Testing loss: 0.06651282234408057
Testing accuracy: 0.9787
Epoch 105
-----
Training loss: 0.008813553256976107
Training accuracy: 0.9994833333333333
Testing loss: 0.06701735362327498
Testing accuracy: 0.9793
Epoch 106
-----
Training loss: 0.00854187720970561
Training accuracy: 0.9995166666666667
Testing loss: 0.06769475280781792
Testing accuracy: 0.9789
Epoch 107
-----
Training loss: 0.008538797637075185
Training accuracy: 0.99955
Testing loss: 0.06625818465591651
Testing accuracy: 0.9794
Epoch 108
-----
Training loss: 0.008361506115769347
Training accuracy: 0.9995166666666667
Testing loss: 0.0676391025994768
Testing accuracy: 0.978
Epoch 109
-----
Training loss: 0.008178581606410443
Training accuracy: 0.9995666666666667
Testing loss: 0.06737047252779127
Testing accuracy: 0.9783
Epoch 110
-----
Training loss: 0.008089277276955544
Training accuracy: 0.9996666666666667
Testing loss: 0.06677327303892108
```



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Testing accuracy: 0.9791
Epoch 111
-----
Training loss: 0.00793936174294601
Training accuracy: 0.99965
Testing loss: 0.06724988101317197
Testing accuracy: 0.979
Epoch 112
-----
Training loss: 0.007860090633419652
Training accuracy: 0.99965
Testing loss: 0.06735580720031148
Testing accuracy: 0.979
Epoch 113
-----
Training loss: 0.007709181570882599
Training accuracy: 0.9996833333333334
Testing loss: 0.06751475322014314
Testing accuracy: 0.979
Epoch 114
-----
Training loss: 0.0076142088405167065
Training accuracy: 0.9997
Testing loss: 0.06781869550134725
Testing accuracy: 0.9781
Epoch 115
-----
Training loss: 0.0074949473613873125
Training accuracy: 0.99965
Testing loss: 0.06650980046185054
Testing accuracy: 0.979
Epoch 116
-----
Training loss: 0.00734987333783259
Training accuracy: 0.9997333333333334
Testing loss: 0.06998736013074043
Testing accuracy: 0.9785
Epoch 117
-----
Training loss: 0.007301950066412489
Training accuracy: 0.9996333333333334
Testing loss: 0.06825412074430211
Testing accuracy: 0.9784
Epoch 118
-----
Training loss: 0.007159646451380104
Training accuracy: 0.9998
Testing loss: 0.06664840326715664
```

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Testing accuracy: 0.9789
Epoch 119
-----
Training loss: 0.007055519710419078
Training accuracy: 0.9997166666666667
Testing loss: 0.06735013192148796
Testing accuracy: 0.9791
Epoch 120
-----
Training loss: 0.006950564776360989
Training accuracy: 0.9998
Testing loss: 0.06753005824425513
Testing accuracy: 0.9788
Epoch 121
-----
Training loss: 0.006867542178618412
Training accuracy: 0.99985
Testing loss: 0.06818180617184533
Testing accuracy: 0.9786
Epoch 122
-----
Training loss: 0.006795811935731521
Training accuracy: 0.9998333333333334
Testing loss: 0.06960368013101374
Testing accuracy: 0.9792
Epoch 123
-----
Training loss: 0.006659980156024297
Training accuracy: 0.9998333333333334
Testing loss: 0.06817641198430448
Testing accuracy: 0.9793
Epoch 124
-----
Training loss: 0.006580986308554808
Training accuracy: 0.99985
Testing loss: 0.06826619884654714
Testing accuracy: 0.9793
Epoch 125
-----
Training loss: 0.0065149835935483374
Training accuracy: 0.9999166666666667
Testing loss: 0.06779137904500696
Testing accuracy: 0.979
Epoch 126
-----
Training loss: 0.006404385839216411
Training accuracy: 0.9999
Testing loss: 0.06888246305759961

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Testing accuracy: 0.9789
Epoch 127
-----
Training loss: 0.006327177657373249
Training accuracy: 0.9998833333333333
Testing loss: 0.06995875779042543
Testing accuracy: 0.9795
Epoch 128
-----
Training loss: 0.006237672612071038
Training accuracy: 0.99995
Testing loss: 0.06906669827142528
Testing accuracy: 0.9785
Epoch 129
-----
Training loss: 0.006147448801901191
Training accuracy: 0.9999166666666667
Testing loss: 0.06845886952682713
Testing accuracy: 0.9789
Epoch 130
-----
Training loss: 0.006078996459394693
Training accuracy: 0.99995
Testing loss: 0.0674116819233865
Testing accuracy: 0.9788
Epoch 131
-----
Training loss: 0.00601456071815143
Training accuracy: 0.9999333333333333
Testing loss: 0.06786266459110578
Testing accuracy: 0.9788
Epoch 132
-----
Training loss: 0.005952075289065639
Training accuracy: 0.9998333333333334
Testing loss: 0.06893391151998524
Testing accuracy: 0.9787
Epoch 133
-----
Training loss: 0.005870421701855958
Training accuracy: 0.9998833333333333
Testing loss: 0.068902883476987
Testing accuracy: 0.9802
Epoch 134
-----
Training loss: 0.005811825119083127
Training accuracy: 0.9999333333333333
Testing loss: 0.07070456557887884

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Testing accuracy: 0.9787  
Epoch 135  
-----  
Training loss: 0.005715199885951976  
Training accuracy: 0.99995  
Testing loss: 0.06889299565116477  
Testing accuracy: 0.9791  
Epoch 136  
-----  
Training loss: 0.005638244329889615  
Training accuracy: 0.99995  
Testing loss: 0.06971421299700975  
Testing accuracy: 0.9784  
Epoch 137  
-----  
Training loss: 0.005583656463089089  
Training accuracy: 0.9999333333333333  
Testing loss: 0.06893057013108472  
Testing accuracy: 0.9791  
Epoch 138  
-----  
Training loss: 0.005547916591291626  
Training accuracy: 0.99995  
Testing loss: 0.07058654595937604  
Testing accuracy: 0.9789  
Epoch 139  
-----  
Training loss: 0.005441675257589668  
Training accuracy: 0.99995  
Testing loss: 0.06872336668849205  
Testing accuracy: 0.9789  
Epoch 140  
-----  
Training loss: 0.005412201634856562  
Training accuracy: 0.99995  
Testing loss: 0.06866823321810454  
Testing accuracy: 0.9793  
Epoch 141  
-----  
Training loss: 0.005327314309310168  
Training accuracy: 0.99995  
Testing loss: 0.06902343671562025  
Testing accuracy: 0.979  
Epoch 142  
-----  
Training loss: 0.005277665450113515  
Training accuracy: 0.9999666666666667  
Testing loss: 0.06983448583988627

```

Testing accuracy: 0.979
Epoch 143
-----
Training loss: 0.0052222829175802565
Training accuracy: 0.9999833333333333
Testing loss: 0.06918390046369143
Testing accuracy: 0.9789
Epoch 144
-----
Training loss: 0.005142253423544268
Training accuracy: 0.9999666666666667
Testing loss: 0.06914388178069156
Testing accuracy: 0.9788
Epoch 145
-----
Training loss: 0.005090569619213541
Training accuracy: 0.9999666666666667
Testing loss: 0.06927117773044
Testing accuracy: 0.9789
Epoch 146
-----
Training loss: 0.00504945669186612
Training accuracy: 0.9999833333333333
Testing loss: 0.06947986802155194
Testing accuracy: 0.9787
Epoch 147
-----
Training loss: 0.005008308436193814
Training accuracy: 1.0
Testing loss: 0.06928543610406364
Testing accuracy: 0.9793
Epoch 148
-----
Training loss: 0.00492951550980409
Training accuracy: 0.9999833333333333
Testing loss: 0.06930064155562976
Testing accuracy: 0.9787
Epoch 149
-----
Training loss: 0.0048876281769325335
Training accuracy: 0.9999833333333333
Testing loss: 0.07004771341723953
Testing accuracy: 0.9792
Epoch 150
-----
Training loss: 0.004834089356164138
Training accuracy: 0.9999666666666667
Testing loss: 0.0691032542188646

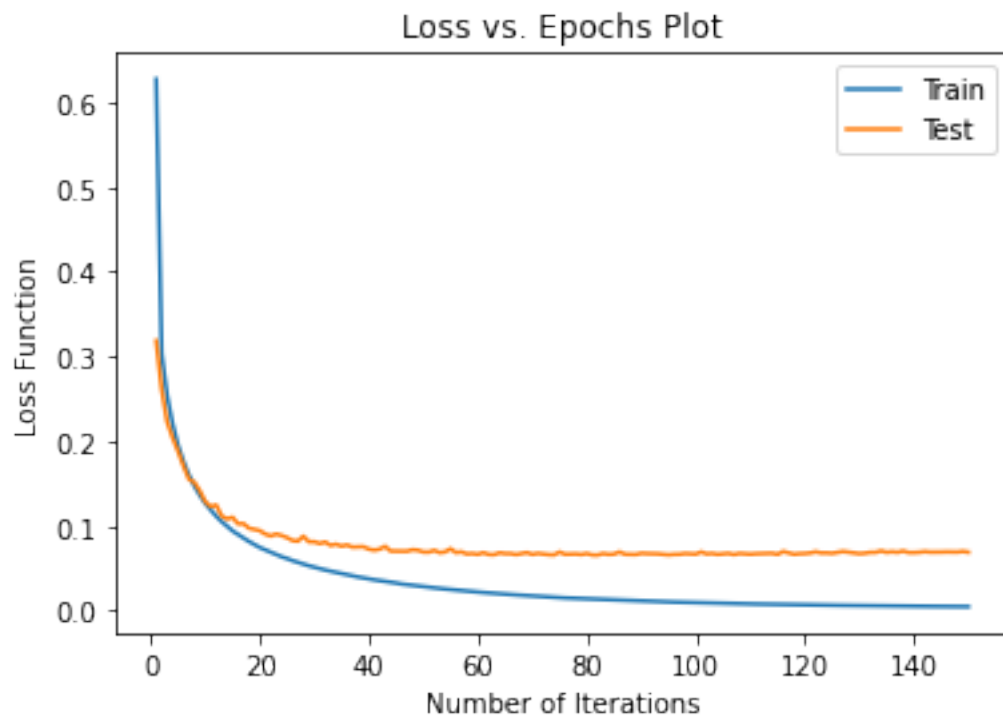
```

Testing accuracy: 0.9791

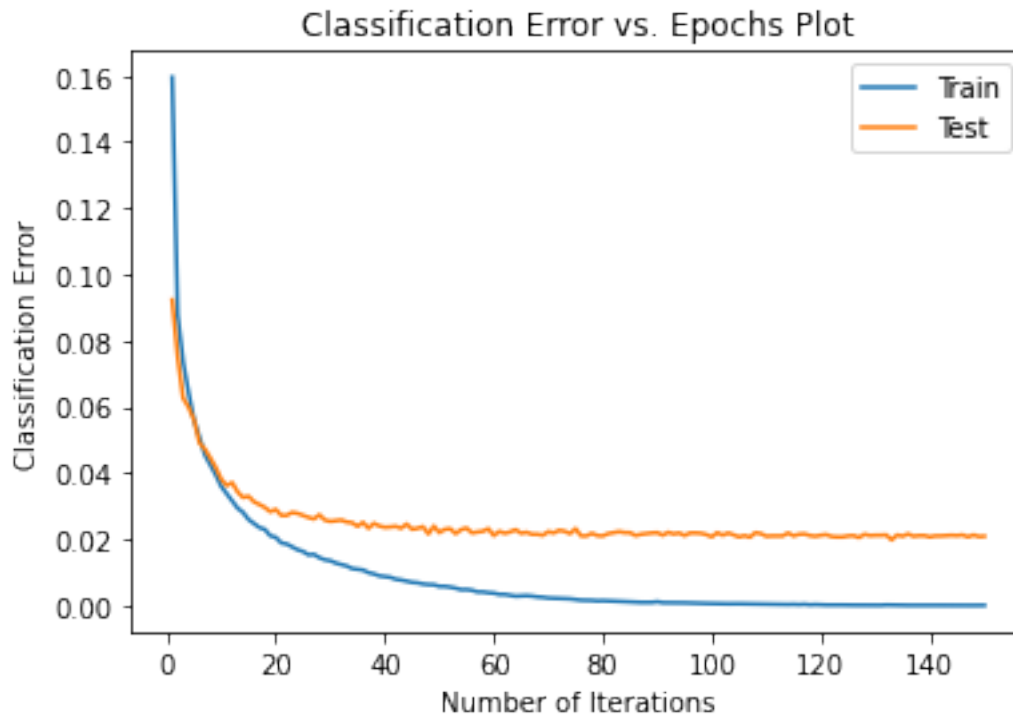
Done

Total Time Consumed: 2515.852424144745

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



#### 5.1.4 Seed 4

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
model4 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model4.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(4)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model4,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model4,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.6387938571135203
Training accuracy: 0.8376833333333333
Testing loss: 0.327108277257081
Testing accuracy: 0.9088

```

Epoch 2

```

-----
Training loss: 0.3063377214113871
Training accuracy: 0.9117166666666666
Testing loss: 0.2847654082023414
Testing accuracy: 0.919

```

Epoch 3

```

-----
Training loss: 0.2570360112428665
Training accuracy: 0.9252833333333333
Testing loss: 0.24353571131730536
Testing accuracy: 0.9284

```

Epoch 4

```

-----
Training loss: 0.22377142219344776
Training accuracy: 0.9352166666666667
Testing loss: 0.20938302626370625
Testing accuracy: 0.9386

```

Epoch 5

```

-----
Training loss: 0.19823398996591568
Training accuracy: 0.9429666666666666
Testing loss: 0.1897248747242484
Testing accuracy: 0.9414

```

Epoch 6

```

-----
Training loss: 0.17865585875908535
Training accuracy: 0.9485
Testing loss: 0.17651596084047275

```



```
Testing accuracy: 0.9465
Epoch 7
-----
Training loss: 0.16306293034950892
Training accuracy: 0.95275
Testing loss: 0.15603646014336567
Testing accuracy: 0.9529
Epoch 8
-----
Training loss: 0.14983580660521983
Training accuracy: 0.9569166666666666
Testing loss: 0.14552591221442648
Testing accuracy: 0.9574
Epoch 9
-----
Training loss: 0.1385823468744755
Training accuracy: 0.9603333333333334
Testing loss: 0.14587530051209743
Testing accuracy: 0.9548
Epoch 10
-----
Training loss: 0.12960443982879322
Training accuracy: 0.9630333333333333
Testing loss: 0.1321466170536105
Testing accuracy: 0.9594
Epoch 11
-----
Training loss: 0.12089379221697648
Training accuracy: 0.9657666666666667
Testing loss: 0.13023914058639366
Testing accuracy: 0.9591
Epoch 12
-----
Training loss: 0.11314011441369852
Training accuracy: 0.96845
Testing loss: 0.1214095290845177
Testing accuracy: 0.9622
Epoch 13
-----
Training loss: 0.10675544499754906
Training accuracy: 0.9702833333333334
Testing loss: 0.11695243165513892
Testing accuracy: 0.9642
Epoch 14
-----
Training loss: 0.10091197741230329
Training accuracy: 0.9725
Testing loss: 0.11659352538312316
```

```
Testing accuracy: 0.965
Epoch 15
-----
Training loss: 0.09616475216150284
Training accuracy: 0.9738166666666667
Testing loss: 0.10676892350908297
Testing accuracy: 0.9666
Epoch 16
-----
Training loss: 0.09129153818587463
Training accuracy: 0.9749
Testing loss: 0.10748085928902884
Testing accuracy: 0.9674
Epoch 17
-----
Training loss: 0.08693076737026374
Training accuracy: 0.9764833333333334
Testing loss: 0.10508139695450189
Testing accuracy: 0.9681
Epoch 18
-----
Training loss: 0.08277206984559694
Training accuracy: 0.9773666666666667
Testing loss: 0.0991498275191351
Testing accuracy: 0.9696
Epoch 19
-----
Training loss: 0.07945136344730853
Training accuracy: 0.9784166666666667
Testing loss: 0.10627151901127806
Testing accuracy: 0.9658
Epoch 20
-----
Training loss: 0.07603040711085002
Training accuracy: 0.9794666666666667
Testing loss: 0.09516217082050765
Testing accuracy: 0.9694
Epoch 21
-----
Training loss: 0.07269285312692324
Training accuracy: 0.9805333333333334
Testing loss: 0.09479975541994261
Testing accuracy: 0.9696
Epoch 22
-----
Training loss: 0.06964338892598947
Training accuracy: 0.9813333333333333
Testing loss: 0.09296097953441985
```

```

Testing accuracy: 0.9714
Epoch 23
-----
Training loss: 0.06706315632015467
Training accuracy: 0.9820666666666666
Testing loss: 0.08946504361429222
Testing accuracy: 0.9721
Epoch 24
-----
Training loss: 0.06472140645881494
Training accuracy: 0.98255
Testing loss: 0.08566452707549568
Testing accuracy: 0.9736
Epoch 25
-----
Training loss: 0.062316141505539414
Training accuracy: 0.98355
Testing loss: 0.08887612889669123
Testing accuracy: 0.9728
Epoch 26
-----
Training loss: 0.06013067276676496
Training accuracy: 0.9841
Testing loss: 0.08562456184677827
Testing accuracy: 0.973
Epoch 27
-----
Training loss: 0.057921950818101565
Training accuracy: 0.9847333333333333
Testing loss: 0.08852957607881659
Testing accuracy: 0.9724
Epoch 28
-----
Training loss: 0.0561898629412055
Training accuracy: 0.9854
Testing loss: 0.08349381391386128
Testing accuracy: 0.9743
Epoch 29
-----
Training loss: 0.0542407548263669
Training accuracy: 0.98635
Testing loss: 0.0827769927300845
Testing accuracy: 0.974
Epoch 30
-----
Training loss: 0.0523498174354434
Training accuracy: 0.98635
Testing loss: 0.0827965239317981

```

```

Testing accuracy: 0.9739
Epoch 31
-----
Training loss: 0.05060713540017605
Training accuracy: 0.9872166666666666
Testing loss: 0.0776113259196756
Testing accuracy: 0.9752
Epoch 32
-----
Training loss: 0.04899439578950405
Training accuracy: 0.9875333333333334
Testing loss: 0.08082419792249514
Testing accuracy: 0.9749
Epoch 33
-----
Training loss: 0.04759151279677947
Training accuracy: 0.9877333333333334
Testing loss: 0.07923352640050992
Testing accuracy: 0.975
Epoch 34
-----
Training loss: 0.04595464290753007
Training accuracy: 0.98855
Testing loss: 0.07869947111459484
Testing accuracy: 0.9748
Epoch 35
-----
Training loss: 0.044538345173497994
Training accuracy: 0.9889833333333333
Testing loss: 0.07849639447429663
Testing accuracy: 0.9753
Epoch 36
-----
Training loss: 0.04327442608475685
Training accuracy: 0.98905
Testing loss: 0.07595213400615249
Testing accuracy: 0.976
Epoch 37
-----
Training loss: 0.04191240785891811
Training accuracy: 0.98995
Testing loss: 0.07643491363117269
Testing accuracy: 0.9756
Epoch 38
-----
Training loss: 0.04051578837434451
Training accuracy: 0.9900833333333333
Testing loss: 0.07362084353348584

```

Testing accuracy: 0.9765

Epoch 39

-----  
Training loss: 0.03934202415744464

Training accuracy: 0.9908166666666667

Testing loss: 0.07545256552992353

Testing accuracy: 0.976

Epoch 40

-----  
Training loss: 0.03823861260265112

Training accuracy: 0.9907333333333334

Testing loss: 0.07371382375550307

Testing accuracy: 0.9755

Epoch 41

-----  
Training loss: 0.03741489744434754

Training accuracy: 0.99115

Testing loss: 0.07624583247942245

Testing accuracy: 0.975

Epoch 42

-----  
Training loss: 0.03594739666332801

Training accuracy: 0.99165

Testing loss: 0.07637952516377447

Testing accuracy: 0.9756

Epoch 43

-----  
Training loss: 0.035109267142166695

Training accuracy: 0.99205

Testing loss: 0.0724785716664402

Testing accuracy: 0.9763

Epoch 44

-----  
Training loss: 0.03406835857157906

Training accuracy: 0.9924333333333333

Testing loss: 0.07247931821639561

Testing accuracy: 0.977

Epoch 45

-----  
Training loss: 0.03310638694812854

Training accuracy: 0.9928166666666667

Testing loss: 0.07193088451412263

Testing accuracy: 0.9761

Epoch 46

-----  
Training loss: 0.03220746281445026

Training accuracy: 0.9929833333333333

Testing loss: 0.07233452421144411

```

Testing accuracy: 0.976
Epoch 47
-----
Training loss: 0.031527012250882884
Training accuracy: 0.9930333333333333
Testing loss: 0.07203190418695853
Testing accuracy: 0.9769
Epoch 48
-----
Training loss: 0.030656536799420913
Training accuracy: 0.9936333333333334
Testing loss: 0.0761864669443031
Testing accuracy: 0.9753
Epoch 49
-----
Training loss: 0.029814277279625337
Training accuracy: 0.9937
Testing loss: 0.07194954937229016
Testing accuracy: 0.9773
Epoch 50
-----
Training loss: 0.02890449251656731
Training accuracy: 0.9944166666666666
Testing loss: 0.0732455289667579
Testing accuracy: 0.9768
Epoch 51
-----
Training loss: 0.02827758066902558
Training accuracy: 0.9944666666666667
Testing loss: 0.07005969404426825
Testing accuracy: 0.9761
Epoch 52
-----
Training loss: 0.027559853856017193
Training accuracy: 0.99455
Testing loss: 0.07524818335333543
Testing accuracy: 0.9759
Epoch 53
-----
Training loss: 0.02683462998569012
Training accuracy: 0.9949333333333333
Testing loss: 0.07196211357523871
Testing accuracy: 0.9771
Epoch 54
-----
Training loss: 0.02604257485518853
Training accuracy: 0.9950666666666667
Testing loss: 0.0775712423447733

```

```

Testing accuracy: 0.9755
Epoch 55
-----
Training loss: 0.025369165460268656
Training accuracy: 0.99525
Testing loss: 0.06988799464696081
Testing accuracy: 0.9776
Epoch 56
-----
Training loss: 0.024761614483843248
Training accuracy: 0.9955166666666667
Testing loss: 0.06973495179265263
Testing accuracy: 0.977
Epoch 57
-----
Training loss: 0.024134051693727572
Training accuracy: 0.9961166666666667
Testing loss: 0.0746461063842912
Testing accuracy: 0.9754
Epoch 58
-----
Training loss: 0.023562898881485064
Training accuracy: 0.9959333333333333
Testing loss: 0.06966043294149386
Testing accuracy: 0.9767
Epoch 59
-----
Training loss: 0.022942424326886732
Training accuracy: 0.9962
Testing loss: 0.07078670715664033
Testing accuracy: 0.9765
Epoch 60
-----
Training loss: 0.0224755755285422
Training accuracy: 0.9963833333333333
Testing loss: 0.07035526985029696
Testing accuracy: 0.9772
Epoch 61
-----
Training loss: 0.021891058028240998
Training accuracy: 0.9964666666666666
Testing loss: 0.07218907586340408
Testing accuracy: 0.9771
Epoch 62
-----
Training loss: 0.021418804906432828
Training accuracy: 0.99645
Testing loss: 0.07281563649618417

```

```
Testing accuracy: 0.9762
Epoch 63
-----
Training loss: 0.020905930050462485
Training accuracy: 0.9968833333333333
Testing loss: 0.07001097242579243
Testing accuracy: 0.9773
Epoch 64
-----
Training loss: 0.020426947568977873
Training accuracy: 0.9968666666666667
Testing loss: 0.07131513928442862
Testing accuracy: 0.9767
Epoch 65
-----
Training loss: 0.01986450089663267
Training accuracy: 0.9972333333333333
Testing loss: 0.06890093643888594
Testing accuracy: 0.9779
Epoch 66
-----
Training loss: 0.019511050120741127
Training accuracy: 0.9973
Testing loss: 0.07127086600959064
Testing accuracy: 0.9763
Epoch 67
-----
Training loss: 0.01898989761173725
Training accuracy: 0.99735
Testing loss: 0.06892135313854428
Testing accuracy: 0.9775
Epoch 68
-----
Training loss: 0.018491475894798836
Training accuracy: 0.9973333333333333
Testing loss: 0.06867801117307394
Testing accuracy: 0.9773
Epoch 69
-----
Training loss: 0.01807048909403384
Training accuracy: 0.9976666666666667
Testing loss: 0.068179257452832
Testing accuracy: 0.9783
Epoch 70
-----
Training loss: 0.017709854138394196
Training accuracy: 0.9978333333333333
Testing loss: 0.0693680733778947
```



```

Testing accuracy: 0.9771
Epoch 71
-----
Training loss: 0.017176460211599867
Training accuracy: 0.9978666666666667
Testing loss: 0.07186458274354315
Testing accuracy: 0.977
Epoch 72
-----
Training loss: 0.017035003617654244
Training accuracy: 0.9978666666666667
Testing loss: 0.06926156076525522
Testing accuracy: 0.9773
Epoch 73
-----
Training loss: 0.016562397183229525
Training accuracy: 0.9982333333333333
Testing loss: 0.06916155865427795
Testing accuracy: 0.977
Epoch 74
-----
Training loss: 0.01628909975749751
Training accuracy: 0.9980333333333333
Testing loss: 0.06842535956922895
Testing accuracy: 0.9771
Epoch 75
-----
Training loss: 0.01583683783436815
Training accuracy: 0.9982833333333333
Testing loss: 0.06981363458036902
Testing accuracy: 0.9771
Epoch 76
-----
Training loss: 0.015493170734122395
Training accuracy: 0.9982333333333333
Testing loss: 0.06910855009125629
Testing accuracy: 0.9772
Epoch 77
-----
Training loss: 0.01523880427243809
Training accuracy: 0.9983166666666666
Testing loss: 0.06907730820517584
Testing accuracy: 0.9779
Epoch 78
-----
Training loss: 0.014881272613753875
Training accuracy: 0.9984166666666666
Testing loss: 0.06832491677064614

```

```

Testing accuracy: 0.9774
Epoch 79
-----
Training loss: 0.014647934875575204
Training accuracy: 0.9984666666666666
Testing loss: 0.06914624545847772
Testing accuracy: 0.9779
Epoch 80
-----
Training loss: 0.014255341774970292
Training accuracy: 0.99865
Testing loss: 0.06899467408419795
Testing accuracy: 0.978
Epoch 81
-----
Training loss: 0.013876792880271872
Training accuracy: 0.9987666666666667
Testing loss: 0.0693741527810147
Testing accuracy: 0.9769
Epoch 82
-----
Training loss: 0.013655056757479906
Training accuracy: 0.9988166666666667
Testing loss: 0.07106489164632031
Testing accuracy: 0.9775
Epoch 83
-----
Training loss: 0.013446604910617074
Training accuracy: 0.99895
Testing loss: 0.0687413680186246
Testing accuracy: 0.9781
Epoch 84
-----
Training loss: 0.013225594508772096
Training accuracy: 0.9989333333333333
Testing loss: 0.07019608581266633
Testing accuracy: 0.9774
Epoch 85
-----
Training loss: 0.012931861380984386
Training accuracy: 0.999
Testing loss: 0.06989689063203705
Testing accuracy: 0.9784
Epoch 86
-----
Training loss: 0.012682561063642303
Training accuracy: 0.9990166666666667
Testing loss: 0.06924718728431375

```

```

Testing accuracy: 0.9771
Epoch 87
-----
Training loss: 0.012324340140074492
Training accuracy: 0.9990833333333333
Testing loss: 0.07371954866803614
Testing accuracy: 0.9762
Epoch 88
-----
Training loss: 0.012151438442741832
Training accuracy: 0.9991333333333333
Testing loss: 0.07002172253693745
Testing accuracy: 0.9775
Epoch 89
-----
Training loss: 0.011992216798601052
Training accuracy: 0.9991
Testing loss: 0.06922038513306931
Testing accuracy: 0.9776
Epoch 90
-----
Training loss: 0.011663540852318207
Training accuracy: 0.9992333333333333
Testing loss: 0.0694972559680664
Testing accuracy: 0.9777
Epoch 91
-----
Training loss: 0.011506530862301589
Training accuracy: 0.9993
Testing loss: 0.06907318371487485
Testing accuracy: 0.9777
Epoch 92
-----
Training loss: 0.011265984961514671
Training accuracy: 0.99925
Testing loss: 0.06974320884372825
Testing accuracy: 0.9773
Epoch 93
-----
Training loss: 0.01106386939343065
Training accuracy: 0.9992666666666666
Testing loss: 0.06912224759513833
Testing accuracy: 0.9777
Epoch 94
-----
Training loss: 0.01082209925527374
Training accuracy: 0.9995
Testing loss: 0.06876028143944646

```

```

Testing accuracy: 0.9782
Epoch 95
-----
Training loss: 0.010693694477031628
Training accuracy: 0.9993666666666666
Testing loss: 0.06891880782653287
Testing accuracy: 0.9781
Epoch 96
-----
Training loss: 0.010461665558815003
Training accuracy: 0.99955
Testing loss: 0.06980944444294901
Testing accuracy: 0.9774
Epoch 97
-----
Training loss: 0.0103232901616022
Training accuracy: 0.9994333333333333
Testing loss: 0.06966664469771229
Testing accuracy: 0.9783
Epoch 98
-----
Training loss: 0.010104975041374564
Training accuracy: 0.9994833333333333
Testing loss: 0.07052796258840259
Testing accuracy: 0.978
Epoch 99
-----
Training loss: 0.009997064795034627
Training accuracy: 0.9995
Testing loss: 0.06932129752584941
Testing accuracy: 0.978
Epoch 100
-----
Training loss: 0.009785800569628677
Training accuracy: 0.9994666666666666
Testing loss: 0.07027284852169739
Testing accuracy: 0.9772
Epoch 101
-----
Training loss: 0.009551258139001826
Training accuracy: 0.9995833333333333
Testing loss: 0.0701301208264224
Testing accuracy: 0.9776
Epoch 102
-----
Training loss: 0.009403408562143644
Training accuracy: 0.9995666666666667
Testing loss: 0.07030046504038344

```

```

Testing accuracy: 0.9775
Epoch 103
-----
Training loss: 0.009313180183681349
Training accuracy: 0.9995833333333334
Testing loss: 0.06963375392874145
Testing accuracy: 0.9776
Epoch 104
-----
Training loss: 0.009145351218928894
Training accuracy: 0.9996666666666667
Testing loss: 0.06939730721905496
Testing accuracy: 0.9774
Epoch 105
-----
Training loss: 0.009000096177123487
Training accuracy: 0.9995666666666667
Testing loss: 0.07138563892181227
Testing accuracy: 0.977
Epoch 106
-----
Training loss: 0.008890836455921333
Training accuracy: 0.9996833333333334
Testing loss: 0.06970063076654129
Testing accuracy: 0.9781
Epoch 107
-----
Training loss: 0.008690155699104071
Training accuracy: 0.9997
Testing loss: 0.07027838029305504
Testing accuracy: 0.978
Epoch 108
-----
Training loss: 0.008569910700991749
Training accuracy: 0.9996333333333334
Testing loss: 0.07067500322443214
Testing accuracy: 0.978
Epoch 109
-----
Training loss: 0.008452537161422273
Training accuracy: 0.9997666666666667
Testing loss: 0.07002698776614703
Testing accuracy: 0.9778
Epoch 110
-----
Training loss: 0.00835958243024846
Training accuracy: 0.9997333333333334
Testing loss: 0.06908518137413248

```

```
Testing accuracy: 0.9776
Epoch 111
-----
Training loss: 0.008236034621081004
Training accuracy: 0.9997
Testing loss: 0.07086330926294919
Testing accuracy: 0.9779
Epoch 112
-----
Training loss: 0.008070423095238706
Training accuracy: 0.9997333333333334
Testing loss: 0.07115728736063169
Testing accuracy: 0.9774
Epoch 113
-----
Training loss: 0.007960275094831984
Training accuracy: 0.9997333333333334
Testing loss: 0.07049882835797538
Testing accuracy: 0.9776
Epoch 114
-----
Training loss: 0.007847363772429526
Training accuracy: 0.9997333333333334
Testing loss: 0.0694041233443044
Testing accuracy: 0.9777
Epoch 115
-----
Training loss: 0.007720605273917318
Training accuracy: 0.9998
Testing loss: 0.0704799172102183
Testing accuracy: 0.9777
Epoch 116
-----
Training loss: 0.007627094945311546
Training accuracy: 0.9997666666666667
Testing loss: 0.07165246472655422
Testing accuracy: 0.9773
Epoch 117
-----
Training loss: 0.007480006791775426
Training accuracy: 0.9998
Testing loss: 0.07037421775934329
Testing accuracy: 0.9782
Epoch 118
-----
Training loss: 0.007344394759709636
Training accuracy: 0.9998
Testing loss: 0.07191774180858948
```

```

Testing accuracy: 0.9781
Epoch 119
-----
Training loss: 0.007292759921774268
Training accuracy: 0.9998166666666667
Testing loss: 0.06937162018793333
Testing accuracy: 0.9782
Epoch 120
-----
Training loss: 0.007188335724547505
Training accuracy: 0.9998333333333334
Testing loss: 0.07002351016835398
Testing accuracy: 0.978
Epoch 121
-----
Training loss: 0.007050886113507052
Training accuracy: 0.9998333333333334
Testing loss: 0.0696137261333739
Testing accuracy: 0.978
Epoch 122
-----
Training loss: 0.006980646389039854
Training accuracy: 0.9998
Testing loss: 0.07200446920647363
Testing accuracy: 0.9781
Epoch 123
-----
Training loss: 0.006893772433511912
Training accuracy: 0.9998333333333334
Testing loss: 0.07036954350213395
Testing accuracy: 0.978
Epoch 124
-----
Training loss: 0.006780027519663175
Training accuracy: 0.9998
Testing loss: 0.06992789827121101
Testing accuracy: 0.9782
Epoch 125
-----
Training loss: 0.006660991628592213
Training accuracy: 0.99985
Testing loss: 0.07091155800906122
Testing accuracy: 0.9777
Epoch 126
-----
Training loss: 0.006622998624450217
Training accuracy: 0.9998833333333333
Testing loss: 0.06978621812363801

```

Testing accuracy: 0.978  
Epoch 127  
-----  
Training loss: 0.006489247857220471  
Training accuracy: 0.99985  
Testing loss: 0.07151268632392174  
Testing accuracy: 0.9777  
Epoch 128  
-----  
Training loss: 0.006423732471217712  
Training accuracy: 0.9998666666666667  
Testing loss: 0.07069962352490539  
Testing accuracy: 0.9775  
Epoch 129  
-----  
Training loss: 0.00636374511414518  
Training accuracy: 0.9998666666666667  
Testing loss: 0.07247185385986202  
Testing accuracy: 0.9778  
Epoch 130  
-----  
Training loss: 0.006244120875404527  
Training accuracy: 0.9998833333333333  
Testing loss: 0.07104895644336286  
Testing accuracy: 0.9775  
Epoch 131  
-----  
Training loss: 0.006197275074757635  
Training accuracy: 0.9998833333333333  
Testing loss: 0.0708931079816524  
Testing accuracy: 0.9776  
Epoch 132  
-----  
Training loss: 0.006133670689041416  
Training accuracy: 0.9998333333333334  
Testing loss: 0.0708321913532545  
Testing accuracy: 0.9781  
Epoch 133  
-----  
Training loss: 0.006049494902851681  
Training accuracy: 0.9999166666666667  
Testing loss: 0.0710182906713138  
Testing accuracy: 0.9778  
Epoch 134  
-----  
Training loss: 0.0059623424656689164  
Training accuracy: 0.9999  
Testing loss: 0.07047091752207678



```

Testing accuracy: 0.9779
Epoch 135
-----
Training loss: 0.005895899903556953
Training accuracy: 0.9999166666666667
Testing loss: 0.07121780769125363
Testing accuracy: 0.9781
Epoch 136
-----
Training loss: 0.005817759224710365
Training accuracy: 0.9998833333333333
Testing loss: 0.07116642856234863
Testing accuracy: 0.978
Epoch 137
-----
Training loss: 0.005745001530554145
Training accuracy: 0.9999166666666667
Testing loss: 0.07173534783951428
Testing accuracy: 0.9781
Epoch 138
-----
Training loss: 0.005710864639220138
Training accuracy: 0.9998833333333333
Testing loss: 0.07031010496274384
Testing accuracy: 0.9784
Epoch 139
-----
Training loss: 0.005631798241349558
Training accuracy: 0.9999333333333333
Testing loss: 0.07173264010087883
Testing accuracy: 0.9772
Epoch 140
-----
Training loss: 0.005529566305503249
Training accuracy: 0.9999166666666667
Testing loss: 0.07196543804980862
Testing accuracy: 0.9776
Epoch 141
-----
Training loss: 0.00547903025696675
Training accuracy: 0.9998666666666667
Testing loss: 0.07129571966791323
Testing accuracy: 0.9777
Epoch 142
-----
Training loss: 0.005397447049617767
Training accuracy: 0.9999333333333333
Testing loss: 0.07168955177070194

```

```

Testing accuracy: 0.9779
Epoch 143
-----
Training loss: 0.00536970240821441
Training accuracy: 0.9999166666666667
Testing loss: 0.0716669736708111
Testing accuracy: 0.9778
Epoch 144
-----
Training loss: 0.00529274628519391
Training accuracy: 0.9999333333333333
Testing loss: 0.07153236336900799
Testing accuracy: 0.9783
Epoch 145
-----
Training loss: 0.005250829192964981
Training accuracy: 0.9999333333333333
Testing loss: 0.07212245351283449
Testing accuracy: 0.9776
Epoch 146
-----
Training loss: 0.0051888586825070285
Training accuracy: 0.9999333333333333
Testing loss: 0.07146773155212141
Testing accuracy: 0.9781
Epoch 147
-----
Training loss: 0.005119074944034219
Training accuracy: 0.9999666666666667
Testing loss: 0.07179223608105462
Testing accuracy: 0.9787
Epoch 148
-----
Training loss: 0.005057351817314823
Training accuracy: 0.99995
Testing loss: 0.0718565427751583
Testing accuracy: 0.9778
Epoch 149
-----
Training loss: 0.005017208254554619
Training accuracy: 0.9999666666666667
Testing loss: 0.0710598316991251
Testing accuracy: 0.9782
Epoch 150
-----
Training loss: 0.004969649045045177
Training accuracy: 0.9999333333333333
Testing loss: 0.07346645700537664

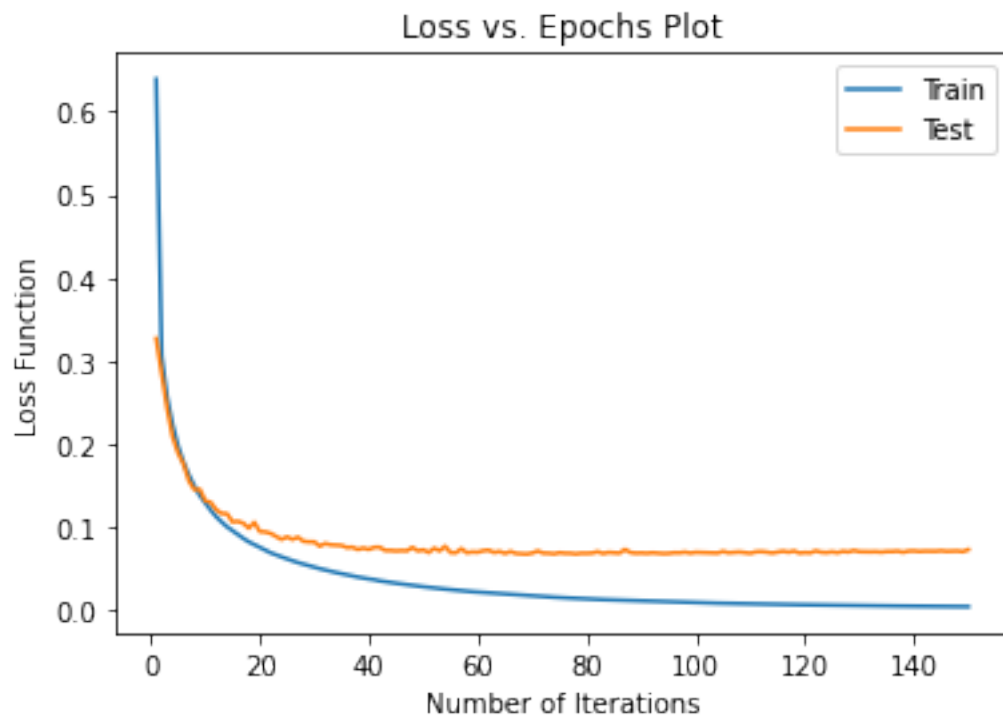
```

Testing accuracy: 0.9778

Done

Total Time Consumed: 1568.7101199626923

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.1.5 Seed 5

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
model5 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model5.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(5)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model5,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model5,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.6322024107138315
Training accuracy: 0.83795
Testing loss: 0.33491543362474746
Testing accuracy: 0.9038

```

Epoch 2

```

-----
Training loss: 0.30600347589651744
Training accuracy: 0.9118333333333334
Testing loss: 0.27709104132595336
Testing accuracy: 0.9228

```

Epoch 3

```

-----
Training loss: 0.2575241854429245
Training accuracy: 0.9256833333333333
Testing loss: 0.23937038567130733
Testing accuracy: 0.9305

```

Epoch 4

```

-----
Training loss: 0.2254486405332883
Training accuracy: 0.9345666666666667
Testing loss: 0.21035708320938099
Testing accuracy: 0.9388

```

Epoch 5

```

-----
Training loss: 0.20008997386693955
Training accuracy: 0.94155
Testing loss: 0.18809371211441459
Testing accuracy: 0.9436

```

Epoch 6

```

-----
Training loss: 0.18083900736371677
Training accuracy: 0.9475166666666667
Testing loss: 0.16897280246114274

```

```
Testing accuracy: 0.9494
Epoch 7
-----
Training loss: 0.16424803241888683
Training accuracy: 0.95255
Testing loss: 0.15793848971415098
Testing accuracy: 0.9518
Epoch 8
-----
Training loss: 0.15078175825277965
Training accuracy: 0.9569166666666666
Testing loss: 0.1532241040306866
Testing accuracy: 0.9534
Epoch 9
-----
Training loss: 0.1397219939549764
Training accuracy: 0.9599666666666666
Testing loss: 0.14256187633961248
Testing accuracy: 0.9575
Epoch 10
-----
Training loss: 0.13004043015241623
Training accuracy: 0.9630166666666666
Testing loss: 0.128929743709363
Testing accuracy: 0.9623
Epoch 11
-----
Training loss: 0.12089615505337716
Training accuracy: 0.96585
Testing loss: 0.1265020739215954
Testing accuracy: 0.9616
Epoch 12
-----
Training loss: 0.1137754653096199
Training accuracy: 0.9679333333333333
Testing loss: 0.12180105959818621
Testing accuracy: 0.9641
Epoch 13
-----
Training loss: 0.10699973811705907
Training accuracy: 0.9699
Testing loss: 0.11801761794526866
Testing accuracy: 0.9655
Epoch 14
-----
Training loss: 0.10109810003439586
Training accuracy: 0.9718833333333333
Testing loss: 0.11236212733587261
```

```
Testing accuracy: 0.9661
Epoch 15
-----
Training loss: 0.09563083829979102
Training accuracy: 0.97375
Testing loss: 0.10699908133999557
Testing accuracy: 0.9688
Epoch 16
-----
Training loss: 0.09077945325473945
Training accuracy: 0.97535
Testing loss: 0.10255673902619417
Testing accuracy: 0.969
Epoch 17
-----
Training loss: 0.08603947063585123
Training accuracy: 0.9761333333333333
Testing loss: 0.09952031512548969
Testing accuracy: 0.9697
Epoch 18
-----
Training loss: 0.08193035748004913
Training accuracy: 0.9774833333333334
Testing loss: 0.09768015770300938
Testing accuracy: 0.9701
Epoch 19
-----
Training loss: 0.07816065749526024
Training accuracy: 0.9785833333333334
Testing loss: 0.09354805515094358
Testing accuracy: 0.9715
Epoch 20
-----
Training loss: 0.07487729400396347
Training accuracy: 0.9797333333333333
Testing loss: 0.09380117636529883
Testing accuracy: 0.9714
Epoch 21
-----
Training loss: 0.07187280515233675
Training accuracy: 0.98035
Testing loss: 0.0927598871124588
Testing accuracy: 0.9713
Epoch 22
-----
Training loss: 0.06894114153782527
Training accuracy: 0.9812166666666666
Testing loss: 0.09119745060374403
```

```

Testing accuracy: 0.9717
Epoch 23
-----
Training loss: 0.0659692367086808
Training accuracy: 0.9821
Testing loss: 0.08899143544636715
Testing accuracy: 0.9728
Epoch 24
-----
Training loss: 0.06369948302259047
Training accuracy: 0.9828666666666667
Testing loss: 0.0895043390856427
Testing accuracy: 0.9724
Epoch 25
-----
Training loss: 0.061178527291615804
Training accuracy: 0.9832833333333333
Testing loss: 0.08661572191460877
Testing accuracy: 0.9734
Epoch 26
-----
Training loss: 0.05881535935153564
Training accuracy: 0.9840666666666666
Testing loss: 0.08589979423696448
Testing accuracy: 0.9733
Epoch 27
-----
Training loss: 0.0569383931795756
Training accuracy: 0.9847833333333333
Testing loss: 0.08205285970311446
Testing accuracy: 0.9753
Epoch 28
-----
Training loss: 0.05452165767302116
Training accuracy: 0.9856
Testing loss: 0.08474295378134698
Testing accuracy: 0.9736
Epoch 29
-----
Training loss: 0.05278796925346057
Training accuracy: 0.98655
Testing loss: 0.07984582415135329
Testing accuracy: 0.9757
Epoch 30
-----
Training loss: 0.05093391983807087
Training accuracy: 0.9868333333333333
Testing loss: 0.08325887841593688

```



```

Testing accuracy: 0.9741
Epoch 31
-----
Training loss: 0.04918845046311617
Training accuracy: 0.9876166666666667
Testing loss: 0.08489648531529174
Testing accuracy: 0.9744
Epoch 32
-----
Training loss: 0.04757751196995377
Training accuracy: 0.98805
Testing loss: 0.07801244012525033
Testing accuracy: 0.9751
Epoch 33
-----
Training loss: 0.04585477871745825
Training accuracy: 0.98855
Testing loss: 0.07736069136625452
Testing accuracy: 0.9751
Epoch 34
-----
Training loss: 0.04445323384453853
Training accuracy: 0.9891166666666666
Testing loss: 0.07719749545642904
Testing accuracy: 0.9763
Epoch 35
-----
Training loss: 0.04306902268826961
Training accuracy: 0.9895333333333334
Testing loss: 0.07585448641804562
Testing accuracy: 0.9758
Epoch 36
-----
Training loss: 0.04157686215887467
Training accuracy: 0.9901333333333333
Testing loss: 0.07554195983821799
Testing accuracy: 0.9774
Epoch 37
-----
Training loss: 0.040638938916226226
Training accuracy: 0.9901833333333333
Testing loss: 0.07662756839369655
Testing accuracy: 0.976
Epoch 38
-----
Training loss: 0.03917019494821628
Training accuracy: 0.9907666666666667
Testing loss: 0.07904179743639413

```

```

Testing accuracy: 0.9755
Epoch 39
-----
Training loss: 0.038068008843064306
Training accuracy: 0.9908666666666667
Testing loss: 0.07882080860673242
Testing accuracy: 0.9771
Epoch 40
-----
Training loss: 0.036873410260677336
Training accuracy: 0.99155
Testing loss: 0.07510745279775684
Testing accuracy: 0.9765
Epoch 41
-----
Training loss: 0.035941690878073376
Training accuracy: 0.9921833333333333
Testing loss: 0.07510599018531336
Testing accuracy: 0.9754
Epoch 42
-----
Training loss: 0.03482655551234881
Training accuracy: 0.9923333333333333
Testing loss: 0.07440879760357509
Testing accuracy: 0.9771
Epoch 43
-----
Training loss: 0.033806037040551504
Training accuracy: 0.9922666666666666
Testing loss: 0.07477726423697677
Testing accuracy: 0.9776
Epoch 44
-----
Training loss: 0.03280478459422787
Training accuracy: 0.9929333333333333
Testing loss: 0.07358021133840321
Testing accuracy: 0.9771
Epoch 45
-----
Training loss: 0.031923237548768524
Training accuracy: 0.99315
Testing loss: 0.0725743719791863
Testing accuracy: 0.9784
Epoch 46
-----
Training loss: 0.03096608359515667
Training accuracy: 0.99345
Testing loss: 0.07783613550019966

```

```

Testing accuracy: 0.9753
Epoch 47
-----
Training loss: 0.030204985966036716
Training accuracy: 0.9938833333333333
Testing loss: 0.07403459543789363
Testing accuracy: 0.9775
Epoch 48
-----
Training loss: 0.02914726906567812
Training accuracy: 0.994
Testing loss: 0.07473335569060058
Testing accuracy: 0.9773
Epoch 49
-----
Training loss: 0.02850592011337479
Training accuracy: 0.9942833333333333
Testing loss: 0.07284118341590473
Testing accuracy: 0.9775
Epoch 50
-----
Training loss: 0.027750068388382593
Training accuracy: 0.9946333333333334
Testing loss: 0.07177397440585076
Testing accuracy: 0.977
Epoch 51
-----
Training loss: 0.026998395866093535
Training accuracy: 0.99485
Testing loss: 0.0702416662536087
Testing accuracy: 0.9784
Epoch 52
-----
Training loss: 0.02607337143023809
Training accuracy: 0.9951
Testing loss: 0.07147302662146984
Testing accuracy: 0.9782
Epoch 53
-----
Training loss: 0.025510228800276914
Training accuracy: 0.9954666666666667
Testing loss: 0.07107050618554234
Testing accuracy: 0.9783
Epoch 54
-----
Training loss: 0.024823803949107725
Training accuracy: 0.99565
Testing loss: 0.07070542490080141

```

```

Testing accuracy: 0.9785
Epoch 55
-----
Training loss: 0.02415078254813949
Training accuracy: 0.9956833333333334
Testing loss: 0.0718522825794425
Testing accuracy: 0.9779
Epoch 56
-----
Training loss: 0.023546002763509752
Training accuracy: 0.9960166666666667
Testing loss: 0.0698203612385899
Testing accuracy: 0.9786
Epoch 57
-----
Training loss: 0.023077787808453043
Training accuracy: 0.99605
Testing loss: 0.07055965637800041
Testing accuracy: 0.9784
Epoch 58
-----
Training loss: 0.02237554072116812
Training accuracy: 0.9961166666666667
Testing loss: 0.07151791254194916
Testing accuracy: 0.9789
Epoch 59
-----
Training loss: 0.0219304759559532
Training accuracy: 0.9965
Testing loss: 0.07190729489781342
Testing accuracy: 0.9782
Epoch 60
-----
Training loss: 0.02131240109503269
Training accuracy: 0.99665
Testing loss: 0.0737098326793854
Testing accuracy: 0.9777
Epoch 61
-----
Training loss: 0.020852958561231694
Training accuracy: 0.9967
Testing loss: 0.06944982877155398
Testing accuracy: 0.9791
Epoch 62
-----
Training loss: 0.02037683965737621
Training accuracy: 0.9969
Testing loss: 0.06965626589064101

```

```
Testing accuracy: 0.9793
Epoch 63
-----
Training loss: 0.01981749746973316
Training accuracy: 0.9971
Testing loss: 0.07033368365269653
Testing accuracy: 0.9786
Epoch 64
-----
Training loss: 0.01940155954870085
Training accuracy: 0.9970666666666667
Testing loss: 0.07021547076559276
Testing accuracy: 0.9787
Epoch 65
-----
Training loss: 0.01886273528126379
Training accuracy: 0.9974666666666666
Testing loss: 0.0710561811111298
Testing accuracy: 0.9788
Epoch 66
-----
Training loss: 0.018519463974113266
Training accuracy: 0.9972166666666666
Testing loss: 0.0715096037646542
Testing accuracy: 0.9792
Epoch 67
-----
Training loss: 0.018010727931559087
Training accuracy: 0.9977333333333334
Testing loss: 0.06980256769497684
Testing accuracy: 0.9795
Epoch 68
-----
Training loss: 0.017633118875821432
Training accuracy: 0.9976166666666667
Testing loss: 0.06910060805559254
Testing accuracy: 0.979
Epoch 69
-----
Training loss: 0.017237792784844837
Training accuracy: 0.9977333333333334
Testing loss: 0.07247405571145284
Testing accuracy: 0.9789
Epoch 70
-----
Training loss: 0.016822316746910412
Training accuracy: 0.99795
Testing loss: 0.07034022986791008
```

```
Testing accuracy: 0.9788
Epoch 71
-----
Training loss: 0.01650489784516394
Training accuracy: 0.99785
Testing loss: 0.07113258555163718
Testing accuracy: 0.9791
Epoch 72
-----
Training loss: 0.016125148630266387
Training accuracy: 0.9980333333333333
Testing loss: 0.06973097559396818
Testing accuracy: 0.979
Epoch 73
-----
Training loss: 0.01567197386324406
Training accuracy: 0.99825
Testing loss: 0.07015601515615727
Testing accuracy: 0.9785
Epoch 74
-----
Training loss: 0.015416329031189283
Training accuracy: 0.9983166666666666
Testing loss: 0.0692328098215234
Testing accuracy: 0.9787
Epoch 75
-----
Training loss: 0.015024140694737434
Training accuracy: 0.9983333333333333
Testing loss: 0.07110332763475027
Testing accuracy: 0.9789
Epoch 76
-----
Training loss: 0.014625693811600407
Training accuracy: 0.99855
Testing loss: 0.0699155830517174
Testing accuracy: 0.9795
Epoch 77
-----
Training loss: 0.01445819833241403
Training accuracy: 0.9984166666666666
Testing loss: 0.07107628077998235
Testing accuracy: 0.9785
Epoch 78
-----
Training loss: 0.014204744722197453
Training accuracy: 0.9984666666666666
Testing loss: 0.06992991310603631
```

```

Testing accuracy: 0.9795
Epoch 79
-----
Training loss: 0.013862636714428663
Training accuracy: 0.9986666666666667
Testing loss: 0.07014493106502541
Testing accuracy: 0.9792
Epoch 80
-----
Training loss: 0.01352041905199488
Training accuracy: 0.99865
Testing loss: 0.06988241258789163
Testing accuracy: 0.9792
Epoch 81
-----
Training loss: 0.0132800035794576
Training accuracy: 0.99885
Testing loss: 0.06991769964613946
Testing accuracy: 0.9793
Epoch 82
-----
Training loss: 0.013065583958600958
Training accuracy: 0.9988166666666667
Testing loss: 0.07071576814707013
Testing accuracy: 0.9787
Epoch 83
-----
Training loss: 0.0127813659992069
Training accuracy: 0.9989833333333333
Testing loss: 0.0687950451021931
Testing accuracy: 0.9791
Epoch 84
-----
Training loss: 0.012414791594818234
Training accuracy: 0.9990666666666667
Testing loss: 0.0701657248702446
Testing accuracy: 0.9798
Epoch 85
-----
Training loss: 0.0122292470994095
Training accuracy: 0.9990333333333333
Testing loss: 0.07008094551296798
Testing accuracy: 0.979
Epoch 86
-----
Training loss: 0.012120726145183046
Training accuracy: 0.9991
Testing loss: 0.07065079320862794

```

```

Testing accuracy: 0.9794
Epoch 87
-----
Training loss: 0.01184931697808206
Training accuracy: 0.9990833333333333
Testing loss: 0.07042147064207797
Testing accuracy: 0.9798
Epoch 88
-----
Training loss: 0.011593506746118268
Training accuracy: 0.9991666666666666
Testing loss: 0.06998755267204325
Testing accuracy: 0.9791
Epoch 89
-----
Training loss: 0.011330001687196395
Training accuracy: 0.99925
Testing loss: 0.06943643632178806
Testing accuracy: 0.9791
Epoch 90
-----
Training loss: 0.011118830584362149
Training accuracy: 0.9993333333333333
Testing loss: 0.07121733665039205
Testing accuracy: 0.9796
Epoch 91
-----
Training loss: 0.010920568741485476
Training accuracy: 0.9993
Testing loss: 0.07079415050169133
Testing accuracy: 0.9795
Epoch 92
-----
Training loss: 0.010774973276878397
Training accuracy: 0.9993
Testing loss: 0.07154193912798859
Testing accuracy: 0.9786
Epoch 93
-----
Training loss: 0.010604326340556145
Training accuracy: 0.9993333333333333
Testing loss: 0.07001142248594362
Testing accuracy: 0.9796
Epoch 94
-----
Training loss: 0.010383907588322958
Training accuracy: 0.99935
Testing loss: 0.06931838257220473

```



```

Testing accuracy: 0.98
Epoch 95
-----
Training loss: 0.010222465733935435
Training accuracy: 0.9993333333333333
Testing loss: 0.07023067879386745
Testing accuracy: 0.9797
Epoch 96
-----
Training loss: 0.010020732653513552
Training accuracy: 0.9993166666666666
Testing loss: 0.07210633594462659
Testing accuracy: 0.9792
Epoch 97
-----
Training loss: 0.009867919445844989
Training accuracy: 0.9994666666666666
Testing loss: 0.0701754989004605
Testing accuracy: 0.9795
Epoch 98
-----
Training loss: 0.009685964122538766
Training accuracy: 0.99945
Testing loss: 0.06995251444079409
Testing accuracy: 0.9795
Epoch 99
-----
Training loss: 0.009548049928372104
Training accuracy: 0.99945
Testing loss: 0.07018181147976263
Testing accuracy: 0.9795
Epoch 100
-----
Training loss: 0.009339426988301178
Training accuracy: 0.9995833333333334
Testing loss: 0.06983788731021534
Testing accuracy: 0.9797
Epoch 101
-----
Training loss: 0.009203233560174703
Training accuracy: 0.9994833333333333
Testing loss: 0.07233550645645329
Testing accuracy: 0.98
Epoch 102
-----
Training loss: 0.009079418522243698
Training accuracy: 0.9994666666666666
Testing loss: 0.07020827299236042

```

```

Testing accuracy: 0.9802
Epoch 103
-----
Training loss: 0.008972053926810622
Training accuracy: 0.9995166666666667
Testing loss: 0.07027996214148204
Testing accuracy: 0.9799
Epoch 104
-----
Training loss: 0.008744578179158271
Training accuracy: 0.9995666666666667
Testing loss: 0.07121078350068112
Testing accuracy: 0.9794
Epoch 105
-----
Training loss: 0.008642506530508399
Training accuracy: 0.9996
Testing loss: 0.07024095267588332
Testing accuracy: 0.98
Epoch 106
-----
Training loss: 0.008450919128085176
Training accuracy: 0.9996833333333334
Testing loss: 0.07243579399333021
Testing accuracy: 0.9789
Epoch 107
-----
Training loss: 0.008327991406433284
Training accuracy: 0.9996166666666667
Testing loss: 0.07061995954065922
Testing accuracy: 0.9797
Epoch 108
-----
Training loss: 0.00825206131612261
Training accuracy: 0.9996
Testing loss: 0.07099175354270086
Testing accuracy: 0.9795
Epoch 109
-----
Training loss: 0.008165496695538363
Training accuracy: 0.99965
Testing loss: 0.07069286056660756
Testing accuracy: 0.98
Epoch 110
-----
Training loss: 0.007958203493493299
Training accuracy: 0.9996833333333334
Testing loss: 0.07056901190032483

```

```
Testing accuracy: 0.9797
Epoch 111
-----
Training loss: 0.007861004435333113
Training accuracy: 0.9997
Testing loss: 0.07070783878065598
Testing accuracy: 0.9795
Epoch 112
-----
Training loss: 0.007730153306511541
Training accuracy: 0.99975
Testing loss: 0.07127787874845468
Testing accuracy: 0.9797
Epoch 113
-----
Training loss: 0.007639858120058973
Training accuracy: 0.9997833333333334
Testing loss: 0.07297708150807614
Testing accuracy: 0.9793
Epoch 114
-----
Training loss: 0.007551476868924995
Training accuracy: 0.9996833333333334
Testing loss: 0.07029323856150553
Testing accuracy: 0.9797
Epoch 115
-----
Training loss: 0.007415909052888552
Training accuracy: 0.9997333333333334
Testing loss: 0.07065124151365132
Testing accuracy: 0.9797
Epoch 116
-----
Training loss: 0.0073063279046987496
Training accuracy: 0.9997333333333334
Testing loss: 0.0706186599697277
Testing accuracy: 0.98
Epoch 117
-----
Training loss: 0.007199900809116661
Training accuracy: 0.9998
Testing loss: 0.07115247189460298
Testing accuracy: 0.9792
Epoch 118
-----
Training loss: 0.007072701590073605
Training accuracy: 0.9998666666666667
Testing loss: 0.07142899239956324
```

```
Testing accuracy: 0.9798
Epoch 119
-----
Training loss: 0.00704317073635757
Training accuracy: 0.9997666666666667
Testing loss: 0.07154899753687999
Testing accuracy: 0.9796
Epoch 120
-----
Training loss: 0.00686964733650287
Training accuracy: 0.9998166666666667
Testing loss: 0.07107273136505822
Testing accuracy: 0.9794
Epoch 121
-----
Training loss: 0.006799128479945163
Training accuracy: 0.9998
Testing loss: 0.07151600931308404
Testing accuracy: 0.9789
Epoch 122
-----
Training loss: 0.006650101688473175
Training accuracy: 0.99985
Testing loss: 0.07293324263256257
Testing accuracy: 0.9794
Epoch 123
-----
Training loss: 0.006632418876700103
Training accuracy: 0.9998333333333334
Testing loss: 0.07295179756648934
Testing accuracy: 0.9794
Epoch 124
-----
Training loss: 0.006507891403697431
Training accuracy: 0.9998166666666667
Testing loss: 0.07173429315562722
Testing accuracy: 0.9796
Epoch 125
-----
Training loss: 0.006439727002227058
Training accuracy: 0.9998333333333334
Testing loss: 0.0714310954442058
Testing accuracy: 0.9798
Epoch 126
-----
Training loss: 0.006360409302109232
Training accuracy: 0.9998666666666667
Testing loss: 0.0721291750862269
```

```
Testing accuracy: 0.9796
Epoch 127
-----
Training loss: 0.006278401655331254
Training accuracy: 0.9998833333333333
Testing loss: 0.07268792286123725
Testing accuracy: 0.9798
Epoch 128
-----
Training loss: 0.006196259911668798
Training accuracy: 0.9999333333333333
Testing loss: 0.07260569702288147
Testing accuracy: 0.9793
Epoch 129
-----
Training loss: 0.006097446185785035
Training accuracy: 0.9998333333333334
Testing loss: 0.0717502097502072
Testing accuracy: 0.9801
Epoch 130
-----
Training loss: 0.006011492842808366
Training accuracy: 0.9998666666666667
Testing loss: 0.07193833118516679
Testing accuracy: 0.9801
Epoch 131
-----
Training loss: 0.005960319844074548
Training accuracy: 0.9998833333333333
Testing loss: 0.07185393974561671
Testing accuracy: 0.9797
Epoch 132
-----
Training loss: 0.005928520404888938
Training accuracy: 0.9999
Testing loss: 0.071925338524895
Testing accuracy: 0.9797
Epoch 133
-----
Training loss: 0.005827515915237988
Training accuracy: 0.9999
Testing loss: 0.07191747506846122
Testing accuracy: 0.98
Epoch 134
-----
Training loss: 0.00574281349144876
Training accuracy: 0.9998833333333333
Testing loss: 0.07136104662515591
```

```

Testing accuracy: 0.9801
Epoch 135
-----
Training loss: 0.005678194584014515
Training accuracy: 0.9999333333333333
Testing loss: 0.0727857692088564
Testing accuracy: 0.9795
Epoch 136
-----
Training loss: 0.005597565867130955
Training accuracy: 0.9999666666666667
Testing loss: 0.07238748391562254
Testing accuracy: 0.98
Epoch 137
-----
Training loss: 0.005527481214143336
Training accuracy: 0.9999333333333333
Testing loss: 0.073078362720538
Testing accuracy: 0.9795
Epoch 138
-----
Training loss: 0.005460806602301697
Training accuracy: 0.9999166666666667
Testing loss: 0.07227911998867799
Testing accuracy: 0.9796
Epoch 139
-----
Training loss: 0.005425223762293657
Training accuracy: 0.9999166666666667
Testing loss: 0.07214862874940417
Testing accuracy: 0.9796
Epoch 140
-----
Training loss: 0.005341188845659295
Training accuracy: 0.99995
Testing loss: 0.0730561619256712
Testing accuracy: 0.9794
Epoch 141
-----
Training loss: 0.00527744752013435
Training accuracy: 0.9999333333333333
Testing loss: 0.07227215446920318
Testing accuracy: 0.9797
Epoch 142
-----
Training loss: 0.005214274658386906
Training accuracy: 0.9999666666666667
Testing loss: 0.07231670926817378

```

```

Testing accuracy: 0.9798
Epoch 143
-----
Training loss: 0.005160392145377894
Training accuracy: 0.9999666666666667
Testing loss: 0.07355905591679299
Testing accuracy: 0.9795
Epoch 144
-----
Training loss: 0.005113626423974832
Training accuracy: 0.99995
Testing loss: 0.07220120052825571
Testing accuracy: 0.9797
Epoch 145
-----
Training loss: 0.005045853187702596
Training accuracy: 0.99995
Testing loss: 0.0725667671164035
Testing accuracy: 0.979
Epoch 146
-----
Training loss: 0.005004919127126535
Training accuracy: 0.9999666666666667
Testing loss: 0.07299006846195805
Testing accuracy: 0.9796
Epoch 147
-----
Training loss: 0.004948621470450113
Training accuracy: 0.99995
Testing loss: 0.0727087565164592
Testing accuracy: 0.9796
Epoch 148
-----
Training loss: 0.004842472962848842
Training accuracy: 0.9999833333333333
Testing loss: 0.07584267039709149
Testing accuracy: 0.9795
Epoch 149
-----
Training loss: 0.004847515224292874
Training accuracy: 0.9999666666666667
Testing loss: 0.07259559147371347
Testing accuracy: 0.9798
Epoch 150
-----
Training loss: 0.004773031557165086
Training accuracy: 0.9999666666666667
Testing loss: 0.07311917277932416

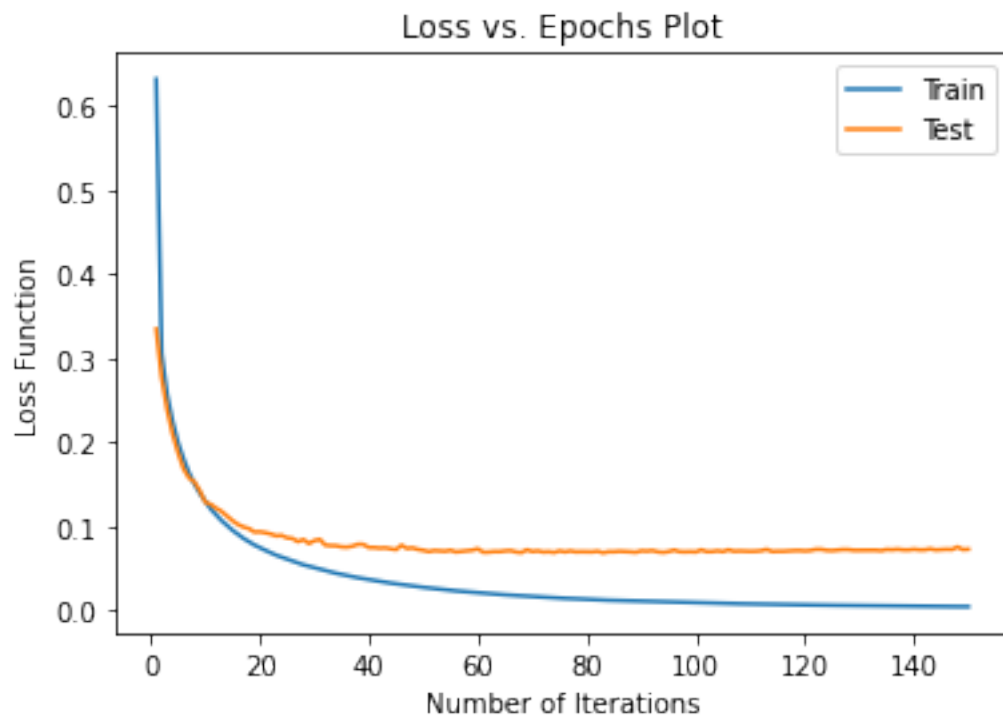
```

Testing accuracy: 0.9793

Done

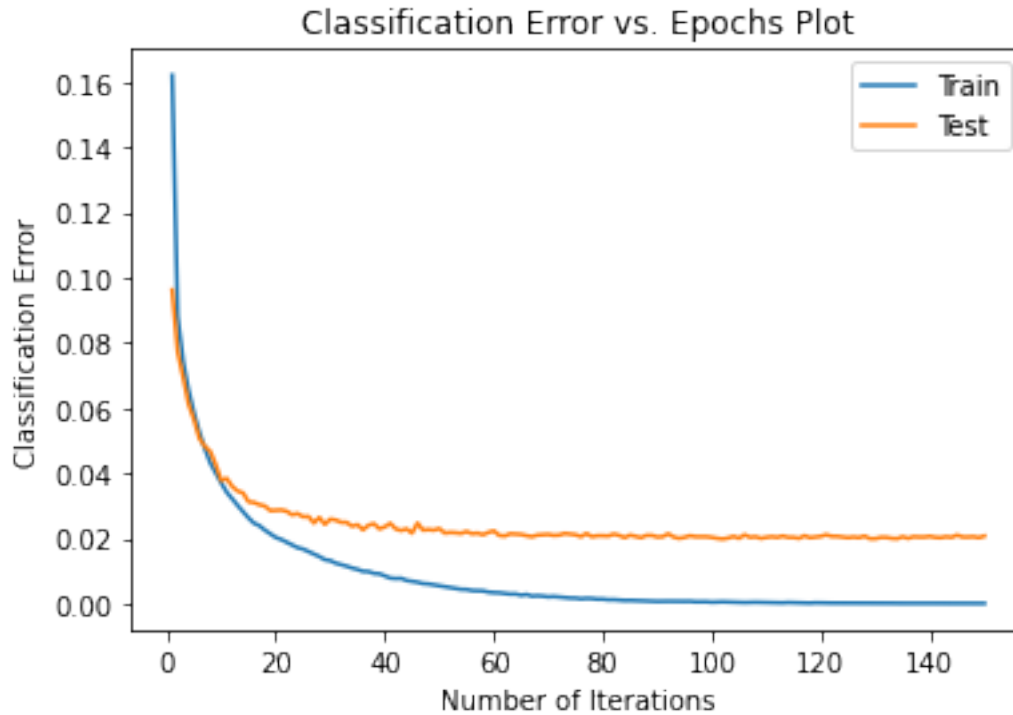
Total Time Consumed: 1580.045905828476

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```





## 5.2 3.(c)

We choose our best paramaters based on the highest testing accuracy and lowest loss on test set, which is the parameters set from seed 3.

Testing Accuracy:

Seed 1: 97.8%;

Seed 2: 97.85%;

Seed 3: 97.91%;

Seed 4: 97.78%;

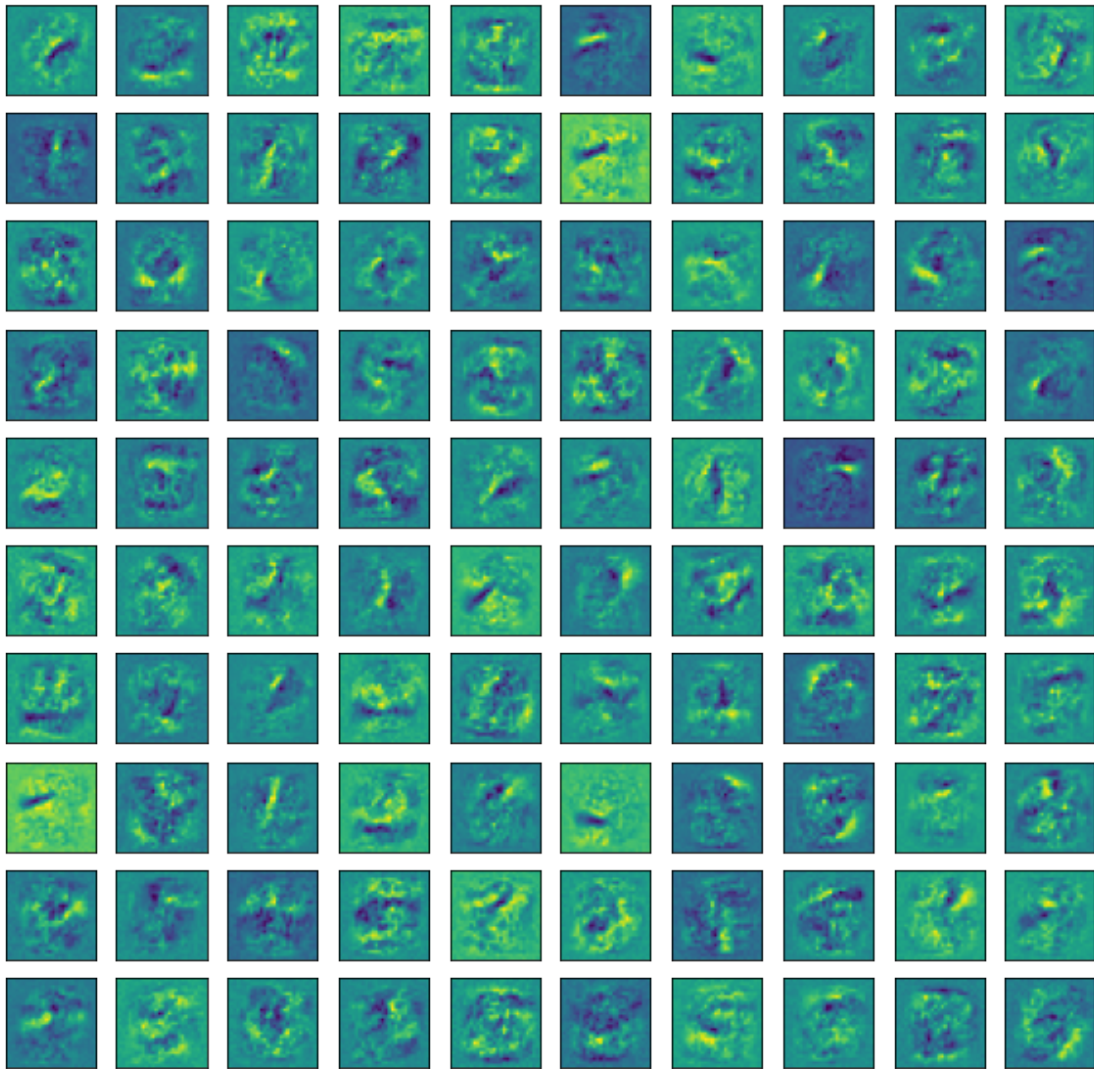
Seed 5: 97.93%.

```
[ ]: # Check the dimension of First Layer Wights
model3.state_dict()['layer1.weight'].shape
```

```
[ ]: torch.Size([100, 784])
```

```
[ ]: # Return the Weights for First Linear Layers (784 * 100)
weights = model3.state_dict()['layer1.weight']
plt.figure(figsize = (10,10))
for i in range(weights.shape[0]):
    plt.subplot(10,10,i+1)
    # Total of 100 figures of dimension 28 * 28
    plt.imshow(weights[i].reshape(28,28))
    plt.xticks([])
```

```
plt.yticks([])
```



### 5.3 3.(d)

#### 5.3.1 Learning Rate = 0.01

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.01
batch_size = 64
num_epochs = 150
model_lr01 = ANN(input_size, num_classes)
```

```
# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model_lr01.parameters(), lr = learning_rate)
```

```
[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model_lr01,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model_lr01,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 1.7808692644755046
Training accuracy: 0.60885
Testing loss: 1.206184435042606
Testing accuracy: 0.7893
Epoch 2
```

```
-----
Training loss: 0.9264847495714823
Training accuracy: 0.81615
Testing loss: 0.7096677456691767
Testing accuracy: 0.8467
Epoch 3
```

```
-----
Training loss: 0.6306786789258321
Training accuracy: 0.8559166666666667
Testing loss: 0.5391353943924995
Testing accuracy: 0.8757
Epoch 4
```

```
-----
Training loss: 0.511672999827067
Training accuracy: 0.8752833333333333
```

```

Testing loss: 0.45568568140837795
Testing accuracy: 0.8859
Epoch 5
-----
Training loss: 0.4484058856010437
Training accuracy: 0.8844
Testing loss: 0.4096206498753493
Testing accuracy: 0.8949
Epoch 6
-----
Training loss: 0.4093689453919729
Training accuracy: 0.8922166666666667
Testing loss: 0.37811679587622354
Testing accuracy: 0.8997
Epoch 7
-----
Training loss: 0.3825381880442301
Training accuracy: 0.8967833333333334
Testing loss: 0.35666136680894595
Testing accuracy: 0.9045
Epoch 8
-----
Training loss: 0.3627032481193542
Training accuracy: 0.9003666666666666
Testing loss: 0.3395142769737608
Testing accuracy: 0.9062
Epoch 9
-----
Training loss: 0.3473243293762207
Training accuracy: 0.9027
Testing loss: 0.32710855999949634
Testing accuracy: 0.9092
Epoch 10
-----
Training loss: 0.3350122767607371
Training accuracy: 0.90575
Testing loss: 0.31737723870641865
Testing accuracy: 0.9111
Epoch 11
-----
Training loss: 0.3244753135124842
Training accuracy: 0.9076
Testing loss: 0.3075979955636772
Testing accuracy: 0.9129
Epoch 12
-----
Training loss: 0.3155258938948313
Training accuracy: 0.9104166666666667

```

```

Testing loss: 0.29958177875181674
Testing accuracy: 0.9161
Epoch 13
-----
Training loss: 0.3076034644842148
Training accuracy: 0.9122666666666667
Testing loss: 0.2918835721767632
Testing accuracy: 0.9178
Epoch 14
-----
Training loss: 0.30065340338548024
Training accuracy: 0.9142166666666667
Testing loss: 0.28606976108376386
Testing accuracy: 0.9195
Epoch 15
-----
Training loss: 0.2941448521733284
Training accuracy: 0.9157666666666666
Testing loss: 0.2811041929919249
Testing accuracy: 0.9196
Epoch 16
-----
Training loss: 0.28835496436754865
Training accuracy: 0.9173666666666667
Testing loss: 0.2765343437908561
Testing accuracy: 0.9222
Epoch 17
-----
Training loss: 0.2828945194244385
Training accuracy: 0.9193666666666667
Testing loss: 0.2709124076897931
Testing accuracy: 0.9239
Epoch 18
-----
Training loss: 0.2777108714739482
Training accuracy: 0.92065
Testing loss: 0.2672903443787508
Testing accuracy: 0.9254
Epoch 19
-----
Training loss: 0.2728662002603213
Training accuracy: 0.9215166666666667
Testing loss: 0.26294563084271305
Testing accuracy: 0.9259
Epoch 20
-----
Training loss: 0.268121173175176
Training accuracy: 0.9231333333333334

```

```

Testing loss: 0.2587053101913185
Testing accuracy: 0.9271
Epoch 21
-----
Training loss: 0.26378694298267363
Training accuracy: 0.92425
Testing loss: 0.2548293281038096
Testing accuracy: 0.9283
Epoch 22
-----
Training loss: 0.259473123383522
Training accuracy: 0.9256666666666666
Testing loss: 0.253236986127249
Testing accuracy: 0.9296
Epoch 23
-----
Training loss: 0.25543509148756666
Training accuracy: 0.92715
Testing loss: 0.2489758051314931
Testing accuracy: 0.9288
Epoch 24
-----
Training loss: 0.2515054748535156
Training accuracy: 0.92815
Testing loss: 0.24568495671650406
Testing accuracy: 0.9309
Epoch 25
-----
Training loss: 0.2476899479866028
Training accuracy: 0.9294166666666667
Testing loss: 0.24067378521060487
Testing accuracy: 0.9322
Epoch 26
-----
Training loss: 0.24407083934148152
Training accuracy: 0.93025
Testing loss: 0.2386662386547608
Testing accuracy: 0.9324
Epoch 27
-----
Training loss: 0.24053434751033784
Training accuracy: 0.9316666666666666
Testing loss: 0.2349552939034951
Testing accuracy: 0.9341
Epoch 28
-----
Training loss: 0.23696225564479828
Training accuracy: 0.93215

```

```

Testing loss: 0.23147201234368003
Testing accuracy: 0.9346
Epoch 29
-----
Training loss: 0.23364864200750987
Training accuracy: 0.9335666666666667
Testing loss: 0.22883860211653315
Testing accuracy: 0.9345
Epoch 30
-----
Training loss: 0.230331347378095
Training accuracy: 0.9342833333333334
Testing loss: 0.22737534700115775
Testing accuracy: 0.9355
Epoch 31
-----
Training loss: 0.2272032705307007
Training accuracy: 0.9353
Testing loss: 0.2224740033411676
Testing accuracy: 0.9369
Epoch 32
-----
Training loss: 0.22415159885088604
Training accuracy: 0.9361
Testing loss: 0.22243081223053537
Testing accuracy: 0.9368
Epoch 33
-----
Training loss: 0.22121195180416106
Training accuracy: 0.9368
Testing loss: 0.2162978960924847
Testing accuracy: 0.9374
Epoch 34
-----
Training loss: 0.21806490513881047
Training accuracy: 0.93805
Testing loss: 0.21609377431546806
Testing accuracy: 0.9385
Epoch 35
-----
Training loss: 0.21529465717077256
Training accuracy: 0.93885
Testing loss: 0.21311593359443032
Testing accuracy: 0.9393
Epoch 36
-----
Training loss: 0.21249121418793995
Training accuracy: 0.9393333333333334

```

Testing loss: 0.20963294490887102  
Testing accuracy: 0.9393  
Epoch 37  
-----  
Training loss: 0.20972935839096704  
Training accuracy: 0.9403166666666667  
Testing loss: 0.20828689494804972  
Testing accuracy: 0.9402  
Epoch 38  
-----  
Training loss: 0.20719110460281373  
Training accuracy: 0.9414333333333333  
Testing loss: 0.2048786517446208  
Testing accuracy: 0.9409  
Epoch 39  
-----  
Training loss: 0.2045655973672867  
Training accuracy: 0.9424833333333333  
Testing loss: 0.20235070704844346  
Testing accuracy: 0.9413  
Epoch 40  
-----  
Training loss: 0.20187531934579214  
Training accuracy: 0.9429333333333333  
Testing loss: 0.20117121322709283  
Testing accuracy: 0.9409  
Epoch 41  
-----  
Training loss: 0.19967154372930526  
Training accuracy: 0.94345  
Testing loss: 0.19767808121670583  
Testing accuracy: 0.9436  
Epoch 42  
-----  
Training loss: 0.19700533466736475  
Training accuracy: 0.9444666666666667  
Testing loss: 0.19497211785263316  
Testing accuracy: 0.9445  
Epoch 43  
-----  
Training loss: 0.1948171989162763  
Training accuracy: 0.9449666666666666  
Testing loss: 0.19346291301356758  
Testing accuracy: 0.9443  
Epoch 44  
-----  
Training loss: 0.1926126419901848  
Training accuracy: 0.9461166666666667



Testing loss: 0.19144687213146003

Testing accuracy: 0.9444

Epoch 45

-----  
Training loss: 0.1903902610262235

Training accuracy: 0.94645

Testing loss: 0.18938903652938308

Testing accuracy: 0.9451

Epoch 46

-----  
Training loss: 0.18820208927790325

Training accuracy: 0.9472

Testing loss: 0.1876673785981479

Testing accuracy: 0.9449

Epoch 47

-----  
Training loss: 0.18601674021085104

Training accuracy: 0.9478166666666666

Testing loss: 0.1854684420736732

Testing accuracy: 0.9468

Epoch 48

-----  
Training loss: 0.18401888471047084

Training accuracy: 0.9482

Testing loss: 0.18370598825109993

Testing accuracy: 0.9468

Epoch 49

-----  
Training loss: 0.18194778651793797

Training accuracy: 0.9486833333333333

Testing loss: 0.1835221632318512

Testing accuracy: 0.9472

Epoch 50

-----  
Training loss: 0.18003231031894684

Training accuracy: 0.9494

Testing loss: 0.17982670598348993

Testing accuracy: 0.9469

Epoch 51

-----  
Training loss: 0.17805676403641701

Training accuracy: 0.9498666666666666

Testing loss: 0.17871920728854312

Testing accuracy: 0.9475

Epoch 52

-----  
Training loss: 0.17613249828418095

Training accuracy: 0.95055

```

Testing loss: 0.17616608036551507
Testing accuracy: 0.9492
Epoch 53
-----
Training loss: 0.17430133972962697
Training accuracy: 0.9507666666666666
Testing loss: 0.17440397542705582
Testing accuracy: 0.949
Epoch 54
-----
Training loss: 0.1723412936806679
Training accuracy: 0.9514833333333333
Testing loss: 0.1748290810567938
Testing accuracy: 0.9504
Epoch 55
-----
Training loss: 0.17071093243757884
Training accuracy: 0.9519833333333333
Testing loss: 0.17095427490343715
Testing accuracy: 0.9508
Epoch 56
-----
Training loss: 0.1689429802417755
Training accuracy: 0.9526166666666667
Testing loss: 0.17109943556178148
Testing accuracy: 0.9498
Epoch 57
-----
Training loss: 0.1672386299888293
Training accuracy: 0.9527333333333333
Testing loss: 0.16898610651682897
Testing accuracy: 0.9507
Epoch 58
-----
Training loss: 0.16535200067559877
Training accuracy: 0.95325
Testing loss: 0.1685189712009612
Testing accuracy: 0.9506
Epoch 59
-----
Training loss: 0.16385491853555043
Training accuracy: 0.9539166666666666
Testing loss: 0.16784343301395702
Testing accuracy: 0.9512
Epoch 60
-----
Training loss: 0.16228809366822242
Training accuracy: 0.95425

```

```
Testing loss: 0.165519077805387
Testing accuracy: 0.9525
Epoch 61
-----
Training loss: 0.16056129478216172
Training accuracy: 0.9550833333333333
Testing loss: 0.16296382540255594
Testing accuracy: 0.9532
Epoch 62
-----
Training loss: 0.1589625334819158
Training accuracy: 0.95505
Testing loss: 0.16210283073270396
Testing accuracy: 0.9526
Epoch 63
-----
Training loss: 0.15764799923896788
Training accuracy: 0.9556333333333333
Testing loss: 0.16052082404019727
Testing accuracy: 0.9536
Epoch 64
-----
Training loss: 0.15611842673222223
Training accuracy: 0.95565
Testing loss: 0.15976659827836
Testing accuracy: 0.9534
Epoch 65
-----
Training loss: 0.15460749317010244
Training accuracy: 0.95625
Testing loss: 0.15878316719725633
Testing accuracy: 0.9538
Epoch 66
-----
Training loss: 0.15328773842453958
Training accuracy: 0.9566833333333333
Testing loss: 0.1594701491675939
Testing accuracy: 0.9539
Epoch 67
-----
Training loss: 0.15181589952111244
Training accuracy: 0.9572
Testing loss: 0.15693975134402705
Testing accuracy: 0.9541
Epoch 68
-----
Training loss: 0.15052301412820815
Training accuracy: 0.9572166666666667
```

```
Testing loss: 0.15435057271058392
Testing accuracy: 0.9553
Epoch 69
-----
Training loss: 0.14906094225843747
Training accuracy: 0.9578166666666666
Testing loss: 0.15343922725433756
Testing accuracy: 0.9563
Epoch 70
-----
Training loss: 0.1477207093656063
Training accuracy: 0.9586333333333333
Testing loss: 0.15356098226965612
Testing accuracy: 0.9557
Epoch 71
-----
Training loss: 0.1464056947827339
Training accuracy: 0.9588333333333333
Testing loss: 0.15111499659384892
Testing accuracy: 0.9556
Epoch 72
-----
Training loss: 0.14508588072657586
Training accuracy: 0.9593666666666667
Testing loss: 0.1516760832564846
Testing accuracy: 0.9568
Epoch 73
-----
Training loss: 0.1437655645132065
Training accuracy: 0.9594833333333334
Testing loss: 0.15068983538135602
Testing accuracy: 0.957
Epoch 74
-----
Training loss: 0.14263191869854927
Training accuracy: 0.9598666666666666
Testing loss: 0.14979969833497028
Testing accuracy: 0.9567
Epoch 75
-----
Training loss: 0.14140135136246682
Training accuracy: 0.9605333333333334
Testing loss: 0.14706466657815465
Testing accuracy: 0.9569
Epoch 76
-----
Training loss: 0.1402292089164257
Training accuracy: 0.9605833333333333
```

```
Testing loss: 0.14560104296750323
Testing accuracy: 0.9566
Epoch 77
-----
Training loss: 0.1390185518582662
Training accuracy: 0.9611833333333333
Testing loss: 0.14522021028930973
Testing accuracy: 0.9571
Epoch 78
-----
Training loss: 0.13791871974865597
Training accuracy: 0.96105
Testing loss: 0.14323137439550107
Testing accuracy: 0.9584
Epoch 79
-----
Training loss: 0.13673841081261634
Training accuracy: 0.9615833333333333
Testing loss: 0.14324459730155148
Testing accuracy: 0.9588
Epoch 80
-----
Training loss: 0.1356525739610195
Training accuracy: 0.96235
Testing loss: 0.1422482315261083
Testing accuracy: 0.9594
Epoch 81
-----
Training loss: 0.1344664696653684
Training accuracy: 0.9626
Testing loss: 0.14111597641448306
Testing accuracy: 0.9593
Epoch 82
-----
Training loss: 0.13347167543172836
Training accuracy: 0.96285
Testing loss: 0.14112075292475665
Testing accuracy: 0.9591
Epoch 83
-----
Training loss: 0.132344939772288
Training accuracy: 0.9633
Testing loss: 0.13955119703036206
Testing accuracy: 0.9596
Epoch 84
-----
Training loss: 0.13136770650545757
Training accuracy: 0.9635166666666667
```

```
Testing loss: 0.13805403158804225
Testing accuracy: 0.9614
Epoch 85
-----
Training loss: 0.13027709549069405
Training accuracy: 0.9640333333333333
Testing loss: 0.13807203945745328
Testing accuracy: 0.9607
Epoch 86
-----
Training loss: 0.1291813988149166
Training accuracy: 0.9642
Testing loss: 0.13887510007354104
Testing accuracy: 0.961
Epoch 87
-----
Training loss: 0.12825492442647615
Training accuracy: 0.9644166666666667
Testing loss: 0.1353139540026332
Testing accuracy: 0.9608
Epoch 88
-----
Training loss: 0.1272840635538101
Training accuracy: 0.9649
Testing loss: 0.134764492025326
Testing accuracy: 0.9607
Epoch 89
-----
Training loss: 0.12628087976177532
Training accuracy: 0.9651666666666666
Testing loss: 0.13486326474008287
Testing accuracy: 0.9614
Epoch 90
-----
Training loss: 0.12530430631637574
Training accuracy: 0.9651166666666666
Testing loss: 0.13360935072325597
Testing accuracy: 0.9618
Epoch 91
-----
Training loss: 0.12440205927888552
Training accuracy: 0.9658
Testing loss: 0.13404291457716067
Testing accuracy: 0.9611
Epoch 92
-----
Training loss: 0.12346265977025032
Training accuracy: 0.9659833333333333
```

```
Testing loss: 0.13154815853970825
Testing accuracy: 0.9621
Epoch 93
-----
Training loss: 0.12251246776978175
Training accuracy: 0.9663833333333334
Testing loss: 0.13126374965023463
Testing accuracy: 0.9621
Epoch 94
-----
Training loss: 0.12168264975150427
Training accuracy: 0.9662666666666667
Testing loss: 0.1306703499500539
Testing accuracy: 0.9625
Epoch 95
-----
Training loss: 0.12062807232836882
Training accuracy: 0.967
Testing loss: 0.13025208646846806
Testing accuracy: 0.9617
Epoch 96
-----
Training loss: 0.11986839814980825
Training accuracy: 0.9671
Testing loss: 0.1292197299634765
Testing accuracy: 0.9626
Epoch 97
-----
Training loss: 0.11900292130510012
Training accuracy: 0.9673
Testing loss: 0.12946359167812735
Testing accuracy: 0.963
Epoch 98
-----
Training loss: 0.11805931944648425
Training accuracy: 0.9672
Testing loss: 0.13109718436363396
Testing accuracy: 0.9631
Epoch 99
-----
Training loss: 0.11730908675789833
Training accuracy: 0.9675
Testing loss: 0.1280865431614932
Testing accuracy: 0.9637
Epoch 100
-----
Training loss: 0.11642993235985438
Training accuracy: 0.9681166666666666
```

```
Testing loss: 0.12626370455429053
Testing accuracy: 0.9636
Epoch 101
-----
Training loss: 0.11564000693758329
Training accuracy: 0.9682
Testing loss: 0.1265802010656542
Testing accuracy: 0.9639
Epoch 102
-----
Training loss: 0.11481973573764165
Training accuracy: 0.96855
Testing loss: 0.12507801739036278
Testing accuracy: 0.9634
Epoch 103
-----
Training loss: 0.11404108251333236
Training accuracy: 0.9687833333333333
Testing loss: 0.12452991115771661
Testing accuracy: 0.9633
Epoch 104
-----
Training loss: 0.1132469576338927
Training accuracy: 0.9687833333333333
Testing loss: 0.12406129461185188
Testing accuracy: 0.9638
Epoch 105
-----
Training loss: 0.11251176809867224
Training accuracy: 0.9689333333333333
Testing loss: 0.12725495415366
Testing accuracy: 0.9641
Epoch 106
-----
Training loss: 0.11168555513620376
Training accuracy: 0.9695333333333334
Testing loss: 0.12208762777981105
Testing accuracy: 0.9633
Epoch 107
-----
Training loss: 0.11095961155692736
Training accuracy: 0.9695166666666667
Testing loss: 0.12223353146747419
Testing accuracy: 0.9642
Epoch 108
-----
Training loss: 0.11015822094877561
Training accuracy: 0.9696166666666667
```



```

Testing loss: 0.12157424496617286
Testing accuracy: 0.9642
Epoch 109
-----
Training loss: 0.10938057454824447
Training accuracy: 0.9700333333333333
Testing loss: 0.12197746001895826
Testing accuracy: 0.9646
Epoch 110
-----
Training loss: 0.10874603382945061
Training accuracy: 0.9701333333333333
Testing loss: 0.12083143598524629
Testing accuracy: 0.9648
Epoch 111
-----
Training loss: 0.10802905961573124
Training accuracy: 0.9704333333333334
Testing loss: 0.1200733864383333
Testing accuracy: 0.9643
Epoch 112
-----
Training loss: 0.10733841822346052
Training accuracy: 0.9706333333333333
Testing loss: 0.11860056720958774
Testing accuracy: 0.9648
Epoch 113
-----
Training loss: 0.1066253562728564
Training accuracy: 0.9707833333333333
Testing loss: 0.11864785803778535
Testing accuracy: 0.9655
Epoch 114
-----
Training loss: 0.10586935744583607
Training accuracy: 0.9709
Testing loss: 0.11757330259509907
Testing accuracy: 0.9652
Epoch 115
-----
Training loss: 0.1051717900643746
Training accuracy: 0.9714
Testing loss: 0.11701297160878682
Testing accuracy: 0.9648
Epoch 116
-----
Training loss: 0.10452881636222204
Training accuracy: 0.9714166666666667

```

```

Testing loss: 0.11732533188524899
Testing accuracy: 0.9648
Epoch 117
-----
Training loss: 0.10381940387785435
Training accuracy: 0.9717
Testing loss: 0.1164009128430277
Testing accuracy: 0.9652
Epoch 118
-----
Training loss: 0.1031852244814237
Training accuracy: 0.9719833333333333
Testing loss: 0.11741850629543803
Testing accuracy: 0.9659
Epoch 119
-----
Training loss: 0.10255912828644116
Training accuracy: 0.9722333333333333
Testing loss: 0.1165758176309288
Testing accuracy: 0.966
Epoch 120
-----
Training loss: 0.1018798095971346
Training accuracy: 0.9723666666666667
Testing loss: 0.11576611413412792
Testing accuracy: 0.9661
Epoch 121
-----
Training loss: 0.1012116657892863
Training accuracy: 0.9724666666666667
Testing loss: 0.11391875382726359
Testing accuracy: 0.9662
Epoch 122
-----
Training loss: 0.10070661010940869
Training accuracy: 0.97255
Testing loss: 0.11357411529845113
Testing accuracy: 0.9663
Epoch 123
-----
Training loss: 0.09998978741168976
Training accuracy: 0.9729333333333333
Testing loss: 0.11268304669221116
Testing accuracy: 0.9667
Epoch 124
-----
Training loss: 0.09937975533207258
Training accuracy: 0.9732

```

Testing loss: 0.11287749572923989  
Testing accuracy: 0.9671  
Epoch 125  
-----  
Training loss: 0.09883435918688774  
Training accuracy: 0.97335  
Testing loss: 0.11259389446846618  
Testing accuracy: 0.9671  
Epoch 126  
-----  
Training loss: 0.09809003491898377  
Training accuracy: 0.9734833333333334  
Testing loss: 0.11248129306088207  
Testing accuracy: 0.9676  
Epoch 127  
-----  
Training loss: 0.09761316413283348  
Training accuracy: 0.9736166666666667  
Testing loss: 0.11183607807252438  
Testing accuracy: 0.9666  
Epoch 128  
-----  
Training loss: 0.09702866865893205  
Training accuracy: 0.9738833333333333  
Testing loss: 0.11035474720796581  
Testing accuracy: 0.9673  
Epoch 129  
-----  
Training loss: 0.09641095222135385  
Training accuracy: 0.97415  
Testing loss: 0.11126299707847796  
Testing accuracy: 0.9676  
Epoch 130  
-----  
Training loss: 0.09584624721109868  
Training accuracy: 0.9744166666666667  
Testing loss: 0.10992433324124024  
Testing accuracy: 0.9675  
Epoch 131  
-----  
Training loss: 0.09522831853826841  
Training accuracy: 0.9745  
Testing loss: 0.10991213454087828  
Testing accuracy: 0.968  
Epoch 132  
-----  
Training loss: 0.09475206487178803  
Training accuracy: 0.9745

```

Testing loss: 0.10895141011851418
Testing accuracy: 0.9678
Epoch 133
-----
Training loss: 0.09421664990385373
Training accuracy: 0.97485
Testing loss: 0.10913709150093376
Testing accuracy: 0.9676
Epoch 134
-----
Training loss: 0.09355053089459738
Training accuracy: 0.9748166666666667
Testing loss: 0.10809325791041183
Testing accuracy: 0.9678
Epoch 135
-----
Training loss: 0.0930795419861873
Training accuracy: 0.9752666666666666
Testing loss: 0.10809477168331101
Testing accuracy: 0.9675
Epoch 136
-----
Training loss: 0.09253353774150212
Training accuracy: 0.9749833333333333
Testing loss: 0.10733061951769006
Testing accuracy: 0.9674
Epoch 137
-----
Training loss: 0.09196200502812862
Training accuracy: 0.9754833333333334
Testing loss: 0.10729189170821077
Testing accuracy: 0.9685
Epoch 138
-----
Training loss: 0.09151488586862883
Training accuracy: 0.9755166666666667
Testing loss: 0.10643765034901488
Testing accuracy: 0.9678
Epoch 139
-----
Training loss: 0.09093997897605101
Training accuracy: 0.9755166666666667
Testing loss: 0.10604654442352854
Testing accuracy: 0.9688
Epoch 140
-----
Training loss: 0.09038139551281929
Training accuracy: 0.9757833333333333

```

```

Testing loss: 0.1063027576347635
Testing accuracy: 0.9689
Epoch 141
-----
Training loss: 0.08991326395968596
Training accuracy: 0.9756833333333333
Testing loss: 0.10531129295326722
Testing accuracy: 0.9686
Epoch 142
-----
Training loss: 0.08941385318835576
Training accuracy: 0.9760666666666666
Testing loss: 0.10548719922733155
Testing accuracy: 0.968
Epoch 143
-----
Training loss: 0.08891953357756138
Training accuracy: 0.9763666666666667
Testing loss: 0.10452419254857644
Testing accuracy: 0.9695
Epoch 144
-----
Training loss: 0.08844140873452028
Training accuracy: 0.9762833333333333
Testing loss: 0.10424712475887529
Testing accuracy: 0.9687
Epoch 145
-----
Training loss: 0.08796837033033371
Training accuracy: 0.9766166666666667
Testing loss: 0.10419784087070803
Testing accuracy: 0.9687
Epoch 146
-----
Training loss: 0.08744318627913793
Training accuracy: 0.9767333333333333
Testing loss: 0.10538439221300516
Testing accuracy: 0.9682
Epoch 147
-----
Training loss: 0.086920312388738
Training accuracy: 0.97695
Testing loss: 0.10315709473316077
Testing accuracy: 0.9698
Epoch 148
-----
Training loss: 0.08647689293225606
Training accuracy: 0.9769

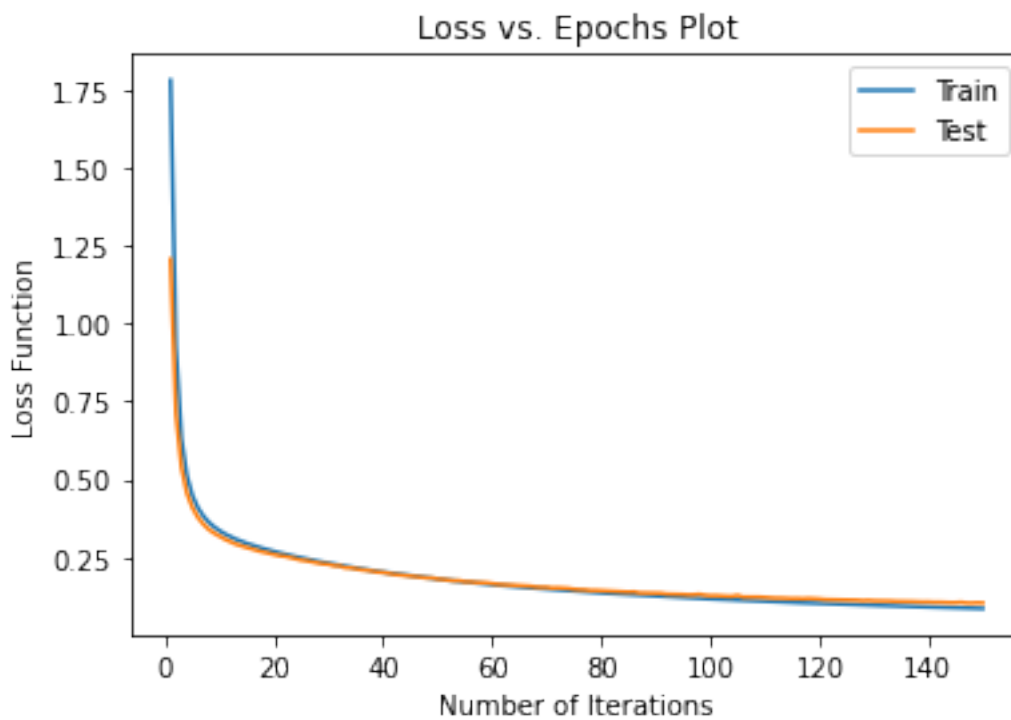
```

```

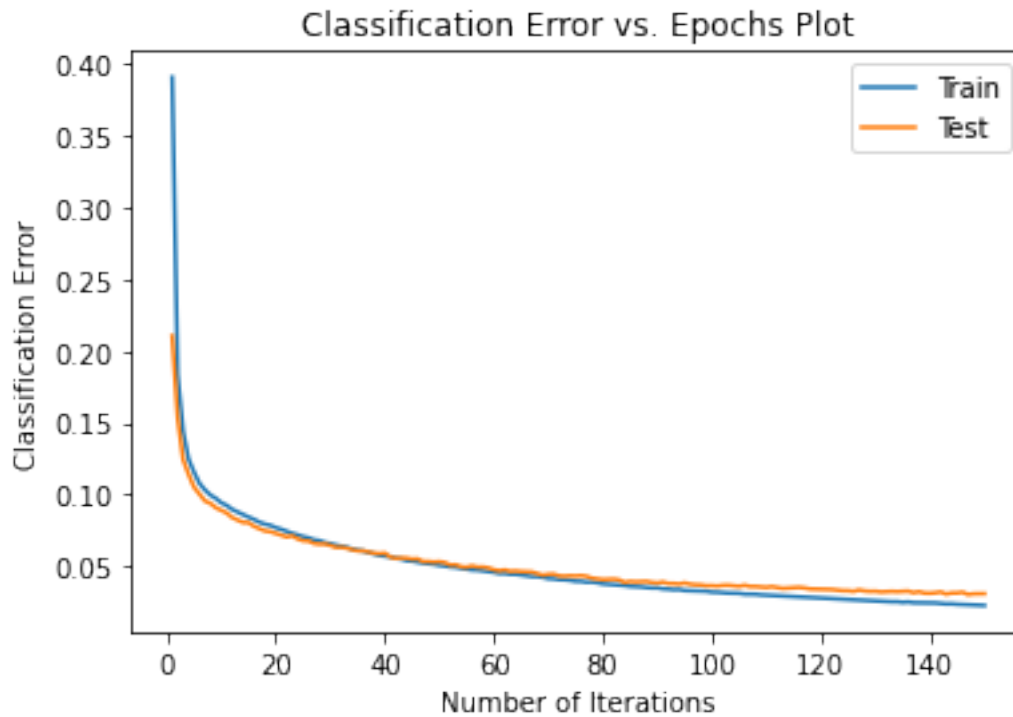
Testing loss: 0.10277136237283421
Testing accuracy: 0.9693
Epoch 149
-----
Training loss: 0.08596996157467365
Training accuracy: 0.9772333333333333
Testing loss: 0.10377107514365083
Testing accuracy: 0.9692
Epoch 150
-----
Training loss: 0.08549223419924577
Training accuracy: 0.9774333333333334
Testing loss: 0.10312806817874977
Testing accuracy: 0.9692
Done
Total Time Consumed: 1646.3181989192963

```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.3.2 Learning Rate = 0.2

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.2
batch_size = 64
num_epochs = 150
model_lr2 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model_lr2.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model_lr2,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model_lr2,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.4925297539154688
Training accuracy: 0.8610333333333333
Testing loss: 0.2701097254160863
Testing accuracy: 0.9235

```

Epoch 2

```

-----
Training loss: 0.25443291803995766
Training accuracy: 0.9249
Testing loss: 0.20727835612217332
Testing accuracy: 0.9378

```

Epoch 3

```

-----
Training loss: 0.20102468764384587
Training accuracy: 0.9416666666666667
Testing loss: 0.19862253370748204
Testing accuracy: 0.9387

```

Epoch 4

```

-----
Training loss: 0.1674269131700198
Training accuracy: 0.95095
Testing loss: 0.15315754612563712
Testing accuracy: 0.9538

```

Epoch 5

```

-----
Training loss: 0.14438400362531345
Training accuracy: 0.9577833333333333
Testing loss: 0.14660975853111713
Testing accuracy: 0.9555

```

Epoch 6

```

-----
Training loss: 0.12727981328368188
Training accuracy: 0.9636666666666667
Testing loss: 0.1204746461052234

```



```

Testing accuracy: 0.9644
Epoch 7
-----
Training loss: 0.1133786259005467
Training accuracy: 0.9672
Testing loss: 0.118737856602403
Testing accuracy: 0.9649
Epoch 8
-----
Training loss: 0.10195640126566093
Training accuracy: 0.9713833333333334
Testing loss: 0.12001199837014744
Testing accuracy: 0.9641
Epoch 9
-----
Training loss: 0.09349287947714328
Training accuracy: 0.9733333333333334
Testing loss: 0.10460447082236694
Testing accuracy: 0.9689
Epoch 10
-----
Training loss: 0.08612477659781774
Training accuracy: 0.97545
Testing loss: 0.09507047276421907
Testing accuracy: 0.9719
Epoch 11
-----
Training loss: 0.07951829469005267
Training accuracy: 0.9778
Testing loss: 0.1088857735702946
Testing accuracy: 0.9671
Epoch 12
-----
Training loss: 0.07389787371853987
Training accuracy: 0.9789166666666667
Testing loss: 0.09229508737564847
Testing accuracy: 0.9721
Epoch 13
-----
Training loss: 0.06855464845697085
Training accuracy: 0.98115
Testing loss: 0.08965911410132031
Testing accuracy: 0.9731
Epoch 14
-----
Training loss: 0.06526318501681089
Training accuracy: 0.9819166666666667
Testing loss: 0.09215567603256482

```

```
Testing accuracy: 0.9708
Epoch 15
-----
Training loss: 0.06061850598230958
Training accuracy: 0.98345
Testing loss: 0.08042022779844939
Testing accuracy: 0.9733
Epoch 16
-----
Training loss: 0.05694580808977286
Training accuracy: 0.9844166666666667
Testing loss: 0.08492186650704996
Testing accuracy: 0.9743
Epoch 17
-----
Training loss: 0.053458352835973104
Training accuracy: 0.98575
Testing loss: 0.08821301149192509
Testing accuracy: 0.9716
Epoch 18
-----
Training loss: 0.05043653239160776
Training accuracy: 0.98635
Testing loss: 0.0777721361814743
Testing accuracy: 0.976
Epoch 19
-----
Training loss: 0.04820246458450953
Training accuracy: 0.9869833333333333
Testing loss: 0.07938349165117285
Testing accuracy: 0.9746
Epoch 20
-----
Training loss: 0.04532757030154268
Training accuracy: 0.9879333333333333
Testing loss: 0.08227783849071356
Testing accuracy: 0.9737
Epoch 21
-----
Training loss: 0.04317888357043266
Training accuracy: 0.9891166666666666
Testing loss: 0.07703905368733938
Testing accuracy: 0.975
Epoch 22
-----
Training loss: 0.04046037737478812
Training accuracy: 0.9897166666666667
Testing loss: 0.07846138935393779
```

```

Testing accuracy: 0.976
Epoch 23
-----
Training loss: 0.0387261828991274
Training accuracy: 0.9902833333333333
Testing loss: 0.07486358031654244
Testing accuracy: 0.976
Epoch 24
-----
Training loss: 0.036523745447645584
Training accuracy: 0.991
Testing loss: 0.07553136148371371
Testing accuracy: 0.9762
Epoch 25
-----
Training loss: 0.035290890874216954
Training accuracy: 0.99155
Testing loss: 0.0712745359529308
Testing accuracy: 0.9772
Epoch 26
-----
Training loss: 0.033141161876171825
Training accuracy: 0.9923833333333333
Testing loss: 0.07263521940275362
Testing accuracy: 0.9766
Epoch 27
-----
Training loss: 0.031753245503207045
Training accuracy: 0.9925333333333334
Testing loss: 0.07076759306286835
Testing accuracy: 0.9778
Epoch 28
-----
Training loss: 0.029704038719832897
Training accuracy: 0.9935166666666667
Testing loss: 0.07765605284648526
Testing accuracy: 0.9749
Epoch 29
-----
Training loss: 0.028499297967304785
Training accuracy: 0.9936666666666667
Testing loss: 0.07462403493796944
Testing accuracy: 0.977
Epoch 30
-----
Training loss: 0.027436882142722607
Training accuracy: 0.9942
Testing loss: 0.07525085037645356

```

```
Testing accuracy: 0.9774
Epoch 31
-----
Training loss: 0.02589911768188079
Training accuracy: 0.9949
Testing loss: 0.0725952782860963
Testing accuracy: 0.977
Epoch 32
-----
Training loss: 0.02503665080318848
Training accuracy: 0.9946666666666667
Testing loss: 0.06919588010378513
Testing accuracy: 0.9795
Epoch 33
-----
Training loss: 0.02391785683060686
Training accuracy: 0.9951333333333333
Testing loss: 0.07736310055835327
Testing accuracy: 0.9746
Epoch 34
-----
Training loss: 0.022843148454402884
Training accuracy: 0.9954666666666667
Testing loss: 0.08864421266647186
Testing accuracy: 0.9742
Epoch 35
-----
Training loss: 0.02152468349374831
Training accuracy: 0.9960666666666667
Testing loss: 0.08413204117411166
Testing accuracy: 0.9737
Epoch 36
-----
Training loss: 0.020564908726637562
Training accuracy: 0.9963666666666666
Testing loss: 0.0709129943553904
Testing accuracy: 0.9772
Epoch 37
-----
Training loss: 0.019820378629863262
Training accuracy: 0.9965833333333334
Testing loss: 0.0711614066144677
Testing accuracy: 0.9784
Epoch 38
-----
Training loss: 0.01915211446726074
Training accuracy: 0.9966
Testing loss: 0.07113665191510063
```

```
Testing accuracy: 0.9786
Epoch 39
-----
Training loss: 0.017962089524790645
Training accuracy: 0.9970833333333333
Testing loss: 0.07312907522490877
Testing accuracy: 0.9774
Epoch 40
-----
Training loss: 0.01750570562146604
Training accuracy: 0.9970833333333333
Testing loss: 0.06779545284125503
Testing accuracy: 0.9778
Epoch 41
-----
Training loss: 0.016795794728025795
Training accuracy: 0.9975333333333334
Testing loss: 0.06979758772038065
Testing accuracy: 0.9778
Epoch 42
-----
Training loss: 0.01585656350882103
Training accuracy: 0.9975333333333334
Testing loss: 0.06822891030341956
Testing accuracy: 0.9786
Epoch 43
-----
Training loss: 0.01541141320882986
Training accuracy: 0.9976833333333334
Testing loss: 0.07183910508871458
Testing accuracy: 0.9781
Epoch 44
-----
Training loss: 0.01467274236616989
Training accuracy: 0.9982
Testing loss: 0.0674765701311163
Testing accuracy: 0.9786
Epoch 45
-----
Training loss: 0.014182580518287916
Training accuracy: 0.9979833333333333
Testing loss: 0.06786551538433666
Testing accuracy: 0.9793
Epoch 46
-----
Training loss: 0.013793713323399424
Training accuracy: 0.99835
Testing loss: 0.0684737177876382
```

```
Testing accuracy: 0.9791
Epoch 47
-----
Training loss: 0.013176126104344925
Training accuracy: 0.9984
Testing loss: 0.06991640167981149
Testing accuracy: 0.9786
Epoch 48
-----
Training loss: 0.012685350521778067
Training accuracy: 0.9986333333333334
Testing loss: 0.07190884013399244
Testing accuracy: 0.9769
Epoch 49
-----
Training loss: 0.01197722979572912
Training accuracy: 0.9989166666666667
Testing loss: 0.06874381633739396
Testing accuracy: 0.9777
Epoch 50
-----
Training loss: 0.011734955999627709
Training accuracy: 0.9988666666666667
Testing loss: 0.06862439261675236
Testing accuracy: 0.9786
Epoch 51
-----
Training loss: 0.011451761904358863
Training accuracy: 0.9989333333333333
Testing loss: 0.06997465320112432
Testing accuracy: 0.9787
Epoch 52
-----
Training loss: 0.010825172662797073
Training accuracy: 0.9991166666666667
Testing loss: 0.06980828143682948
Testing accuracy: 0.9794
Epoch 53
-----
Training loss: 0.010441504501923918
Training accuracy: 0.9991166666666667
Testing loss: 0.06959842487885676
Testing accuracy: 0.9785
Epoch 54
-----
Training loss: 0.010195269589684903
Training accuracy: 0.9991833333333333
Testing loss: 0.06981171721112055
```

```

Testing accuracy: 0.9786
Epoch 55
-----
Training loss: 0.009765104685847958
Training accuracy: 0.9992833333333333
Testing loss: 0.06931551215891388
Testing accuracy: 0.9781
Epoch 56
-----
Training loss: 0.009437771815185746
Training accuracy: 0.9994666666666666
Testing loss: 0.07014182741030055
Testing accuracy: 0.979
Epoch 57
-----
Training loss: 0.009167944742242496
Training accuracy: 0.99945
Testing loss: 0.07055318477240266
Testing accuracy: 0.9783
Epoch 58
-----
Training loss: 0.008927622020741304
Training accuracy: 0.9993666666666666
Testing loss: 0.07116899648340194
Testing accuracy: 0.9785
Epoch 59
-----
Training loss: 0.00849285482770453
Training accuracy: 0.9995666666666667
Testing loss: 0.07185219459467015
Testing accuracy: 0.9789
Epoch 60
-----
Training loss: 0.008295987420901657
Training accuracy: 0.9995
Testing loss: 0.07020232256666525
Testing accuracy: 0.9792
Epoch 61
-----
Training loss: 0.008089884131525954
Training accuracy: 0.9995666666666667
Testing loss: 0.06910578676374854
Testing accuracy: 0.9784
Epoch 62
-----
Training loss: 0.007869202172445754
Training accuracy: 0.9996166666666667
Testing loss: 0.0704833958935657

```

```

Testing accuracy: 0.9788
Epoch 63
-----
Training loss: 0.007586781045918664
Training accuracy: 0.9997
Testing loss: 0.07012671821158985
Testing accuracy: 0.9787
Epoch 64
-----
Training loss: 0.007354234546795488
Training accuracy: 0.9997166666666667
Testing loss: 0.06996953323117167
Testing accuracy: 0.9787
Epoch 65
-----
Training loss: 0.007203063073133429
Training accuracy: 0.9997166666666667
Testing loss: 0.07050420910529318
Testing accuracy: 0.979
Epoch 66
-----
Training loss: 0.006976654252037406
Training accuracy: 0.9996833333333334
Testing loss: 0.07134280046359132
Testing accuracy: 0.9785
Epoch 67
-----
Training loss: 0.006807751687678198
Training accuracy: 0.9997
Testing loss: 0.07305724521398924
Testing accuracy: 0.9791
Epoch 68
-----
Training loss: 0.006652937766723334
Training accuracy: 0.9997666666666667
Testing loss: 0.06970735861190186
Testing accuracy: 0.9787
Epoch 69
-----
Training loss: 0.006432958323756854
Training accuracy: 0.9997666666666667
Testing loss: 0.07241308516793095
Testing accuracy: 0.9788
Epoch 70
-----
Training loss: 0.006328333899813394
Training accuracy: 0.99975
Testing loss: 0.07052952911968752

```



```
Testing accuracy: 0.9791
Epoch 71
-----
Training loss: 0.00607731867376715
Training accuracy: 0.9998333333333334
Testing loss: 0.07163553673975692
Testing accuracy: 0.9785
Epoch 72
-----
Training loss: 0.00600382646759972
Training accuracy: 0.9998166666666667
Testing loss: 0.0710974369449452
Testing accuracy: 0.9786
Epoch 73
-----
Training loss: 0.005785220237883429
Training accuracy: 0.9998833333333333
Testing loss: 0.06994598310004778
Testing accuracy: 0.9786
Epoch 74
-----
Training loss: 0.005650826175697148
Training accuracy: 0.9998666666666667
Testing loss: 0.07055194467116313
Testing accuracy: 0.9791
Epoch 75
-----
Training loss: 0.005516783919123312
Training accuracy: 0.9999
Testing loss: 0.07629340961664488
Testing accuracy: 0.9779
Epoch 76
-----
Training loss: 0.005385696309742828
Training accuracy: 0.99985
Testing loss: 0.07120001221529451
Testing accuracy: 0.9792
Epoch 77
-----
Training loss: 0.00521462804597492
Training accuracy: 0.9999
Testing loss: 0.0713379085212234
Testing accuracy: 0.9796
Epoch 78
-----
Training loss: 0.005170952374550204
Training accuracy: 0.9999
Testing loss: 0.07150931294360881
```

```
Testing accuracy: 0.9792
Epoch 79
-----
Training loss: 0.0050751867307350035
Training accuracy: 0.9998833333333333
Testing loss: 0.07209605508770164
Testing accuracy: 0.9793
Epoch 80
-----
Training loss: 0.004893801237611721
Training accuracy: 0.9999166666666667
Testing loss: 0.07080297978152966
Testing accuracy: 0.9792
Epoch 81
-----
Training loss: 0.004811737191785748
Training accuracy: 0.9999166666666667
Testing loss: 0.07196845738128255
Testing accuracy: 0.9788
Epoch 82
-----
Training loss: 0.004700003798026591
Training accuracy: 0.9999166666666667
Testing loss: 0.07129359422740972
Testing accuracy: 0.9793
Epoch 83
-----
Training loss: 0.004587836965577056
Training accuracy: 0.9999333333333333
Testing loss: 0.07188645583966
Testing accuracy: 0.9788
Epoch 84
-----
Training loss: 0.004511233770598968
Training accuracy: 0.9999666666666667
Testing loss: 0.07125367572739465
Testing accuracy: 0.9786
Epoch 85
-----
Training loss: 0.004433901558257639
Training accuracy: 0.9999666666666667
Testing loss: 0.07201005288126884
Testing accuracy: 0.9796
Epoch 86
-----
Training loss: 0.004353871261763076
Training accuracy: 0.9999666666666667
Testing loss: 0.0784993202085933
```

```
Testing accuracy: 0.9772
Epoch 87
-----
Training loss: 0.004254544389123718
Training accuracy: 0.9999666666666667
Testing loss: 0.0717004301941473
Testing accuracy: 0.9793
Epoch 88
-----
Training loss: 0.004195479281091442
Training accuracy: 0.9999666666666667
Testing loss: 0.0708480121858513
Testing accuracy: 0.9788
Epoch 89
-----
Training loss: 0.004077013465606918
Training accuracy: 0.9999833333333333
Testing loss: 0.07260486650337009
Testing accuracy: 0.9796
Epoch 90
-----
Training loss: 0.003998002691318591
Training accuracy: 0.99995
Testing loss: 0.07294425980768546
Testing accuracy: 0.9789
Epoch 91
-----
Training loss: 0.003960302305283646
Training accuracy: 0.9999666666666667
Testing loss: 0.07291673844721715
Testing accuracy: 0.979
Epoch 92
-----
Training loss: 0.00395624058128645
Training accuracy: 0.9999833333333333
Testing loss: 0.07339627039359266
Testing accuracy: 0.9792
Epoch 93
-----
Training loss: 0.003829025805120667
Training accuracy: 0.9999666666666667
Testing loss: 0.0716601332344091
Testing accuracy: 0.9792
Epoch 94
-----
Training loss: 0.00371944929578652
Training accuracy: 0.9999833333333333
Testing loss: 0.0725861732539525
```

```
Testing accuracy: 0.9791
Epoch 95
-----
Training loss: 0.0036782553180431327
Training accuracy: 0.9999666666666667
Testing loss: 0.07228931835756168
Testing accuracy: 0.9792
Epoch 96
-----
Training loss: 0.0035981927440191307
Training accuracy: 1.0
Testing loss: 0.07325168819667974
Testing accuracy: 0.9791
Epoch 97
-----
Training loss: 0.0035509341386457285
Training accuracy: 0.9999833333333333
Testing loss: 0.07446653870079714
Testing accuracy: 0.9785
Epoch 98
-----
Training loss: 0.0034926445910396673
Training accuracy: 0.9999833333333333
Testing loss: 0.07478805728572581
Testing accuracy: 0.9786
Epoch 99
-----
Training loss: 0.00344458821201697
Training accuracy: 1.0
Testing loss: 0.07190293104815665
Testing accuracy: 0.9793
Epoch 100
-----
Training loss: 0.0033948308615013956
Training accuracy: 1.0
Testing loss: 0.0722229470333691
Testing accuracy: 0.9794
Epoch 101
-----
Training loss: 0.003326039656593154
Training accuracy: 1.0
Testing loss: 0.07273712117153748
Testing accuracy: 0.9799
Epoch 102
-----
Training loss: 0.003257676115166396
Training accuracy: 1.0
Testing loss: 0.07332874422115837
```

Testing accuracy: 0.9789  
Epoch 103  
-----  
Training loss: 0.003214887089080488  
Training accuracy: 1.0  
Testing loss: 0.0731534343307384  
Testing accuracy: 0.979  
Epoch 104  
-----  
Training loss: 0.0031904069625151655  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07368535147223526  
Testing accuracy: 0.979  
Epoch 105  
-----  
Training loss: 0.003111799949283401  
Training accuracy: 1.0  
Testing loss: 0.07863199440810598  
Testing accuracy: 0.9787  
Epoch 106  
-----  
Training loss: 0.0030738159011118116  
Training accuracy: 1.0  
Testing loss: 0.07363302770992415  
Testing accuracy: 0.9789  
Epoch 107  
-----  
Training loss: 0.0030456077925550443  
Training accuracy: 1.0  
Testing loss: 0.07464189421879365  
Testing accuracy: 0.9789  
Epoch 108  
-----  
Training loss: 0.0029739598741444447  
Training accuracy: 1.0  
Testing loss: 0.07205953967170256  
Testing accuracy: 0.9797  
Epoch 109  
-----  
Training loss: 0.0029526330659165978  
Training accuracy: 1.0  
Testing loss: 0.07533392970410181  
Testing accuracy: 0.9795  
Epoch 110  
-----  
Training loss: 0.002904335692462822  
Training accuracy: 1.0  
Testing loss: 0.07433199979272927

```
Testing accuracy: 0.979
Epoch 111
-----
Training loss: 0.002875184680505966
Training accuracy: 1.0
Testing loss: 0.07518885812692858
Testing accuracy: 0.9791
Epoch 112
-----
Training loss: 0.002832484073098749
Training accuracy: 1.0
Testing loss: 0.07503062639249027
Testing accuracy: 0.9784
Epoch 113
-----
Training loss: 0.002799818608475228
Training accuracy: 1.0
Testing loss: 0.07445236858148069
Testing accuracy: 0.98
Epoch 114
-----
Training loss: 0.0027408694688851633
Training accuracy: 1.0
Testing loss: 0.07426790912783182
Testing accuracy: 0.9793
Epoch 115
-----
Training loss: 0.002712811127770692
Training accuracy: 1.0
Testing loss: 0.07414938604698207
Testing accuracy: 0.9794
Epoch 116
-----
Training loss: 0.0026843708453699947
Training accuracy: 1.0
Testing loss: 0.07450840418052024
Testing accuracy: 0.9793
Epoch 117
-----
Training loss: 0.002649035831571867
Training accuracy: 1.0
Testing loss: 0.07409427277921776
Testing accuracy: 0.979
Epoch 118
-----
Training loss: 0.0026145864131549993
Training accuracy: 1.0
Testing loss: 0.07731498637945527
```

Testing accuracy: 0.9797  
Epoch 119  
-----  
Training loss: 0.0025680917933272817  
Training accuracy: 1.0  
Testing loss: 0.07399494288293466  
Testing accuracy: 0.98  
Epoch 120  
-----  
Training loss: 0.0025491863538045435  
Training accuracy: 1.0  
Testing loss: 0.0755894440774966  
Testing accuracy: 0.979  
Epoch 121  
-----  
Training loss: 0.0025108630111441016  
Training accuracy: 1.0  
Testing loss: 0.07423356228690094  
Testing accuracy: 0.9792  
Epoch 122  
-----  
Training loss: 0.002495454161334783  
Training accuracy: 1.0  
Testing loss: 0.07432122742364207  
Testing accuracy: 0.9789  
Epoch 123  
-----  
Training loss: 0.002451919825266426  
Training accuracy: 1.0  
Testing loss: 0.07445174296591194  
Testing accuracy: 0.9794  
Epoch 124  
-----  
Training loss: 0.0024239760239763808  
Training accuracy: 1.0  
Testing loss: 0.07559779215089467  
Testing accuracy: 0.9792  
Epoch 125  
-----  
Training loss: 0.0024076716179183373  
Training accuracy: 1.0  
Testing loss: 0.07520163387829841  
Testing accuracy: 0.9789  
Epoch 126  
-----  
Training loss: 0.002355409509704138  
Training accuracy: 1.0  
Testing loss: 0.0755511977873701

```
Testing accuracy: 0.9793
Epoch 127
-----
Training loss: 0.0023514406482689084
Training accuracy: 1.0
Testing loss: 0.07517929834938032
Testing accuracy: 0.9795
Epoch 128
-----
Training loss: 0.002311989712404708
Training accuracy: 1.0
Testing loss: 0.07526580248241962
Testing accuracy: 0.9792
Epoch 129
-----
Training loss: 0.0022910758479032668
Training accuracy: 1.0
Testing loss: 0.07510154452849666
Testing accuracy: 0.9797
Epoch 130
-----
Training loss: 0.0022610178499016913
Training accuracy: 1.0
Testing loss: 0.07570058751479088
Testing accuracy: 0.9793
Epoch 131
-----
Training loss: 0.002231805898156017
Training accuracy: 1.0
Testing loss: 0.07633675028092471
Testing accuracy: 0.979
Epoch 132
-----
Training loss: 0.0022180036797343444
Training accuracy: 1.0
Testing loss: 0.07544934200474701
Testing accuracy: 0.9794
Epoch 133
-----
Training loss: 0.002191202354027579
Training accuracy: 1.0
Testing loss: 0.07548102140752895
Testing accuracy: 0.9791
Epoch 134
-----
Training loss: 0.0021566875309217723
Training accuracy: 1.0
Testing loss: 0.07589318083152828
```



```
Testing accuracy: 0.9791
Epoch 135
-----
Training loss: 0.002149154946487397
Training accuracy: 1.0
Testing loss: 0.07498593769110569
Testing accuracy: 0.9795
Epoch 136
-----
Training loss: 0.0021162893165523806
Training accuracy: 1.0
Testing loss: 0.07543831114278317
Testing accuracy: 0.979
Epoch 137
-----
Training loss: 0.002097629610231767
Training accuracy: 1.0
Testing loss: 0.07595425159650021
Testing accuracy: 0.979
Epoch 138
-----
Training loss: 0.00207057424314941
Training accuracy: 1.0
Testing loss: 0.07623816314850382
Testing accuracy: 0.9789
Epoch 139
-----
Training loss: 0.002049423862900585
Training accuracy: 1.0
Testing loss: 0.07734956013062483
Testing accuracy: 0.9791
Epoch 140
-----
Training loss: 0.002033738537163784
Training accuracy: 1.0
Testing loss: 0.075623072078192
Testing accuracy: 0.9792
Epoch 141
-----
Training loss: 0.0020161910391412676
Training accuracy: 1.0
Testing loss: 0.07615856941599194
Testing accuracy: 0.9795
Epoch 142
-----
Training loss: 0.0019987772130717835
Training accuracy: 1.0
Testing loss: 0.07622479341381413
```

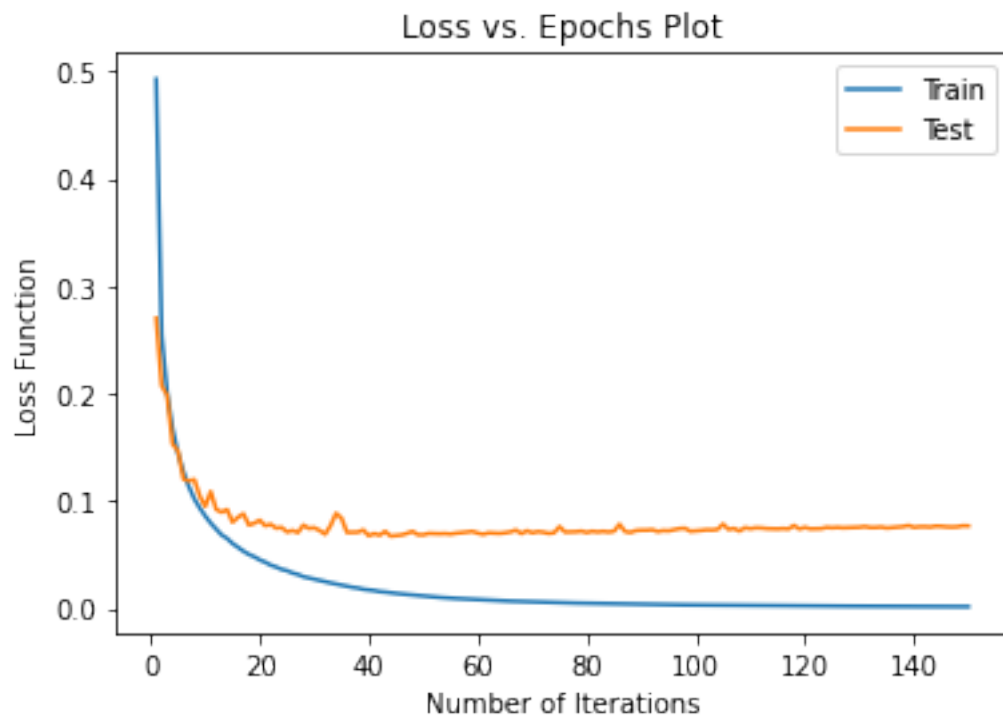
```
Testing accuracy: 0.9795
Epoch 143
-----
Training loss: 0.0019739849221737434
Training accuracy: 1.0
Testing loss: 0.07587931882723525
Testing accuracy: 0.9795
Epoch 144
-----
Training loss: 0.0019482200229695688
Training accuracy: 1.0
Testing loss: 0.07672034193254461
Testing accuracy: 0.9788
Epoch 145
-----
Training loss: 0.0019406232096099605
Training accuracy: 1.0
Testing loss: 0.07655026603736292
Testing accuracy: 0.9791
Epoch 146
-----
Training loss: 0.0019176464373401056
Training accuracy: 1.0
Testing loss: 0.07606521519038167
Testing accuracy: 0.9795
Epoch 147
-----
Training loss: 0.0018952961156144738
Training accuracy: 1.0
Testing loss: 0.07588975075750974
Testing accuracy: 0.9793
Epoch 148
-----
Training loss: 0.0018799007528306295
Training accuracy: 1.0
Testing loss: 0.07612740300346617
Testing accuracy: 0.9794
Epoch 149
-----
Training loss: 0.0018639077450769643
Training accuracy: 1.0
Testing loss: 0.07706059070132008
Testing accuracy: 0.9792
Epoch 150
-----
Training loss: 0.001839626108808443
Training accuracy: 1.0
Testing loss: 0.07687620854406763
```

Testing accuracy: 0.9791

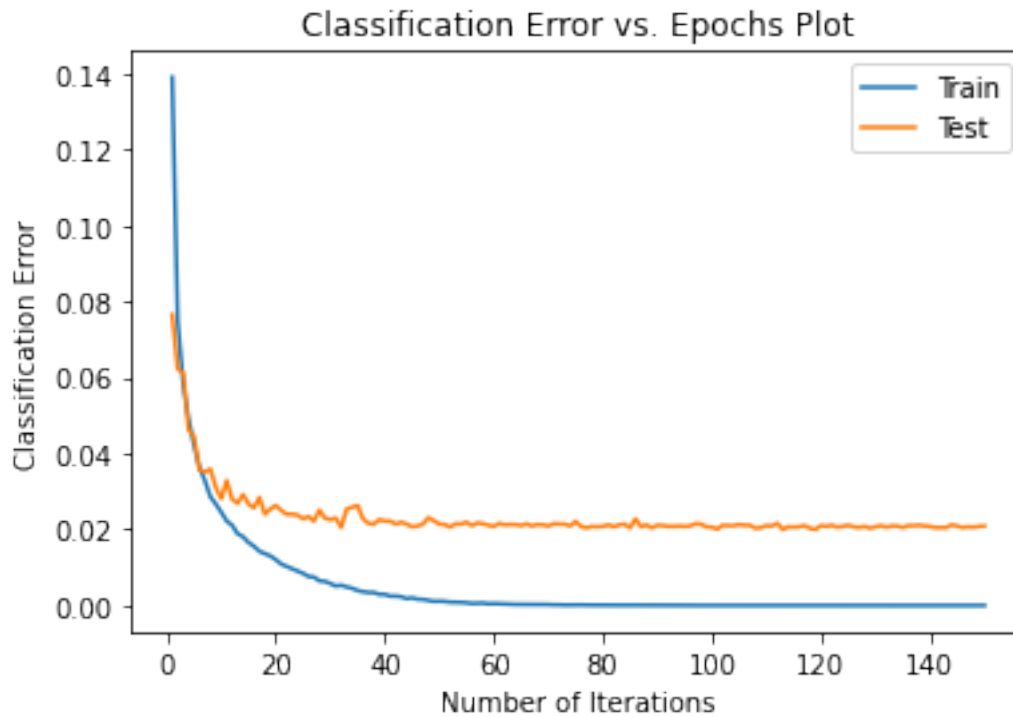
Done

Total Time Consumed: 1664.1122517585754

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.3.3 Learning Rate = 0.5

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.5
batch_size = 64
num_epochs = 150
model_lr5 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model_lr5.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model_lr5,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model_lr5,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Training loss: 0.4216313532034556  
 Training accuracy: 0.8694333333333333  
 Testing loss: 0.2060676057389967  
 Testing accuracy: 0.9393  
 Epoch 2

-----  
 Training loss: 0.19004056726098062  
 Training accuracy: 0.94295  
 Testing loss: 0.1550792233460838  
 Testing accuracy: 0.9528  
 Epoch 3

-----  
 Training loss: 0.14102522436380385  
 Training accuracy: 0.9579333333333333  
 Testing loss: 0.1441990660835698  
 Testing accuracy: 0.9574  
 Epoch 4

-----  
 Training loss: 0.11476427598098914  
 Training accuracy: 0.9659166666666666  
 Testing loss: 0.12140255162765266  
 Testing accuracy: 0.9615  
 Epoch 5

-----  
 Training loss: 0.0984937423268954  
 Training accuracy: 0.97095  
 Testing loss: 0.10719659830781685  
 Testing accuracy: 0.9654  
 Epoch 6

-----  
 Training loss: 0.08611776315172513  
 Training accuracy: 0.9748666666666667  
 Testing loss: 0.10067640834304083  
 Testing accuracy: 0.9695  
 Epoch 7

-----  
Training loss: 0.07579260809024176  
Training accuracy: 0.9773666666666667  
Testing loss: 0.09759145166582553  
Testing accuracy: 0.9697  
Epoch 8  
-----

Training loss: 0.06752846385538579  
Training accuracy: 0.9798166666666667  
Testing loss: 0.12305012049900878  
Testing accuracy: 0.9598  
Epoch 9  
-----

Training loss: 0.06128741878320773  
Training accuracy: 0.98155  
Testing loss: 0.09115228290331497  
Testing accuracy: 0.9719  
Epoch 10  
-----

Training loss: 0.055301758289833865  
Training accuracy: 0.9836666666666667  
Testing loss: 0.08387586636065393  
Testing accuracy: 0.9739  
Epoch 11  
-----

Training loss: 0.05074074465185404  
Training accuracy: 0.9850166666666667  
Testing loss: 0.10728366142079519  
Testing accuracy: 0.9673  
Epoch 12  
-----

Training loss: 0.04554408260012666  
Training accuracy: 0.98705  
Testing loss: 0.09287637627867472  
Testing accuracy: 0.9708  
Epoch 13  
-----

Training loss: 0.04125535024628043  
Training accuracy: 0.9880333333333333  
Testing loss: 0.08290776017027059  
Testing accuracy: 0.9744  
Epoch 14  
-----

Training loss: 0.0390311948950092  
Training accuracy: 0.9886833333333334  
Testing loss: 0.08089281531691456  
Testing accuracy: 0.9738  
Epoch 15

-----  
Training loss: 0.035351994730656346  
Training accuracy: 0.99015  
Testing loss: 0.08080041504488772  
Testing accuracy: 0.9751  
Epoch 16

-----  
Training loss: 0.031465888233234485  
Training accuracy: 0.9918  
Testing loss: 0.07825953820809295  
Testing accuracy: 0.9764  
Epoch 17

-----  
Training loss: 0.02892143629565835  
Training accuracy: 0.9924333333333333  
Testing loss: 0.07813696378091599  
Testing accuracy: 0.9751  
Epoch 18

-----  
Training loss: 0.026526071316748858  
Training accuracy: 0.9932833333333333  
Testing loss: 0.07560914854080102  
Testing accuracy: 0.9781  
Epoch 19

-----  
Training loss: 0.02402132819071412  
Training accuracy: 0.9940166666666667  
Testing loss: 0.0765466629683224  
Testing accuracy: 0.9754  
Epoch 20

-----  
Training loss: 0.023346207033346097  
Training accuracy: 0.9941333333333333  
Testing loss: 0.0742349490066575  
Testing accuracy: 0.9766  
Epoch 21

-----  
Training loss: 0.021206472239643337  
Training accuracy: 0.9949333333333333  
Testing loss: 0.08253444961693351  
Testing accuracy: 0.9741  
Epoch 22

-----  
Training loss: 0.01927007776548465  
Training accuracy: 0.99575  
Testing loss: 0.08281791528129274  
Testing accuracy: 0.976  
Epoch 23

-----  
Training loss: 0.017389663130727907  
Training accuracy: 0.99655  
Testing loss: 0.07610374049633552  
Testing accuracy: 0.9765  
Epoch 24

-----  
Training loss: 0.015831584352006513  
Training accuracy: 0.9968833333333333  
Testing loss: 0.07763053823535325  
Testing accuracy: 0.9768  
Epoch 25

-----  
Training loss: 0.015678206380829215  
Training accuracy: 0.9968166666666667  
Testing loss: 0.07531330880195876  
Testing accuracy: 0.9777  
Epoch 26

-----  
Training loss: 0.013433079586178065  
Training accuracy: 0.9977  
Testing loss: 0.07409634973236899  
Testing accuracy: 0.9779  
Epoch 27

-----  
Training loss: 0.012260141726645331  
Training accuracy: 0.9980666666666667  
Testing loss: 0.0768430375436226  
Testing accuracy: 0.9767  
Epoch 28

-----  
Training loss: 0.011101756295561791  
Training accuracy: 0.9983166666666666  
Testing loss: 0.07764884797859177  
Testing accuracy: 0.9765  
Epoch 29

-----  
Training loss: 0.010275062171431879  
Training accuracy: 0.99855  
Testing loss: 0.08159310969295704  
Testing accuracy: 0.9763  
Epoch 30

-----  
Training loss: 0.009543377214732269  
Training accuracy: 0.99875  
Testing loss: 0.07892950089013642  
Testing accuracy: 0.977  
Epoch 31



-----  
Training loss: 0.00848511403761804  
Training accuracy: 0.9992666666666666  
Testing loss: 0.07659793664422479  
Testing accuracy: 0.9759  
Epoch 32

-----  
Training loss: 0.007871461728028953  
Training accuracy: 0.9993166666666666  
Testing loss: 0.0778664206143522  
Testing accuracy: 0.9771  
Epoch 33

-----  
Training loss: 0.0073423395502070585  
Training accuracy: 0.9993833333333333  
Testing loss: 0.07561372121414882  
Testing accuracy: 0.9775  
Epoch 34

-----  
Training loss: 0.007092240309125433  
Training accuracy: 0.99935  
Testing loss: 0.093815027982305  
Testing accuracy: 0.9742  
Epoch 35

-----  
Training loss: 0.006690849634073675  
Training accuracy: 0.9993833333333333  
Testing loss: 0.08129010875679694  
Testing accuracy: 0.9763  
Epoch 36

-----  
Training loss: 0.006022247443037729  
Training accuracy: 0.9995166666666667  
Testing loss: 0.07985559114585719  
Testing accuracy: 0.9764  
Epoch 37

-----  
Training loss: 0.005606045510495703  
Training accuracy: 0.99965  
Testing loss: 0.07846162613528739  
Testing accuracy: 0.9779  
Epoch 38

-----  
Training loss: 0.005248547890782356  
Training accuracy: 0.99975  
Testing loss: 0.08005420009569994  
Testing accuracy: 0.9763  
Epoch 39

-----  
Training loss: 0.0048327276679687205  
Training accuracy: 0.9998  
Testing loss: 0.07904447993162758  
Testing accuracy: 0.9774  
Epoch 40  
-----

Training loss: 0.004753809805493802  
Training accuracy: 0.9997833333333334  
Testing loss: 0.0778658375469152  
Testing accuracy: 0.9773  
Epoch 41  
-----

Training loss: 0.004341491195342193  
Training accuracy: 0.9998666666666667  
Testing loss: 0.07924401194819658  
Testing accuracy: 0.9769  
Epoch 42  
-----

Training loss: 0.00427965102205053  
Training accuracy: 0.9998333333333334  
Testing loss: 0.07888929415672163  
Testing accuracy: 0.9778  
Epoch 43  
-----

Training loss: 0.003930885046254843  
Training accuracy: 0.99985  
Testing loss: 0.0779023173633684  
Testing accuracy: 0.9774  
Epoch 44  
-----

Training loss: 0.004207527306055029  
Training accuracy: 0.99985  
Testing loss: 0.07870387660571564  
Testing accuracy: 0.9776  
Epoch 45  
-----

Training loss: 0.0036417334208109727  
Training accuracy: 0.9998833333333333  
Testing loss: 0.08027218035340701  
Testing accuracy: 0.978  
Epoch 46  
-----

Training loss: 0.0036139803860957423  
Training accuracy: 0.9998833333333333  
Testing loss: 0.0807234970704433  
Testing accuracy: 0.9765  
Epoch 47

-----  
Training loss: 0.0033893403553093473  
Training accuracy: 0.9999  
Testing loss: 0.07911427169128034  
Testing accuracy: 0.9772  
Epoch 48

-----  
Training loss: 0.00315837465574344  
Training accuracy: 0.9999666666666667  
Testing loss: 0.07828200275484758  
Testing accuracy: 0.978  
Epoch 49

-----  
Training loss: 0.0030430448159420244  
Training accuracy: 0.9999666666666667  
Testing loss: 0.0817950240701176  
Testing accuracy: 0.9777  
Epoch 50

-----  
Training loss: 0.0029266599944482246  
Training accuracy: 0.9999666666666667  
Testing loss: 0.07931445269731606  
Testing accuracy: 0.9779  
Epoch 51

-----  
Training loss: 0.0028332406549093623  
Training accuracy: 0.9999666666666667  
Testing loss: 0.08006338637795264  
Testing accuracy: 0.9778  
Epoch 52

-----  
Training loss: 0.0027392340429127217  
Training accuracy: 0.9999666666666667  
Testing loss: 0.082392453574531  
Testing accuracy: 0.9777  
Epoch 53

-----  
Training loss: 0.0026200231050296377  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08109654926574066  
Testing accuracy: 0.9776  
Epoch 54

-----  
Training loss: 0.002538303793175146  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08225843300420055  
Testing accuracy: 0.9779  
Epoch 55

-----  
Training loss: 0.0024673730792322507  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08015171606479224  
Testing accuracy: 0.9777  
Epoch 56

-----  
Training loss: 0.0024017921037816753  
Training accuracy: 0.99995  
Testing loss: 0.08298686016899694  
Testing accuracy: 0.9766  
Epoch 57

-----  
Training loss: 0.0023208419065922498  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08211923848910281  
Testing accuracy: 0.9771  
Epoch 58

-----  
Training loss: 0.002262587865597258  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0813745995121489  
Testing accuracy: 0.9775  
Epoch 59

-----  
Training loss: 0.0021807285546014705  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08505152158585977  
Testing accuracy: 0.9768  
Epoch 60

-----  
Training loss: 0.002130844250709439  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08204288619320549  
Testing accuracy: 0.9776  
Epoch 61

-----  
Training loss: 0.00207568864171238  
Training accuracy: 1.0  
Testing loss: 0.08176352409571765  
Testing accuracy: 0.9778  
Epoch 62

-----  
Training loss: 0.002023745298354576  
Training accuracy: 1.0  
Testing loss: 0.08258525452967348  
Testing accuracy: 0.9772  
Epoch 63

-----  
Training loss: 0.0019800172126696754  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08200666929575152  
Testing accuracy: 0.9772  
Epoch 64

-----  
Training loss: 0.0019232352179009468  
Training accuracy: 1.0  
Testing loss: 0.08265337879824375  
Testing accuracy: 0.9775  
Epoch 65

-----  
Training loss: 0.0018648520837848386  
Training accuracy: 1.0  
Testing loss: 0.082561725445068  
Testing accuracy: 0.9778  
Epoch 66

-----  
Training loss: 0.0018291039389325306  
Training accuracy: 1.0  
Testing loss: 0.08321343811308954  
Testing accuracy: 0.9773  
Epoch 67

-----  
Training loss: 0.0018033599752311905  
Training accuracy: 1.0  
Testing loss: 0.08493116423343071  
Testing accuracy: 0.9771  
Epoch 68

-----  
Training loss: 0.001749693542610233  
Training accuracy: 1.0  
Testing loss: 0.08289560186213245  
Testing accuracy: 0.9778  
Epoch 69

-----  
Training loss: 0.0017144940769299865  
Training accuracy: 1.0  
Testing loss: 0.08390895629529307  
Testing accuracy: 0.9773  
Epoch 70

-----  
Training loss: 0.0016854314092236262  
Training accuracy: 1.0  
Testing loss: 0.08522652238891956  
Testing accuracy: 0.9769  
Epoch 71

-----  
Training loss: 0.0016424526539165526  
Training accuracy: 1.0  
Testing loss: 0.08407044693179559  
Testing accuracy: 0.9768  
Epoch 72

-----  
Training loss: 0.0016154623776829492  
Training accuracy: 1.0  
Testing loss: 0.08425094221720834  
Testing accuracy: 0.9775  
Epoch 73

-----  
Training loss: 0.0015713193726570656  
Training accuracy: 1.0  
Testing loss: 0.08393804853945928  
Testing accuracy: 0.9773  
Epoch 74

-----  
Training loss: 0.0015599688270905366  
Training accuracy: 1.0  
Testing loss: 0.0850065218742231  
Testing accuracy: 0.9769  
Epoch 75

-----  
Training loss: 0.0015062688294177253  
Training accuracy: 1.0  
Testing loss: 0.08577728014666243  
Testing accuracy: 0.9772  
Epoch 76

-----  
Training loss: 0.0014841863376631713  
Training accuracy: 1.0  
Testing loss: 0.08449294903852449  
Testing accuracy: 0.9773  
Epoch 77

-----  
Training loss: 0.001457607372958834  
Training accuracy: 1.0  
Testing loss: 0.08637000228964967  
Testing accuracy: 0.9771  
Epoch 78

-----  
Training loss: 0.0014425463923951611  
Training accuracy: 1.0  
Testing loss: 0.0847399005406781  
Testing accuracy: 0.9777  
Epoch 79

-----  
Training loss: 0.0014162289914675056  
Training accuracy: 1.0  
Testing loss: 0.08472418525755987  
Testing accuracy: 0.9777  
Epoch 80  
-----

Training loss: 0.0013831941468873993  
Training accuracy: 1.0  
Testing loss: 0.0855595749705751  
Testing accuracy: 0.9773  
Epoch 81  
-----

Training loss: 0.0013541749841261966  
Training accuracy: 1.0  
Testing loss: 0.08507414793218526  
Testing accuracy: 0.9772  
Epoch 82  
-----

Training loss: 0.0013390220908137658  
Training accuracy: 1.0  
Testing loss: 0.08603112134807388  
Testing accuracy: 0.977  
Epoch 83  
-----

Training loss: 0.001310501682246104  
Training accuracy: 1.0  
Testing loss: 0.08556360133499454  
Testing accuracy: 0.9773  
Epoch 84  
-----

Training loss: 0.001285850143704253  
Training accuracy: 1.0  
Testing loss: 0.08513763752301776  
Testing accuracy: 0.9777  
Epoch 85  
-----

Training loss: 0.0012706142086768523  
Training accuracy: 1.0  
Testing loss: 0.08729665610119167  
Testing accuracy: 0.9774  
Epoch 86  
-----

Training loss: 0.0012527268435728427  
Training accuracy: 1.0  
Testing loss: 0.08878738895442542  
Testing accuracy: 0.9776  
Epoch 87

-----  
Training loss: 0.0012281980170014625  
Training accuracy: 1.0  
Testing loss: 0.08594855527041494  
Testing accuracy: 0.9773  
Epoch 88  
-----

Training loss: 0.0012133286506403238  
Training accuracy: 1.0  
Testing loss: 0.08559336271515164  
Testing accuracy: 0.9771  
Epoch 89  
-----

Training loss: 0.001188362587747785  
Training accuracy: 1.0  
Testing loss: 0.08603743712638748  
Testing accuracy: 0.9767  
Epoch 90  
-----

Training loss: 0.0011709822246804833  
Training accuracy: 1.0  
Testing loss: 0.08631717908910956  
Testing accuracy: 0.9771  
Epoch 91  
-----

Training loss: 0.0011531280529064438  
Training accuracy: 1.0  
Testing loss: 0.0868458246556778  
Testing accuracy: 0.9775  
Epoch 92  
-----

Training loss: 0.001141356321387381  
Training accuracy: 1.0  
Testing loss: 0.08805482071324973  
Testing accuracy: 0.9772  
Epoch 93  
-----

Training loss: 0.0011288680600157629  
Training accuracy: 1.0  
Testing loss: 0.0874560212565936  
Testing accuracy: 0.977  
Epoch 94  
-----

Training loss: 0.001105071620301654  
Training accuracy: 1.0  
Testing loss: 0.08768052492008224  
Testing accuracy: 0.9777  
Epoch 95



-----  
Training loss: 0.0010889290700356166  
Training accuracy: 1.0  
Testing loss: 0.0873312529291962  
Testing accuracy: 0.9773  
Epoch 96

-----  
Training loss: 0.0010725312680083638  
Training accuracy: 1.0  
Testing loss: 0.08712983238532106  
Testing accuracy: 0.9776  
Epoch 97

-----  
Training loss: 0.0010616728324598322  
Training accuracy: 1.0  
Testing loss: 0.08801481705088507  
Testing accuracy: 0.9769  
Epoch 98

-----  
Training loss: 0.0010442313506112745  
Training accuracy: 1.0  
Testing loss: 0.09083358753323525  
Testing accuracy: 0.9769  
Epoch 99

-----  
Training loss: 0.001033203378354665  
Training accuracy: 1.0  
Testing loss: 0.0878557097461059  
Testing accuracy: 0.9772  
Epoch 100

-----  
Training loss: 0.0010179848679807038  
Training accuracy: 1.0  
Testing loss: 0.08768659005472496  
Testing accuracy: 0.9774  
Epoch 101

-----  
Training loss: 0.00100901670443515  
Training accuracy: 1.0  
Testing loss: 0.08818187126441218  
Testing accuracy: 0.9772  
Epoch 102

-----  
Training loss: 0.0009920692504461234  
Training accuracy: 1.0  
Testing loss: 0.0880503625259364  
Testing accuracy: 0.9773  
Epoch 103

-----  
Training loss: 0.000980551443900913  
Training accuracy: 1.0  
Testing loss: 0.08770844655438248  
Testing accuracy: 0.9774  
Epoch 104  
-----

Training loss: 0.0009674782708714095  
Training accuracy: 1.0  
Testing loss: 0.08780677242945675  
Testing accuracy: 0.9772  
Epoch 105  
-----

Training loss: 0.0009547324965281102  
Training accuracy: 1.0  
Testing loss: 0.09242414250418118  
Testing accuracy: 0.9776  
Epoch 106  
-----

Training loss: 0.0009379119003346811  
Training accuracy: 1.0  
Testing loss: 0.08855878459359649  
Testing accuracy: 0.9773  
Epoch 107  
-----

Training loss: 0.0009306840385853623  
Training accuracy: 1.0  
Testing loss: 0.08954082931626209  
Testing accuracy: 0.9774  
Epoch 108  
-----

Training loss: 0.0009156319093250204  
Training accuracy: 1.0  
Testing loss: 0.08745906034178266  
Testing accuracy: 0.9775  
Epoch 109  
-----

Training loss: 0.0009080944273698454  
Training accuracy: 1.0  
Testing loss: 0.09065905127518256  
Testing accuracy: 0.9776  
Epoch 110  
-----

Training loss: 0.0008980070287516962  
Training accuracy: 1.0  
Testing loss: 0.09016950634919155  
Testing accuracy: 0.9771  
Epoch 111

-----  
Training loss: 0.000891881449186864  
Training accuracy: 1.0  
Testing loss: 0.0919438423278601  
Testing accuracy: 0.9777  
Epoch 112

-----  
Training loss: 0.0008804985864010329  
Training accuracy: 1.0  
Testing loss: 0.08914826931145485  
Testing accuracy: 0.9777  
Epoch 113

-----  
Training loss: 0.0008667161711957306  
Training accuracy: 1.0  
Testing loss: 0.08924881766152058  
Testing accuracy: 0.9776  
Epoch 114

-----  
Training loss: 0.0008561823192052543  
Training accuracy: 1.0  
Testing loss: 0.08938445400125584  
Testing accuracy: 0.9772  
Epoch 115

-----  
Training loss: 0.0008475035264447797  
Training accuracy: 1.0  
Testing loss: 0.08888121287414995  
Testing accuracy: 0.9776  
Epoch 116

-----  
Training loss: 0.0008391840621227554  
Training accuracy: 1.0  
Testing loss: 0.08895142880688454  
Testing accuracy: 0.9776  
Epoch 117

-----  
Training loss: 0.000830397814376435  
Training accuracy: 1.0  
Testing loss: 0.090148911446872  
Testing accuracy: 0.9773  
Epoch 118

-----  
Training loss: 0.0008232364597575118  
Training accuracy: 1.0  
Testing loss: 0.09267540606202937  
Testing accuracy: 0.9771  
Epoch 119

-----  
Training loss: 0.0008125144094228745  
Training accuracy: 1.0  
Testing loss: 0.09063793954494472  
Testing accuracy: 0.9779  
Epoch 120  
-----

Training loss: 0.000804433288363119  
Training accuracy: 1.0  
Testing loss: 0.08939848971556112  
Testing accuracy: 0.9778  
Epoch 121  
-----

Training loss: 0.0007916497698131328  
Training accuracy: 1.0  
Testing loss: 0.08967227303344388  
Testing accuracy: 0.9776  
Epoch 122  
-----

Training loss: 0.0007878048190536599  
Training accuracy: 1.0  
Testing loss: 0.08956937269701316  
Testing accuracy: 0.9774  
Epoch 123  
-----

Training loss: 0.0007785665879646937  
Training accuracy: 1.0  
Testing loss: 0.08965589720359114  
Testing accuracy: 0.9773  
Epoch 124  
-----

Training loss: 0.0007719495796482079  
Training accuracy: 1.0  
Testing loss: 0.09045504709349049  
Testing accuracy: 0.9775  
Epoch 125  
-----

Training loss: 0.0007642854857918185  
Training accuracy: 1.0  
Testing loss: 0.09016742879978254  
Testing accuracy: 0.9772  
Epoch 126  
-----

Training loss: 0.0007541910259402357  
Training accuracy: 1.0  
Testing loss: 0.09158454588625527  
Testing accuracy: 0.9777  
Epoch 127

-----  
Training loss: 0.0007488620323206609  
Training accuracy: 1.0  
Testing loss: 0.0906101290668972  
Testing accuracy: 0.9773  
Epoch 128

-----  
Training loss: 0.0007397542388818693  
Training accuracy: 1.0  
Testing loss: 0.090462379166418  
Testing accuracy: 0.9776  
Epoch 129

-----  
Training loss: 0.0007324902708923522  
Training accuracy: 1.0  
Testing loss: 0.09062200501662379  
Testing accuracy: 0.9774  
Epoch 130

-----  
Training loss: 0.0007267364408355206  
Training accuracy: 1.0  
Testing loss: 0.09067437140397401  
Testing accuracy: 0.9773  
Epoch 131

-----  
Training loss: 0.0007172816119506023  
Training accuracy: 1.0  
Testing loss: 0.09081544614101131  
Testing accuracy: 0.9774  
Epoch 132

-----  
Training loss: 0.0007161734139740777  
Training accuracy: 1.0  
Testing loss: 0.09096211179383515  
Testing accuracy: 0.9768  
Epoch 133

-----  
Training loss: 0.0007069630235200748  
Training accuracy: 1.0  
Testing loss: 0.09171801729413798  
Testing accuracy: 0.9776  
Epoch 134

-----  
Training loss: 0.0006995820315554738  
Training accuracy: 1.0  
Testing loss: 0.09079311857189817  
Testing accuracy: 0.9775  
Epoch 135

-----  
Training loss: 0.0006925140889633137  
Training accuracy: 1.0  
Testing loss: 0.09128898486580661  
Testing accuracy: 0.9773  
Epoch 136

-----  
Training loss: 0.0006856925714955045  
Training accuracy: 1.0  
Testing loss: 0.0907474029262381  
Testing accuracy: 0.9771  
Epoch 137

-----  
Training loss: 0.0006813715106497208  
Training accuracy: 1.0  
Testing loss: 0.09112362144441058  
Testing accuracy: 0.9772  
Epoch 138

-----  
Training loss: 0.0006733931670120606  
Training accuracy: 1.0  
Testing loss: 0.09070798490463591  
Testing accuracy: 0.9775  
Epoch 139

-----  
Training loss: 0.0006679537694901228  
Training accuracy: 1.0  
Testing loss: 0.09180916901179188  
Testing accuracy: 0.977  
Epoch 140

-----  
Training loss: 0.0006610080862728258  
Training accuracy: 1.0  
Testing loss: 0.09133595619998557  
Testing accuracy: 0.9776  
Epoch 141

-----  
Training loss: 0.0006567125138749058  
Training accuracy: 1.0  
Testing loss: 0.09177406488288976  
Testing accuracy: 0.9775  
Epoch 142

-----  
Training loss: 0.0006513515304463605  
Training accuracy: 1.0  
Testing loss: 0.09188645164175314  
Testing accuracy: 0.9775  
Epoch 143

-----  
Training loss: 0.0006451546800128805  
Training accuracy: 1.0  
Testing loss: 0.09229739177875683  
Testing accuracy: 0.9779  
Epoch 144

-----  
Training loss: 0.0006396115970254565  
Training accuracy: 1.0  
Testing loss: 0.09157222971259164  
Testing accuracy: 0.9776  
Epoch 145

-----  
Training loss: 0.0006343340152331318  
Training accuracy: 1.0  
Testing loss: 0.09254599747190156  
Testing accuracy: 0.9774  
Epoch 146

-----  
Training loss: 0.0006294708639150486  
Training accuracy: 1.0  
Testing loss: 0.09198092977619421  
Testing accuracy: 0.9774  
Epoch 147

-----  
Training loss: 0.0006229055388869407  
Training accuracy: 1.0  
Testing loss: 0.09234617491610309  
Testing accuracy: 0.9776  
Epoch 148

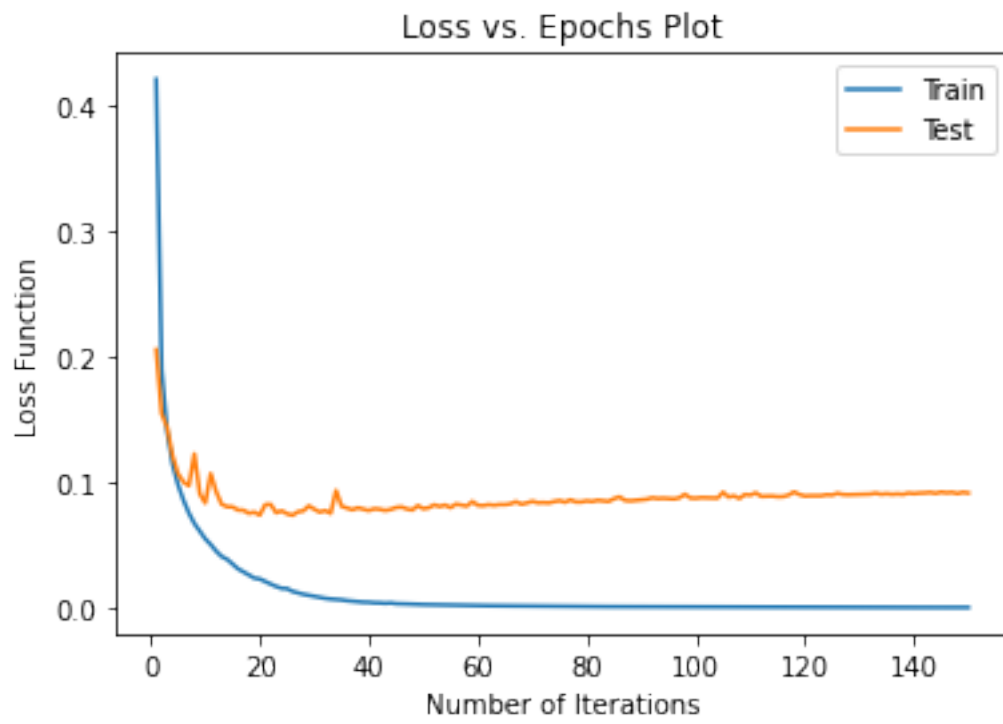
-----  
Training loss: 0.0006190512772736839  
Training accuracy: 1.0  
Testing loss: 0.09141055725000104  
Testing accuracy: 0.9781  
Epoch 149

-----  
Training loss: 0.0006144244657751794  
Training accuracy: 1.0  
Testing loss: 0.09238077717859915  
Testing accuracy: 0.9781  
Epoch 150

-----  
Training loss: 0.000607493310716624  
Training accuracy: 1.0  
Testing loss: 0.0918055038210829  
Testing accuracy: 0.9773  
Done

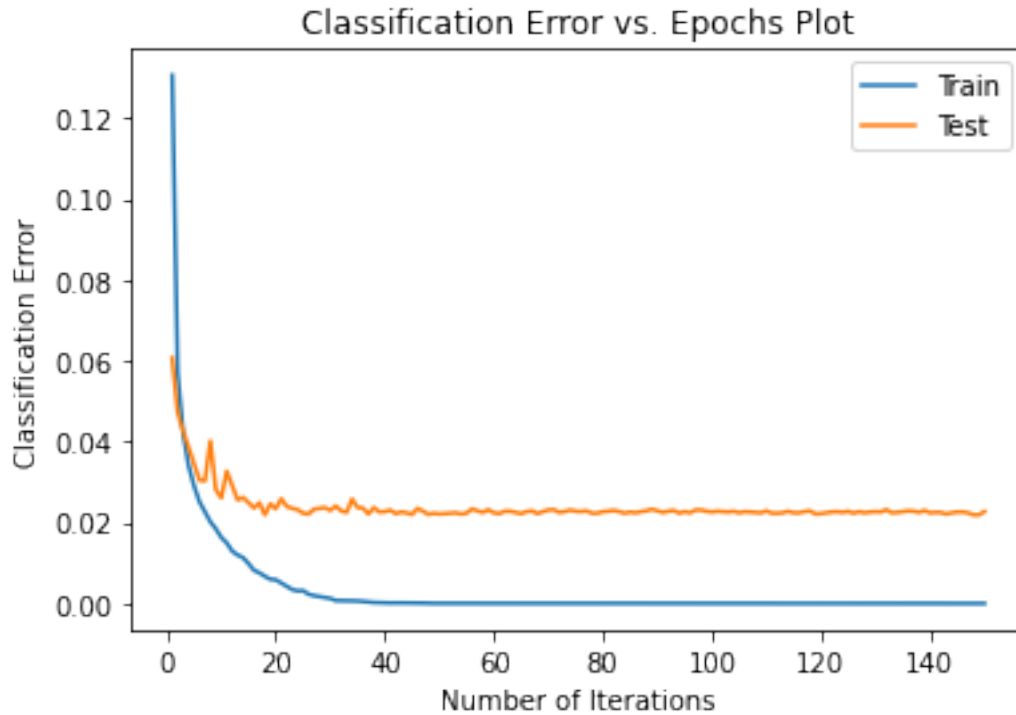
Total Time Consumed: 1644.9831507205963

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```





#### 5.3.4 Momentum = 0.5

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.5
model_m5 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model_m5.parameters(), lr = learning_rate, momentum = ↵
↵momentum)
```

```
[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size, ↵
↵shuffle = True)
```

```

test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle_
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model_m5,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model_m5,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.4837591945886612
Training accuracy: 0.8675333333333334
Testing loss: 0.2681346757301859
Testing accuracy: 0.9243

```

Epoch 2

```

-----
Training loss: 0.2510717252175013
Training accuracy: 0.9259333333333334
Testing loss: 0.20560706098368214
Testing accuracy: 0.9374

```

Epoch 3

```

-----
Training loss: 0.19865883144537608
Training accuracy: 0.9425
Testing loss: 0.18493597396904496
Testing accuracy: 0.9444

```

Epoch 4

```

-----
Training loss: 0.16550074379046759
Training accuracy: 0.9516
Testing loss: 0.15071089562787943
Testing accuracy: 0.9562

```

Epoch 5

```

-----
Training loss: 0.14243549240430195
Training accuracy: 0.9588166666666667
Testing loss: 0.13868545797789933
Testing accuracy: 0.959

```

Epoch 6

```

-----

```

```
Training loss: 0.12593183087110518
Training accuracy: 0.9638
Testing loss: 0.11866975684834134
Testing accuracy: 0.965
Epoch 7
-----
Training loss: 0.11189230486253897
Training accuracy: 0.96785
Testing loss: 0.11831869158870095
Testing accuracy: 0.9645
Epoch 8
-----
Training loss: 0.10088319437106451
Training accuracy: 0.9717166666666667
Testing loss: 0.10891067889180912
Testing accuracy: 0.967
Epoch 9
-----
Training loss: 0.0924744322190682
Training accuracy: 0.9737333333333333
Testing loss: 0.10149718626479434
Testing accuracy: 0.9698
Epoch 10
-----
Training loss: 0.08525628445744514
Training accuracy: 0.9758
Testing loss: 0.09433117020685391
Testing accuracy: 0.972
Epoch 11
-----
Training loss: 0.07849215224583944
Training accuracy: 0.9783333333333334
Testing loss: 0.09575573388178638
Testing accuracy: 0.9704
Epoch 12
-----
Training loss: 0.07291718404094379
Training accuracy: 0.9796666666666667
Testing loss: 0.09408237865776013
Testing accuracy: 0.971
Epoch 13
-----
Training loss: 0.06767859050780535
Training accuracy: 0.9814166666666667
Testing loss: 0.08967452497476605
Testing accuracy: 0.9732
Epoch 14
-----
```

```

Training loss: 0.0646466949040691
Training accuracy: 0.98255
Testing loss: 0.08691911784054082
Testing accuracy: 0.9727
Epoch 15
-----
Training loss: 0.06020486508111159
Training accuracy: 0.9833833333333334
Testing loss: 0.0792586056835902
Testing accuracy: 0.9749
Epoch 16
-----
Training loss: 0.05664738740275303
Training accuracy: 0.9846666666666667
Testing loss: 0.08427508216897014
Testing accuracy: 0.9746
Epoch 17
-----
Training loss: 0.05312106940150261
Training accuracy: 0.9855833333333334
Testing loss: 0.08169347572786982
Testing accuracy: 0.9743
Epoch 18
-----
Training loss: 0.049942257839938005
Training accuracy: 0.9868666666666667
Testing loss: 0.07782925918674582
Testing accuracy: 0.9761
Epoch 19
-----
Training loss: 0.04761424238135417
Training accuracy: 0.9872833333333333
Testing loss: 0.07785618394037863
Testing accuracy: 0.9746
Epoch 20
-----
Training loss: 0.044694264877587556
Training accuracy: 0.9885333333333334
Testing loss: 0.07626274415250321
Testing accuracy: 0.9764
Epoch 21
-----
Training loss: 0.0425637226631244
Training accuracy: 0.9895166666666667
Testing loss: 0.07195328280424616
Testing accuracy: 0.977
Epoch 22
-----

```

```

Training loss: 0.04007314221560955
Training accuracy: 0.9898333333333333
Testing loss: 0.07840808450131659
Testing accuracy: 0.9751
Epoch 23
-----
Training loss: 0.03863096417561174
Training accuracy: 0.99035
Testing loss: 0.07469563919362748
Testing accuracy: 0.9768
Epoch 24
-----
Training loss: 0.036215980222945414
Training accuracy: 0.99145
Testing loss: 0.07543900774518965
Testing accuracy: 0.9761
Epoch 25
-----
Training loss: 0.03485296547437708
Training accuracy: 0.9916166666666667
Testing loss: 0.0703683802205476
Testing accuracy: 0.9777
Epoch 26
-----
Training loss: 0.032941979540139436
Training accuracy: 0.9923666666666666
Testing loss: 0.07196315955429984
Testing accuracy: 0.9779
Epoch 27
-----
Training loss: 0.03151656443675359
Training accuracy: 0.99255
Testing loss: 0.07110367516340439
Testing accuracy: 0.978
Epoch 28
-----
Training loss: 0.029538894126315912
Training accuracy: 0.9937
Testing loss: 0.07785768163906541
Testing accuracy: 0.9749
Epoch 29
-----
Training loss: 0.028239830253769953
Training accuracy: 0.9941833333333333
Testing loss: 0.0752163535357708
Testing accuracy: 0.9764
Epoch 30
-----

```

Training loss: 0.027252450654655695  
Training accuracy: 0.9941333333333333  
Testing loss: 0.07242559662213324  
Testing accuracy: 0.977  
Epoch 31

-----  
Training loss: 0.025675957886129617  
Training accuracy: 0.9948833333333333  
Testing loss: 0.0727280125342262  
Testing accuracy: 0.9762  
Epoch 32

-----  
Training loss: 0.02480227345228195  
Training accuracy: 0.99475  
Testing loss: 0.06895895097641998  
Testing accuracy: 0.9786  
Epoch 33

-----  
Training loss: 0.02357355776404341  
Training accuracy: 0.9955  
Testing loss: 0.07536905391993012  
Testing accuracy: 0.976  
Epoch 34

-----  
Training loss: 0.022610101514557997  
Training accuracy: 0.9958666666666667  
Testing loss: 0.07448723873755284  
Testing accuracy: 0.9775  
Epoch 35

-----  
Training loss: 0.021367358679076034  
Training accuracy: 0.9961666666666666  
Testing loss: 0.07666020439848731  
Testing accuracy: 0.9759  
Epoch 36

-----  
Training loss: 0.0202554188032945  
Training accuracy: 0.9963833333333333  
Testing loss: 0.06980292265048357  
Testing accuracy: 0.9773  
Epoch 37

-----  
Training loss: 0.019599609592805305  
Training accuracy: 0.9968833333333333  
Testing loss: 0.07027595451362668  
Testing accuracy: 0.9776  
Epoch 38

```
Training loss: 0.018727107155385118
Training accuracy: 0.9968
Testing loss: 0.06772619774149861
Testing accuracy: 0.9784
Epoch 39
-----
Training loss: 0.01778526801938812
Training accuracy: 0.9973333333333333
Testing loss: 0.07030996121169561
Testing accuracy: 0.9778
Epoch 40
-----
Training loss: 0.0172722153339535
Training accuracy: 0.99735
Testing loss: 0.06752337477018665
Testing accuracy: 0.977
Epoch 41
-----
Training loss: 0.01664008265013496
Training accuracy: 0.9976
Testing loss: 0.06889718209962793
Testing accuracy: 0.9766
Epoch 42
-----
Training loss: 0.015726954316409924
Training accuracy: 0.9978
Testing loss: 0.06845350551736322
Testing accuracy: 0.9784
Epoch 43
-----
Training loss: 0.015100218194971482
Training accuracy: 0.9980666666666667
Testing loss: 0.06827422709183495
Testing accuracy: 0.978
Epoch 44
-----
Training loss: 0.014501608312626679
Training accuracy: 0.9982333333333333
Testing loss: 0.06763790091399584
Testing accuracy: 0.9787
Epoch 45
-----
Training loss: 0.013849582287793358
Training accuracy: 0.9983333333333333
Testing loss: 0.06903102840919784
Testing accuracy: 0.9775
Epoch 46
-----
```

Training loss: 0.013431748011087378  
Training accuracy: 0.9983666666666666  
Testing loss: 0.0690334069710907  
Testing accuracy: 0.9776  
Epoch 47

-----  
Training loss: 0.013074228159214059  
Training accuracy: 0.9983833333333333  
Testing loss: 0.0705218841551631  
Testing accuracy: 0.9774  
Epoch 48

-----  
Training loss: 0.012515044484784205  
Training accuracy: 0.9987833333333334  
Testing loss: 0.07136426412998728  
Testing accuracy: 0.9765  
Epoch 49

-----  
Training loss: 0.011822395853698254  
Training accuracy: 0.9988333333333334  
Testing loss: 0.06843702238020458  
Testing accuracy: 0.9774  
Epoch 50

-----  
Training loss: 0.011457280115907392  
Training accuracy: 0.9990666666666667  
Testing loss: 0.06915107477533447  
Testing accuracy: 0.9775  
Epoch 51

-----  
Training loss: 0.011230076878766218  
Training accuracy: 0.9991166666666667  
Testing loss: 0.06907225002098687  
Testing accuracy: 0.9772  
Epoch 52

-----  
Training loss: 0.010626016239201029  
Training accuracy: 0.9990833333333333  
Testing loss: 0.06989359608955183  
Testing accuracy: 0.9779  
Epoch 53

-----  
Training loss: 0.010342141520914932  
Training accuracy: 0.99925  
Testing loss: 0.07087176210383415  
Testing accuracy: 0.9773  
Epoch 54



```

Training loss: 0.010015411863600214
Training accuracy: 0.99925
Testing loss: 0.06995355964498891
Testing accuracy: 0.9781
Epoch 55
-----
Training loss: 0.009649070400123794
Training accuracy: 0.99935
Testing loss: 0.06905339648027661
Testing accuracy: 0.9778
Epoch 56
-----
Training loss: 0.009245713616348803
Training accuracy: 0.9995
Testing loss: 0.07027252577838435
Testing accuracy: 0.9778
Epoch 57
-----
Training loss: 0.009009660788749655
Training accuracy: 0.9994
Testing loss: 0.06919397734428881
Testing accuracy: 0.9772
Epoch 58
-----
Training loss: 0.008778431873768568
Training accuracy: 0.9995
Testing loss: 0.0709907481614441
Testing accuracy: 0.9781
Epoch 59
-----
Training loss: 0.008366618372872472
Training accuracy: 0.9996
Testing loss: 0.07239002589088907
Testing accuracy: 0.9777
Epoch 60
-----
Training loss: 0.008156546443017821
Training accuracy: 0.99955
Testing loss: 0.06943989442780045
Testing accuracy: 0.9788
Epoch 61
-----
Training loss: 0.007924869438757498
Training accuracy: 0.9996666666666667
Testing loss: 0.06980679933557132
Testing accuracy: 0.978
Epoch 62
-----

```

Training loss: 0.007754510128994783  
Training accuracy: 0.9996666666666667  
Testing loss: 0.07084751267514079  
Testing accuracy: 0.9778  
Epoch 63

-----  
Training loss: 0.0074452302635957795  
Training accuracy: 0.99975  
Testing loss: 0.07021115599222374  
Testing accuracy: 0.9773  
Epoch 64

-----  
Training loss: 0.007284546071011573  
Training accuracy: 0.99965  
Testing loss: 0.07047380428096861  
Testing accuracy: 0.9782  
Epoch 65

-----  
Training loss: 0.007083597064577043  
Training accuracy: 0.9996833333333334  
Testing loss: 0.07055055424660017  
Testing accuracy: 0.9782  
Epoch 66

-----  
Training loss: 0.006878613477759064  
Training accuracy: 0.9997666666666667  
Testing loss: 0.07057196038899718  
Testing accuracy: 0.9776  
Epoch 67

-----  
Training loss: 0.006723928015989562  
Training accuracy: 0.9997333333333334  
Testing loss: 0.07249346023661256  
Testing accuracy: 0.9778  
Epoch 68

-----  
Training loss: 0.006563047890861829  
Training accuracy: 0.9997333333333334  
Testing loss: 0.06950470179676785  
Testing accuracy: 0.9777  
Epoch 69

-----  
Training loss: 0.0063667139169449605  
Training accuracy: 0.9998166666666667  
Testing loss: 0.07173974132854907  
Testing accuracy: 0.9781  
Epoch 70

Training loss: 0.006213999762137731  
Training accuracy: 0.9997833333333334  
Testing loss: 0.07141661972762531  
Testing accuracy: 0.978  
Epoch 71

-----  
Training loss: 0.006001104979775846  
Training accuracy: 0.99985  
Testing loss: 0.07213380786732645  
Testing accuracy: 0.9776  
Epoch 72

-----  
Training loss: 0.005895735934966554  
Training accuracy: 0.9998166666666667  
Testing loss: 0.07084561713283828  
Testing accuracy: 0.9779  
Epoch 73

-----  
Training loss: 0.005731016340603431  
Training accuracy: 0.9998833333333333  
Testing loss: 0.07031280825127385  
Testing accuracy: 0.9783  
Epoch 74

-----  
Training loss: 0.005631252056981126  
Training accuracy: 0.99985  
Testing loss: 0.07135062534651263  
Testing accuracy: 0.9778  
Epoch 75

-----  
Training loss: 0.0054549680520469945  
Training accuracy: 0.9999  
Testing loss: 0.07176648702763117  
Testing accuracy: 0.9781  
Epoch 76

-----  
Training loss: 0.005332146563691398  
Training accuracy: 0.9999  
Testing loss: 0.07088535512088662  
Testing accuracy: 0.978  
Epoch 77

-----  
Training loss: 0.00516809562286362  
Training accuracy: 0.9999  
Testing loss: 0.07248612609988517  
Testing accuracy: 0.9781  
Epoch 78

Training loss: 0.0051139391382845735  
Training accuracy: 0.9999166666666667  
Testing loss: 0.07111031184333323  
Testing accuracy: 0.9782  
Epoch 79

-----  
Training loss: 0.005014702259624998  
Training accuracy: 0.9999166666666667  
Testing loss: 0.07274268616945928  
Testing accuracy: 0.9774  
Epoch 80

-----  
Training loss: 0.00485194886441653  
Training accuracy: 0.99995  
Testing loss: 0.07186327395207326  
Testing accuracy: 0.9774  
Epoch 81

-----  
Training loss: 0.0047575502247083935  
Training accuracy: 0.99995  
Testing loss: 0.07224971871151274  
Testing accuracy: 0.9774  
Epoch 82

-----  
Training loss: 0.00467854645208766  
Training accuracy: 0.9999333333333333  
Testing loss: 0.07160237753410842  
Testing accuracy: 0.9778  
Epoch 83

-----  
Training loss: 0.004556496493394176  
Training accuracy: 0.99995  
Testing loss: 0.07122196820801847  
Testing accuracy: 0.9778  
Epoch 84

-----  
Training loss: 0.004489303210532913  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07176197143004626  
Testing accuracy: 0.9779  
Epoch 85

-----  
Training loss: 0.0043934017270803455  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07298106507095657  
Testing accuracy: 0.9783  
Epoch 86

Training loss: 0.004306374428638567  
Training accuracy: 0.9999666666666667  
Testing loss: 0.0742351957329899  
Testing accuracy: 0.9771  
Epoch 87

-----  
Training loss: 0.0042172302478303515  
Training accuracy: 0.9999666666666667  
Testing loss: 0.0718305079480722  
Testing accuracy: 0.9775  
Epoch 88

-----  
Training loss: 0.0041502039593334  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07131791975390712  
Testing accuracy: 0.9776  
Epoch 89

-----  
Training loss: 0.004023091015902658  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07315378255621607  
Testing accuracy: 0.9772  
Epoch 90

-----  
Training loss: 0.003950521958836665  
Training accuracy: 0.9999666666666667  
Testing loss: 0.07316566714301415  
Testing accuracy: 0.9775  
Epoch 91

-----  
Training loss: 0.003898021285670499  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07273804500645656  
Testing accuracy: 0.978  
Epoch 92

-----  
Training loss: 0.003868172961225112  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07342930122484026  
Testing accuracy: 0.9785  
Epoch 93

-----  
Training loss: 0.0037747773652585842  
Training accuracy: 0.9999833333333333  
Testing loss: 0.07208998619050831  
Testing accuracy: 0.9783  
Epoch 94

```

Training loss: 0.003686779227697601
Training accuracy: 0.9999833333333333
Testing loss: 0.07293910403649922
Testing accuracy: 0.9775
Epoch 95
-----
Training loss: 0.0036330831184051933
Training accuracy: 0.9999833333333333
Testing loss: 0.07247601636421458
Testing accuracy: 0.9781
Epoch 96
-----
Training loss: 0.0035573810912668704
Training accuracy: 0.9999833333333333
Testing loss: 0.07383059639302765
Testing accuracy: 0.9776
Epoch 97
-----
Training loss: 0.0035121098360357183
Training accuracy: 0.9999833333333333
Testing loss: 0.07521601852584203
Testing accuracy: 0.9776
Epoch 98
-----
Training loss: 0.0034579748284692567
Training accuracy: 1.0
Testing loss: 0.07550592023629404
Testing accuracy: 0.978
Epoch 99
-----
Training loss: 0.0034055933743870506
Training accuracy: 1.0
Testing loss: 0.07265494318173273
Testing accuracy: 0.9778
Epoch 100
-----
Training loss: 0.003341041858121753
Training accuracy: 1.0
Testing loss: 0.07288863306796878
Testing accuracy: 0.9776
Epoch 101
-----
Training loss: 0.0032901259340035417
Training accuracy: 1.0
Testing loss: 0.07336722532784785
Testing accuracy: 0.9781
Epoch 102
-----

```

```

Training loss: 0.003228292203322053
Training accuracy: 1.0
Testing loss: 0.07414760759543734
Testing accuracy: 0.978
Epoch 103
-----
Training loss: 0.0031879110802469465
Training accuracy: 1.0
Testing loss: 0.07359095624385543
Testing accuracy: 0.978
Epoch 104
-----
Training loss: 0.0031546784858840207
Training accuracy: 1.0
Testing loss: 0.07348702618834461
Testing accuracy: 0.9775
Epoch 105
-----
Training loss: 0.003084850747634967
Training accuracy: 1.0
Testing loss: 0.08012081810961341
Testing accuracy: 0.9774
Epoch 106
-----
Training loss: 0.0030387868230231105
Training accuracy: 1.0
Testing loss: 0.07407277296716198
Testing accuracy: 0.9778
Epoch 107
-----
Training loss: 0.0030040705488373837
Training accuracy: 1.0
Testing loss: 0.0756670521261915
Testing accuracy: 0.9778
Epoch 108
-----
Training loss: 0.0029449116627064845
Training accuracy: 1.0
Testing loss: 0.07262399018008801
Testing accuracy: 0.9774
Epoch 109
-----
Training loss: 0.0029240036664375415
Training accuracy: 1.0
Testing loss: 0.07526305395495117
Testing accuracy: 0.9777
Epoch 110
-----

```

```
Training loss: 0.002868292860640213
Training accuracy: 1.0
Testing loss: 0.07477356564212044
Testing accuracy: 0.9774
Epoch 111
-----
Training loss: 0.00284811939841602
Training accuracy: 1.0
Testing loss: 0.07545020533199155
Testing accuracy: 0.9775
Epoch 112
-----
Training loss: 0.002808059459971264
Training accuracy: 1.0
Testing loss: 0.07542251169075002
Testing accuracy: 0.9773
Epoch 113
-----
Training loss: 0.002771858114221444
Training accuracy: 1.0
Testing loss: 0.07485217684071666
Testing accuracy: 0.9772
Epoch 114
-----
Training loss: 0.0026997655767947437
Training accuracy: 1.0
Testing loss: 0.07456787577945187
Testing accuracy: 0.9772
Epoch 115
-----
Training loss: 0.002680628293287009
Training accuracy: 1.0
Testing loss: 0.07511366203992337
Testing accuracy: 0.9775
Epoch 116
-----
Training loss: 0.0026611629291592785
Training accuracy: 1.0
Testing loss: 0.07438073363073562
Testing accuracy: 0.9775
Epoch 117
-----
Training loss: 0.0026139450012861443
Training accuracy: 1.0
Testing loss: 0.07444936431448307
Testing accuracy: 0.9779
Epoch 118
-----
```



```
Training loss: 0.002590313291766991
Training accuracy: 1.0
Testing loss: 0.07867106544239458
Testing accuracy: 0.9774
Epoch 119
-----
Training loss: 0.0025495033454770843
Training accuracy: 1.0
Testing loss: 0.07429842204359734
Testing accuracy: 0.978
Epoch 120
-----
Training loss: 0.0025239796287224938
Training accuracy: 1.0
Testing loss: 0.07522342118818705
Testing accuracy: 0.9772
Epoch 121
-----
Training loss: 0.002482509018201381
Training accuracy: 1.0
Testing loss: 0.07447368539662165
Testing accuracy: 0.9776
Epoch 122
-----
Training loss: 0.0024728415971156208
Training accuracy: 1.0
Testing loss: 0.07501781451334928
Testing accuracy: 0.9771
Epoch 123
-----
Training loss: 0.0024270856028112274
Training accuracy: 1.0
Testing loss: 0.07482481170590273
Testing accuracy: 0.9775
Epoch 124
-----
Training loss: 0.002396431345376186
Training accuracy: 1.0
Testing loss: 0.0753193296596651
Testing accuracy: 0.9773
Epoch 125
-----
Training loss: 0.002382217031531036
Training accuracy: 1.0
Testing loss: 0.07587810615681936
Testing accuracy: 0.9777
Epoch 126
-----
```

Training loss: 0.0023364077193041644  
Training accuracy: 1.0  
Testing loss: 0.07540712350086683  
Testing accuracy: 0.9777  
Epoch 127

-----  
Training loss: 0.002322553948654483  
Training accuracy: 1.0  
Testing loss: 0.07555449181117686  
Testing accuracy: 0.9773  
Epoch 128

-----  
Training loss: 0.0022847003359658022  
Training accuracy: 1.0  
Testing loss: 0.07617807611292911  
Testing accuracy: 0.9778  
Epoch 129

-----  
Training loss: 0.002268413922873636  
Training accuracy: 1.0  
Testing loss: 0.07548190616842383  
Testing accuracy: 0.9772  
Epoch 130

-----  
Training loss: 0.002240426592575386  
Training accuracy: 1.0  
Testing loss: 0.07635128741567082  
Testing accuracy: 0.9772  
Epoch 131

-----  
Training loss: 0.0022063776354926327  
Training accuracy: 1.0  
Testing loss: 0.0771486752022912  
Testing accuracy: 0.9775  
Epoch 132

-----  
Training loss: 0.0021920518851528564  
Training accuracy: 1.0  
Testing loss: 0.07615772117539917  
Testing accuracy: 0.9778  
Epoch 133

-----  
Training loss: 0.0021707543928952268  
Training accuracy: 1.0  
Testing loss: 0.07569641591335949  
Testing accuracy: 0.9775  
Epoch 134

Training loss: 0.0021377461472836634  
Training accuracy: 1.0  
Testing loss: 0.07623266273365017  
Testing accuracy: 0.9771  
Epoch 135

-----  
Training loss: 0.002125391514537235  
Training accuracy: 1.0  
Testing loss: 0.07527032073484852  
Testing accuracy: 0.9772  
Epoch 136

-----  
Training loss: 0.002094755230657756  
Training accuracy: 1.0  
Testing loss: 0.07585281586114341  
Testing accuracy: 0.9776  
Epoch 137

-----  
Training loss: 0.002077110916764165  
Training accuracy: 1.0  
Testing loss: 0.0764408967972868  
Testing accuracy: 0.9776  
Epoch 138

-----  
Training loss: 0.002053069640385608  
Training accuracy: 1.0  
Testing loss: 0.07628810055317375  
Testing accuracy: 0.9776  
Epoch 139

-----  
Training loss: 0.0020258560184544575  
Training accuracy: 1.0  
Testing loss: 0.07793672493463204  
Testing accuracy: 0.9775  
Epoch 140

-----  
Training loss: 0.0020121282051317395  
Training accuracy: 1.0  
Testing loss: 0.0759045210858632  
Testing accuracy: 0.9775  
Epoch 141

-----  
Training loss: 0.0019928988381288947  
Training accuracy: 1.0  
Testing loss: 0.07648043596474187  
Testing accuracy: 0.9777  
Epoch 142

Training loss: 0.0019753919212458036  
Training accuracy: 1.0  
Testing loss: 0.07663375870576782  
Testing accuracy: 0.9778  
Epoch 143

-----  
Training loss: 0.001949868322784702  
Training accuracy: 1.0  
Testing loss: 0.07643391023564988  
Testing accuracy: 0.9779  
Epoch 144

-----  
Training loss: 0.0019306835833471268  
Training accuracy: 1.0  
Testing loss: 0.07702105389479741  
Testing accuracy: 0.9778  
Epoch 145

-----  
Training loss: 0.0019192819078608105  
Training accuracy: 1.0  
Testing loss: 0.0769148735866354  
Testing accuracy: 0.9771  
Epoch 146

-----  
Training loss: 0.0018967741231278826  
Training accuracy: 1.0  
Testing loss: 0.07638835921052363  
Testing accuracy: 0.9772  
Epoch 147

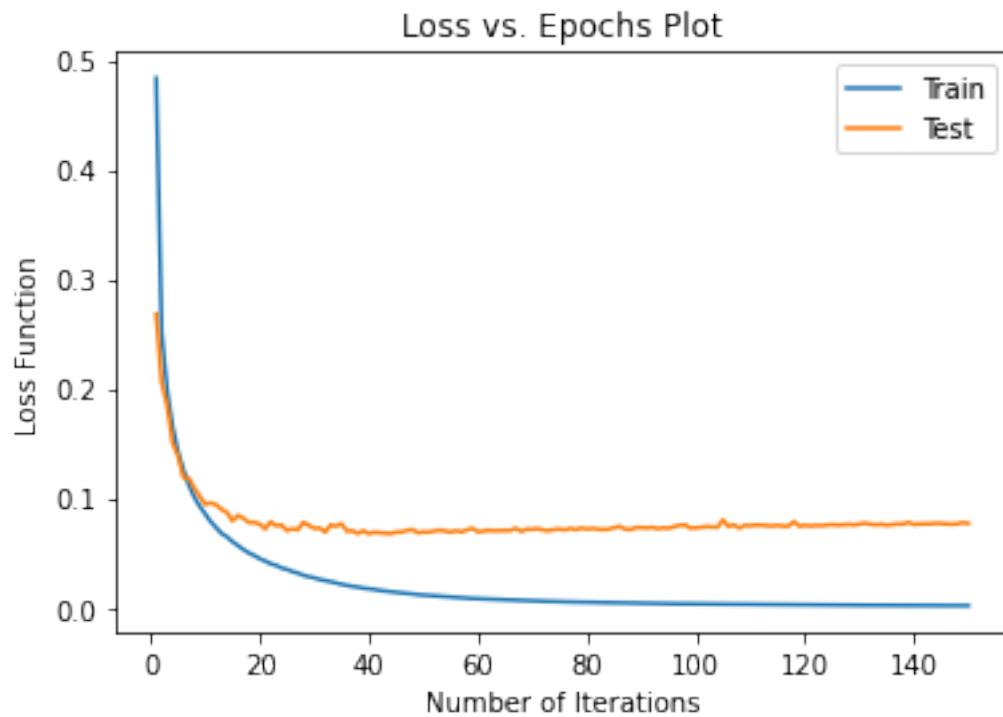
-----  
Training loss: 0.001875468409775446  
Training accuracy: 1.0  
Testing loss: 0.07621417288293256  
Testing accuracy: 0.9776  
Epoch 148

-----  
Training loss: 0.0018661790055998911  
Training accuracy: 1.0  
Testing loss: 0.07662340051644322  
Testing accuracy: 0.977  
Epoch 149

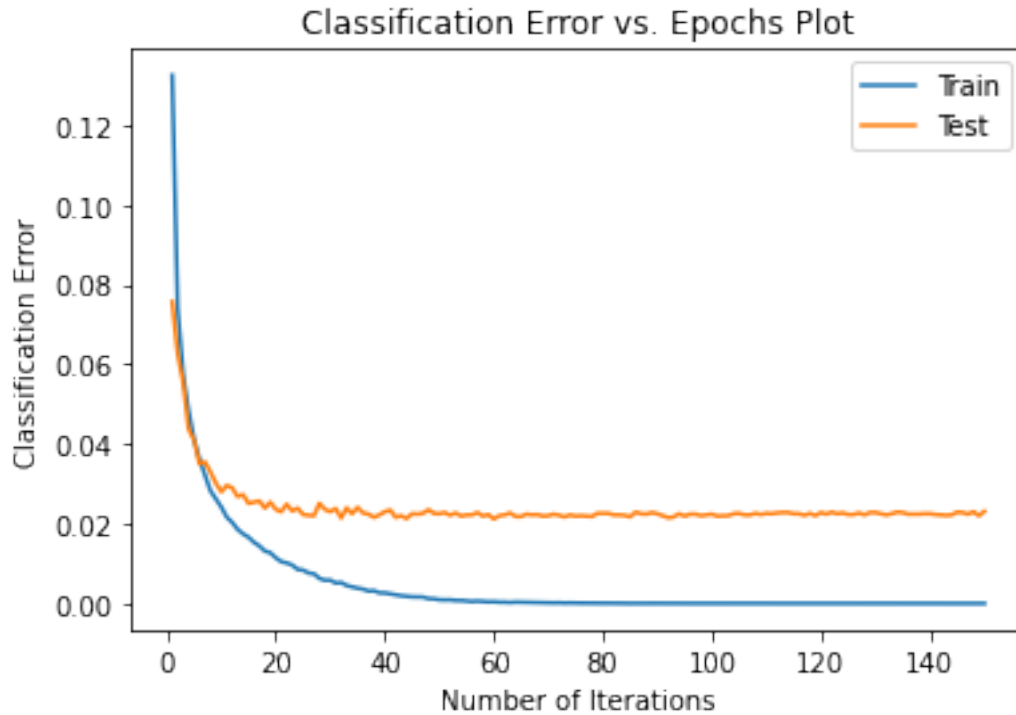
-----  
Training loss: 0.0018460067151347176  
Training accuracy: 1.0  
Testing loss: 0.07761342773565454  
Testing accuracy: 0.978  
Epoch 150

Training loss: 0.0018188752548924337  
Training accuracy: 1.0  
Testing loss: 0.07697768278276677  
Testing accuracy: 0.9769  
Done  
Total Time Consumed: 1595.3003423213959

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.3.5 Momentum = 0.9

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.9
model_m9 = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(model_m9.parameters(), lr = learning_rate, momentum = ↵
↵momentum)
```

```
[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size, ↵
↵shuffle = True)
```

```

test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle_
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader,model_m9,loss,optimizer))
    test_loss_record.append(test_loop(test_loader,model_m9,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.3392916478792826
Training accuracy: 0.8969166666666667
Testing loss: 0.18708914504119545
Testing accuracy: 0.9447

```

Epoch 2

```

-----
Training loss: 0.17288960444529852
Training accuracy: 0.9479333333333333
Testing loss: 0.16911711313637198
Testing accuracy: 0.9486

```

Epoch 3

```

-----
Training loss: 0.1385043405155341
Training accuracy: 0.9576833333333333
Testing loss: 0.13538975030136335
Testing accuracy: 0.9588

```

Epoch 4

```

-----
Training loss: 0.1137163160259525
Training accuracy: 0.96465
Testing loss: 0.12845375989771382
Testing accuracy: 0.9606

```

Epoch 5

```

-----
Training loss: 0.10006115541060766
Training accuracy: 0.9690833333333333
Testing loss: 0.10900107583114106
Testing accuracy: 0.9674

```

Epoch 6

```

-----

```

Training loss: 0.08733368518749873  
Training accuracy: 0.9727833333333333  
Testing loss: 0.10248412942857879  
Testing accuracy: 0.9692  
Epoch 7

-----  
Training loss: 0.08084460683216652  
Training accuracy: 0.97515  
Testing loss: 0.12353549227355771  
Testing accuracy: 0.9633  
Epoch 8

-----  
Training loss: 0.07183215239445369  
Training accuracy: 0.9775333333333334  
Testing loss: 0.10860776305080029  
Testing accuracy: 0.9672  
Epoch 9

-----  
Training loss: 0.06815559768105546  
Training accuracy: 0.97815  
Testing loss: 0.10464360014458371  
Testing accuracy: 0.9693  
Epoch 10

-----  
Training loss: 0.05977067381292581  
Training accuracy: 0.9810833333333333  
Testing loss: 0.0907891824408464  
Testing accuracy: 0.9733  
Epoch 11

-----  
Training loss: 0.059487795096139114  
Training accuracy: 0.9805166666666667  
Testing loss: 0.09831072538379271  
Testing accuracy: 0.968  
Epoch 12

-----  
Training loss: 0.054394173530489205  
Training accuracy: 0.9826666666666667  
Testing loss: 0.09497136086415334  
Testing accuracy: 0.9709  
Epoch 13

-----  
Training loss: 0.05023728249308963  
Training accuracy: 0.98405  
Testing loss: 0.08963859876451694  
Testing accuracy: 0.9736  
Epoch 14



```
Training loss: 0.04733191684087117
Training accuracy: 0.9849833333333333
Testing loss: 0.08746010824373573
Testing accuracy: 0.9728
Epoch 15
-----
Training loss: 0.04125695842442413
Training accuracy: 0.9872166666666666
Testing loss: 0.0860392417874377
Testing accuracy: 0.9737
Epoch 16
-----
Training loss: 0.03636408651980261
Training accuracy: 0.9882333333333333
Testing loss: 0.09407347324897482
Testing accuracy: 0.9722
Epoch 17
-----
Training loss: 0.038080684717123704
Training accuracy: 0.9876833333333334
Testing loss: 0.08998666844734103
Testing accuracy: 0.9703
Epoch 18
-----
Training loss: 0.03184825262650848
Training accuracy: 0.9898333333333333
Testing loss: 0.09108657187153436
Testing accuracy: 0.9741
Epoch 19
-----
Training loss: 0.02980452329556768
Training accuracy: 0.9907333333333334
Testing loss: 0.07801716006472173
Testing accuracy: 0.9752
Epoch 20
-----
Training loss: 0.027299574650699893
Training accuracy: 0.9912333333333333
Testing loss: 0.09684220382166658
Testing accuracy: 0.9708
Epoch 21
-----
Training loss: 0.02572000036581109
Training accuracy: 0.99205
Testing loss: 0.08445076401357296
Testing accuracy: 0.9735
Epoch 22
-----
```

```
Training loss: 0.02258771910723299
Training accuracy: 0.9929
Testing loss: 0.09490800216040651
Testing accuracy: 0.9717
Epoch 23
-----
Training loss: 0.01977631607639293
Training accuracy: 0.9944833333333334
Testing loss: 0.09842030730715413
Testing accuracy: 0.9717
Epoch 24
-----
Training loss: 0.019920857168811684
Training accuracy: 0.99405
Testing loss: 0.09214528122988001
Testing accuracy: 0.9748
Epoch 25
-----
Training loss: 0.016550616283342243
Training accuracy: 0.9954666666666667
Testing loss: 0.0856430234686341
Testing accuracy: 0.976
Epoch 26
-----
Training loss: 0.014591319474329551
Training accuracy: 0.99595
Testing loss: 0.0887628015965686
Testing accuracy: 0.9747
Epoch 27
-----
Training loss: 0.01377143565636749
Training accuracy: 0.9963
Testing loss: 0.08931612354557913
Testing accuracy: 0.976
Epoch 28
-----
Training loss: 0.010449649132912358
Training accuracy: 0.9978666666666667
Testing loss: 0.0946262071241334
Testing accuracy: 0.9739
Epoch 29
-----
Training loss: 0.011120211119142671
Training accuracy: 0.9974166666666666
Testing loss: 0.09095879259095142
Testing accuracy: 0.976
Epoch 30
-----
```

```
Training loss: 0.010126749457015345
Training accuracy: 0.99755
Testing loss: 0.08906363003930243
Testing accuracy: 0.9763
Epoch 31
-----
Training loss: 0.008802560457990815
Training accuracy: 0.9981333333333333
Testing loss: 0.09131564625544818
Testing accuracy: 0.9749
Epoch 32
-----
Training loss: 0.008175479775636147
Training accuracy: 0.9984166666666666
Testing loss: 0.09360772755907576
Testing accuracy: 0.9754
Epoch 33
-----
Training loss: 0.006425619933288544
Training accuracy: 0.9990333333333333
Testing loss: 0.08853705267453044
Testing accuracy: 0.975
Epoch 34
-----
Training loss: 0.004346919734636322
Training accuracy: 0.9996166666666667
Testing loss: 0.08624861747468376
Testing accuracy: 0.9769
Epoch 35
-----
Training loss: 0.003946697086359685
Training accuracy: 0.99965
Testing loss: 0.08766255384254726
Testing accuracy: 0.9771
Epoch 36
-----
Training loss: 0.0036626973311572027
Training accuracy: 0.9997666666666667
Testing loss: 0.08912959649260185
Testing accuracy: 0.9763
Epoch 37
-----
Training loss: 0.0034168789367812376
Training accuracy: 0.9996833333333334
Testing loss: 0.08783636696300778
Testing accuracy: 0.9764
Epoch 38
-----
```

Training loss: 0.0028238069178226095  
Training accuracy: 0.9999  
Testing loss: 0.0854591802289045  
Testing accuracy: 0.9774  
Epoch 39

-----  
Training loss: 0.0025531144849878424  
Training accuracy: 0.9998833333333333  
Testing loss: 0.08734804974716145  
Testing accuracy: 0.977  
Epoch 40

-----  
Training loss: 0.0024357779132512707  
Training accuracy: 0.9999166666666667  
Testing loss: 0.08803225702559427  
Testing accuracy: 0.9771  
Epoch 41

-----  
Training loss: 0.0022028395182142656  
Training accuracy: 0.9999166666666667  
Testing loss: 0.08806514180195667  
Testing accuracy: 0.9773  
Epoch 42

-----  
Training loss: 0.0020262483320043732  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08874244237419479  
Testing accuracy: 0.977  
Epoch 43

-----  
Training loss: 0.0019673627532397707  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08834963838388987  
Testing accuracy: 0.9769  
Epoch 44

-----  
Training loss: 0.0018526369922872011  
Training accuracy: 0.9999833333333333  
Testing loss: 0.08804023114776767  
Testing accuracy: 0.9779  
Epoch 45

-----  
Training loss: 0.0017991218943304071  
Training accuracy: 0.9999666666666667  
Testing loss: 0.08874912556399114  
Testing accuracy: 0.9777  
Epoch 46

Training loss: 0.0016852285980945452  
Training accuracy: 0.9999833333333333  
Testing loss: 0.09063779789462069  
Testing accuracy: 0.9766  
Epoch 47

-----  
Training loss: 0.001638069524282279  
Training accuracy: 0.9999833333333333  
Testing loss: 0.09037327005232797  
Testing accuracy: 0.9772  
Epoch 48

-----  
Training loss: 0.0015809741950516278  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0891760318035076  
Testing accuracy: 0.9776  
Epoch 49

-----  
Training loss: 0.0015378308527947714  
Training accuracy: 0.9999833333333333  
Testing loss: 0.09042640956715424  
Testing accuracy: 0.9777  
Epoch 50

-----  
Training loss: 0.001448394891487745  
Training accuracy: 0.9999833333333333  
Testing loss: 0.09061596772792822  
Testing accuracy: 0.9771  
Epoch 51

-----  
Training loss: 0.0014337695606208096  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0916701415510126  
Testing accuracy: 0.9765  
Epoch 52

-----  
Training loss: 0.0013720853364948805  
Training accuracy: 0.9999833333333333  
Testing loss: 0.09264771274533264  
Testing accuracy: 0.9775  
Epoch 53

-----  
Training loss: 0.0013113000522833318  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0921657349708361  
Testing accuracy: 0.9775  
Epoch 54

Training loss: 0.0012753291497162233  
Training accuracy: 1.0  
Testing loss: 0.09131095408733376  
Testing accuracy: 0.9775  
Epoch 55

-----  
Training loss: 0.001245487772343525  
Training accuracy: 1.0  
Testing loss: 0.09157231587387923  
Testing accuracy: 0.9773  
Epoch 56

-----  
Training loss: 0.001194065529856986  
Training accuracy: 1.0  
Testing loss: 0.09428939466278669  
Testing accuracy: 0.9771  
Epoch 57

-----  
Training loss: 0.0011778583049153288  
Training accuracy: 1.0  
Testing loss: 0.09166739206432267  
Testing accuracy: 0.9771  
Epoch 58

-----  
Training loss: 0.0011376931485099096  
Training accuracy: 1.0  
Testing loss: 0.09282989772230388  
Testing accuracy: 0.9773  
Epoch 59

-----  
Training loss: 0.0011204806888243184  
Training accuracy: 1.0  
Testing loss: 0.09430653272001266  
Testing accuracy: 0.977  
Epoch 60

-----  
Training loss: 0.0010848203314914524  
Training accuracy: 1.0  
Testing loss: 0.09270780316663751  
Testing accuracy: 0.9769  
Epoch 61

-----  
Training loss: 0.001051164231891744  
Training accuracy: 1.0  
Testing loss: 0.09299818177783126  
Testing accuracy: 0.9772  
Epoch 62

Training loss: 0.0010248804034180164  
Training accuracy: 1.0  
Testing loss: 0.0935159759695351  
Testing accuracy: 0.9774  
Epoch 63

-----  
Training loss: 0.0010070816814977054  
Training accuracy: 1.0  
Testing loss: 0.09379628318981831  
Testing accuracy: 0.9775  
Epoch 64

-----  
Training loss: 0.0009889112623796487  
Training accuracy: 1.0  
Testing loss: 0.09347850408831057  
Testing accuracy: 0.9773  
Epoch 65

-----  
Training loss: 0.0009511079448430488  
Training accuracy: 1.0  
Testing loss: 0.09542101470232277  
Testing accuracy: 0.9776  
Epoch 66

-----  
Training loss: 0.000939725465226608  
Training accuracy: 1.0  
Testing loss: 0.09567736665207364  
Testing accuracy: 0.9775  
Epoch 67

-----  
Training loss: 0.0009216351715188163  
Training accuracy: 1.0  
Testing loss: 0.0947245361022414  
Testing accuracy: 0.9778  
Epoch 68

-----  
Training loss: 0.0009006297658973684  
Training accuracy: 1.0  
Testing loss: 0.09400640447855005  
Testing accuracy: 0.9769  
Epoch 69

-----  
Training loss: 0.0008844055370350058  
Training accuracy: 1.0  
Testing loss: 0.09477345593684987  
Testing accuracy: 0.9774  
Epoch 70

-----

Training loss: 0.0008605634128985305  
Training accuracy: 1.0  
Testing loss: 0.09640293646452557  
Testing accuracy: 0.9769  
Epoch 71

-----  
Training loss: 0.0008502159407828003  
Training accuracy: 1.0  
Testing loss: 0.09496422321239048  
Testing accuracy: 0.9773  
Epoch 72

-----  
Training loss: 0.0008405827623636773  
Training accuracy: 1.0  
Testing loss: 0.09638151533884637  
Testing accuracy: 0.9771  
Epoch 73

-----  
Training loss: 0.0008150801616371609  
Training accuracy: 1.0  
Testing loss: 0.0953795625561267  
Testing accuracy: 0.9775  
Epoch 74

-----  
Training loss: 0.0008006265261753773  
Training accuracy: 1.0  
Testing loss: 0.09534269448558452  
Testing accuracy: 0.9774  
Epoch 75

-----  
Training loss: 0.0007853798067274814  
Training accuracy: 1.0  
Testing loss: 0.09528002262002493  
Testing accuracy: 0.9772  
Epoch 76

-----  
Training loss: 0.0007740513942398441  
Training accuracy: 1.0  
Testing loss: 0.0961034322718446  
Testing accuracy: 0.9773  
Epoch 77

-----  
Training loss: 0.0007608792539181499  
Training accuracy: 1.0  
Testing loss: 0.0971116507581619  
Testing accuracy: 0.9772  
Epoch 78



Training loss: 0.0007462965532749271  
Training accuracy: 1.0  
Testing loss: 0.09586128624864527  
Testing accuracy: 0.9775  
Epoch 79

-----  
Training loss: 0.0007348578512396974  
Training accuracy: 1.0  
Testing loss: 0.0974399135254322  
Testing accuracy: 0.9765  
Epoch 80

-----  
Training loss: 0.0007184696331076945  
Training accuracy: 1.0  
Testing loss: 0.09638273810226675  
Testing accuracy: 0.9775  
Epoch 81

-----  
Training loss: 0.0007095293265990525  
Training accuracy: 1.0  
Testing loss: 0.09644342658291075  
Testing accuracy: 0.9774  
Epoch 82

-----  
Training loss: 0.0006980226743267849  
Training accuracy: 1.0  
Testing loss: 0.09733141591578906  
Testing accuracy: 0.977  
Epoch 83

-----  
Training loss: 0.0006894200241348396  
Training accuracy: 1.0  
Testing loss: 0.09640101113343302  
Testing accuracy: 0.9771  
Epoch 84

-----  
Training loss: 0.0006745754104844915  
Training accuracy: 1.0  
Testing loss: 0.09707352366632992  
Testing accuracy: 0.9772  
Epoch 85

-----  
Training loss: 0.0006687076918043506  
Training accuracy: 1.0  
Testing loss: 0.09743615390457047  
Testing accuracy: 0.9773  
Epoch 86

Training loss: 0.0006592999702203087  
Training accuracy: 1.0  
Testing loss: 0.09846696845405205  
Testing accuracy: 0.9773  
Epoch 87

-----  
Training loss: 0.0006455063875919829  
Training accuracy: 1.0  
Testing loss: 0.09766113676262758  
Testing accuracy: 0.9772  
Epoch 88

-----  
Training loss: 0.0006379315659054555  
Training accuracy: 1.0  
Testing loss: 0.09672144621741886  
Testing accuracy: 0.9774  
Epoch 89

-----  
Training loss: 0.0006274380796414334  
Training accuracy: 1.0  
Testing loss: 0.09777422547473863  
Testing accuracy: 0.9774  
Epoch 90

-----  
Training loss: 0.0006195101318492865  
Training accuracy: 1.0  
Testing loss: 0.09688063267854585  
Testing accuracy: 0.9775  
Epoch 91

-----  
Training loss: 0.0006101263078317667  
Training accuracy: 1.0  
Testing loss: 0.0975841147770251  
Testing accuracy: 0.9773  
Epoch 92

-----  
Training loss: 0.0006020532289403491  
Training accuracy: 1.0  
Testing loss: 0.09729845600371742  
Testing accuracy: 0.9774  
Epoch 93

-----  
Training loss: 0.0005947224760466876  
Training accuracy: 1.0  
Testing loss: 0.0974678894229438  
Testing accuracy: 0.9775  
Epoch 94

Training loss: 0.0005874073521311705  
Training accuracy: 1.0  
Testing loss: 0.09823945795603328  
Testing accuracy: 0.9771  
Epoch 95

-----  
Training loss: 0.0005786141173526024  
Training accuracy: 1.0  
Testing loss: 0.09859439234426234  
Testing accuracy: 0.9774  
Epoch 96

-----  
Training loss: 0.0005706319593630421  
Training accuracy: 1.0  
Testing loss: 0.09848220883058548  
Testing accuracy: 0.977  
Epoch 97

-----  
Training loss: 0.0005629017968933719  
Training accuracy: 1.0  
Testing loss: 0.10010170661210331  
Testing accuracy: 0.9773  
Epoch 98

-----  
Training loss: 0.0005548066576826386  
Training accuracy: 1.0  
Testing loss: 0.10169832845995941  
Testing accuracy: 0.9768  
Epoch 99

-----  
Training loss: 0.0005483140853544076  
Training accuracy: 1.0  
Testing loss: 0.09839310568053303  
Testing accuracy: 0.977  
Epoch 100

-----  
Training loss: 0.0005424411749583669  
Training accuracy: 1.0  
Testing loss: 0.09969931957529743  
Testing accuracy: 0.9767  
Epoch 101

-----  
Training loss: 0.0005358913891133852  
Training accuracy: 1.0  
Testing loss: 0.0990720389201936  
Testing accuracy: 0.9772  
Epoch 102

Training loss: 0.0005276825185865164  
Training accuracy: 1.0  
Testing loss: 0.09928972486944708  
Testing accuracy: 0.9775  
Epoch 103

-----  
Training loss: 0.0005225239602072785  
Training accuracy: 1.0  
Testing loss: 0.09963027544869822  
Testing accuracy: 0.9775  
Epoch 104

-----  
Training loss: 0.0005162996599373097  
Training accuracy: 1.0  
Testing loss: 0.09836246847704491  
Testing accuracy: 0.9774  
Epoch 105

-----  
Training loss: 0.0005084767430574478  
Training accuracy: 1.0  
Testing loss: 0.10550353498366598  
Testing accuracy: 0.9769  
Epoch 106

-----  
Training loss: 0.0005024293658634027  
Training accuracy: 1.0  
Testing loss: 0.09977191117054847  
Testing accuracy: 0.977  
Epoch 107

-----  
Training loss: 0.0004979191645300792  
Training accuracy: 1.0  
Testing loss: 0.10022630083260117  
Testing accuracy: 0.9771  
Epoch 108

-----  
Training loss: 0.0004907683973045399  
Training accuracy: 1.0  
Testing loss: 0.09907420777156281  
Testing accuracy: 0.977  
Epoch 109

-----  
Training loss: 0.0004855508984454597  
Training accuracy: 1.0  
Testing loss: 0.10309130217886313  
Testing accuracy: 0.9767  
Epoch 110

Training loss: 0.00048279823278814244  
Training accuracy: 1.0  
Testing loss: 0.10165091632912825  
Testing accuracy: 0.977  
Epoch 111

-----  
Training loss: 0.00047674195575721874  
Training accuracy: 1.0  
Testing loss: 0.10160658639245754  
Testing accuracy: 0.9772  
Epoch 112

-----  
Training loss: 0.00047188269270118327  
Training accuracy: 1.0  
Testing loss: 0.10033293305419809  
Testing accuracy: 0.977  
Epoch 113

-----  
Training loss: 0.00046608276361366735  
Training accuracy: 1.0  
Testing loss: 0.10172780094879874  
Testing accuracy: 0.9768  
Epoch 114

-----  
Training loss: 0.0004605791994603351  
Training accuracy: 1.0  
Testing loss: 0.1009685326282912  
Testing accuracy: 0.9769  
Epoch 115

-----  
Training loss: 0.0004559997944859788  
Training accuracy: 1.0  
Testing loss: 0.10075474663894647  
Testing accuracy: 0.9766  
Epoch 116

-----  
Training loss: 0.0004513279098357695  
Training accuracy: 1.0  
Testing loss: 0.10183634249672181  
Testing accuracy: 0.9771  
Epoch 117

-----  
Training loss: 0.0004444815508206375  
Training accuracy: 1.0  
Testing loss: 0.10060867060235017  
Testing accuracy: 0.9775  
Epoch 118

-----

Training loss: 0.0004417276287179751  
Training accuracy: 1.0  
Testing loss: 0.10388762281570289  
Testing accuracy: 0.9768  
Epoch 119

-----  
Training loss: 0.00043592040771327445  
Training accuracy: 1.0  
Testing loss: 0.10136224927647991  
Testing accuracy: 0.9772  
Epoch 120

-----  
Training loss: 0.00043238552699719244  
Training accuracy: 1.0  
Testing loss: 0.10076340641285098  
Testing accuracy: 0.9767  
Epoch 121

-----  
Training loss: 0.00042925548326262894  
Training accuracy: 1.0  
Testing loss: 0.10055533266951816  
Testing accuracy: 0.9769  
Epoch 122

-----  
Training loss: 0.00042544672841516635  
Training accuracy: 1.0  
Testing loss: 0.10105824105980314  
Testing accuracy: 0.9768  
Epoch 123

-----  
Training loss: 0.00041931854393721245  
Training accuracy: 1.0  
Testing loss: 0.10152918177596906  
Testing accuracy: 0.9767  
Epoch 124

-----  
Training loss: 0.00041556430810014717  
Training accuracy: 1.0  
Testing loss: 0.101227589533896  
Testing accuracy: 0.9769  
Epoch 125

-----  
Training loss: 0.000412258932304879  
Training accuracy: 1.0  
Testing loss: 0.10198409874060793  
Testing accuracy: 0.977  
Epoch 126

-----

Training loss: 0.0004079270554919882  
Training accuracy: 1.0  
Testing loss: 0.10249853777697504  
Testing accuracy: 0.977  
Epoch 127

-----  
Training loss: 0.0004034297170777184  
Training accuracy: 1.0  
Testing loss: 0.10290780529557063  
Testing accuracy: 0.977  
Epoch 128

-----  
Training loss: 0.0004004782502849897  
Training accuracy: 1.0  
Testing loss: 0.10182090127154937  
Testing accuracy: 0.9768  
Epoch 129

-----  
Training loss: 0.0003959777855547145  
Training accuracy: 1.0  
Testing loss: 0.1025880473918188  
Testing accuracy: 0.9772  
Epoch 130

-----  
Training loss: 0.00039343213911633936  
Training accuracy: 1.0  
Testing loss: 0.10198885572286008  
Testing accuracy: 0.977  
Epoch 131

-----  
Training loss: 0.00038817368488331945  
Training accuracy: 1.0  
Testing loss: 0.10315224542605074  
Testing accuracy: 0.9769  
Epoch 132

-----  
Training loss: 0.0003847934708678319  
Training accuracy: 1.0  
Testing loss: 0.10199283698543145  
Testing accuracy: 0.9768  
Epoch 133

-----  
Training loss: 0.0003833496054110583  
Training accuracy: 1.0  
Testing loss: 0.10253436001114825  
Testing accuracy: 0.9769  
Epoch 134

Training loss: 0.00037653117400671663  
Training accuracy: 1.0  
Testing loss: 0.10215640240132914  
Testing accuracy: 0.9769  
Epoch 135

-----  
Training loss: 0.0003749979404383339  
Training accuracy: 1.0  
Testing loss: 0.10220182936458294  
Testing accuracy: 0.977  
Epoch 136

-----  
Training loss: 0.00037220468218632355  
Training accuracy: 1.0  
Testing loss: 0.10202964630429004  
Testing accuracy: 0.9772  
Epoch 137

-----  
Training loss: 0.00036896448604141675  
Training accuracy: 1.0  
Testing loss: 0.10245811171262176  
Testing accuracy: 0.977  
Epoch 138

-----  
Training loss: 0.00036473257242081067  
Training accuracy: 1.0  
Testing loss: 0.10258795083494884  
Testing accuracy: 0.9771  
Epoch 139

-----  
Training loss: 0.00036221285810849316  
Training accuracy: 1.0  
Testing loss: 0.10281825441225995  
Testing accuracy: 0.9768  
Epoch 140

-----  
Training loss: 0.0003584002950112335  
Training accuracy: 1.0  
Testing loss: 0.10361504424147414  
Testing accuracy: 0.977  
Epoch 141

-----  
Training loss: 0.0003562891506978  
Training accuracy: 1.0  
Testing loss: 0.10289207709200845  
Testing accuracy: 0.9769  
Epoch 142



Training loss: 0.0003534923404901444  
Training accuracy: 1.0  
Testing loss: 0.10305061623558645  
Testing accuracy: 0.977  
Epoch 143

-----  
Training loss: 0.0003499566288742547  
Training accuracy: 1.0  
Testing loss: 0.10258499713613471  
Testing accuracy: 0.9771  
Epoch 144

-----  
Training loss: 0.00034740538240487996  
Training accuracy: 1.0  
Testing loss: 0.10278240618463547  
Testing accuracy: 0.9769  
Epoch 145

-----  
Training loss: 0.0003440994698767706  
Training accuracy: 1.0  
Testing loss: 0.10309174934429544  
Testing accuracy: 0.9772  
Epoch 146

-----  
Training loss: 0.00034148884502938016  
Training accuracy: 1.0  
Testing loss: 0.10318135759058397  
Testing accuracy: 0.9775  
Epoch 147

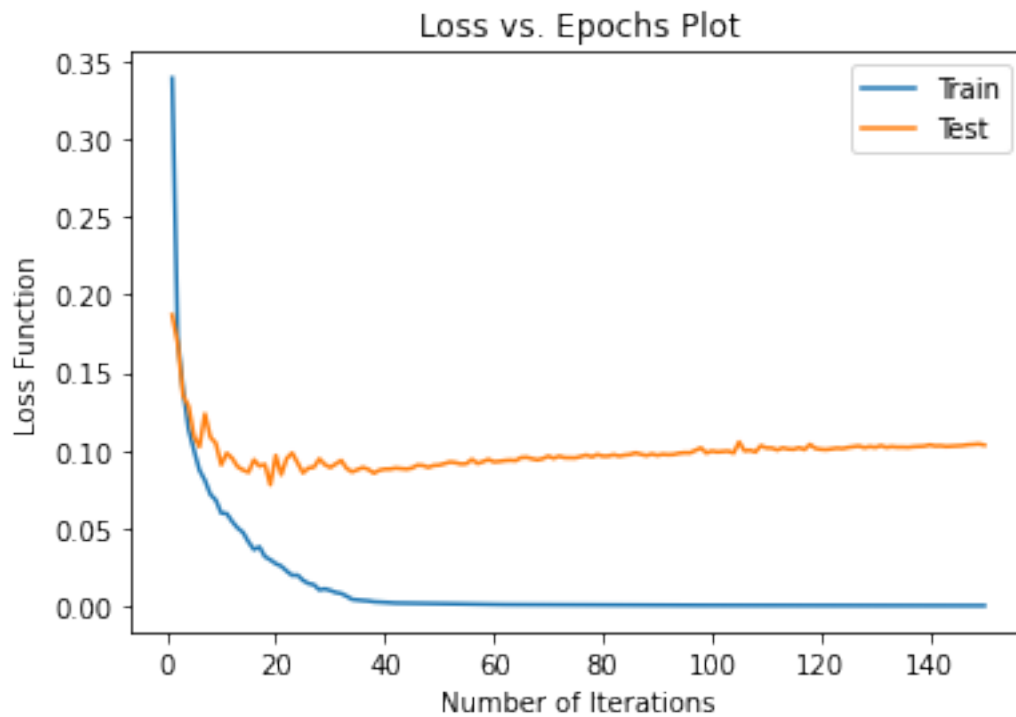
-----  
Training loss: 0.00033837862680084074  
Training accuracy: 1.0  
Testing loss: 0.10372570107412372  
Testing accuracy: 0.9768  
Epoch 148

-----  
Training loss: 0.00033638607357667447  
Training accuracy: 1.0  
Testing loss: 0.10387071188185015  
Testing accuracy: 0.9768  
Epoch 149

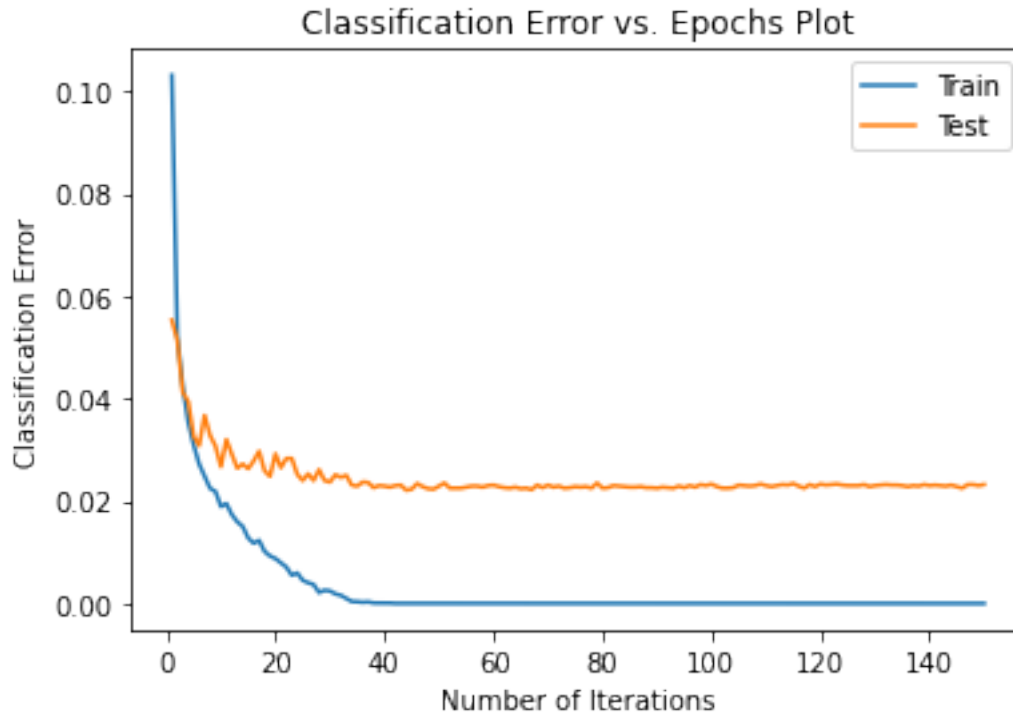
-----  
Training loss: 0.00033256490144412966  
Training accuracy: 1.0  
Testing loss: 0.10423249166842942  
Testing accuracy: 0.977  
Epoch 150

Training loss: 0.0003309348310683466  
Training accuracy: 1.0  
Testing loss: 0.10345700150651065  
Testing accuracy: 0.9768  
Done  
Total Time Consumed: 1593.0215620994568

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.3.6 Best Combination of Hyperparameters

From above plots, it can be observed that: 1. With a total number of 150 epochs, learning rate = 0.2, 0.5, momentum = 0.5, 0.9 combined with learning rate = 0.1, the models all suffer from overfitting. In another word, the testing loss and testing missclassification increase at the end of training process;

2. With learning rate = 0.01, the convergence process is slow and inefficient.

Therefore, in terms of efficiency and stability in local minimum, we choose a decaying learning rate which start at 0.2 at the beginning and decay to 0.02 after 30 epochs and 0.002 after 120 epochs to ensure both efficiency and stability.

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.2
batch_size = 64
num_epochs = 150
momentum = 0.5
best_ANN = ANN(input_size, num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(best_ANN.parameters(), lr = learning_rate, momentum = 0.5)
```

```
scheduler1 = optim.lr_scheduler.MultiStepLR(optimizer, milestones=[30,120],  
↳gamma=0.1)
```

```
[ ]: # Set Seed  
torch.manual_seed(1)  
  
# Data Loading  
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,  
↳shuffle = True)  
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle_  
↳= True)  
  
start_time = time.time()  
test_loss_record = []  
train_loss_record = []  
for i in range(num_epochs):  
    print(f"Epoch {i+1}\n-----")  
    train_loss_record.append(train_loop(train_loader,best_ANN,loss,optimizer))  
    test_loss_record.append(test_loop(test_loader,best_ANN,loss))  
    scheduler1.step()  
print('Done')  
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----  
Training loss: 0.20079905929168065  
Training accuracy: 0.9413833333333333  
Testing loss: 0.15954857249595936  
Testing accuracy: 0.953  
Epoch 2
```

```
-----  
Training loss: 0.15190874659021694  
Training accuracy: 0.9547166666666667  
Testing loss: 0.1338784081659689  
Testing accuracy: 0.9596  
Epoch 3
```

```
-----  
Training loss: 0.12296052929957707  
Training accuracy: 0.9639666666666666  
Testing loss: 0.12871403236440412  
Testing accuracy: 0.9621  
Epoch 4
```

```
-----  
Training loss: 0.10417695813477039  
Training accuracy: 0.9695833333333334
```

```
Testing loss: 0.10734542478231868
Testing accuracy: 0.9683
Epoch 5
-----
Training loss: 0.0911015936901172
Training accuracy: 0.9737833333333333
Testing loss: 0.10990347884073379
Testing accuracy: 0.9664
Epoch 6
-----
Training loss: 0.08066220927834511
Training accuracy: 0.9766166666666667
Testing loss: 0.09080003348481692
Testing accuracy: 0.9717
Epoch 7
-----
Training loss: 0.07140253787140051
Training accuracy: 0.9787166666666667
Testing loss: 0.09127787017162628
Testing accuracy: 0.9721
Epoch 8
-----
Training loss: 0.06302185124804577
Training accuracy: 0.9815833333333334
Testing loss: 0.09290427813650506
Testing accuracy: 0.9722
Epoch 9
-----
Training loss: 0.05810399713665247
Training accuracy: 0.9832166666666666
Testing loss: 0.08660202729070832
Testing accuracy: 0.9738
Epoch 10
-----
Training loss: 0.05265853990912438
Training accuracy: 0.9848833333333333
Testing loss: 0.07561694523378922
Testing accuracy: 0.9767
Epoch 11
-----
Training loss: 0.048983246206740536
Training accuracy: 0.9856833333333334
Testing loss: 0.08171654757776647
Testing accuracy: 0.9739
Epoch 12
-----
Training loss: 0.043951990876098475
Training accuracy: 0.9878166666666667
```

```

Testing loss: 0.08128708083135118
Testing accuracy: 0.9728
Epoch 13
-----
Training loss: 0.039590534640848635
Training accuracy: 0.9886166666666667
Testing loss: 0.08370636946337807
Testing accuracy: 0.9733
Epoch 14
-----
Training loss: 0.037255617037415506
Training accuracy: 0.9897333333333334
Testing loss: 0.07319515871675981
Testing accuracy: 0.9755
Epoch 15
-----
Training loss: 0.03372354771842559
Training accuracy: 0.9905666666666667
Testing loss: 0.07640270519983854
Testing accuracy: 0.9757
Epoch 16
-----
Training loss: 0.03068542413637042
Training accuracy: 0.9920666666666667
Testing loss: 0.07464511527614609
Testing accuracy: 0.9749
Epoch 17
-----
Training loss: 0.02825725683582326
Training accuracy: 0.9928833333333333
Testing loss: 0.07264061559252678
Testing accuracy: 0.9768
Epoch 18
-----
Training loss: 0.02588946180517475
Training accuracy: 0.9935
Testing loss: 0.07299322034024698
Testing accuracy: 0.9775
Epoch 19
-----
Training loss: 0.024066987660465142
Training accuracy: 0.9941
Testing loss: 0.07605299094149096
Testing accuracy: 0.9744
Epoch 20
-----
Training loss: 0.022289182392631966
Training accuracy: 0.9949166666666667

```

```
Testing loss: 0.07035947314635584
Testing accuracy: 0.9772
Epoch 21
-----
Training loss: 0.020383423882350326
Training accuracy: 0.9955833333333334
Testing loss: 0.07089817308625028
Testing accuracy: 0.9776
Epoch 22
-----
Training loss: 0.01871926601032416
Training accuracy: 0.9962333333333333
Testing loss: 0.07663896392918174
Testing accuracy: 0.9766
Epoch 23
-----
Training loss: 0.018098479845002294
Training accuracy: 0.9961166666666667
Testing loss: 0.07227134715712327
Testing accuracy: 0.9774
Epoch 24
-----
Training loss: 0.01634335420237233
Training accuracy: 0.9967666666666667
Testing loss: 0.07563142175934497
Testing accuracy: 0.9775
Epoch 25
-----
Training loss: 0.015250801891088486
Training accuracy: 0.9972166666666666
Testing loss: 0.07370430729529898
Testing accuracy: 0.9772
Epoch 26
-----
Training loss: 0.013742485567058127
Training accuracy: 0.9977666666666667
Testing loss: 0.07444831177260086
Testing accuracy: 0.9771
Epoch 27
-----
Training loss: 0.012798981273236374
Training accuracy: 0.99795
Testing loss: 0.07134593267121299
Testing accuracy: 0.9781
Epoch 28
-----
Training loss: 0.011959365191062292
Training accuracy: 0.9983333333333333
```

```
Testing loss: 0.08563614168477239
Testing accuracy: 0.9745
Epoch 29
-----
Training loss: 0.011115939695822696
Training accuracy: 0.9987666666666667
Testing loss: 0.0744814723878387
Testing accuracy: 0.9776
Epoch 30
-----
Training loss: 0.010620116077363491
Training accuracy: 0.9986666666666667
Testing loss: 0.07517120504461133
Testing accuracy: 0.9783
Epoch 31
-----
Training loss: 0.007381215767438213
Training accuracy: 0.9994833333333333
Testing loss: 0.06993899905978507
Testing accuracy: 0.9789
Epoch 32
-----
Training loss: 0.006996035001240671
Training accuracy: 0.9996166666666667
Testing loss: 0.07042365063613601
Testing accuracy: 0.9789
Epoch 33
-----
Training loss: 0.006933186800995221
Training accuracy: 0.9995833333333334
Testing loss: 0.06997317933903081
Testing accuracy: 0.979
Epoch 34
-----
Training loss: 0.006869842504275342
Training accuracy: 0.9995833333333334
Testing loss: 0.07001805068868669
Testing accuracy: 0.979
Epoch 35
-----
Training loss: 0.006822681705094874
Training accuracy: 0.9996
Testing loss: 0.07026856528835336
Testing accuracy: 0.9789
Epoch 36
-----
Training loss: 0.006762621701477716
Training accuracy: 0.9996333333333334
```



```

Testing loss: 0.07068948611501415
Testing accuracy: 0.9789
Epoch 37
-----
Training loss: 0.00671679349988699
Training accuracy: 0.9996666666666667
Testing loss: 0.07063209721714757
Testing accuracy: 0.9785
Epoch 38
-----
Training loss: 0.006683293585975965
Training accuracy: 0.9996833333333334
Testing loss: 0.07088559631786197
Testing accuracy: 0.9788
Epoch 39
-----
Training loss: 0.006648449926450848
Training accuracy: 0.9996666666666667
Testing loss: 0.0701336161015484
Testing accuracy: 0.9788
Epoch 40
-----
Training loss: 0.0065942664764200645
Training accuracy: 0.9997
Testing loss: 0.06986497132964788
Testing accuracy: 0.9785
Epoch 41
-----
Training loss: 0.006554990017662445
Training accuracy: 0.9996333333333334
Testing loss: 0.07121857427947437
Testing accuracy: 0.9785
Epoch 42
-----
Training loss: 0.006523300759928922
Training accuracy: 0.9996666666666667
Testing loss: 0.0709071303762282
Testing accuracy: 0.9792
Epoch 43
-----
Training loss: 0.006485642663110048
Training accuracy: 0.9996666666666667
Testing loss: 0.07022983329385447
Testing accuracy: 0.9792
Epoch 44
-----
Training loss: 0.00644954034499824
Training accuracy: 0.9997

```

```
Testing loss: 0.07017383233968104
Testing accuracy: 0.9787
Epoch 45
-----
Training loss: 0.006401451125896226
Training accuracy: 0.9996666666666667
Testing loss: 0.0701312614415007
Testing accuracy: 0.9788
Epoch 46
-----
Training loss: 0.006374199518033614
Training accuracy: 0.99965
Testing loss: 0.0702498492912336
Testing accuracy: 0.9791
Epoch 47
-----
Training loss: 0.006340668495309849
Training accuracy: 0.9996833333333334
Testing loss: 0.07030396430403184
Testing accuracy: 0.9786
Epoch 48
-----
Training loss: 0.00632361586963137
Training accuracy: 0.9997
Testing loss: 0.07060188534120869
Testing accuracy: 0.9785
Epoch 49
-----
Training loss: 0.006281173651386052
Training accuracy: 0.9996833333333334
Testing loss: 0.07161587767249603
Testing accuracy: 0.9789
Epoch 50
-----
Training loss: 0.006234561907189588
Training accuracy: 0.9997333333333334
Testing loss: 0.07038859787707033
Testing accuracy: 0.979
Epoch 51
-----
Training loss: 0.006230950887811681
Training accuracy: 0.9997
Testing loss: 0.07058224327799976
Testing accuracy: 0.9786
Epoch 52
-----
Training loss: 0.006166951755806804
Training accuracy: 0.9997333333333334
```

Testing loss: 0.07128324595748618  
Testing accuracy: 0.9785  
Epoch 53  
-----  
Training loss: 0.006154926686237256  
Training accuracy: 0.9997333333333334  
Testing loss: 0.07042144997502162  
Testing accuracy: 0.9792  
Epoch 54  
-----  
Training loss: 0.006118408139546712  
Training accuracy: 0.9997333333333334  
Testing loss: 0.07136072501077488  
Testing accuracy: 0.9788  
Epoch 55  
-----  
Training loss: 0.006101337343392273  
Training accuracy: 0.9997666666666667  
Testing loss: 0.07038864517135095  
Testing accuracy: 0.9786  
Epoch 56  
-----  
Training loss: 0.006056408883196612  
Training accuracy: 0.99975  
Testing loss: 0.0709012293443677  
Testing accuracy: 0.9787  
Epoch 57  
-----  
Training loss: 0.006032499381092687  
Training accuracy: 0.9997166666666667  
Testing loss: 0.07063068895527327  
Testing accuracy: 0.979  
Epoch 58  
-----  
Training loss: 0.00600253666791444  
Training accuracy: 0.9997666666666667  
Testing loss: 0.0710744619644603  
Testing accuracy: 0.9789  
Epoch 59  
-----  
Training loss: 0.005974246283558508  
Training accuracy: 0.9997166666666667  
Testing loss: 0.07177904253576402  
Testing accuracy: 0.9789  
Epoch 60  
-----  
Training loss: 0.005940721844695508  
Training accuracy: 0.9997333333333334

```
Testing loss: 0.07057526415424528
Testing accuracy: 0.979
Epoch 61
-----
Training loss: 0.005901284020704528
Training accuracy: 0.99975
Testing loss: 0.0706745230149371
Testing accuracy: 0.9791
Epoch 62
-----
Training loss: 0.005874178706792493
Training accuracy: 0.9997833333333334
Testing loss: 0.07073173122806771
Testing accuracy: 0.979
Epoch 63
-----
Training loss: 0.005845208413712681
Training accuracy: 0.9997833333333334
Testing loss: 0.07078300494438179
Testing accuracy: 0.9787
Epoch 64
-----
Training loss: 0.005818729452074816
Training accuracy: 0.9997833333333334
Testing loss: 0.07091446922073188
Testing accuracy: 0.979
Epoch 65
-----
Training loss: 0.005787265371593337
Training accuracy: 0.9997833333333334
Testing loss: 0.07129798265349024
Testing accuracy: 0.979
Epoch 66
-----
Training loss: 0.005764267009496689
Training accuracy: 0.9997833333333334
Testing loss: 0.07274892105080283
Testing accuracy: 0.9788
Epoch 67
-----
Training loss: 0.005738737979407112
Training accuracy: 0.9997833333333334
Testing loss: 0.07262903439017475
Testing accuracy: 0.9791
Epoch 68
-----
Training loss: 0.005718798931191365
Training accuracy: 0.9997666666666667
```

```
Testing loss: 0.07094617508563872
Testing accuracy: 0.9792
Epoch 69
-----
Training loss: 0.0056801731061190365
Training accuracy: 0.9997666666666667
Testing loss: 0.07094410991564595
Testing accuracy: 0.9788
Epoch 70
-----
Training loss: 0.005669464448591073
Training accuracy: 0.99975
Testing loss: 0.07125138863179667
Testing accuracy: 0.9791
Epoch 71
-----
Training loss: 0.005644015228313704
Training accuracy: 0.99975
Testing loss: 0.07143740556024869
Testing accuracy: 0.9791
Epoch 72
-----
Training loss: 0.005623445865046233
Training accuracy: 0.9997666666666667
Testing loss: 0.07228801583657694
Testing accuracy: 0.9789
Epoch 73
-----
Training loss: 0.005579028232675046
Training accuracy: 0.9998
Testing loss: 0.07109861358018461
Testing accuracy: 0.9785
Epoch 74
-----
Training loss: 0.005554821643916269
Training accuracy: 0.9998
Testing loss: 0.07223748631262263
Testing accuracy: 0.9787
Epoch 75
-----
Training loss: 0.0055272793578604856
Training accuracy: 0.9998166666666667
Testing loss: 0.07105296359480519
Testing accuracy: 0.979
Epoch 76
-----
Training loss: 0.0055112608024850485
Training accuracy: 0.99975
```

```
Testing loss: 0.0709381450448114
Testing accuracy: 0.9788
Epoch 77
-----
Training loss: 0.0054755219124878445
Training accuracy: 0.9998
Testing loss: 0.07166186500055964
Testing accuracy: 0.9793
Epoch 78
-----
Training loss: 0.005459594855488589
Training accuracy: 0.9997833333333334
Testing loss: 0.07074477448989044
Testing accuracy: 0.9792
Epoch 79
-----
Training loss: 0.005436490265994022
Training accuracy: 0.9998166666666667
Testing loss: 0.07086120920765931
Testing accuracy: 0.9788
Epoch 80
-----
Training loss: 0.0054157255079597235
Training accuracy: 0.9997833333333334
Testing loss: 0.07124246584969295
Testing accuracy: 0.9786
Epoch 81
-----
Training loss: 0.005382007292378694
Training accuracy: 0.9998
Testing loss: 0.07120455227196099
Testing accuracy: 0.9789
Epoch 82
-----
Training loss: 0.005372293641262998
Training accuracy: 0.9998
Testing loss: 0.071303125599156
Testing accuracy: 0.9788
Epoch 83
-----
Training loss: 0.0053367568765456475
Training accuracy: 0.9998166666666667
Testing loss: 0.07177380360010419
Testing accuracy: 0.9789
Epoch 84
-----
Training loss: 0.005316923381822805
Training accuracy: 0.9998666666666667
```

```
Testing loss: 0.07157710930228732
Testing accuracy: 0.9786
Epoch 85
-----
Training loss: 0.005297539619915187
Training accuracy: 0.99985
Testing loss: 0.07153315419942188
Testing accuracy: 0.979
Epoch 86
-----
Training loss: 0.005269909352033089
Training accuracy: 0.9998333333333334
Testing loss: 0.07343978111396372
Testing accuracy: 0.9785
Epoch 87
-----
Training loss: 0.005246070080560943
Training accuracy: 0.9998666666666667
Testing loss: 0.07125633557132077
Testing accuracy: 0.9792
Epoch 88
-----
Training loss: 0.005230678374630709
Training accuracy: 0.9998833333333333
Testing loss: 0.07120357241828563
Testing accuracy: 0.979
Epoch 89
-----
Training loss: 0.00520303822029382
Training accuracy: 0.9998833333333333
Testing loss: 0.07154002524712152
Testing accuracy: 0.979
Epoch 90
-----
Training loss: 0.005175506349404653
Training accuracy: 0.99985
Testing loss: 0.07141450625157672
Testing accuracy: 0.9787
Epoch 91
-----
Training loss: 0.0051628024535874525
Training accuracy: 0.9998666666666667
Testing loss: 0.07133368437569944
Testing accuracy: 0.9791
Epoch 92
-----
Training loss: 0.005145996297926952
Training accuracy: 0.9998666666666667
```

```
Testing loss: 0.07148569771147979
Testing accuracy: 0.9789
Epoch 93
-----
Training loss: 0.00511856530594329
Training accuracy: 0.9998666666666667
Testing loss: 0.0712372920928956
Testing accuracy: 0.9789
Epoch 94
-----
Training loss: 0.005097314299860349
Training accuracy: 0.9998666666666667
Testing loss: 0.07145462577916373
Testing accuracy: 0.9786
Epoch 95
-----
Training loss: 0.005069915370767316
Training accuracy: 0.9998833333333333
Testing loss: 0.07156284708658732
Testing accuracy: 0.979
Epoch 96
-----
Training loss: 0.005048270582097272
Training accuracy: 0.9998666666666667
Testing loss: 0.07133743538636904
Testing accuracy: 0.9788
Epoch 97
-----
Training loss: 0.005027999232243747
Training accuracy: 0.9999
Testing loss: 0.07317008998928663
Testing accuracy: 0.9786
Epoch 98
-----
Training loss: 0.0050146759171038864
Training accuracy: 0.9999
Testing loss: 0.07411433656953548
Testing accuracy: 0.9789
Epoch 99
-----
Training loss: 0.004998877865634859
Training accuracy: 0.9999
Testing loss: 0.07169308372444004
Testing accuracy: 0.9789
Epoch 100
-----
Training loss: 0.004964643292222172
Training accuracy: 0.9998833333333333
```



```
Testing loss: 0.07163755783042278
Testing accuracy: 0.979
Epoch 101
-----
Training loss: 0.004954053663058827
Training accuracy: 0.9998833333333333
Testing loss: 0.07261959633087016
Testing accuracy: 0.979
Epoch 102
-----
Training loss: 0.004933183895610273
Training accuracy: 0.9999
Testing loss: 0.07159532606138279
Testing accuracy: 0.979
Epoch 103
-----
Training loss: 0.0049090170712520675
Training accuracy: 0.9999
Testing loss: 0.07156172703698005
Testing accuracy: 0.9791
Epoch 104
-----
Training loss: 0.004889069430716336
Training accuracy: 0.9998833333333333
Testing loss: 0.07180838556485666
Testing accuracy: 0.9789
Epoch 105
-----
Training loss: 0.004866214248165488
Training accuracy: 0.9998833333333333
Testing loss: 0.07641411707554885
Testing accuracy: 0.9788
Epoch 106
-----
Training loss: 0.004844179323067268
Training accuracy: 0.9999
Testing loss: 0.07178830352764218
Testing accuracy: 0.9792
Epoch 107
-----
Training loss: 0.00482727496859928
Training accuracy: 0.9998833333333333
Testing loss: 0.07280348490769412
Testing accuracy: 0.9791
Epoch 108
-----
Training loss: 0.004802633332864692
Training accuracy: 0.9999
```

```
Testing loss: 0.07169552864454935
Testing accuracy: 0.9788
Epoch 109
-----
Training loss: 0.004780567697280397
Training accuracy: 0.9998833333333333
Testing loss: 0.07317078265414875
Testing accuracy: 0.9793
Epoch 110
-----
Training loss: 0.004770114871735374
Training accuracy: 0.9998833333333333
Testing loss: 0.07279533024648928
Testing accuracy: 0.9788
Epoch 111
-----
Training loss: 0.004754797898605466
Training accuracy: 0.9998833333333333
Testing loss: 0.07320057654384061
Testing accuracy: 0.9788
Epoch 112
-----
Training loss: 0.004738244215926776
Training accuracy: 0.9999
Testing loss: 0.07167481549475697
Testing accuracy: 0.979
Epoch 113
-----
Training loss: 0.004712813145946711
Training accuracy: 0.9999
Testing loss: 0.07226994173722875
Testing accuracy: 0.979
Epoch 114
-----
Training loss: 0.004696335450435678
Training accuracy: 0.9999
Testing loss: 0.07209347270834734
Testing accuracy: 0.9792
Epoch 115
-----
Training loss: 0.004674927672278136
Training accuracy: 0.9999
Testing loss: 0.07199356314412149
Testing accuracy: 0.979
Epoch 116
-----
Training loss: 0.004657429178742071
Training accuracy: 0.9999
```

```
Testing loss: 0.07205625997476611
Testing accuracy: 0.9794
Epoch 117
-----
Training loss: 0.004629959511384368
Training accuracy: 0.9999
Testing loss: 0.07211945468269193
Testing accuracy: 0.9789
Epoch 118
-----
Training loss: 0.0046189804775019485
Training accuracy: 0.9999
Testing loss: 0.07501982964329112
Testing accuracy: 0.9793
Epoch 119
-----
Training loss: 0.0046068315137798585
Training accuracy: 0.9999
Testing loss: 0.07310184714040321
Testing accuracy: 0.979
Epoch 120
-----
Training loss: 0.004584988025048127
Training accuracy: 0.9999
Testing loss: 0.07323698628809493
Testing accuracy: 0.9789
Epoch 121
-----
Training loss: 0.004490700317670902
Training accuracy: 0.9999166666666667
Testing loss: 0.07193197164192179
Testing accuracy: 0.9789
Epoch 122
-----
Training loss: 0.004483656691232075
Training accuracy: 0.9999166666666667
Testing loss: 0.0718868265750736
Testing accuracy: 0.9789
Epoch 123
-----
Training loss: 0.004480705584771931
Training accuracy: 0.9999166666666667
Testing loss: 0.07187722750292842
Testing accuracy: 0.9788
Epoch 124
-----
Training loss: 0.004478124114405364
Training accuracy: 0.9999166666666667
```

```
Testing loss: 0.07197767857515555
Testing accuracy: 0.979
Epoch 125
-----
Training loss: 0.004476721387325476
Training accuracy: 0.9999166666666667
Testing loss: 0.0718782637032879
Testing accuracy: 0.9788
Epoch 126
-----
Training loss: 0.00447390885859107
Training accuracy: 0.9999166666666667
Testing loss: 0.0722848806733408
Testing accuracy: 0.9788
Epoch 127
-----
Training loss: 0.004472739961370826
Training accuracy: 0.9999166666666667
Testing loss: 0.07207363425823711
Testing accuracy: 0.9788
Epoch 128
-----
Training loss: 0.004471182057711606
Training accuracy: 0.9999166666666667
Testing loss: 0.07192970605609363
Testing accuracy: 0.9788
Epoch 129
-----
Training loss: 0.00446931248207887
Training accuracy: 0.9999166666666667
Testing loss: 0.07301153978229068
Testing accuracy: 0.979
Epoch 130
-----
Training loss: 0.004467459381433825
Training accuracy: 0.9999166666666667
Testing loss: 0.07196500536445884
Testing accuracy: 0.9789
Epoch 131
-----
Training loss: 0.004465642593925198
Training accuracy: 0.9999166666666667
Testing loss: 0.07295311929785593
Testing accuracy: 0.9789
Epoch 132
-----
Training loss: 0.004463963396971424
Training accuracy: 0.9999166666666667
```

```
Testing loss: 0.07192582024927222
Testing accuracy: 0.9789
Epoch 133
-----
Training loss: 0.004462521078220258
Training accuracy: 0.9999166666666667
Testing loss: 0.0719475414993977
Testing accuracy: 0.979
Epoch 134
-----
Training loss: 0.004459763889449338
Training accuracy: 0.9999166666666667
Testing loss: 0.07197040912345241
Testing accuracy: 0.979
Epoch 135
-----
Training loss: 0.004458889943640679
Training accuracy: 0.9999166666666667
Testing loss: 0.07194643422247914
Testing accuracy: 0.9788
Epoch 136
-----
Training loss: 0.004457227982246938
Training accuracy: 0.9999166666666667
Testing loss: 0.0719470199515263
Testing accuracy: 0.979
Epoch 137
-----
Training loss: 0.0044557137884820505
Training accuracy: 0.9999166666666667
Testing loss: 0.07194887807408858
Testing accuracy: 0.979
Epoch 138
-----
Training loss: 0.004453874891996384
Training accuracy: 0.9999166666666667
Testing loss: 0.07194013790665699
Testing accuracy: 0.979
Epoch 139
-----
Training loss: 0.0044523819280167425
Training accuracy: 0.9999166666666667
Testing loss: 0.07193138422874532
Testing accuracy: 0.979
Epoch 140
-----
Training loss: 0.004450821887391309
Training accuracy: 0.9999166666666667
```

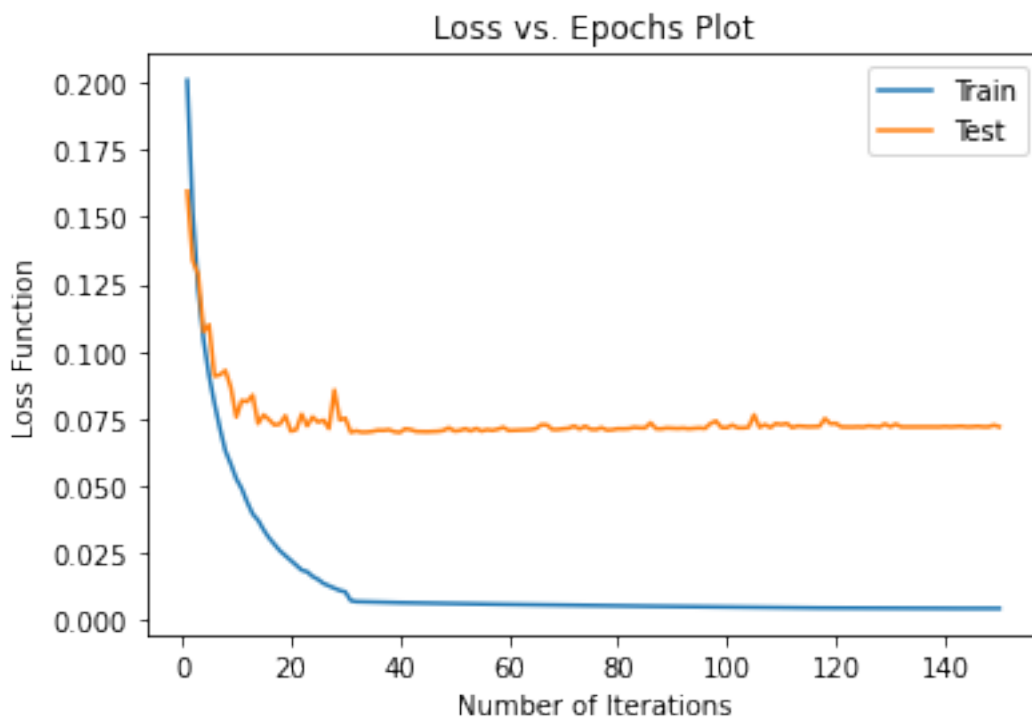
```
Testing loss: 0.07207250226641987
Testing accuracy: 0.9789
Epoch 141
-----
Training loss: 0.0044488484828112025
Training accuracy: 0.9999166666666667
Testing loss: 0.07195433448135533
Testing accuracy: 0.9789
Epoch 142
-----
Training loss: 0.004447421500800798
Training accuracy: 0.9999166666666667
Testing loss: 0.07210443823177154
Testing accuracy: 0.9789
Epoch 143
-----
Training loss: 0.004445386728085578
Training accuracy: 0.9999166666666667
Testing loss: 0.07217172131826212
Testing accuracy: 0.9789
Epoch 144
-----
Training loss: 0.00444413762462015
Training accuracy: 0.9999166666666667
Testing loss: 0.07195585658369663
Testing accuracy: 0.9789
Epoch 145
-----
Training loss: 0.004442237627785653
Training accuracy: 0.9999166666666667
Testing loss: 0.07199395173318257
Testing accuracy: 0.9789
Epoch 146
-----
Training loss: 0.004440590786980465
Training accuracy: 0.9999166666666667
Testing loss: 0.07215002177217916
Testing accuracy: 0.979
Epoch 147
-----
Training loss: 0.0044386008342107135
Training accuracy: 0.9999166666666667
Testing loss: 0.07196757114740017
Testing accuracy: 0.979
Epoch 148
-----
Training loss: 0.004436740980359415
Training accuracy: 0.9999166666666667
```

```

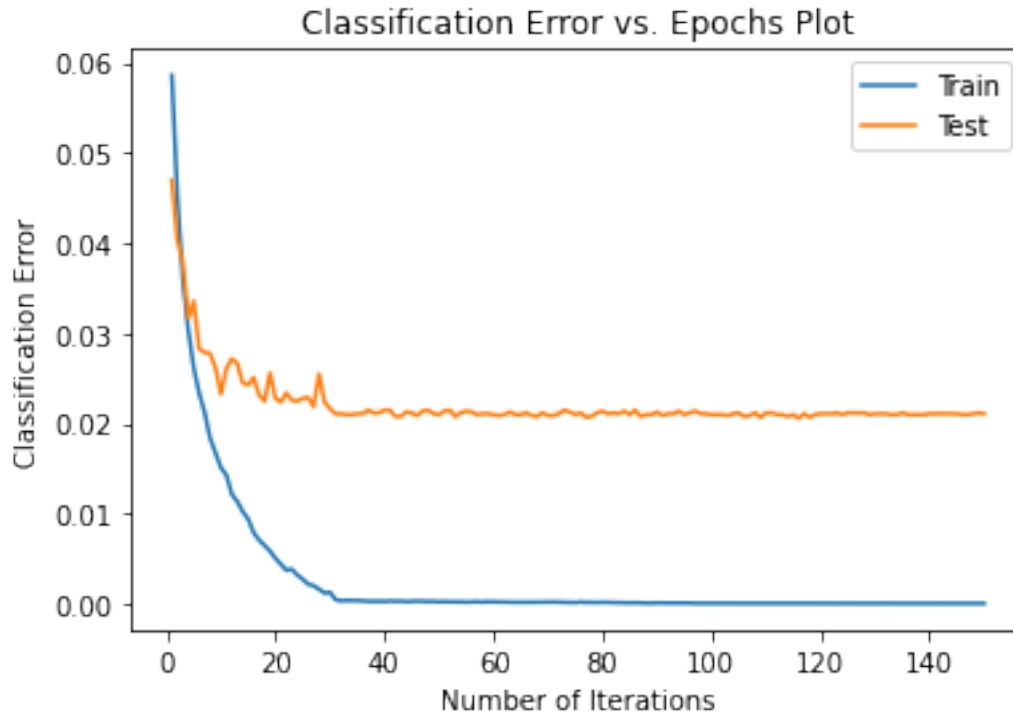
Testing loss: 0.07194048427208476
Testing accuracy: 0.9789
Epoch 149
-----
Training loss: 0.004435865914076567
Training accuracy: 0.9999166666666667
Testing loss: 0.07258787291190456
Testing accuracy: 0.9788
Epoch 150
-----
Training loss: 0.004433837470846871
Training accuracy: 0.9999166666666667
Testing loss: 0.07194930211381648
Testing accuracy: 0.9789
Done
Total Time Consumed: 1537.6013321876526

```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



Test Accuracy As Follow:

Learning Rate = 0.01: 96.92%;

Learning Rate = 0.2: 97.91%;

Learning Rate = 0.5: 97.73%;

Momentum = 0.5 & Learning Rate = 0.1: 97.69%;

Momentum = 0.9 & Learning Rate = 0.1: 97.68%; Decaying Learning Rate 0.2/0.02/0.002: 97.89%.

The highest accuracy is obtained from the model with learning rate = 0.2 despite of the sudden increase in loss and misclassification error. In contrast, decaying learning rate avoid sudden increase in loss and result in high enough accuracy.

#### 5.4 4.(a) & (b)

```
[ ]: # Create a Convolutional Neural Network
class CNN(nn.Module):
    def __init__(self, num_classes):
        super(CNN, self).__init__() # Input Shape 1 * 28 * 28
        self.cv1 = nn.Conv2d(1, 64, 5) # Output Shape 64 * 24 * 24
        self.cv2 = nn.Conv2d(64, 16, 3) # Output Shape 16 * 22 * 22
        self.pool1 = nn.MaxPool2d(3, stride = 2) # Output Shape 16 * 10 * 10
        self.fc1 = nn.Linear(1600, 800) # Output Shape 800
        self.fc2 = nn.Linear(800, 256) # Output Shape 256
        self.fc3 = nn.Linear(256, num_classes) # Output Shape: num_classes

    def forward(self, x):
```



```

x = F.relu(self.cv1(x))
x = F.relu(self.cv2(x))
x = self.pool1(x)
x = x.reshape(-1, 1600)
x = F.relu(self.fc1(x))
x = F.relu(self.fc2(x))
x = self.fc3(x)
return x

```

```

[ ]: def train_loop(dataloader, model, loss_fn, optimizer):
    running_loss, correct = 0, 0
    size = len(dataloader.dataset)
    for batch, (X, y) in enumerate(dataloader):
        # Compute prediction and loss
        pred = model(X)
        loss = loss_fn(pred, y)
        running_loss += loss.item() * X.size(0)
        correct += (pred.argmax(1) == y).type(torch.float).sum().item()
        # Backpropagation
        optimizer.zero_grad()
        loss.backward()
        optimizer.step()
    running_loss = running_loss / size
    correct /= size
    print('Training loss: {}'.format(running_loss))
    print('Training accuracy: {}'.format(correct))
    return running_loss, correct

def test_loop(dataloader, model, loss_fn):
    size = len(dataloader.dataset)
    num_batches = len(dataloader)
    test_loss, correct = 0, 0

    with torch.no_grad():
        for X, y in dataloader:
            pred = model(X)
            test_loss += loss_fn(pred, y).item()
            correct += (pred.argmax(1) == y).type(torch.float).sum().item()

    test_loss /= num_batches
    correct /= size
    print('Testing loss: {}'.format(test_loss))
    print('Testing accuracy: {}'.format(correct))
    return test_loss, correct

```

### 5.4.1 Seed 1

```
[ ]: # Define HyperParameters

num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
CNN1 = CNN(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN1.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, CNN1, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, CNN1, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 0.23483781525914868
Training accuracy: 0.9274666666666667
Testing loss: 0.05640225810930133
Testing accuracy: 0.9825
Epoch 2
```

```
-----
Training loss: 0.04643248018311957
Training accuracy: 0.9854666666666667
Testing loss: 0.03702776619325137
Testing accuracy: 0.9877
Epoch 3
```

-----  
Training loss: 0.030869980712576458  
Training accuracy: 0.9903166666666666  
Testing loss: 0.04583512690321655  
Testing accuracy: 0.9849  
Epoch 4

-----  
Training loss: 0.021660239316849038  
Training accuracy: 0.99315  
Testing loss: 0.02964059705938699  
Testing accuracy: 0.9904  
Epoch 5

-----  
Training loss: 0.015875860552598414  
Training accuracy: 0.99485  
Testing loss: 0.09220002398430963  
Testing accuracy: 0.9705  
Epoch 6

-----  
Training loss: 0.012063402197517765  
Training accuracy: 0.99635  
Testing loss: 0.02953362416429297  
Testing accuracy: 0.9903  
Epoch 7

-----  
Training loss: 0.008550128715188475  
Training accuracy: 0.9974833333333334  
Testing loss: 0.02423046939528466  
Testing accuracy: 0.9927  
Epoch 8

-----  
Training loss: 0.005880619930652029  
Training accuracy: 0.9983833333333333  
Testing loss: 0.027405848577936518  
Testing accuracy: 0.9926  
Epoch 9

-----  
Training loss: 0.005555605271776343  
Training accuracy: 0.9981333333333333  
Testing loss: 0.03495728502806232  
Testing accuracy: 0.9908  
Epoch 10

-----  
Training loss: 0.0054345604360263675  
Training accuracy: 0.99845  
Testing loss: 0.030590967818628256  
Testing accuracy: 0.9912  
Epoch 11

-----  
Training loss: 0.002512465896330347  
Training accuracy: 0.9994333333333333  
Testing loss: 0.02970175391776028  
Testing accuracy: 0.9928  
Epoch 12

-----  
Training loss: 0.0017058286638681845  
Training accuracy: 0.9995166666666667  
Testing loss: 0.03376552802153887  
Testing accuracy: 0.9914  
Epoch 13

-----  
Training loss: 0.0009934994493410463  
Training accuracy: 0.9997833333333334  
Testing loss: 0.029156622080389678  
Testing accuracy: 0.9935  
Epoch 14

-----  
Training loss: 0.000903606749922407  
Training accuracy: 0.9998  
Testing loss: 0.029651990225561725  
Testing accuracy: 0.9932  
Epoch 15

-----  
Training loss: 0.0005844836253216878  
Training accuracy: 0.99985  
Testing loss: 0.02972046877258135  
Testing accuracy: 0.9934  
Epoch 16

-----  
Training loss: 0.0004975925590554349  
Training accuracy: 0.9999  
Testing loss: 0.03025222883621402  
Testing accuracy: 0.9935  
Epoch 17

-----  
Training loss: 0.00021782299166362313  
Training accuracy: 0.99995  
Testing loss: 0.03075736828724498  
Testing accuracy: 0.9935  
Epoch 18

-----  
Training loss: 0.0002746545883344576  
Training accuracy: 0.9999333333333333  
Testing loss: 0.031363270298391956  
Testing accuracy: 0.9934  
Epoch 19

-----  
Training loss: 0.00029576371039745483  
Training accuracy: 0.99995  
Testing loss: 0.032071171165428895  
Testing accuracy: 0.9933  
Epoch 20

-----  
Training loss: 0.00016858587729448875  
Training accuracy: 0.99995  
Testing loss: 0.03187850391386527  
Testing accuracy: 0.9932  
Epoch 21

-----  
Training loss: 0.0001259885097017521  
Training accuracy: 0.9999666666666667  
Testing loss: 0.0325952054148625  
Testing accuracy: 0.9935  
Epoch 22

-----  
Training loss: 8.149333061316497e-05  
Training accuracy: 1.0  
Testing loss: 0.0326381444875716  
Testing accuracy: 0.9934  
Epoch 23

-----  
Training loss: 7.401076952736124e-05  
Training accuracy: 0.9999833333333333  
Testing loss: 0.033062057570214326  
Testing accuracy: 0.9933  
Epoch 24

-----  
Training loss: 6.43675007965271e-05  
Training accuracy: 1.0  
Testing loss: 0.033331248835909794  
Testing accuracy: 0.9933  
Epoch 25

-----  
Training loss: 6.293883892980693e-05  
Training accuracy: 1.0  
Testing loss: 0.03358708934002933  
Testing accuracy: 0.9933  
Epoch 26

-----  
Training loss: 4.212821269259971e-05  
Training accuracy: 1.0  
Testing loss: 0.03381091637101218  
Testing accuracy: 0.9933  
Epoch 27

-----  
Training loss: 3.772212176053908e-05  
Training accuracy: 1.0  
Testing loss: 0.034224254772882996  
Testing accuracy: 0.9932  
Epoch 28  
-----

Training loss: 3.7119620767347785e-05  
Training accuracy: 1.0  
Testing loss: 0.03440158259169398  
Testing accuracy: 0.9932  
Epoch 29  
-----

Training loss: 3.2636620572399976e-05  
Training accuracy: 1.0  
Testing loss: 0.0345196623408093  
Testing accuracy: 0.9931  
Epoch 30  
-----

Training loss: 3.010450454888248e-05  
Training accuracy: 1.0  
Testing loss: 0.035626003702056014  
Testing accuracy: 0.9933  
Epoch 31  
-----

Training loss: 2.7974513896724318e-05  
Training accuracy: 1.0  
Testing loss: 0.03498922530661058  
Testing accuracy: 0.9932  
Epoch 32  
-----

Training loss: 2.7228887236167528e-05  
Training accuracy: 1.0  
Testing loss: 0.03520228719304305  
Testing accuracy: 0.9932  
Epoch 33  
-----

Training loss: 2.5742020975846577e-05  
Training accuracy: 1.0  
Testing loss: 0.03541536087630418  
Testing accuracy: 0.9932  
Epoch 34  
-----

Training loss: 2.4202208149016848e-05  
Training accuracy: 1.0  
Testing loss: 0.03547281828983865  
Testing accuracy: 0.9932  
Epoch 35

-----  
Training loss: 2.245114663549638e-05  
Training accuracy: 1.0  
Testing loss: 0.03569304116143262  
Testing accuracy: 0.9933  
Epoch 36

-----  
Training loss: 2.1305031363232985e-05  
Training accuracy: 1.0  
Testing loss: 0.03582085447295707  
Testing accuracy: 0.9933  
Epoch 37

-----  
Training loss: 2.1079389424167517e-05  
Training accuracy: 1.0  
Testing loss: 0.037967889278698104  
Testing accuracy: 0.9932  
Epoch 38

-----  
Training loss: 1.9709999159694882e-05  
Training accuracy: 1.0  
Testing loss: 0.03609113911606075  
Testing accuracy: 0.9932  
Epoch 39

-----  
Training loss: 1.8908873359566297e-05  
Training accuracy: 1.0  
Testing loss: 0.03626031888438258  
Testing accuracy: 0.9932  
Epoch 40

-----  
Training loss: 1.8571067974994075e-05  
Training accuracy: 1.0  
Testing loss: 0.03636597788754157  
Testing accuracy: 0.9932  
Epoch 41

-----  
Training loss: 1.7722565746484048e-05  
Training accuracy: 1.0  
Testing loss: 0.03651758708230512  
Testing accuracy: 0.9932  
Epoch 42

-----  
Training loss: 1.6760727707900123e-05  
Training accuracy: 1.0  
Testing loss: 0.03694901974789308  
Testing accuracy: 0.9932  
Epoch 43

-----  
Training loss: 1.6376140166705493e-05  
Training accuracy: 1.0  
Testing loss: 0.036727299361055704  
Testing accuracy: 0.9932  
Epoch 44  
-----

Training loss: 1.5776953442726337e-05  
Training accuracy: 1.0  
Testing loss: 0.036900950789865196  
Testing accuracy: 0.9932  
Epoch 45  
-----

Training loss: 1.5285114085455713e-05  
Training accuracy: 1.0  
Testing loss: 0.03702843207697927  
Testing accuracy: 0.9932  
Epoch 46  
-----

Training loss: 1.4852131218826752e-05  
Training accuracy: 1.0  
Testing loss: 0.0371476138961718  
Testing accuracy: 0.9932  
Epoch 47  
-----

Training loss: 1.4231707685752208e-05  
Training accuracy: 1.0  
Testing loss: 0.03722156972414518  
Testing accuracy: 0.9932  
Epoch 48  
-----

Training loss: 1.3786491661719917e-05  
Training accuracy: 1.0  
Testing loss: 0.03727711923467694  
Testing accuracy: 0.9932  
Epoch 49  
-----

Training loss: 1.3467033783472834e-05  
Training accuracy: 1.0  
Testing loss: 0.04025161869410788  
Testing accuracy: 0.9932  
Epoch 50  
-----

Training loss: 1.3091302427731221e-05  
Training accuracy: 1.0  
Testing loss: 0.03754575591629366  
Testing accuracy: 0.9932  
Epoch 51



-----  
Training loss: 1.258319812783384e-05  
Training accuracy: 1.0  
Testing loss: 0.03761144477018994  
Testing accuracy: 0.9932  
Epoch 52

-----  
Training loss: 1.2070318300123973e-05  
Training accuracy: 1.0  
Testing loss: 0.03769728748043356  
Testing accuracy: 0.9932  
Epoch 53

-----  
Training loss: 1.2128009770766823e-05  
Training accuracy: 1.0  
Testing loss: 0.03777418753701622  
Testing accuracy: 0.9932  
Epoch 54

-----  
Training loss: 1.1499413963149507e-05  
Training accuracy: 1.0  
Testing loss: 0.03786256702478156  
Testing accuracy: 0.9932  
Epoch 55

-----  
Training loss: 1.1362875882304854e-05  
Training accuracy: 1.0  
Testing loss: 0.037948932231427694  
Testing accuracy: 0.9932  
Epoch 56

-----  
Training loss: 1.1160563210849735e-05  
Training accuracy: 1.0  
Testing loss: 0.04111093736567708  
Testing accuracy: 0.9932  
Epoch 57

-----  
Training loss: 1.0837236623800924e-05  
Training accuracy: 1.0  
Testing loss: 0.03813873362853799  
Testing accuracy: 0.9932  
Epoch 58

-----  
Training loss: 1.0619625014855315e-05  
Training accuracy: 1.0  
Testing loss: 0.03821593384016812  
Testing accuracy: 0.9932  
Epoch 59

-----  
Training loss: 1.0377407525343448e-05  
Training accuracy: 1.0  
Testing loss: 0.03829796579156842  
Testing accuracy: 0.9932  
Epoch 60  
-----

Training loss: 1.0129670470622068e-05  
Training accuracy: 1.0  
Testing loss: 0.03839110261099515  
Testing accuracy: 0.9932  
Epoch 61  
-----

Training loss: 9.874227377731278e-06  
Training accuracy: 1.0  
Testing loss: 0.03845130935234726  
Testing accuracy: 0.9932  
Epoch 62  
-----

Training loss: 9.679142869369172e-06  
Training accuracy: 1.0  
Testing loss: 0.03851224960048703  
Testing accuracy: 0.9932  
Epoch 63  
-----

Training loss: 9.426228043944936e-06  
Training accuracy: 1.0  
Testing loss: 0.03859726193152162  
Testing accuracy: 0.9932  
Epoch 64  
-----

Training loss: 9.253583357470182e-06  
Training accuracy: 1.0  
Testing loss: 0.03867992824260788  
Testing accuracy: 0.9932  
Epoch 65  
-----

Training loss: 9.068066924749729e-06  
Training accuracy: 1.0  
Testing loss: 0.0387925287631855  
Testing accuracy: 0.9932  
Epoch 66  
-----

Training loss: 8.85517720678403e-06  
Training accuracy: 1.0  
Testing loss: 0.041836315812138  
Testing accuracy: 0.9932  
Epoch 67

-----  
Training loss: 8.693211423986706e-06  
Training accuracy: 1.0  
Testing loss: 0.03885187180788328  
Testing accuracy: 0.9932  
Epoch 68  
-----

Training loss: 8.486376913991952e-06  
Training accuracy: 1.0  
Testing loss: 0.03891423884839088  
Testing accuracy: 0.9931  
Epoch 69  
-----

Training loss: 8.35956591882289e-06  
Training accuracy: 1.0  
Testing loss: 0.03900721815501641  
Testing accuracy: 0.9932  
Epoch 70  
-----

Training loss: 8.22101080838884e-06  
Training accuracy: 1.0  
Testing loss: 0.039069356970527755  
Testing accuracy: 0.9932  
Epoch 71  
-----

Training loss: 8.063437268833695e-06  
Training accuracy: 1.0  
Testing loss: 0.03914313601215383  
Testing accuracy: 0.9932  
Epoch 72  
-----

Training loss: 7.928924169195402e-06  
Training accuracy: 1.0  
Testing loss: 0.04041995326805593  
Testing accuracy: 0.9932  
Epoch 73  
-----

Training loss: 7.745915386457133e-06  
Training accuracy: 1.0  
Testing loss: 0.03926009399035243  
Testing accuracy: 0.9932  
Epoch 74  
-----

Training loss: 7.64003719549938e-06  
Training accuracy: 1.0  
Testing loss: 0.03936252759693493  
Testing accuracy: 0.9932  
Epoch 75

-----  
Training loss: 7.4886324074277865e-06  
Training accuracy: 1.0  
Testing loss: 0.03938757371489972  
Testing accuracy: 0.9932  
Epoch 76

-----  
Training loss: 7.340641653792564e-06  
Training accuracy: 1.0  
Testing loss: 0.03943201793930314  
Testing accuracy: 0.9932  
Epoch 77

-----  
Training loss: 7.228817901044948e-06  
Training accuracy: 1.0  
Testing loss: 0.039483468740891516  
Testing accuracy: 0.9932  
Epoch 78

-----  
Training loss: 7.113134626290811e-06  
Training accuracy: 1.0  
Testing loss: 0.039536654155317624  
Testing accuracy: 0.9932  
Epoch 79

-----  
Training loss: 6.976387412524924e-06  
Training accuracy: 1.0  
Testing loss: 0.03961139380943782  
Testing accuracy: 0.9932  
Epoch 80

-----  
Training loss: 6.894739149442467e-06  
Training accuracy: 1.0  
Testing loss: 0.03966557852633275  
Testing accuracy: 0.9932  
Epoch 81

-----  
Training loss: 6.735204645248771e-06  
Training accuracy: 1.0  
Testing loss: 0.039710272933888256  
Testing accuracy: 0.9932  
Epoch 82

-----  
Training loss: 6.678099418308984e-06  
Training accuracy: 1.0  
Testing loss: 0.03978154433228065  
Testing accuracy: 0.9932  
Epoch 83

-----  
Training loss: 6.535736106369209e-06  
Training accuracy: 1.0  
Testing loss: 0.039824556746027445  
Testing accuracy: 0.9931  
Epoch 84

-----  
Training loss: 6.383314275051314e-06  
Training accuracy: 1.0  
Testing loss: 0.03988029499532926  
Testing accuracy: 0.9932  
Epoch 85

-----  
Training loss: 6.390199865745079e-06  
Training accuracy: 1.0  
Testing loss: 0.03993148887825506  
Testing accuracy: 0.9932  
Epoch 86

-----  
Training loss: 6.256393543846647e-06  
Training accuracy: 1.0  
Testing loss: 0.039978778494065656  
Testing accuracy: 0.9932  
Epoch 87

-----  
Training loss: 6.169687869941498e-06  
Training accuracy: 1.0  
Testing loss: 0.0400249313383857  
Testing accuracy: 0.9931  
Epoch 88

-----  
Training loss: 6.08545103190868e-06  
Training accuracy: 1.0  
Testing loss: 0.04008860481928488  
Testing accuracy: 0.9931  
Epoch 89

-----  
Training loss: 5.951341795523864e-06  
Training accuracy: 1.0  
Testing loss: 0.040140304211040895  
Testing accuracy: 0.9932  
Epoch 90

-----  
Training loss: 5.921291130489692e-06  
Training accuracy: 1.0  
Testing loss: 0.040200945042983875  
Testing accuracy: 0.9932  
Epoch 91

-----  
Training loss: 5.827532279129363e-06  
Training accuracy: 1.0  
Testing loss: 0.04023881316107512  
Testing accuracy: 0.9932  
Epoch 92

-----  
Training loss: 5.731598101140752e-06  
Training accuracy: 1.0  
Testing loss: 0.040294495279508055  
Testing accuracy: 0.9932  
Epoch 93

-----  
Training loss: 5.662929613965062e-06  
Training accuracy: 1.0  
Testing loss: 0.040347348663528064  
Testing accuracy: 0.9932  
Epoch 94

-----  
Training loss: 5.58076204120456e-06  
Training accuracy: 1.0  
Testing loss: 0.04040161244634346  
Testing accuracy: 0.9932  
Epoch 95

-----  
Training loss: 5.502241069291477e-06  
Training accuracy: 1.0  
Testing loss: 0.04043234222069659  
Testing accuracy: 0.9932  
Epoch 96

-----  
Training loss: 5.418600708620621e-06  
Training accuracy: 1.0  
Testing loss: 0.040478887183356856  
Testing accuracy: 0.9932  
Epoch 97

-----  
Training loss: 5.3681319995181555e-06  
Training accuracy: 1.0  
Testing loss: 0.04054542958985091  
Testing accuracy: 0.9932  
Epoch 98

-----  
Training loss: 5.2789313515631874e-06  
Training accuracy: 1.0  
Testing loss: 0.04318564866950861  
Testing accuracy: 0.9932  
Epoch 99

-----  
Training loss: 5.224647263208245e-06  
Training accuracy: 1.0  
Testing loss: 0.04062993843955125  
Testing accuracy: 0.9932  
Epoch 100

-----  
Training loss: 5.153860223855252e-06  
Training accuracy: 1.0  
Testing loss: 0.040671424266955455  
Testing accuracy: 0.9931  
Epoch 101

-----  
Training loss: 5.0881131044661745e-06  
Training accuracy: 1.0  
Testing loss: 0.0407149143714771  
Testing accuracy: 0.9931  
Epoch 102

-----  
Training loss: 5.030067548148291e-06  
Training accuracy: 1.0  
Testing loss: 0.040747272806888286  
Testing accuracy: 0.9932  
Epoch 103

-----  
Training loss: 4.9504804974066725e-06  
Training accuracy: 1.0  
Testing loss: 0.040789339060372104  
Testing accuracy: 0.9931  
Epoch 104

-----  
Training loss: 4.8952372619455765e-06  
Training accuracy: 1.0  
Testing loss: 0.040828976956905676  
Testing accuracy: 0.9931  
Epoch 105

-----  
Training loss: 4.850281288764909e-06  
Training accuracy: 1.0  
Testing loss: 0.0446736588365752  
Testing accuracy: 0.9931  
Epoch 106

-----  
Training loss: 4.786369603823933e-06  
Training accuracy: 1.0  
Testing loss: 0.04091643233413659  
Testing accuracy: 0.9931  
Epoch 107

-----  
Training loss: 4.736452799982871e-06  
Training accuracy: 1.0  
Testing loss: 0.04096201141458113  
Testing accuracy: 0.9931  
Epoch 108  
-----

Training loss: 4.656668515043923e-06  
Training accuracy: 1.0  
Testing loss: 0.04099814752616109  
Testing accuracy: 0.9931  
Epoch 109  
-----

Training loss: 4.636631143620325e-06  
Training accuracy: 1.0  
Testing loss: 0.04103965227430293  
Testing accuracy: 0.9931  
Epoch 110  
-----

Training loss: 4.562722350379526e-06  
Training accuracy: 1.0  
Testing loss: 0.04254908733236499  
Testing accuracy: 0.9931  
Epoch 111  
-----

Training loss: 4.528204706905943e-06  
Training accuracy: 1.0  
Testing loss: 0.04114398917978125  
Testing accuracy: 0.9931  
Epoch 112  
-----

Training loss: 4.468018464958116e-06  
Training accuracy: 1.0  
Testing loss: 0.04115939964806951  
Testing accuracy: 0.9931  
Epoch 113  
-----

Training loss: 4.4168627633344685e-06  
Training accuracy: 1.0  
Testing loss: 0.04137151655474156  
Testing accuracy: 0.9931  
Epoch 114  
-----

Training loss: 4.364279317640533e-06  
Training accuracy: 1.0  
Testing loss: 0.04124245146526402  
Testing accuracy: 0.9932  
Epoch 115



-----  
Training loss: 4.317640765860394e-06  
Training accuracy: 1.0  
Testing loss: 0.04127586108738943  
Testing accuracy: 0.9931  
Epoch 116

-----  
Training loss: 4.263080678545468e-06  
Training accuracy: 1.0  
Testing loss: 0.04193794520537772  
Testing accuracy: 0.993  
Epoch 117

-----  
Training loss: 4.2266705260241605e-06  
Training accuracy: 1.0  
Testing loss: 0.041355258719399206  
Testing accuracy: 0.9932  
Epoch 118

-----  
Training loss: 4.17409460773636e-06  
Training accuracy: 1.0  
Testing loss: 0.04139895301672893  
Testing accuracy: 0.9931  
Epoch 119

-----  
Training loss: 4.139169770981136e-06  
Training accuracy: 1.0  
Testing loss: 0.042419624189835366  
Testing accuracy: 0.993  
Epoch 120

-----  
Training loss: 4.100209774831498e-06  
Training accuracy: 1.0  
Testing loss: 0.04146527027352948  
Testing accuracy: 0.9931  
Epoch 121

-----  
Training loss: 4.053392631609162e-06  
Training accuracy: 1.0  
Testing loss: 0.041495846156913894  
Testing accuracy: 0.993  
Epoch 122

-----  
Training loss: 4.013230534512857e-06  
Training accuracy: 1.0  
Testing loss: 0.041530470279262065  
Testing accuracy: 0.9931  
Epoch 123

-----  
Training loss: 3.973389271497396e-06  
Training accuracy: 1.0  
Testing loss: 0.04157595978717134  
Testing accuracy: 0.993  
Epoch 124

-----  
Training loss: 3.929498912310218e-06  
Training accuracy: 1.0  
Testing loss: 0.041619551088992915  
Testing accuracy: 0.993  
Epoch 125

-----  
Training loss: 3.887085749412952e-06  
Training accuracy: 1.0  
Testing loss: 0.04163618694155638  
Testing accuracy: 0.993  
Epoch 126

-----  
Training loss: 3.852090906727312e-06  
Training accuracy: 1.0  
Testing loss: 0.04177852891086611  
Testing accuracy: 0.993  
Epoch 127

-----  
Training loss: 3.806311128417287e-06  
Training accuracy: 1.0  
Testing loss: 0.04170951800067369  
Testing accuracy: 0.993  
Epoch 128

-----  
Training loss: 3.781668592385401e-06  
Training accuracy: 1.0  
Testing loss: 0.04174193576933556  
Testing accuracy: 0.993  
Epoch 129

-----  
Training loss: 3.7343017370766063e-06  
Training accuracy: 1.0  
Testing loss: 0.041775964902189204  
Testing accuracy: 0.993  
Epoch 130

-----  
Training loss: 3.7076528170093325e-06  
Training accuracy: 1.0  
Testing loss: 0.04181557522698061  
Testing accuracy: 0.993  
Epoch 131

-----  
Training loss: 3.6727499580331132e-06  
Training accuracy: 1.0  
Testing loss: 0.0439957183149819  
Testing accuracy: 0.993  
Epoch 132

-----  
Training loss: 3.6303702008931775e-06  
Training accuracy: 1.0  
Testing loss: 0.04188594700646721  
Testing accuracy: 0.993  
Epoch 133

-----  
Training loss: 3.6043955925237013e-06  
Training accuracy: 1.0  
Testing loss: 0.041905876082575004  
Testing accuracy: 0.993  
Epoch 134

-----  
Training loss: 3.5662423344518856e-06  
Training accuracy: 1.0  
Testing loss: 0.04194229319005841  
Testing accuracy: 0.993  
Epoch 135

-----  
Training loss: 3.536475417527048e-06  
Training accuracy: 1.0  
Testing loss: 0.0419799986369246  
Testing accuracy: 0.993  
Epoch 136

-----  
Training loss: 3.501660509874919e-06  
Training accuracy: 1.0  
Testing loss: 0.04201369947775495  
Testing accuracy: 0.993  
Epoch 137

-----  
Training loss: 3.4716096156907145e-06  
Training accuracy: 1.0  
Testing loss: 0.04205294360493034  
Testing accuracy: 0.993  
Epoch 138

-----  
Training loss: 3.4385352123681654e-06  
Training accuracy: 1.0  
Testing loss: 0.042118123960240714  
Testing accuracy: 0.993  
Epoch 139

-----  
Training loss: 3.412518417327585e-06  
Training accuracy: 1.0  
Testing loss: 0.042102941362672626  
Testing accuracy: 0.993  
Epoch 140

-----  
Training loss: 3.374747727936267e-06  
Training accuracy: 1.0  
Testing loss: 0.04214094452742755  
Testing accuracy: 0.993  
Epoch 141

-----  
Training loss: 3.3497405887198778e-06  
Training accuracy: 1.0  
Testing loss: 0.0421807014405766  
Testing accuracy: 0.993  
Epoch 142

-----  
Training loss: 3.322042565168933e-06  
Training accuracy: 1.0  
Testing loss: 0.04220367269467192  
Testing accuracy: 0.993  
Epoch 143

-----  
Training loss: 3.2924856131810288e-06  
Training accuracy: 1.0  
Testing loss: 0.042232814471531946  
Testing accuracy: 0.993  
Epoch 144

-----  
Training loss: 3.2644889508670617e-06  
Training accuracy: 1.0  
Testing loss: 0.04225834253705329  
Testing accuracy: 0.993  
Epoch 145

-----  
Training loss: 3.2321513510465156e-06  
Training accuracy: 1.0  
Testing loss: 0.04228846240926057  
Testing accuracy: 0.993  
Epoch 146

-----  
Training loss: 3.2083727570954088e-06  
Training accuracy: 1.0  
Testing loss: 0.04231675434723491  
Testing accuracy: 0.993  
Epoch 147

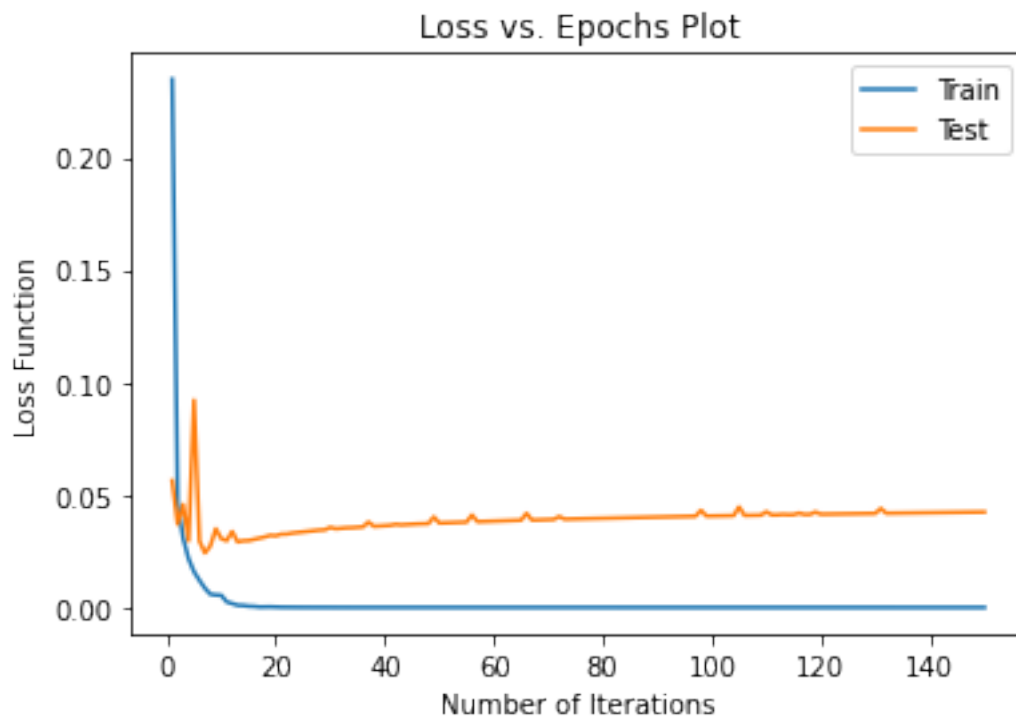
```
-----  
Training loss: 3.1802327762970133e-06  
Training accuracy: 1.0  
Testing loss: 0.04234576457546252  
Testing accuracy: 0.993  
Epoch 148
```

```
-----  
Training loss: 3.1555951005358906e-06  
Training accuracy: 1.0  
Testing loss: 0.04237484509139601  
Testing accuracy: 0.993  
Epoch 149
```

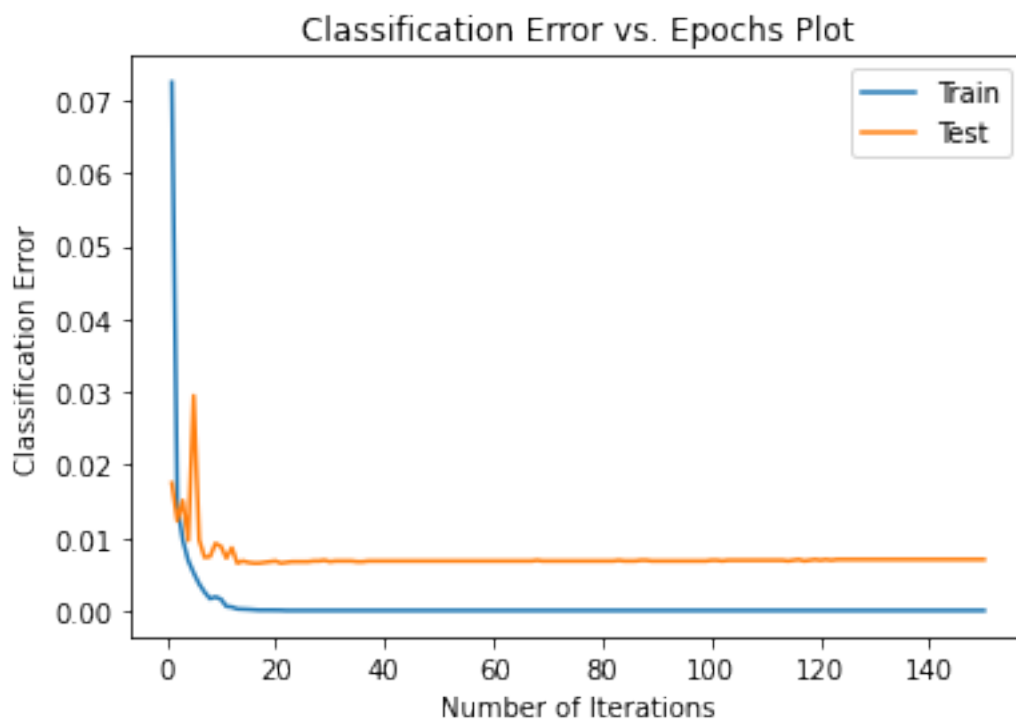
```
-----  
Training loss: 3.126598569304543e-06  
Training accuracy: 1.0  
Testing loss: 0.04240555025117501  
Testing accuracy: 0.993  
Epoch 150
```

```
-----  
Training loss: 3.1031300633317234e-06  
Training accuracy: 1.0  
Testing loss: 0.04244150756425748  
Testing accuracy: 0.993  
Done  
Total Time Consumed: 12548.940795660019
```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```

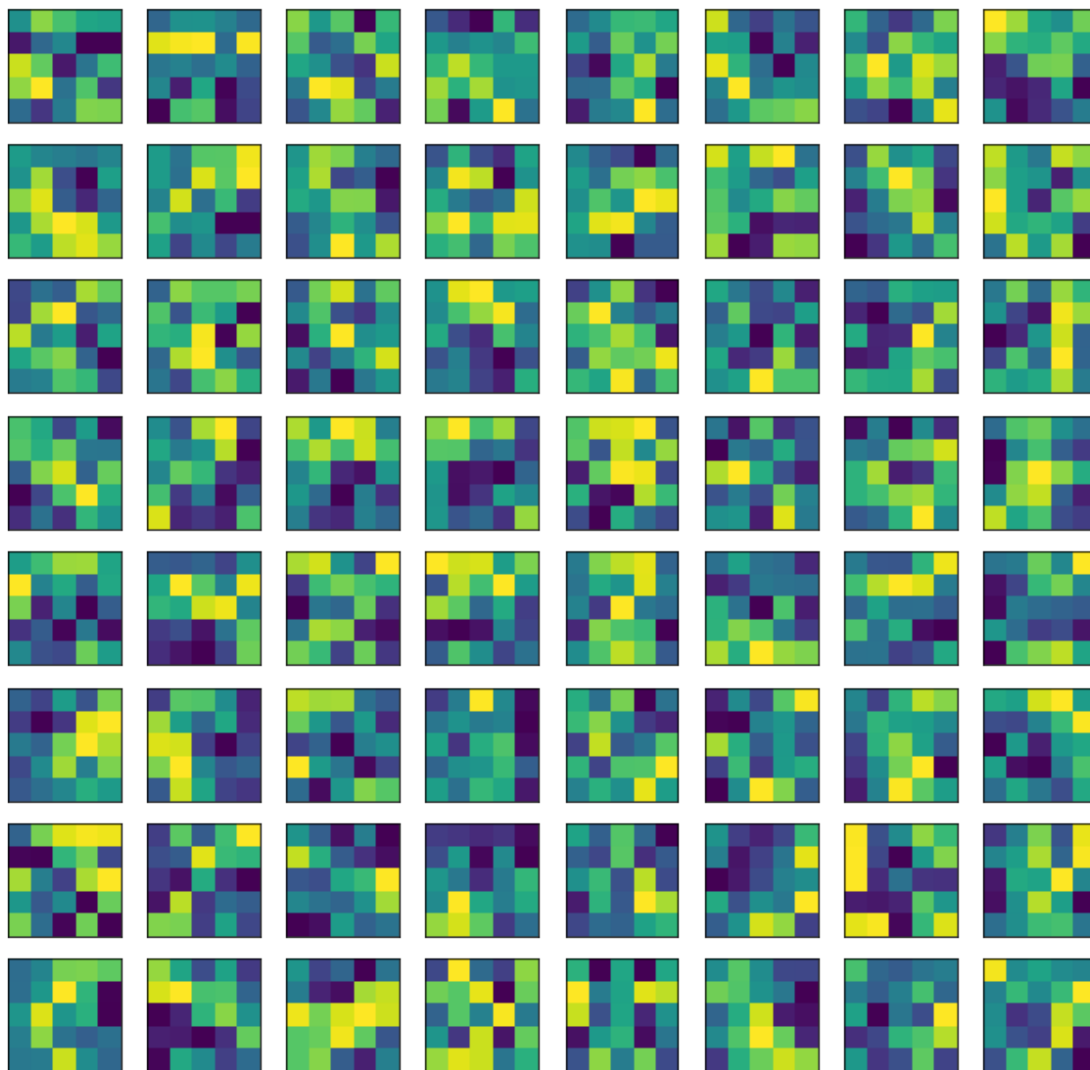


```
[ ]: error_plot(train_loss_record, test_loss_record)
```



## 5.5 4.(c)

```
[ ]: weights = CNN1.state_dict()['cv1.weight']
plt.figure(figsize = (10,10))
for i in range(len(weights)):
    plt.subplot(8,8,i+1)
    plt.imshow(weights[i].reshape(5,5))
    plt.xticks([])
    plt.yticks([])
```



## 5.6 4.(d)

### 5.6.1 Learning Rate = 0.01

```
[ ]: # Define HyperParameters
num_classes = 10
learning_rate = 0.01
batch_size = 64
num_epochs = 150
CNN_LR01 = CNN(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_LR01.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↳ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↳ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, CNN_LR01, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, CNN_LR01, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 0.9147390956322352
Training accuracy: 0.7185833333333334
Testing loss: 0.2223067750833976
Testing accuracy: 0.9322
Epoch 2
```

```
-----
Training loss: 0.16861830121278762
Training accuracy: 0.9472833333333334
Testing loss: 0.15890299277320788
Testing accuracy: 0.9471
```



Epoch 3

-----  
Training loss: 0.11189363651573658

Training accuracy: 0.9654

Testing loss: 0.094345892844781

Testing accuracy: 0.9705

Epoch 4

-----  
Training loss: 0.08813865966747204

Training accuracy: 0.9731333333333333

Testing loss: 0.07058608751213119

Testing accuracy: 0.9775

Epoch 5

-----  
Training loss: 0.07220804946323235

Training accuracy: 0.9770833333333333

Testing loss: 0.14196179600752842

Testing accuracy: 0.9509

Epoch 6

-----  
Training loss: 0.061073552124698956

Training accuracy: 0.9811666666666666

Testing loss: 0.06316689352332881

Testing accuracy: 0.9796

Epoch 7

-----  
Training loss: 0.05317714537655314

Training accuracy: 0.9833833333333334

Testing loss: 0.04681228650407569

Testing accuracy: 0.9857

Epoch 8

-----  
Training loss: 0.04640239378561576

Training accuracy: 0.9856666666666667

Testing loss: 0.05569822466961897

Testing accuracy: 0.9811

Epoch 9

-----  
Training loss: 0.04239380287565291

Training accuracy: 0.98665

Testing loss: 0.03942948249821213

Testing accuracy: 0.9869

Epoch 10

-----  
Training loss: 0.0377753185680757

Training accuracy: 0.9886166666666667

Testing loss: 0.03645840652619198

Testing accuracy: 0.9879

Epoch 11

-----  
Training loss: 0.0346015849818786  
Training accuracy: 0.9896833333333334  
Testing loss: 0.06034158637664121  
Testing accuracy: 0.9791  
Epoch 12

-----  
Training loss: 0.0316903981183966  
Training accuracy: 0.9904833333333334  
Testing loss: 0.04090277055444516  
Testing accuracy: 0.9851  
Epoch 13

-----  
Training loss: 0.028179382771765814  
Training accuracy: 0.99125  
Testing loss: 0.03577002559070754  
Testing accuracy: 0.987  
Epoch 14

-----  
Training loss: 0.026176860454306006  
Training accuracy: 0.9918  
Testing loss: 0.028331480751994546  
Testing accuracy: 0.9901  
Epoch 15

-----  
Training loss: 0.023583940781342485  
Training accuracy: 0.9929333333333333  
Testing loss: 0.031553099832273605  
Testing accuracy: 0.9884  
Epoch 16

-----  
Training loss: 0.021627779911396403  
Training accuracy: 0.9933166666666666  
Testing loss: 0.0294930039672181  
Testing accuracy: 0.9902  
Epoch 17

-----  
Training loss: 0.020361900017069032  
Training accuracy: 0.9938  
Testing loss: 0.029276145704440582  
Testing accuracy: 0.9895  
Epoch 18

-----  
Training loss: 0.018600768479704856  
Training accuracy: 0.99435  
Testing loss: 0.03757876748142017  
Testing accuracy: 0.9873

Epoch 19

-----  
Training loss: 0.01711525277751498  
Training accuracy: 0.9947666666666667  
Testing loss: 0.02990205097457121  
Testing accuracy: 0.9891  
Epoch 20

-----  
Training loss: 0.015355741186471036  
Training accuracy: 0.9956333333333334  
Testing loss: 0.025057676681102356  
Testing accuracy: 0.9907  
Epoch 21

-----  
Training loss: 0.014057602063938975  
Training accuracy: 0.9958666666666667  
Testing loss: 0.026403492137902433  
Testing accuracy: 0.9917  
Epoch 22

-----  
Training loss: 0.013120833693848302  
Training accuracy: 0.9960666666666667  
Testing loss: 0.02616471070614584  
Testing accuracy: 0.9911  
Epoch 23

-----  
Training loss: 0.011945123119900624  
Training accuracy: 0.99665  
Testing loss: 0.026841238488452095  
Testing accuracy: 0.9904  
Epoch 24

-----  
Training loss: 0.01089970137559964  
Training accuracy: 0.9970666666666667  
Testing loss: 0.02586101675745334  
Testing accuracy: 0.9908  
Epoch 25

-----  
Training loss: 0.010414375177483694  
Training accuracy: 0.997  
Testing loss: 0.02634297160327562  
Testing accuracy: 0.9911  
Epoch 26

-----  
Training loss: 0.009490304776436339  
Training accuracy: 0.9975333333333334  
Testing loss: 0.024955676666314115  
Testing accuracy: 0.9911

Epoch 27

-----  
Training loss: 0.00868633071113533  
Training accuracy: 0.9977666666666667  
Testing loss: 0.028553537520252623  
Testing accuracy: 0.9905  
Epoch 28

-----  
Training loss: 0.008215594449065005  
Training accuracy: 0.9977333333333334  
Testing loss: 0.028012578139099395  
Testing accuracy: 0.9902  
Epoch 29

-----  
Training loss: 0.007428702745004557  
Training accuracy: 0.9981833333333333  
Testing loss: 0.0259881400354733  
Testing accuracy: 0.9902  
Epoch 30

-----  
Training loss: 0.006826544001089254  
Training accuracy: 0.99835  
Testing loss: 0.02691351302159219  
Testing accuracy: 0.9906  
Epoch 31

-----  
Training loss: 0.006232598191808211  
Training accuracy: 0.9986  
Testing loss: 0.026639219935798788  
Testing accuracy: 0.9908  
Epoch 32

-----  
Training loss: 0.006110428825544659  
Training accuracy: 0.9987  
Testing loss: 0.02534642060419654  
Testing accuracy: 0.9915  
Epoch 33

-----  
Training loss: 0.005119571634770061  
Training accuracy: 0.9989333333333333  
Testing loss: 0.025848226820468712  
Testing accuracy: 0.9914  
Epoch 34

-----  
Training loss: 0.0049692346245244455  
Training accuracy: 0.9990333333333333  
Testing loss: 0.052601449964768225  
Testing accuracy: 0.984

Epoch 35

-----  
Training loss: 0.004517632649617735  
Training accuracy: 0.9991333333333333  
Testing loss: 0.02667526737785671  
Testing accuracy: 0.9921  
Epoch 36

-----  
Training loss: 0.00424408342136303  
Training accuracy: 0.9990833333333333  
Testing loss: 0.026683031500947522  
Testing accuracy: 0.9913  
Epoch 37

-----  
Training loss: 0.004100401161025123  
Training accuracy: 0.9990166666666667  
Testing loss: 0.030565227487380643  
Testing accuracy: 0.9902  
Epoch 38

-----  
Training loss: 0.0038024298934362984  
Training accuracy: 0.9991833333333333  
Testing loss: 0.027320708173346055  
Testing accuracy: 0.9908  
Epoch 39

-----  
Training loss: 0.0032030711632299548  
Training accuracy: 0.9994666666666666  
Testing loss: 0.02959805952730004  
Testing accuracy: 0.9914  
Epoch 40

-----  
Training loss: 0.0031194339802265553  
Training accuracy: 0.99945  
Testing loss: 0.02569899987839522  
Testing accuracy: 0.991  
Epoch 41

-----  
Training loss: 0.002917379799632666  
Training accuracy: 0.99945  
Testing loss: 0.027724060736192283  
Testing accuracy: 0.991  
Epoch 42

-----  
Training loss: 0.0027186260145070263  
Training accuracy: 0.99945  
Testing loss: 0.028221302797316588  
Testing accuracy: 0.9912

Epoch 43

-----  
Training loss: 0.0023632783327164363  
Training accuracy: 0.99965  
Testing loss: 0.025760067938639983  
Testing accuracy: 0.9921  
Epoch 44

-----  
Training loss: 0.0023908834672775508  
Training accuracy: 0.9995333333333334  
Testing loss: 0.0272202495456814  
Testing accuracy: 0.9916  
Epoch 45

-----  
Training loss: 0.0022399213062240355  
Training accuracy: 0.9995833333333334  
Testing loss: 0.028328792545111194  
Testing accuracy: 0.9911  
Epoch 46

-----  
Training loss: 0.0020952090508001373  
Training accuracy: 0.9996833333333334  
Testing loss: 0.02755091542432093  
Testing accuracy: 0.9916  
Epoch 47

-----  
Training loss: 0.0019419140855687148  
Training accuracy: 0.9996166666666667  
Testing loss: 0.028778737381636943  
Testing accuracy: 0.9915  
Epoch 48

-----  
Training loss: 0.0016874947468924803  
Training accuracy: 0.9997666666666667  
Testing loss: 0.028094417890141738  
Testing accuracy: 0.9916  
Epoch 49

-----  
Training loss: 0.001514070878123069  
Training accuracy: 0.9998166666666667  
Testing loss: 0.029188222054292553  
Testing accuracy: 0.9915  
Epoch 50

-----  
Training loss: 0.0015442477233057919  
Training accuracy: 0.9997666666666667  
Testing loss: 0.028939528006077898  
Testing accuracy: 0.9915

Epoch 51

-----  
Training loss: 0.0014502554773993324  
Training accuracy: 0.9997833333333334  
Testing loss: 0.028609420175697124  
Testing accuracy: 0.9913  
Epoch 52

-----  
Training loss: 0.0012731189334144195  
Training accuracy: 0.9998166666666667  
Testing loss: 0.02729490919413203  
Testing accuracy: 0.9914  
Epoch 53

-----  
Training loss: 0.001201584219634242  
Training accuracy: 0.9998666666666667  
Testing loss: 0.029631009548031714  
Testing accuracy: 0.9907  
Epoch 54

-----  
Training loss: 0.001246900870425937  
Training accuracy: 0.9998333333333334  
Testing loss: 0.02847628353744831  
Testing accuracy: 0.9915  
Epoch 55

-----  
Training loss: 0.0010031811566281249  
Training accuracy: 0.9999166666666667  
Testing loss: 0.02846444942252286  
Testing accuracy: 0.9915  
Epoch 56

-----  
Training loss: 0.0010530998904985608  
Training accuracy: 0.99985  
Testing loss: 0.029679599128233286  
Testing accuracy: 0.9916  
Epoch 57

-----  
Training loss: 0.0009247651749319629  
Training accuracy: 0.9999  
Testing loss: 0.028993139482784088  
Testing accuracy: 0.992  
Epoch 58

-----  
Training loss: 0.0009406730944905576  
Training accuracy: 0.9998833333333333  
Testing loss: 0.029600163542529846  
Testing accuracy: 0.9912

Epoch 59

-----  
Training loss: 0.0008824862979514971  
Training accuracy: 0.9998833333333333  
Testing loss: 0.028742033932717653  
Testing accuracy: 0.9916  
Epoch 60

-----  
Training loss: 0.0007406191694404697  
Training accuracy: 0.99995  
Testing loss: 0.02901035119821766  
Testing accuracy: 0.9914  
Epoch 61

-----  
Training loss: 0.0007286016079209124  
Training accuracy: 0.9999333333333333  
Testing loss: 0.029774663712435246  
Testing accuracy: 0.9918  
Epoch 62

-----  
Training loss: 0.000765863420782019  
Training accuracy: 0.9999166666666667  
Testing loss: 0.029421140506352098  
Testing accuracy: 0.9914  
Epoch 63

-----  
Training loss: 0.0006746556019779139  
Training accuracy: 0.9999166666666667  
Testing loss: 0.029800595704919206  
Testing accuracy: 0.9915  
Epoch 64

-----  
Training loss: 0.0006173178294659011  
Training accuracy: 0.99995  
Testing loss: 0.030034723527381457  
Testing accuracy: 0.9915  
Epoch 65

-----  
Training loss: 0.0005901691770662182  
Training accuracy: 0.99995  
Testing loss: 0.030149119263381177  
Testing accuracy: 0.9919  
Epoch 66

-----  
Training loss: 0.0005604082619200198  
Training accuracy: 0.9999666666666667  
Testing loss: 0.03163713151601259  
Testing accuracy: 0.9916



Epoch 67

-----  
Training loss: 0.0005647347932334621  
Training accuracy: 0.99995  
Testing loss: 0.030810951453720013  
Testing accuracy: 0.9916  
Epoch 68

-----  
Training loss: 0.0004923154789180747  
Training accuracy: 0.9999666666666667  
Testing loss: 0.030853144333780325  
Testing accuracy: 0.9916  
Epoch 69

-----  
Training loss: 0.0005046592912831935  
Training accuracy: 0.99995  
Testing loss: 0.03030234889996781  
Testing accuracy: 0.9913  
Epoch 70

-----  
Training loss: 0.0005925433403056861  
Training accuracy: 0.9999166666666667  
Testing loss: 0.030553890218624282  
Testing accuracy: 0.9916  
Epoch 71

-----  
Training loss: 0.0005164741892705934  
Training accuracy: 0.9999333333333333  
Testing loss: 0.030985263389670677  
Testing accuracy: 0.9916  
Epoch 72

-----  
Training loss: 0.00045882309187509235  
Training accuracy: 0.9999666666666667  
Testing loss: 0.03204445823201148  
Testing accuracy: 0.9913  
Epoch 73

-----  
Training loss: 0.0004075699961495654  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03116060344013844  
Testing accuracy: 0.9913  
Epoch 74

-----  
Training loss: 0.00045664465203347694  
Training accuracy: 0.99995  
Testing loss: 0.03176535289115896  
Testing accuracy: 0.9918

Epoch 75

-----  
Training loss: 0.00038304815696619697  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03147631776976155  
Testing accuracy: 0.9914  
Epoch 76

-----  
Training loss: 0.0004924205629846255  
Training accuracy: 0.99995  
Testing loss: 0.03063708073316711  
Testing accuracy: 0.9917  
Epoch 77

-----  
Training loss: 0.0003610144017007163  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03117513080670581  
Testing accuracy: 0.9919  
Epoch 78

-----  
Training loss: 0.00033519346514743426  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03102514514496726  
Testing accuracy: 0.9914  
Epoch 79

-----  
Training loss: 0.0003303965417625174  
Training accuracy: 1.0  
Testing loss: 0.031673139439257064  
Testing accuracy: 0.9913  
Epoch 80

-----  
Training loss: 0.00037368147730509617  
Training accuracy: 0.99995  
Testing loss: 0.03242007765248864  
Testing accuracy: 0.9916  
Epoch 81

-----  
Training loss: 0.00029548521454829217  
Training accuracy: 1.0  
Testing loss: 0.031178802124150907  
Testing accuracy: 0.9915  
Epoch 82

-----  
Training loss: 0.0003351226834877404  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03124434400960688  
Testing accuracy: 0.9914

Epoch 83

-----  
Training loss: 0.0002946067552907455  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03157282027099294  
Testing accuracy: 0.9914  
Epoch 84

-----  
Training loss: 0.0002720896059652053  
Training accuracy: 1.0  
Testing loss: 0.031583616340611256  
Testing accuracy: 0.9916  
Epoch 85

-----  
Training loss: 0.0002964121308600928  
Training accuracy: 1.0  
Testing loss: 0.03464371280037444  
Testing accuracy: 0.9914  
Epoch 86

-----  
Training loss: 0.0002958009039606319  
Training accuracy: 1.0  
Testing loss: 0.032920593238220865  
Testing accuracy: 0.9912  
Epoch 87

-----  
Training loss: 0.00025693568028230707  
Training accuracy: 1.0  
Testing loss: 0.03216097408535121  
Testing accuracy: 0.9918  
Epoch 88

-----  
Training loss: 0.0002791148785451696  
Training accuracy: 1.0  
Testing loss: 0.03233869867718658  
Testing accuracy: 0.9916  
Epoch 89

-----  
Training loss: 0.00023908897532758905  
Training accuracy: 1.0  
Testing loss: 0.032165332029146565  
Testing accuracy: 0.9914  
Epoch 90

-----  
Training loss: 0.0003174744658915112  
Training accuracy: 0.99995  
Testing loss: 0.031970007292450246  
Testing accuracy: 0.9911

Epoch 91

-----  
Training loss: 0.0002631487376164538  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03236790741816056  
Testing accuracy: 0.9917  
Epoch 92

-----  
Training loss: 0.00023347901090170733  
Training accuracy: 1.0  
Testing loss: 0.032421687292495845  
Testing accuracy: 0.9914  
Epoch 93

-----  
Training loss: 0.00033500975014133776  
Training accuracy: 0.9999333333333333  
Testing loss: 0.032484657033649  
Testing accuracy: 0.992  
Epoch 94

-----  
Training loss: 0.0002214942981116716  
Training accuracy: 1.0  
Testing loss: 0.03273436788867984  
Testing accuracy: 0.9915  
Epoch 95

-----  
Training loss: 0.0002201120296242152  
Training accuracy: 1.0  
Testing loss: 0.03262961799223188  
Testing accuracy: 0.9912  
Epoch 96

-----  
Training loss: 0.000210378999635365  
Training accuracy: 1.0  
Testing loss: 0.032317403925876204  
Testing accuracy: 0.9914  
Epoch 97

-----  
Training loss: 0.00020575538583282954  
Training accuracy: 1.0  
Testing loss: 0.03279898560641663  
Testing accuracy: 0.9913  
Epoch 98

-----  
Training loss: 0.00019618784421642583  
Training accuracy: 1.0  
Testing loss: 0.034804828717334195  
Testing accuracy: 0.9915

Epoch 99

-----  
Training loss: 0.0001913946645317386

Training accuracy: 1.0

Testing loss: 0.03268425111452272

Testing accuracy: 0.991

Epoch 100

-----  
Training loss: 0.00019528813634848727

Training accuracy: 1.0

Testing loss: 0.03308716860684185

Testing accuracy: 0.9916

Epoch 101

-----  
Training loss: 0.0001890466419001617

Training accuracy: 1.0

Testing loss: 0.03287960960205443

Testing accuracy: 0.9913

Epoch 102

-----  
Training loss: 0.0001867844461101716

Training accuracy: 1.0

Testing loss: 0.03301469984316947

Testing accuracy: 0.9914

Epoch 103

-----  
Training loss: 0.00017519328150009605

Training accuracy: 1.0

Testing loss: 0.03279968112250953

Testing accuracy: 0.9911

Epoch 104

-----  
Training loss: 0.00017511177342294105

Training accuracy: 1.0

Testing loss: 0.03406448205730174

Testing accuracy: 0.9913

Epoch 105

-----  
Training loss: 0.0001740099308349727

Training accuracy: 1.0

Testing loss: 0.035044857842951034

Testing accuracy: 0.9912

Epoch 106

-----  
Training loss: 0.00016691111690124671

Training accuracy: 1.0

Testing loss: 0.033242140239615615

Testing accuracy: 0.9914

Epoch 107

-----  
Training loss: 0.0001694777172188272

Training accuracy: 1.0

Testing loss: 0.03339300875765272

Testing accuracy: 0.9914

Epoch 108

-----  
Training loss: 0.00015605785392035614

Training accuracy: 1.0

Testing loss: 0.03324752366729105

Testing accuracy: 0.9916

Epoch 109

-----  
Training loss: 0.00016715724215961625

Training accuracy: 1.0

Testing loss: 0.03421843393815527

Testing accuracy: 0.9914

Epoch 110

-----  
Training loss: 0.00015727642401275262

Training accuracy: 1.0

Testing loss: 0.034321017249316105

Testing accuracy: 0.9912

Epoch 111

-----  
Training loss: 0.00015769640896160886

Training accuracy: 1.0

Testing loss: 0.0348704549539582

Testing accuracy: 0.9917

Epoch 112

-----  
Training loss: 0.00015255120572455782

Training accuracy: 1.0

Testing loss: 0.033920430666922526

Testing accuracy: 0.9916

Epoch 113

-----  
Training loss: 0.00014709611229595795

Training accuracy: 1.0

Testing loss: 0.03383226393199273

Testing accuracy: 0.9915

Epoch 114

-----  
Training loss: 0.00014395151443883758

Training accuracy: 1.0

Testing loss: 0.03379225652857368

Testing accuracy: 0.9915

Epoch 115  
-----  
Training loss: 0.00014368163343278867  
Training accuracy: 1.0  
Testing loss: 0.03407763129588578  
Testing accuracy: 0.9913  
Epoch 116  
-----  
Training loss: 0.00014194067896532942  
Training accuracy: 1.0  
Testing loss: 0.03398549149500965  
Testing accuracy: 0.9914  
Epoch 117  
-----  
Training loss: 0.00013859397264271442  
Training accuracy: 1.0  
Testing loss: 0.034276775936555356  
Testing accuracy: 0.9915  
Epoch 118  
-----  
Training loss: 0.00013787177172521297  
Training accuracy: 1.0  
Testing loss: 0.03396150503776677  
Testing accuracy: 0.9911  
Epoch 119  
-----  
Training loss: 0.00013460103962916037  
Training accuracy: 1.0  
Testing loss: 0.03371761760071289  
Testing accuracy: 0.9914  
Epoch 120  
-----  
Training loss: 0.000134724879974965  
Training accuracy: 1.0  
Testing loss: 0.034263537656426785  
Testing accuracy: 0.9914  
Epoch 121  
-----  
Training loss: 0.0001284375670527273  
Training accuracy: 1.0  
Testing loss: 0.03423212421756752  
Testing accuracy: 0.9914  
Epoch 122  
-----  
Training loss: 0.0001319850342525721  
Training accuracy: 1.0  
Testing loss: 0.034130964819786114  
Testing accuracy: 0.9916

Epoch 123

-----  
Training loss: 0.000129840334815943

Training accuracy: 1.0

Testing loss: 0.03417049360145439

Testing accuracy: 0.9913

Epoch 124

-----  
Training loss: 0.00012469995810367133

Training accuracy: 1.0

Testing loss: 0.03439035275588432

Testing accuracy: 0.9912

Epoch 125

-----  
Training loss: 0.0001228249773692975

Training accuracy: 1.0

Testing loss: 0.03425263090741325

Testing accuracy: 0.9914

Epoch 126

-----  
Training loss: 0.00012049055767080669

Training accuracy: 1.0

Testing loss: 0.03458047689402583

Testing accuracy: 0.9915

Epoch 127

-----  
Training loss: 0.00011971141936110143

Training accuracy: 1.0

Testing loss: 0.03454797427093735

Testing accuracy: 0.9915

Epoch 128

-----  
Training loss: 0.0001175902662978236

Training accuracy: 1.0

Testing loss: 0.03452667037602896

Testing accuracy: 0.9914

Epoch 129

-----  
Training loss: 0.00011573769601758007

Training accuracy: 1.0

Testing loss: 0.03446059370404575

Testing accuracy: 0.9913

Epoch 130

-----  
Training loss: 0.00011555500490314141

Training accuracy: 1.0

Testing loss: 0.034897243988685565

Testing accuracy: 0.9914

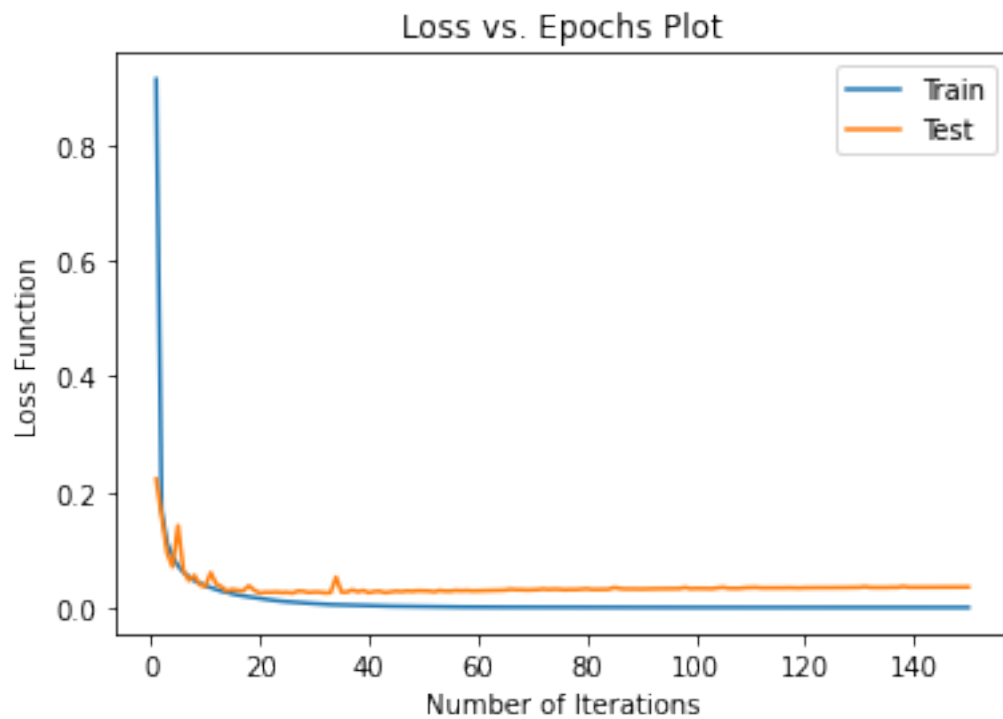


```
Epoch 131
-----
Training loss: 0.00011222918127829568
Training accuracy: 1.0
Testing loss: 0.036096200620409545
Testing accuracy: 0.9913
Epoch 132
-----
Training loss: 0.00011000673641647912
Training accuracy: 1.0
Testing loss: 0.03475512589419817
Testing accuracy: 0.9914
Epoch 133
-----
Training loss: 0.00011118635802295102
Training accuracy: 1.0
Testing loss: 0.03463294429058609
Testing accuracy: 0.9916
Epoch 134
-----
Training loss: 0.00010846953646281084
Training accuracy: 1.0
Testing loss: 0.0350157908633226
Testing accuracy: 0.9912
Epoch 135
-----
Training loss: 0.0001096052317220104
Training accuracy: 1.0
Testing loss: 0.03468806099093366
Testing accuracy: 0.9915
Epoch 136
-----
Training loss: 0.00010582137517097294
Training accuracy: 1.0
Testing loss: 0.03505792018064905
Testing accuracy: 0.9913
Epoch 137
-----
Training loss: 0.00010266784587759805
Training accuracy: 1.0
Testing loss: 0.03487632829657093
Testing accuracy: 0.9914
Epoch 138
-----
Training loss: 0.00010397818880783991
Training accuracy: 1.0
Testing loss: 0.0365278456775216
Testing accuracy: 0.9913
```

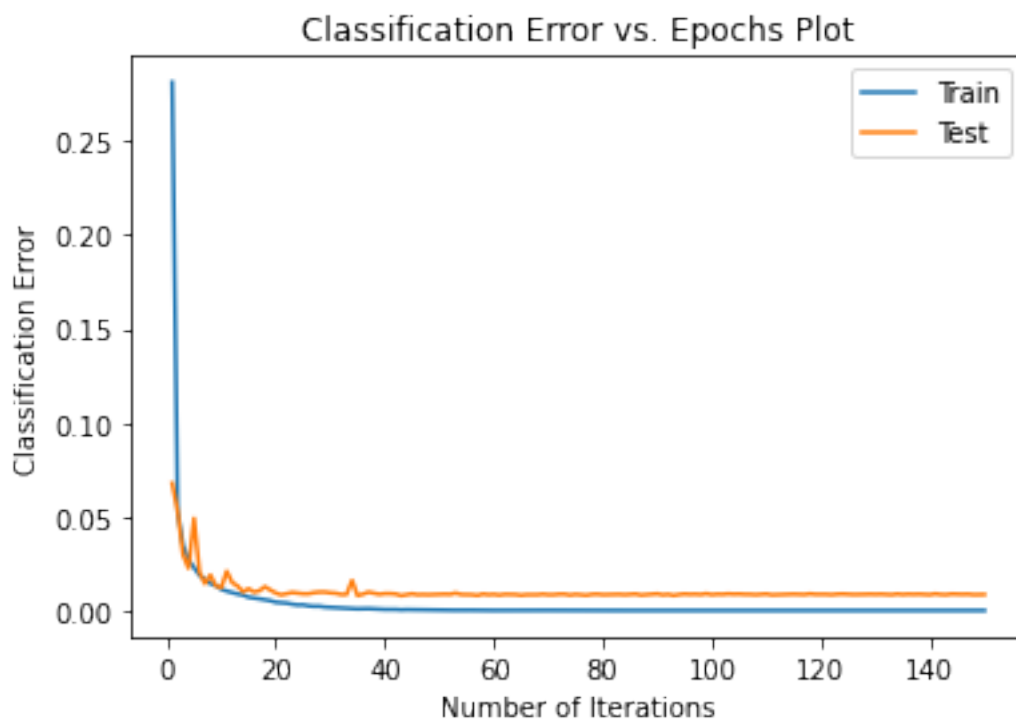
Epoch 139  
-----  
Training loss: 0.00010257162789309101  
Training accuracy: 1.0  
Testing loss: 0.03513964306461766  
Testing accuracy: 0.9914  
Epoch 140  
-----  
Training loss: 9.948016075483489e-05  
Training accuracy: 1.0  
Testing loss: 0.03528387384461609  
Testing accuracy: 0.9916  
Epoch 141  
-----  
Training loss: 9.863727354947211e-05  
Training accuracy: 1.0  
Testing loss: 0.03516274066935688  
Testing accuracy: 0.9911  
Epoch 142  
-----  
Training loss: 9.997595499852044e-05  
Training accuracy: 1.0  
Testing loss: 0.03517166309769052  
Testing accuracy: 0.9915  
Epoch 143  
-----  
Training loss: 9.653084035221582e-05  
Training accuracy: 1.0  
Testing loss: 0.03516476198450062  
Testing accuracy: 0.9916  
Epoch 144  
-----  
Training loss: 9.707461802408944e-05  
Training accuracy: 1.0  
Testing loss: 0.035095206511904925  
Testing accuracy: 0.9912  
Epoch 145  
-----  
Training loss: 9.537751577445306e-05  
Training accuracy: 1.0  
Testing loss: 0.035277643715926336  
Testing accuracy: 0.9913  
Epoch 146  
-----  
Training loss: 9.288571081948097e-05  
Training accuracy: 1.0  
Testing loss: 0.03530381299742929  
Testing accuracy: 0.9914

```
Epoch 147
-----
Training loss: 9.358758682909259e-05
Training accuracy: 1.0
Testing loss: 0.03549088607873031
Testing accuracy: 0.9913
Epoch 148
-----
Training loss: 9.177869800500578e-05
Training accuracy: 1.0
Testing loss: 0.03514231338190829
Testing accuracy: 0.9916
Epoch 149
-----
Training loss: 8.94019980278396e-05
Training accuracy: 1.0
Testing loss: 0.03539245483965937
Testing accuracy: 0.9915
Epoch 150
-----
Training loss: 8.868720827417368e-05
Training accuracy: 1.0
Testing loss: 0.03548213354702057
Testing accuracy: 0.9915
Done
Total Time Consumed: 12588.902533054352
```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.6.2 Learning Rate = 0.2

```
[ ]: # Define HyperParameters
num_classes = 10
learning_rate = 0.2
batch_size = 64
num_epochs = 150
CNN_LR2 = CNN(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_LR2.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, CNN_LR2, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, CNN_LR2, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 0.2089302817231665
Training accuracy: 0.9349333333333333
Testing loss: 0.04776030449585242
Testing accuracy: 0.985
Epoch 2
```

```
-----
Training loss: 0.041457102549045034
Training accuracy: 0.98695
Testing loss: 0.030822439185213178
Testing accuracy: 0.991
```

Epoch 3

-----  
Training loss: 0.026506554342464853  
Training accuracy: 0.9916166666666667  
Testing loss: 0.06431465027342212  
Testing accuracy: 0.9798  
Epoch 4

-----  
Training loss: 0.01860000006131595  
Training accuracy: 0.99405  
Testing loss: 0.034020055487220306  
Testing accuracy: 0.9894  
Epoch 5

-----  
Training loss: 0.013268378283649993  
Training accuracy: 0.99575  
Testing loss: 0.1342589622293006  
Testing accuracy: 0.9672  
Epoch 6

-----  
Training loss: 0.011221977371177734  
Training accuracy: 0.9962666666666666  
Testing loss: 0.04131159391648919  
Testing accuracy: 0.9892  
Epoch 7

-----  
Training loss: 0.006440405894046853  
Training accuracy: 0.99785  
Testing loss: 0.03930812160379687  
Testing accuracy: 0.9894  
Epoch 8

-----  
Training loss: 0.005062768639245769  
Training accuracy: 0.9983833333333333  
Testing loss: 0.03773211048511907  
Testing accuracy: 0.9907  
Epoch 9

-----  
Training loss: 0.003395272835735371  
Training accuracy: 0.9991  
Testing loss: 0.03704907740510265  
Testing accuracy: 0.9905  
Epoch 10

-----  
Training loss: 0.003646750007977607  
Training accuracy: 0.9989166666666667  
Testing loss: 0.05199047172215041  
Testing accuracy: 0.9877

Epoch 11

-----  
Training loss: 0.003582980596514972  
Training accuracy: 0.9988833333333333  
Testing loss: 0.04044341990474114  
Testing accuracy: 0.9906  
Epoch 12

-----  
Training loss: 0.0024923696909139835  
Training accuracy: 0.9993  
Testing loss: 0.037781126949100435  
Testing accuracy: 0.9918  
Epoch 13

-----  
Training loss: 0.0006192079170453401  
Training accuracy: 0.99985  
Testing loss: 0.03781777899171135  
Testing accuracy: 0.9923  
Epoch 14

-----  
Training loss: 0.00030914225398772716  
Training accuracy: 0.9999  
Testing loss: 0.03944799478901505  
Testing accuracy: 0.992  
Epoch 15

-----  
Training loss: 0.00028013150726883385  
Training accuracy: 0.99995  
Testing loss: 0.039582629624615305  
Testing accuracy: 0.9923  
Epoch 16

-----  
Training loss: 0.0002207928154235977  
Training accuracy: 0.99995  
Testing loss: 0.04054096075697329  
Testing accuracy: 0.9921  
Epoch 17

-----  
Training loss: 8.850484407686186e-05  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04080954474197599  
Testing accuracy: 0.9923  
Epoch 18

-----  
Training loss: 8.347806098359929e-05  
Training accuracy: 0.9999666666666667  
Testing loss: 0.041749138830894414  
Testing accuracy: 0.9924

Epoch 19

-----  
Training loss: 3.484004085283251e-05  
Training accuracy: 1.0  
Testing loss: 0.04214976139844117  
Testing accuracy: 0.9926  
Epoch 20

-----  
Training loss: 2.891627876244485e-05  
Training accuracy: 1.0  
Testing loss: 0.042623958669882236  
Testing accuracy: 0.9925  
Epoch 21

-----  
Training loss: 2.362868127516447e-05  
Training accuracy: 1.0  
Testing loss: 0.04312203494278512  
Testing accuracy: 0.9925  
Epoch 22

-----  
Training loss: 2.0533284145313027e-05  
Training accuracy: 1.0  
Testing loss: 0.0435640650471605  
Testing accuracy: 0.9925  
Epoch 23

-----  
Training loss: 1.8538040508228805e-05  
Training accuracy: 1.0  
Testing loss: 0.043932360968114766  
Testing accuracy: 0.9925  
Epoch 24

-----  
Training loss: 1.6842001620210922e-05  
Training accuracy: 1.0  
Testing loss: 0.04426223979485708  
Testing accuracy: 0.9925  
Epoch 25

-----  
Training loss: 1.5402732415618557e-05  
Training accuracy: 1.0  
Testing loss: 0.044519052429068375  
Testing accuracy: 0.9924  
Epoch 26

-----  
Training loss: 1.4082642982723688e-05  
Training accuracy: 1.0  
Testing loss: 0.044826164572456625  
Testing accuracy: 0.9924



Epoch 27

-----  
Training loss: 1.318712398171371e-05  
Training accuracy: 1.0  
Testing loss: 0.04512181279889365  
Testing accuracy: 0.9924  
Epoch 28

-----  
Training loss: 1.2192092653763708e-05  
Training accuracy: 1.0  
Testing loss: 0.04548972934587274  
Testing accuracy: 0.9925  
Epoch 29

-----  
Training loss: 1.14462865319832e-05  
Training accuracy: 1.0  
Testing loss: 0.04560784492895201  
Testing accuracy: 0.9924  
Epoch 30

-----  
Training loss: 1.0688435414103856e-05  
Training accuracy: 1.0  
Testing loss: 0.045858811264338724  
Testing accuracy: 0.9924  
Epoch 31

-----  
Training loss: 1.0071978343874713e-05  
Training accuracy: 1.0  
Testing loss: 0.046107291029520936  
Testing accuracy: 0.9924  
Epoch 32

-----  
Training loss: 9.58532118634352e-06  
Training accuracy: 1.0  
Testing loss: 0.04630335027255799  
Testing accuracy: 0.9924  
Epoch 33

-----  
Training loss: 9.05458436821706e-06  
Training accuracy: 1.0  
Testing loss: 0.046505123187903154  
Testing accuracy: 0.9926  
Epoch 34

-----  
Training loss: 8.603691091784426e-06  
Training accuracy: 1.0  
Testing loss: 0.04669902805548037  
Testing accuracy: 0.9926

Epoch 35

-----  
Training loss: 8.155943628812542e-06  
Training accuracy: 1.0  
Testing loss: 0.04688562137097402  
Testing accuracy: 0.9926  
Epoch 36

-----  
Training loss: 7.796065731392923e-06  
Training accuracy: 1.0  
Testing loss: 0.04706325009456687  
Testing accuracy: 0.9926  
Epoch 37

-----  
Training loss: 7.535864983687309e-06  
Training accuracy: 1.0  
Testing loss: 0.04986583527017385  
Testing accuracy: 0.9926  
Epoch 38

-----  
Training loss: 7.177231829849381e-06  
Training accuracy: 1.0  
Testing loss: 0.04741474056801018  
Testing accuracy: 0.9926  
Epoch 39

-----  
Training loss: 6.904835735493127e-06  
Training accuracy: 1.0  
Testing loss: 0.04758283605998639  
Testing accuracy: 0.9926  
Epoch 40

-----  
Training loss: 6.649974009356186e-06  
Training accuracy: 1.0  
Testing loss: 0.04771679361745689  
Testing accuracy: 0.9926  
Epoch 41

-----  
Training loss: 6.397725308663027e-06  
Training accuracy: 1.0  
Testing loss: 0.0478900969422779  
Testing accuracy: 0.9926  
Epoch 42

-----  
Training loss: 6.132147054448585e-06  
Training accuracy: 1.0  
Testing loss: 0.04802069739711624  
Testing accuracy: 0.9926

Epoch 43

-----  
Training loss: 5.9510348654827775e-06

Training accuracy: 1.0

Testing loss: 0.0481482625688236

Testing accuracy: 0.9926

Epoch 44

-----  
Training loss: 5.768522287960328e-06

Training accuracy: 1.0

Testing loss: 0.04829358360288605

Testing accuracy: 0.9926

Epoch 45

-----  
Training loss: 5.578429173630302e-06

Training accuracy: 1.0

Testing loss: 0.048435420541160894

Testing accuracy: 0.9926

Epoch 46

-----  
Training loss: 5.400716824030738e-06

Training accuracy: 1.0

Testing loss: 0.048580006452416474

Testing accuracy: 0.9926

Epoch 47

-----  
Training loss: 5.220507927773117e-06

Training accuracy: 1.0

Testing loss: 0.048712170609421596

Testing accuracy: 0.9926

Epoch 48

-----  
Training loss: 5.060134040183684e-06

Training accuracy: 1.0

Testing loss: 0.04881334868711184

Testing accuracy: 0.9926

Epoch 49

-----  
Training loss: 4.930853173904381e-06

Training accuracy: 1.0

Testing loss: 0.05112134219477599

Testing accuracy: 0.9926

Epoch 50

-----  
Training loss: 4.783897514943902e-06

Training accuracy: 1.0

Testing loss: 0.04907268146086975

Testing accuracy: 0.9926

Epoch 51

-----  
Training loss: 4.644505920834992e-06  
Training accuracy: 1.0  
Testing loss: 0.04914498572212404  
Testing accuracy: 0.9926  
Epoch 52

-----  
Training loss: 4.493040855027886e-06  
Training accuracy: 1.0  
Testing loss: 0.04926842060811481  
Testing accuracy: 0.9926  
Epoch 53

-----  
Training loss: 4.418485710778341e-06  
Training accuracy: 1.0  
Testing loss: 0.04936127275779159  
Testing accuracy: 0.9926  
Epoch 54

-----  
Training loss: 4.269682669786216e-06  
Training accuracy: 1.0  
Testing loss: 0.049470258448409986  
Testing accuracy: 0.9926  
Epoch 55

-----  
Training loss: 4.176696446199913e-06  
Training accuracy: 1.0  
Testing loss: 0.04957528092057632  
Testing accuracy: 0.9926  
Epoch 56

-----  
Training loss: 4.096711905659352e-06  
Training accuracy: 1.0  
Testing loss: 0.05396411391807961  
Testing accuracy: 0.9926  
Epoch 57

-----  
Training loss: 3.987280939817239e-06  
Training accuracy: 1.0  
Testing loss: 0.04977760656776915  
Testing accuracy: 0.9926  
Epoch 58

-----  
Training loss: 3.891899124784478e-06  
Training accuracy: 1.0  
Testing loss: 0.049881370239856324  
Testing accuracy: 0.9926

Epoch 59

-----  
Training loss: 3.80390405334173e-06  
Training accuracy: 1.0  
Testing loss: 0.04997092185315347  
Testing accuracy: 0.9926  
Epoch 60

-----  
Training loss: 3.721144371891209e-06  
Training accuracy: 1.0  
Testing loss: 0.05006151144611757  
Testing accuracy: 0.9926  
Epoch 61

-----  
Training loss: 3.6319526669152205e-06  
Training accuracy: 1.0  
Testing loss: 0.050151627323136765  
Testing accuracy: 0.9926  
Epoch 62

-----  
Training loss: 3.557674905851371e-06  
Training accuracy: 1.0  
Testing loss: 0.050236142440742086  
Testing accuracy: 0.9926  
Epoch 63

-----  
Training loss: 3.47797959958136e-06  
Training accuracy: 1.0  
Testing loss: 0.050316827974540915  
Testing accuracy: 0.9926  
Epoch 64

-----  
Training loss: 3.406194864794898e-06  
Training accuracy: 1.0  
Testing loss: 0.050402849207566006  
Testing accuracy: 0.9926  
Epoch 65

-----  
Training loss: 3.3349667825985328e-06  
Training accuracy: 1.0  
Testing loss: 0.05050231992236067  
Testing accuracy: 0.9926  
Epoch 66

-----  
Training loss: 3.2700233993435764e-06  
Training accuracy: 1.0  
Testing loss: 0.05283681416189315  
Testing accuracy: 0.9926

Epoch 67

-----  
Training loss: 3.2038616620051622e-06  
Training accuracy: 1.0  
Testing loss: 0.0506484338223239  
Testing accuracy: 0.9926  
Epoch 68

-----  
Training loss: 3.137145084836964e-06  
Training accuracy: 1.0  
Testing loss: 0.05072904497291929  
Testing accuracy: 0.9926  
Epoch 69

-----  
Training loss: 3.087698966220979e-06  
Training accuracy: 1.0  
Testing loss: 0.05080437801845181  
Testing accuracy: 0.9926  
Epoch 70

-----  
Training loss: 3.0296227394237246e-06  
Training accuracy: 1.0  
Testing loss: 0.050882839503377034  
Testing accuracy: 0.9926  
Epoch 71

-----  
Training loss: 2.969799372708337e-06  
Training accuracy: 1.0  
Testing loss: 0.050958747184973174  
Testing accuracy: 0.9926  
Epoch 72

-----  
Training loss: 2.9188051066868798e-06  
Training accuracy: 1.0  
Testing loss: 0.05270559931146319  
Testing accuracy: 0.9926  
Epoch 73

-----  
Training loss: 2.861979590567998e-06  
Training accuracy: 1.0  
Testing loss: 0.05110934079095538  
Testing accuracy: 0.9926  
Epoch 74

-----  
Training loss: 2.815229667433054e-06  
Training accuracy: 1.0  
Testing loss: 0.05245314669711523  
Testing accuracy: 0.9926

Epoch 75

-----  
Training loss: 2.765020490367931e-06  
Training accuracy: 1.0  
Testing loss: 0.051257131038975966  
Testing accuracy: 0.9926  
Epoch 76

-----  
Training loss: 2.714227197577538e-06  
Training accuracy: 1.0  
Testing loss: 0.05131863123635904  
Testing accuracy: 0.9926  
Epoch 77

-----  
Training loss: 2.6738194672531063e-06  
Training accuracy: 1.0  
Testing loss: 0.05137734248696796  
Testing accuracy: 0.9926  
Epoch 78

-----  
Training loss: 2.6294730003709076e-06  
Training accuracy: 1.0  
Testing loss: 0.0514475936808423  
Testing accuracy: 0.9926  
Epoch 79

-----  
Training loss: 2.5845088830328913e-06  
Training accuracy: 1.0  
Testing loss: 0.051515352889166165  
Testing accuracy: 0.9926  
Epoch 80

-----  
Training loss: 2.545361204385088e-06  
Training accuracy: 1.0  
Testing loss: 0.051653729938199174  
Testing accuracy: 0.9926  
Epoch 81

-----  
Training loss: 2.5020571670703854e-06  
Training accuracy: 1.0  
Testing loss: 0.051654056166784416  
Testing accuracy: 0.9926  
Epoch 82

-----  
Training loss: 2.4618856649648063e-06  
Training accuracy: 1.0  
Testing loss: 0.05172002231241376  
Testing accuracy: 0.9926

Epoch 83

-----  
Training loss: 2.4228419636076616e-06  
Training accuracy: 1.0  
Testing loss: 0.051776520524546524  
Testing accuracy: 0.9926  
Epoch 84

-----  
Training loss: 2.3841691759307317e-06  
Training accuracy: 1.0  
Testing loss: 0.051838921684548456  
Testing accuracy: 0.9926  
Epoch 85

-----  
Training loss: 2.3564944510739613e-06  
Training accuracy: 1.0  
Testing loss: 0.051913814963375736  
Testing accuracy: 0.9926  
Epoch 86

-----  
Training loss: 2.3173205042708626e-06  
Training accuracy: 1.0  
Testing loss: 0.051965144195960086  
Testing accuracy: 0.9926  
Epoch 87

-----  
Training loss: 2.285188017484548e-06  
Training accuracy: 1.0  
Testing loss: 0.0520198384881579  
Testing accuracy: 0.9926  
Epoch 88

-----  
Training loss: 2.252135562176368e-06  
Training accuracy: 1.0  
Testing loss: 0.052079731797806075  
Testing accuracy: 0.9926  
Epoch 89

-----  
Training loss: 2.2169017399376637e-06  
Training accuracy: 1.0  
Testing loss: 0.052136019269224655  
Testing accuracy: 0.9926  
Epoch 90

-----  
Training loss: 2.189672288531123e-06  
Training accuracy: 1.0  
Testing loss: 0.05219547084854047  
Testing accuracy: 0.9926



Epoch 91

-----  
Training loss: 2.1591793209590073e-06  
Training accuracy: 1.0  
Testing loss: 0.05225351682085735  
Testing accuracy: 0.9926  
Epoch 92

-----  
Training loss: 2.1276109426349167e-06  
Training accuracy: 1.0  
Testing loss: 0.05230843223084403  
Testing accuracy: 0.9926  
Epoch 93

-----  
Training loss: 2.102067351609449e-06  
Training accuracy: 1.0  
Testing loss: 0.052370000177749405  
Testing accuracy: 0.9926  
Epoch 94

-----  
Training loss: 2.072709115776661e-06  
Training accuracy: 1.0  
Testing loss: 0.052424612432554744  
Testing accuracy: 0.9926  
Epoch 95

-----  
Training loss: 2.0446726593550107e-06  
Training accuracy: 1.0  
Testing loss: 0.05258000809754094  
Testing accuracy: 0.9926  
Epoch 96

-----  
Training loss: 2.017453155857396e-06  
Training accuracy: 1.0  
Testing loss: 0.05253338938670347  
Testing accuracy: 0.9926  
Epoch 97

-----  
Training loss: 1.993045006859499e-06  
Training accuracy: 1.0  
Testing loss: 0.052592044409853794  
Testing accuracy: 0.9926  
Epoch 98

-----  
Training loss: 1.966273453952283e-06  
Training accuracy: 1.0  
Testing loss: 0.057834645339116926  
Testing accuracy: 0.9926

Epoch 99

-----  
Training loss: 1.9417113638696765e-06

Training accuracy: 1.0

Testing loss: 0.052691104766173315

Testing accuracy: 0.9926

Epoch 100

-----  
Training loss: 1.917561232639997e-06

Training accuracy: 1.0

Testing loss: 0.052744036831337056

Testing accuracy: 0.9926

Epoch 101

-----  
Training loss: 1.8938095662844508e-06

Training accuracy: 1.0

Testing loss: 0.05279016081972631

Testing accuracy: 0.9926

Epoch 102

-----  
Training loss: 1.8714154080829103e-06

Training accuracy: 1.0

Testing loss: 0.05284061576837076

Testing accuracy: 0.9926

Epoch 103

-----  
Training loss: 1.8467558519282315e-06

Training accuracy: 1.0

Testing loss: 0.05289320441104969

Testing accuracy: 0.9926

Epoch 104

-----  
Training loss: 1.826147037310714e-06

Training accuracy: 1.0

Testing loss: 0.052980460960738475

Testing accuracy: 0.9926

Epoch 105

-----  
Training loss: 1.8050691939372143e-06

Training accuracy: 1.0

Testing loss: 0.05882521917346069

Testing accuracy: 0.9926

Epoch 106

-----  
Training loss: 1.7833595984074672e-06

Training accuracy: 1.0

Testing loss: 0.053035605788628884

Testing accuracy: 0.9926

Epoch 107

-----  
Training loss: 1.7632451465428763e-06

Training accuracy: 1.0

Testing loss: 0.05308802817988465

Testing accuracy: 0.9926

Epoch 108

-----  
Training loss: 1.7404094183315047e-06

Training accuracy: 1.0

Testing loss: 0.05313278097352946

Testing accuracy: 0.9926

Epoch 109

-----  
Training loss: 1.7254865767016034e-06

Training accuracy: 1.0

Testing loss: 0.05321722991244941

Testing accuracy: 0.9926

Epoch 110

-----  
Training loss: 1.7034986489273743e-06

Training accuracy: 1.0

Testing loss: 0.05475023318498959

Testing accuracy: 0.9926

Epoch 111

-----  
Training loss: 1.6858906496077945e-06

Training accuracy: 1.0

Testing loss: 0.05330117883253808

Testing accuracy: 0.9926

Epoch 112

-----  
Training loss: 1.6668442391607621e-06

Training accuracy: 1.0

Testing loss: 0.05332017886192634

Testing accuracy: 0.9926

Epoch 113

-----  
Training loss: 1.6485733051110194e-06

Training accuracy: 1.0

Testing loss: 0.05349464011427315

Testing accuracy: 0.9926

Epoch 114

-----  
Training loss: 1.6301427878569068e-06

Training accuracy: 1.0

Testing loss: 0.053408515379672415

Testing accuracy: 0.9926

Epoch 115  
-----  
Training loss: 1.6121127928829063e-06  
Training accuracy: 1.0  
Testing loss: 0.05345206680678649  
Testing accuracy: 0.9926  
Epoch 116  
-----  
Training loss: 1.5949730758768746e-06  
Training accuracy: 1.0  
Testing loss: 0.05350078762668007  
Testing accuracy: 0.9926  
Epoch 117  
-----  
Training loss: 1.5786366260305348e-06  
Training accuracy: 1.0  
Testing loss: 0.053543249999604255  
Testing accuracy: 0.9926  
Epoch 118  
-----  
Training loss: 1.5623437955799347e-06  
Training accuracy: 1.0  
Testing loss: 0.053590375334710096  
Testing accuracy: 0.9926  
Epoch 119  
-----  
Training loss: 1.5472095357020285e-06  
Training accuracy: 1.0  
Testing loss: 0.054904832236689106  
Testing accuracy: 0.9926  
Epoch 120  
-----  
Training loss: 1.5312690876169672e-06  
Training accuracy: 1.0  
Testing loss: 0.053670322778265056  
Testing accuracy: 0.9926  
Epoch 121  
-----  
Training loss: 1.5156743123935e-06  
Training accuracy: 1.0  
Testing loss: 0.053714864064894625  
Testing accuracy: 0.9926  
Epoch 122  
-----  
Training loss: 1.5006836908627956e-06  
Training accuracy: 1.0  
Testing loss: 0.05375773475542047  
Testing accuracy: 0.9926

Epoch 123

-----  
Training loss: 1.4857850397014262e-06

Training accuracy: 1.0

Testing loss: 0.05379640637550264

Testing accuracy: 0.9926

Epoch 124

-----  
Training loss: 1.471012129132158e-06

Training accuracy: 1.0

Testing loss: 0.05384112102956188

Testing accuracy: 0.9926

Epoch 125

-----  
Training loss: 1.4566706918341054e-06

Training accuracy: 1.0

Testing loss: 0.05387568031670617

Testing accuracy: 0.9926

Epoch 126

-----  
Training loss: 1.442592968658237e-06

Training accuracy: 1.0

Testing loss: 0.054620326864614224

Testing accuracy: 0.9926

Epoch 127

-----  
Training loss: 1.4277865887837748e-06

Training accuracy: 1.0

Testing loss: 0.05395500475514787

Testing accuracy: 0.9926

Epoch 128

-----  
Training loss: 1.415770242552128e-06

Training accuracy: 1.0

Testing loss: 0.05399617854779159

Testing accuracy: 0.9926

Epoch 129

-----  
Training loss: 1.4012076470386602e-06

Training accuracy: 1.0

Testing loss: 0.05403520593143401

Testing accuracy: 0.9926

Epoch 130

-----  
Training loss: 1.3894024566929157e-06

Training accuracy: 1.0

Testing loss: 0.054075988718155395

Testing accuracy: 0.9926

Epoch 131  
-----  
Training loss: 1.3760270720270047e-06  
Training accuracy: 1.0  
Testing loss: 0.05806104017098433  
Testing accuracy: 0.9926  
Epoch 132  
-----  
Training loss: 1.3624167131225087e-06  
Training accuracy: 1.0  
Testing loss: 0.05414999934760904  
Testing accuracy: 0.9926  
Epoch 133  
-----  
Training loss: 1.3517623155437993e-06  
Training accuracy: 1.0  
Testing loss: 0.054183691279234406  
Testing accuracy: 0.9926  
Epoch 134  
-----  
Training loss: 1.339210970321029e-06  
Training accuracy: 1.0  
Testing loss: 0.05422297607396676  
Testing accuracy: 0.9926  
Epoch 135  
-----  
Training loss: 1.3270491163818103e-06  
Training accuracy: 1.0  
Testing loss: 0.054259966225981435  
Testing accuracy: 0.9926  
Epoch 136  
-----  
Training loss: 1.3150589552509473e-06  
Training accuracy: 1.0  
Testing loss: 0.05429497885586267  
Testing accuracy: 0.9926  
Epoch 137  
-----  
Training loss: 1.3036984160092876e-06  
Training accuracy: 1.0  
Testing loss: 0.054331442015384604  
Testing accuracy: 0.9926  
Epoch 138  
-----  
Training loss: 1.2919077579249224e-06  
Training accuracy: 1.0  
Testing loss: 0.054647559119913015  
Testing accuracy: 0.9926

Epoch 139

-----  
Training loss: 1.2810727529539416e-06

Training accuracy: 1.0

Testing loss: 0.05439992963738654

Testing accuracy: 0.9926

Epoch 140

-----  
Training loss: 1.269640274302238e-06

Training accuracy: 1.0

Testing loss: 0.05443643358021591

Testing accuracy: 0.9926

Epoch 141

-----  
Training loss: 1.2587463907798006e-06

Training accuracy: 1.0

Testing loss: 0.05447331653475406

Testing accuracy: 0.9926

Epoch 142

-----  
Training loss: 1.2486231446101687e-06

Training accuracy: 1.0

Testing loss: 0.05451019542950286

Testing accuracy: 0.9926

Epoch 143

-----  
Training loss: 1.23822004685555e-06

Training accuracy: 1.0

Testing loss: 0.054542105574825445

Testing accuracy: 0.9926

Epoch 144

-----  
Training loss: 1.2278027353643732e-06

Training accuracy: 1.0

Testing loss: 0.05457673759905064

Testing accuracy: 0.9926

Epoch 145

-----  
Training loss: 1.216873129299619e-06

Training accuracy: 1.0

Testing loss: 0.05460495132936273

Testing accuracy: 0.9926

Epoch 146

-----  
Training loss: 1.20768358360183e-06

Training accuracy: 1.0

Testing loss: 0.05464217070257097

Testing accuracy: 0.9926

Epoch 147

-----  
Training loss: 1.1975885834723716e-06  
Training accuracy: 1.0  
Testing loss: 0.054675198363849195  
Testing accuracy: 0.9926  
Epoch 148

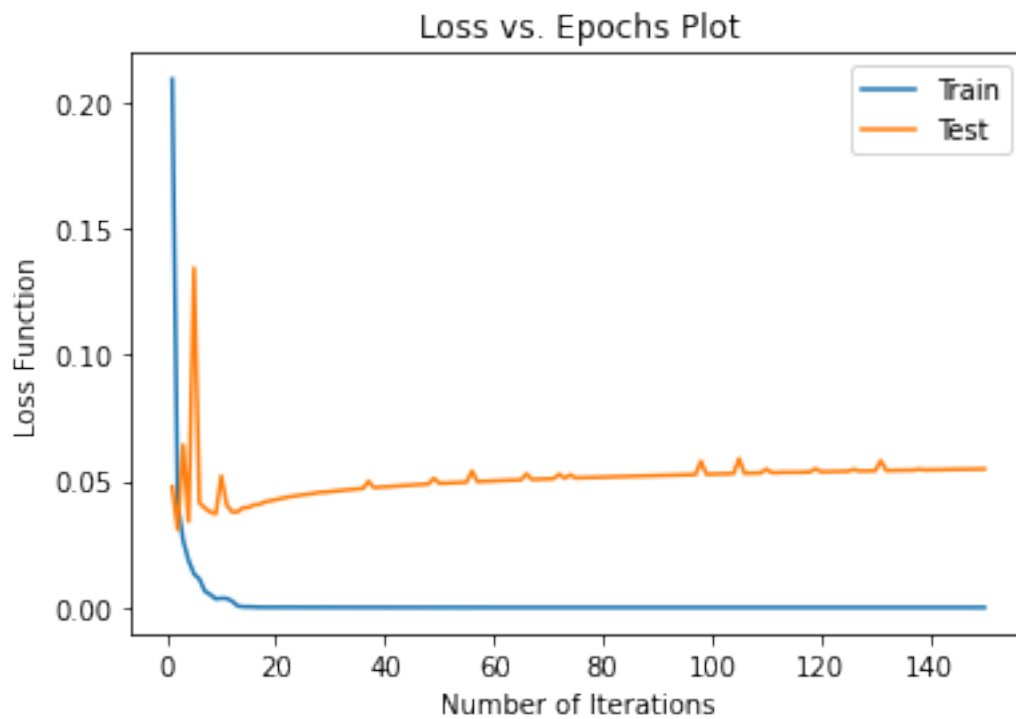
-----  
Training loss: 1.187819524044779e-06  
Training accuracy: 1.0  
Testing loss: 0.05470923627910345  
Testing accuracy: 0.9926  
Epoch 149

-----  
Training loss: 1.1782456453889979e-06  
Training accuracy: 1.0  
Testing loss: 0.05474162230653884  
Testing accuracy: 0.9926  
Epoch 150

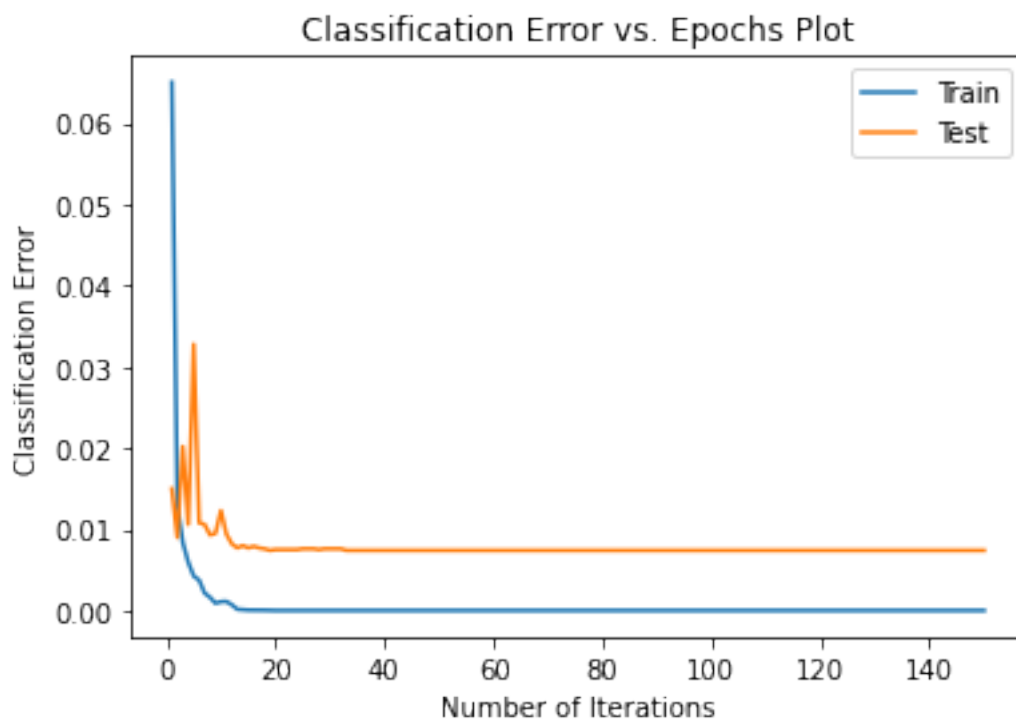
-----  
Training loss: 1.1692942482570837e-06  
Training accuracy: 1.0  
Testing loss: 0.05477516130904493  
Testing accuracy: 0.9926  
Done  
Total Time Consumed: 12669.866517066956

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```





```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.6.3 Learning Rate = 0.5

```
[ ]: # Define HyperParameters
num_classes = 10
learning_rate = 0.5
batch_size = 64
num_epochs = 150
CNN_LR5 = CNN(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_LR5.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, CNN_LR5, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, CNN_LR5, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 2.2977896980285646
Training accuracy: 0.11411666666666667
Testing loss: 2.3013590384444082
Testing accuracy: 0.1135
Epoch 2
```

```
-----
Training loss: 2.3030576077779132
Training accuracy: 0.10805
Testing loss: 2.3053683703112755
Testing accuracy: 0.1028
```

Epoch 3

-----  
Training loss: 2.3029731824239095  
Training accuracy: 0.10966666666666666  
Testing loss: 2.302881722237654  
Testing accuracy: 0.1032  
Epoch 4

-----  
Training loss: 2.3030292484283446  
Training accuracy: 0.10638333333333333  
Testing loss: 2.301590334837604  
Testing accuracy: 0.1135  
Epoch 5

-----  
Training loss: 2.302662353515625  
Training accuracy: 0.10756666666666667  
Testing loss: 2.303895078646909  
Testing accuracy: 0.1028  
Epoch 6

-----  
Training loss: 2.3030753377278645  
Training accuracy: 0.10811666666666667  
Testing loss: 2.3030293823047807  
Testing accuracy: 0.0982  
Epoch 7

-----  
Training loss: 2.303076411819458  
Training accuracy: 0.10703333333333333  
Testing loss: 2.3027482898371994  
Testing accuracy: 0.1032  
Epoch 8

-----  
Training loss: 2.30314365234375  
Training accuracy: 0.108  
Testing loss: 2.3014451166626753  
Testing accuracy: 0.1135  
Epoch 9

-----  
Training loss: 2.3029968475341795  
Training accuracy: 0.10798333333333333  
Testing loss: 2.3029848891458693  
Testing accuracy: 0.1135  
Epoch 10

-----  
Training loss: 2.3030668306986493  
Training accuracy: 0.10793333333333334  
Testing loss: 2.3027230189864043  
Testing accuracy: 0.1009

```
Epoch 11
-----
Training loss: 2.3029636603037518
Training accuracy: 0.1091
Testing loss: 2.302410613199708
Testing accuracy: 0.1135
Epoch 12
-----
Training loss: 2.3031625793457033
Training accuracy: 0.1066
Testing loss: 2.3025957019465744
Testing accuracy: 0.1135
Epoch 13
-----
Training loss: 2.3029320859273277
Training accuracy: 0.10848333333333333
Testing loss: 2.301978794632444
Testing accuracy: 0.1135
Epoch 14
-----
Training loss: 2.303188980356852
Training accuracy: 0.1076
Testing loss: 2.3050528757131783
Testing accuracy: 0.101
Epoch 15
-----
Training loss: 2.3030507617950438
Training accuracy: 0.10873333333333333
Testing loss: 2.3039931597983
Testing accuracy: 0.1028
Epoch 16
-----
Training loss: 2.303032177988688
Training accuracy: 0.10888333333333333
Testing loss: 2.302849549396782
Testing accuracy: 0.1135
Epoch 17
-----
Training loss: 2.3031362524668375
Training accuracy: 0.10628333333333333
Testing loss: 2.3035639714283547
Testing accuracy: 0.0974
Epoch 18
-----
Training loss: 2.3030075669606527
Training accuracy: 0.10878333333333333
Testing loss: 2.302580447713281
Testing accuracy: 0.1135
```

Epoch 19

-----  
Training loss: 2.3029439468383788  
Training accuracy: 0.10766666666666666  
Testing loss: 2.304168400491119  
Testing accuracy: 0.1135  
Epoch 20

-----  
Training loss: 2.3030681776682536  
Training accuracy: 0.10751666666666666  
Testing loss: 2.3027207502134286  
Testing accuracy: 0.1135  
Epoch 21

-----  
Training loss: 2.3031087509155275  
Training accuracy: 0.10756666666666667  
Testing loss: 2.3022988009604677  
Testing accuracy: 0.1135  
Epoch 22

-----  
Training loss: 2.302964143371582  
Training accuracy: 0.10885  
Testing loss: 2.302784127034959  
Testing accuracy: 0.1032  
Epoch 23

-----  
Training loss: 2.3030068408966065  
Training accuracy: 0.10738333333333333  
Testing loss: 2.3023792649530304  
Testing accuracy: 0.1135  
Epoch 24

-----  
Training loss: 2.3031457856496176  
Training accuracy: 0.10936666666666667  
Testing loss: 2.301977819697872  
Testing accuracy: 0.1135  
Epoch 25

-----  
Training loss: 2.3029953362782796  
Training accuracy: 0.10836666666666667  
Testing loss: 2.3027012074828908  
Testing accuracy: 0.101  
Epoch 26

-----  
Training loss: 2.302948648707072  
Training accuracy: 0.1078  
Testing loss: 2.3034466694874367  
Testing accuracy: 0.1135

Epoch 27

-----  
Training loss: 2.3029970569610594  
Training accuracy: 0.10868333333333334  
Testing loss: 2.302420667781951  
Testing accuracy: 0.1028  
Epoch 28

-----  
Training loss: 2.3031433828989663  
Training accuracy: 0.10676666666666666  
Testing loss: 2.3030755292078493  
Testing accuracy: 0.1135  
Epoch 29

-----  
Training loss: 2.303125401687622  
Training accuracy: 0.10771666666666667  
Testing loss: 2.3014056545913597  
Testing accuracy: 0.1135  
Epoch 30

-----  
Training loss: 2.3031364074707033  
Training accuracy: 0.10826666666666666  
Testing loss: 2.3039740696074857  
Testing accuracy: 0.1135  
Epoch 31

-----  
Training loss: 2.3030500025431313  
Training accuracy: 0.10661666666666667  
Testing loss: 2.3021602843217788  
Testing accuracy: 0.1135  
Epoch 32

-----  
Training loss: 2.303145868174235  
Training accuracy: 0.10736666666666667  
Testing loss: 2.30262785504578  
Testing accuracy: 0.1135  
Epoch 33

-----  
Training loss: 2.3032426385243734  
Training accuracy: 0.10821666666666667  
Testing loss: 2.3028403345946296  
Testing accuracy: 0.1135  
Epoch 34

-----  
Training loss: 2.303308168284098  
Training accuracy: 0.10815  
Testing loss: 2.3016227354669265  
Testing accuracy: 0.1135

Epoch 35

-----  
Training loss: 2.303050172042847  
Training accuracy: 0.10708333333333334  
Testing loss: 2.3026185369795296  
Testing accuracy: 0.101  
Epoch 36

-----  
Training loss: 2.303193164952596  
Training accuracy: 0.10725  
Testing loss: 2.3049516161535957  
Testing accuracy: 0.098  
Epoch 37

-----  
Training loss: 2.3029320364634196  
Training accuracy: 0.10758333333333334  
Testing loss: 2.303555505290912  
Testing accuracy: 0.1135  
Epoch 38

-----  
Training loss: 2.3032876628875734  
Training accuracy: 0.10873333333333333  
Testing loss: 2.302504039873743  
Testing accuracy: 0.1028  
Epoch 39

-----  
Training loss: 2.302868956120809  
Training accuracy: 0.10885  
Testing loss: 2.3045337807600665  
Testing accuracy: 0.1009  
Epoch 40

-----  
Training loss: 2.302749787648519  
Training accuracy: 0.1072  
Testing loss: 2.303399840737604  
Testing accuracy: 0.1028  
Epoch 41

-----  
Training loss: 2.302965182240804  
Training accuracy: 0.10901666666666666  
Testing loss: 2.3032408094709846  
Testing accuracy: 0.1135  
Epoch 42

-----  
Training loss: 2.3028209225972494  
Training accuracy: 0.108  
Testing loss: 2.3039526817904914  
Testing accuracy: 0.098

Epoch 43

-----  
Training loss: 2.302993395614624  
Training accuracy: 0.10858333333333334  
Testing loss: 2.30249421611713  
Testing accuracy: 0.1135  
Epoch 44

-----  
Training loss: 2.3029762264251707  
Training accuracy: 0.10861666666666667  
Testing loss: 2.3028340020756812  
Testing accuracy: 0.1028  
Epoch 45

-----  
Training loss: 2.303000676981608  
Training accuracy: 0.1084  
Testing loss: 2.3032414761318525  
Testing accuracy: 0.101  
Epoch 46

-----  
Training loss: 2.302988634490967  
Training accuracy: 0.1087  
Testing loss: 2.302085586414216  
Testing accuracy: 0.1135  
Epoch 47

-----  
Training loss: 2.3030238320668537  
Training accuracy: 0.10808333333333334  
Testing loss: 2.302541508036814  
Testing accuracy: 0.1135  
Epoch 48

-----  
Training loss: 2.3026256401062013  
Training accuracy: 0.10921666666666667  
Testing loss: 2.3024759535576886  
Testing accuracy: 0.1135  
Epoch 49

-----  
Training loss: 2.302789342625936  
Training accuracy: 0.1086  
Testing loss: 2.302574511546238  
Testing accuracy: 0.1135  
Epoch 50

-----  
Training loss: 2.302988170750936  
Training accuracy: 0.10716666666666666  
Testing loss: 2.3038537654147784  
Testing accuracy: 0.1135



Epoch 51

-----  
Training loss: 2.3029151275634767  
Training accuracy: 0.1087  
Testing loss: 2.3026678577350204  
Testing accuracy: 0.1032  
Epoch 52

-----  
Training loss: 2.3029262427012127  
Training accuracy: 0.10841666666666666  
Testing loss: 2.3041545418417377  
Testing accuracy: 0.1032  
Epoch 53

-----  
Training loss: 2.303250472640991  
Training accuracy: 0.10706666666666667  
Testing loss: 2.3015394271559018  
Testing accuracy: 0.1135  
Epoch 54

-----  
Training loss: 2.303261474863688  
Training accuracy: 0.10883333333333334  
Testing loss: 2.304182907578292  
Testing accuracy: 0.1009  
Epoch 55

-----  
Training loss: 2.3029441553751626  
Training accuracy: 0.10638333333333333  
Testing loss: 2.303321561995585  
Testing accuracy: 0.1135  
Epoch 56

-----  
Training loss: 2.3030617703755696  
Training accuracy: 0.10808333333333334  
Testing loss: 2.301893753610599  
Testing accuracy: 0.1135  
Epoch 57

-----  
Training loss: 2.3029571919759113  
Training accuracy: 0.10738333333333333  
Testing loss: 2.3038592004472283  
Testing accuracy: 0.1009  
Epoch 58

-----  
Training loss: 2.302747559738159  
Training accuracy: 0.10785  
Testing loss: 2.3024553447771985  
Testing accuracy: 0.1135

Epoch 59

-----  
Training loss: 2.3032881169637043  
Training accuracy: 0.10748333333333333  
Testing loss: 2.3033878909554453  
Testing accuracy: 0.101  
Epoch 60

-----  
Training loss: 2.303195159403483  
Training accuracy: 0.10638333333333333  
Testing loss: 2.301389994894623  
Testing accuracy: 0.1135  
Epoch 61

-----  
Training loss: 2.3030097836812335  
Training accuracy: 0.10858333333333334  
Testing loss: 2.302772508305349  
Testing accuracy: 0.101  
Epoch 62

-----  
Training loss: 2.302814958190918  
Training accuracy: 0.10638333333333333  
Testing loss: 2.303015651216932  
Testing accuracy: 0.1135  
Epoch 63

-----  
Training loss: 2.30292451171875  
Training accuracy: 0.11113333333333333  
Testing loss: 2.301960276949937  
Testing accuracy: 0.1135  
Epoch 64

-----  
Training loss: 2.303109311421712  
Training accuracy: 0.10856666666666667  
Testing loss: 2.303843022911412  
Testing accuracy: 0.1135  
Epoch 65

-----  
Training loss: 2.3032160214742023  
Training accuracy: 0.10783333333333334  
Testing loss: 2.3019389240605057  
Testing accuracy: 0.1135  
Epoch 66

-----  
Training loss: 2.3028600583394367  
Training accuracy: 0.10903333333333333  
Testing loss: 2.30277882715699  
Testing accuracy: 0.1135

Epoch 67

-----  
Training loss: 2.3030176120758057  
Training accuracy: 0.10735  
Testing loss: 2.302571776566232  
Testing accuracy: 0.1135  
Epoch 68

-----  
Training loss: 2.303004251607259  
Training accuracy: 0.10773333333333333  
Testing loss: 2.3025988909848936  
Testing accuracy: 0.1135  
Epoch 69

-----  
Training loss: 2.303144520060221  
Training accuracy: 0.1071  
Testing loss: 2.3023617115749677  
Testing accuracy: 0.1135  
Epoch 70

-----  
Training loss: 2.303126631673177  
Training accuracy: 0.10873333333333333  
Testing loss: 2.304495758311764  
Testing accuracy: 0.1028  
Epoch 71

-----  
Training loss: 2.302963572184245  
Training accuracy: 0.10778333333333333  
Testing loss: 2.301145470066435  
Testing accuracy: 0.1135  
Epoch 72

-----  
Training loss: 2.3029262969970703  
Training accuracy: 0.10711666666666667  
Testing loss: 2.3047711029174223  
Testing accuracy: 0.1135  
Epoch 73

-----  
Training loss: 2.302962600326538  
Training accuracy: 0.10806666666666667  
Testing loss: 2.3056684405940353  
Testing accuracy: 0.098  
Epoch 74

-----  
Training loss: 2.303060266494751  
Training accuracy: 0.10926666666666666  
Testing loss: 2.3036184736118197  
Testing accuracy: 0.0982

Epoch 75

-----  
Training loss: 2.3029466367085774  
Training accuracy: 0.10713333333333333  
Testing loss: 2.303104666387959  
Testing accuracy: 0.1135  
Epoch 76

-----  
Training loss: 2.303185501352946  
Training accuracy: 0.1091  
Testing loss: 2.302968839171586  
Testing accuracy: 0.1135  
Epoch 77

-----  
Training loss: 2.3028848567962648  
Training accuracy: 0.1084  
Testing loss: 2.301617403698575  
Testing accuracy: 0.1135  
Epoch 78

-----  
Training loss: 2.3028587193806964  
Training accuracy: 0.10808333333333334  
Testing loss: 2.3032127656754415  
Testing accuracy: 0.1028  
Epoch 79

-----  
Training loss: 2.303066215642293  
Training accuracy: 0.10838333333333333  
Testing loss: 2.3034833662069527  
Testing accuracy: 0.101  
Epoch 80

-----  
Training loss: 2.3031109900156657  
Training accuracy: 0.10791666666666666  
Testing loss: 2.304677468196602  
Testing accuracy: 0.1135  
Epoch 81

-----  
Training loss: 2.3031054152170816  
Training accuracy: 0.10776666666666666  
Testing loss: 2.3019167587255978  
Testing accuracy: 0.1135  
Epoch 82

-----  
Training loss: 2.3031437271118165  
Training accuracy: 0.10775  
Testing loss: 2.3024531610452446  
Testing accuracy: 0.1135

Epoch 83

-----  
Training loss: 2.302979979960124  
Training accuracy: 0.10928333333333333  
Testing loss: 2.3041485145593144  
Testing accuracy: 0.1135  
Epoch 84

-----  
Training loss: 2.3030706457773844  
Training accuracy: 0.10738333333333333  
Testing loss: 2.305281991411926  
Testing accuracy: 0.1135  
Epoch 85

-----  
Training loss: 2.302991769917806  
Training accuracy: 0.10871666666666667  
Testing loss: 2.302102669029479  
Testing accuracy: 0.1135  
Epoch 86

-----  
Training loss: 2.303063491566976  
Training accuracy: 0.1099  
Testing loss: 2.3027258329330738  
Testing accuracy: 0.1135  
Epoch 87

-----  
Training loss: 2.3028549668629963  
Training accuracy: 0.10766666666666666  
Testing loss: 2.302994665826202  
Testing accuracy: 0.1135  
Epoch 88

-----  
Training loss: 2.303124933115641  
Training accuracy: 0.10616666666666667  
Testing loss: 2.302022432825368  
Testing accuracy: 0.1135  
Epoch 89

-----  
Training loss: 2.3031507322947182  
Training accuracy: 0.10793333333333334  
Testing loss: 2.30177383210249  
Testing accuracy: 0.1135  
Epoch 90

-----  
Training loss: 2.3029629525502524  
Training accuracy: 0.10783333333333334  
Testing loss: 2.3033033404380654  
Testing accuracy: 0.1135

Epoch 91

-----  
Training loss: 2.3029420026143392  
Training accuracy: 0.10858333333333334  
Testing loss: 2.3065384041731525  
Testing accuracy: 0.098  
Epoch 92

-----  
Training loss: 2.3031918752034506  
Training accuracy: 0.10658333333333334  
Testing loss: 2.3052680492401123  
Testing accuracy: 0.1135  
Epoch 93

-----  
Training loss: 2.303057669576009  
Training accuracy: 0.10923333333333334  
Testing loss: 2.3022152420821462  
Testing accuracy: 0.1135  
Epoch 94

-----  
Training loss: 2.3028225995381675  
Training accuracy: 0.10725  
Testing loss: 2.3055594741918477  
Testing accuracy: 0.101  
Epoch 95

-----  
Training loss: 2.303106586964925  
Training accuracy: 0.1085  
Testing loss: 2.3027120669176626  
Testing accuracy: 0.1135  
Epoch 96

-----  
Training loss: 2.3028893232981362  
Training accuracy: 0.10838333333333333  
Testing loss: 2.304517187130679  
Testing accuracy: 0.1135  
Epoch 97

-----  
Training loss: 2.303141141382853  
Training accuracy: 0.10741666666666666  
Testing loss: 2.304834002901794  
Testing accuracy: 0.1028  
Epoch 98

-----  
Training loss: 2.3031670384724934  
Training accuracy: 0.10836666666666667  
Testing loss: 2.303812195540993  
Testing accuracy: 0.1135

Epoch 99

-----  
Training loss: 2.302893346405029

Training accuracy: 0.10745

Testing loss: 2.3034117161088687

Testing accuracy: 0.1135

Epoch 100

-----  
Training loss: 2.303087755711873

Training accuracy: 0.10855

Testing loss: 2.304377100270265

Testing accuracy: 0.1135

Epoch 101

-----  
Training loss: 2.3027882223765057

Training accuracy: 0.10821666666666667

Testing loss: 2.3044781760804973

Testing accuracy: 0.1028

Epoch 102

-----  
Training loss: 2.3031255930582684

Training accuracy: 0.10835

Testing loss: 2.303267635357608

Testing accuracy: 0.0982

Epoch 103

-----  
Training loss: 2.3030394158681236

Training accuracy: 0.10711666666666667

Testing loss: 2.301827986528919

Testing accuracy: 0.1135

Epoch 104

-----  
Training loss: 2.303037624104818

Training accuracy: 0.10786666666666667

Testing loss: 2.303088040868188

Testing accuracy: 0.1135

Epoch 105

-----  
Training loss: 2.303162813568115

Training accuracy: 0.10788333333333333

Testing loss: 2.301348895783637

Testing accuracy: 0.1135

Epoch 106

-----  
Training loss: 2.3031214636484783

Training accuracy: 0.10823333333333333

Testing loss: 2.3027126910580193

Testing accuracy: 0.1135

Epoch 107  
-----  
Training loss: 2.3029418347676596  
Training accuracy: 0.10706666666666667  
Testing loss: 2.302367011452936  
Testing accuracy: 0.1135  
Epoch 108  
-----  
Training loss: 2.303094165420532  
Training accuracy: 0.10676666666666666  
Testing loss: 2.30254293247393  
Testing accuracy: 0.1135  
Epoch 109  
-----  
Training loss: 2.3032624106089274  
Training accuracy: 0.10991666666666666  
Testing loss: 2.3040299445960173  
Testing accuracy: 0.1028  
Epoch 110  
-----  
Training loss: 2.303060353469849  
Training accuracy: 0.10825  
Testing loss: 2.3029107607094343  
Testing accuracy: 0.1028  
Epoch 111  
-----  
Training loss: 2.302928988138835  
Training accuracy: 0.10816666666666666  
Testing loss: 2.3043807433668975  
Testing accuracy: 0.1135  
Epoch 112  
-----  
Training loss: 2.303014803568522  
Training accuracy: 0.10918333333333333  
Testing loss: 2.3020722729385277  
Testing accuracy: 0.1135  
Epoch 113  
-----  
Training loss: 2.3031701227823893  
Training accuracy: 0.10771666666666667  
Testing loss: 2.3015951943245665  
Testing accuracy: 0.1032  
Epoch 114  
-----  
Training loss: 2.303026941426595  
Training accuracy: 0.10901666666666666  
Testing loss: 2.303541664864607  
Testing accuracy: 0.1135



```
Epoch 115
-----
Training loss: 2.303053249867757
Training accuracy: 0.10738333333333333
Testing loss: 2.3026820975504103
Testing accuracy: 0.1028
Epoch 116
-----
Training loss: 2.3032063187917076
Training accuracy: 0.10748333333333333
Testing loss: 2.302297681759877
Testing accuracy: 0.1135
Epoch 117
-----
Training loss: 2.3029727394104005
Training accuracy: 0.10971666666666667
Testing loss: 2.302801227873298
Testing accuracy: 0.1135
Epoch 118
-----
Training loss: 2.3031035268147786
Training accuracy: 0.10815
Testing loss: 2.3039155872004806
Testing accuracy: 0.1028
Epoch 119
-----
Training loss: 2.303129127883911
Training accuracy: 0.10803333333333333
Testing loss: 2.303567445961533
Testing accuracy: 0.098
Epoch 120
-----
Training loss: 2.302952397918701
Training accuracy: 0.10776666666666666
Testing loss: 2.303891579816296
Testing accuracy: 0.1135
Epoch 121
-----
Training loss: 2.3029783226013185
Training accuracy: 0.10746666666666667
Testing loss: 2.302473403845623
Testing accuracy: 0.1135
Epoch 122
-----
Training loss: 2.3030968973795574
Training accuracy: 0.10666666666666667
Testing loss: 2.3026374783485557
Testing accuracy: 0.1135
```

```
Epoch 123
-----
Training loss: 2.3030973200480145
Training accuracy: 0.11001666666666667
Testing loss: 2.3031145827785418
Testing accuracy: 0.101
Epoch 124
-----
Training loss: 2.302834259033203
Training accuracy: 0.1076
Testing loss: 2.3035315343528797
Testing accuracy: 0.0982
Epoch 125
-----
Training loss: 2.3030507151285806
Training accuracy: 0.1079
Testing loss: 2.3023608550903902
Testing accuracy: 0.1135
Epoch 126
-----
Training loss: 2.3028796091715495
Training accuracy: 0.1069
Testing loss: 2.3013741468927664
Testing accuracy: 0.1135
Epoch 127
-----
Training loss: 2.30317592086792
Training accuracy: 0.10888333333333333
Testing loss: 2.3026585123341556
Testing accuracy: 0.0974
Epoch 128
-----
Training loss: 2.3031219495137534
Training accuracy: 0.10693333333333334
Testing loss: 2.30700959977071
Testing accuracy: 0.1028
Epoch 129
-----
Training loss: 2.3029434637705486
Training accuracy: 0.10908333333333334
Testing loss: 2.303231620484856
Testing accuracy: 0.101
Epoch 130
-----
Training loss: 2.303134822591146
Training accuracy: 0.10741666666666666
Testing loss: 2.302988752438005
Testing accuracy: 0.1135
```

Epoch 131

-----  
Training loss: 2.303114233271281  
Training accuracy: 0.10718333333333334  
Testing loss: 2.3048633268684338  
Testing accuracy: 0.1032  
Epoch 132

-----  
Training loss: 2.3032626622517904  
Training accuracy: 0.10708333333333334  
Testing loss: 2.302040189694447  
Testing accuracy: 0.1135  
Epoch 133

-----  
Training loss: 2.30326283976237  
Training accuracy: 0.10825  
Testing loss: 2.302114031117433  
Testing accuracy: 0.1135  
Epoch 134

-----  
Training loss: 2.303124631500244  
Training accuracy: 0.1065  
Testing loss: 2.3035341630316086  
Testing accuracy: 0.1135  
Epoch 135

-----  
Training loss: 2.302932134628296  
Training accuracy: 0.10766666666666666  
Testing loss: 2.3036507937558897  
Testing accuracy: 0.1135  
Epoch 136

-----  
Training loss: 2.303051688130697  
Training accuracy: 0.10725  
Testing loss: 2.303615245090169  
Testing accuracy: 0.1135  
Epoch 137

-----  
Training loss: 2.30309324760437  
Training accuracy: 0.10816666666666666  
Testing loss: 2.3027684369664283  
Testing accuracy: 0.1135  
Epoch 138

-----  
Training loss: 2.3030762439727783  
Training accuracy: 0.10716666666666666  
Testing loss: 2.301491974265712  
Testing accuracy: 0.1135

Epoch 139

-----  
Training loss: 2.3030397095998127  
Training accuracy: 0.10751666666666666  
Testing loss: 2.3040217836950996  
Testing accuracy: 0.1135  
Epoch 140

-----  
Training loss: 2.3030417530059815  
Training accuracy: 0.1081  
Testing loss: 2.304021602982928  
Testing accuracy: 0.1028  
Epoch 141

-----  
Training loss: 2.3030098785400392  
Training accuracy: 0.10846666666666667  
Testing loss: 2.3022786462382907  
Testing accuracy: 0.1135  
Epoch 142

-----  
Training loss: 2.302873988215129  
Training accuracy: 0.109  
Testing loss: 2.3027824292517014  
Testing accuracy: 0.1135  
Epoch 143

-----  
Training loss: 2.3030135917663572  
Training accuracy: 0.10753333333333333  
Testing loss: 2.3025028098161053  
Testing accuracy: 0.1009  
Epoch 144

-----  
Training loss: 2.3030178588867187  
Training accuracy: 0.10825  
Testing loss: 2.303429064477325  
Testing accuracy: 0.1028  
Epoch 145

-----  
Training loss: 2.303018695831299  
Training accuracy: 0.10866666666666666  
Testing loss: 2.302502052039857  
Testing accuracy: 0.1135  
Epoch 146

-----  
Training loss: 2.3031751199086505  
Training accuracy: 0.10701666666666666  
Testing loss: 2.3020717171347065  
Testing accuracy: 0.1135

Epoch 147

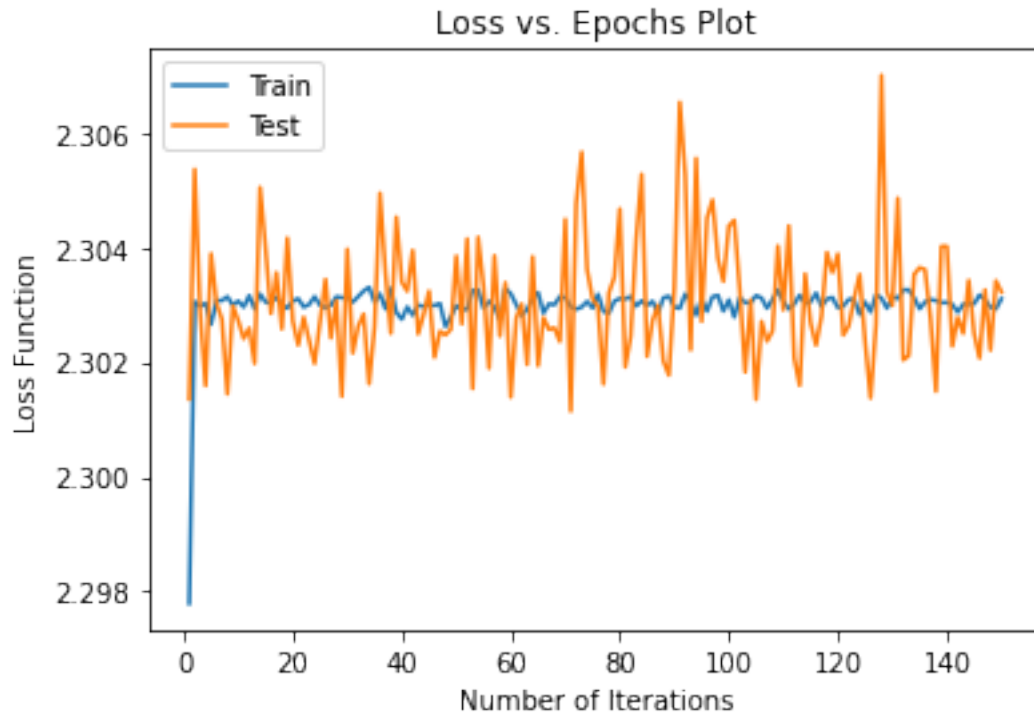
-----  
Training loss: 2.3030889399210612  
Training accuracy: 0.10763333333333333  
Testing loss: 2.3032627470174414  
Testing accuracy: 0.1135  
Epoch 148

-----  
Training loss: 2.3029620525360106  
Training accuracy: 0.1077  
Testing loss: 2.3022100318009686  
Testing accuracy: 0.1135  
Epoch 149

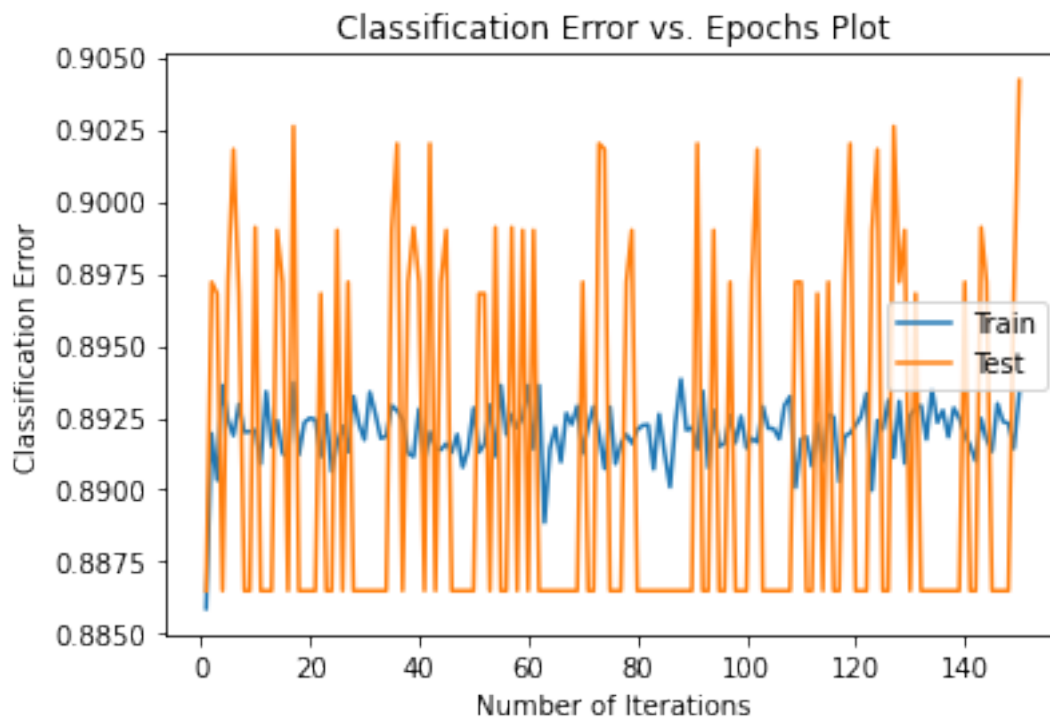
-----  
Training loss: 2.302933682759603  
Training accuracy: 0.10856666666666667  
Testing loss: 2.3034211374392175  
Testing accuracy: 0.1032  
Epoch 150

-----  
Training loss: 2.3031059563954672  
Training accuracy: 0.10663333333333333  
Testing loss: 2.3032253699697507  
Testing accuracy: 0.0958  
Done  
Total Time Consumed: 12123.119775533676

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



#### 5.6.4 Momentum = 0.5

```
[ ]: # Define HyperParameters
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.5
CNN_M5 = CNN(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_M5.parameters(), lr = learning_rate, momentum =
    ↪momentum)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, CNN_M5, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, CNN_M5, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 0.180715152340134
Training accuracy: 0.9433666666666667
Testing loss: 0.04683813768450859
Testing accuracy: 0.9849
Epoch 2
```

```
-----
Training loss: 0.042554442864377054
Training accuracy: 0.98725
```

```

Testing loss: 0.03202736334227156
Testing accuracy: 0.9898
Epoch 3
-----
Training loss: 0.028105365255490566
Training accuracy: 0.9913
Testing loss: 0.04125671813436517
Testing accuracy: 0.9875
Epoch 4
-----
Training loss: 0.019487615456276884
Training accuracy: 0.9938666666666667
Testing loss: 0.03095214008865285
Testing accuracy: 0.9898
Epoch 5
-----
Training loss: 0.013805045191047248
Training accuracy: 0.9955166666666667
Testing loss: 0.04373322473973322
Testing accuracy: 0.9871
Epoch 6
-----
Training loss: 0.012323121504830973
Training accuracy: 0.9961833333333333
Testing loss: 0.04019418065197051
Testing accuracy: 0.9875
Epoch 7
-----
Training loss: 0.00839773865436097
Training accuracy: 0.9972833333333333
Testing loss: 0.027502095446093076
Testing accuracy: 0.991
Epoch 8
-----
Training loss: 0.006551870532213555
Training accuracy: 0.99785
Testing loss: 0.03817285390739312
Testing accuracy: 0.99
Epoch 9
-----
Training loss: 0.005139951034003025
Training accuracy: 0.99825
Testing loss: 0.03933025920923683
Testing accuracy: 0.9912
Epoch 10
-----
Training loss: 0.005061507795881092
Training accuracy: 0.9983166666666666

```



```
Testing loss: 0.031718484642931415
Testing accuracy: 0.9922
Epoch 11
-----
Training loss: 0.0027135205770994616
Training accuracy: 0.9991166666666667
Testing loss: 0.03668973745329735
Testing accuracy: 0.9907
Epoch 12
-----
Training loss: 0.0027349852796984125
Training accuracy: 0.9992
Testing loss: 0.03925682152309526
Testing accuracy: 0.9905
Epoch 13
-----
Training loss: 0.001226258465395017
Training accuracy: 0.9996
Testing loss: 0.0318044892264224
Testing accuracy: 0.9921
Epoch 14
-----
Training loss: 0.0019451206497230183
Training accuracy: 0.9993333333333333
Testing loss: 0.035867910693591465
Testing accuracy: 0.9919
Epoch 15
-----
Training loss: 0.005009638391418866
Training accuracy: 0.9985333333333334
Testing loss: 0.03250122707212487
Testing accuracy: 0.9922
Epoch 16
-----
Training loss: 0.00360722986959344
Training accuracy: 0.9989166666666667
Testing loss: 0.03342667725538901
Testing accuracy: 0.9926
Epoch 17
-----
Training loss: 0.001998765774880197
Training accuracy: 0.99945
Testing loss: 0.03629543102736289
Testing accuracy: 0.9915
Epoch 18
-----
Training loss: 0.001040667039697405
Training accuracy: 0.9996666666666667
```

```

Testing loss: 0.03390209008339689
Testing accuracy: 0.9924
Epoch 19
-----
Training loss: 0.001127950585593093
Training accuracy: 0.9996833333333334
Testing loss: 0.03392457347419128
Testing accuracy: 0.9925
Epoch 20
-----
Training loss: 0.0002091552019154013
Training accuracy: 0.9999666666666667
Testing loss: 0.03307697095277353
Testing accuracy: 0.9922
Epoch 21
-----
Training loss: 5.218170334163877e-05
Training accuracy: 1.0
Testing loss: 0.03425501133956408
Testing accuracy: 0.9928
Epoch 22
-----
Training loss: 3.057479210338438e-05
Training accuracy: 1.0
Testing loss: 0.03478915391982403
Testing accuracy: 0.993
Epoch 23
-----
Training loss: 2.5274229355049254e-05
Training accuracy: 1.0
Testing loss: 0.035455018126310495
Testing accuracy: 0.993
Epoch 24
-----
Training loss: 2.076453098460481e-05
Training accuracy: 1.0
Testing loss: 0.03564792886288223
Testing accuracy: 0.9931
Epoch 25
-----
Training loss: 1.7980315347842197e-05
Training accuracy: 1.0
Testing loss: 0.03600405914297068
Testing accuracy: 0.9933
Epoch 26
-----
Training loss: 1.585933664572998e-05
Training accuracy: 1.0

```

Testing loss: 0.03631738122576397  
Testing accuracy: 0.9934  
Epoch 27  
-----  
Training loss: 1.4314276045463833e-05  
Training accuracy: 1.0  
Testing loss: 0.03664883121193685  
Testing accuracy: 0.9934  
Epoch 28  
-----  
Training loss: 1.2966939557818217e-05  
Training accuracy: 1.0  
Testing loss: 0.03696103217918053  
Testing accuracy: 0.9935  
Epoch 29  
-----  
Training loss: 1.191902563634848e-05  
Training accuracy: 1.0  
Testing loss: 0.037134119678208365  
Testing accuracy: 0.9935  
Epoch 30  
-----  
Training loss: 1.0911694018945303e-05  
Training accuracy: 1.0  
Testing loss: 0.03770655700001205  
Testing accuracy: 0.9934  
Epoch 31  
-----  
Training loss: 1.0126844310378757e-05  
Training accuracy: 1.0  
Testing loss: 0.03757713081159957  
Testing accuracy: 0.9934  
Epoch 32  
-----  
Training loss: 9.52740569885826e-06  
Training accuracy: 1.0  
Testing loss: 0.03779858568907149  
Testing accuracy: 0.9933  
Epoch 33  
-----  
Training loss: 8.901814824772932e-06  
Training accuracy: 1.0  
Testing loss: 0.037986345221248795  
Testing accuracy: 0.9934  
Epoch 34  
-----  
Training loss: 8.367720471040249e-06  
Training accuracy: 1.0

Testing loss: 0.03816667072917595  
Testing accuracy: 0.9934  
Epoch 35  
-----  
Training loss: 7.861528657833243e-06  
Training accuracy: 1.0  
Testing loss: 0.038299938699484934  
Testing accuracy: 0.9933  
Epoch 36  
-----  
Training loss: 7.414206197753614e-06  
Training accuracy: 1.0  
Testing loss: 0.03855740276275493  
Testing accuracy: 0.9934  
Epoch 37  
-----  
Training loss: 7.136198156136686e-06  
Training accuracy: 1.0  
Testing loss: 0.038764844760075655  
Testing accuracy: 0.9934  
Epoch 38  
-----  
Training loss: 6.752254072849103e-06  
Training accuracy: 1.0  
Testing loss: 0.038808981440404275  
Testing accuracy: 0.9934  
Epoch 39  
-----  
Training loss: 6.4481900673677944e-06  
Training accuracy: 1.0  
Testing loss: 0.03895368335754849  
Testing accuracy: 0.9934  
Epoch 40  
-----  
Training loss: 6.1766723210012015e-06  
Training accuracy: 1.0  
Testing loss: 0.03909185103320609  
Testing accuracy: 0.9934  
Epoch 41  
-----  
Training loss: 5.922045523423354e-06  
Training accuracy: 1.0  
Testing loss: 0.039238094355274054  
Testing accuracy: 0.9934  
Epoch 42  
-----  
Training loss: 5.657197515722127e-06  
Training accuracy: 1.0

Testing loss: 0.03937147756596271  
Testing accuracy: 0.9933  
Epoch 43  
-----  
Training loss: 5.437825663680466e-06  
Training accuracy: 1.0  
Testing loss: 0.039463038042700994  
Testing accuracy: 0.9933  
Epoch 44  
-----  
Training loss: 5.259341059623661e-06  
Training accuracy: 1.0  
Testing loss: 0.03959492512171924  
Testing accuracy: 0.9934  
Epoch 45  
-----  
Training loss: 5.062049482490257e-06  
Training accuracy: 1.0  
Testing loss: 0.03973023020274261  
Testing accuracy: 0.9933  
Epoch 46  
-----  
Training loss: 4.8890403720959574e-06  
Training accuracy: 1.0  
Testing loss: 0.039865723200496146  
Testing accuracy: 0.9933  
Epoch 47  
-----  
Training loss: 4.7085689891442685e-06  
Training accuracy: 1.0  
Testing loss: 0.03996175722862241  
Testing accuracy: 0.9934  
Epoch 48  
-----  
Training loss: 4.544959721762135e-06  
Training accuracy: 1.0  
Testing loss: 0.04006309003020484  
Testing accuracy: 0.9933  
Epoch 49  
-----  
Training loss: 4.417424881540792e-06  
Training accuracy: 1.0  
Testing loss: 0.04265944447802328  
Testing accuracy: 0.9933  
Epoch 50  
-----  
Training loss: 4.2784907173782475e-06  
Training accuracy: 1.0

Testing loss: 0.04028468084324006  
Testing accuracy: 0.9932  
Epoch 51  
-----  
Training loss: 4.145598233164568e-06  
Training accuracy: 1.0  
Testing loss: 0.04038271756447944  
Testing accuracy: 0.9933  
Epoch 52  
-----  
Training loss: 4.004507217806955e-06  
Training accuracy: 1.0  
Testing loss: 0.040449093854656636  
Testing accuracy: 0.9933  
Epoch 53  
-----  
Training loss: 3.916941372242869e-06  
Training accuracy: 1.0  
Testing loss: 0.04056433557448016  
Testing accuracy: 0.9933  
Epoch 54  
-----  
Training loss: 3.7878019165421033e-06  
Training accuracy: 1.0  
Testing loss: 0.04063823371516644  
Testing accuracy: 0.9932  
Epoch 55  
-----  
Training loss: 3.6957075146150467e-06  
Training accuracy: 1.0  
Testing loss: 0.04072616013150027  
Testing accuracy: 0.9932  
Epoch 56  
-----  
Training loss: 3.610371891529122e-06  
Training accuracy: 1.0  
Testing loss: 0.04323006484122807  
Testing accuracy: 0.9933  
Epoch 57  
-----  
Training loss: 3.510879202652717e-06  
Training accuracy: 1.0  
Testing loss: 0.040922893215221745  
Testing accuracy: 0.9933  
Epoch 58  
-----  
Training loss: 3.4241893207952974e-06  
Training accuracy: 1.0

Testing loss: 0.04099053434542408  
Testing accuracy: 0.9933  
Epoch 59  
-----  
Training loss: 3.341274858102494e-06  
Training accuracy: 1.0  
Testing loss: 0.04107418190812802  
Testing accuracy: 0.9933  
Epoch 60  
-----  
Training loss: 3.2608780644506415e-06  
Training accuracy: 1.0  
Testing loss: 0.04115177787128771  
Testing accuracy: 0.9933  
Epoch 61  
-----  
Training loss: 3.183014004101044e-06  
Training accuracy: 1.0  
Testing loss: 0.04123177869364051  
Testing accuracy: 0.9933  
Epoch 62  
-----  
Training loss: 3.111026086755331e-06  
Training accuracy: 1.0  
Testing loss: 0.041307706390763595  
Testing accuracy: 0.9933  
Epoch 63  
-----  
Training loss: 3.036905063542624e-06  
Training accuracy: 1.0  
Testing loss: 0.041396789977537506  
Testing accuracy: 0.9933  
Epoch 64  
-----  
Training loss: 2.9735915066056625e-06  
Training accuracy: 1.0  
Testing loss: 0.04145893289178521  
Testing accuracy: 0.9933  
Epoch 65  
-----  
Training loss: 2.909011386879238e-06  
Training accuracy: 1.0  
Testing loss: 0.04153779902896818  
Testing accuracy: 0.9933  
Epoch 66  
-----  
Training loss: 2.8465125548154426e-06  
Training accuracy: 1.0

Testing loss: 0.04417643363243047  
Testing accuracy: 0.9933  
Epoch 67  
-----  
Training loss: 2.7881986070415363e-06  
Training accuracy: 1.0  
Testing loss: 0.041657281287998546  
Testing accuracy: 0.9933  
Epoch 68  
-----  
Training loss: 2.7257935554661826e-06  
Training accuracy: 1.0  
Testing loss: 0.041714262545283785  
Testing accuracy: 0.9933  
Epoch 69  
-----  
Training loss: 2.675544608796206e-06  
Training accuracy: 1.0  
Testing loss: 0.041785555467117444  
Testing accuracy: 0.9933  
Epoch 70  
-----  
Training loss: 2.6264446751300834e-06  
Training accuracy: 1.0  
Testing loss: 0.041860571639534355  
Testing accuracy: 0.9933  
Epoch 71  
-----  
Training loss: 2.5730718409092173e-06  
Training accuracy: 1.0  
Testing loss: 0.041932561257253614  
Testing accuracy: 0.9933  
Epoch 72  
-----  
Training loss: 2.5245716245123617e-06  
Training accuracy: 1.0  
Testing loss: 0.043957918425389805  
Testing accuracy: 0.9933  
Epoch 73  
-----  
Training loss: 2.4746456195587758e-06  
Training accuracy: 1.0  
Testing loss: 0.04205635154468059  
Testing accuracy: 0.9933  
Epoch 74  
-----  
Training loss: 2.432396004808979e-06  
Training accuracy: 1.0



Testing loss: 0.04232987064697909  
Testing accuracy: 0.9933  
Epoch 75  
-----  
Training loss: 2.3867835836066814e-06  
Training accuracy: 1.0  
Testing loss: 0.042170356403621205  
Testing accuracy: 0.9933  
Epoch 76  
-----  
Training loss: 2.3419269262004622e-06  
Training accuracy: 1.0  
Testing loss: 0.042219208945019626  
Testing accuracy: 0.9933  
Epoch 77  
-----  
Training loss: 2.304336349442811e-06  
Training accuracy: 1.0  
Testing loss: 0.042280174706048716  
Testing accuracy: 0.9933  
Epoch 78  
-----  
Training loss: 2.263671084035342e-06  
Training accuracy: 1.0  
Testing loss: 0.042361820840577546  
Testing accuracy: 0.9933  
Epoch 79  
-----  
Training loss: 2.2226101669768165e-06  
Training accuracy: 1.0  
Testing loss: 0.042402367581467676  
Testing accuracy: 0.9933  
Epoch 80  
-----  
Training loss: 2.1906117808859687e-06  
Training accuracy: 1.0  
Testing loss: 0.04315167876535022  
Testing accuracy: 0.9933  
Epoch 81  
-----  
Training loss: 2.149603288765434e-06  
Training accuracy: 1.0  
Testing loss: 0.04249844036965827  
Testing accuracy: 0.9933  
Epoch 82  
-----  
Training loss: 2.1166423391173104e-06  
Training accuracy: 1.0

Testing loss: 0.04254824640806346  
Testing accuracy: 0.9933  
Epoch 83  
-----  
Training loss: 2.08152434867479e-06  
Training accuracy: 1.0  
Testing loss: 0.042596140505459845  
Testing accuracy: 0.9933  
Epoch 84  
-----  
Training loss: 2.046238954927541e-06  
Training accuracy: 1.0  
Testing loss: 0.04266801393722287  
Testing accuracy: 0.9933  
Epoch 85  
-----  
Training loss: 2.0188660299608566e-06  
Training accuracy: 1.0  
Testing loss: 0.042726801233441275  
Testing accuracy: 0.9933  
Epoch 86  
-----  
Training loss: 1.986757812628781e-06  
Training accuracy: 1.0  
Testing loss: 0.04307921477536974  
Testing accuracy: 0.9933  
Epoch 87  
-----  
Training loss: 1.9572807285718123e-06  
Training accuracy: 1.0  
Testing loss: 0.04281349721254995  
Testing accuracy: 0.9933  
Epoch 88  
-----  
Training loss: 1.9277360189126587e-06  
Training accuracy: 1.0  
Testing loss: 0.04285958843797859  
Testing accuracy: 0.9933  
Epoch 89  
-----  
Training loss: 1.8975631581663302e-06  
Training accuracy: 1.0  
Testing loss: 0.04291857130607445  
Testing accuracy: 0.9933  
Epoch 90  
-----  
Training loss: 1.8721306020157869e-06  
Training accuracy: 1.0

Testing loss: 0.04298253680514857  
Testing accuracy: 0.9933  
Epoch 91  
-----  
Training loss: 1.845340554033707e-06  
Training accuracy: 1.0  
Testing loss: 0.04299571543595002  
Testing accuracy: 0.9933  
Epoch 92  
-----  
Training loss: 1.8190577207164438e-06  
Training accuracy: 1.0  
Testing loss: 0.04304364976996202  
Testing accuracy: 0.9933  
Epoch 93  
-----  
Training loss: 1.795027977349406e-06  
Training accuracy: 1.0  
Testing loss: 0.04309187732118226  
Testing accuracy: 0.9933  
Epoch 94  
-----  
Training loss: 1.7709682159605223e-06  
Training accuracy: 1.0  
Testing loss: 0.04313862609397058  
Testing accuracy: 0.9933  
Epoch 95  
-----  
Training loss: 1.7456912158806403e-06  
Training accuracy: 1.0  
Testing loss: 0.043192956756014256  
Testing accuracy: 0.9933  
Epoch 96  
-----  
Training loss: 1.7211868819513161e-06  
Training accuracy: 1.0  
Testing loss: 0.043226451660240174  
Testing accuracy: 0.9933  
Epoch 97  
-----  
Training loss: 1.6995730035940683e-06  
Training accuracy: 1.0  
Testing loss: 0.0432678780585438  
Testing accuracy: 0.9933  
Epoch 98  
-----  
Training loss: 1.676885334960095e-06  
Training accuracy: 1.0

```
Testing loss: 0.047067106194780134
Testing accuracy: 0.9933
Epoch 99
-----
Training loss: 1.6554195212802843e-06
Training accuracy: 1.0
Testing loss: 0.043371047434600594
Testing accuracy: 0.9934
Epoch 100
-----
Training loss: 1.6339429311556113e-06
Training accuracy: 1.0
Testing loss: 0.04339405742587771
Testing accuracy: 0.9934
Epoch 101
-----
Training loss: 1.6131132333651266e-06
Training accuracy: 1.0
Testing loss: 0.04343346027640304
Testing accuracy: 0.9934
Epoch 102
-----
Training loss: 1.5938407938604607e-06
Training accuracy: 1.0
Testing loss: 0.04348024220646451
Testing accuracy: 0.9934
Epoch 103
-----
Training loss: 1.572378771393327e-06
Training accuracy: 1.0
Testing loss: 0.04351334871430749
Testing accuracy: 0.9934
Epoch 104
-----
Training loss: 1.5540537583620543e-06
Training accuracy: 1.0
Testing loss: 0.04356470377011099
Testing accuracy: 0.9934
Epoch 105
-----
Training loss: 1.5360993287746539e-06
Training accuracy: 1.0
Testing loss: 0.04812000362441241
Testing accuracy: 0.9934
Epoch 106
-----
Training loss: 1.516387517824569e-06
Training accuracy: 1.0
```

Testing loss: 0.043646623563278246  
Testing accuracy: 0.9934  
Epoch 107  
-----  
Training loss: 1.5001976797523279e-06  
Training accuracy: 1.0  
Testing loss: 0.04367769380684906  
Testing accuracy: 0.9934  
Epoch 108  
-----  
Training loss: 1.4800061245506887e-06  
Training accuracy: 1.0  
Testing loss: 0.04370891795987598  
Testing accuracy: 0.9934  
Epoch 109  
-----  
Training loss: 1.4664385171466658e-06  
Training accuracy: 1.0  
Testing loss: 0.04375304401890459  
Testing accuracy: 0.9933  
Epoch 110  
-----  
Training loss: 1.4479597443755192e-06  
Training accuracy: 1.0  
Testing loss: 0.04675134239856213  
Testing accuracy: 0.9934  
Epoch 111  
-----  
Training loss: 1.431489122737517e-06  
Training accuracy: 1.0  
Testing loss: 0.04383281287122468  
Testing accuracy: 0.9933  
Epoch 112  
-----  
Training loss: 1.4158212995713626e-06  
Training accuracy: 1.0  
Testing loss: 0.043862810371846396  
Testing accuracy: 0.9934  
Epoch 113  
-----  
Training loss: 1.4001421418208556e-06  
Training accuracy: 1.0  
Testing loss: 0.043931880338258296  
Testing accuracy: 0.9933  
Epoch 114  
-----  
Training loss: 1.3839725262866883e-06  
Training accuracy: 1.0

Testing loss: 0.04394388511061675  
Testing accuracy: 0.9933  
Epoch 115  
-----  
Training loss: 1.3687106165433486e-06  
Training accuracy: 1.0  
Testing loss: 0.04397238912404984  
Testing accuracy: 0.9933  
Epoch 116  
-----  
Training loss: 1.35404024356743e-06  
Training accuracy: 1.0  
Testing loss: 0.04401269438986787  
Testing accuracy: 0.9933  
Epoch 117  
-----  
Training loss: 1.3399236224172976e-06  
Training accuracy: 1.0  
Testing loss: 0.044048772760128106  
Testing accuracy: 0.9933  
Epoch 118  
-----  
Training loss: 1.3255589250375028e-06  
Training accuracy: 1.0  
Testing loss: 0.044077060728815384  
Testing accuracy: 0.9933  
Epoch 119  
-----  
Training loss: 1.3115998684251432e-06  
Training accuracy: 1.0  
Testing loss: 0.044607707505703226  
Testing accuracy: 0.9933  
Epoch 120  
-----  
Training loss: 1.2984192033059117e-06  
Training accuracy: 1.0  
Testing loss: 0.044148401545665704  
Testing accuracy: 0.9933  
Epoch 121  
-----  
Training loss: 1.2848707773853127e-06  
Training accuracy: 1.0  
Testing loss: 0.04418160170038271  
Testing accuracy: 0.9933  
Epoch 122  
-----  
Training loss: 1.2716747531336856e-06  
Training accuracy: 1.0

Testing loss: 0.04421561161713837  
Testing accuracy: 0.9933  
Epoch 123  
-----  
Training loss: 1.2590368373889048e-06  
Training accuracy: 1.0  
Testing loss: 0.0442502002005135  
Testing accuracy: 0.9933  
Epoch 124  
-----  
Training loss: 1.2458407902445381e-06  
Training accuracy: 1.0  
Testing loss: 0.044315807495651637  
Testing accuracy: 0.9933  
Epoch 125  
-----  
Training loss: 1.233672739501183e-06  
Training accuracy: 1.0  
Testing loss: 0.044311270133561204  
Testing accuracy: 0.9933  
Epoch 126  
-----  
Training loss: 1.221927986626999e-06  
Training accuracy: 1.0  
Testing loss: 0.044377335671561345  
Testing accuracy: 0.9933  
Epoch 127  
-----  
Training loss: 1.208574996483828e-06  
Training accuracy: 1.0  
Testing loss: 0.04438326198593425  
Testing accuracy: 0.9933  
Epoch 128  
-----  
Training loss: 1.1981755632549588e-06  
Training accuracy: 1.0  
Testing loss: 0.04441016989720655  
Testing accuracy: 0.9933  
Epoch 129  
-----  
Training loss: 1.1858148726913005e-06  
Training accuracy: 1.0  
Testing loss: 0.04443779924978148  
Testing accuracy: 0.9933  
Epoch 130  
-----  
Training loss: 1.1752533620196459e-06  
Training accuracy: 1.0

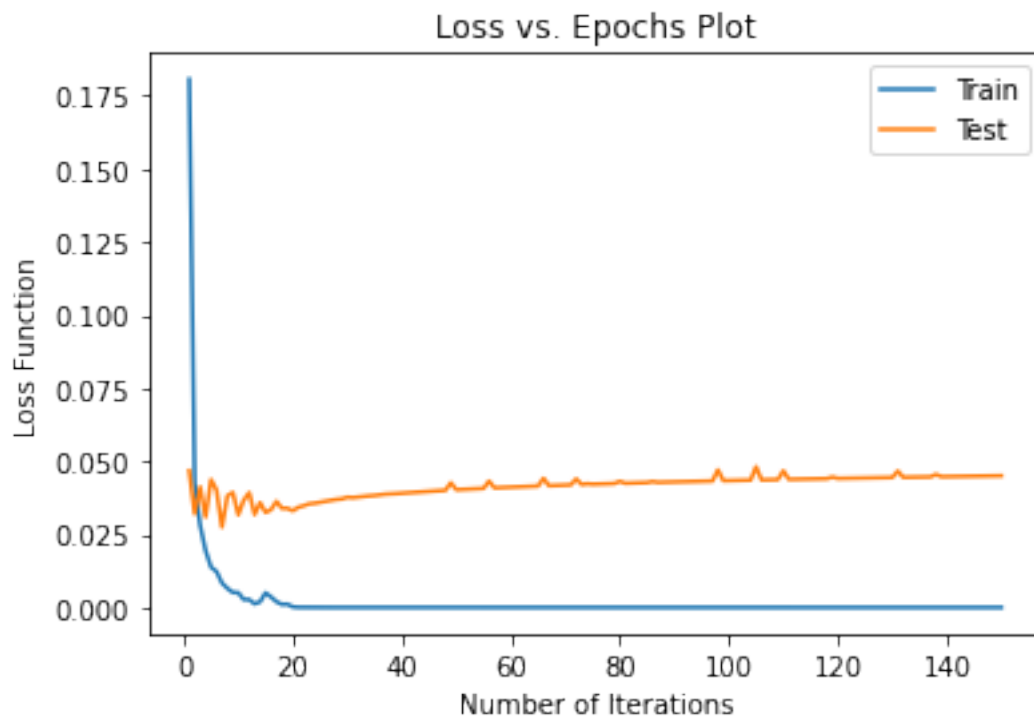
Testing loss: 0.04446864407162142  
Testing accuracy: 0.9933  
Epoch 131  
-----  
Training loss: 1.1642972187951036e-06  
Training accuracy: 1.0  
Testing loss: 0.04665209728907062  
Testing accuracy: 0.9933  
Epoch 132  
-----  
Training loss: 1.1526935958009687e-06  
Training accuracy: 1.0  
Testing loss: 0.0445282553867093  
Testing accuracy: 0.9933  
Epoch 133  
-----  
Training loss: 1.142736368519574e-06  
Training accuracy: 1.0  
Testing loss: 0.04456472892921847  
Testing accuracy: 0.9933  
Epoch 134  
-----  
Training loss: 1.1322730454014145e-06  
Training accuracy: 1.0  
Testing loss: 0.044593723676699906  
Testing accuracy: 0.9933  
Epoch 135  
-----  
Training loss: 1.1215952384391178e-06  
Training accuracy: 1.0  
Testing loss: 0.04462289321276527  
Testing accuracy: 0.9933  
Epoch 136  
-----  
Training loss: 1.111434703809048e-06  
Training accuracy: 1.0  
Testing loss: 0.04465295986181513  
Testing accuracy: 0.9933  
Epoch 137  
-----  
Training loss: 1.1013887587809043e-06  
Training accuracy: 1.0  
Testing loss: 0.04468317611397797  
Testing accuracy: 0.9933  
Epoch 138  
-----  
Training loss: 1.0916659720885254e-06  
Training accuracy: 1.0



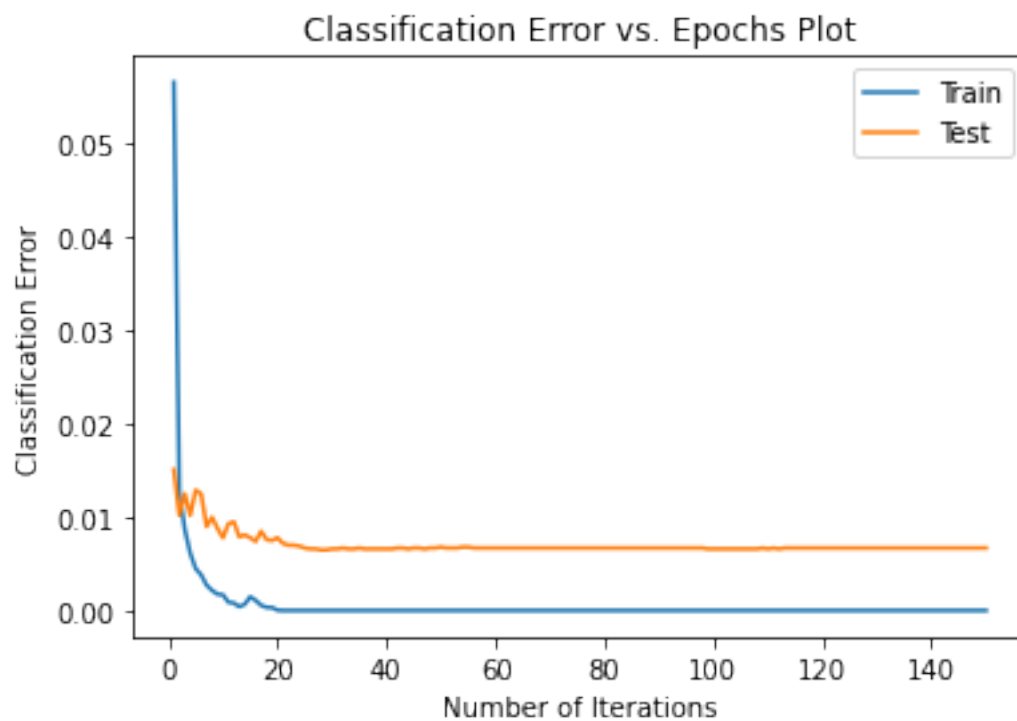
Testing loss: 0.04552305603934384  
Testing accuracy: 0.9933  
Epoch 139  
-----  
Training loss: 1.082047445056844e-06  
Training accuracy: 1.0  
Testing loss: 0.044744017401781556  
Testing accuracy: 0.9933  
Epoch 140  
-----  
Training loss: 1.0720641993075948e-06  
Training accuracy: 1.0  
Testing loss: 0.04477584141508995  
Testing accuracy: 0.9933  
Epoch 141  
-----  
Training loss: 1.062937977451502e-06  
Training accuracy: 1.0  
Testing loss: 0.04480506233079289  
Testing accuracy: 0.9933  
Epoch 142  
-----  
Training loss: 1.0539972015921013e-06  
Training accuracy: 1.0  
Testing loss: 0.04483103218634874  
Testing accuracy: 0.9933  
Epoch 143  
-----  
Training loss: 1.0443742044600413e-06  
Training accuracy: 1.0  
Testing loss: 0.04485779499083603  
Testing accuracy: 0.9933  
Epoch 144  
-----  
Training loss: 1.0357764051401356e-06  
Training accuracy: 1.0  
Testing loss: 0.044883762158390045  
Testing accuracy: 0.9933  
Epoch 145  
-----  
Training loss: 1.026843971119836e-06  
Training accuracy: 1.0  
Testing loss: 0.04491611701716365  
Testing accuracy: 0.9933  
Epoch 146  
-----  
Training loss: 1.018775878966475e-06  
Training accuracy: 1.0

```
Testing loss: 0.044941548994026435
Testing accuracy: 0.9933
Epoch 147
-----
Training loss: 1.0100551456784974e-06
Training accuracy: 1.0
Testing loss: 0.04496813711154021
Testing accuracy: 0.9933
Epoch 148
-----
Training loss: 1.0017532258244681e-06
Training accuracy: 1.0
Testing loss: 0.044995226126858294
Testing accuracy: 0.9933
Epoch 149
-----
Training loss: 9.934872538387652e-07
Training accuracy: 1.0
Testing loss: 0.045024986489028
Testing accuracy: 0.9933
Epoch 150
-----
Training loss: 9.855384467548114e-07
Training accuracy: 1.0
Testing loss: 0.045051719675051595
Testing accuracy: 0.9933
Done
Total Time Consumed: 12694.520086288452
```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.6.5 Momentum = 0.9

```
[ ]: # Define HyperParameters
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.9
CNN_M9 = CNN(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_M9.parameters(), lr = learning_rate, momentum =
    ↪momentum)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪= True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, CNN_M9, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, CNN_M9, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 0.20817018909572313
Training accuracy: 0.9414333333333333
Testing loss: 0.1289030188882937
Testing accuracy: 0.9677
Epoch 2
```

```
-----
Training loss: 0.08631866215982785
Training accuracy: 0.9771666666666666
```

```

Testing loss: 0.07061145777651331
Testing accuracy: 0.9823
Epoch 3
-----
Training loss: 0.07611314592754158
Training accuracy: 0.9805833333333334
Testing loss: 0.08315154938561142
Testing accuracy: 0.9788
Epoch 4
-----
Training loss: 0.07339582383890325
Training accuracy: 0.9820833333333333
Testing loss: 0.07707149930488152
Testing accuracy: 0.98
Epoch 5
-----
Training loss: 0.05222453261972793
Training accuracy: 0.9858666666666667
Testing loss: 0.06808744737905136
Testing accuracy: 0.9829
Epoch 6
-----
Training loss: 0.08474098649344718
Training accuracy: 0.9802166666666666
Testing loss: 0.13058465796190605
Testing accuracy: 0.9716
Epoch 7
-----
Training loss: 0.08239391322442534
Training accuracy: 0.9810166666666666
Testing loss: 0.0897940115440636
Testing accuracy: 0.9806
Epoch 8
-----
Training loss: 0.07235337934977336
Training accuracy: 0.9840833333333333
Testing loss: 0.07990140357269063
Testing accuracy: 0.9812
Epoch 9
-----
Training loss: 0.08937237097371932
Training accuracy: 0.9813833333333334
Testing loss: 0.1540185439891247
Testing accuracy: 0.9683
Epoch 10
-----
Training loss: 0.20567435507761547
Training accuracy: 0.9615833333333333

```

```

Testing loss: 0.3504745115994648
Testing accuracy: 0.9201
Epoch 11
-----
Training loss: 1.5462555255781083
Training accuracy: 0.46158333333333335
Testing loss: 2.026553778891351
Testing accuracy: 0.1993
Epoch 12
-----
Training loss: 2.0423387537002564
Training accuracy: 0.19001666666666667
Testing loss: 1.9445701366776873
Testing accuracy: 0.2074
Epoch 13
-----
Training loss: 1.9707307458877563
Training accuracy: 0.19965
Testing loss: 1.9341075511495018
Testing accuracy: 0.2084
Epoch 14
-----
Training loss: 1.9743990491231282
Training accuracy: 0.19686666666666666
Testing loss: 2.004194091080101
Testing accuracy: 0.1865
Epoch 15
-----
Training loss: 1.9920973326365152
Training accuracy: 0.19763333333333333
Testing loss: 1.9609910386383154
Testing accuracy: 0.2089
Epoch 16
-----
Training loss: 1.9487576741536459
Training accuracy: 0.19946666666666665
Testing loss: 1.9355666060356578
Testing accuracy: 0.2071
Epoch 17
-----
Training loss: 1.9459692786534628
Training accuracy: 0.19908333333333333
Testing loss: 1.9334862558705033
Testing accuracy: 0.2089
Epoch 18
-----
Training loss: 1.974188456916809
Training accuracy: 0.20055

```

```
Testing loss: 1.9591863740022015
Testing accuracy: 0.2115
Epoch 19
-----
Training loss: 1.9550206127166747
Training accuracy: 0.20266666666666666
Testing loss: 1.9534330588237496
Testing accuracy: 0.207
Epoch 20
-----
Training loss: 1.9799586819966635
Training accuracy: 0.19968333333333332
Testing loss: 1.9881963426140463
Testing accuracy: 0.1724
Epoch 21
-----
Training loss: 2.020880210494995
Training accuracy: 0.2024
Testing loss: 2.1235337538324344
Testing accuracy: 0.1797
Epoch 22
-----
Training loss: 2.0671837694803874
Training accuracy: 0.19695
Testing loss: 2.0184155694997994
Testing accuracy: 0.2076
Epoch 23
-----
Training loss: 2.0453492738087973
Training accuracy: 0.19628333333333334
Testing loss: 2.0082312571774623
Testing accuracy: 0.2004
Epoch 24
-----
Training loss: 2.014487942568461
Training accuracy: 0.20428333333333334
Testing loss: 2.003676813119536
Testing accuracy: 0.2073
Epoch 25
-----
Training loss: 2.021019331741333
Training accuracy: 0.20483333333333334
Testing loss: 2.0207484937777185
Testing accuracy: 0.2099
Epoch 26
-----
Training loss: 2.013124983215332
Training accuracy: 0.20753333333333332
```

```

Testing loss: 1.9958808566354642
Testing accuracy: 0.2088
Epoch 27
-----
Training loss: 1.9975662812550863
Training accuracy: 0.20665
Testing loss: 1.9825642693574261
Testing accuracy: 0.208
Epoch 28
-----
Training loss: 1.991959060160319
Training accuracy: 0.20793333333333333
Testing loss: 1.9830012480924084
Testing accuracy: 0.2083
Epoch 29
-----
Training loss: 1.9924109086990356
Training accuracy: 0.20668333333333333
Testing loss: 1.9792698538227447
Testing accuracy: 0.2086
Epoch 30
-----
Training loss: 1.992362139383952
Training accuracy: 0.20578333333333335
Testing loss: 1.9838620667244977
Testing accuracy: 0.211
Epoch 31
-----
Training loss: 1.99228335908254
Training accuracy: 0.20755
Testing loss: 1.9813139415850305
Testing accuracy: 0.206
Epoch 32
-----
Training loss: 1.9921158734639486
Training accuracy: 0.20801666666666666
Testing loss: 1.9825073586907356
Testing accuracy: 0.2086
Epoch 33
-----
Training loss: 1.9922141293207805
Training accuracy: 0.20795
Testing loss: 1.9834900281991168
Testing accuracy: 0.2078
Epoch 34
-----
Training loss: 1.9921396701812744
Training accuracy: 0.20571666666666666

```



```

Testing loss: 1.9813619069992356
Testing accuracy: 0.2078
Epoch 35
-----
Training loss: 1.9921463686625163
Training accuracy: 0.20805
Testing loss: 1.9816802702132303
Testing accuracy: 0.2086
Epoch 36
-----
Training loss: 1.9923654965718587
Training accuracy: 0.20675
Testing loss: 1.985383550072931
Testing accuracy: 0.2083
Epoch 37
-----
Training loss: 1.9920611541748048
Training accuracy: 0.20793333333333333
Testing loss: 1.983697027157826
Testing accuracy: 0.2116
Epoch 38
-----
Training loss: 1.992774199549357
Training accuracy: 0.2078
Testing loss: 1.9827045688203946
Testing accuracy: 0.2116
Epoch 39
-----
Training loss: 1.9918770966847739
Training accuracy: 0.20858333333333334
Testing loss: 1.9840899721072738
Testing accuracy: 0.2109
Epoch 40
-----
Training loss: 1.9920638203303018
Training accuracy: 0.20868333333333333
Testing loss: 1.982617946187402
Testing accuracy: 0.2135
Epoch 41
-----
Training loss: 1.9922221436818441
Training accuracy: 0.20728333333333335
Testing loss: 1.9838233517993027
Testing accuracy: 0.2078
Epoch 42
-----
Training loss: 1.9921444582621257
Training accuracy: 0.2083

```

```

Testing loss: 1.9829728565398295
Testing accuracy: 0.2083
Epoch 43
-----
Training loss: 1.9917953313827514
Training accuracy: 0.2094
Testing loss: 1.9814976833428546
Testing accuracy: 0.211
Epoch 44
-----
Training loss: 1.9924509291330974
Training accuracy: 0.20628333333333335
Testing loss: 1.9814672796589554
Testing accuracy: 0.2116
Epoch 45
-----
Training loss: 1.9921624917348226
Training accuracy: 0.20846666666666666
Testing loss: 1.9849051153583892
Testing accuracy: 0.2109
Epoch 46
-----
Training loss: 1.9920093852361043
Training accuracy: 0.20761666666666667
Testing loss: 1.9807579411063225
Testing accuracy: 0.2109
Epoch 47
-----
Training loss: 1.9922480801900229
Training accuracy: 0.20696666666666666
Testing loss: 1.9805382239590785
Testing accuracy: 0.2078
Epoch 48
-----
Training loss: 1.9919530637105305
Training accuracy: 0.2074
Testing loss: 1.9834453983671347
Testing accuracy: 0.211
Epoch 49
-----
Training loss: 1.991838273747762
Training accuracy: 0.20685
Testing loss: 1.983413282473376
Testing accuracy: 0.2109
Epoch 50
-----
Training loss: 1.992232896486918
Training accuracy: 0.20701666666666665

```

```
Testing loss: 1.9856877919215306
Testing accuracy: 0.2116
Epoch 51
-----
Training loss: 1.9922203146616617
Training accuracy: 0.20758333333333334
Testing loss: 1.9803724592658365
Testing accuracy: 0.2135
Epoch 52
-----
Training loss: 1.9923214646657308
Training accuracy: 0.206
Testing loss: 1.9832879593417903
Testing accuracy: 0.2078
Epoch 53
-----
Training loss: 1.9923575355529786
Training accuracy: 0.20543333333333333
Testing loss: 1.980902137270399
Testing accuracy: 0.206
Epoch 54
-----
Training loss: 1.9923559020996093
Training accuracy: 0.20733333333333334
Testing loss: 1.984177556007531
Testing accuracy: 0.206
Epoch 55
-----
Training loss: 1.9921753168741863
Training accuracy: 0.20705
Testing loss: 1.9848009142906042
Testing accuracy: 0.211
Epoch 56
-----
Training loss: 1.9923287846883138
Training accuracy: 0.20746666666666666
Testing loss: 1.9806536580346952
Testing accuracy: 0.2109
Epoch 57
-----
Training loss: 1.9920771483103434
Training accuracy: 0.2086
Testing loss: 1.982470177541113
Testing accuracy: 0.211
Epoch 58
-----
Training loss: 1.9915809508005777
Training accuracy: 0.2093
```

```

Testing loss: 1.9826771605546307
Testing accuracy: 0.2109
Epoch 59
-----
Training loss: 1.9921022050221762
Training accuracy: 0.20711666666666667
Testing loss: 1.984551589959746
Testing accuracy: 0.2078
Epoch 60
-----
Training loss: 1.9922221718470257
Training accuracy: 0.20698333333333332
Testing loss: 1.9807825377033015
Testing accuracy: 0.2109
Epoch 61
-----
Training loss: 1.9921321107228598
Training accuracy: 0.20695
Testing loss: 1.9823281385336713
Testing accuracy: 0.211
Epoch 62
-----
Training loss: 1.9920814683278403
Training accuracy: 0.20818333333333333
Testing loss: 1.9839773375517245
Testing accuracy: 0.2109
Epoch 63
-----
Training loss: 1.9920750480016072
Training accuracy: 0.20628333333333335
Testing loss: 1.9826942173538693
Testing accuracy: 0.2083
Epoch 64
-----
Training loss: 1.99228460261027
Training accuracy: 0.20885
Testing loss: 1.9809747926748482
Testing accuracy: 0.2083
Epoch 65
-----
Training loss: 1.9923874581019083
Training accuracy: 0.20713333333333334
Testing loss: 1.981255151663616
Testing accuracy: 0.211
Epoch 66
-----
Training loss: 1.9919980639775594
Training accuracy: 0.20936666666666667

```

```
Testing loss: 1.9825624698286604
Testing accuracy: 0.2116
Epoch 67
-----
Training loss: 1.9921900620142619
Training accuracy: 0.20751666666666665
Testing loss: 1.9836059778359285
Testing accuracy: 0.2109
Epoch 68
-----
Training loss: 1.9924771799723306
Training accuracy: 0.20783333333333334
Testing loss: 1.9817095835497425
Testing accuracy: 0.206
Epoch 69
-----
Training loss: 1.9919772200266521
Training accuracy: 0.2059
Testing loss: 1.9849467763475552
Testing accuracy: 0.2135
Epoch 70
-----
Training loss: 1.9917937410990396
Training accuracy: 0.20563333333333333
Testing loss: 1.9822376898139904
Testing accuracy: 0.2135
Epoch 71
-----
Training loss: 1.9919784571965535
Training accuracy: 0.20763333333333334
Testing loss: 1.9811772092892106
Testing accuracy: 0.2135
Epoch 72
-----
Training loss: 1.9922885160446167
Training accuracy: 0.20786666666666667
Testing loss: 1.9833675243292646
Testing accuracy: 0.206
Epoch 73
-----
Training loss: 1.992109639676412
Training accuracy: 0.20791666666666667
Testing loss: 1.9848478159327416
Testing accuracy: 0.2083
Epoch 74
-----
Training loss: 1.9921553029378256
Training accuracy: 0.20691666666666667
```

```

Testing loss: 1.9825466028444327
Testing accuracy: 0.2116
Epoch 75
-----
Training loss: 1.9923308486938476
Training accuracy: 0.20535
Testing loss: 1.982772641121202
Testing accuracy: 0.2109
Epoch 76
-----
Training loss: 1.99241114915212
Training accuracy: 0.2056
Testing loss: 1.9845195424025226
Testing accuracy: 0.2078
Epoch 77
-----
Training loss: 1.9919811806996663
Training accuracy: 0.20761666666666667
Testing loss: 1.9812019471150295
Testing accuracy: 0.2135
Epoch 78
-----
Training loss: 1.9921527930577596
Training accuracy: 0.20753333333333332
Testing loss: 1.9853057481680707
Testing accuracy: 0.2116
Epoch 79
-----
Training loss: 1.992171258163452
Training accuracy: 0.20831666666666668
Testing loss: 1.9820563519836232
Testing accuracy: 0.2109
Epoch 80
-----
Training loss: 1.9918467821756998
Training accuracy: 0.2088
Testing loss: 1.9866967877005315
Testing accuracy: 0.2116
Epoch 81
-----
Training loss: 1.9923947204589845
Training accuracy: 0.2062
Testing loss: 1.9836293663948206
Testing accuracy: 0.2116
Epoch 82
-----
Training loss: 1.992209599240621
Training accuracy: 0.20641666666666666

```

```

Testing loss: 1.9814121677617358
Testing accuracy: 0.2083
Epoch 83
-----
Training loss: 1.9922338773727417
Training accuracy: 0.20823333333333333
Testing loss: 1.9826914793366839
Testing accuracy: 0.2083
Epoch 84
-----
Training loss: 1.9920896902720133
Training accuracy: 0.20585
Testing loss: 1.9855036894986584
Testing accuracy: 0.2116
Epoch 85
-----
Training loss: 1.9918421600341798
Training accuracy: 0.20798333333333333
Testing loss: 1.9820752842411113
Testing accuracy: 0.2116
Epoch 86
-----
Training loss: 1.992443253771464
Training accuracy: 0.20693333333333333
Testing loss: 1.983071100939611
Testing accuracy: 0.211
Epoch 87
-----
Training loss: 1.9921811331431072
Training accuracy: 0.20636666666666667
Testing loss: 1.9820750298773406
Testing accuracy: 0.2078
Epoch 88
-----
Training loss: 1.9920023131052653
Training accuracy: 0.20701666666666665
Testing loss: 1.9817814401760223
Testing accuracy: 0.2078
Epoch 89
-----
Training loss: 1.9922591481526692
Training accuracy: 0.20761666666666667
Testing loss: 1.9822211599653694
Testing accuracy: 0.2078
Epoch 90
-----
Training loss: 1.992368780962626
Training accuracy: 0.20778333333333332

```

```

Testing loss: 1.9850575483528672
Testing accuracy: 0.2083
Epoch 91
-----
Training loss: 1.9923163948059082
Training accuracy: 0.20613333333333334
Testing loss: 1.991588408779946
Testing accuracy: 0.2083
Epoch 92
-----
Training loss: 1.9924397747675577
Training accuracy: 0.20733333333333334
Testing loss: 1.9864320124790167
Testing accuracy: 0.2116
Epoch 93
-----
Training loss: 1.9923525268554687
Training accuracy: 0.2071
Testing loss: 1.9812949296015843
Testing accuracy: 0.211
Epoch 94
-----
Training loss: 1.991912016805013
Training accuracy: 0.2087
Testing loss: 1.9863531566729211
Testing accuracy: 0.2109
Epoch 95
-----
Training loss: 1.992399071184794
Training accuracy: 0.20571666666666666
Testing loss: 1.9827344911113667
Testing accuracy: 0.2135
Epoch 96
-----
Training loss: 1.9920817368825277
Training accuracy: 0.20746666666666666
Testing loss: 1.9860589375161821
Testing accuracy: 0.2078
Epoch 97
-----
Training loss: 1.9919071217854818
Training accuracy: 0.20698333333333332
Testing loss: 1.9833829873686384
Testing accuracy: 0.206
Epoch 98
-----
Training loss: 1.9923865253448487
Training accuracy: 0.20586666666666667

```



```
Testing loss: 1.9856578954465829
Testing accuracy: 0.2116
Epoch 99
-----
Training loss: 1.9915476121266682
Training accuracy: 0.20765
Testing loss: 1.983847502690212
Testing accuracy: 0.2135
Epoch 100
-----
Training loss: 1.9920742647806804
Training accuracy: 0.20601666666666665
Testing loss: 1.984231120461871
Testing accuracy: 0.2116
Epoch 101
-----
Training loss: 1.9916952328999837
Training accuracy: 0.20766666666666667
Testing loss: 1.9869143909709468
Testing accuracy: 0.2109
Epoch 102
-----
Training loss: 1.9926369088490805
Training accuracy: 0.20686666666666667
Testing loss: 1.9807727321697648
Testing accuracy: 0.211
Epoch 103
-----
Training loss: 1.9921365463256835
Training accuracy: 0.20823333333333333
Testing loss: 1.9811867095862226
Testing accuracy: 0.2116
Epoch 104
-----
Training loss: 1.9920095715204875
Training accuracy: 0.20695
Testing loss: 1.9833938042828991
Testing accuracy: 0.2116
Epoch 105
-----
Training loss: 1.9923288781483968
Training accuracy: 0.20703333333333335
Testing loss: 1.9809084872531284
Testing accuracy: 0.2078
Epoch 106
-----
Training loss: 1.9925976524353026
Training accuracy: 0.20645
```

Testing loss: 1.9833229666302918  
Testing accuracy: 0.2078  
Epoch 107  
-----  
Training loss: 1.9917864632924398  
Training accuracy: 0.20835  
Testing loss: 1.984365116259095  
Testing accuracy: 0.206  
Epoch 108  
-----  
Training loss: 1.9918824485778808  
Training accuracy: 0.20726666666666665  
Testing loss: 1.9834155800995554  
Testing accuracy: 0.206  
Epoch 109  
-----  
Training loss: 1.9920862076441448  
Training accuracy: 0.20611666666666667  
Testing loss: 1.9855508530975148  
Testing accuracy: 0.2116  
Epoch 110  
-----  
Training loss: 1.9920807116190593  
Training accuracy: 0.20738333333333334  
Testing loss: 1.9827748461134116  
Testing accuracy: 0.2116  
Epoch 111  
-----  
Training loss: 1.9916786909103394  
Training accuracy: 0.20935  
Testing loss: 1.9856807077006928  
Testing accuracy: 0.1996  
Epoch 112  
-----  
Training loss: 1.992169359588623  
Training accuracy: 0.20678333333333335  
Testing loss: 1.9836595248264872  
Testing accuracy: 0.2109  
Epoch 113  
-----  
Training loss: 1.9925344467163086  
Training accuracy: 0.20693333333333333  
Testing loss: 1.9806081459021112  
Testing accuracy: 0.2135  
Epoch 114  
-----  
Training loss: 1.992515900293986  
Training accuracy: 0.20746666666666666

```

Testing loss: 1.9836166694665411
Testing accuracy: 0.1996
Epoch 115
-----
Training loss: 1.992210505549113
Training accuracy: 0.20751666666666665
Testing loss: 1.9816321764781977
Testing accuracy: 0.2116
Epoch 116
-----
Training loss: 1.9919333447774252
Training accuracy: 0.20568333333333333
Testing loss: 1.984942064923086
Testing accuracy: 0.2083
Epoch 117
-----
Training loss: 1.99193046875
Training accuracy: 0.20861666666666667
Testing loss: 1.9831224702725745
Testing accuracy: 0.206
Epoch 118
-----
Training loss: 1.9923867312749226
Training accuracy: 0.20601666666666665
Testing loss: 1.9829394012499766
Testing accuracy: 0.2116
Epoch 119
-----
Training loss: 1.992279683939616
Training accuracy: 0.2083
Testing loss: 1.9856363496962626
Testing accuracy: 0.2083
Epoch 120
-----
Training loss: 1.9921608512878417
Training accuracy: 0.20751666666666665
Testing loss: 1.984167307045809
Testing accuracy: 0.206
Epoch 121
-----
Training loss: 1.9920184918721517
Training accuracy: 0.20836666666666667
Testing loss: 1.9835973089667642
Testing accuracy: 0.2116
Epoch 122
-----
Training loss: 1.9922578983942667
Training accuracy: 0.20575

```

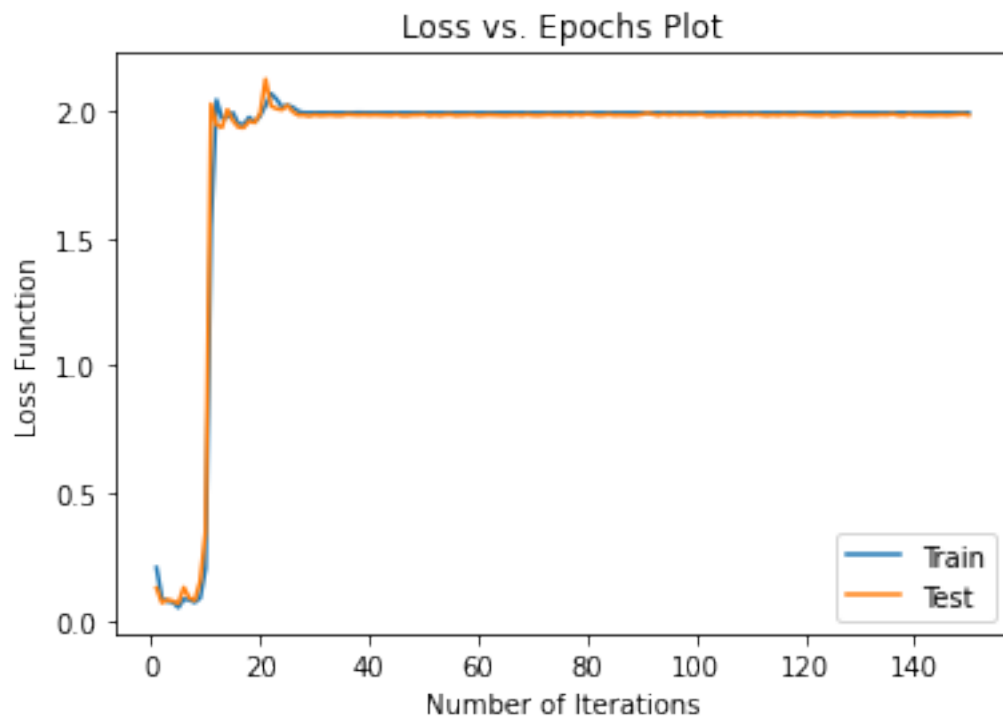
```
Testing loss: 1.981585243704972
Testing accuracy: 0.2083
Epoch 123
-----
Training loss: 1.9921219305674236
Training accuracy: 0.20863333333333334
Testing loss: 1.9816317216605897
Testing accuracy: 0.2109
Epoch 124
-----
Training loss: 1.9919613970438639
Training accuracy: 0.21006666666666668
Testing loss: 1.9856682909522088
Testing accuracy: 0.2086
Epoch 125
-----
Training loss: 1.9920578506469726
Training accuracy: 0.20793333333333333
Testing loss: 1.9800541575547237
Testing accuracy: 0.2116
Epoch 126
-----
Training loss: 1.9920733070373535
Training accuracy: 0.20848333333333333
Testing loss: 1.981566568089139
Testing accuracy: 0.2086
Epoch 127
-----
Training loss: 1.9924097906748455
Training accuracy: 0.203
Testing loss: 1.9835104281735267
Testing accuracy: 0.2078
Epoch 128
-----
Training loss: 1.9924441992441813
Training accuracy: 0.20615
Testing loss: 1.9854762493425113
Testing accuracy: 0.2116
Epoch 129
-----
Training loss: 1.9919031286875406
Training accuracy: 0.20781666666666668
Testing loss: 1.982618447321995
Testing accuracy: 0.2109
Epoch 130
-----
Training loss: 1.992487372080485
Training accuracy: 0.20756666666666668
```

```
Testing loss: 1.9826846160706442
Testing accuracy: 0.206
Epoch 131
-----
Training loss: 1.9922196413675943
Training accuracy: 0.20783333333333334
Testing loss: 1.9838701061382416
Testing accuracy: 0.2135
Epoch 132
-----
Training loss: 1.9919928586959839
Training accuracy: 0.20983333333333334
Testing loss: 1.981698831175543
Testing accuracy: 0.206
Epoch 133
-----
Training loss: 1.9924087942759197
Training accuracy: 0.20655
Testing loss: 1.9824694144498012
Testing accuracy: 0.2083
Epoch 134
-----
Training loss: 1.9921483725229898
Training accuracy: 0.20781666666666668
Testing loss: 1.9841960440775392
Testing accuracy: 0.2116
Epoch 135
-----
Training loss: 1.9920632869720458
Training accuracy: 0.20915
Testing loss: 1.983121915228048
Testing accuracy: 0.2109
Epoch 136
-----
Training loss: 1.9924291774749756
Training accuracy: 0.20721666666666666
Testing loss: 1.9872142949681373
Testing accuracy: 0.2109
Epoch 137
-----
Training loss: 1.9919596384684244
Training accuracy: 0.20708333333333334
Testing loss: 1.982356404043307
Testing accuracy: 0.2086
Epoch 138
-----
Training loss: 1.9924652101516724
Training accuracy: 0.207
```

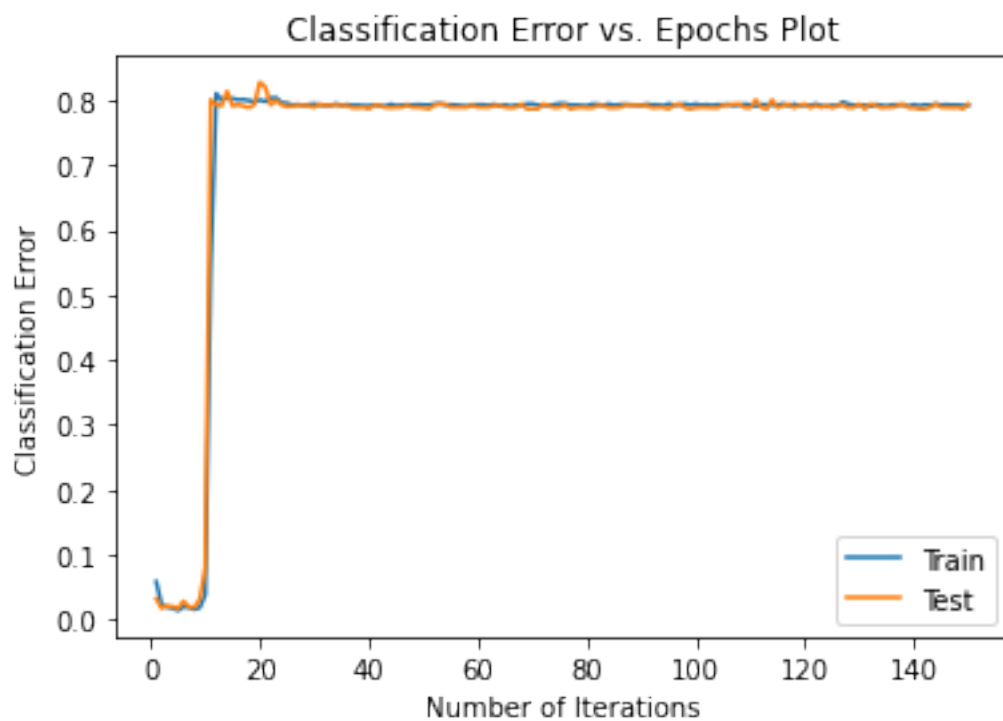
Testing loss: 1.9803062571082146  
Testing accuracy: 0.206  
Epoch 139  
-----  
Training loss: 1.9919149847666422  
Training accuracy: 0.20956666666666668  
Testing loss: 1.9863860303429282  
Testing accuracy: 0.2116  
Epoch 140  
-----  
Training loss: 1.9918357103983562  
Training accuracy: 0.20688333333333334  
Testing loss: 1.9824887628008605  
Testing accuracy: 0.2116  
Epoch 141  
-----  
Training loss: 1.9921747174580893  
Training accuracy: 0.20876666666666666  
Testing loss: 1.9830990999367586  
Testing accuracy: 0.2135  
Epoch 142  
-----  
Training loss: 1.9923405223846435  
Training accuracy: 0.20703333333333335  
Testing loss: 1.9823857872349442  
Testing accuracy: 0.2135  
Epoch 143  
-----  
Training loss: 1.9920253810882569  
Training accuracy: 0.20783333333333334  
Testing loss: 1.9815405576851717  
Testing accuracy: 0.211  
Epoch 144  
-----  
Training loss: 1.9921710927963256  
Training accuracy: 0.20601666666666665  
Testing loss: 1.9824620553642323  
Testing accuracy: 0.206  
Epoch 145  
-----  
Training loss: 1.9920716412862143  
Training accuracy: 0.20743333333333333  
Testing loss: 1.983175361232393  
Testing accuracy: 0.2109  
Epoch 146  
-----  
Training loss: 1.9925027039845784  
Training accuracy: 0.20686666666666667

```
Testing loss: 1.9815585400648177
Testing accuracy: 0.211
Epoch 147
-----
Training loss: 1.9921326773961385
Training accuracy: 0.20763333333333334
Testing loss: 1.9830607077118698
Testing accuracy: 0.2116
Epoch 148
-----
Training loss: 1.9924712814966838
Training accuracy: 0.20736666666666667
Testing loss: 1.9837056360426981
Testing accuracy: 0.2109
Epoch 149
-----
Training loss: 1.9919794542948406
Training accuracy: 0.20831666666666668
Testing loss: 1.9863241872969706
Testing accuracy: 0.2135
Epoch 150
-----
Training loss: 1.9924615599314373
Training accuracy: 0.20821666666666666
Testing loss: 1.9824326569866981
Testing accuracy: 0.206
Done
Total Time Consumed: 9160.461714982986
```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```





### 5.6.6 Best Combination of Hyperparameters

Testing Accuracy As Follow:

Learning Rate = 0.1: 99.3%;

Learning Rate = 0.01: 99.15%;

Learning Rate = 0.2: 99.26%;

Learning Rate = 0.5: 9.58%;

Momentum = 0.5 & Learning Rate = 0.1: 99.33%;

Momentum = 0.9 & Learning Rate = 0.1: 2.06%.

From above, we can see that models with learning rate = 0.2 or 0.1 suffer from the problem of overfitting. The model with learning rate = 0.5 and model with momentum = 0.9 cannot reach to local minimum. Therefore, we can conclude that learning rate = 0.1 & momentum = 0.5 is the best hyperparameters choice in terms of efficiency and accuracy.

### 5.7 5.(a) & (b)

```
[ ]: # Data Type Convert
transform = transforms.Compose(
    [transforms.Resize((32,32)), # Resize image to 32 * 32 to fit LeNet-5
     transforms.ToTensor(),
     transforms.Normalize((0.5,), (0.5,))])

# Read Data
train_data = MNIST(root='../data/mnist/', train=True, download=True, transform=
    ↪= transform)

test_data = MNIST(root='../data/ mnist/', train=False, download=True, transform=
    ↪= transform)
```

```
[ ]: # Create a LeNet-5
class LeNet5(nn.Module):
    def __init__(self, num_classes):
        super(LeNet5, self).__init__()
        self.conv1 = nn.Sequential(
            nn.Conv2d(1, 6, 5),
            nn.BatchNorm2d(6),
            nn.ReLU(),
            nn.MaxPool2d(2)
        )
        self.conv2 = nn.Sequential(
            nn.Conv2d(6, 16, 5),
            nn.BatchNorm2d(16),
            nn.ReLU(),
            nn.MaxPool2d(2)
        )
```

```

        self.linear1 = nn.Linear(400, 120)
        self.linear2 = nn.Linear(120, 84)
        self.linear3 = nn.Linear(84, num_classes)

    def forward(self, x):
        x = self.conv1(x)
        x = self.conv2(x)
        x = x.reshape(x.size(0), -1)
        x = F.relu(self.linear1(x))
        x = F.relu(self.linear2(x))
        x = self.linear3(x)
        return x

```

### 5.7.1 Seed 1

```

[ ]: # Define HyperParameters
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
lenet1 = LeNet5(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(lenet1.parameters(), lr = learning_rate)

```

```

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, lenet1, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, lenet1, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

-----  
Training loss: 0.19397162635475398

Training accuracy: 0.94175

Testing loss: 0.058634764790701066

Testing accuracy: 0.9826

Epoch 2

-----  
Training loss: 0.05534263921951254

Training accuracy: 0.9827

Testing loss: 0.04509820124122557

Testing accuracy: 0.9848

Epoch 3

-----  
Training loss: 0.0414981879664585

Training accuracy: 0.9869

Testing loss: 0.04919673209404869

Testing accuracy: 0.9845

Epoch 4

-----  
Training loss: 0.03239848137460649

Training accuracy: 0.9898666666666667

Testing loss: 0.03407000073018205

Testing accuracy: 0.9885

Epoch 5

-----  
Training loss: 0.026397477308226128

Training accuracy: 0.9915166666666667

Testing loss: 0.07600413198852733

Testing accuracy: 0.9738

Epoch 6

-----  
Training loss: 0.022175171821129817

Training accuracy: 0.9931166666666666

Testing loss: 0.028007456362484747

Testing accuracy: 0.9903

Epoch 7

-----  
Training loss: 0.01826322187737872

Training accuracy: 0.9942833333333333

Testing loss: 0.028042814099523878

Testing accuracy: 0.9905

Epoch 8

-----  
Training loss: 0.01583645630700048

Training accuracy: 0.99495

Testing loss: 0.034106364994418104

Testing accuracy: 0.9894

Epoch 9

-----  
Training loss: 0.013772936336145115  
Training accuracy: 0.9954  
Testing loss: 0.03414427002137052  
Testing accuracy: 0.9896  
Epoch 10

-----  
Training loss: 0.012053806938727697  
Training accuracy: 0.9961  
Testing loss: 0.027868875367626264  
Testing accuracy: 0.991  
Epoch 11

-----  
Training loss: 0.010514289241782777  
Training accuracy: 0.9966  
Testing loss: 0.04772730098309138  
Testing accuracy: 0.9843  
Epoch 12

-----  
Training loss: 0.010467163829074706  
Training accuracy: 0.9965666666666667  
Testing loss: 0.04103849526786892  
Testing accuracy: 0.9884  
Epoch 13

-----  
Training loss: 0.007580007183664323  
Training accuracy: 0.9976333333333334  
Testing loss: 0.029653879675514045  
Testing accuracy: 0.9913  
Epoch 14

-----  
Training loss: 0.007116467664821539  
Training accuracy: 0.9977  
Testing loss: 0.030453668012469397  
Testing accuracy: 0.9914  
Epoch 15

-----  
Training loss: 0.005509000250882915  
Training accuracy: 0.99845  
Testing loss: 0.026284808468233584  
Testing accuracy: 0.9928  
Epoch 16

-----  
Training loss: 0.004476011284374302  
Training accuracy: 0.9987  
Testing loss: 0.027521987351528474  
Testing accuracy: 0.9923

Epoch 17

-----  
Training loss: 0.003691191973909978  
Training accuracy: 0.9990833333333333  
Testing loss: 0.03124013359455064  
Testing accuracy: 0.9925  
Epoch 18

-----  
Training loss: 0.003457429989076142  
Training accuracy: 0.9989833333333333  
Testing loss: 0.03470013574593152  
Testing accuracy: 0.9917  
Epoch 19

-----  
Training loss: 0.002547247615896049  
Training accuracy: 0.99945  
Testing loss: 0.029568938059223997  
Testing accuracy: 0.9934  
Epoch 20

-----  
Training loss: 0.0023301009104941236  
Training accuracy: 0.9994166666666666  
Testing loss: 0.028960058208638794  
Testing accuracy: 0.9928  
Epoch 21

-----  
Training loss: 0.0026130938922667457  
Training accuracy: 0.9992666666666666  
Testing loss: 0.028501200561628127  
Testing accuracy: 0.9934  
Epoch 22

-----  
Training loss: 0.002011822648930274  
Training accuracy: 0.99945  
Testing loss: 0.03318817670400717  
Testing accuracy: 0.9923  
Epoch 23

-----  
Training loss: 0.00202075156971041  
Training accuracy: 0.99935  
Testing loss: 0.03329448301046448  
Testing accuracy: 0.9918  
Epoch 24

-----  
Training loss: 0.0014585708466181434  
Training accuracy: 0.9996666666666667  
Testing loss: 0.030349606485044645  
Testing accuracy: 0.9932

Epoch 25

-----  
Training loss: 0.0009837790266875952  
Training accuracy: 0.99975  
Testing loss: 0.03139910890762734  
Testing accuracy: 0.9934  
Epoch 26

-----  
Training loss: 0.0007046274641264972  
Training accuracy: 0.99985  
Testing loss: 0.031663890273018594  
Testing accuracy: 0.9932  
Epoch 27

-----  
Training loss: 0.0005306430116284901  
Training accuracy: 0.9998833333333333  
Testing loss: 0.031588407125513696  
Testing accuracy: 0.993  
Epoch 28

-----  
Training loss: 0.0003538439199952639  
Training accuracy: 0.9999333333333333  
Testing loss: 0.03146608739868257  
Testing accuracy: 0.9933  
Epoch 29

-----  
Training loss: 0.0002922865059748953  
Training accuracy: 0.99995  
Testing loss: 0.03279723636076055  
Testing accuracy: 0.9934  
Epoch 30

-----  
Training loss: 0.00028220546753997646  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03406627196387865  
Testing accuracy: 0.9934  
Epoch 31

-----  
Training loss: 0.00028852546035477647  
Training accuracy: 0.99995  
Testing loss: 0.033407763873779334  
Testing accuracy: 0.9935  
Epoch 32

-----  
Training loss: 0.00019384507257639902  
Training accuracy: 1.0  
Testing loss: 0.03348380512817498  
Testing accuracy: 0.9932

Epoch 33

-----  
Training loss: 0.0001888590624262027  
Training accuracy: 1.0  
Testing loss: 0.03328345710044187  
Testing accuracy: 0.993  
Epoch 34

-----  
Training loss: 0.00016712117771589875  
Training accuracy: 1.0  
Testing loss: 0.03443878582696844  
Testing accuracy: 0.9936  
Epoch 35

-----  
Training loss: 0.00015026098396364205  
Training accuracy: 1.0  
Testing loss: 0.03358712381916206  
Testing accuracy: 0.9936  
Epoch 36

-----  
Training loss: 0.00014157692436136434  
Training accuracy: 1.0  
Testing loss: 0.03515135406183093  
Testing accuracy: 0.993  
Epoch 37

-----  
Training loss: 0.00013815025580624934  
Training accuracy: 1.0  
Testing loss: 0.0351735926176442  
Testing accuracy: 0.9933  
Epoch 38

-----  
Training loss: 0.00012815884978501041  
Training accuracy: 1.0  
Testing loss: 0.03485769051528154  
Testing accuracy: 0.9933  
Epoch 39

-----  
Training loss: 0.00010900472118692997  
Training accuracy: 1.0  
Testing loss: 0.03498354180833336  
Testing accuracy: 0.9933  
Epoch 40

-----  
Training loss: 0.00012125162219989155  
Training accuracy: 1.0  
Testing loss: 0.03438782921117257  
Testing accuracy: 0.9936

```
Epoch 41
-----
Training loss: 0.00011219188277106203
Training accuracy: 1.0
Testing loss: 0.03552516317946154
Testing accuracy: 0.9936
Epoch 42
-----
Training loss: 0.00018640288813102568
Training accuracy: 0.9999833333333333
Testing loss: 0.03502617033480113
Testing accuracy: 0.9931
Epoch 43
-----
Training loss: 0.00011543220947552299
Training accuracy: 1.0
Testing loss: 0.03523115757668244
Testing accuracy: 0.993
Epoch 44
-----
Training loss: 9.545707066471702e-05
Training accuracy: 1.0
Testing loss: 0.03616383062527732
Testing accuracy: 0.9932
Epoch 45
-----
Training loss: 7.710349061050769e-05
Training accuracy: 1.0
Testing loss: 0.036439744262021234
Testing accuracy: 0.9929
Epoch 46
-----
Training loss: 9.88703611821137e-05
Training accuracy: 1.0
Testing loss: 0.036795469224957446
Testing accuracy: 0.9933
Epoch 47
-----
Training loss: 8.082735905847282e-05
Training accuracy: 1.0
Testing loss: 0.03610340269382281
Testing accuracy: 0.993
Epoch 48
-----
Training loss: 7.207423822943611e-05
Training accuracy: 1.0
Testing loss: 0.03637214594290952
Testing accuracy: 0.9933
```



Epoch 49

-----  
Training loss: 7.139004278784189e-05  
Training accuracy: 1.0  
Testing loss: 0.03585095237140079  
Testing accuracy: 0.9933  
Epoch 50

-----  
Training loss: 7.080637049859319e-05  
Training accuracy: 1.0  
Testing loss: 0.03846548670145924  
Testing accuracy: 0.9931  
Epoch 51

-----  
Training loss: 7.24087032349909e-05  
Training accuracy: 1.0  
Testing loss: 0.036987770229988275  
Testing accuracy: 0.9932  
Epoch 52

-----  
Training loss: 5.996711007680536e-05  
Training accuracy: 1.0  
Testing loss: 0.03705003485517314  
Testing accuracy: 0.993  
Epoch 53

-----  
Training loss: 6.990502540889167e-05  
Training accuracy: 1.0  
Testing loss: 0.03706880292529732  
Testing accuracy: 0.9934  
Epoch 54

-----  
Training loss: 6.789495050695725e-05  
Training accuracy: 1.0  
Testing loss: 0.03732277729548196  
Testing accuracy: 0.9935  
Epoch 55

-----  
Training loss: 5.949446255596058e-05  
Training accuracy: 1.0  
Testing loss: 0.037118282253887754  
Testing accuracy: 0.9934  
Epoch 56

-----  
Training loss: 5.225183287837657e-05  
Training accuracy: 1.0  
Testing loss: 0.03816182548004808  
Testing accuracy: 0.9931

Epoch 57

-----  
Training loss: 5.6234086404915236e-05

Training accuracy: 1.0

Testing loss: 0.037958516859476

Testing accuracy: 0.993

Epoch 58

-----  
Training loss: 5.238644463278111e-05

Training accuracy: 1.0

Testing loss: 0.03672090224654361

Testing accuracy: 0.9932

Epoch 59

-----  
Training loss: 5.1864538107552485e-05

Training accuracy: 1.0

Testing loss: 0.03788459695076031

Testing accuracy: 0.9937

Epoch 60

-----  
Training loss: 5.098015950856904e-05

Training accuracy: 1.0

Testing loss: 0.03865808374595342

Testing accuracy: 0.993

Epoch 61

-----  
Training loss: 5.179533046989775e-05

Training accuracy: 1.0

Testing loss: 0.03892342043819669

Testing accuracy: 0.9932

Epoch 62

-----  
Training loss: 5.748168436178579e-05

Training accuracy: 1.0

Testing loss: 0.03811624251968563

Testing accuracy: 0.9929

Epoch 63

-----  
Training loss: 5.187466228420779e-05

Training accuracy: 1.0

Testing loss: 0.038356941006686775

Testing accuracy: 0.9935

Epoch 64

-----  
Training loss: 4.4718082431289e-05

Training accuracy: 1.0

Testing loss: 0.03707179136824441

Testing accuracy: 0.9933

Epoch 65

-----  
Training loss: 4.872669295786522e-05  
Training accuracy: 1.0  
Testing loss: 0.03825309747996248  
Testing accuracy: 0.9933  
Epoch 66

-----  
Training loss: 4.422765385584929e-05  
Training accuracy: 1.0  
Testing loss: 0.03897850995293709  
Testing accuracy: 0.9934  
Epoch 67

-----  
Training loss: 4.178980241642864e-05  
Training accuracy: 1.0  
Testing loss: 0.03939585142598807  
Testing accuracy: 0.993  
Epoch 68

-----  
Training loss: 4.341432181809447e-05  
Training accuracy: 1.0  
Testing loss: 0.03821166472571016  
Testing accuracy: 0.9929  
Epoch 69

-----  
Training loss: 4.278596555694148e-05  
Training accuracy: 1.0  
Testing loss: 0.03896003598976122  
Testing accuracy: 0.9928  
Epoch 70

-----  
Training loss: 4.191119347763106e-05  
Training accuracy: 1.0  
Testing loss: 0.03883416732956591  
Testing accuracy: 0.9931  
Epoch 71

-----  
Training loss: 3.669795313516365e-05  
Training accuracy: 1.0  
Testing loss: 0.037581092608888186  
Testing accuracy: 0.9932  
Epoch 72

-----  
Training loss: 4.1834457510102394e-05  
Training accuracy: 1.0  
Testing loss: 0.04105117089241992  
Testing accuracy: 0.9933

Epoch 73

-----  
Training loss: 4.261750612470874e-05  
Training accuracy: 1.0  
Testing loss: 0.039808329050841425  
Testing accuracy: 0.9934  
Epoch 74

-----  
Training loss: 3.797337831682235e-05  
Training accuracy: 1.0  
Testing loss: 0.038990292121019794  
Testing accuracy: 0.9937  
Epoch 75

-----  
Training loss: 3.6280755057117156e-05  
Training accuracy: 1.0  
Testing loss: 0.040009825051411915  
Testing accuracy: 0.9934  
Epoch 76

-----  
Training loss: 3.347283570330954e-05  
Training accuracy: 1.0  
Testing loss: 0.03868163386223673  
Testing accuracy: 0.9933  
Epoch 77

-----  
Training loss: 3.7748859921730115e-05  
Training accuracy: 1.0  
Testing loss: 0.040085569191669314  
Testing accuracy: 0.9933  
Epoch 78

-----  
Training loss: 3.478503958444274e-05  
Training accuracy: 1.0  
Testing loss: 0.040006426090928644  
Testing accuracy: 0.9933  
Epoch 79

-----  
Training loss: 4.997921443909282e-05  
Training accuracy: 1.0  
Testing loss: 0.03895789083633114  
Testing accuracy: 0.9931  
Epoch 80

-----  
Training loss: 3.424530751098208e-05  
Training accuracy: 1.0  
Testing loss: 0.03948707877870615  
Testing accuracy: 0.9927

Epoch 81

-----  
Training loss: 3.2748584857883144e-05  
Training accuracy: 1.0  
Testing loss: 0.03954787186825851  
Testing accuracy: 0.9934  
Epoch 82

-----  
Training loss: 3.063018792782799e-05  
Training accuracy: 1.0  
Testing loss: 0.04063351568517994  
Testing accuracy: 0.9933  
Epoch 83

-----  
Training loss: 3.276986149662271e-05  
Training accuracy: 1.0  
Testing loss: 0.03909400239691132  
Testing accuracy: 0.9933  
Epoch 84

-----  
Training loss: 3.0234642488614346e-05  
Training accuracy: 1.0  
Testing loss: 0.04063134604257935  
Testing accuracy: 0.9937  
Epoch 85

-----  
Training loss: 3.0621621088166266e-05  
Training accuracy: 1.0  
Testing loss: 0.04003408126539897  
Testing accuracy: 0.9932  
Epoch 86

-----  
Training loss: 2.658445009514961e-05  
Training accuracy: 1.0  
Testing loss: 0.0397004878817791  
Testing accuracy: 0.9932  
Epoch 87

-----  
Training loss: 3.451894925453587e-05  
Training accuracy: 1.0  
Testing loss: 0.04058619588769538  
Testing accuracy: 0.9932  
Epoch 88

-----  
Training loss: 3.0185164425106946e-05  
Training accuracy: 1.0  
Testing loss: 0.03901586952136875  
Testing accuracy: 0.993

Epoch 89

-----  
Training loss: 2.868709482559749e-05  
Training accuracy: 1.0  
Testing loss: 0.040956287460917735  
Testing accuracy: 0.993  
Epoch 90

-----  
Training loss: 2.829637562138411e-05  
Training accuracy: 1.0  
Testing loss: 0.04068795357147413  
Testing accuracy: 0.9934  
Epoch 91

-----  
Training loss: 2.7370564797139234e-05  
Training accuracy: 1.0  
Testing loss: 0.040110300539966615  
Testing accuracy: 0.9934  
Epoch 92

-----  
Training loss: 2.8005982644284325e-05  
Training accuracy: 1.0  
Testing loss: 0.040439558705394875  
Testing accuracy: 0.9932  
Epoch 93

-----  
Training loss: 2.6701883029283026e-05  
Training accuracy: 1.0  
Testing loss: 0.03944927169206728  
Testing accuracy: 0.9929  
Epoch 94

-----  
Training loss: 2.791824585732871e-05  
Training accuracy: 1.0  
Testing loss: 0.04078471164846295  
Testing accuracy: 0.9933  
Epoch 95

-----  
Training loss: 2.7224386904469592e-05  
Training accuracy: 1.0  
Testing loss: 0.040021639228898946  
Testing accuracy: 0.9932  
Epoch 96

-----  
Training loss: 3.413301549259925e-05  
Training accuracy: 1.0  
Testing loss: 0.04072046051300499  
Testing accuracy: 0.9932

Epoch 97

-----  
Training loss: 2.7123900608287007e-05  
Training accuracy: 1.0  
Testing loss: 0.03988714417322276  
Testing accuracy: 0.9931  
Epoch 98

-----  
Training loss: 2.461042246632085e-05  
Training accuracy: 1.0  
Testing loss: 0.04255444813851276  
Testing accuracy: 0.9932  
Epoch 99

-----  
Training loss: 2.4567427265533108e-05  
Training accuracy: 1.0  
Testing loss: 0.03905859192794055  
Testing accuracy: 0.9931  
Epoch 100

-----  
Training loss: 2.3616660602872486e-05  
Training accuracy: 1.0  
Testing loss: 0.03960107024394464  
Testing accuracy: 0.9935  
Epoch 101

-----  
Training loss: 2.244960245535026e-05  
Training accuracy: 1.0  
Testing loss: 0.042700778120912906  
Testing accuracy: 0.9926  
Epoch 102

-----  
Training loss: 2.166846848835166e-05  
Training accuracy: 1.0  
Testing loss: 0.04116824514490419  
Testing accuracy: 0.9935  
Epoch 103

-----  
Training loss: 2.2275563248276835e-05  
Training accuracy: 1.0  
Testing loss: 0.041379267810263534  
Testing accuracy: 0.9933  
Epoch 104

-----  
Training loss: 2.4209481420805427e-05  
Training accuracy: 1.0  
Testing loss: 0.04103620541596206  
Testing accuracy: 0.9934

Epoch 105  
-----  
Training loss: 2.281976712972842e-05  
Training accuracy: 1.0  
Testing loss: 0.04863076588721829  
Testing accuracy: 0.9933  
Epoch 106  
-----  
Training loss: 2.1870531567261155e-05  
Training accuracy: 1.0  
Testing loss: 0.042069785173941214  
Testing accuracy: 0.9931  
Epoch 107  
-----  
Training loss: 2.2559428783964107e-05  
Training accuracy: 1.0  
Testing loss: 0.041485992689889895  
Testing accuracy: 0.9932  
Epoch 108  
-----  
Training loss: 2.148365971608506e-05  
Training accuracy: 1.0  
Testing loss: 0.04120107345684891  
Testing accuracy: 0.9935  
Epoch 109  
-----  
Training loss: 2.0116303005633302e-05  
Training accuracy: 1.0  
Testing loss: 0.03995213080073204  
Testing accuracy: 0.9933  
Epoch 110  
-----  
Training loss: 2.0471877639924447e-05  
Training accuracy: 1.0  
Testing loss: 0.04485396725296903  
Testing accuracy: 0.9932  
Epoch 111  
-----  
Training loss: 1.9199216099806903e-05  
Training accuracy: 1.0  
Testing loss: 0.04180392920525531  
Testing accuracy: 0.9932  
Epoch 112  
-----  
Training loss: 2.1156433078053283e-05  
Training accuracy: 1.0  
Testing loss: 0.040569343157446175  
Testing accuracy: 0.9931



Epoch 113  
-----  
Training loss: 1.9256531742372712e-05  
Training accuracy: 1.0  
Testing loss: 0.040531576996296295  
Testing accuracy: 0.993  
Epoch 114  
-----  
Training loss: 1.8760791982469745e-05  
Training accuracy: 1.0  
Testing loss: 0.04191477071423369  
Testing accuracy: 0.9935  
Epoch 115  
-----  
Training loss: 1.9997993553119286e-05  
Training accuracy: 1.0  
Testing loss: 0.0410074648960488  
Testing accuracy: 0.9929  
Epoch 116  
-----  
Training loss: 1.9646828720744244e-05  
Training accuracy: 1.0  
Testing loss: 0.041752976350026755  
Testing accuracy: 0.9928  
Epoch 117  
-----  
Training loss: 1.9011582672119095e-05  
Training accuracy: 1.0  
Testing loss: 0.04229225513121721  
Testing accuracy: 0.9933  
Epoch 118  
-----  
Training loss: 1.9785255359506118e-05  
Training accuracy: 1.0  
Testing loss: 0.04167666654020261  
Testing accuracy: 0.993  
Epoch 119  
-----  
Training loss: 1.9326043778890304e-05  
Training accuracy: 1.0  
Testing loss: 0.04168199945927571  
Testing accuracy: 0.9936  
Epoch 120  
-----  
Training loss: 1.782123832602866e-05  
Training accuracy: 1.0  
Testing loss: 0.04127559851246526  
Testing accuracy: 0.9934

Epoch 121

-----  
Training loss: 1.911855317548768e-05  
Training accuracy: 1.0  
Testing loss: 0.041273979047252676  
Testing accuracy: 0.9935  
Epoch 122

-----  
Training loss: 1.7024072591936702e-05  
Training accuracy: 1.0  
Testing loss: 0.04158677022380853  
Testing accuracy: 0.9932  
Epoch 123

-----  
Training loss: 1.802626060120076e-05  
Training accuracy: 1.0  
Testing loss: 0.041909805321740934  
Testing accuracy: 0.9934  
Epoch 124

-----  
Training loss: 1.962526131153801e-05  
Training accuracy: 1.0  
Testing loss: 0.04256482798197862  
Testing accuracy: 0.9932  
Epoch 125

-----  
Training loss: 1.8421996594308253e-05  
Training accuracy: 1.0  
Testing loss: 0.04323681763687436  
Testing accuracy: 0.9935  
Epoch 126

-----  
Training loss: 1.7021174433639647e-05  
Training accuracy: 1.0  
Testing loss: 0.042075392908608476  
Testing accuracy: 0.9933  
Epoch 127

-----  
Training loss: 2.1448994422582028e-05  
Training accuracy: 1.0  
Testing loss: 0.041389821158254125  
Testing accuracy: 0.9932  
Epoch 128

-----  
Training loss: 1.788771418546548e-05  
Training accuracy: 1.0  
Testing loss: 0.04225852834958513  
Testing accuracy: 0.9932

Epoch 129

-----  
Training loss: 1.7095436189129505e-05

Training accuracy: 1.0

Testing loss: 0.04285984410567446

Testing accuracy: 0.9931

Epoch 130

-----  
Training loss: 1.6717295411942127e-05

Training accuracy: 1.0

Testing loss: 0.04193922454711676

Testing accuracy: 0.993

Epoch 131

-----  
Training loss: 1.7342629598990436e-05

Training accuracy: 1.0

Testing loss: 0.044346333185900824

Testing accuracy: 0.9934

Epoch 132

-----  
Training loss: 1.744271982602482e-05

Training accuracy: 1.0

Testing loss: 0.04274768291729376

Testing accuracy: 0.9931

Epoch 133

-----  
Training loss: 1.701137647517624e-05

Training accuracy: 1.0

Testing loss: 0.041443055966413185

Testing accuracy: 0.993

Epoch 134

-----  
Training loss: 1.663903793381607e-05

Training accuracy: 1.0

Testing loss: 0.043703525056329476

Testing accuracy: 0.993

Epoch 135

-----  
Training loss: 1.668186033726696e-05

Training accuracy: 1.0

Testing loss: 0.04119496648645637

Testing accuracy: 0.9934

Epoch 136

-----  
Training loss: 1.6156287395949083e-05

Training accuracy: 1.0

Testing loss: 0.04254541674404246

Testing accuracy: 0.9931

Epoch 137

-----  
Training loss: 1.5461167122917986e-05

Training accuracy: 1.0

Testing loss: 0.0440833671379623

Testing accuracy: 0.9934

Epoch 138

-----  
Training loss: 1.5231937849415544e-05

Training accuracy: 1.0

Testing loss: 0.04186102777976932

Testing accuracy: 0.9937

Epoch 139

-----  
Training loss: 1.4502362168929632e-05

Training accuracy: 1.0

Testing loss: 0.04271189222208491

Testing accuracy: 0.9938

Epoch 140

-----  
Training loss: 1.5368516631312447e-05

Training accuracy: 1.0

Testing loss: 0.04234912373337727

Testing accuracy: 0.9935

Epoch 141

-----  
Training loss: 1.5528466313945205e-05

Training accuracy: 1.0

Testing loss: 0.04232405227786814

Testing accuracy: 0.9934

Epoch 142

-----  
Training loss: 1.6580683597561455e-05

Training accuracy: 1.0

Testing loss: 0.04407251986000664

Testing accuracy: 0.9932

Epoch 143

-----  
Training loss: 1.4777675225353448e-05

Training accuracy: 1.0

Testing loss: 0.04176971201851095

Testing accuracy: 0.9934

Epoch 144

-----  
Training loss: 1.5070324762732667e-05

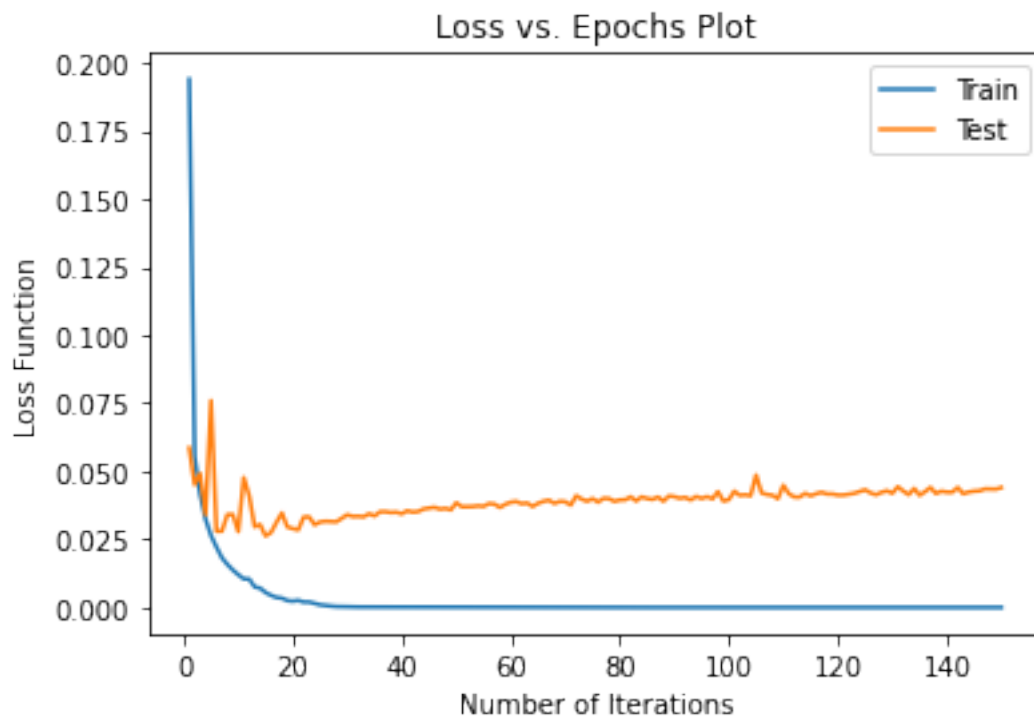
Training accuracy: 1.0

Testing loss: 0.04238694930476744

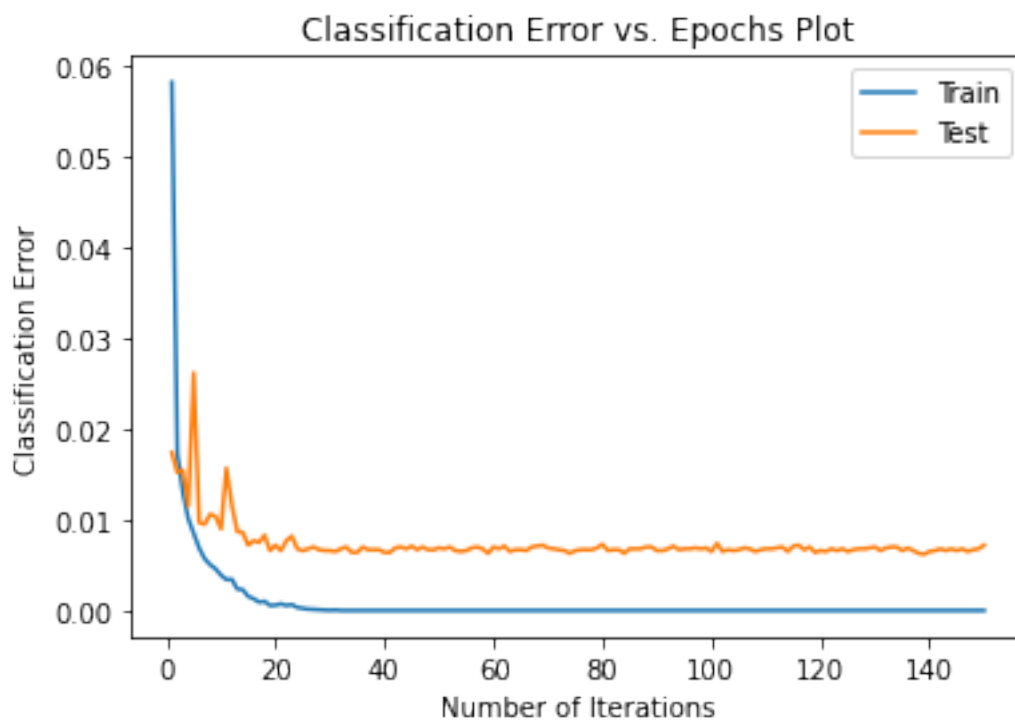
Testing accuracy: 0.9932

```
Epoch 145
-----
Training loss: 1.3329200685658312e-05
Training accuracy: 1.0
Testing loss: 0.04273467759851401
Testing accuracy: 0.9934
Epoch 146
-----
Training loss: 1.5467186949845293e-05
Training accuracy: 1.0
Testing loss: 0.04284253930583245
Testing accuracy: 0.9932
Epoch 147
-----
Training loss: 1.4798382654105069e-05
Training accuracy: 1.0
Testing loss: 0.043548218715578534
Testing accuracy: 0.9935
Epoch 148
-----
Training loss: 1.3752031161733905e-05
Training accuracy: 1.0
Testing loss: 0.04352315932414446
Testing accuracy: 0.9933
Epoch 149
-----
Training loss: 1.625455695057963e-05
Training accuracy: 1.0
Testing loss: 0.04344961309059233
Testing accuracy: 0.9932
Epoch 150
-----
Training loss: 1.4582791715096021e-05
Training accuracy: 1.0
Testing loss: 0.04402841517735529
Testing accuracy: 0.9928
Done
Total Time Consumed: 4036.5661137104034
```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



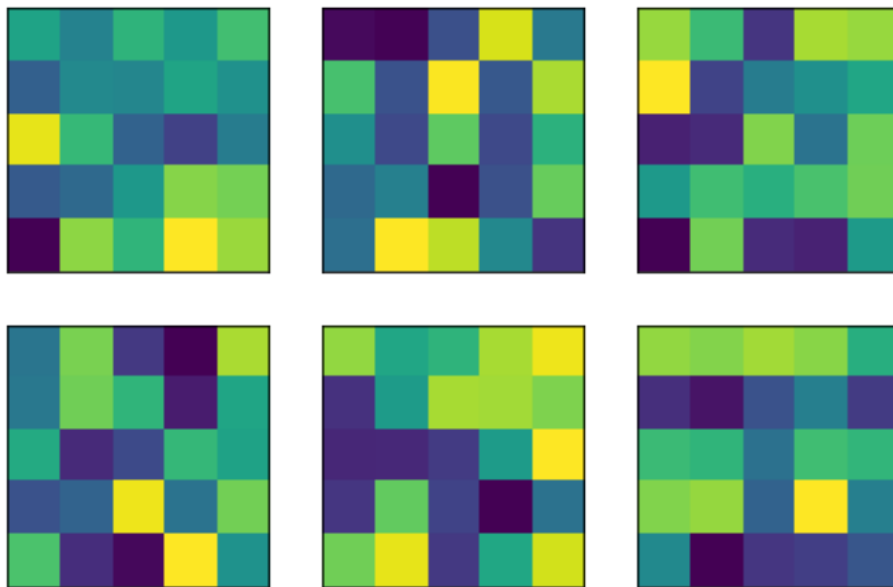
## 5.8 5.(c)

```
[ ]: # Check The Shape of Weights for the first Convolutional Layer
lenet1.state_dict()['conv1.0.weight'].shape
```

```
[ ]: torch.Size([6, 1, 5, 5])
```

There are 6 filters for the first Convolutional Layer, which is corresponding to the number of output channel. The dimension for each filter is 5 \* 5.

```
[ ]: weights = lenet1.state_dict()['conv1.0.weight']
for i in range(len(weights)):
    plt.subplot(2,3,i+1)
    plt.imshow(weights[i].reshape(5,5))
    plt.xticks([])
    plt.yticks([])
```



## 5.9 5.(d)

### 5.9.1 Learning Rate = 0.01

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.01
batch_size = 64
```

```

num_epochs = 150
lenet_lr01 = LeNet5(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(lenet_lr01.parameters(), lr = learning_rate)

```

```

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, lenet_lr01, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, lenet_lr01, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.6853841362794241
Training accuracy: 0.8327166666666667
Testing loss: 0.1440351867609343
Testing accuracy: 0.9612
Epoch 2

```

```

-----
Training loss: 0.124516569540898
Training accuracy: 0.9641166666666666
Testing loss: 0.08905586863684047
Testing accuracy: 0.9726
Epoch 3

```

```

-----
Training loss: 0.08921225286821524
Training accuracy: 0.9738333333333333
Testing loss: 0.07716064344925486
Testing accuracy: 0.9775
Epoch 4

```



-----  
Training loss: 0.0727513346195221  
Training accuracy: 0.9788833333333333  
Testing loss: 0.05842110099698043  
Testing accuracy: 0.9813  
Epoch 5

-----  
Training loss: 0.062294406992197036  
Training accuracy: 0.9814333333333334  
Testing loss: 0.058281122677170547  
Testing accuracy: 0.9816  
Epoch 6

-----  
Training loss: 0.055664934312055506  
Training accuracy: 0.9834333333333334  
Testing loss: 0.04969028602383888  
Testing accuracy: 0.9848  
Epoch 7

-----  
Training loss: 0.05004930052086711  
Training accuracy: 0.9852833333333333  
Testing loss: 0.04324156747519922  
Testing accuracy: 0.9866  
Epoch 8

-----  
Training loss: 0.04555297642946243  
Training accuracy: 0.9863166666666666  
Testing loss: 0.0404401386904109  
Testing accuracy: 0.9875  
Epoch 9

-----  
Training loss: 0.04224445067445437  
Training accuracy: 0.9879  
Testing loss: 0.03824028265247252  
Testing accuracy: 0.988  
Epoch 10

-----  
Training loss: 0.03946336271104713  
Training accuracy: 0.98855  
Testing loss: 0.035418308365223986  
Testing accuracy: 0.989  
Epoch 11

-----  
Training loss: 0.03775591925891737  
Training accuracy: 0.9891  
Testing loss: 0.041184143800952824  
Testing accuracy: 0.9862  
Epoch 12

-----  
Training loss: 0.03518525798333188  
Training accuracy: 0.9896666666666667  
Testing loss: 0.03767330904497178  
Testing accuracy: 0.9879  
Epoch 13

-----  
Training loss: 0.03308605942415695  
Training accuracy: 0.9904  
Testing loss: 0.03557140109237509  
Testing accuracy: 0.9884  
Epoch 14

-----  
Training loss: 0.03207313349843025  
Training accuracy: 0.9907  
Testing loss: 0.0325633672008196  
Testing accuracy: 0.9903  
Epoch 15

-----  
Training loss: 0.030032797196755806  
Training accuracy: 0.9911833333333333  
Testing loss: 0.03261285029710597  
Testing accuracy: 0.9897  
Epoch 16

-----  
Training loss: 0.02874695601761341  
Training accuracy: 0.9916166666666667  
Testing loss: 0.032723086823822016  
Testing accuracy: 0.9888  
Epoch 17

-----  
Training loss: 0.02708489206364999  
Training accuracy: 0.9920166666666667  
Testing loss: 0.032760058503722544  
Testing accuracy: 0.9896  
Epoch 18

-----  
Training loss: 0.026253857762242358  
Training accuracy: 0.9924333333333333  
Testing loss: 0.03291416505372425  
Testing accuracy: 0.9899  
Epoch 19

-----  
Training loss: 0.02505554897906259  
Training accuracy: 0.99275  
Testing loss: 0.031369435338445814  
Testing accuracy: 0.9904  
Epoch 20

-----  
Training loss: 0.024021875475905837  
Training accuracy: 0.9931166666666666  
Testing loss: 0.030768106171748584  
Testing accuracy: 0.9909  
Epoch 21

-----  
Training loss: 0.02310575866503641  
Training accuracy: 0.993  
Testing loss: 0.03123249966728317  
Testing accuracy: 0.9898  
Epoch 22

-----  
Training loss: 0.02157617830131203  
Training accuracy: 0.9938  
Testing loss: 0.030947014130726102  
Testing accuracy: 0.9902  
Epoch 23

-----  
Training loss: 0.020847178943268953  
Training accuracy: 0.9940166666666667  
Testing loss: 0.03129688755588333  
Testing accuracy: 0.9902  
Epoch 24

-----  
Training loss: 0.02012002068137129  
Training accuracy: 0.9941  
Testing loss: 0.03151482568903986  
Testing accuracy: 0.9902  
Epoch 25

-----  
Training loss: 0.01962006763772418  
Training accuracy: 0.9944333333333333  
Testing loss: 0.030568091903225916  
Testing accuracy: 0.99  
Epoch 26

-----  
Training loss: 0.018283936327385404  
Training accuracy: 0.9945833333333334  
Testing loss: 0.029146383915231475  
Testing accuracy: 0.9912  
Epoch 27

-----  
Training loss: 0.017730647678859533  
Training accuracy: 0.9949333333333333  
Testing loss: 0.02879374493899678  
Testing accuracy: 0.9912  
Epoch 28

-----  
Training loss: 0.017102326982934027  
Training accuracy: 0.9952166666666666  
Testing loss: 0.033599060511877936  
Testing accuracy: 0.9895  
Epoch 29

-----  
Training loss: 0.01629581368723884  
Training accuracy: 0.9952  
Testing loss: 0.03478378547944283  
Testing accuracy: 0.9891  
Epoch 30

-----  
Training loss: 0.016149495731263112  
Training accuracy: 0.9953833333333333  
Testing loss: 0.030322982658258384  
Testing accuracy: 0.9906  
Epoch 31

-----  
Training loss: 0.015050914971064776  
Training accuracy: 0.99555  
Testing loss: 0.032062578874055864  
Testing accuracy: 0.9898  
Epoch 32

-----  
Training loss: 0.014783570308797062  
Training accuracy: 0.9959333333333333  
Testing loss: 0.029688603314422784  
Testing accuracy: 0.991  
Epoch 33

-----  
Training loss: 0.01374487945510385  
Training accuracy: 0.9964166666666666  
Testing loss: 0.03326363719749163  
Testing accuracy: 0.9897  
Epoch 34

-----  
Training loss: 0.01343947806704479  
Training accuracy: 0.9964666666666666  
Testing loss: 0.032844924297892625  
Testing accuracy: 0.99  
Epoch 35

-----  
Training loss: 0.012809986971473942  
Training accuracy: 0.9964666666666666  
Testing loss: 0.032380903799644416  
Testing accuracy: 0.9905  
Epoch 36

-----  
Training loss: 0.012349396564625203  
Training accuracy: 0.9966333333333334  
Testing loss: 0.031534334623635224  
Testing accuracy: 0.9901  
Epoch 37

-----  
Training loss: 0.011854392119217664  
Training accuracy: 0.9969166666666667  
Testing loss: 0.03166118300995185  
Testing accuracy: 0.9905  
Epoch 38

-----  
Training loss: 0.011264501216759284  
Training accuracy: 0.99705  
Testing loss: 0.030268464645461304  
Testing accuracy: 0.9905  
Epoch 39

-----  
Training loss: 0.010645394162274897  
Training accuracy: 0.9972666666666666  
Testing loss: 0.030535743818736995  
Testing accuracy: 0.99  
Epoch 40

-----  
Training loss: 0.010783291723206639  
Training accuracy: 0.9969833333333333  
Testing loss: 0.02925391841850727  
Testing accuracy: 0.9909  
Epoch 41

-----  
Training loss: 0.010350095879185634  
Training accuracy: 0.9972833333333333  
Testing loss: 0.03449295082123606  
Testing accuracy: 0.9896  
Epoch 42

-----  
Training loss: 0.009920026277626554  
Training accuracy: 0.9974833333333334  
Testing loss: 0.030034461966270853  
Testing accuracy: 0.9909  
Epoch 43

-----  
Training loss: 0.009659275149422077  
Training accuracy: 0.9973166666666666  
Testing loss: 0.030223834013587136  
Testing accuracy: 0.9911  
Epoch 44

-----  
Training loss: 0.008951548031919325  
Training accuracy: 0.9979666666666667  
Testing loss: 0.031457902640893994  
Testing accuracy: 0.9904  
Epoch 45

-----  
Training loss: 0.008729218642871517  
Training accuracy: 0.99755  
Testing loss: 0.03155299870105079  
Testing accuracy: 0.9907  
Epoch 46

-----  
Training loss: 0.008477574550166416  
Training accuracy: 0.99785  
Testing loss: 0.032045546842269616  
Testing accuracy: 0.9902  
Epoch 47

-----  
Training loss: 0.008159447219998886  
Training accuracy: 0.99805  
Testing loss: 0.032904373804421704  
Testing accuracy: 0.9899  
Epoch 48

-----  
Training loss: 0.007633271543409986  
Training accuracy: 0.9982333333333333  
Testing loss: 0.032140044898514346  
Testing accuracy: 0.9906  
Epoch 49

-----  
Training loss: 0.007460292148916051  
Training accuracy: 0.9982  
Testing loss: 0.03311756298158786  
Testing accuracy: 0.9899  
Epoch 50

-----  
Training loss: 0.007262833504316707  
Training accuracy: 0.9981833333333333  
Testing loss: 0.03511552228410669  
Testing accuracy: 0.9907  
Epoch 51

-----  
Training loss: 0.00693091190753039  
Training accuracy: 0.9982833333333333  
Testing loss: 0.033731254427467626  
Testing accuracy: 0.9908  
Epoch 52

-----  
Training loss: 0.006484195118560456  
Training accuracy: 0.9985833333333334  
Testing loss: 0.031881474379663634  
Testing accuracy: 0.9905  
Epoch 53

-----  
Training loss: 0.006420417156869856  
Training accuracy: 0.9985166666666667  
Testing loss: 0.032248620121214454  
Testing accuracy: 0.9907  
Epoch 54

-----  
Training loss: 0.006227298151352443  
Training accuracy: 0.9986  
Testing loss: 0.03382764399360501  
Testing accuracy: 0.9899  
Epoch 55

-----  
Training loss: 0.005748250924237072  
Training accuracy: 0.9988  
Testing loss: 0.03341757033825155  
Testing accuracy: 0.9899  
Epoch 56

-----  
Training loss: 0.005505777985204865  
Training accuracy: 0.9989833333333333  
Testing loss: 0.03441953513399434  
Testing accuracy: 0.9914  
Epoch 57

-----  
Training loss: 0.005530035869951826  
Training accuracy: 0.9987666666666667  
Testing loss: 0.037662256225349626  
Testing accuracy: 0.9888  
Epoch 58

-----  
Training loss: 0.005148271966723648  
Training accuracy: 0.9988666666666667  
Testing loss: 0.03729099085249354  
Testing accuracy: 0.9896  
Epoch 59

-----  
Training loss: 0.0051506766567744  
Training accuracy: 0.99895  
Testing loss: 0.03301962516290042  
Testing accuracy: 0.9906  
Epoch 60

-----  
Training loss: 0.004928450081800111  
Training accuracy: 0.9989166666666667  
Testing loss: 0.03437382992145503  
Testing accuracy: 0.9909  
Epoch 61  
-----

Training loss: 0.004686724409709374  
Training accuracy: 0.9991666666666666  
Testing loss: 0.03340144460864371  
Testing accuracy: 0.9906  
Epoch 62  
-----

Training loss: 0.004350406630539025  
Training accuracy: 0.9994  
Testing loss: 0.0343149535730648  
Testing accuracy: 0.9905  
Epoch 63  
-----

Training loss: 0.004168827322174912  
Training accuracy: 0.9994166666666666  
Testing loss: 0.034525909034545395  
Testing accuracy: 0.9906  
Epoch 64  
-----

Training loss: 0.0042039003263538086  
Training accuracy: 0.9992833333333333  
Testing loss: 0.03402546707772793  
Testing accuracy: 0.9904  
Epoch 65  
-----

Training loss: 0.003934546895627864  
Training accuracy: 0.9993166666666666  
Testing loss: 0.036144630977586224  
Testing accuracy: 0.9906  
Epoch 66  
-----

Training loss: 0.003777389367184757  
Training accuracy: 0.9994833333333333  
Testing loss: 0.036348114153581586  
Testing accuracy: 0.9903  
Epoch 67  
-----

Training loss: 0.003619971886962109  
Training accuracy: 0.9995833333333334  
Testing loss: 0.035794741003240226  
Testing accuracy: 0.9906  
Epoch 68



-----  
Training loss: 0.003456727045943262  
Training accuracy: 0.99945  
Testing loss: 0.03472236731306494  
Testing accuracy: 0.9908  
Epoch 69

-----  
Training loss: 0.003822369162795561  
Training accuracy: 0.99935  
Testing loss: 0.03753703491755839  
Testing accuracy: 0.9895  
Epoch 70

-----  
Training loss: 0.0033720124788485313  
Training accuracy: 0.9995666666666667  
Testing loss: 0.03386894804398658  
Testing accuracy: 0.9909  
Epoch 71

-----  
Training loss: 0.0030849528476498867  
Training accuracy: 0.9996  
Testing loss: 0.03746256488880512  
Testing accuracy: 0.9902  
Epoch 72

-----  
Training loss: 0.003135042700821456  
Training accuracy: 0.9995166666666667  
Testing loss: 0.03651389839132016  
Testing accuracy: 0.9905  
Epoch 73

-----  
Training loss: 0.0029579937213925103  
Training accuracy: 0.99965  
Testing loss: 0.0372809280458806  
Testing accuracy: 0.9899  
Epoch 74

-----  
Training loss: 0.0027935133006996085  
Training accuracy: 0.9997  
Testing loss: 0.03633751017045212  
Testing accuracy: 0.9905  
Epoch 75

-----  
Training loss: 0.0027625495280420484  
Training accuracy: 0.9997333333333334  
Testing loss: 0.036220257466814065  
Testing accuracy: 0.9908  
Epoch 76

-----  
Training loss: 0.002654631925892318  
Training accuracy: 0.9997833333333334  
Testing loss: 0.03677144641523616  
Testing accuracy: 0.9896  
Epoch 77

-----  
Training loss: 0.002586893526544251  
Training accuracy: 0.9997333333333334  
Testing loss: 0.03608509654049546  
Testing accuracy: 0.9905  
Epoch 78

-----  
Training loss: 0.002570092681636258  
Training accuracy: 0.9997166666666667  
Testing loss: 0.03549808806579027  
Testing accuracy: 0.9904  
Epoch 79

-----  
Training loss: 0.0026818078920351884  
Training accuracy: 0.9996333333333334  
Testing loss: 0.0371634047357017  
Testing accuracy: 0.99  
Epoch 80

-----  
Training loss: 0.0021903243314756156  
Training accuracy: 0.9998666666666667  
Testing loss: 0.03728417131174969  
Testing accuracy: 0.99  
Epoch 81

-----  
Training loss: 0.002175385652615417  
Training accuracy: 0.9999  
Testing loss: 0.03720593635376749  
Testing accuracy: 0.9902  
Epoch 82

-----  
Training loss: 0.0021550629289248417  
Training accuracy: 0.9998  
Testing loss: 0.03660068338554576  
Testing accuracy: 0.9902  
Epoch 83

-----  
Training loss: 0.0021680238273048113  
Training accuracy: 0.9998  
Testing loss: 0.03632706266921125  
Testing accuracy: 0.9907  
Epoch 84

-----  
Training loss: 0.0020750828061223726  
Training accuracy: 0.9998833333333333  
Testing loss: 0.03696084444044381  
Testing accuracy: 0.9902  
Epoch 85

-----  
Training loss: 0.0020924516660452354  
Training accuracy: 0.9998333333333334  
Testing loss: 0.038569891332105734  
Testing accuracy: 0.9902  
Epoch 86

-----  
Training loss: 0.0019215374966772894  
Training accuracy: 0.9998833333333333  
Testing loss: 0.037663459899304606  
Testing accuracy: 0.9911  
Epoch 87

-----  
Training loss: 0.0021226436380815963  
Training accuracy: 0.9998166666666667  
Testing loss: 0.036900483308579694  
Testing accuracy: 0.9907  
Epoch 88

-----  
Training loss: 0.0018633306323376018  
Training accuracy: 0.9999  
Testing loss: 0.03704945758113209  
Testing accuracy: 0.9907  
Epoch 89

-----  
Training loss: 0.0018299377975228709  
Training accuracy: 0.9998833333333333  
Testing loss: 0.0372092721212145  
Testing accuracy: 0.9906  
Epoch 90

-----  
Training loss: 0.0017073264868755359  
Training accuracy: 0.9999  
Testing loss: 0.03783965572265689  
Testing accuracy: 0.99  
Epoch 91

-----  
Training loss: 0.0017329936448688386  
Training accuracy: 0.9998666666666667  
Testing loss: 0.0375356020044964  
Testing accuracy: 0.9913  
Epoch 92

-----  
Training loss: 0.0016568119165089835  
Training accuracy: 0.9998833333333333  
Testing loss: 0.03722223497210808  
Testing accuracy: 0.9909  
Epoch 93

-----  
Training loss: 0.0014906565994834333  
Training accuracy: 0.99995  
Testing loss: 0.03994288896005652  
Testing accuracy: 0.9906  
Epoch 94

-----  
Training loss: 0.0015165529895806685  
Training accuracy: 0.99995  
Testing loss: 0.03920368832267202  
Testing accuracy: 0.9906  
Epoch 95

-----  
Training loss: 0.0014410444382199784  
Training accuracy: 0.9999333333333333  
Testing loss: 0.03827437598054901  
Testing accuracy: 0.9906  
Epoch 96

-----  
Training loss: 0.0014906648134502272  
Training accuracy: 0.9999166666666667  
Testing loss: 0.0385189266487675  
Testing accuracy: 0.9909  
Epoch 97

-----  
Training loss: 0.001421716617873608  
Training accuracy: 0.9999166666666667  
Testing loss: 0.03903562058428416  
Testing accuracy: 0.9907  
Epoch 98

-----  
Training loss: 0.0012830351315584266  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04011178688568318  
Testing accuracy: 0.9906  
Epoch 99

-----  
Training loss: 0.0013120469963773455  
Training accuracy: 0.99995  
Testing loss: 0.03960320105916311  
Testing accuracy: 0.9908  
Epoch 100

-----  
Training loss: 0.001334489220554436  
Training accuracy: 0.9999333333333333  
Testing loss: 0.040242604823691464  
Testing accuracy: 0.9906  
Epoch 101

-----  
Training loss: 0.001330837859583941  
Training accuracy: 0.99995  
Testing loss: 0.04015756465878729  
Testing accuracy: 0.9901  
Epoch 102

-----  
Training loss: 0.001269576115522068  
Training accuracy: 0.99995  
Testing loss: 0.03920506038528425  
Testing accuracy: 0.9909  
Epoch 103

-----  
Training loss: 0.0012037342034188138  
Training accuracy: 0.99995  
Testing loss: 0.042099955165728606  
Testing accuracy: 0.9906  
Epoch 104

-----  
Training loss: 0.0013499930690241552  
Training accuracy: 0.99985  
Testing loss: 0.039824209948141766  
Testing accuracy: 0.9904  
Epoch 105

-----  
Training loss: 0.0011690997708404514  
Training accuracy: 0.99995  
Testing loss: 0.04472038574366689  
Testing accuracy: 0.9904  
Epoch 106

-----  
Training loss: 0.001155248685903886  
Training accuracy: 0.9999666666666667  
Testing loss: 0.039852818765204245  
Testing accuracy: 0.9906  
Epoch 107

-----  
Training loss: 0.0011074175137817898  
Training accuracy: 0.99995  
Testing loss: 0.040439403954345615  
Testing accuracy: 0.9905  
Epoch 108

-----  
Training loss: 0.0010519709404924167  
Training accuracy: 0.9999666666666667  
Testing loss: 0.03944070951609458  
Testing accuracy: 0.9902  
Epoch 109

-----  
Training loss: 0.0009887544907105621  
Training accuracy: 0.99995  
Testing loss: 0.03867266048359997  
Testing accuracy: 0.9911  
Epoch 110

-----  
Training loss: 0.0009639208650866446  
Training accuracy: 0.9999666666666667  
Testing loss: 0.04089129404627303  
Testing accuracy: 0.9908  
Epoch 111

-----  
Training loss: 0.0009648848696023681  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04055143473022813  
Testing accuracy: 0.9905  
Epoch 112

-----  
Training loss: 0.0009406153717170431  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03950301809870099  
Testing accuracy: 0.9909  
Epoch 113

-----  
Training loss: 0.0009736271841815324  
Training accuracy: 0.9999666666666667  
Testing loss: 0.03955290645000879  
Testing accuracy: 0.9911  
Epoch 114

-----  
Training loss: 0.0008894408032101638  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04106691221031898  
Testing accuracy: 0.9901  
Epoch 115

-----  
Training loss: 0.0008258374143491285  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04194101328156052  
Testing accuracy: 0.9904  
Epoch 116

-----  
Training loss: 0.0009105113140072111  
Training accuracy: 0.99995  
Testing loss: 0.041587790919351345  
Testing accuracy: 0.9909  
Epoch 117

-----  
Training loss: 0.0007917407320198738  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04134127252002006  
Testing accuracy: 0.9904  
Epoch 118

-----  
Training loss: 0.0008714506029743158  
Training accuracy: 0.9999666666666667  
Testing loss: 0.04122678145032951  
Testing accuracy: 0.9907  
Epoch 119

-----  
Training loss: 0.0007976645178311931  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0403158684280735  
Testing accuracy: 0.9914  
Epoch 120

-----  
Training loss: 0.0007640114258693453  
Training accuracy: 0.9999833333333333  
Testing loss: 0.041487588309777564  
Testing accuracy: 0.9902  
Epoch 121

-----  
Training loss: 0.0007638183581470609  
Training accuracy: 1.0  
Testing loss: 0.0421960832641741  
Testing accuracy: 0.99  
Epoch 122

-----  
Training loss: 0.0007307332405250539  
Training accuracy: 0.9999833333333333  
Testing loss: 0.0437962778291485  
Testing accuracy: 0.9904  
Epoch 123

-----  
Training loss: 0.0006748409113033025  
Training accuracy: 0.9999833333333333  
Testing loss: 0.042001105217973504  
Testing accuracy: 0.9902  
Epoch 124

-----  
Training loss: 0.0007900411342687827  
Training accuracy: 0.99995  
Testing loss: 0.04043197556194943  
Testing accuracy: 0.9906  
Epoch 125

-----  
Training loss: 0.000652935262771886  
Training accuracy: 1.0  
Testing loss: 0.04204838130818603  
Testing accuracy: 0.9906  
Epoch 126

-----  
Training loss: 0.0006598247188447809  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04267591175906549  
Testing accuracy: 0.9906  
Epoch 127

-----  
Training loss: 0.0006482242494574166  
Training accuracy: 1.0  
Testing loss: 0.042658558166161584  
Testing accuracy: 0.9903  
Epoch 128

-----  
Training loss: 0.0006417131746352727  
Training accuracy: 1.0  
Testing loss: 0.04327228852867662  
Testing accuracy: 0.9904  
Epoch 129

-----  
Training loss: 0.0006303967951391921  
Training accuracy: 1.0  
Testing loss: 0.043182170534283575  
Testing accuracy: 0.9903  
Epoch 130

-----  
Training loss: 0.000632116409588707  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04371468908710861  
Testing accuracy: 0.9908  
Epoch 131

-----  
Training loss: 0.0006417759134579683  
Training accuracy: 0.9999833333333333  
Testing loss: 0.044807347345451325  
Testing accuracy: 0.9904  
Epoch 132



-----  
Training loss: 0.0006404606796095322  
Training accuracy: 0.9999833333333333  
Testing loss: 0.04164179433534228  
Testing accuracy: 0.99  
Epoch 133

-----  
Training loss: 0.0005846622391880373  
Training accuracy: 1.0  
Testing loss: 0.04742048415070545  
Testing accuracy: 0.9902  
Epoch 134

-----  
Training loss: 0.000591876695699951  
Training accuracy: 0.9999833333333333  
Testing loss: 0.046061743362244646  
Testing accuracy: 0.9904  
Epoch 135

-----  
Training loss: 0.0005814164147639531  
Training accuracy: 1.0  
Testing loss: 0.042709891108579486  
Testing accuracy: 0.9911  
Epoch 136

-----  
Training loss: 0.000556427323835942  
Training accuracy: 1.0  
Testing loss: 0.042764879358078996  
Testing accuracy: 0.9908  
Epoch 137

-----  
Training loss: 0.0005367978124872025  
Training accuracy: 1.0  
Testing loss: 0.042144661205324806  
Testing accuracy: 0.9907  
Epoch 138

-----  
Training loss: 0.0005392867764485951  
Training accuracy: 1.0  
Testing loss: 0.04382203845870017  
Testing accuracy: 0.9901  
Epoch 139

-----  
Training loss: 0.000551600994781135  
Training accuracy: 0.9999666666666667  
Testing loss: 0.04395979430554614  
Testing accuracy: 0.9901  
Epoch 140

-----  
Training loss: 0.0005067565274044076  
Training accuracy: 1.0  
Testing loss: 0.042796910197083  
Testing accuracy: 0.9906  
Epoch 141  
-----

Training loss: 0.0005236479913271978  
Training accuracy: 1.0  
Testing loss: 0.042175407392388856  
Testing accuracy: 0.9907  
Epoch 142  
-----

Training loss: 0.0005087167394022496  
Training accuracy: 1.0  
Testing loss: 0.0461057850321699  
Testing accuracy: 0.9902  
Epoch 143  
-----

Training loss: 0.0004879738079022597  
Training accuracy: 1.0  
Testing loss: 0.04303701318418638  
Testing accuracy: 0.9903  
Epoch 144  
-----

Training loss: 0.0005376372616345786  
Training accuracy: 1.0  
Testing loss: 0.04393965218168076  
Testing accuracy: 0.9905  
Epoch 145  
-----

Training loss: 0.0004911063619996033  
Training accuracy: 1.0  
Testing loss: 0.04255938783232087  
Testing accuracy: 0.99  
Epoch 146  
-----

Training loss: 0.000488977523464079  
Training accuracy: 1.0  
Testing loss: 0.044564863307380964  
Testing accuracy: 0.9906  
Epoch 147  
-----

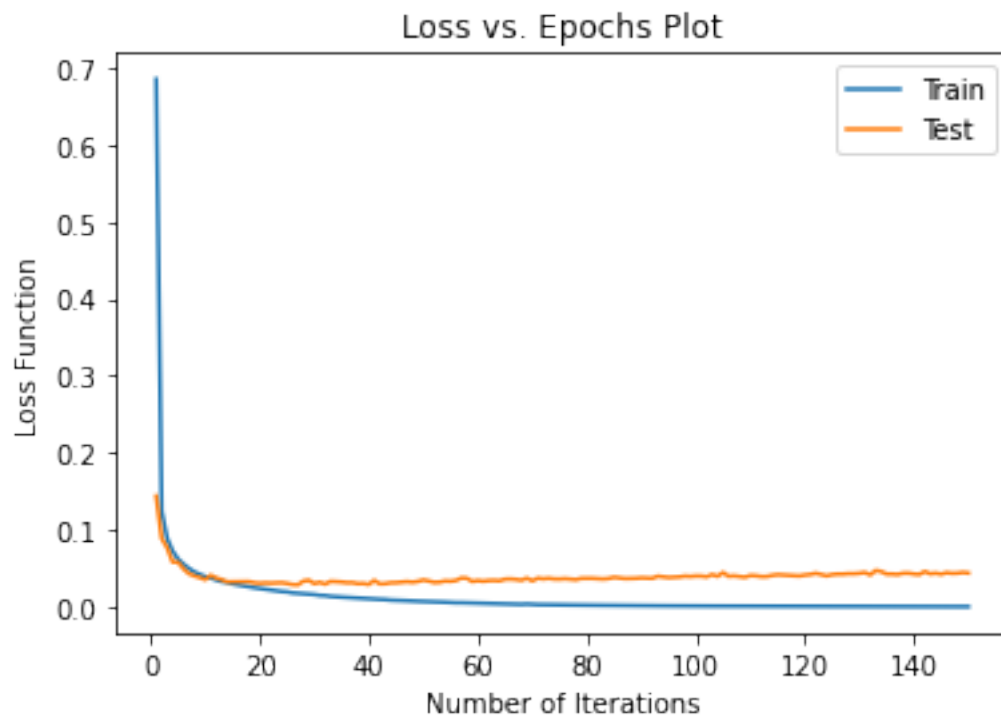
Training loss: 0.0005031857828049396  
Training accuracy: 1.0  
Testing loss: 0.04367930745009725  
Testing accuracy: 0.9896  
Epoch 148

```
-----  
Training loss: 0.000442941040044146  
Training accuracy: 1.0  
Testing loss: 0.043918272687562515  
Testing accuracy: 0.9904  
Epoch 149  
-----
```

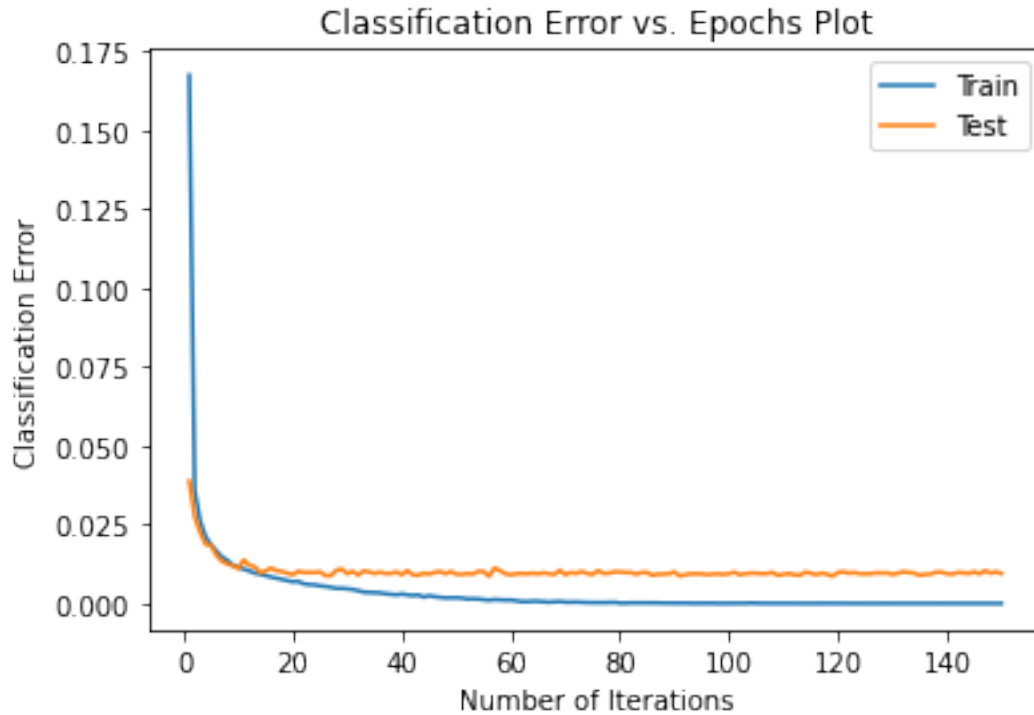
```
Training loss: 0.00044231477923422063  
Training accuracy: 1.0  
Testing loss: 0.04487169916267842  
Testing accuracy: 0.99  
Epoch 150  
-----
```

```
Training loss: 0.0004450947775752866  
Training accuracy: 1.0  
Testing loss: 0.04410535063619623  
Testing accuracy: 0.9905  
Done  
Total Time Consumed: 3934.9700717926025
```

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.9.2 Learning Rate = 0.2

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.2
batch_size = 64
num_epochs = 150
lenet_lr2 = LeNet5(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(lenet_lr2.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, lenet_lr2, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, lenet_lr2, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.1814465950275461
Training accuracy: 0.9436
Testing loss: 0.06795152381898918
Testing accuracy: 0.9781

```

Epoch 2

```

-----
Training loss: 0.04988939085776607
Training accuracy: 0.9843166666666666
Testing loss: 0.03892700129023984
Testing accuracy: 0.9879

```

Epoch 3

```

-----
Training loss: 0.03657733850255609
Training accuracy: 0.98865
Testing loss: 0.033855288078160184
Testing accuracy: 0.9891

```

Epoch 4

```

-----
Training loss: 0.026789985394943507
Training accuracy: 0.99165
Testing loss: 0.030583737193010628
Testing accuracy: 0.9901

```

Epoch 5

```

-----
Training loss: 0.022650966536051906
Training accuracy: 0.9928
Testing loss: 0.08107857554142547
Testing accuracy: 0.9731

```

Epoch 6

```

-----
Training loss: 0.019456638929480685
Training accuracy: 0.99385
Testing loss: 0.028167668684603717

```

```
Testing accuracy: 0.9905
Epoch 7
-----
Training loss: 0.015102186766402641
Training accuracy: 0.99515
Testing loss: 0.029538231576769908
Testing accuracy: 0.9917
Epoch 8
-----
Training loss: 0.012807160680314216
Training accuracy: 0.99625
Testing loss: 0.029642012931727565
Testing accuracy: 0.9919
Epoch 9
-----
Training loss: 0.011085858963045757
Training accuracy: 0.9967833333333334
Testing loss: 0.03642704158225749
Testing accuracy: 0.9888
Epoch 10
-----
Training loss: 0.009892658150867404
Training accuracy: 0.9970666666666667
Testing loss: 0.03049647868873224
Testing accuracy: 0.9907
Epoch 11
-----
Training loss: 0.007879321417573373
Training accuracy: 0.9978333333333333
Testing loss: 0.03160914111777526
Testing accuracy: 0.9912
Epoch 12
-----
Training loss: 0.0071420246429581315
Training accuracy: 0.99805
Testing loss: 0.03537440080436931
Testing accuracy: 0.9905
Epoch 13
-----
Training loss: 0.005205267905775933
Training accuracy: 0.9984
Testing loss: 0.030243842845593345
Testing accuracy: 0.9916
Epoch 14
-----
Training loss: 0.007195832413398117
Training accuracy: 0.9976
Testing loss: 0.032048209963106596
```

```
Testing accuracy: 0.9922
Epoch 15
-----
Training loss: 0.005225377206901127
Training accuracy: 0.9984833333333333
Testing loss: 0.027778236635478293
Testing accuracy: 0.9927
Epoch 16
-----
Training loss: 0.003593238151553184
Training accuracy: 0.99895
Testing loss: 0.03189007550959886
Testing accuracy: 0.992
Epoch 17
-----
Training loss: 0.002132624687409043
Training accuracy: 0.9994333333333333
Testing loss: 0.03282472175654186
Testing accuracy: 0.9915
Epoch 18
-----
Training loss: 0.001699292831444897
Training accuracy: 0.9996
Testing loss: 0.030260698866503594
Testing accuracy: 0.9916
Epoch 19
-----
Training loss: 0.0017564585627257354
Training accuracy: 0.9996
Testing loss: 0.030073395068647316
Testing accuracy: 0.992
Epoch 20
-----
Training loss: 0.001222474517490476
Training accuracy: 0.9996833333333334
Testing loss: 0.029722488879395475
Testing accuracy: 0.9923
Epoch 21
-----
Training loss: 0.00043315542524111756
Training accuracy: 0.9999
Testing loss: 0.1219948995738169
Testing accuracy: 0.9789
Epoch 22
-----
Training loss: 0.010620355884790478
Training accuracy: 0.9968833333333333
Testing loss: 0.038693682485436684
```

```
Testing accuracy: 0.9904
Epoch 23
-----
Training loss: 0.002556240227820429
Training accuracy: 0.99915
Testing loss: 0.0325917876521958
Testing accuracy: 0.9926
Epoch 24
-----
Training loss: 0.002440469345690781
Training accuracy: 0.9993166666666666
Testing loss: 0.034291039379681094
Testing accuracy: 0.9922
Epoch 25
-----
Training loss: 0.002596453193707263
Training accuracy: 0.99905
Testing loss: 0.03695142836865445
Testing accuracy: 0.9909
Epoch 26
-----
Training loss: 0.0020739269339510127
Training accuracy: 0.9993666666666666
Testing loss: 0.048508351182993896
Testing accuracy: 0.9889
Epoch 27
-----
Training loss: 0.0016028300318438444
Training accuracy: 0.9996333333333334
Testing loss: 0.030299432202687555
Testing accuracy: 0.9933
Epoch 28
-----
Training loss: 0.0002804254375883678
Training accuracy: 0.9999333333333333
Testing loss: 0.03119423092627779
Testing accuracy: 0.9927
Epoch 29
-----
Training loss: 0.00014366165891932118
Training accuracy: 1.0
Testing loss: 0.03069268227716067
Testing accuracy: 0.993
Epoch 30
-----
Training loss: 0.00010800125903869761
Training accuracy: 0.9999833333333333
Testing loss: 0.033448687237855435
```



```
Testing accuracy: 0.993
Epoch 31
-----
Training loss: 0.00014788276811287537
Training accuracy: 0.9999833333333333
Testing loss: 0.03316123218577978
Testing accuracy: 0.9928
Epoch 32
-----
Training loss: 0.00010592366287674888
Training accuracy: 1.0
Testing loss: 0.03222036554548216
Testing accuracy: 0.9928
Epoch 33
-----
Training loss: 7.618500502845696e-05
Training accuracy: 1.0
Testing loss: 0.03302794850017494
Testing accuracy: 0.9928
Epoch 34
-----
Training loss: 6.8334635127583e-05
Training accuracy: 1.0
Testing loss: 0.032805821656144464
Testing accuracy: 0.9933
Epoch 35
-----
Training loss: 5.7367352007167936e-05
Training accuracy: 1.0
Testing loss: 0.032756703010450285
Testing accuracy: 0.9932
Epoch 36
-----
Training loss: 4.776970844171634e-05
Training accuracy: 1.0
Testing loss: 0.03385450132530479
Testing accuracy: 0.993
Epoch 37
-----
Training loss: 5.428301301455711e-05
Training accuracy: 1.0
Testing loss: 0.03373138517691021
Testing accuracy: 0.993
Epoch 38
-----
Training loss: 4.5741893015468804e-05
Training accuracy: 1.0
Testing loss: 0.03484593865006841
```

```
Testing accuracy: 0.9932
Epoch 39
-----
Training loss: 4.5481689778371974e-05
Training accuracy: 1.0
Testing loss: 0.03337783074114828
Testing accuracy: 0.9927
Epoch 40
-----
Training loss: 4.155455058635293e-05
Training accuracy: 1.0
Testing loss: 0.03355695147153039
Testing accuracy: 0.9934
Epoch 41
-----
Training loss: 4.797791950906477e-05
Training accuracy: 1.0
Testing loss: 0.03357669590704978
Testing accuracy: 0.993
Epoch 42
-----
Training loss: 3.764361538716704e-05
Training accuracy: 1.0
Testing loss: 0.03339869040239806
Testing accuracy: 0.9934
Epoch 43
-----
Training loss: 3.627036719130056e-05
Training accuracy: 1.0
Testing loss: 0.03346072727456713
Testing accuracy: 0.9935
Epoch 44
-----
Training loss: 3.022876079798292e-05
Training accuracy: 1.0
Testing loss: 0.03479030343180317
Testing accuracy: 0.9928
Epoch 45
-----
Training loss: 2.7773942025562567e-05
Training accuracy: 1.0
Testing loss: 0.034358961258495364
Testing accuracy: 0.9934
Epoch 46
-----
Training loss: 2.8204786366499945e-05
Training accuracy: 1.0
Testing loss: 0.03494137789954897
```

```
Testing accuracy: 0.9927
Epoch 47
-----
Training loss: 2.7107578638217453e-05
Training accuracy: 1.0
Testing loss: 0.03624638714908312
Testing accuracy: 0.9921
Epoch 48
-----
Training loss: 2.4985228009006968e-05
Training accuracy: 1.0
Testing loss: 0.03478535238570696
Testing accuracy: 0.9932
Epoch 49
-----
Training loss: 2.2486687743438813e-05
Training accuracy: 1.0
Testing loss: 0.03564842296030267
Testing accuracy: 0.9924
Epoch 50
-----
Training loss: 2.4767468564549708e-05
Training accuracy: 1.0
Testing loss: 0.036447923485125384
Testing accuracy: 0.9931
Epoch 51
-----
Training loss: 2.5132027896788855e-05
Training accuracy: 1.0
Testing loss: 0.03686401544313576
Testing accuracy: 0.9922
Epoch 52
-----
Training loss: 2.4457685181436162e-05
Training accuracy: 1.0
Testing loss: 0.035958693505336994
Testing accuracy: 0.9932
Epoch 53
-----
Training loss: 2.9195748785504705e-05
Training accuracy: 1.0
Testing loss: 0.036904534849846925
Testing accuracy: 0.9925
Epoch 54
-----
Training loss: 2.0333020705414264e-05
Training accuracy: 1.0
Testing loss: 0.03769756659754278
```

```
Testing accuracy: 0.9923
Epoch 55
-----
Training loss: 1.857289832747734e-05
Training accuracy: 1.0
Testing loss: 0.03627732190401642
Testing accuracy: 0.9924
Epoch 56
-----
Training loss: 1.926780069296292e-05
Training accuracy: 1.0
Testing loss: 0.03831204024385944
Testing accuracy: 0.9929
Epoch 57
-----
Training loss: 2.035142970436953e-05
Training accuracy: 1.0
Testing loss: 0.036911201422370636
Testing accuracy: 0.9935
Epoch 58
-----
Training loss: 1.9550796660760975e-05
Training accuracy: 1.0
Testing loss: 0.03629953036082121
Testing accuracy: 0.9937
Epoch 59
-----
Training loss: 1.741082709994449e-05
Training accuracy: 1.0
Testing loss: 0.03604405942519813
Testing accuracy: 0.993
Epoch 60
-----
Training loss: 1.5707120491687358e-05
Training accuracy: 1.0
Testing loss: 0.03618372533666801
Testing accuracy: 0.9932
Epoch 61
-----
Training loss: 1.592278144941801e-05
Training accuracy: 1.0
Testing loss: 0.036545188373277526
Testing accuracy: 0.9926
Epoch 62
-----
Training loss: 1.6835084628090394e-05
Training accuracy: 1.0
Testing loss: 0.03557461039969391
```

Testing accuracy: 0.9932  
Epoch 63  
-----  
Training loss: 1.5887613990518308e-05  
Training accuracy: 1.0  
Testing loss: 0.036326100588725325  
Testing accuracy: 0.9928  
Epoch 64  
-----  
Training loss: 1.5224194325150838e-05  
Training accuracy: 1.0  
Testing loss: 0.037012322102121714  
Testing accuracy: 0.9932  
Epoch 65  
-----  
Training loss: 1.4479444370647106e-05  
Training accuracy: 1.0  
Testing loss: 0.037719903568274524  
Testing accuracy: 0.9926  
Epoch 66  
-----  
Training loss: 1.2665801534086185e-05  
Training accuracy: 1.0  
Testing loss: 0.03622714709175527  
Testing accuracy: 0.993  
Epoch 67  
-----  
Training loss: 1.3239629755847205e-05  
Training accuracy: 1.0  
Testing loss: 0.03765624854999654  
Testing accuracy: 0.9931  
Epoch 68  
-----  
Training loss: 1.55838100369247e-05  
Training accuracy: 1.0  
Testing loss: 0.03657665264219368  
Testing accuracy: 0.9929  
Epoch 69  
-----  
Training loss: 1.3995705536695506e-05  
Training accuracy: 1.0  
Testing loss: 0.03806512608732511  
Testing accuracy: 0.9933  
Epoch 70  
-----  
Training loss: 1.4156722248852086e-05  
Training accuracy: 1.0  
Testing loss: 0.037521937082859495

```
Testing accuracy: 0.9925
Epoch 71
-----
Training loss: 1.2039146984659628e-05
Training accuracy: 1.0
Testing loss: 0.03609252165728329
Testing accuracy: 0.9939
Epoch 72
-----
Training loss: 1.2664620225198556e-05
Training accuracy: 1.0
Testing loss: 0.03878439832395942
Testing accuracy: 0.9928
Epoch 73
-----
Training loss: 1.3045518242541594e-05
Training accuracy: 1.0
Testing loss: 0.03642547564946531
Testing accuracy: 0.9933
Epoch 74
-----
Training loss: 1.2027397655264001e-05
Training accuracy: 1.0
Testing loss: 0.03690317761074436
Testing accuracy: 0.9926
Epoch 75
-----
Training loss: 1.2329365047766197e-05
Training accuracy: 1.0
Testing loss: 0.03914570050129199
Testing accuracy: 0.9926
Epoch 76
-----
Training loss: 1.0888022636321774e-05
Training accuracy: 1.0
Testing loss: 0.03807899060907916
Testing accuracy: 0.993
Epoch 77
-----
Training loss: 1.3172026903304258e-05
Training accuracy: 1.0
Testing loss: 0.03756884585768402
Testing accuracy: 0.9932
Epoch 78
-----
Training loss: 1.222179787637548e-05
Training accuracy: 1.0
Testing loss: 0.03684630488561334
```

```
Testing accuracy: 0.9932
Epoch 79
-----
Training loss: 1.4359652303244749e-05
Training accuracy: 1.0
Testing loss: 0.03773811858958689
Testing accuracy: 0.993
Epoch 80
-----
Training loss: 1.279906353365483e-05
Training accuracy: 1.0
Testing loss: 0.036881554327090955
Testing accuracy: 0.993
Epoch 81
-----
Training loss: 1.0878828863833334e-05
Training accuracy: 1.0
Testing loss: 0.03629745445278629
Testing accuracy: 0.9935
Epoch 82
-----
Training loss: 1.0405607892654936e-05
Training accuracy: 1.0
Testing loss: 0.03743095774217764
Testing accuracy: 0.993
Epoch 83
-----
Training loss: 1.0497835221134721e-05
Training accuracy: 1.0
Testing loss: 0.03755928278049847
Testing accuracy: 0.9931
Epoch 84
-----
Training loss: 1.1029322845482999e-05
Training accuracy: 1.0
Testing loss: 0.03676919018195938
Testing accuracy: 0.9932
Epoch 85
-----
Training loss: 1.0564072196091108e-05
Training accuracy: 1.0
Testing loss: 0.037479834875430836
Testing accuracy: 0.9931
Epoch 86
-----
Training loss: 9.315984149775029e-06
Training accuracy: 1.0
Testing loss: 0.03749358708206959
```

```
Testing accuracy: 0.9929
Epoch 87
-----
Training loss: 1.1008274150005921e-05
Training accuracy: 1.0
Testing loss: 0.03771851457326755
Testing accuracy: 0.993
Epoch 88
-----
Training loss: 1.2647915461349157e-05
Training accuracy: 1.0
Testing loss: 0.03848841561192357
Testing accuracy: 0.9927
Epoch 89
-----
Training loss: 9.665445454388433e-06
Training accuracy: 1.0
Testing loss: 0.037769509153521785
Testing accuracy: 0.9929
Epoch 90
-----
Training loss: 1.1298775953174337e-05
Training accuracy: 1.0
Testing loss: 0.038188583828698636
Testing accuracy: 0.9933
Epoch 91
-----
Training loss: 1.080924177608118e-05
Training accuracy: 1.0
Testing loss: 0.037971399075186124
Testing accuracy: 0.9934
Epoch 92
-----
Training loss: 8.566411484450735e-06
Training accuracy: 1.0
Testing loss: 0.03808695835294007
Testing accuracy: 0.9929
Epoch 93
-----
Training loss: 8.960398687202798e-06
Training accuracy: 1.0
Testing loss: 0.03758774938733193
Testing accuracy: 0.9933
Epoch 94
-----
Training loss: 1.1367850174242023e-05
Training accuracy: 1.0
Testing loss: 0.03891844804873643
```



Testing accuracy: 0.9928  
Epoch 95  
-----  
Training loss: 1.1114933199389417e-05  
Training accuracy: 1.0  
Testing loss: 0.03844763389069457  
Testing accuracy: 0.993  
Epoch 96  
-----  
Training loss: 9.604509106692304e-06  
Training accuracy: 1.0  
Testing loss: 0.03769174745393057  
Testing accuracy: 0.9933  
Epoch 97  
-----  
Training loss: 8.60428622393113e-06  
Training accuracy: 1.0  
Testing loss: 0.03730167886599694  
Testing accuracy: 0.9931  
Epoch 98  
-----  
Training loss: 8.493341562895533e-06  
Training accuracy: 1.0  
Testing loss: 0.038630266334752535  
Testing accuracy: 0.9933  
Epoch 99  
-----  
Training loss: 8.040012689748484e-06  
Training accuracy: 1.0  
Testing loss: 0.03875593843362908  
Testing accuracy: 0.993  
Epoch 100  
-----  
Training loss: 8.524321020184188e-06  
Training accuracy: 1.0  
Testing loss: 0.03649104630207144  
Testing accuracy: 0.9935  
Epoch 101  
-----  
Training loss: 7.5272448008901685e-06  
Training accuracy: 1.0  
Testing loss: 0.03953008843356746  
Testing accuracy: 0.9932  
Epoch 102  
-----  
Training loss: 7.410584789584836e-06  
Training accuracy: 1.0  
Testing loss: 0.03778345100548079

```
Testing accuracy: 0.9935
Epoch 103
-----
Training loss: 7.277842772500876e-06
Training accuracy: 1.0
Testing loss: 0.03863787528163675
Testing accuracy: 0.9931
Epoch 104
-----
Training loss: 7.126900463428498e-06
Training accuracy: 1.0
Testing loss: 0.0393080948395476
Testing accuracy: 0.9931
Epoch 105
-----
Training loss: 7.72049852242039e-06
Training accuracy: 1.0
Testing loss: 0.044024445828855285
Testing accuracy: 0.9927
Epoch 106
-----
Training loss: 7.955984042540484e-06
Training accuracy: 1.0
Testing loss: 0.03797984233700329
Testing accuracy: 0.9932
Epoch 107
-----
Training loss: 7.573548771287619e-06
Training accuracy: 1.0
Testing loss: 0.03837378870014773
Testing accuracy: 0.9936
Epoch 108
-----
Training loss: 6.904358682509581e-06
Training accuracy: 1.0
Testing loss: 0.03924236695027973
Testing accuracy: 0.9928
Epoch 109
-----
Training loss: 7.634126087158203e-06
Training accuracy: 1.0
Testing loss: 0.03941870784284293
Testing accuracy: 0.993
Epoch 110
-----
Training loss: 6.893761644302998e-06
Training accuracy: 1.0
Testing loss: 0.041652535337755495
```

Testing accuracy: 0.9939  
Epoch 111  
-----  
Training loss: 7.183880133042208e-06  
Training accuracy: 1.0  
Testing loss: 0.03831688106530334  
Testing accuracy: 0.993  
Epoch 112  
-----  
Training loss: 6.812475373778189e-06  
Training accuracy: 1.0  
Testing loss: 0.038034924989450374  
Testing accuracy: 0.9938  
Epoch 113  
-----  
Training loss: 6.768713765235053e-06  
Training accuracy: 1.0  
Testing loss: 0.03801376461883529  
Testing accuracy: 0.9929  
Epoch 114  
-----  
Training loss: 6.265171076723419e-06  
Training accuracy: 1.0  
Testing loss: 0.040612995073353884  
Testing accuracy: 0.9923  
Epoch 115  
-----  
Training loss: 6.770169132749023e-06  
Training accuracy: 1.0  
Testing loss: 0.03952987221583457  
Testing accuracy: 0.993  
Epoch 116  
-----  
Training loss: 6.361069101267228e-06  
Training accuracy: 1.0  
Testing loss: 0.04071940468585285  
Testing accuracy: 0.9926  
Epoch 117  
-----  
Training loss: 6.2665103324665236e-06  
Training accuracy: 1.0  
Testing loss: 0.03907305518993577  
Testing accuracy: 0.9934  
Epoch 118  
-----  
Training loss: 6.583375084612916e-06  
Training accuracy: 1.0  
Testing loss: 0.03907703981911733

```
Testing accuracy: 0.9931
Epoch 119
-----
Training loss: 6.499026717222971e-06
Training accuracy: 1.0
Testing loss: 0.039249472936407404
Testing accuracy: 0.9928
Epoch 120
-----
Training loss: 5.973557631120367e-06
Training accuracy: 1.0
Testing loss: 0.03978875366730323
Testing accuracy: 0.9928
Epoch 121
-----
Training loss: 6.34465655565298e-06
Training accuracy: 1.0
Testing loss: 0.03988875747856368
Testing accuracy: 0.9925
Epoch 122
-----
Training loss: 5.872939495169168e-06
Training accuracy: 1.0
Testing loss: 0.03913823051010579
Testing accuracy: 0.9933
Epoch 123
-----
Training loss: 6.650856684599778e-06
Training accuracy: 1.0
Testing loss: 0.03812232034484224
Testing accuracy: 0.9938
Epoch 124
-----
Training loss: 6.3591919940356215e-06
Training accuracy: 1.0
Testing loss: 0.03854710540574209
Testing accuracy: 0.9933
Epoch 125
-----
Training loss: 6.276720479852216e-06
Training accuracy: 1.0
Testing loss: 0.0394851445361731
Testing accuracy: 0.9928
Epoch 126
-----
Training loss: 6.4419403878221244e-06
Training accuracy: 1.0
Testing loss: 0.03954414420224707
```

Testing accuracy: 0.9934  
Epoch 127  
-----  
Training loss: 1.2247107689553497e-05  
Training accuracy: 1.0  
Testing loss: 0.03939837854311626  
Testing accuracy: 0.9928  
Epoch 128  
-----  
Training loss: 7.691056608956497e-06  
Training accuracy: 1.0  
Testing loss: 0.041033607847354055  
Testing accuracy: 0.993  
Epoch 129  
-----  
Training loss: 7.042922090398681e-06  
Training accuracy: 1.0  
Testing loss: 0.04009997054205273  
Testing accuracy: 0.9932  
Epoch 130  
-----  
Training loss: 5.878386541970926e-06  
Training accuracy: 1.0  
Testing loss: 0.03984043030732757  
Testing accuracy: 0.9929  
Epoch 131  
-----  
Training loss: 5.6230203525404455e-06  
Training accuracy: 1.0  
Testing loss: 0.03984784600608049  
Testing accuracy: 0.9932  
Epoch 132  
-----  
Training loss: 6.190158521033714e-06  
Training accuracy: 1.0  
Testing loss: 0.040934256630078124  
Testing accuracy: 0.9928  
Epoch 133  
-----  
Training loss: 6.53787907236989e-06  
Training accuracy: 1.0  
Testing loss: 0.03963493964761869  
Testing accuracy: 0.9929  
Epoch 134  
-----  
Training loss: 5.672078898883252e-06  
Training accuracy: 1.0  
Testing loss: 0.04067403510203906

```
Testing accuracy: 0.9933
Epoch 135
-----
Training loss: 5.552181696231055e-06
Training accuracy: 1.0
Testing loss: 0.0397533108911313
Testing accuracy: 0.993
Epoch 136
-----
Training loss: 5.2132676596582905e-06
Training accuracy: 1.0
Testing loss: 0.04027258284286145
Testing accuracy: 0.9928
Epoch 137
-----
Training loss: 5.0401214696169204e-06
Training accuracy: 1.0
Testing loss: 0.04043481917751398
Testing accuracy: 0.9929
Epoch 138
-----
Training loss: 5.040802923594375e-06
Training accuracy: 1.0
Testing loss: 0.040012407436171474
Testing accuracy: 0.993
Epoch 139
-----
Training loss: 4.923786942659447e-06
Training accuracy: 1.0
Testing loss: 0.03957686848101758
Testing accuracy: 0.9931
Epoch 140
-----
Training loss: 4.58799565900172e-06
Training accuracy: 1.0
Testing loss: 0.03863222574140354
Testing accuracy: 0.9929
Epoch 141
-----
Training loss: 5.056455416250453e-06
Training accuracy: 1.0
Testing loss: 0.03876661355924117
Testing accuracy: 0.9934
Epoch 142
-----
Training loss: 5.761898009214287e-06
Training accuracy: 1.0
Testing loss: 0.04133491318590776
```

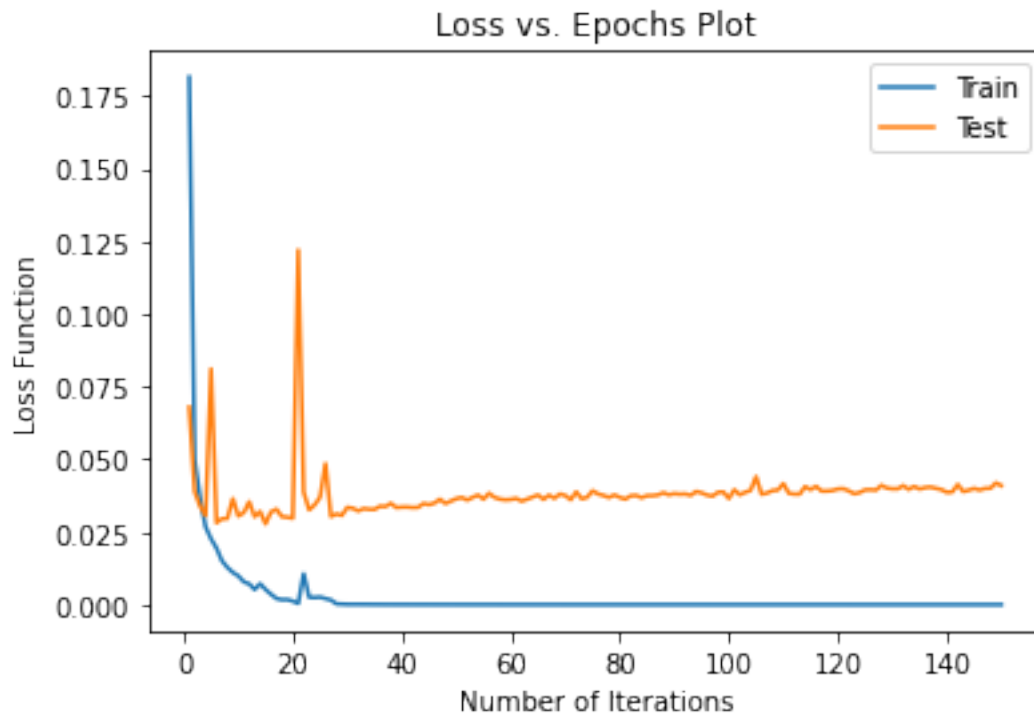
```
Testing accuracy: 0.9925
Epoch 143
-----
Training loss: 4.717113129878333e-06
Training accuracy: 1.0
Testing loss: 0.038898815887822735
Testing accuracy: 0.9936
Epoch 144
-----
Training loss: 5.140151931243508e-06
Training accuracy: 1.0
Testing loss: 0.03934538917735486
Testing accuracy: 0.9933
Epoch 145
-----
Training loss: 5.14306861737334e-06
Training accuracy: 1.0
Testing loss: 0.03998215290989094
Testing accuracy: 0.9933
Epoch 146
-----
Training loss: 6.649423876181615e-06
Training accuracy: 1.0
Testing loss: 0.039419567705241985
Testing accuracy: 0.9934
Epoch 147
-----
Training loss: 4.762724557276362e-06
Training accuracy: 1.0
Testing loss: 0.03997581643517876
Testing accuracy: 0.9933
Epoch 148
-----
Training loss: 5.021514747297573e-06
Training accuracy: 1.0
Testing loss: 0.04001449196087214
Testing accuracy: 0.9929
Epoch 149
-----
Training loss: 5.0625996964041535e-06
Training accuracy: 1.0
Testing loss: 0.04185487570073184
Testing accuracy: 0.9927
Epoch 150
-----
Training loss: 5.131235439945551e-06
Training accuracy: 1.0
Testing loss: 0.04092913825159425
```

Testing accuracy: 0.9931

Done

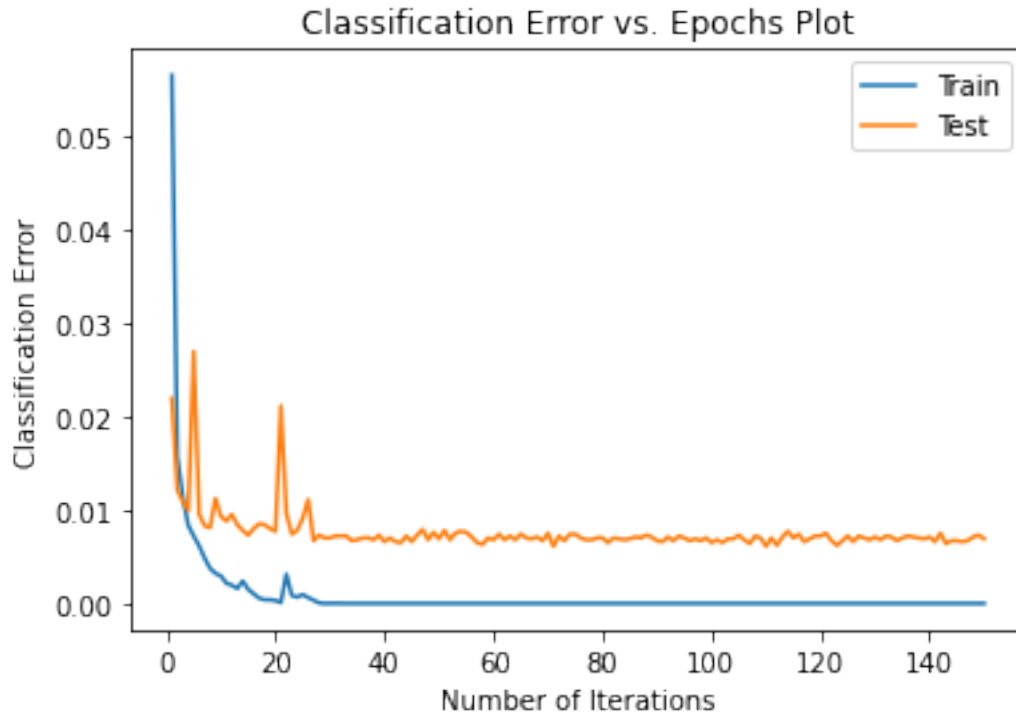
Total Time Consumed: 3915.7037913799286

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```





### 5.9.3 Learning Rate = 0.5

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.5
batch_size = 64
num_epochs = 150
lenet_lr5 = LeNet5(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(lenet_lr5.parameters(), lr = learning_rate)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size,
    ↪ shuffle = True)
test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle
    ↪ = True)
```

```

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, lenet_lr5, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, lenet_lr5, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.21703040427838763
Training accuracy: 0.9325
Testing loss: 0.06896933227937645
Testing accuracy: 0.9799

```

Epoch 2

```

-----
Training loss: 0.055042807489757734
Training accuracy: 0.9832833333333333
Testing loss: 0.05495754222587273
Testing accuracy: 0.9834

```

Epoch 3

```

-----
Training loss: 0.04120508547729502
Training accuracy: 0.98745
Testing loss: 0.07400287756886167
Testing accuracy: 0.9774

```

Epoch 4

```

-----
Training loss: 0.0316856589142854
Training accuracy: 0.99005
Testing loss: 0.042369604229357594
Testing accuracy: 0.9877

```

Epoch 5

```

-----
Training loss: 0.02660630459910414
Training accuracy: 0.9916833333333334
Testing loss: 0.07389882639507248
Testing accuracy: 0.9784

```

Epoch 6

```

-----
Training loss: 0.023085295110878847
Training accuracy: 0.99285
Testing loss: 0.03407763715977647

```

```
Testing accuracy: 0.9891
Epoch 7
-----
Training loss: 0.01969771814712634
Training accuracy: 0.9937166666666667
Testing loss: 0.04106518867367042
Testing accuracy: 0.9873
Epoch 8
-----
Training loss: 0.01665150822219827
Training accuracy: 0.9947166666666667
Testing loss: 0.04487779281627843
Testing accuracy: 0.9874
Epoch 9
-----
Training loss: 0.013576598716393346
Training accuracy: 0.9956666666666667
Testing loss: 0.040076961680094836
Testing accuracy: 0.9886
Epoch 10
-----
Training loss: 0.01400309455272897
Training accuracy: 0.9956166666666667
Testing loss: 0.0405403308967643
Testing accuracy: 0.9889
Epoch 11
-----
Training loss: 0.01223670397248643
Training accuracy: 0.9961
Testing loss: 0.03449236026260982
Testing accuracy: 0.99
Epoch 12
-----
Training loss: 0.011810750257866555
Training accuracy: 0.9962833333333333
Testing loss: 0.034725733009178784
Testing accuracy: 0.9915
Epoch 13
-----
Training loss: 0.01061492558157964
Training accuracy: 0.99665
Testing loss: 0.03591440234004329
Testing accuracy: 0.9917
Epoch 14
-----
Training loss: 0.008154360064176823
Training accuracy: 0.9974166666666666
Testing loss: 0.03562671506823903
```

```
Testing accuracy: 0.991
Epoch 15
-----
Training loss: 0.008910284467863433
Training accuracy: 0.9970666666666667
Testing loss: 0.038142667945009
Testing accuracy: 0.9907
Epoch 16
-----
Training loss: 0.00797409962979121
Training accuracy: 0.9974666666666666
Testing loss: 0.03863246266614711
Testing accuracy: 0.9904
Epoch 17
-----
Training loss: 0.007513484189246568
Training accuracy: 0.99745
Testing loss: 0.03670974385246606
Testing accuracy: 0.9911
Epoch 18
-----
Training loss: 0.004849689497489938
Training accuracy: 0.9986
Testing loss: 0.03766001996330192
Testing accuracy: 0.9916
Epoch 19
-----
Training loss: 0.003305581162385594
Training accuracy: 0.9990666666666667
Testing loss: 0.04372929179534234
Testing accuracy: 0.9909
Epoch 20
-----
Training loss: 0.005608468134839435
Training accuracy: 0.9984
Testing loss: 0.038094457134978194
Testing accuracy: 0.991
Epoch 21
-----
Training loss: 0.0054387461404519855
Training accuracy: 0.9981
Testing loss: 0.04064863594143948
Testing accuracy: 0.9915
Epoch 22
-----
Training loss: 0.00661039535495341
Training accuracy: 0.99785
Testing loss: 0.04150438209717575
```

```
Testing accuracy: 0.991
Epoch 23
-----
Training loss: 0.005788316931493803
Training accuracy: 0.99825
Testing loss: 0.03706433478068873
Testing accuracy: 0.9925
Epoch 24
-----
Training loss: 0.004460552774276736
Training accuracy: 0.99875
Testing loss: 0.056787220181379945
Testing accuracy: 0.9886
Epoch 25
-----
Training loss: 0.005411899377931634
Training accuracy: 0.9984
Testing loss: 0.050502544816314984
Testing accuracy: 0.9903
Epoch 26
-----
Training loss: 0.005659570256568592
Training accuracy: 0.9982333333333333
Testing loss: 0.04997525461221436
Testing accuracy: 0.9897
Epoch 27
-----
Training loss: 0.005942561842489552
Training accuracy: 0.9982
Testing loss: 0.04253660269662638
Testing accuracy: 0.9912
Epoch 28
-----
Training loss: 0.004760185713646812
Training accuracy: 0.9985
Testing loss: 0.05038077561293266
Testing accuracy: 0.9905
Epoch 29
-----
Training loss: 0.0034263608423950854
Training accuracy: 0.9989
Testing loss: 0.04587120306119725
Testing accuracy: 0.9907
Epoch 30
-----
Training loss: 0.004348716520307387
Training accuracy: 0.99865
Testing loss: 0.06407627432440895
```

```
Testing accuracy: 0.9882
Epoch 31
-----
Training loss: 0.005126387689486697
Training accuracy: 0.99845
Testing loss: 0.06072040227006326
Testing accuracy: 0.989
Epoch 32
-----
Training loss: 0.004422908905026937
Training accuracy: 0.9986833333333334
Testing loss: 0.05698745935220615
Testing accuracy: 0.9899
Epoch 33
-----
Training loss: 0.0028860570072191537
Training accuracy: 0.9991833333333333
Testing loss: 0.058452218190135956
Testing accuracy: 0.9894
Epoch 34
-----
Training loss: 0.0008326239263335007
Training accuracy: 0.99975
Testing loss: 0.048542795243092206
Testing accuracy: 0.9914
Epoch 35
-----
Training loss: 0.00025943584930886155
Training accuracy: 0.9999333333333333
Testing loss: 0.050002985829399514
Testing accuracy: 0.9917
Epoch 36
-----
Training loss: 0.0003009774016076719
Training accuracy: 0.9999
Testing loss: 0.05207401777946973
Testing accuracy: 0.9921
Epoch 37
-----
Training loss: 8.090988997974052e-05
Training accuracy: 0.9999833333333333
Testing loss: 0.05296934662425115
Testing accuracy: 0.9922
Epoch 38
-----
Training loss: 5.31432690354747e-05
Training accuracy: 1.0
Testing loss: 0.05464082651489968
```

```
Testing accuracy: 0.9918
Epoch 39
-----
Training loss: 3.462202428351364e-05
Training accuracy: 1.0
Testing loss: 0.05367641715381159
Testing accuracy: 0.9924
Epoch 40
-----
Training loss: 2.92761248019963e-05
Training accuracy: 1.0
Testing loss: 0.05389371586859138
Testing accuracy: 0.9915
Epoch 41
-----
Training loss: 2.6384798742876826e-05
Training accuracy: 1.0
Testing loss: 0.05509181515903209
Testing accuracy: 0.9923
Epoch 42
-----
Training loss: 2.3262712355737727e-05
Training accuracy: 1.0
Testing loss: 0.05535830087164803
Testing accuracy: 0.9919
Epoch 43
-----
Training loss: 1.8871785842813673e-05
Training accuracy: 1.0
Testing loss: 0.05498640040070931
Testing accuracy: 0.9922
Epoch 44
-----
Training loss: 1.656794299159176e-05
Training accuracy: 1.0
Testing loss: 0.05569084976741001
Testing accuracy: 0.9917
Epoch 45
-----
Training loss: 1.4682273513408006e-05
Training accuracy: 1.0
Testing loss: 0.05688046442371668
Testing accuracy: 0.9921
Epoch 46
-----
Training loss: 1.5588041685148823e-05
Training accuracy: 1.0
Testing loss: 0.05712691433994259
```

```
Testing accuracy: 0.9919
Epoch 47
-----
Training loss: 1.4746465939461592e-05
Training accuracy: 1.0
Testing loss: 0.05754108090185383
Testing accuracy: 0.9914
Epoch 48
-----
Training loss: 1.2203487570646961e-05
Training accuracy: 1.0
Testing loss: 0.05772423662317405
Testing accuracy: 0.9922
Epoch 49
-----
Training loss: 1.6127422314672893e-05
Training accuracy: 1.0
Testing loss: 0.06309443615383635
Testing accuracy: 0.9913
Epoch 50
-----
Training loss: 3.321260260945588e-05
Training accuracy: 1.0
Testing loss: 0.06172389021657855
Testing accuracy: 0.9915
Epoch 51
-----
Training loss: 1.225536220959486e-05
Training accuracy: 1.0
Testing loss: 0.05721432822693102
Testing accuracy: 0.992
Epoch 52
-----
Training loss: 1.0974550346751854e-05
Training accuracy: 1.0
Testing loss: 0.060652830396415426
Testing accuracy: 0.9922
Epoch 53
-----
Training loss: 1.0288842596962767e-05
Training accuracy: 1.0
Testing loss: 0.060001883229824936
Testing accuracy: 0.992
Epoch 54
-----
Training loss: 1.023661500145631e-05
Training accuracy: 1.0
Testing loss: 0.060846211126193185
```



Testing accuracy: 0.9919  
Epoch 55  
-----  
Training loss: 8.95889036119281e-06  
Training accuracy: 1.0  
Testing loss: 0.06037680512365635  
Testing accuracy: 0.9917  
Epoch 56  
-----  
Training loss: 8.626123372511192e-06  
Training accuracy: 1.0  
Testing loss: 0.06141764674040234  
Testing accuracy: 0.9921  
Epoch 57  
-----  
Training loss: 8.530466057399976e-06  
Training accuracy: 1.0  
Testing loss: 0.060904905684273064  
Testing accuracy: 0.9923  
Epoch 58  
-----  
Training loss: 7.2650170389772245e-06  
Training accuracy: 1.0  
Testing loss: 0.06090755729948439  
Testing accuracy: 0.992  
Epoch 59  
-----  
Training loss: 6.499201706312618e-06  
Training accuracy: 1.0  
Testing loss: 0.05947959196309289  
Testing accuracy: 0.992  
Epoch 60  
-----  
Training loss: 7.191883920904256e-06  
Training accuracy: 1.0  
Testing loss: 0.06038891271796762  
Testing accuracy: 0.9915  
Epoch 61  
-----  
Training loss: 6.356177399770857e-06  
Training accuracy: 1.0  
Testing loss: 0.06156574756423872  
Testing accuracy: 0.9917  
Epoch 62  
-----  
Training loss: 6.1290905461498585e-06  
Training accuracy: 1.0  
Testing loss: 0.06042785425698118

```
Testing accuracy: 0.9918
Epoch 63
-----
Training loss: 6.659078530566731e-06
Training accuracy: 1.0
Testing loss: 0.061550642016232816
Testing accuracy: 0.9922
Epoch 64
-----
Training loss: 5.996334155805035e-06
Training accuracy: 1.0
Testing loss: 0.05884259629354177
Testing accuracy: 0.9921
Epoch 65
-----
Training loss: 5.679212068657217e-06
Training accuracy: 1.0
Testing loss: 0.06147203274973625
Testing accuracy: 0.9923
Epoch 66
-----
Training loss: 5.377868635875297e-06
Training accuracy: 1.0
Testing loss: 0.0662169549428078
Testing accuracy: 0.9919
Epoch 67
-----
Training loss: 4.959870987516268e-06
Training accuracy: 1.0
Testing loss: 0.06113635747275192
Testing accuracy: 0.9921
Epoch 68
-----
Training loss: 5.417800782607785e-06
Training accuracy: 1.0
Testing loss: 0.06157975300595193
Testing accuracy: 0.9915
Epoch 69
-----
Training loss: 5.319640592998453e-06
Training accuracy: 1.0
Testing loss: 0.06170189519073914
Testing accuracy: 0.9919
Epoch 70
-----
Training loss: 5.63890940199947e-06
Training accuracy: 1.0
Testing loss: 0.06251150162507159
```

```
Testing accuracy: 0.9914
Epoch 71
-----
Training loss: 4.529988359781711e-06
Training accuracy: 1.0
Testing loss: 0.05992290287731323
Testing accuracy: 0.9917
Epoch 72
-----
Training loss: 4.422768929328195e-06
Training accuracy: 1.0
Testing loss: 0.06568324205299293
Testing accuracy: 0.992
Epoch 73
-----
Training loss: 4.273984783171395e-06
Training accuracy: 1.0
Testing loss: 0.0623160257201194
Testing accuracy: 0.9917
Epoch 74
-----
Training loss: 5.183193433685554e-06
Training accuracy: 1.0
Testing loss: 0.06258390098637738
Testing accuracy: 0.992
Epoch 75
-----
Training loss: 4.462279821297225e-06
Training accuracy: 1.0
Testing loss: 0.06389878573596938
Testing accuracy: 0.9921
Epoch 76
-----
Training loss: 4.200697920188053e-06
Training accuracy: 1.0
Testing loss: 0.06390325978166951
Testing accuracy: 0.9917
Epoch 77
-----
Training loss: 4.383281189732339e-06
Training accuracy: 1.0
Testing loss: 0.06388214191559755
Testing accuracy: 0.9915
Epoch 78
-----
Training loss: 4.530651813671819e-06
Training accuracy: 1.0
Testing loss: 0.061502963879405896
```

```
Testing accuracy: 0.9924
Epoch 79
-----
Training loss: 4.47071634946461e-06
Training accuracy: 1.0
Testing loss: 0.06381485022446451
Testing accuracy: 0.9917
Epoch 80
-----
Training loss: 4.458276450591943e-06
Training accuracy: 1.0
Testing loss: 0.06231812338484106
Testing accuracy: 0.992
Epoch 81
-----
Training loss: 3.7967120597297564e-06
Training accuracy: 1.0
Testing loss: 0.0632656752872263
Testing accuracy: 0.9917
Epoch 82
-----
Training loss: 4.223327084128315e-06
Training accuracy: 1.0
Testing loss: 0.0637902223671128
Testing accuracy: 0.9914
Epoch 83
-----
Training loss: 3.7145189562481327e-06
Training accuracy: 1.0
Testing loss: 0.06395506698289251
Testing accuracy: 0.9917
Epoch 84
-----
Training loss: 3.978425370531606e-06
Training accuracy: 1.0
Testing loss: 0.06347208563046776
Testing accuracy: 0.992
Epoch 85
-----
Training loss: 3.720637675534751e-06
Training accuracy: 1.0
Testing loss: 0.06655956943457642
Testing accuracy: 0.9915
Epoch 86
-----
Training loss: 3.4868800951243156e-06
Training accuracy: 1.0
Testing loss: 0.06397638537495381
```

```
Testing accuracy: 0.9917
Epoch 87
-----
Training loss: 3.7956056235159963e-06
Training accuracy: 1.0
Testing loss: 0.06419494079374544
Testing accuracy: 0.9924
Epoch 88
-----
Training loss: 3.3750988866490416e-06
Training accuracy: 1.0
Testing loss: 0.06237212055679297
Testing accuracy: 0.9918
Epoch 89
-----
Training loss: 3.3382647878379855e-06
Training accuracy: 1.0
Testing loss: 0.06373969820036747
Testing accuracy: 0.9917
Epoch 90
-----
Training loss: 3.2915343976544163e-06
Training accuracy: 1.0
Testing loss: 0.06305086733283141
Testing accuracy: 0.9918
Epoch 91
-----
Training loss: 3.0305792837040713e-06
Training accuracy: 1.0
Testing loss: 0.06371824581572484
Testing accuracy: 0.9921
Epoch 92
-----
Training loss: 2.8604449163295226e-06
Training accuracy: 1.0
Testing loss: 0.06277396802443241
Testing accuracy: 0.9917
Epoch 93
-----
Training loss: 2.852618576146071e-06
Training accuracy: 1.0
Testing loss: 0.06287547246418354
Testing accuracy: 0.992
Epoch 94
-----
Training loss: 7.137042746179389e-06
Training accuracy: 1.0
Testing loss: 0.06624987066945999
```

```
Testing accuracy: 0.9915
Epoch 95
-----
Training loss: 4.40217922594807e-06
Training accuracy: 1.0
Testing loss: 0.06338173172596133
Testing accuracy: 0.9921
Epoch 96
-----
Training loss: 3.457173885822229e-06
Training accuracy: 1.0
Testing loss: 0.06510769744956559
Testing accuracy: 0.9918
Epoch 97
-----
Training loss: 2.607477643024699e-06
Training accuracy: 1.0
Testing loss: 0.06383823463174375
Testing accuracy: 0.9922
Epoch 98
-----
Training loss: 2.7688382670068754e-06
Training accuracy: 1.0
Testing loss: 0.06747568491956923
Testing accuracy: 0.9918
Epoch 99
-----
Training loss: 2.6613314701337506e-06
Training accuracy: 1.0
Testing loss: 0.06226683385450559
Testing accuracy: 0.9924
Epoch 100
-----
Training loss: 3.0393311073331357e-06
Training accuracy: 1.0
Testing loss: 0.06408641379276678
Testing accuracy: 0.9921
Epoch 101
-----
Training loss: 3.292423535501143e-06
Training accuracy: 1.0
Testing loss: 0.06611504704038926
Testing accuracy: 0.9915
Epoch 102
-----
Training loss: 2.6185860913064593e-06
Training accuracy: 1.0
Testing loss: 0.06538149368380526
```

```
Testing accuracy: 0.9922
Epoch 103
-----
Training loss: 2.4570234249717753e-06
Training accuracy: 1.0
Testing loss: 0.0643804259942315
Testing accuracy: 0.9919
Epoch 104
-----
Training loss: 2.857886128823613e-06
Training accuracy: 1.0
Testing loss: 0.06529409298329107
Testing accuracy: 0.992
Epoch 105
-----
Training loss: 2.599949291994008e-06
Training accuracy: 1.0
Testing loss: 0.07599586613416266
Testing accuracy: 0.992
Epoch 106
-----
Training loss: 3.3269712715749005e-06
Training accuracy: 1.0
Testing loss: 0.0644607178338616
Testing accuracy: 0.9922
Epoch 107
-----
Training loss: 2.325400443149069e-06
Training accuracy: 1.0
Testing loss: 0.06485455509677414
Testing accuracy: 0.9918
Epoch 108
-----
Training loss: 2.4312186497872073e-06
Training accuracy: 1.0
Testing loss: 0.06415775838119767
Testing accuracy: 0.9919
Epoch 109
-----
Training loss: 2.379051269410226e-06
Training accuracy: 1.0
Testing loss: 0.06449576821307029
Testing accuracy: 0.9918
Epoch 110
-----
Training loss: 2.4905982740929032e-06
Training accuracy: 1.0
Testing loss: 0.06832427176040146
```

```
Testing accuracy: 0.9915
Epoch 111
-----
Training loss: 2.158104742400013e-06
Training accuracy: 1.0
Testing loss: 0.07083207811834177
Testing accuracy: 0.9913
Epoch 112
-----
Training loss: 2.3157100022311047e-06
Training accuracy: 1.0
Testing loss: 0.06422282994136064
Testing accuracy: 0.9918
Epoch 113
-----
Training loss: 2.645450989188921e-06
Training accuracy: 1.0
Testing loss: 0.06629634872519857
Testing accuracy: 0.9917
Epoch 114
-----
Training loss: 2.604420552482149e-06
Training accuracy: 1.0
Testing loss: 0.0662157200843874
Testing accuracy: 0.9916
Epoch 115
-----
Training loss: 2.078924469215456e-06
Training accuracy: 1.0
Testing loss: 0.06628338178258895
Testing accuracy: 0.9916
Epoch 116
-----
Training loss: 2.1870143518206932e-06
Training accuracy: 1.0
Testing loss: 0.06816747540249268
Testing accuracy: 0.9917
Epoch 117
-----
Training loss: 1.914145602725744e-06
Training accuracy: 1.0
Testing loss: 0.06435939204298714
Testing accuracy: 0.992
Epoch 118
-----
Training loss: 2.2355284243706326e-06
Training accuracy: 1.0
Testing loss: 0.06763831441998626
```



```
Testing accuracy: 0.9915
Epoch 119
-----
Training loss: 2.027487548946401e-06
Training accuracy: 1.0
Testing loss: 0.06612522010334153
Testing accuracy: 0.9924
Epoch 120
-----
Training loss: 2.111834583582587e-06
Training accuracy: 1.0
Testing loss: 0.06616867505855645
Testing accuracy: 0.9919
Epoch 121
-----
Training loss: 2.222603800216187e-06
Training accuracy: 1.0
Testing loss: 0.06795767604007771
Testing accuracy: 0.9921
Epoch 122
-----
Training loss: 2.2335495193298508e-06
Training accuracy: 1.0
Testing loss: 0.067784749996036
Testing accuracy: 0.9917
Epoch 123
-----
Training loss: 1.8664805682766664e-06
Training accuracy: 1.0
Testing loss: 0.06438473189732476
Testing accuracy: 0.992
Epoch 124
-----
Training loss: 1.995286599483966e-06
Training accuracy: 1.0
Testing loss: 0.06446801687649859
Testing accuracy: 0.9918
Epoch 125
-----
Training loss: 2.648042288223825e-06
Training accuracy: 1.0
Testing loss: 0.06646979450954615
Testing accuracy: 0.9916
Epoch 126
-----
Training loss: 1.8350560572515681e-06
Training accuracy: 1.0
Testing loss: 0.06759454129897731
```

```
Testing accuracy: 0.9921
Epoch 127
-----
Training loss: 1.9805709242457206e-06
Training accuracy: 1.0
Testing loss: 0.06336309331220864
Testing accuracy: 0.9921
Epoch 128
-----
Training loss: 1.958165813393009e-06
Training accuracy: 1.0
Testing loss: 0.06582615546399233
Testing accuracy: 0.9917
Epoch 129
-----
Training loss: 1.7691148924583898e-06
Training accuracy: 1.0
Testing loss: 0.06860190115898768
Testing accuracy: 0.9914
Epoch 130
-----
Training loss: 1.8277214840306754e-06
Training accuracy: 1.0
Testing loss: 0.06593790978948255
Testing accuracy: 0.9918
Epoch 131
-----
Training loss: 1.8464362759165928e-06
Training accuracy: 1.0
Testing loss: 0.06672017628723047
Testing accuracy: 0.9917
Epoch 132
-----
Training loss: 1.8507556223722094e-06
Training accuracy: 1.0
Testing loss: 0.06741740030918099
Testing accuracy: 0.9921
Epoch 133
-----
Training loss: 1.7038869182837146e-06
Training accuracy: 1.0
Testing loss: 0.0646099820929427
Testing accuracy: 0.9922
Epoch 134
-----
Training loss: 1.8808353735832857e-06
Training accuracy: 1.0
Testing loss: 0.06950868632892697
```

```
Testing accuracy: 0.9917
Epoch 135
-----
Training loss: 1.736622369269488e-06
Training accuracy: 1.0
Testing loss: 0.067080600875423
Testing accuracy: 0.992
Epoch 136
-----
Training loss: 1.6457530317506298e-06
Training accuracy: 1.0
Testing loss: 0.06868624240819415
Testing accuracy: 0.9916
Epoch 137
-----
Training loss: 1.8128167921980538e-06
Training accuracy: 1.0
Testing loss: 0.06908780886719547
Testing accuracy: 0.9917
Epoch 138
-----
Training loss: 1.682971544595091e-06
Training accuracy: 1.0
Testing loss: 0.06795473397586102
Testing accuracy: 0.9922
Epoch 139
-----
Training loss: 1.5878822969142448e-06
Training accuracy: 1.0
Testing loss: 0.06658533182940435
Testing accuracy: 0.9918
Epoch 140
-----
Training loss: 1.6310375201056122e-06
Training accuracy: 1.0
Testing loss: 0.0660810685485527
Testing accuracy: 0.992
Epoch 141
-----
Training loss: 1.6028924942615911e-06
Training accuracy: 1.0
Testing loss: 0.0661675701192775
Testing accuracy: 0.9919
Epoch 142
-----
Training loss: 1.7227320440397875e-06
Training accuracy: 1.0
Testing loss: 0.06761047022556399
```

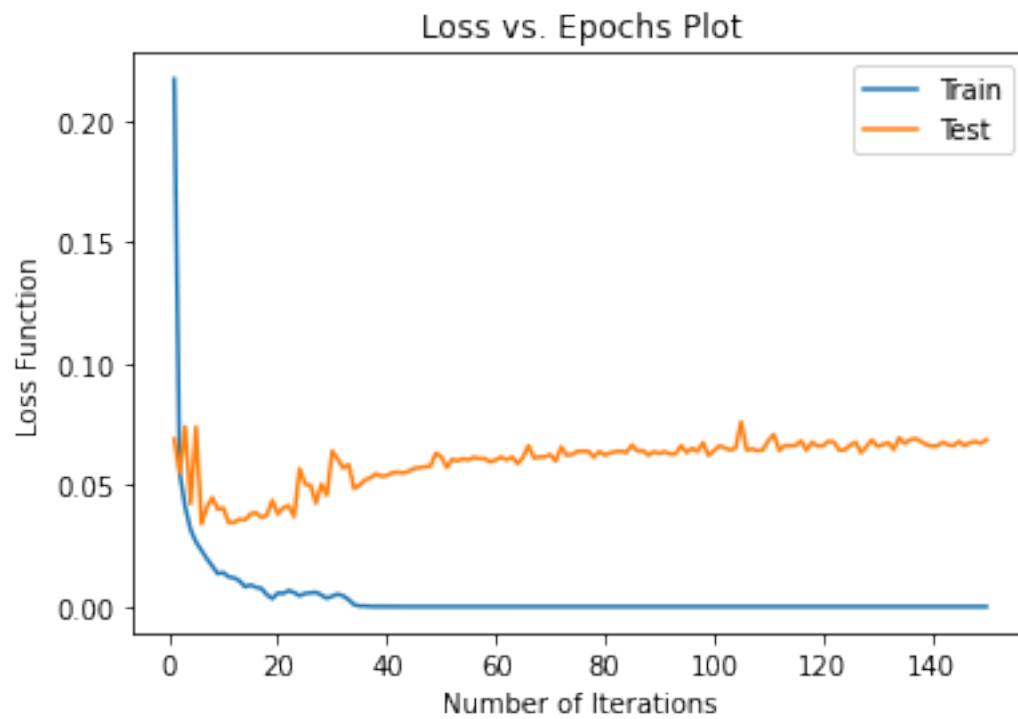
```
Testing accuracy: 0.9918
Epoch 143
-----
Training loss: 1.727663775857143e-06
Training accuracy: 1.0
Testing loss: 0.06659090574497833
Testing accuracy: 0.9915
Epoch 144
-----
Training loss: 1.4816121118094826e-06
Training accuracy: 1.0
Testing loss: 0.06628445942999124
Testing accuracy: 0.9923
Epoch 145
-----
Training loss: 1.8546865484642201e-06
Training accuracy: 1.0
Testing loss: 0.06796745905506939
Testing accuracy: 0.9922
Epoch 146
-----
Training loss: 1.963682683681256e-06
Training accuracy: 1.0
Testing loss: 0.06623026276865966
Testing accuracy: 0.9926
Epoch 147
-----
Training loss: 1.5482048146196804e-06
Training accuracy: 1.0
Testing loss: 0.06744550133410579
Testing accuracy: 0.9919
Epoch 148
-----
Training loss: 1.406682278875356e-06
Training accuracy: 1.0
Testing loss: 0.06794087455985383
Testing accuracy: 0.9916
Epoch 149
-----
Training loss: 1.8548044113316564e-06
Training accuracy: 1.0
Testing loss: 0.06711860543498284
Testing accuracy: 0.992
Epoch 150
-----
Training loss: 1.5943670391360836e-06
Training accuracy: 1.0
Testing loss: 0.06872838344718186
```

Testing accuracy: 0.9918

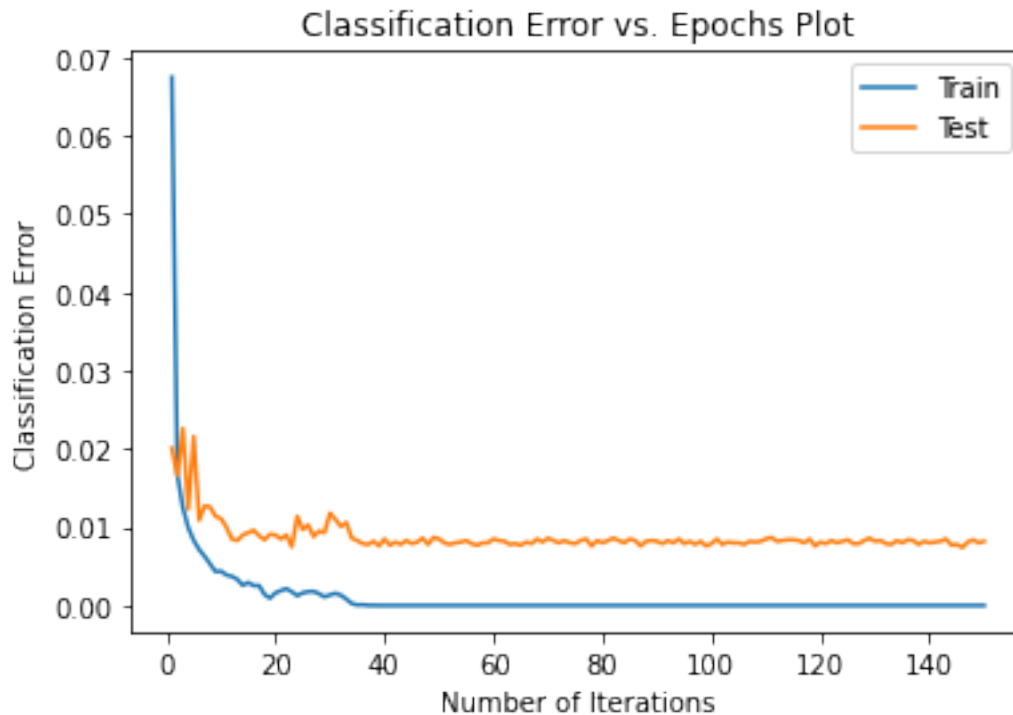
Done

Total Time Consumed: 3969.2474732398987

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



#### 5.9.4 Momentum = 0.5

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.5
lenet_m5 = LeNet5(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(lenet_m5.parameters(), lr = learning_rate, momentum = 0.5)
```

```
[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size, shuffle = True)
```

```

test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle_
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, lenet_m5, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, lenet_m5, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.14802460279762744
Training accuracy: 0.9540833333333333
Testing loss: 0.07082441506112457
Testing accuracy: 0.9775

```

Epoch 2

```

-----
Training loss: 0.049307311786711217
Training accuracy: 0.9846166666666667
Testing loss: 0.03900724802511762
Testing accuracy: 0.9869

```

Epoch 3

```

-----
Training loss: 0.035793078905840714
Training accuracy: 0.9888166666666667
Testing loss: 0.035257294713994074
Testing accuracy: 0.9882

```

Epoch 4

```

-----
Training loss: 0.027371712402192255
Training accuracy: 0.9912833333333333
Testing loss: 0.03188755950882325
Testing accuracy: 0.99

```

Epoch 5

```

-----
Training loss: 0.021755737696168943
Training accuracy: 0.9933
Testing loss: 0.042698904627060615
Testing accuracy: 0.9862

```

Epoch 6

```

-----

```

```
Training loss: 0.018178562711598352
Training accuracy: 0.99395
Testing loss: 0.029803083038827328
Testing accuracy: 0.9909
Epoch 7
-----
Training loss: 0.016132891090074555
Training accuracy: 0.9946333333333334
Testing loss: 0.02815124349817663
Testing accuracy: 0.9909
Epoch 8
-----
Training loss: 0.013035634695505723
Training accuracy: 0.9956666666666667
Testing loss: 0.030239465634952518
Testing accuracy: 0.9907
Epoch 9
-----
Training loss: 0.012143609064444899
Training accuracy: 0.9959666666666667
Testing loss: 0.027640887979895563
Testing accuracy: 0.9919
Epoch 10
-----
Training loss: 0.009009066085264203
Training accuracy: 0.9971666666666666
Testing loss: 0.03147729635208061
Testing accuracy: 0.9915
Epoch 11
-----
Training loss: 0.00800312742520861
Training accuracy: 0.9971333333333333
Testing loss: 0.03034697799114021
Testing accuracy: 0.9914
Epoch 12
-----
Training loss: 0.006466977949628199
Training accuracy: 0.9980666666666667
Testing loss: 0.03669083762639032
Testing accuracy: 0.9907
Epoch 13
-----
Training loss: 0.0072904691024062536
Training accuracy: 0.9975666666666667
Testing loss: 0.05872593818185703
Testing accuracy: 0.9856
Epoch 14
-----
```



Training loss: 0.007773412765059523  
Training accuracy: 0.9973333333333333  
Testing loss: 0.03047356163804313  
Testing accuracy: 0.9929  
Epoch 15

-----  
Training loss: 0.004976682467204227  
Training accuracy: 0.9984166666666666  
Testing loss: 0.029050709769939446  
Testing accuracy: 0.9922  
Epoch 16

-----  
Training loss: 0.004633579876037644  
Training accuracy: 0.9984833333333333  
Testing loss: 0.02548591755879851  
Testing accuracy: 0.993  
Epoch 17

-----  
Training loss: 0.0032790899788747384  
Training accuracy: 0.9989833333333333  
Testing loss: 0.025733808553164275  
Testing accuracy: 0.9935  
Epoch 18

-----  
Training loss: 0.0029122880108060295  
Training accuracy: 0.9990833333333333  
Testing loss: 0.027490265809890287  
Testing accuracy: 0.9935  
Epoch 19

-----  
Training loss: 0.002067437759421106  
Training accuracy: 0.9994166666666666  
Testing loss: 0.026203953854954765  
Testing accuracy: 0.9936  
Epoch 20

-----  
Training loss: 0.0015316260316377338  
Training accuracy: 0.9996  
Testing loss: 0.028682669620665204  
Testing accuracy: 0.993  
Epoch 21

-----  
Training loss: 0.0008701790688644905  
Training accuracy: 0.99975  
Testing loss: 0.029683130541553412  
Testing accuracy: 0.9926  
Epoch 22

Training loss: 0.0006860437162055556  
Training accuracy: 0.9998  
Testing loss: 0.029790235270581254  
Testing accuracy: 0.9927  
Epoch 23

-----  
Training loss: 0.0009351371187827075  
Training accuracy: 0.99985  
Testing loss: 0.03150173070364808  
Testing accuracy: 0.993  
Epoch 24

-----  
Training loss: 0.0003558681069698423  
Training accuracy: 0.9999  
Testing loss: 0.03297772937890945  
Testing accuracy: 0.9925  
Epoch 25

-----  
Training loss: 0.00026136715143940494  
Training accuracy: 1.0  
Testing loss: 0.0322869889773639  
Testing accuracy: 0.9932  
Epoch 26

-----  
Training loss: 0.00014366208604175198  
Training accuracy: 1.0  
Testing loss: 0.03035026371101279  
Testing accuracy: 0.9931  
Epoch 27

-----  
Training loss: 0.00013001345883884976  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03129952741915683  
Testing accuracy: 0.9931  
Epoch 28

-----  
Training loss: 0.00010490349189626945  
Training accuracy: 1.0  
Testing loss: 0.031103285992537172  
Testing accuracy: 0.993  
Epoch 29

-----  
Training loss: 8.123012034343825e-05  
Training accuracy: 1.0  
Testing loss: 0.03164824102233625  
Testing accuracy: 0.9932  
Epoch 30

Training loss: 0.0001386949365420738  
Training accuracy: 1.0  
Testing loss: 0.031593186157202885  
Testing accuracy: 0.9931  
Epoch 31

-----  
Training loss: 7.95727488886565e-05  
Training accuracy: 1.0  
Testing loss: 0.031592565214014816  
Testing accuracy: 0.9937  
Epoch 32

-----  
Training loss: 6.395042601113611e-05  
Training accuracy: 1.0  
Testing loss: 0.0313639564822838  
Testing accuracy: 0.9935  
Epoch 33

-----  
Training loss: 6.008113635669048e-05  
Training accuracy: 1.0  
Testing loss: 0.033055669569188255  
Testing accuracy: 0.9935  
Epoch 34

-----  
Training loss: 5.752503945008555e-05  
Training accuracy: 1.0  
Testing loss: 0.03280000563015707  
Testing accuracy: 0.9936  
Epoch 35

-----  
Training loss: 5.122493764311713e-05  
Training accuracy: 1.0  
Testing loss: 0.03283919566590907  
Testing accuracy: 0.9935  
Epoch 36

-----  
Training loss: 4.79283685493319e-05  
Training accuracy: 1.0  
Testing loss: 0.03471088620026613  
Testing accuracy: 0.9933  
Epoch 37

-----  
Training loss: 4.5630823851691107e-05  
Training accuracy: 1.0  
Testing loss: 0.034917149135313214  
Testing accuracy: 0.993  
Epoch 38

-----

Training loss: 4.447589395693103e-05  
Training accuracy: 1.0  
Testing loss: 0.03452004363982374  
Testing accuracy: 0.9932  
Epoch 39

-----  
Training loss: 3.9557063410438786e-05  
Training accuracy: 1.0  
Testing loss: 0.033274300724212634  
Testing accuracy: 0.9932  
Epoch 40

-----  
Training loss: 3.569826247052189e-05  
Training accuracy: 1.0  
Testing loss: 0.032334302524814396  
Testing accuracy: 0.9932  
Epoch 41

-----  
Training loss: 3.6974972631445506e-05  
Training accuracy: 1.0  
Testing loss: 0.03404944906363719  
Testing accuracy: 0.9934  
Epoch 42

-----  
Training loss: 3.449440421138282e-05  
Training accuracy: 1.0  
Testing loss: 0.033178646495206604  
Testing accuracy: 0.9931  
Epoch 43

-----  
Training loss: 4.165584147590167e-05  
Training accuracy: 1.0  
Testing loss: 0.032531979041223194  
Testing accuracy: 0.9934  
Epoch 44

-----  
Training loss: 2.9623499671941526e-05  
Training accuracy: 1.0  
Testing loss: 0.034659798544758195  
Testing accuracy: 0.9932  
Epoch 45

-----  
Training loss: 2.6109501530951108e-05  
Training accuracy: 1.0  
Testing loss: 0.035087305909611455  
Testing accuracy: 0.9933  
Epoch 46

Training loss: 2.831281045199615e-05  
Training accuracy: 1.0  
Testing loss: 0.03388092959676024  
Testing accuracy: 0.9932  
Epoch 47

-----  
Training loss: 2.7067477353570033e-05  
Training accuracy: 1.0  
Testing loss: 0.03501997955528559  
Testing accuracy: 0.993  
Epoch 48

-----  
Training loss: 2.3392244394194487e-05  
Training accuracy: 1.0  
Testing loss: 0.03546751615879918  
Testing accuracy: 0.9933  
Epoch 49

-----  
Training loss: 2.4214934676034143e-05  
Training accuracy: 1.0  
Testing loss: 0.037659155466812685  
Testing accuracy: 0.9932  
Epoch 50

-----  
Training loss: 2.531664980888273e-05  
Training accuracy: 1.0  
Testing loss: 0.03580971401293965  
Testing accuracy: 0.9934  
Epoch 51

-----  
Training loss: 2.262515409875784e-05  
Training accuracy: 1.0  
Testing loss: 0.03458312318111397  
Testing accuracy: 0.9935  
Epoch 52

-----  
Training loss: 2.266083433428925e-05  
Training accuracy: 1.0  
Testing loss: 0.036168955198058884  
Testing accuracy: 0.9932  
Epoch 53

-----  
Training loss: 2.2948434360158624e-05  
Training accuracy: 1.0  
Testing loss: 0.036377405390404  
Testing accuracy: 0.9934  
Epoch 54

Training loss: 2.4715301136903753e-05  
Training accuracy: 1.0  
Testing loss: 0.037152509025855644  
Testing accuracy: 0.993  
Epoch 55

-----  
Training loss: 2.1032096726559977e-05  
Training accuracy: 1.0  
Testing loss: 0.035395636844534645  
Testing accuracy: 0.9934  
Epoch 56

-----  
Training loss: 1.9937567462393937e-05  
Training accuracy: 1.0  
Testing loss: 0.03761241374036134  
Testing accuracy: 0.9928  
Epoch 57

-----  
Training loss: 2.0747382641213717e-05  
Training accuracy: 1.0  
Testing loss: 0.036662735530148066  
Testing accuracy: 0.9933  
Epoch 58

-----  
Training loss: 1.8050789597558512e-05  
Training accuracy: 1.0  
Testing loss: 0.03624345756221427  
Testing accuracy: 0.9934  
Epoch 59

-----  
Training loss: 1.815717453561021e-05  
Training accuracy: 1.0  
Testing loss: 0.036315219258833596  
Testing accuracy: 0.9934  
Epoch 60

-----  
Training loss: 1.7010935110104104e-05  
Training accuracy: 1.0  
Testing loss: 0.035463040044655045  
Testing accuracy: 0.9933  
Epoch 61

-----  
Training loss: 1.6298889240806128e-05  
Training accuracy: 1.0  
Testing loss: 0.03630637666179348  
Testing accuracy: 0.9935  
Epoch 62

Training loss: 1.685003340036649e-05  
Training accuracy: 1.0  
Testing loss: 0.035158785581215296  
Testing accuracy: 0.9935  
Epoch 63

-----  
Training loss: 1.687159827686493e-05  
Training accuracy: 1.0  
Testing loss: 0.0355284025148813  
Testing accuracy: 0.993  
Epoch 64

-----  
Training loss: 1.552466708710985e-05  
Training accuracy: 1.0  
Testing loss: 0.03605624434482939  
Testing accuracy: 0.9932  
Epoch 65

-----  
Training loss: 1.736224813070019e-05  
Training accuracy: 1.0  
Testing loss: 0.03665108860969312  
Testing accuracy: 0.993  
Epoch 66

-----  
Training loss: 1.4279919950440719e-05  
Training accuracy: 1.0  
Testing loss: 0.038025048402900385  
Testing accuracy: 0.9933  
Epoch 67

-----  
Training loss: 1.387270314035689e-05  
Training accuracy: 1.0  
Testing loss: 0.036782504595588045  
Testing accuracy: 0.9934  
Epoch 68

-----  
Training loss: 1.563807074708355e-05  
Training accuracy: 1.0  
Testing loss: 0.03667999506069565  
Testing accuracy: 0.9934  
Epoch 69

-----  
Training loss: 1.6235646848223103e-05  
Training accuracy: 1.0  
Testing loss: 0.036179868054605435  
Testing accuracy: 0.9934  
Epoch 70

Training loss: 1.7373246495882927e-05  
Training accuracy: 1.0  
Testing loss: 0.03630816050642046  
Testing accuracy: 0.9932  
Epoch 71

-----  
Training loss: 1.3284611105373756e-05  
Training accuracy: 1.0  
Testing loss: 0.03639254247688491  
Testing accuracy: 0.9939  
Epoch 72

-----  
Training loss: 1.4158907681657359e-05  
Training accuracy: 1.0  
Testing loss: 0.038397699080190445  
Testing accuracy: 0.993  
Epoch 73

-----  
Training loss: 1.3927204304380562e-05  
Training accuracy: 1.0  
Testing loss: 0.03674660639872001  
Testing accuracy: 0.993  
Epoch 74

-----  
Training loss: 1.2728579092965594e-05  
Training accuracy: 1.0  
Testing loss: 0.038374332232196356  
Testing accuracy: 0.9931  
Epoch 75

-----  
Training loss: 1.3522514216324784e-05  
Training accuracy: 1.0  
Testing loss: 0.03717194212852411  
Testing accuracy: 0.9933  
Epoch 76

-----  
Training loss: 1.2427809232432925e-05  
Training accuracy: 1.0  
Testing loss: 0.03710695589885869  
Testing accuracy: 0.9931  
Epoch 77

-----  
Training loss: 1.4503437254007541e-05  
Training accuracy: 1.0  
Testing loss: 0.037220793380218206  
Testing accuracy: 0.9934  
Epoch 78



Training loss: 1.3496302557308108e-05  
Training accuracy: 1.0  
Testing loss: 0.03869244272486027  
Testing accuracy: 0.9932  
Epoch 79

-----  
Training loss: 0.007242641530319123  
Training accuracy: 0.9982166666666666  
Testing loss: 0.05307468656021166  
Testing accuracy: 0.9896  
Epoch 80

-----  
Training loss: 0.008213981292146476  
Training accuracy: 0.9975333333333334  
Testing loss: 0.03527971333533509  
Testing accuracy: 0.9921  
Epoch 81

-----  
Training loss: 0.0068431024051939255  
Training accuracy: 0.9978  
Testing loss: 0.052446172317181114  
Testing accuracy: 0.9881  
Epoch 82

-----  
Training loss: 0.004013135978827207  
Training accuracy: 0.99865  
Testing loss: 0.043785670090437344  
Testing accuracy: 0.9908  
Epoch 83

-----  
Training loss: 0.00311175142133734  
Training accuracy: 0.9991  
Testing loss: 0.036045161431650576  
Testing accuracy: 0.9922  
Epoch 84

-----  
Training loss: 0.0022839734478199867  
Training accuracy: 0.9993  
Testing loss: 0.04270493082941693  
Testing accuracy: 0.9906  
Epoch 85

-----  
Training loss: 0.0018404300002579778  
Training accuracy: 0.9993166666666666  
Testing loss: 0.03911231763466748  
Testing accuracy: 0.9918  
Epoch 86

Training loss: 0.0007014929128046788  
Training accuracy: 0.9998  
Testing loss: 0.03540326279519203  
Testing accuracy: 0.993  
Epoch 87

-----  
Training loss: 0.00022460514856523635  
Training accuracy: 0.9999833333333333  
Testing loss: 0.03666260778554178  
Testing accuracy: 0.9923  
Epoch 88

-----  
Training loss: 0.00024214511590968377  
Training accuracy: 0.99995  
Testing loss: 0.033432139096295624  
Testing accuracy: 0.9928  
Epoch 89

-----  
Training loss: 7.007408497357316e-05  
Training accuracy: 1.0  
Testing loss: 0.034489125684199276  
Testing accuracy: 0.9926  
Epoch 90

-----  
Training loss: 5.808732403127834e-05  
Training accuracy: 1.0  
Testing loss: 0.03431270041916886  
Testing accuracy: 0.9931  
Epoch 91

-----  
Training loss: 4.8803171145012435e-05  
Training accuracy: 1.0  
Testing loss: 0.034978227715199664  
Testing accuracy: 0.9926  
Epoch 92

-----  
Training loss: 3.887182235473195e-05  
Training accuracy: 1.0  
Testing loss: 0.03467236936638895  
Testing accuracy: 0.9925  
Epoch 93

-----  
Training loss: 3.4558578978862185e-05  
Training accuracy: 1.0  
Testing loss: 0.034522296826861275  
Testing accuracy: 0.9922  
Epoch 94

Training loss: 3.8139743936379014e-05  
Training accuracy: 1.0  
Testing loss: 0.03641773444713579  
Testing accuracy: 0.9918  
Epoch 95

-----  
Training loss: 3.0743565194210614e-05  
Training accuracy: 1.0  
Testing loss: 0.03525372474142829  
Testing accuracy: 0.9924  
Epoch 96

-----  
Training loss: 3.003297101536795e-05  
Training accuracy: 1.0  
Testing loss: 0.035405787637249726  
Testing accuracy: 0.9925  
Epoch 97

-----  
Training loss: 2.6314963521986812e-05  
Training accuracy: 1.0  
Testing loss: 0.034816207498873854  
Testing accuracy: 0.9932  
Epoch 98

-----  
Training loss: 2.554290479805393e-05  
Training accuracy: 1.0  
Testing loss: 0.0355966332606219  
Testing accuracy: 0.9929  
Epoch 99

-----  
Training loss: 2.3088289808516056e-05  
Training accuracy: 1.0  
Testing loss: 0.035293801358608316  
Testing accuracy: 0.9926  
Epoch 100

-----  
Training loss: 2.453427926447714e-05  
Training accuracy: 1.0  
Testing loss: 0.03526948996289456  
Testing accuracy: 0.9927  
Epoch 101

-----  
Training loss: 2.0491204073790805e-05  
Training accuracy: 1.0  
Testing loss: 0.037251382779989885  
Testing accuracy: 0.9923  
Epoch 102

Training loss: 1.8245748161113085e-05  
Training accuracy: 1.0  
Testing loss: 0.036805505248681064  
Testing accuracy: 0.9927  
Epoch 103

-----  
Training loss: 1.813520806921704e-05  
Training accuracy: 1.0  
Testing loss: 0.036387706532790956  
Testing accuracy: 0.9922  
Epoch 104

-----  
Training loss: 1.9807043148510554e-05  
Training accuracy: 1.0  
Testing loss: 0.03778595838960098  
Testing accuracy: 0.9925  
Epoch 105

-----  
Training loss: 1.761664544041063e-05  
Training accuracy: 1.0  
Testing loss: 0.040568048493845855  
Testing accuracy: 0.993  
Epoch 106

-----  
Training loss: 1.9878503219836337e-05  
Training accuracy: 1.0  
Testing loss: 0.03644357573634224  
Testing accuracy: 0.993  
Epoch 107

-----  
Training loss: 1.4810376491201774e-05  
Training accuracy: 1.0  
Testing loss: 0.03683381512515125  
Testing accuracy: 0.9928  
Epoch 108

-----  
Training loss: 1.565347630422167e-05  
Training accuracy: 1.0  
Testing loss: 0.03728697028955565  
Testing accuracy: 0.9926  
Epoch 109

-----  
Training loss: 1.3853540961859896e-05  
Training accuracy: 1.0  
Testing loss: 0.0364378295251864  
Testing accuracy: 0.993  
Epoch 110

Training loss: 1.4775450461857294e-05  
Training accuracy: 1.0  
Testing loss: 0.03777743225370811  
Testing accuracy: 0.9926  
Epoch 111

-----  
Training loss: 1.386330971272945e-05  
Training accuracy: 1.0  
Testing loss: 0.03797287766755059  
Testing accuracy: 0.9923  
Epoch 112

-----  
Training loss: 1.3732745192891826e-05  
Training accuracy: 1.0  
Testing loss: 0.03701693446065382  
Testing accuracy: 0.9929  
Epoch 113

-----  
Training loss: 1.344500522696812e-05  
Training accuracy: 1.0  
Testing loss: 0.036455950322788054  
Testing accuracy: 0.993  
Epoch 114

-----  
Training loss: 1.2393395149624217e-05  
Training accuracy: 1.0  
Testing loss: 0.03850214986437804  
Testing accuracy: 0.9923  
Epoch 115

-----  
Training loss: 1.191467861262036e-05  
Training accuracy: 1.0  
Testing loss: 0.038359127616944606  
Testing accuracy: 0.9929  
Epoch 116

-----  
Training loss: 1.2061107420287343e-05  
Training accuracy: 1.0  
Testing loss: 0.03854053034213878  
Testing accuracy: 0.9924  
Epoch 117

-----  
Training loss: 1.1534647294510355e-05  
Training accuracy: 1.0  
Testing loss: 0.038626906256984485  
Testing accuracy: 0.9928  
Epoch 118

Training loss: 1.1417066718579132e-05  
Training accuracy: 1.0  
Testing loss: 0.038437423777916785  
Testing accuracy: 0.9928  
Epoch 119

-----  
Training loss: 1.0698443273556534e-05  
Training accuracy: 1.0  
Testing loss: 0.037500324673349995  
Testing accuracy: 0.9932  
Epoch 120

-----  
Training loss: 1.1352451766502606e-05  
Training accuracy: 1.0  
Testing loss: 0.0387378944905047  
Testing accuracy: 0.9924  
Epoch 121

-----  
Training loss: 1.0672090832889818e-05  
Training accuracy: 1.0  
Testing loss: 0.037785920674634585  
Testing accuracy: 0.993  
Epoch 122

-----  
Training loss: 1.100964263926135e-05  
Training accuracy: 1.0  
Testing loss: 0.03880996636388766  
Testing accuracy: 0.9928  
Epoch 123

-----  
Training loss: 1.0100831127489822e-05  
Training accuracy: 1.0  
Testing loss: 0.039191144066528565  
Testing accuracy: 0.9927  
Epoch 124

-----  
Training loss: 1.034404369313151e-05  
Training accuracy: 1.0  
Testing loss: 0.03850894471396092  
Testing accuracy: 0.9926  
Epoch 125

-----  
Training loss: 9.31378702843979e-06  
Training accuracy: 1.0  
Testing loss: 0.03917196895810714  
Testing accuracy: 0.9926  
Epoch 126

Training loss: 9.374658283206473e-06  
Training accuracy: 1.0  
Testing loss: 0.04012526045465196  
Testing accuracy: 0.9926  
Epoch 127

-----  
Training loss: 9.714653271286266e-06  
Training accuracy: 1.0  
Testing loss: 0.037545388753635535  
Testing accuracy: 0.9929  
Epoch 128

-----  
Training loss: 9.253175773933482e-06  
Training accuracy: 1.0  
Testing loss: 0.03912102792581474  
Testing accuracy: 0.9925  
Epoch 129

-----  
Training loss: 9.45347187096767e-06  
Training accuracy: 1.0  
Testing loss: 0.03947551184425105  
Testing accuracy: 0.9927  
Epoch 130

-----  
Training loss: 8.631735222134058e-06  
Training accuracy: 1.0  
Testing loss: 0.03851353880834424  
Testing accuracy: 0.9923  
Epoch 131

-----  
Training loss: 9.033248920832194e-06  
Training accuracy: 1.0  
Testing loss: 0.04183244893419592  
Testing accuracy: 0.993  
Epoch 132

-----  
Training loss: 8.317377234687366e-06  
Training accuracy: 1.0  
Testing loss: 0.03899955475507961  
Testing accuracy: 0.9926  
Epoch 133

-----  
Training loss: 8.058712077523704e-06  
Training accuracy: 1.0  
Testing loss: 0.03843555380788441  
Testing accuracy: 0.9931  
Epoch 134

Training loss: 8.133229866912354e-06  
Training accuracy: 1.0  
Testing loss: 0.04054628496415361  
Testing accuracy: 0.9927  
Epoch 135

-----  
Training loss: 8.353954764289994e-06  
Training accuracy: 1.0  
Testing loss: 0.03951096198702066  
Testing accuracy: 0.9925  
Epoch 136

-----  
Training loss: 7.394534942414547e-06  
Training accuracy: 1.0  
Testing loss: 0.039989509729019095  
Testing accuracy: 0.9929  
Epoch 137

-----  
Training loss: 7.603085433261233e-06  
Training accuracy: 1.0  
Testing loss: 0.040716325222786835  
Testing accuracy: 0.9926  
Epoch 138

-----  
Training loss: 7.269929232513542e-06  
Training accuracy: 1.0  
Testing loss: 0.03976432240026168  
Testing accuracy: 0.9928  
Epoch 139

-----  
Training loss: 6.990331526800731e-06  
Training accuracy: 1.0  
Testing loss: 0.03979632531229316  
Testing accuracy: 0.9925  
Epoch 140

-----  
Training loss: 6.907521052549489e-06  
Training accuracy: 1.0  
Testing loss: 0.03817599549541538  
Testing accuracy: 0.9926  
Epoch 141

-----  
Training loss: 7.72178590403089e-06  
Training accuracy: 1.0  
Testing loss: 0.039691906068643125  
Testing accuracy: 0.9926  
Epoch 142



Training loss: 2.6176678898631185e-05  
Training accuracy: 1.0  
Testing loss: 0.042768849656673935  
Testing accuracy: 0.9921  
Epoch 143

-----  
Training loss: 9.76568206070058e-06  
Training accuracy: 1.0  
Testing loss: 0.0406374625863434  
Testing accuracy: 0.9927  
Epoch 144

-----  
Training loss: 7.641917411780004e-06  
Training accuracy: 1.0  
Testing loss: 0.04068535987331669  
Testing accuracy: 0.9928  
Epoch 145

-----  
Training loss: 8.052175381764689e-06  
Training accuracy: 1.0  
Testing loss: 0.039529426699542965  
Testing accuracy: 0.9926  
Epoch 146

-----  
Training loss: 7.88168587883599e-06  
Training accuracy: 1.0  
Testing loss: 0.040643173748970175  
Testing accuracy: 0.9926  
Epoch 147

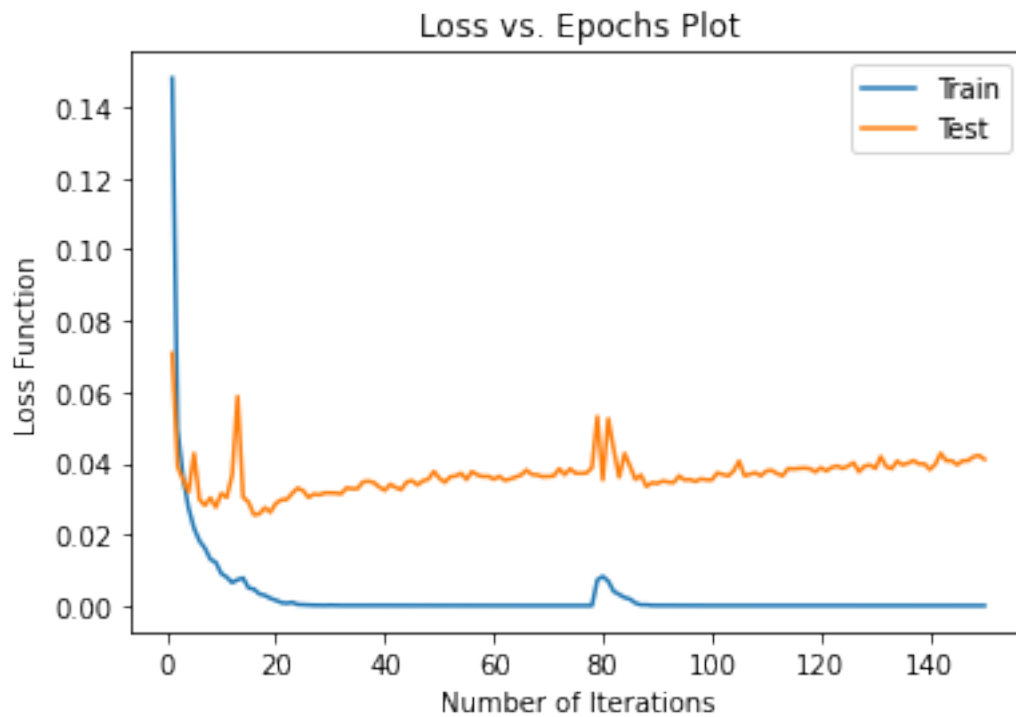
-----  
Training loss: 7.097311363806588e-06  
Training accuracy: 1.0  
Testing loss: 0.04067560501179887  
Testing accuracy: 0.9925  
Epoch 148

-----  
Training loss: 7.021238699312112e-06  
Training accuracy: 1.0  
Testing loss: 0.04177320204862419  
Testing accuracy: 0.9928  
Epoch 149

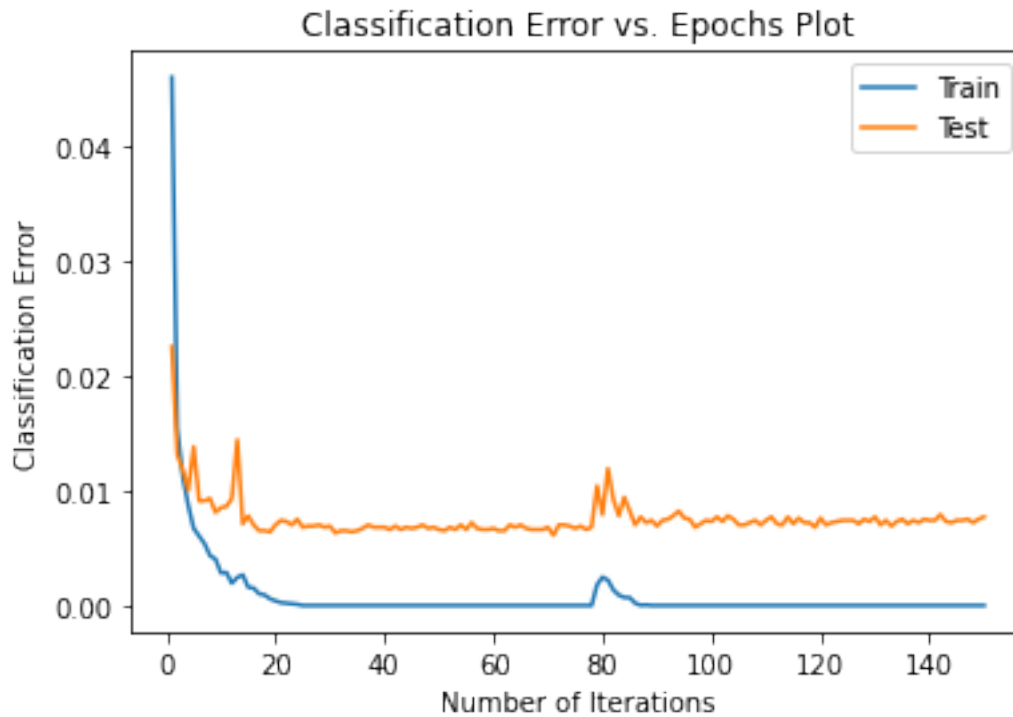
-----  
Training loss: 8.387193341591607e-06  
Training accuracy: 1.0  
Testing loss: 0.04217856402775224  
Testing accuracy: 0.9925  
Epoch 150

Training loss: 6.85179277173269e-06  
Training accuracy: 1.0  
Testing loss: 0.04108311490360397  
Testing accuracy: 0.9923  
Done  
Total Time Consumed: 3967.5846617221832

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.9.5 Momentum = 0.9

```
[ ]: # Define HyperParameters
input_size = 784
num_classes = 10
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.9
lenet_m9 = LeNet5(num_classes)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(lenet_m9.parameters(), lr = learning_rate, momentum = ↵
↵momentum)

[ ]: # Set Seed
torch.manual_seed(1)

# Data Loading
train_loader = DataLoader(dataset = train_data, batch_size = batch_size, ↵
↵shuffle = True)
```

```

test_loader = DataLoader(dataset = test_data, batch_size = batch_size, shuffle_
    ↪ = True)

start_time = time.time()
test_loss_record = []
train_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop(train_loader, lenet_m9, loss, optimizer))
    test_loss_record.append(test_loop(test_loader, lenet_m9, loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 0.17066763468831778
Training accuracy: 0.9496
Testing loss: 0.045336998713270994
Testing accuracy: 0.9869
Epoch 2

```

```

-----
Training loss: 0.061761704346304756
Training accuracy: 0.9827
Testing loss: 0.03981207929396628
Testing accuracy: 0.9888
Epoch 3

```

```

-----
Training loss: 0.051439117785325894
Training accuracy: 0.9856
Testing loss: 0.03529274272476619
Testing accuracy: 0.9897
Epoch 4

```

```

-----
Training loss: 0.03837745738786956
Training accuracy: 0.9891166666666666
Testing loss: 0.04577708432738592
Testing accuracy: 0.9862
Epoch 5

```

```

-----
Training loss: 0.034237265561070915
Training accuracy: 0.9902
Testing loss: 0.04323852910103805
Testing accuracy: 0.9886
Epoch 6

```

```
Training loss: 0.027768395057091645
Training accuracy: 0.9922
Testing loss: 0.056058517946474436
Testing accuracy: 0.986
Epoch 7
-----
Training loss: 0.023926500808548492
Training accuracy: 0.9932333333333333
Testing loss: 0.034517118934313744
Testing accuracy: 0.9909
Epoch 8
-----
Training loss: 0.022609415652408885
Training accuracy: 0.9935833333333334
Testing loss: 0.03970549501402483
Testing accuracy: 0.9898
Epoch 9
-----
Training loss: 0.021500940262777053
Training accuracy: 0.9936666666666667
Testing loss: 0.03970104145574988
Testing accuracy: 0.9884
Epoch 10
-----
Training loss: 0.016895687141511736
Training accuracy: 0.9946666666666667
Testing loss: 0.04527262157596411
Testing accuracy: 0.9877
Epoch 11
-----
Training loss: 0.02055213569041225
Training accuracy: 0.99385
Testing loss: 0.05299503270993036
Testing accuracy: 0.9877
Epoch 12
-----
Training loss: 0.016631531640607863
Training accuracy: 0.9948833333333333
Testing loss: 0.04841194348204122
Testing accuracy: 0.9901
Epoch 13
-----
Training loss: 0.01316436546137023
Training accuracy: 0.99595
Testing loss: 0.04077447138085769
Testing accuracy: 0.9909
Epoch 14
-----
```

```
Training loss: 0.013311808857163487
Training accuracy: 0.99605
Testing loss: 0.05025653665007916
Testing accuracy: 0.989
Epoch 15
-----
Training loss: 0.01306950572739952
Training accuracy: 0.9962166666666666
Testing loss: 0.05281527234521323
Testing accuracy: 0.9898
Epoch 16
-----
Training loss: 0.013053440515429823
Training accuracy: 0.9960166666666667
Testing loss: 0.06480714593540635
Testing accuracy: 0.9892
Epoch 17
-----
Training loss: 0.015628985169472497
Training accuracy: 0.9957
Testing loss: 0.05632557297206398
Testing accuracy: 0.9902
Epoch 18
-----
Training loss: 0.011923712850689723
Training accuracy: 0.9967166666666667
Testing loss: 0.044916297327545415
Testing accuracy: 0.9895
Epoch 19
-----
Training loss: 0.013496769397177104
Training accuracy: 0.99595
Testing loss: 0.061419602231616785
Testing accuracy: 0.9896
Epoch 20
-----
Training loss: 0.012529166172450883
Training accuracy: 0.9964
Testing loss: 0.05425091877581853
Testing accuracy: 0.9898
Epoch 21
-----
Training loss: 0.010590808256873568
Training accuracy: 0.9967666666666667
Testing loss: 0.08267535834646775
Testing accuracy: 0.9867
Epoch 22
-----
```

```
Training loss: 0.014764811296321864
Training accuracy: 0.9961
Testing loss: 0.0643301122399746
Testing accuracy: 0.9875
Epoch 23
-----
Training loss: 0.01147463927273214
Training accuracy: 0.9965
Testing loss: 0.04491312280872767
Testing accuracy: 0.9913
Epoch 24
-----
Training loss: 0.010934571326312544
Training accuracy: 0.9969333333333333
Testing loss: 0.039704164436996765
Testing accuracy: 0.9918
Epoch 25
-----
Training loss: 0.006685647422339796
Training accuracy: 0.99785
Testing loss: 0.04928899649243644
Testing accuracy: 0.9898
Epoch 26
-----
Training loss: 0.01029868623234604
Training accuracy: 0.9970833333333333
Testing loss: 0.04135400247086916
Testing accuracy: 0.9923
Epoch 27
-----
Training loss: 0.0089404114406039
Training accuracy: 0.9977166666666667
Testing loss: 0.051736151862496436
Testing accuracy: 0.9901
Epoch 28
-----
Training loss: 0.004942604590644148
Training accuracy: 0.9984166666666666
Testing loss: 0.07167545570818927
Testing accuracy: 0.9906
Epoch 29
-----
Training loss: 0.0070746767327688935
Training accuracy: 0.9981
Testing loss: 0.05904656301931415
Testing accuracy: 0.9899
Epoch 30
-----
```

```
Training loss: 0.009543657839453878
Training accuracy: 0.99765
Testing loss: 0.0681781665120011
Testing accuracy: 0.9888
Epoch 31
-----
Training loss: 0.007787878963918987
Training accuracy: 0.9977166666666667
Testing loss: 0.0875443104364324
Testing accuracy: 0.9888
Epoch 32
-----
Training loss: 0.014958209606235888
Training accuracy: 0.99585
Testing loss: 0.06271614354779184
Testing accuracy: 0.9905
Epoch 33
-----
Training loss: 0.010174449632895188
Training accuracy: 0.9968333333333333
Testing loss: 0.05367779133025123
Testing accuracy: 0.9919
Epoch 34
-----
Training loss: 0.00933940428485931
Training accuracy: 0.9975833333333334
Testing loss: 0.07208483519755442
Testing accuracy: 0.9904
Epoch 35
-----
Training loss: 0.009601106228159323
Training accuracy: 0.99765
Testing loss: 0.06799324368220616
Testing accuracy: 0.9916
Epoch 36
-----
Training loss: 0.014115642383391261
Training accuracy: 0.9966166666666667
Testing loss: 0.06464426936158787
Testing accuracy: 0.9903
Epoch 37
-----
Training loss: 0.004469443272853709
Training accuracy: 0.99885
Testing loss: 0.06099983089763951
Testing accuracy: 0.9918
Epoch 38
-----
```



```
Training loss: 0.004073032459805151
Training accuracy: 0.99885
Testing loss: 0.05525873056558258
Testing accuracy: 0.9918
Epoch 39
-----
Training loss: 0.0038466344297905034
Training accuracy: 0.9991166666666667
Testing loss: 0.06052886806347577
Testing accuracy: 0.9905
Epoch 40
-----
Training loss: 0.014119398213806417
Training accuracy: 0.9966
Testing loss: 0.053927423897383094
Testing accuracy: 0.9916
Epoch 41
-----
Training loss: 0.0071217110790622335
Training accuracy: 0.99835
Testing loss: 0.06464561295719967
Testing accuracy: 0.9899
Epoch 42
-----
Training loss: 0.00829703034506172
Training accuracy: 0.9976333333333334
Testing loss: 0.0667975150955856
Testing accuracy: 0.9907
Epoch 43
-----
Training loss: 0.00889458740036187
Training accuracy: 0.9978666666666667
Testing loss: 0.07008999337607372
Testing accuracy: 0.9906
Epoch 44
-----
Training loss: 0.011684660703239433
Training accuracy: 0.9971166666666667
Testing loss: 0.09190216448143657
Testing accuracy: 0.9877
Epoch 45
-----
Training loss: 0.015005546004460635
Training accuracy: 0.9960166666666667
Testing loss: 0.07476047340839814
Testing accuracy: 0.9893
Epoch 46
-----
```

```
Training loss: 0.01064941565917009
Training accuracy: 0.9972
Testing loss: 0.0774949454734835
Testing accuracy: 0.9898
Epoch 47
-----
Training loss: 0.005632454645433203
Training accuracy: 0.9985666666666667
Testing loss: 0.09478667554010287
Testing accuracy: 0.99
Epoch 48
-----
Training loss: 0.01672032231874089
Training accuracy: 0.9961333333333333
Testing loss: 0.061590299420929806
Testing accuracy: 0.9896
Epoch 49
-----
Training loss: 0.006790196625619126
Training accuracy: 0.9982
Testing loss: 0.07496196418130398
Testing accuracy: 0.9914
Epoch 50
-----
Training loss: 0.005947396498487396
Training accuracy: 0.9986333333333334
Testing loss: 0.08355038443188154
Testing accuracy: 0.9887
Epoch 51
-----
Training loss: 0.011531229374415197
Training accuracy: 0.9972
Testing loss: 0.06497916162277698
Testing accuracy: 0.9913
Epoch 52
-----
Training loss: 0.00617431713331874
Training accuracy: 0.9986166666666667
Testing loss: 0.08525653115898497
Testing accuracy: 0.9899
Epoch 53
-----
Training loss: 0.0022123722144052967
Training accuracy: 0.9993
Testing loss: 0.07133022228754184
Testing accuracy: 0.9921
Epoch 54
-----
```

Training loss: 0.004752085982167124  
Training accuracy: 0.9986666666666667  
Testing loss: 0.0945886678551492  
Testing accuracy: 0.9883  
Epoch 55

-----  
Training loss: 0.00860968971383429  
Training accuracy: 0.9979833333333333  
Testing loss: 0.08509391843077228  
Testing accuracy: 0.9913  
Epoch 56

-----  
Training loss: 0.005478527094599222  
Training accuracy: 0.9983833333333333  
Testing loss: 0.09682550080019732  
Testing accuracy: 0.9901  
Epoch 57

-----  
Training loss: 0.006963371064203383  
Training accuracy: 0.9986333333333334  
Testing loss: 0.08969683270576313  
Testing accuracy: 0.9911  
Epoch 58

-----  
Training loss: 0.005929581920332981  
Training accuracy: 0.9984666666666666  
Testing loss: 0.07570477168018835  
Testing accuracy: 0.9903  
Epoch 59

-----  
Training loss: 0.0068050446781206244  
Training accuracy: 0.9985333333333334  
Testing loss: 0.0769079450724481  
Testing accuracy: 0.9916  
Epoch 60

-----  
Training loss: 0.0037785469360013635  
Training accuracy: 0.9990666666666667  
Testing loss: 0.08973232762338858  
Testing accuracy: 0.9919  
Epoch 61

-----  
Training loss: 0.003714634072148195  
Training accuracy: 0.9991666666666666  
Testing loss: 0.08284200776409484  
Testing accuracy: 0.9907  
Epoch 62

```
Training loss: 0.010139510082363521
Training accuracy: 0.99765
Testing loss: 0.10066325474615119
Testing accuracy: 0.9886
Epoch 63
-----
Training loss: 0.016957106243442804
Training accuracy: 0.9966
Testing loss: 0.08848439836113944
Testing accuracy: 0.9888
Epoch 64
-----
Training loss: 0.010604456514131553
Training accuracy: 0.9975666666666667
Testing loss: 0.10426531319011402
Testing accuracy: 0.9889
Epoch 65
-----
Training loss: 0.008623193878483653
Training accuracy: 0.9981666666666666
Testing loss: 0.08871912401511912
Testing accuracy: 0.9904
Epoch 66
-----
Training loss: 0.004721925768019766
Training accuracy: 0.99885
Testing loss: 0.08201446185760806
Testing accuracy: 0.9914
Epoch 67
-----
Training loss: 0.006765650693786808
Training accuracy: 0.9986166666666667
Testing loss: 0.08818877248870015
Testing accuracy: 0.9894
Epoch 68
-----
Training loss: 0.00920176107686124
Training accuracy: 0.99805
Testing loss: 0.08153040499091911
Testing accuracy: 0.9909
Epoch 69
-----
Training loss: 0.0060417869434651215
Training accuracy: 0.9985666666666667
Testing loss: 0.08476732842621912
Testing accuracy: 0.9901
Epoch 70
-----
```

Training loss: 0.004387311963422942  
Training accuracy: 0.9990833333333333  
Testing loss: 0.06771031899684085  
Testing accuracy: 0.9907  
Epoch 71

-----  
Training loss: 0.002673284937241595  
Training accuracy: 0.99935  
Testing loss: 0.09485831155063046  
Testing accuracy: 0.9885  
Epoch 72

-----  
Training loss: 0.008383608144511964  
Training accuracy: 0.9980333333333333  
Testing loss: 0.11398837271807734  
Testing accuracy: 0.9897  
Epoch 73

-----  
Training loss: 0.007425961690924127  
Training accuracy: 0.9982833333333333  
Testing loss: 0.08588557811515635  
Testing accuracy: 0.9898  
Epoch 74

-----  
Training loss: 0.0076254976996514325  
Training accuracy: 0.99835  
Testing loss: 0.10056368621667959  
Testing accuracy: 0.9902  
Epoch 75

-----  
Training loss: 0.011391487108562734  
Training accuracy: 0.9978  
Testing loss: 0.09760632697268531  
Testing accuracy: 0.9875  
Epoch 76

-----  
Training loss: 0.006443557136986298  
Training accuracy: 0.9985166666666667  
Testing loss: 0.0967636394487528  
Testing accuracy: 0.9896  
Epoch 77

-----  
Training loss: 0.01543727307873489  
Training accuracy: 0.9967166666666667  
Testing loss: 0.07773233752853179  
Testing accuracy: 0.9904  
Epoch 78

Training loss: 0.006686143668839869  
Training accuracy: 0.9986666666666667  
Testing loss: 0.09463216443514628  
Testing accuracy: 0.99  
Epoch 79

-----  
Training loss: 0.009361474361218583  
Training accuracy: 0.9983166666666666  
Testing loss: 0.08371134622176747  
Testing accuracy: 0.9905  
Epoch 80

-----  
Training loss: 0.004189010417479617  
Training accuracy: 0.9990166666666667  
Testing loss: 0.08987966481418465  
Testing accuracy: 0.9909  
Epoch 81

-----  
Training loss: 0.0037970386242525862  
Training accuracy: 0.9991833333333333  
Testing loss: 0.08399043444920123  
Testing accuracy: 0.991  
Epoch 82

-----  
Training loss: 0.01702449800391266  
Training accuracy: 0.9970166666666667  
Testing loss: 0.12885812355598522  
Testing accuracy: 0.9828  
Epoch 83

-----  
Training loss: 0.012817338659291423  
Training accuracy: 0.9972666666666666  
Testing loss: 0.08149077509245518  
Testing accuracy: 0.9899  
Epoch 84

-----  
Training loss: 0.008974721658789509  
Training accuracy: 0.9977333333333334  
Testing loss: 0.0972073386078382  
Testing accuracy: 0.9903  
Epoch 85

-----  
Training loss: 0.007880000830501247  
Training accuracy: 0.9984833333333333  
Testing loss: 0.10175042297854534  
Testing accuracy: 0.989  
Epoch 86

Training loss: 0.0038985664303653454  
Training accuracy: 0.9989833333333333  
Testing loss: 0.09642419605137006  
Testing accuracy: 0.9914  
Epoch 87

-----  
Training loss: 0.012871352142202195  
Training accuracy: 0.9977166666666667  
Testing loss: 0.10603779219289354  
Testing accuracy: 0.9899  
Epoch 88

-----  
Training loss: 0.008351712123455968  
Training accuracy: 0.9983833333333333  
Testing loss: 0.10216650616092353  
Testing accuracy: 0.9896  
Epoch 89

-----  
Training loss: 0.005251361453481144  
Training accuracy: 0.9989166666666667  
Testing loss: 0.09763872834024052  
Testing accuracy: 0.9908  
Epoch 90

-----  
Training loss: 0.009209953095569726  
Training accuracy: 0.9983333333333333  
Testing loss: 0.18289718513328787  
Testing accuracy: 0.9817  
Epoch 91

-----  
Training loss: 0.007542939321327448  
Training accuracy: 0.9983666666666666  
Testing loss: 0.10332587326803479  
Testing accuracy: 0.9889  
Epoch 92

-----  
Training loss: 0.009733358222204187  
Training accuracy: 0.9978  
Testing loss: 0.0979136402310086  
Testing accuracy: 0.9914  
Epoch 93

-----  
Training loss: 0.005614676862298503  
Training accuracy: 0.99875  
Testing loss: 0.08329012520289886  
Testing accuracy: 0.9916  
Epoch 94

Training loss: 0.0032284043720708726  
Training accuracy: 0.9991333333333333  
Testing loss: 0.09579868954293246  
Testing accuracy: 0.9913  
Epoch 95

-----  
Training loss: 0.006472913612166049  
Training accuracy: 0.9989333333333333  
Testing loss: 0.10269165515312571  
Testing accuracy: 0.9902  
Epoch 96

-----  
Training loss: 0.003301384643337766  
Training accuracy: 0.99935  
Testing loss: 0.0713580248725231  
Testing accuracy: 0.9916  
Epoch 97

-----  
Training loss: 0.004972703033839559  
Training accuracy: 0.99915  
Testing loss: 0.07752433755749077  
Testing accuracy: 0.9919  
Epoch 98

-----  
Training loss: 0.007557943134885041  
Training accuracy: 0.99885  
Testing loss: 0.13178992463794126  
Testing accuracy: 0.9885  
Epoch 99

-----  
Training loss: 0.024897374755972018  
Training accuracy: 0.9958666666666667  
Testing loss: 0.15126346022408102  
Testing accuracy: 0.9864  
Epoch 100

-----  
Training loss: 0.016127400050936606  
Training accuracy: 0.9968833333333333  
Testing loss: 0.08812975208466907  
Testing accuracy: 0.9897  
Epoch 101

-----  
Training loss: 0.0221614021148704  
Training accuracy: 0.9960833333333333  
Testing loss: 0.11999669530538623  
Testing accuracy: 0.9894  
Epoch 102



Training loss: 0.012773767566388912  
Training accuracy: 0.9978166666666667  
Testing loss: 0.07599351909034158  
Testing accuracy: 0.9916  
Epoch 103

-----  
Training loss: 0.004175726792544765  
Training accuracy: 0.9990166666666667  
Testing loss: 0.0915267630521734  
Testing accuracy: 0.9918  
Epoch 104

-----  
Training loss: 0.013408982036126104  
Training accuracy: 0.9974  
Testing loss: 0.09436507946991449  
Testing accuracy: 0.9889  
Epoch 105

-----  
Training loss: 0.005549286335183741  
Training accuracy: 0.9987333333333334  
Testing loss: 0.1507131609523454  
Testing accuracy: 0.9884  
Epoch 106

-----  
Training loss: 0.013869066452654647  
Training accuracy: 0.9977666666666667  
Testing loss: 0.11821778562157878  
Testing accuracy: 0.988  
Epoch 107

-----  
Training loss: 0.024234020475478502  
Training accuracy: 0.9965833333333334  
Testing loss: 0.21488225150806986  
Testing accuracy: 0.9789  
Epoch 108

-----  
Training loss: 0.029659410122243463  
Training accuracy: 0.9951833333333333  
Testing loss: 0.21776521798134857  
Testing accuracy: 0.9839  
Epoch 109

-----  
Training loss: 0.018358016241147652  
Training accuracy: 0.9968  
Testing loss: 0.19470555236449602  
Testing accuracy: 0.9855  
Epoch 110

```
Training loss: 0.029537099612477496
Training accuracy: 0.9952833333333333
Testing loss: 0.151864885232438
Testing accuracy: 0.9865
Epoch 111
-----
Training loss: 0.021806524558911175
Training accuracy: 0.9961666666666666
Testing loss: 0.1246695824443887
Testing accuracy: 0.9882
Epoch 112
-----
Training loss: 0.013845911259991248
Training accuracy: 0.9974333333333333
Testing loss: 0.12653487241238093
Testing accuracy: 0.9902
Epoch 113
-----
Training loss: 0.011458676409211084
Training accuracy: 0.9979
Testing loss: 0.1192339979025917
Testing accuracy: 0.9896
Epoch 114
-----
Training loss: 0.008703115878542493
Training accuracy: 0.9981666666666666
Testing loss: 0.14511017395559106
Testing accuracy: 0.9902
Epoch 115
-----
Training loss: 0.015846296332388574
Training accuracy: 0.99735
Testing loss: 0.11035297760762094
Testing accuracy: 0.9905
Epoch 116
-----
Training loss: 0.010784179007243955
Training accuracy: 0.9980666666666667
Testing loss: 0.12921381425260944
Testing accuracy: 0.9882
Epoch 117
-----
Training loss: 0.025469749065969636
Training accuracy: 0.9961333333333333
Testing loss: 0.11382607103454535
Testing accuracy: 0.9894
Epoch 118
-----
```

```
Training loss: 0.01635371055767879
Training accuracy: 0.9969
Testing loss: 0.11050816037627956
Testing accuracy: 0.9911
Epoch 119
-----
Training loss: 0.017114173808692706
Training accuracy: 0.9972666666666666
Testing loss: 0.11133063756106774
Testing accuracy: 0.988
Epoch 120
-----
Training loss: 0.012411595821901026
Training accuracy: 0.9978166666666667
Testing loss: 0.19873991752699147
Testing accuracy: 0.9833
Epoch 121
-----
Training loss: 0.03608939416957022
Training accuracy: 0.9944833333333334
Testing loss: 0.09000710573301673
Testing accuracy: 0.9893
Epoch 122
-----
Training loss: 0.045338878620126304
Training accuracy: 0.9929166666666667
Testing loss: 0.1344025857506821
Testing accuracy: 0.9872
Epoch 123
-----
Training loss: 0.05805515838376076
Training accuracy: 0.9912166666666666
Testing loss: 0.17719039836923836
Testing accuracy: 0.9858
Epoch 124
-----
Training loss: 0.03438488428714153
Training accuracy: 0.9941
Testing loss: 0.14523504509421212
Testing accuracy: 0.988
Epoch 125
-----
Training loss: 0.09203999862318266
Training accuracy: 0.9863166666666666
Testing loss: 0.18743316380576067
Testing accuracy: 0.9858
Epoch 126
-----
```

Training loss: 0.06191265463780359  
Training accuracy: 0.9907666666666667  
Testing loss: 0.15986622810285867  
Testing accuracy: 0.9831  
Epoch 127

-----  
Training loss: 0.10261499509913227  
Training accuracy: 0.9836666666666667  
Testing loss: 0.10657010687424794  
Testing accuracy: 0.986  
Epoch 128

-----  
Training loss: 0.04405131121820894  
Training accuracy: 0.9923166666666666  
Testing loss: 0.12095692245739578  
Testing accuracy: 0.9863  
Epoch 129

-----  
Training loss: 0.03384868317567377  
Training accuracy: 0.9932833333333333  
Testing loss: 0.10912706421088633  
Testing accuracy: 0.987  
Epoch 130

-----  
Training loss: 0.03396109227753638  
Training accuracy: 0.9940666666666667  
Testing loss: 0.0988729694926046  
Testing accuracy: 0.9866  
Epoch 131

-----  
Training loss: 0.02006664403249093  
Training accuracy: 0.9961166666666667  
Testing loss: 0.12514489367260084  
Testing accuracy: 0.9814  
Epoch 132

-----  
Training loss: 0.05550839682796706  
Training accuracy: 0.9913666666666666  
Testing loss: 0.1395268825151025  
Testing accuracy: 0.9831  
Epoch 133

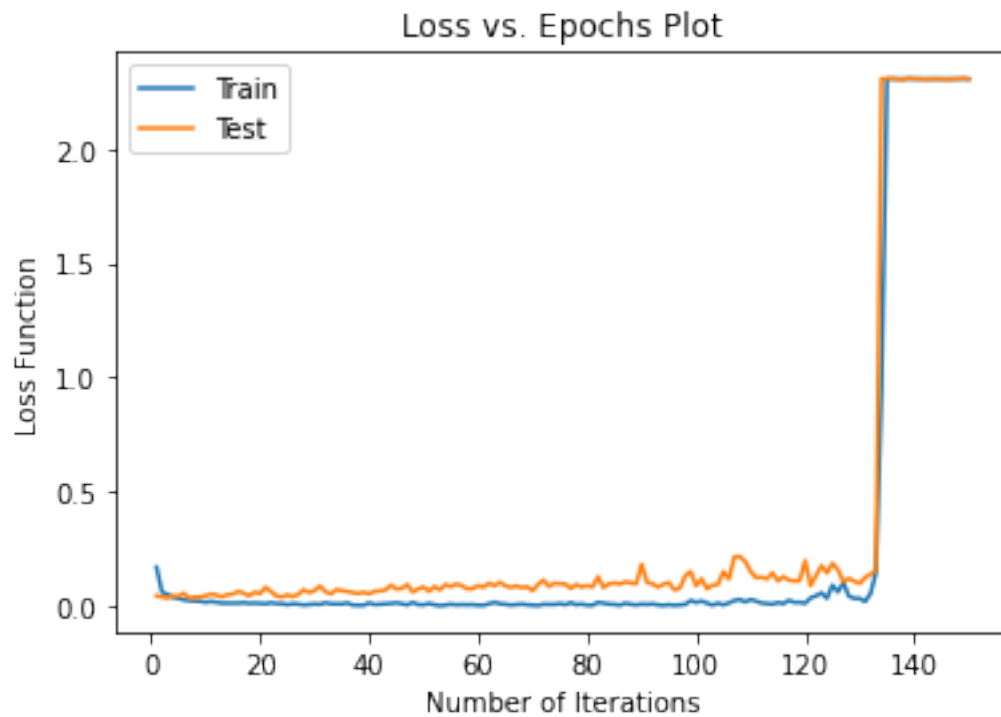
-----  
Training loss: 0.1481880767896825  
Training accuracy: 0.97455  
Testing loss: 0.15664644166163907  
Testing accuracy: 0.9791  
Epoch 134

```
Training loss: 0.9368896305318092
Training accuracy: 0.6958833333333333
Testing loss: 2.305128263060454
Testing accuracy: 0.1028
Epoch 135
-----
Training loss: 2.3047149899800616
Training accuracy: 0.10546666666666667
Testing loss: 2.3058792724730863
Testing accuracy: 0.1135
Epoch 136
-----
Training loss: 2.305048708343506
Training accuracy: 0.10465
Testing loss: 2.3066675754109767
Testing accuracy: 0.101
Epoch 137
-----
Training loss: 2.3044796639760334
Training accuracy: 0.10743333333333334
Testing loss: 2.3026255908285735
Testing accuracy: 0.1135
Epoch 138
-----
Training loss: 2.3050295270284016
Training accuracy: 0.10546666666666667
Testing loss: 2.301941686375126
Testing accuracy: 0.0958
Epoch 139
-----
Training loss: 2.3045275077819825
Training accuracy: 0.10546666666666667
Testing loss: 2.3080710225803838
Testing accuracy: 0.1135
Epoch 140
-----
Training loss: 2.3045927211761477
Training accuracy: 0.106
Testing loss: 2.3055402382164245
Testing accuracy: 0.1028
Epoch 141
-----
Training loss: 2.3047309778849283
Training accuracy: 0.10896666666666667
Testing loss: 2.3045293024391125
Testing accuracy: 0.1135
Epoch 142
-----
```

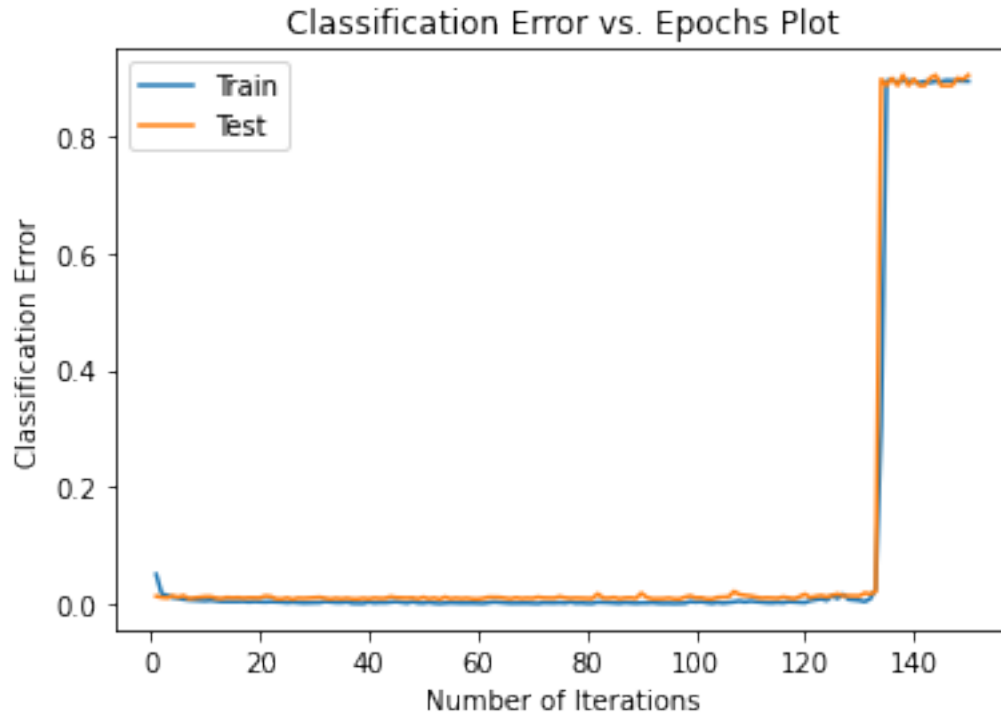
```
Training loss: 2.304771620686849
Training accuracy: 0.10638333333333333
Testing loss: 2.303235805718003
Testing accuracy: 0.1135
Epoch 143
-----
Training loss: 2.3045108472188316
Training accuracy: 0.1082
Testing loss: 2.304215271761463
Testing accuracy: 0.1009
Epoch 144
-----
Training loss: 2.304766842397054
Training accuracy: 0.10643333333333334
Testing loss: 2.304722087398456
Testing accuracy: 0.0958
Epoch 145
-----
Training loss: 2.3045516123453775
Training accuracy: 0.10638333333333333
Testing loss: 2.303768745653189
Testing accuracy: 0.1135
Epoch 146
-----
Training loss: 2.3053220033009847
Training accuracy: 0.10461666666666666
Testing loss: 2.302568605750989
Testing accuracy: 0.1135
Epoch 147
-----
Training loss: 2.3046671095530193
Training accuracy: 0.1052
Testing loss: 2.3040216713194637
Testing accuracy: 0.1135
Epoch 148
-----
Training loss: 2.3049812386830646
Training accuracy: 0.10601666666666666
Testing loss: 2.304904491278776
Testing accuracy: 0.101
Epoch 149
-----
Training loss: 2.3045918497721356
Training accuracy: 0.10596666666666667
Testing loss: 2.3084573806471127
Testing accuracy: 0.1032
Epoch 150
-----
```

Training loss: 2.304912372461955  
Training accuracy: 0.10611666666666666  
Testing loss: 2.303037450571728  
Testing accuracy: 0.0958  
Done  
Total Time Consumed: 3993.699524641037

```
[ ]: loss_plot(train_loss_record, test_loss_record)
```



```
[ ]: error_plot(train_loss_record, test_loss_record)
```



### 5.9.6 Best Combination of Hyperparameters

Testing Accuracy As follow:

Learning Rate = 0.1: 99.28%;

Learning Rate = 0.01: 99.05%;

Learning Rate = 0.2: 99.31%;

Learning Rate = 0.5: 99.18%;

Momentum = 0.5 & Learning Rate = 0.1: 99.23%;

Momentum = 0.9 & Learning Rate = 0.1: 9.58%.

From above, it can be observed that the loss function of LeNet5 can always converge quickly to local minimum with different hyperparameters. However, all models suffer from the problem of overfitting, while for the models with learning rate = 0.2, learning rate = 0.5 and momentum = 0.5, we can observe a sudden surge in loss and misclassification error, which indicates loss function moves away from local minimum. In, addition, it can be observed that the model with momentum = 0.9 moves away from local minimum and cannot return to local minimum. Therefore, we can conclude that momentum is unnecessary for LeNet5 and a small learning rate like 0.1 and 0.01 is good enough.



## 6 V. More about Deep Learning

### 6.1 6.

```
[6]: # Load Data
train_data = pd.read_csv('/train.txt', header = None)
test_data = pd.read_csv('/test.txt', header = None)
val_data = pd.read_csv('/val.txt', header = None)
```

```
[ ]: train_data.shape
```

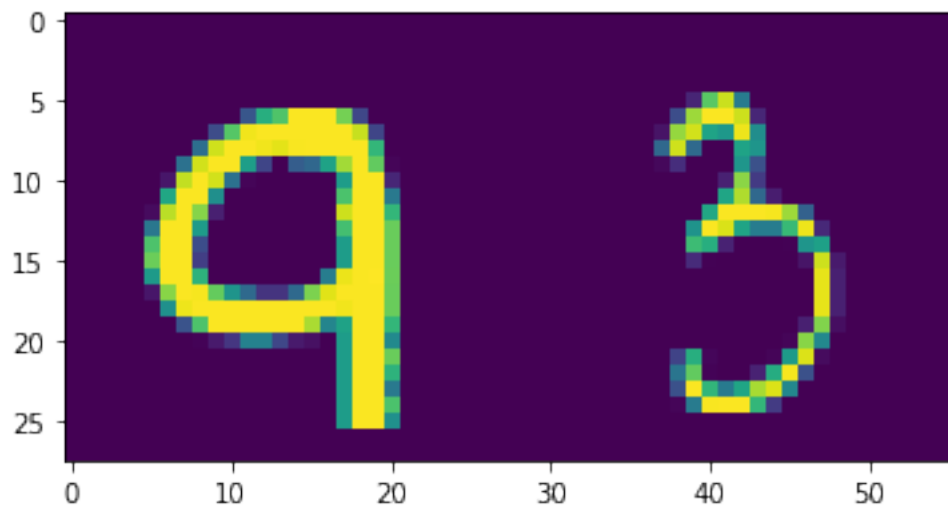
```
[ ]: (20000, 1569)
```

From above, we can see that the number of rows is 20000. We know that each sample is composed of a total of 1568 pixels and one label. Therefore, we know that the pixels are scanned out in row-major order.

```
[ ]: # Define a Function to plot Sample and Return Labels
def sampleplot(index):
    x = train_data.loc[index][:1568]
    y = train_data.loc[index][1568:]
    x = np.array(x).reshape(28,28)
    imshow(x)
    print(y)
```

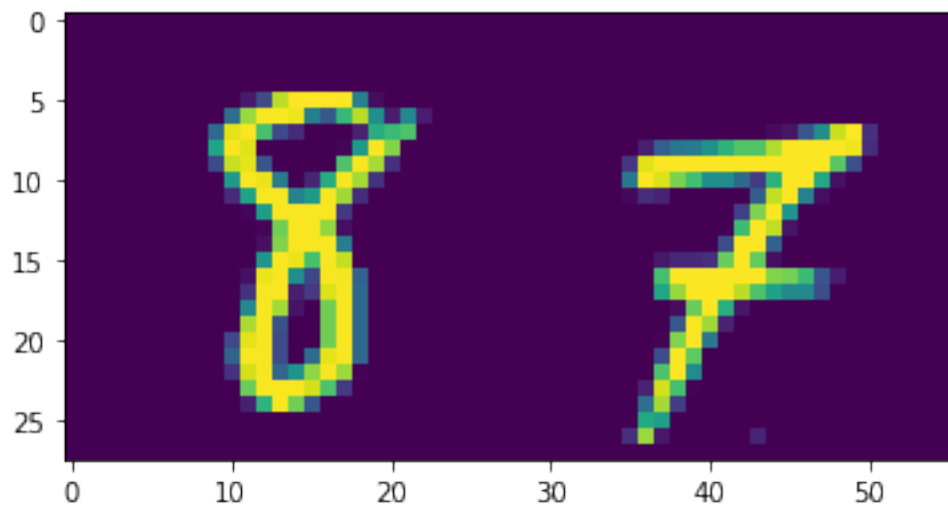
```
[ ]: sampleplot(4)
```

```
1568    12.0
Name: 4, dtype: float64
```



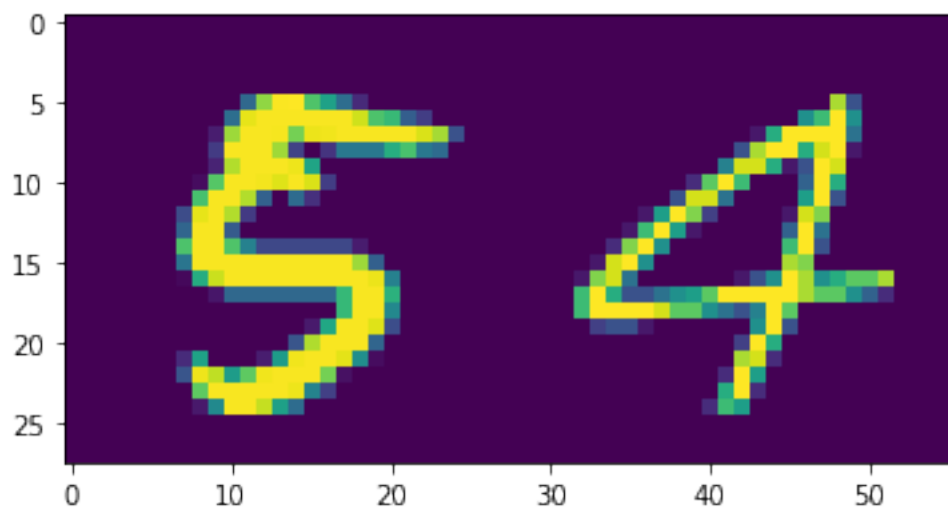
```
[ ]: sampleplot(5)
```

```
1568    15.0  
Name: 5, dtype: float64
```



```
[ ]: sampleplot(6)
```

```
1568     9.0  
Name: 6, dtype: float64
```



From above, we can see that the sum of two digits equal to the last coordinate of each line.

## 6.2 7.(a)

```
[8]: # Data Process
Y_train = np.array(train_data[1568])
Y_train = torch.from_numpy(Y_train).double()
X_train = np.array(train_data[train_data.columns[0:1568]]).
    ↳ reshape(20000,1,28,56)
X_train = torch.from_numpy(X_train).double()

# Test Data
Y_test = np.array(test_data[1568])
Y_test = torch.from_numpy(Y_test).double()
X_test = np.array(test_data[test_data.columns[0:1568]]).reshape(5000,1,28,56)
X_test = torch.from_numpy(X_test).double()

# Validation Data
Y_val = np.array(val_data[1568])
Y_val = torch.from_numpy(Y_val).double()
X_val = np.array(val_data[val_data.columns[0:1568]]).reshape(5000,1,28,56)
X_val = torch.from_numpy(X_val).double()
```

```
[7]: # Define Required Plot Function
def loss_plot1(train,test,val):
    index = []
    train_set = []
    test_set = []
    val_set = []
    for i in range(len(train)):
        index.append(i+1)
        train_set.append(train[i][0])
        test_set.append(test[i][0])
        val_set.append(val[i][0])
    plt.plot(index, train_set, label = "Train")
    plt.plot(index, test_set, label = "Test")
    plt.plot(index, val_set, label = "Validation")
    plt.legend()
    plt.xlabel("Number of Iterations")
    plt.ylabel("Loss Function")
    plt.title("Loss vs. Epochs Plot")

def error_plot1(train,test,val):
    index = []
    train_set = []
    test_set = []
    val_set = []
```

```

for i in range(len(train)):
    index.append(i+1)
    train_set.append(1 - train[i][1])
    test_set.append(1 - test[i][1])
    val_set.append(1 - val[i][1])
plt.plot(index, train_set, label = "Train")
plt.plot(index, test_set, label = "Test")
plt.plot(index, val_set, label = "Validation")
plt.legend()
plt.xlabel("Number of Iterations")
plt.ylabel("Classification Error")
plt.title("Classification Error vs. Epochs Plot")

```

```

[7]: def train_loop7(feature,label, model, loss_fn, optimizer):
    running_loss, correct = 0, 0
    size = len(feature)
    for index, X in enumerate(feature):
        # Compute prediction and loss
        y = label[index]
        pred = model(X)
        loss = loss_fn(pred, y)
        running_loss += loss.item()
        correct += (torch.round(pred) == y).type(torch.float).sum().item()
        # Backpropagation
        optimizer.zero_grad()
        loss.backward()
        optimizer.step()
    running_loss = running_loss / size
    correct /= size
    print('Training loss: {}'.format(running_loss))
    print('Training accuracy: {}'.format(correct))
    return running_loss, correct

def test_loop7(feature,label, model, loss_fn):
    size = len(feature)
    test_loss, correct = 0, 0

    with torch.no_grad():
        for index, X in enumerate(feature):
            pred = model(X)
            y = label[index]
            test_loss += loss_fn(pred, y).item()
            correct += (torch.round(pred) == y).type(torch.float).sum().item()

    test_loss /= size
    correct /= size

```

```

print('Testing loss: {}'.format(test_loss))
print('Testing accuracy: {}'.format(correct))
return test_loss, correct

```

## 6.3 Replication From Paper

```

[8]: class sum_model(nn.Module):
    def __init__(self):
        super(sum_model, self).__init__()
        self.conv1 = nn.Conv2d(1, 32, 3) # Output Shape 26 * 54 * 32
        self.conv2 = nn.Conv2d(32, 16, 3) # Output Shape 24 * 52 * 16
        self.pool1 = nn.MaxPool2d(2) # Output Shape 12 * 26 * 16
        self.do = nn.Dropout(0.25)
        self.flatten = nn.Flatten() # Output Shape 16 * 312
        self.linear1 = nn.Linear(312, 16) # output shape 16 * 16
        self.do2 = nn.Dropout(0.5)
        self.linear2 = nn.Linear(256, 100)
        self.linear3 = nn.Linear(100, 1) # Output Shape 1 Make it Regression

    def forward(self, x):
        x = F.relu(self.conv1(x))
        x = F.relu(self.conv2(x))
        x = self.pool1(x)
        x = self.do(x)
        x = self.flatten(x)
        x = F.relu(self.linear1(x))
        x = x.reshape(-1)
        x = self.do2(x)
        x = F.relu(self.linear2(x))
        x = self.linear3(x)

        return x

```

### 6.3.1 Learning Rate = 1

```

[ ]: # Define HyperParameters
learning_rate = 1
batch_size = 64
num_epochs = 150

net5 = sum_model().double()
# Use the same optimizer Adadelta As in the paper
optimizer = optim.Adadelta(net5.parameters(), lr = learning_rate, rho = 0.95,
    ↪eps = 1e-08, weight_decay = 0)

```

```
# Mean Squared Error Loss Function Used
loss = nn.MSELoss()
```

```
[ ]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop7(X_train,Y_train,net5,loss,optimizer))
    test_loss_record.append(test_loop7(X_test,Y_test,net5,loss))
    val_loss_record.append(test_loop7(X_val,Y_val,net5,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

-----

/usr/local/lib/python3.7/dist-packages/torch/nn/modules/loss.py:529:

UserWarning: Using a target size (torch.Size([])) that is different to the input size (torch.Size([1])). This will likely lead to incorrect results due to broadcasting. Please ensure they have the same size.

return F.mse\_loss(input, target, reduction=self.reduction)

Training loss: 8.733014670041598

Training accuracy: 0.13515

Testing loss: 6.713187465276153

Testing accuracy: 0.161

Testing loss: 6.954100303243907

Testing accuracy: 0.1488

Epoch 2

-----

Training loss: 5.787012530651331

Training accuracy: 0.1701

Testing loss: 5.507572200596529

Testing accuracy: 0.1898

Testing loss: 5.803358649226282

Testing accuracy: 0.1714

Epoch 3

-----

Training loss: 4.941862898710696

Training accuracy: 0.196

Testing loss: 5.249234976399224

Testing accuracy: 0.193

Testing loss: 5.39511510594798

Testing accuracy: 0.1912

Epoch 4

-----

Training loss: 4.488168319734062  
Training accuracy: 0.20445  
Testing loss: 4.923821420960263  
Testing accuracy: 0.2008  
Testing loss: 5.20127244488753  
Testing accuracy: 0.2046  
Epoch 5

-----  
Training loss: 4.12407235509744  
Training accuracy: 0.21025  
Testing loss: 4.102558243606319  
Testing accuracy: 0.227  
Testing loss: 4.311140112294585  
Testing accuracy: 0.223  
Epoch 6

-----  
Training loss: 3.903696928531176  
Training accuracy: 0.21885  
Testing loss: 4.395583455736529  
Testing accuracy: 0.22  
Testing loss: 4.62396529654943  
Testing accuracy: 0.2172  
Epoch 7

-----  
Training loss: 3.784291087213454  
Training accuracy: 0.22505  
Testing loss: 4.186084474389651  
Testing accuracy: 0.2214  
Testing loss: 4.166411959993357  
Testing accuracy: 0.2114  
Epoch 8

-----  
Training loss: 3.653506113600493  
Training accuracy: 0.22485  
Testing loss: 4.093446400085659  
Testing accuracy: 0.2314  
Testing loss: 4.376997469251525  
Testing accuracy: 0.2084  
Epoch 9

-----  
Training loss: 3.585354059358048  
Training accuracy: 0.2308  
Testing loss: 3.8654069942704634  
Testing accuracy: 0.2252  
Testing loss: 3.924457276383871  
Testing accuracy: 0.2296  
Epoch 10

Training loss: 3.462279308969069  
Training accuracy: 0.23935  
Testing loss: 3.3908185057322533  
Testing accuracy: 0.2476  
Testing loss: 3.513940390220104  
Testing accuracy: 0.24  
Epoch 11

-----  
Training loss: 3.285011118821278  
Training accuracy: 0.24185  
Testing loss: 3.3184270477537976  
Testing accuracy: 0.252  
Testing loss: 3.527220143585613  
Testing accuracy: 0.242  
Epoch 12

-----  
Training loss: 3.23259221171138  
Training accuracy: 0.24945  
Testing loss: 3.317747957812496  
Testing accuracy: 0.2586  
Testing loss: 3.534396411472621  
Testing accuracy: 0.239  
Epoch 13

-----  
Training loss: 3.142366090301979  
Training accuracy: 0.25325  
Testing loss: 3.2845270296376445  
Testing accuracy: 0.2572  
Testing loss: 3.424014480348809  
Testing accuracy: 0.2444  
Epoch 14

-----  
Training loss: 3.068482642001299  
Training accuracy: 0.2514  
Testing loss: 3.176041053767035  
Testing accuracy: 0.2606  
Testing loss: 3.2250320876699057  
Testing accuracy: 0.2528  
Epoch 15

-----  
Training loss: 2.9766520596912445  
Training accuracy: 0.2582  
Testing loss: 2.9909552723994146  
Testing accuracy: 0.268  
Testing loss: 3.2419803481365883  
Testing accuracy: 0.255  
Epoch 16



Training loss: 2.9224573640903433  
Training accuracy: 0.2596  
Testing loss: 3.173863727041018  
Testing accuracy: 0.2598  
Testing loss: 3.301064029260468  
Testing accuracy: 0.2436  
Epoch 17

-----  
Training loss: 2.843671421654477  
Training accuracy: 0.2636  
Testing loss: 3.008612110944801  
Testing accuracy: 0.2774  
Testing loss: 2.9812465471345138  
Testing accuracy: 0.2594  
Epoch 18

-----  
Training loss: 2.7705051507188836  
Training accuracy: 0.2696  
Testing loss: 3.027043062570635  
Testing accuracy: 0.287  
Testing loss: 3.0884481575639096  
Testing accuracy: 0.255  
Epoch 19

-----  
Training loss: 2.7174457111000874  
Training accuracy: 0.27805  
Testing loss: 2.861796526364545  
Testing accuracy: 0.286  
Testing loss: 2.8283944930102414  
Testing accuracy: 0.2794  
Epoch 20

-----  
Training loss: 2.6354479800262105  
Training accuracy: 0.2843  
Testing loss: 2.8800074861903764  
Testing accuracy: 0.2976  
Testing loss: 2.9198636012103525  
Testing accuracy: 0.2728  
Epoch 21

-----  
Training loss: 2.5743219706498377  
Training accuracy: 0.2873  
Testing loss: 2.735687050483641  
Testing accuracy: 0.3  
Testing loss: 2.794011744691089  
Testing accuracy: 0.286  
Epoch 22

-----

Training loss: 2.5010033408651386  
Training accuracy: 0.2992  
Testing loss: 2.700600166936531  
Testing accuracy: 0.3012  
Testing loss: 2.753107165930424  
Testing accuracy: 0.2922  
Epoch 23

-----  
Training loss: 2.442503375454857  
Training accuracy: 0.30085  
Testing loss: 2.565548516441767  
Testing accuracy: 0.3002  
Testing loss: 2.639375288001722  
Testing accuracy: 0.2802  
Epoch 24

-----  
Training loss: 2.395775856357823  
Training accuracy: 0.30385  
Testing loss: 2.6535990012944564  
Testing accuracy: 0.2964  
Testing loss: 2.67360781636551  
Testing accuracy: 0.3  
Epoch 25

-----  
Training loss: 2.3660001569782363  
Training accuracy: 0.3092  
Testing loss: 2.60243924384613  
Testing accuracy: 0.3078  
Testing loss: 2.5836231914162284  
Testing accuracy: 0.298  
Epoch 26

-----  
Training loss: 2.3502450403349338  
Training accuracy: 0.3076  
Testing loss: 2.6062960011097465  
Testing accuracy: 0.3086  
Testing loss: 2.5060153147841335  
Testing accuracy: 0.3166  
Epoch 27

-----  
Training loss: 2.3223686153989904  
Training accuracy: 0.31325  
Testing loss: 2.5645712908616156  
Testing accuracy: 0.3276  
Testing loss: 2.543687239766526  
Testing accuracy: 0.3076  
Epoch 28

Training loss: 2.25357653506168  
Training accuracy: 0.32505  
Testing loss: 2.552498267665893  
Testing accuracy: 0.3206  
Testing loss: 2.5396353099018802  
Testing accuracy: 0.3112  
Epoch 29  
-----

Training loss: 2.2291124070147927  
Training accuracy: 0.32965  
Testing loss: 2.5324067946009685  
Testing accuracy: 0.3296  
Testing loss: 2.5448848362259167  
Testing accuracy: 0.32  
Epoch 30  
-----

Training loss: 2.228604252599595  
Training accuracy: 0.33255  
Testing loss: 2.52239099040862  
Testing accuracy: 0.3278  
Testing loss: 2.4983334235436354  
Testing accuracy: 0.3148  
Epoch 31  
-----

Training loss: 2.1947108452529704  
Training accuracy: 0.33135  
Testing loss: 2.4317655558650624  
Testing accuracy: 0.3254  
Testing loss: 2.3520141803249777  
Testing accuracy: 0.323  
Epoch 32  
-----

Training loss: 2.142743076633835  
Training accuracy: 0.3396  
Testing loss: 2.361272691330545  
Testing accuracy: 0.3352  
Testing loss: 2.4510555529388283  
Testing accuracy: 0.3262  
Epoch 33  
-----

Training loss: 2.1796106054238638  
Training accuracy: 0.3432  
Testing loss: 2.3599174779136627  
Testing accuracy: 0.331  
Testing loss: 2.3875072406139455  
Testing accuracy: 0.331  
Epoch 34  
-----

Training loss: 2.1778723296258597  
Training accuracy: 0.3411  
Testing loss: 2.3688984812931344  
Testing accuracy: 0.3334  
Testing loss: 2.4115928885333764  
Testing accuracy: 0.3234  
Epoch 35  
-----

Training loss: 2.1053349753161728  
Training accuracy: 0.34525  
Testing loss: 2.3165321751870405  
Testing accuracy: 0.3538  
Testing loss: 2.2873066484207514  
Testing accuracy: 0.335  
Epoch 36  
-----

Training loss: 2.113441169498997  
Training accuracy: 0.3477  
Testing loss: 2.29607442760989  
Testing accuracy: 0.3518  
Testing loss: 2.3196565935731  
Testing accuracy: 0.338  
Epoch 37  
-----

Training loss: 2.0771308582109125  
Training accuracy: 0.353  
Testing loss: 2.326568050646642  
Testing accuracy: 0.3404  
Testing loss: 2.3070077478225093  
Testing accuracy: 0.341  
Epoch 38  
-----

Training loss: 2.0752262152629806  
Training accuracy: 0.3476  
Testing loss: 2.3717291884293976  
Testing accuracy: 0.3546  
Testing loss: 2.4105798326423065  
Testing accuracy: 0.3486  
Epoch 39  
-----

Training loss: 2.0383547400300737  
Training accuracy: 0.3537  
Testing loss: 2.238749519460723  
Testing accuracy: 0.3596  
Testing loss: 2.3205380410966248  
Testing accuracy: 0.3466  
Epoch 40  
-----

Training loss: 1.9975424786058822  
Training accuracy: 0.35965  
Testing loss: 2.329315495265607  
Testing accuracy: 0.3662  
Testing loss: 2.3317808747380724  
Testing accuracy: 0.344  
Epoch 41

-----  
Training loss: 2.0135864497116924  
Training accuracy: 0.3604  
Testing loss: 2.312382369475135  
Testing accuracy: 0.3608  
Testing loss: 2.3292380889891335  
Testing accuracy: 0.3498  
Epoch 42

-----  
Training loss: 2.0053089920402054  
Training accuracy: 0.36465  
Testing loss: 2.281283207758282  
Testing accuracy: 0.3678  
Testing loss: 2.2607992448561656  
Testing accuracy: 0.3588  
Epoch 43

-----  
Training loss: 1.9600210072608828  
Training accuracy: 0.3647  
Testing loss: 2.246333133277145  
Testing accuracy: 0.3644  
Testing loss: 2.3663953704789065  
Testing accuracy: 0.3482  
Epoch 44

-----  
Training loss: 1.98381679312223  
Training accuracy: 0.3759  
Testing loss: 2.2062254527770992  
Testing accuracy: 0.3742  
Testing loss: 2.1987149561517176  
Testing accuracy: 0.3518  
Epoch 45

-----  
Training loss: 1.9619850226452282  
Training accuracy: 0.3704  
Testing loss: 2.3801993713480094  
Testing accuracy: 0.3686  
Testing loss: 2.3161890490901387  
Testing accuracy: 0.3724  
Epoch 46

Training loss: 1.9438340446265432  
Training accuracy: 0.37125  
Testing loss: 2.288233114940375  
Testing accuracy: 0.373  
Testing loss: 2.228217757326872  
Testing accuracy: 0.3706  
Epoch 47

-----  
Training loss: 1.9840873768573426  
Training accuracy: 0.37705  
Testing loss: 2.2355901968079417  
Testing accuracy: 0.3792  
Testing loss: 2.2362373951354386  
Testing accuracy: 0.3752  
Epoch 48

-----  
Training loss: 1.9297189668578811  
Training accuracy: 0.3789  
Testing loss: 2.183984607404985  
Testing accuracy: 0.3924  
Testing loss: 2.2423387093806038  
Testing accuracy: 0.3688  
Epoch 49

-----  
Training loss: 1.8982031447845402  
Training accuracy: 0.38975  
Testing loss: 2.2172187349819805  
Testing accuracy: 0.3822  
Testing loss: 2.2714723424471157  
Testing accuracy: 0.3812  
Epoch 50

-----  
Training loss: 1.9193513176629822  
Training accuracy: 0.38505  
Testing loss: 2.1792349205815977  
Testing accuracy: 0.3838  
Testing loss: 2.2217637696335566  
Testing accuracy: 0.3692  
Epoch 51

-----  
Training loss: 1.924515741691415  
Training accuracy: 0.3914  
Testing loss: 2.2059254268036486  
Testing accuracy: 0.3822  
Testing loss: 2.2201568224027453  
Testing accuracy: 0.3782  
Epoch 52

-----

Training loss: 1.8813266124090158  
Training accuracy: 0.3868  
Testing loss: 2.197596258354501  
Testing accuracy: 0.38  
Testing loss: 2.184773625879065  
Testing accuracy: 0.381  
Epoch 53  
-----

Training loss: 1.908103186334163  
Training accuracy: 0.39725  
Testing loss: 2.1340584673981424  
Testing accuracy: 0.3836  
Testing loss: 2.231884878165223  
Testing accuracy: 0.3786  
Epoch 54  
-----

Training loss: 1.8666191923677027  
Training accuracy: 0.3972  
Testing loss: 2.11757582041654  
Testing accuracy: 0.3846  
Testing loss: 2.1753238638615358  
Testing accuracy: 0.3824  
Epoch 55  
-----

Training loss: 1.9028535964949795  
Training accuracy: 0.40035  
Testing loss: 2.0814078153349587  
Testing accuracy: 0.4102  
Testing loss: 2.119515148160819  
Testing accuracy: 0.3982  
Epoch 56  
-----

Training loss: 1.8576860986012111  
Training accuracy: 0.4081  
Testing loss: 2.0946481237671217  
Testing accuracy: 0.4004  
Testing loss: 2.1847828635987026  
Testing accuracy: 0.3908  
Epoch 57  
-----

Training loss: 1.8447838867854105  
Training accuracy: 0.4042  
Testing loss: 2.0568748062374302  
Testing accuracy: 0.3994  
Testing loss: 2.1268469933352954  
Testing accuracy: 0.3918  
Epoch 58  
-----

Training loss: 1.8271218320954656  
Training accuracy: 0.4053  
Testing loss: 2.203185683846904  
Testing accuracy: 0.399  
Testing loss: 2.1701563275170543  
Testing accuracy: 0.4016  
Epoch 59  
-----

Training loss: 1.8065688120410888  
Training accuracy: 0.4065  
Testing loss: 2.100802086741472  
Testing accuracy: 0.393  
Testing loss: 2.166471244042894  
Testing accuracy: 0.3846  
Epoch 60  
-----

Training loss: 1.829453502891325  
Training accuracy: 0.4083  
Testing loss: 2.031819385565896  
Testing accuracy: 0.4086  
Testing loss: 2.1289573312356134  
Testing accuracy: 0.402  
Epoch 61  
-----

Training loss: 1.8160670515849917  
Training accuracy: 0.40855  
Testing loss: 2.109106249015629  
Testing accuracy: 0.4024  
Testing loss: 2.1027019111309686  
Testing accuracy: 0.4018  
Epoch 62  
-----

Training loss: 1.7837062793535605  
Training accuracy: 0.41605  
Testing loss: 2.080209353861157  
Testing accuracy: 0.4138  
Testing loss: 2.1691214020400826  
Testing accuracy: 0.3968  
Epoch 63  
-----

Training loss: 1.8314879046702146  
Training accuracy: 0.41375  
Testing loss: 2.0301816271094335  
Testing accuracy: 0.4258  
Testing loss: 2.1465839908858926  
Testing accuracy: 0.4066  
Epoch 64  
-----



Training loss: 1.8486835737383327  
Training accuracy: 0.4204  
Testing loss: 2.073940857687581  
Testing accuracy: 0.4008  
Testing loss: 2.102200066454652  
Testing accuracy: 0.3982  
Epoch 65  
-----

Training loss: 1.804535454194283  
Training accuracy: 0.4187  
Testing loss: 2.0211764925026223  
Testing accuracy: 0.4252  
Testing loss: 2.0848220163326365  
Testing accuracy: 0.4028  
Epoch 66  
-----

Training loss: 1.8011037644971915  
Training accuracy: 0.4237  
Testing loss: 2.011566218411262  
Testing accuracy: 0.4226  
Testing loss: 2.1169917981651154  
Testing accuracy: 0.3998  
Epoch 67  
-----

Training loss: 1.7801868789141444  
Training accuracy: 0.42375  
Testing loss: 2.0730590023036837  
Testing accuracy: 0.4204  
Testing loss: 2.1151474517246105  
Testing accuracy: 0.416  
Epoch 68  
-----

Training loss: 1.8111380263169332  
Training accuracy: 0.4222  
Testing loss: 2.043850088140701  
Testing accuracy: 0.4288  
Testing loss: 2.108984327362147  
Testing accuracy: 0.4196  
Epoch 69  
-----

Training loss: 1.7613439325994211  
Training accuracy: 0.4277  
Testing loss: 2.103953959588703  
Testing accuracy: 0.4386  
Testing loss: 2.1733217185537357  
Testing accuracy: 0.431  
Epoch 70  
-----

Training loss: 1.8107819150748021  
Training accuracy: 0.42985  
Testing loss: 2.080216964335356  
Testing accuracy: 0.4342  
Testing loss: 2.084244300159553  
Testing accuracy: 0.4252  
Epoch 71

-----  
Training loss: 1.7687931806563986  
Training accuracy: 0.433  
Testing loss: 2.0706079469303584  
Testing accuracy: 0.4236  
Testing loss: 2.153171110922802  
Testing accuracy: 0.4072  
Epoch 72

-----  
Training loss: 1.7664612594218743  
Training accuracy: 0.4301  
Testing loss: 2.0620287132771447  
Testing accuracy: 0.4372  
Testing loss: 2.048353553005393  
Testing accuracy: 0.4312  
Epoch 73

-----  
Training loss: 1.7520193670102964  
Training accuracy: 0.43785  
Testing loss: 2.0183319692878356  
Testing accuracy: 0.431  
Testing loss: 2.0513687974457473  
Testing accuracy: 0.4188  
Epoch 74

-----  
Training loss: 1.7175624447809594  
Training accuracy: 0.43875  
Testing loss: 2.0104488953287  
Testing accuracy: 0.4312  
Testing loss: 2.084760526248039  
Testing accuracy: 0.4266  
Epoch 75

-----  
Training loss: 1.7213510496258693  
Training accuracy: 0.4419  
Testing loss: 1.9480835542432877  
Testing accuracy: 0.4552  
Testing loss: 2.058792345382986  
Testing accuracy: 0.4356  
Epoch 76

Training loss: 1.7294134519893676  
Training accuracy: 0.44125  
Testing loss: 2.017621138197888  
Testing accuracy: 0.45  
Testing loss: 2.0047873522547097  
Testing accuracy: 0.4266  
Epoch 77

-----  
Training loss: 1.731638491666911  
Training accuracy: 0.44505  
Testing loss: 1.9760618617070214  
Testing accuracy: 0.435  
Testing loss: 2.1434920468509233  
Testing accuracy: 0.4208  
Epoch 78

-----  
Training loss: 1.7579682995635602  
Training accuracy: 0.44635  
Testing loss: 2.099328409715569  
Testing accuracy: 0.435  
Testing loss: 2.1128582648386787  
Testing accuracy: 0.432  
Epoch 79

-----  
Training loss: 1.7328001959731525  
Training accuracy: 0.4487  
Testing loss: 1.8974510380417233  
Testing accuracy: 0.4346  
Testing loss: 2.0430829403130293  
Testing accuracy: 0.4294  
Epoch 80

-----  
Training loss: 1.706782844905066  
Training accuracy: 0.4484  
Testing loss: 1.990431761580695  
Testing accuracy: 0.4446  
Testing loss: 2.041239588047223  
Testing accuracy: 0.4522  
Epoch 81

-----  
Training loss: 1.6817271781225522  
Training accuracy: 0.4522  
Testing loss: 1.9883596264048735  
Testing accuracy: 0.445  
Testing loss: 2.188434427071776  
Testing accuracy: 0.4158  
Epoch 82

-----

Training loss: 1.688672703066207  
Training accuracy: 0.44815  
Testing loss: 1.9243323452019205  
Testing accuracy: 0.4454  
Testing loss: 2.0792608709302387  
Testing accuracy: 0.4256  
Epoch 83  
-----

Training loss: 1.693941658549069  
Training accuracy: 0.4552  
Testing loss: 1.9856511671537442  
Testing accuracy: 0.449  
Testing loss: 2.0139478736034366  
Testing accuracy: 0.4438  
Epoch 84  
-----

Training loss: 1.6616563393440429  
Training accuracy: 0.45915  
Testing loss: 1.932789825719567  
Testing accuracy: 0.4624  
Testing loss: 2.029463305085905  
Testing accuracy: 0.4448  
Epoch 85  
-----

Training loss: 1.6842375047565918  
Training accuracy: 0.4598  
Testing loss: 2.084089366877987  
Testing accuracy: 0.4598  
Testing loss: 2.1213414057577435  
Testing accuracy: 0.4428  
Epoch 86  
-----

Training loss: 1.6831850924506868  
Training accuracy: 0.46565  
Testing loss: 1.9480253329007178  
Testing accuracy: 0.4656  
Testing loss: 2.0015810588345517  
Testing accuracy: 0.4594  
Epoch 87  
-----

Training loss: 1.6814068779835378  
Training accuracy: 0.46265  
Testing loss: 1.894778515385267  
Testing accuracy: 0.4754  
Testing loss: 2.0109259003286817  
Testing accuracy: 0.4514  
Epoch 88  
-----

Training loss: 1.65679845048017  
Training accuracy: 0.4656  
Testing loss: 1.9444792425159207  
Testing accuracy: 0.4446  
Testing loss: 2.0599150751446045  
Testing accuracy: 0.4386  
Epoch 89  
-----

Training loss: 1.7323644640934133  
Training accuracy: 0.4567  
Testing loss: 1.9595681772821598  
Testing accuracy: 0.4684  
Testing loss: 2.092447853733402  
Testing accuracy: 0.4554  
Epoch 90  
-----

Training loss: 1.6837113108655717  
Training accuracy: 0.4687  
Testing loss: 1.8419846037389442  
Testing accuracy: 0.4772  
Testing loss: 1.9914567915192734  
Testing accuracy: 0.4584  
Epoch 91  
-----

Training loss: 1.6822965911605636  
Training accuracy: 0.47115  
Testing loss: 1.924032930769099  
Testing accuracy: 0.468  
Testing loss: 2.0888143275034965  
Testing accuracy: 0.4562  
Epoch 92  
-----

Training loss: 1.6695920412321557  
Training accuracy: 0.4661  
Testing loss: 1.9523490144987419  
Testing accuracy: 0.4696  
Testing loss: 1.998945276995932  
Testing accuracy: 0.4552  
Epoch 93  
-----

Training loss: 1.6423360590487999  
Training accuracy: 0.4682  
Testing loss: 1.9788216193850938  
Testing accuracy: 0.4664  
Testing loss: 2.0944846280235847  
Testing accuracy: 0.4384  
Epoch 94  
-----

Training loss: 1.638898628846516  
Training accuracy: 0.46995  
Testing loss: 1.992722266464771  
Testing accuracy: 0.4756  
Testing loss: 2.010477000403559  
Testing accuracy: 0.4708  
Epoch 95

-----  
Training loss: 1.6693665807095415  
Training accuracy: 0.47735  
Testing loss: 1.8876570772024497  
Testing accuracy: 0.4882  
Testing loss: 1.9526361437312931  
Testing accuracy: 0.4634  
Epoch 96

-----  
Training loss: 1.6465803874748475  
Training accuracy: 0.4733  
Testing loss: 1.9133188751494357  
Testing accuracy: 0.4742  
Testing loss: 1.9794331697927927  
Testing accuracy: 0.448  
Epoch 97

-----  
Training loss: 1.6519791114181939  
Training accuracy: 0.4795  
Testing loss: 2.019357405787413  
Testing accuracy: 0.4586  
Testing loss: 1.9892918601574823  
Testing accuracy: 0.4562  
Epoch 98

-----  
Training loss: 1.6524447428317661  
Training accuracy: 0.47315  
Testing loss: 1.9875765699560284  
Testing accuracy: 0.4632  
Testing loss: 2.0852819290465368  
Testing accuracy: 0.4668  
Epoch 99

-----  
Training loss: 1.6171510094492532  
Training accuracy: 0.47925  
Testing loss: 1.8053794585714127  
Testing accuracy: 0.493  
Testing loss: 2.000599647334131  
Testing accuracy: 0.4616  
Epoch 100

Training loss: 1.6109104334711815  
Training accuracy: 0.48475  
Testing loss: 2.0320573343866775  
Testing accuracy: 0.471  
Testing loss: 2.0837441576812408  
Testing accuracy: 0.4618  
Epoch 101  
-----

Training loss: 1.6577216188013324  
Training accuracy: 0.47835  
Testing loss: 2.1443075111377152  
Testing accuracy: 0.4742  
Testing loss: 2.096247302527301  
Testing accuracy: 0.4616  
Epoch 102  
-----

Training loss: 1.6585491288323047  
Training accuracy: 0.4825  
Testing loss: 1.9886894384906482  
Testing accuracy: 0.4834  
Testing loss: 2.0195467384773393  
Testing accuracy: 0.48  
Epoch 103  
-----

Training loss: 1.6253474287678409  
Training accuracy: 0.48045  
Testing loss: 1.8847064252886503  
Testing accuracy: 0.4848  
Testing loss: 2.041712396189389  
Testing accuracy: 0.464  
Epoch 104  
-----

Training loss: 1.5863215161896445  
Training accuracy: 0.4839  
Testing loss: 1.9470778317008832  
Testing accuracy: 0.4934  
Testing loss: 1.988192772385352  
Testing accuracy: 0.4752  
Epoch 105  
-----

Training loss: 1.6193699310250669  
Training accuracy: 0.48945  
Testing loss: 1.9799450438869712  
Testing accuracy: 0.4908  
Testing loss: 2.021109267573553  
Testing accuracy: 0.478  
Epoch 106  
-----

Training loss: 1.6205203217411002  
Training accuracy: 0.48105  
Testing loss: 1.84037906052054  
Testing accuracy: 0.4878  
Testing loss: 1.9695725090537093  
Testing accuracy: 0.4646  
Epoch 107

-----  
Training loss: 1.623034887618568  
Training accuracy: 0.4819  
Testing loss: 1.9083679000941323  
Testing accuracy: 0.4888  
Testing loss: 1.964797760694693  
Testing accuracy: 0.4816  
Epoch 108

-----  
Training loss: 1.5925404642621281  
Training accuracy: 0.49255  
Testing loss: 1.7779946711953716  
Testing accuracy: 0.484  
Testing loss: 1.999181252957807  
Testing accuracy: 0.4712  
Epoch 109

-----  
Training loss: 1.58523990417776  
Training accuracy: 0.4872  
Testing loss: 1.8964197437164985  
Testing accuracy: 0.4612  
Testing loss: 2.093902668473851  
Testing accuracy: 0.442  
Epoch 110

-----  
Training loss: 1.5980267546505684  
Training accuracy: 0.4868  
Testing loss: 1.783502197929504  
Testing accuracy: 0.5066  
Testing loss: 1.9302879824189916  
Testing accuracy: 0.4838  
Epoch 111

-----  
Training loss: 1.5862577951853154  
Training accuracy: 0.4965  
Testing loss: 1.8352436630994273  
Testing accuracy: 0.4878  
Testing loss: 2.005351885003675  
Testing accuracy: 0.4706  
Epoch 112



Training loss: 1.5837247798423726  
Training accuracy: 0.49105  
Testing loss: 1.8682017600482035  
Testing accuracy: 0.5024  
Testing loss: 1.9860703662785735  
Testing accuracy: 0.4776  
Epoch 113

-----  
Training loss: 1.5915429354329247  
Training accuracy: 0.4894  
Testing loss: 1.9409979663292296  
Testing accuracy: 0.4914  
Testing loss: 2.0501186478722855  
Testing accuracy: 0.4772  
Epoch 114

-----  
Training loss: 1.595923646710594  
Training accuracy: 0.49245  
Testing loss: 1.9275592176641145  
Testing accuracy: 0.4854  
Testing loss: 2.0915039956278987  
Testing accuracy: 0.4718  
Epoch 115

-----  
Training loss: 1.5985249252759126  
Training accuracy: 0.49485  
Testing loss: 1.8774481296460253  
Testing accuracy: 0.494  
Testing loss: 1.989424523178186  
Testing accuracy: 0.4812  
Epoch 116

-----  
Training loss: 1.5860575203039726  
Training accuracy: 0.4996  
Testing loss: 1.8620073426652162  
Testing accuracy: 0.493  
Testing loss: 2.0192426499659866  
Testing accuracy: 0.4864  
Epoch 117

-----  
Training loss: 1.6121776695160475  
Training accuracy: 0.49675  
Testing loss: 1.914208807421296  
Testing accuracy: 0.49  
Testing loss: 1.9963132595925628  
Testing accuracy: 0.4842  
Epoch 118

Training loss: 1.5875148160247325  
Training accuracy: 0.50115  
Testing loss: 1.798798465248608  
Testing accuracy: 0.511  
Testing loss: 1.9439688978186918  
Testing accuracy: 0.4936  
Epoch 119

-----  
Training loss: 1.5715244214069393  
Training accuracy: 0.493  
Testing loss: 1.8556662267040345  
Testing accuracy: 0.5102  
Testing loss: 1.9115404414874217  
Testing accuracy: 0.4886  
Epoch 120

-----  
Training loss: 1.585981582521949  
Training accuracy: 0.49535  
Testing loss: 1.812086844412811  
Testing accuracy: 0.5076  
Testing loss: 2.0017343896753013  
Testing accuracy: 0.4954  
Epoch 121

-----  
Training loss: 1.6213355391651914  
Training accuracy: 0.49975  
Testing loss: 1.8336014909570006  
Testing accuracy: 0.4944  
Testing loss: 1.9274264010377191  
Testing accuracy: 0.486  
Epoch 122

-----  
Training loss: 1.601659227185773  
Training accuracy: 0.49455  
Testing loss: 2.048732117063391  
Testing accuracy: 0.4796  
Testing loss: 2.050282079409557  
Testing accuracy: 0.484  
Epoch 123

-----  
Training loss: 1.5855627642446415  
Training accuracy: 0.50015  
Testing loss: 1.926560679935409  
Testing accuracy: 0.4746  
Testing loss: 2.013943705105829  
Testing accuracy: 0.467  
Epoch 124

Training loss: 1.5767561289363885  
Training accuracy: 0.50205  
Testing loss: 1.8075956789095693  
Testing accuracy: 0.5094  
Testing loss: 1.897601776929115  
Testing accuracy: 0.4924  
Epoch 125

-----  
Training loss: 1.5807919280656324  
Training accuracy: 0.49945  
Testing loss: 1.9055496157738303  
Testing accuracy: 0.4906  
Testing loss: 2.0267315252724667  
Testing accuracy: 0.4898  
Epoch 126

-----  
Training loss: 1.5702064299741734  
Training accuracy: 0.51105  
Testing loss: 1.852332047157691  
Testing accuracy: 0.5102  
Testing loss: 2.012531850575236  
Testing accuracy: 0.5072  
Epoch 127

-----  
Training loss: 1.5501274607508428  
Training accuracy: 0.51105  
Testing loss: 1.8684543877485227  
Testing accuracy: 0.484  
Testing loss: 1.9740804084622585  
Testing accuracy: 0.4796  
Epoch 128

-----  
Training loss: 1.553593124501719  
Training accuracy: 0.509  
Testing loss: 1.8387865899907083  
Testing accuracy: 0.5136  
Testing loss: 1.9781313130718412  
Testing accuracy: 0.4914  
Epoch 129

-----  
Training loss: 1.5424010474057916  
Training accuracy: 0.5091  
Testing loss: 1.8868864191915353  
Testing accuracy: 0.5148  
Testing loss: 1.8950027466966661  
Testing accuracy: 0.501  
Epoch 130

Training loss: 1.5460387672770524  
Training accuracy: 0.51265  
Testing loss: 1.844595298726744  
Testing accuracy: 0.5172  
Testing loss: 1.9514218784129254  
Testing accuracy: 0.5192  
Epoch 131

-----  
Training loss: 1.585499069461521  
Training accuracy: 0.51695  
Testing loss: 1.8179892469247518  
Testing accuracy: 0.5174  
Testing loss: 1.7939212720365132  
Testing accuracy: 0.525  
Epoch 132

-----  
Training loss: 1.5441633871097067  
Training accuracy: 0.5187  
Testing loss: 1.9368958493360147  
Testing accuracy: 0.4986  
Testing loss: 1.9718511411365438  
Testing accuracy: 0.4952  
Epoch 133

-----  
Training loss: 1.5845343666630294  
Training accuracy: 0.508  
Testing loss: 1.9572610655471456  
Testing accuracy: 0.5126  
Testing loss: 2.0776707210631025  
Testing accuracy: 0.491  
Epoch 134

-----  
Training loss: 1.5652564400620441  
Training accuracy: 0.507  
Testing loss: 1.8742370684512004  
Testing accuracy: 0.5116  
Testing loss: 2.0390067063134776  
Testing accuracy: 0.4918  
Epoch 135

-----  
Training loss: 1.526097817864586  
Training accuracy: 0.5124  
Testing loss: 1.99097206384774  
Testing accuracy: 0.5078  
Testing loss: 2.024256492020756  
Testing accuracy: 0.5074  
Epoch 136

Training loss: 1.5980777035439402  
Training accuracy: 0.50875  
Testing loss: 1.8893712242638503  
Testing accuracy: 0.5078  
Testing loss: 1.9347860063007145  
Testing accuracy: 0.506  
Epoch 137

-----  
Training loss: 1.5474528336796802  
Training accuracy: 0.51115  
Testing loss: 1.7947489259865  
Testing accuracy: 0.4978  
Testing loss: 1.9851837441215252  
Testing accuracy: 0.5026  
Epoch 138

-----  
Training loss: 1.5394631842296262  
Training accuracy: 0.51805  
Testing loss: 1.8830441222924459  
Testing accuracy: 0.5096  
Testing loss: 1.9468269426682938  
Testing accuracy: 0.4958  
Epoch 139

-----  
Training loss: 1.525742339251237  
Training accuracy: 0.51855  
Testing loss: 1.9168763638938058  
Testing accuracy: 0.5046  
Testing loss: 2.077939050235356  
Testing accuracy: 0.4878  
Epoch 140

-----  
Training loss: 1.5486314030919623  
Training accuracy: 0.5196  
Testing loss: 1.8567908776480133  
Testing accuracy: 0.5188  
Testing loss: 1.9926638177674976  
Testing accuracy: 0.4982  
Epoch 141

-----  
Training loss: 1.5588535427646237  
Training accuracy: 0.51965  
Testing loss: 1.801975928192665  
Testing accuracy: 0.5152  
Testing loss: 1.8728090969093125  
Testing accuracy: 0.4962  
Epoch 142

Training loss: 1.5440685750467529  
Training accuracy: 0.5234  
Testing loss: 1.9169008939712442  
Testing accuracy: 0.5114  
Testing loss: 1.9465648718774853  
Testing accuracy: 0.4922  
Epoch 143

-----  
Training loss: 1.514982540671928  
Training accuracy: 0.51935  
Testing loss: 1.8014960363132428  
Testing accuracy: 0.5218  
Testing loss: 1.892124494160241  
Testing accuracy: 0.4944  
Epoch 144

-----  
Training loss: 1.5290563265787729  
Training accuracy: 0.5263  
Testing loss: 1.775306450041759  
Testing accuracy: 0.5322  
Testing loss: 1.8780442037609202  
Testing accuracy: 0.5244  
Epoch 145

-----  
Training loss: 1.5706724282108673  
Training accuracy: 0.51895  
Testing loss: 1.7486532388752356  
Testing accuracy: 0.5342  
Testing loss: 1.9225893706531847  
Testing accuracy: 0.5174  
Epoch 146

-----  
Training loss: 1.5515957331426005  
Training accuracy: 0.52005  
Testing loss: 1.7632555123954146  
Testing accuracy: 0.5194  
Testing loss: 1.9260974041331362  
Testing accuracy: 0.5106  
Epoch 147

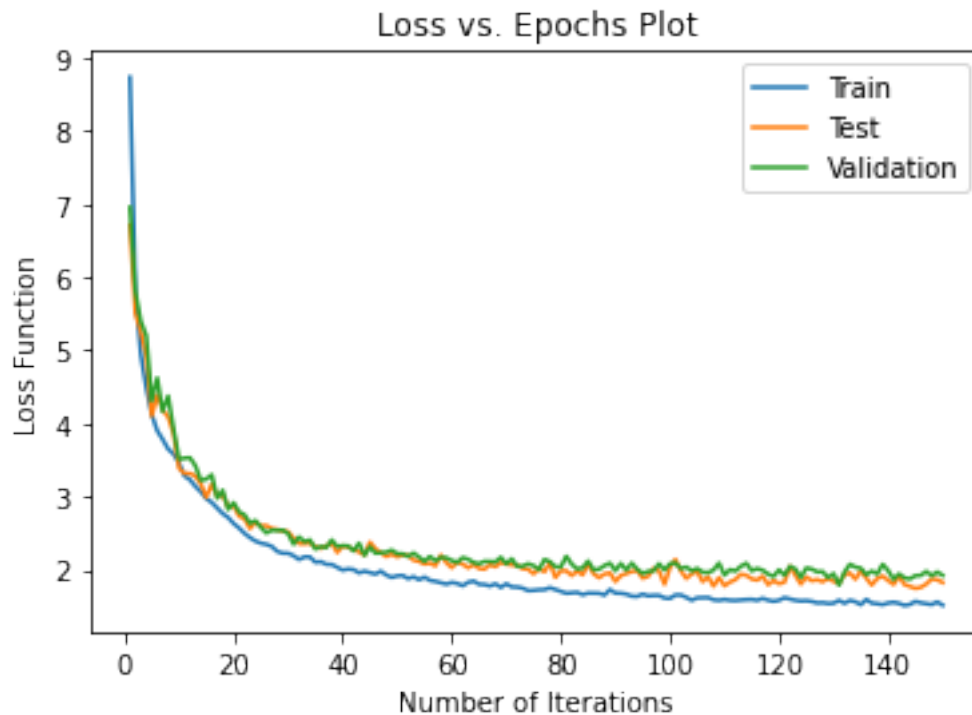
-----  
Training loss: 1.5403988516625928  
Training accuracy: 0.51975  
Testing loss: 1.8076821146092203  
Testing accuracy: 0.508  
Testing loss: 1.980202599345487  
Testing accuracy: 0.5082  
Epoch 148

```

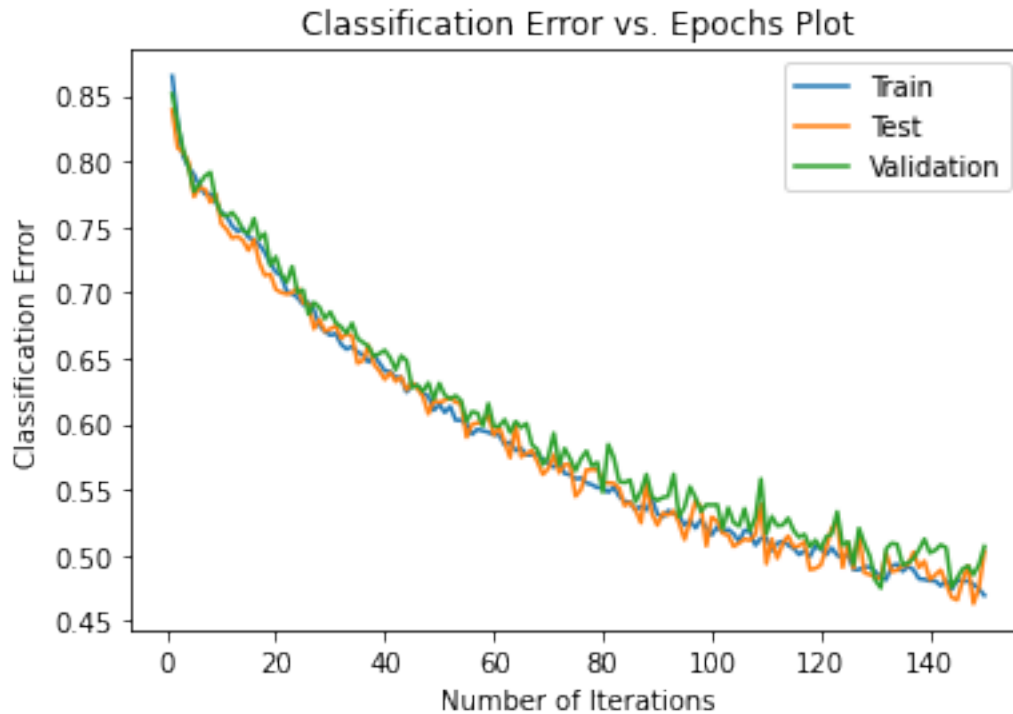
Training loss: 1.527404658607443
Training accuracy: 0.5223
Testing loss: 1.8772588462399402
Testing accuracy: 0.537
Testing loss: 1.920872387404478
Testing accuracy: 0.515
Epoch 149
-----
Training loss: 1.5643940383795754
Training accuracy: 0.52585
Testing loss: 1.8670872639730638
Testing accuracy: 0.5248
Testing loss: 1.9728003869768058
Testing accuracy: 0.5074
Epoch 150
-----
Training loss: 1.5177350499485258
Training accuracy: 0.53075
Testing loss: 1.828810047254856
Testing accuracy: 0.4974
Testing loss: 1.9260915085993904
Testing accuracy: 0.4934
Done
Total Time Consumed: 13236.17884516716

```

```
[ ]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



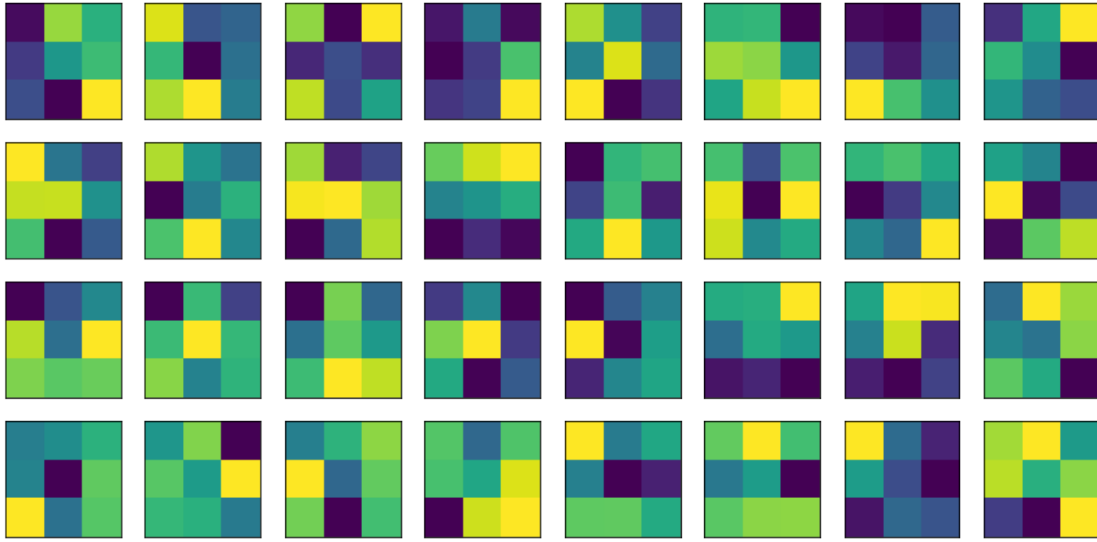
```
[ ]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



### 6.3.2 Weight Visualization

```
[ ]: # Visualize the Weights from First Convolutional Network
weights = net5.state_dict()['conv1.weight']
plt.figure(figsize = (12,6))
for i in range(len(weights)):
    plt.subplot(4,8,i+1)
    plt.imshow(weights[i].reshape(3,3))
    plt.xticks([])
    plt.yticks([])
```





### 6.3.3 Learning Rate = 0.2

```
[ ]: # Define HyperParameters
learning_rate = 0.2
batch_size = 64
num_epochs = 150

sum_2 = sum_model().double()
optimizer = optim.Adadelta(sum_2.parameters(), lr = learning_rate, rho = 0.95,
    ↪eps = 1e-08, weight_decay = 0)
loss = nn.MSELoss()
```

```
[ ]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop7(X_train,Y_train,sum_2,loss,optimizer))
    test_loss_record.append(test_loop7(X_test,Y_test,sum_2,loss))
    val_loss_record.append(test_loop7(X_val,Y_val,sum_2,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

-----

/usr/local/lib/python3.7/dist-packages/torch/nn/modules/loss.py:529:

UserWarning: Using a target size (torch.Size([])) that is different to the input size (torch.Size([1])). This will likely lead to incorrect results due to broadcasting. Please ensure they have the same size.

```
    return F.mse_loss(input, target, reduction=self.reduction)
```

Training loss: 14.068749374372768

Training accuracy: 0.10765

Testing loss: 9.069129284031499

Testing accuracy: 0.1274

Testing loss: 9.965047183380833

Testing accuracy: 0.1206

Epoch 2

-----  
Training loss: 8.54878400986955

Training accuracy: 0.13115

Testing loss: 7.006364061664567

Testing accuracy: 0.1578

Testing loss: 7.754154883440524

Testing accuracy: 0.1396

Epoch 3

-----  
Training loss: 7.0461437565447875

Training accuracy: 0.15045

Testing loss: 6.26751159580526

Testing accuracy: 0.1666

Testing loss: 6.690881291604672

Testing accuracy: 0.1608

Epoch 4

-----  
Training loss: 6.424408579399578

Training accuracy: 0.1526

Testing loss: 6.13325766736777

Testing accuracy: 0.1698

Testing loss: 6.61760538827953

Testing accuracy: 0.1624

Epoch 5

-----  
Training loss: 6.0469635856184105

Training accuracy: 0.16745

Testing loss: 5.8483203989804045

Testing accuracy: 0.1766

Testing loss: 6.27164748967245

Testing accuracy: 0.1706

Epoch 6

-----  
Training loss: 5.820712348169548

Training accuracy: 0.17165

Testing loss: 5.328544892705859

```

Testing accuracy: 0.1858
Testing loss: 5.7617440473374595
Testing accuracy: 0.1754
Epoch 7
-----
Training loss: 5.5950086974992645
Training accuracy: 0.179
Testing loss: 5.3858918802163895
Testing accuracy: 0.1916
Testing loss: 5.681851870102628
Testing accuracy: 0.1824
Epoch 8
-----
Training loss: 5.398661332680233
Training accuracy: 0.17935
Testing loss: 5.1283206235574905
Testing accuracy: 0.1842
Testing loss: 5.462793370341283
Testing accuracy: 0.178
Epoch 9
-----
Training loss: 5.200239498684802
Training accuracy: 0.18405
Testing loss: 4.932144524459172
Testing accuracy: 0.1882
Testing loss: 5.284934076680374
Testing accuracy: 0.1838
Epoch 10
-----
Training loss: 5.088551023912003
Training accuracy: 0.18715
Testing loss: 4.968340723473489
Testing accuracy: 0.1858
Testing loss: 5.37836371224442
Testing accuracy: 0.1832
Epoch 11
-----
Training loss: 5.067926336232215
Training accuracy: 0.1876
Testing loss: 4.777462103128519
Testing accuracy: 0.1886
Testing loss: 4.999729853497495
Testing accuracy: 0.2022
Epoch 12
-----
Training loss: 4.944897177568344
Training accuracy: 0.18555
Testing loss: 4.916183377750944

```

```
Testing accuracy: 0.197
Testing loss: 5.230950836913353
Testing accuracy: 0.1906
Epoch 13
-----
Training loss: 4.80929944558077
Training accuracy: 0.1901
Testing loss: 4.649436597702598
Testing accuracy: 0.2092
Testing loss: 4.968457658317641
Testing accuracy: 0.2062
Epoch 14
-----
Training loss: 4.768154937472618
Training accuracy: 0.1941
Testing loss: 4.694212755334608
Testing accuracy: 0.2058
Testing loss: 5.002249373555377
Testing accuracy: 0.1972
Epoch 15
-----
Training loss: 4.682548338114235
Training accuracy: 0.19895
Testing loss: 4.586051879291807
Testing accuracy: 0.1996
Testing loss: 4.847441950665875
Testing accuracy: 0.1894
Epoch 16
-----
Training loss: 4.592915381264744
Training accuracy: 0.19585
Testing loss: 4.5244823606654485
Testing accuracy: 0.2068
Testing loss: 4.771470113217902
Testing accuracy: 0.1998
Epoch 17
-----
Training loss: 4.489426335281708
Training accuracy: 0.2024
Testing loss: 4.455235372868944
Testing accuracy: 0.218
Testing loss: 4.6145693242415025
Testing accuracy: 0.2052
Epoch 18
-----
Training loss: 4.424819756565805
Training accuracy: 0.20585
Testing loss: 4.461401145812255
```

```

Testing accuracy: 0.2086
Testing loss: 4.658291648734992
Testing accuracy: 0.2094
Epoch 19
-----
Training loss: 4.371130095551685
Training accuracy: 0.21025
Testing loss: 4.395276063398537
Testing accuracy: 0.213
Testing loss: 4.626816592686308
Testing accuracy: 0.2082
Epoch 20
-----
Training loss: 4.356679604743814
Training accuracy: 0.20745
Testing loss: 4.326224635496599
Testing accuracy: 0.2106
Testing loss: 4.42999320813233
Testing accuracy: 0.212
Epoch 21
-----
Training loss: 4.223535782532506
Training accuracy: 0.20725
Testing loss: 4.301307602437882
Testing accuracy: 0.2152
Testing loss: 4.4234433872781524
Testing accuracy: 0.212
Epoch 22
-----
Training loss: 4.209147326933444
Training accuracy: 0.20695
Testing loss: 4.186099178012799
Testing accuracy: 0.2102
Testing loss: 4.414686960224465
Testing accuracy: 0.213
Epoch 23
-----
Training loss: 4.199402247574128
Training accuracy: 0.21335
Testing loss: 4.29068399542552
Testing accuracy: 0.2142
Testing loss: 4.544252237404662
Testing accuracy: 0.2114
Epoch 24
-----
Training loss: 4.0866499738622855
Training accuracy: 0.2115
Testing loss: 4.262831734669238

```

```

Testing accuracy: 0.2236
Testing loss: 4.412199951765541
Testing accuracy: 0.2154
Epoch 25
-----
Training loss: 4.059537881679454
Training accuracy: 0.2118
Testing loss: 4.225883001870723
Testing accuracy: 0.2182
Testing loss: 4.327944235847051
Testing accuracy: 0.2094
Epoch 26
-----
Training loss: 4.065358964479329
Training accuracy: 0.2157
Testing loss: 4.013320043352498
Testing accuracy: 0.2206
Testing loss: 4.267268897394187
Testing accuracy: 0.2178
Epoch 27
-----
Training loss: 3.995686428359779
Training accuracy: 0.2138
Testing loss: 4.1301794955436675
Testing accuracy: 0.2248
Testing loss: 4.321054416301768
Testing accuracy: 0.2156
Epoch 28
-----
Training loss: 3.925868261253537
Training accuracy: 0.2196
Testing loss: 3.9618939729555103
Testing accuracy: 0.2226
Testing loss: 4.169121005766686
Testing accuracy: 0.2116
Epoch 29
-----
Training loss: 3.93590539721161
Training accuracy: 0.22415
Testing loss: 3.964254565958856
Testing accuracy: 0.2254
Testing loss: 4.1699738228686805
Testing accuracy: 0.2154
Epoch 30
-----
Training loss: 3.862209195058192
Training accuracy: 0.22325
Testing loss: 4.003393001331145

```

```
Testing accuracy: 0.229
Testing loss: 4.226430007019551
Testing accuracy: 0.2202
Epoch 31
-----
Training loss: 3.854480049007355
Training accuracy: 0.21985
Testing loss: 3.894764514660115
Testing accuracy: 0.2304
Testing loss: 4.106004081830454
Testing accuracy: 0.2138
Epoch 32
-----
Training loss: 3.8008478615466004
Training accuracy: 0.22255
Testing loss: 3.9470986487419686
Testing accuracy: 0.2346
Testing loss: 4.101865045479755
Testing accuracy: 0.2238
Epoch 33
-----
Training loss: 3.7634796686003873
Training accuracy: 0.22405
Testing loss: 3.9178755083412113
Testing accuracy: 0.2348
Testing loss: 4.069316673564173
Testing accuracy: 0.2212
Epoch 34
-----
Training loss: 3.7247107612748054
Training accuracy: 0.22595
Testing loss: 3.810803602913997
Testing accuracy: 0.2282
Testing loss: 4.013811928665971
Testing accuracy: 0.2128
Epoch 35
-----
Training loss: 3.719460258811204
Training accuracy: 0.228
Testing loss: 3.7900800625401665
Testing accuracy: 0.2358
Testing loss: 3.9795135622734765
Testing accuracy: 0.2288
Epoch 36
-----
Training loss: 3.715859543235933
Training accuracy: 0.22385
Testing loss: 3.878192075918933
```

```
Testing accuracy: 0.2324
Testing loss: 4.025694701930505
Testing accuracy: 0.2244
Epoch 37
-----
Training loss: 3.6400197949062982
Training accuracy: 0.23035
Testing loss: 3.787321756955079
Testing accuracy: 0.2346
Testing loss: 3.953696581147363
Testing accuracy: 0.2162
Epoch 38
-----
Training loss: 3.607276847275799
Training accuracy: 0.22635
Testing loss: 3.6776009309229516
Testing accuracy: 0.238
Testing loss: 3.8550407019132007
Testing accuracy: 0.2244
Epoch 39
-----
Training loss: 3.6243269709270134
Training accuracy: 0.2296
Testing loss: 3.646217285711931
Testing accuracy: 0.2344
Testing loss: 3.803005434007928
Testing accuracy: 0.2184
Epoch 40
-----
Training loss: 3.5498141469326363
Training accuracy: 0.23375
Testing loss: 3.621955517954785
Testing accuracy: 0.2334
Testing loss: 3.8029909360063625
Testing accuracy: 0.2392
Epoch 41
-----
Training loss: 3.5335217990220067
Training accuracy: 0.232
Testing loss: 3.6457073857968294
Testing accuracy: 0.2378
Testing loss: 3.774707736270393
Testing accuracy: 0.2338
Epoch 42
-----
Training loss: 3.522757670340028
Training accuracy: 0.2392
Testing loss: 3.6443173578804635
```



```
Testing accuracy: 0.2388
Testing loss: 3.8346554041726524
Testing accuracy: 0.2258
Epoch 43
-----
Training loss: 3.503661796482141
Training accuracy: 0.23685
Testing loss: 3.533869134451997
Testing accuracy: 0.2434
Testing loss: 3.759534038085744
Testing accuracy: 0.2226
Epoch 44
-----
Training loss: 3.4739456200949337
Training accuracy: 0.24375
Testing loss: 3.5529297535663935
Testing accuracy: 0.2432
Testing loss: 3.7581948761521002
Testing accuracy: 0.2396
Epoch 45
-----
Training loss: 3.450276920641863
Training accuracy: 0.23395
Testing loss: 3.5867328216097834
Testing accuracy: 0.2354
Testing loss: 3.7434004343074805
Testing accuracy: 0.2314
Epoch 46
-----
Training loss: 3.440685439590765
Training accuracy: 0.23885
Testing loss: 3.4757682375799037
Testing accuracy: 0.2416
Testing loss: 3.6831148179648547
Testing accuracy: 0.253
Epoch 47
-----
Training loss: 3.379262276912082
Training accuracy: 0.243
Testing loss: 3.477183144029798
Testing accuracy: 0.2518
Testing loss: 3.6525355268589794
Testing accuracy: 0.2296
Epoch 48
-----
Training loss: 3.3734916474809418
Training accuracy: 0.24125
Testing loss: 3.403575254080977
```

```

Testing accuracy: 0.2544
Testing loss: 3.62582386963918
Testing accuracy: 0.2418
Epoch 49
-----
Training loss: 3.3568373120126265
Training accuracy: 0.241
Testing loss: 3.4069573770372292
Testing accuracy: 0.2442
Testing loss: 3.5961764157949934
Testing accuracy: 0.2344
Epoch 50
-----
Training loss: 3.3273105696262357
Training accuracy: 0.24445
Testing loss: 3.407355070848499
Testing accuracy: 0.248
Testing loss: 3.6086439436097724
Testing accuracy: 0.2326
Epoch 51
-----
Training loss: 3.2879957850040284
Training accuracy: 0.2452
Testing loss: 3.339311802728058
Testing accuracy: 0.2544
Testing loss: 3.4777526471504063
Testing accuracy: 0.2358
Epoch 52
-----
Training loss: 3.278075234590185
Training accuracy: 0.24705
Testing loss: 3.2793107620224613
Testing accuracy: 0.2526
Testing loss: 3.4914759415544205
Testing accuracy: 0.2438
Epoch 53
-----
Training loss: 3.207268190172125
Training accuracy: 0.2469
Testing loss: 3.35765025873973
Testing accuracy: 0.25
Testing loss: 3.5031419365443974
Testing accuracy: 0.2424
Epoch 54
-----
Training loss: 3.1720000459196482
Training accuracy: 0.25375
Testing loss: 3.255083501953365

```

```

Testing accuracy: 0.2632
Testing loss: 3.4642391961350527
Testing accuracy: 0.2484
Epoch 55
-----
Training loss: 3.15593853655478
Training accuracy: 0.2512
Testing loss: 3.1961491561032505
Testing accuracy: 0.253
Testing loss: 3.4519884065591198
Testing accuracy: 0.245
Epoch 56
-----
Training loss: 3.1518520406636807
Training accuracy: 0.2495
Testing loss: 3.208939503333777
Testing accuracy: 0.2592
Testing loss: 3.3802664434430922
Testing accuracy: 0.2444
Epoch 57
-----
Training loss: 3.107166639584964
Training accuracy: 0.25145
Testing loss: 3.213277879437568
Testing accuracy: 0.251
Testing loss: 3.412316324565168
Testing accuracy: 0.2456
Epoch 58
-----
Training loss: 3.106366318806849
Training accuracy: 0.257
Testing loss: 3.3064999424030685
Testing accuracy: 0.257
Testing loss: 3.4186638446379023
Testing accuracy: 0.2514
Epoch 59
-----
Training loss: 3.075622590545094
Training accuracy: 0.2543
Testing loss: 3.3010323404442112
Testing accuracy: 0.2562
Testing loss: 3.4616080992267
Testing accuracy: 0.242
Epoch 60
-----
Training loss: 3.0536353085835897
Training accuracy: 0.25985
Testing loss: 3.1713815434235375

```

```

Testing accuracy: 0.2722
Testing loss: 3.3283563814651718
Testing accuracy: 0.246
Epoch 61
-----
Training loss: 3.0195388105538434
Training accuracy: 0.2571
Testing loss: 3.1252123303011046
Testing accuracy: 0.2572
Testing loss: 3.3166824974002025
Testing accuracy: 0.2488
Epoch 62
-----
Training loss: 3.0142339842685666
Training accuracy: 0.26025
Testing loss: 3.0509811063573684
Testing accuracy: 0.2522
Testing loss: 3.1484363469744263
Testing accuracy: 0.2512
Epoch 63
-----
Training loss: 2.9954945810122107
Training accuracy: 0.2578
Testing loss: 3.184071544054208
Testing accuracy: 0.2618
Testing loss: 3.2769183232864503
Testing accuracy: 0.2504
Epoch 64
-----
Training loss: 2.9517007873804113
Training accuracy: 0.26355
Testing loss: 3.164215918189161
Testing accuracy: 0.2608
Testing loss: 3.279758355172744
Testing accuracy: 0.2506
Epoch 65
-----
Training loss: 2.948880207636337
Training accuracy: 0.2645
Testing loss: 3.00978260264149
Testing accuracy: 0.2698
Testing loss: 3.280191796536772
Testing accuracy: 0.2512
Epoch 66
-----
Training loss: 2.9335563879699387
Training accuracy: 0.26605
Testing loss: 3.0291862729306858

```

```
Testing accuracy: 0.2674
Testing loss: 3.1322620128653176
Testing accuracy: 0.2628
Epoch 67
-----
Training loss: 2.900004835251219
Training accuracy: 0.26625
Testing loss: 3.0767057078327986
Testing accuracy: 0.2638
Testing loss: 3.202587884153879
Testing accuracy: 0.2572
Epoch 68
-----
Training loss: 2.888214943004897
Training accuracy: 0.2647
Testing loss: 2.9500660285598896
Testing accuracy: 0.2726
Testing loss: 3.150149645559081
Testing accuracy: 0.2564
Epoch 69
-----
Training loss: 2.856078697958146
Training accuracy: 0.26445
Testing loss: 2.9989955937573036
Testing accuracy: 0.2712
Testing loss: 3.0634957403245773
Testing accuracy: 0.2674
Epoch 70
-----
Training loss: 2.817620447928111
Training accuracy: 0.26855
Testing loss: 2.8845670936230934
Testing accuracy: 0.2644
Testing loss: 3.1170700273264678
Testing accuracy: 0.2584
Epoch 71
-----
Training loss: 2.8121170963566517
Training accuracy: 0.2746
Testing loss: 2.9760956089313435
Testing accuracy: 0.2658
Testing loss: 3.086286333225669
Testing accuracy: 0.2714
Epoch 72
-----
Training loss: 2.778782516108562
Training accuracy: 0.2757
Testing loss: 2.8904254666490243
```

Testing accuracy: 0.2706  
Testing loss: 3.0506229547357027  
Testing accuracy: 0.2596  
Epoch 73  
-----  
Training loss: 2.751195001725123  
Training accuracy: 0.27725  
Testing loss: 2.9165847163365712  
Testing accuracy: 0.275  
Testing loss: 3.062086644956479  
Testing accuracy: 0.2606  
Epoch 74  
-----  
Training loss: 2.7450369467632134  
Training accuracy: 0.28305  
Testing loss: 2.8656410671019583  
Testing accuracy: 0.2754  
Testing loss: 3.022456828039557  
Testing accuracy: 0.2662  
Epoch 75  
-----  
Training loss: 2.7205058082477356  
Training accuracy: 0.2778  
Testing loss: 2.837008677466492  
Testing accuracy: 0.2816  
Testing loss: 2.975453011201499  
Testing accuracy: 0.2664  
Epoch 76  
-----  
Training loss: 2.737942126554697  
Training accuracy: 0.27815  
Testing loss: 2.8484297694714185  
Testing accuracy: 0.286  
Testing loss: 3.0194396696290404  
Testing accuracy: 0.2804  
Epoch 77  
-----  
Training loss: 2.6854335100309417  
Training accuracy: 0.27845  
Testing loss: 2.8467251531490416  
Testing accuracy: 0.276  
Testing loss: 2.924729156839933  
Testing accuracy: 0.2812  
Epoch 78  
-----  
Training loss: 2.6973669119151076  
Training accuracy: 0.283  
Testing loss: 2.8189105687562956

```
Testing accuracy: 0.2802
Testing loss: 2.927047606559774
Testing accuracy: 0.2678
Epoch 79
-----
Training loss: 2.675928409420693
Training accuracy: 0.2815
Testing loss: 2.7713893484199623
Testing accuracy: 0.2888
Testing loss: 2.960453320382893
Testing accuracy: 0.2694
Epoch 80
-----
Training loss: 2.6316354644989493
Training accuracy: 0.28385
Testing loss: 2.8100230217250677
Testing accuracy: 0.2712
Testing loss: 2.8569181578568252
Testing accuracy: 0.281
Epoch 81
-----
Training loss: 2.6463507044328796
Training accuracy: 0.2834
Testing loss: 2.883942144430327
Testing accuracy: 0.2842
Testing loss: 2.9115744150824883
Testing accuracy: 0.2762
Epoch 82
-----
Training loss: 2.637536366037602
Training accuracy: 0.28695
Testing loss: 2.833525349897062
Testing accuracy: 0.2908
Testing loss: 2.898633493131346
Testing accuracy: 0.2842
Epoch 83
-----
Training loss: 2.5852995257780016
Training accuracy: 0.28865
Testing loss: 2.6926230795087247
Testing accuracy: 0.2912
Testing loss: 2.8816803936650817
Testing accuracy: 0.286
Epoch 84
-----
Training loss: 2.5651339585996724
Training accuracy: 0.2911
Testing loss: 2.7126837771986527
```

```
Testing accuracy: 0.292
Testing loss: 2.822847504341676
Testing accuracy: 0.2854
Epoch 85
-----
Training loss: 2.5521501020605557
Training accuracy: 0.29005
Testing loss: 2.7603795668883815
Testing accuracy: 0.3016
Testing loss: 2.77989728841579
Testing accuracy: 0.284
Epoch 86
-----
Training loss: 2.554156571413983
Training accuracy: 0.28815
Testing loss: 2.8149975432912155
Testing accuracy: 0.2876
Testing loss: 2.7718133005133643
Testing accuracy: 0.3014
Epoch 87
-----
Training loss: 2.5210118876615657
Training accuracy: 0.29825
Testing loss: 2.6644954328172457
Testing accuracy: 0.2956
Testing loss: 2.7394092536580743
Testing accuracy: 0.2932
Epoch 88
-----
Training loss: 2.5194580020209587
Training accuracy: 0.3
Testing loss: 2.739915982282443
Testing accuracy: 0.2876
Testing loss: 2.8081478622274068
Testing accuracy: 0.291
Epoch 89
-----
Training loss: 2.513339711107677
Training accuracy: 0.29755
Testing loss: 2.6741379240834644
Testing accuracy: 0.292
Testing loss: 2.7853460663126954
Testing accuracy: 0.285
Epoch 90
-----
Training loss: 2.4461630885959265
Training accuracy: 0.3015
Testing loss: 2.598123604850634
```



```

Testing accuracy: 0.3014
Testing loss: 2.7833797456467844
Testing accuracy: 0.2994
Epoch 91
-----
Training loss: 2.4632256878609575
Training accuracy: 0.3023
Testing loss: 2.549158664806035
Testing accuracy: 0.3048
Testing loss: 2.700820614477108
Testing accuracy: 0.3016
Epoch 92
-----
Training loss: 2.422074292135401
Training accuracy: 0.30585
Testing loss: 2.6205433174124266
Testing accuracy: 0.3038
Testing loss: 2.7226211474180384
Testing accuracy: 0.2928
Epoch 93
-----
Training loss: 2.416959056719447
Training accuracy: 0.30725
Testing loss: 2.601753211290365
Testing accuracy: 0.2968
Testing loss: 2.723027353767437
Testing accuracy: 0.2864
Epoch 94
-----
Training loss: 2.4017362780377267
Training accuracy: 0.31125
Testing loss: 2.5682708872691786
Testing accuracy: 0.309
Testing loss: 2.624031844461106
Testing accuracy: 0.3076
Epoch 95
-----
Training loss: 2.417550737072307
Training accuracy: 0.30885
Testing loss: 2.5903179184804963
Testing accuracy: 0.3042
Testing loss: 2.6335518561786473
Testing accuracy: 0.2942
Epoch 96
-----
Training loss: 2.3856832163256385
Training accuracy: 0.3086
Testing loss: 2.5027396162756044

```

Testing accuracy: 0.3094  
Testing loss: 2.626719613143361  
Testing accuracy: 0.3094  
Epoch 97  
-----  
Training loss: 2.375599721127106  
Training accuracy: 0.3113  
Testing loss: 2.6662648609900805  
Testing accuracy: 0.3008  
Testing loss: 2.6851070791618707  
Testing accuracy: 0.301  
Epoch 98  
-----  
Training loss: 2.372245380181574  
Training accuracy: 0.3165  
Testing loss: 2.533647881554198  
Testing accuracy: 0.3088  
Testing loss: 2.619602535484249  
Testing accuracy: 0.3002  
Epoch 99  
-----  
Training loss: 2.345095177628622  
Training accuracy: 0.31195  
Testing loss: 2.6145413971240554  
Testing accuracy: 0.3108  
Testing loss: 2.673032123349417  
Testing accuracy: 0.3018  
Epoch 100  
-----  
Training loss: 2.329226751669238  
Training accuracy: 0.3186  
Testing loss: 2.603241265685353  
Testing accuracy: 0.3252  
Testing loss: 2.658849579351207  
Testing accuracy: 0.3116  
Epoch 101  
-----  
Training loss: 2.27750611573614  
Training accuracy: 0.3241  
Testing loss: 2.476406686856212  
Testing accuracy: 0.313  
Testing loss: 2.540399558929799  
Testing accuracy: 0.3042  
Epoch 102  
-----  
Training loss: 2.323282220216334  
Training accuracy: 0.31725  
Testing loss: 2.5743515456400887

```

Testing accuracy: 0.3178
Testing loss: 2.623985180002798
Testing accuracy: 0.3114
Epoch 103
-----
Training loss: 2.3217017612386788
Training accuracy: 0.3194
Testing loss: 2.421819347063268
Testing accuracy: 0.3162
Testing loss: 2.558135091226847
Testing accuracy: 0.3006
Epoch 104
-----
Training loss: 2.259376474993592
Training accuracy: 0.32565
Testing loss: 2.4668582021002656
Testing accuracy: 0.318
Testing loss: 2.547716942019678
Testing accuracy: 0.31
Epoch 105
-----
Training loss: 2.2677479343726743
Training accuracy: 0.32565
Testing loss: 2.461707618378819
Testing accuracy: 0.3182
Testing loss: 2.444131286788199
Testing accuracy: 0.3182
Epoch 106
-----
Training loss: 2.234608908530627
Training accuracy: 0.32915
Testing loss: 2.406248063527923
Testing accuracy: 0.3166
Testing loss: 2.482003910393655
Testing accuracy: 0.3108
Epoch 107
-----
Training loss: 2.2606581952145866
Training accuracy: 0.3271
Testing loss: 2.4631262328402226
Testing accuracy: 0.3258
Testing loss: 2.5015741497619968
Testing accuracy: 0.319
Epoch 108
-----
Training loss: 2.2347270372563814
Training accuracy: 0.32515
Testing loss: 2.417332755225402

```

```
Testing accuracy: 0.3248
Testing loss: 2.591153274174123
Testing accuracy: 0.3248
Epoch 109
-----
Training loss: 2.217834043798946
Training accuracy: 0.3306
Testing loss: 2.4322238429333387
Testing accuracy: 0.3224
Testing loss: 2.5080397161791255
Testing accuracy: 0.3186
Epoch 110
-----
Training loss: 2.244366176219572
Training accuracy: 0.33055
Testing loss: 2.435061821467274
Testing accuracy: 0.3344
Testing loss: 2.4747839634339592
Testing accuracy: 0.3254
Epoch 111
-----
Training loss: 2.2243701300932646
Training accuracy: 0.32785
Testing loss: 2.380735732281239
Testing accuracy: 0.3228
Testing loss: 2.470318038916644
Testing accuracy: 0.3298
Epoch 112
-----
Training loss: 2.1871724782095123
Training accuracy: 0.337
Testing loss: 2.4003361625633133
Testing accuracy: 0.3378
Testing loss: 2.534569452813488
Testing accuracy: 0.3108
Epoch 113
-----
Training loss: 2.1719571706326573
Training accuracy: 0.3325
Testing loss: 2.3304000107761236
Testing accuracy: 0.3218
Testing loss: 2.449033401618253
Testing accuracy: 0.3242
Epoch 114
-----
Training loss: 2.1814320606810447
Training accuracy: 0.33585
Testing loss: 2.423570653552952
```

```

Testing accuracy: 0.3384
Testing loss: 2.4298463622209345
Testing accuracy: 0.3268
Epoch 115
-----
Training loss: 2.1799198137530524
Training accuracy: 0.3332
Testing loss: 2.3654363293559513
Testing accuracy: 0.3372
Testing loss: 2.3950183833285514
Testing accuracy: 0.3212
Epoch 116
-----
Training loss: 2.1678080827269017
Training accuracy: 0.33575
Testing loss: 2.356819333751002
Testing accuracy: 0.3408
Testing loss: 2.5291988730402544
Testing accuracy: 0.3252
Epoch 117
-----
Training loss: 2.165129182947097
Training accuracy: 0.34395
Testing loss: 2.3338146990841193
Testing accuracy: 0.3426
Testing loss: 2.365876537967562
Testing accuracy: 0.3292
Epoch 118
-----
Training loss: 2.1727456281280824
Training accuracy: 0.33935
Testing loss: 2.3189961537459216
Testing accuracy: 0.333
Testing loss: 2.4253587729075674
Testing accuracy: 0.3304
Epoch 119
-----
Training loss: 2.1466449711749567
Training accuracy: 0.34125
Testing loss: 2.2949276505552514
Testing accuracy: 0.3366
Testing loss: 2.3995972714826843
Testing accuracy: 0.334
Epoch 120
-----
Training loss: 2.1674475050010478
Training accuracy: 0.3436
Testing loss: 2.355581598109802

```

```
Testing accuracy: 0.3458
Testing loss: 2.432045275522278
Testing accuracy: 0.3254
Epoch 121
-----
Training loss: 2.122387013850558
Training accuracy: 0.34205
Testing loss: 2.3027253784992077
Testing accuracy: 0.334
Testing loss: 2.3715600056088206
Testing accuracy: 0.3308
Epoch 122
-----
Training loss: 2.1004661903478214
Training accuracy: 0.34775
Testing loss: 2.306011359970019
Testing accuracy: 0.3496
Testing loss: 2.3585979801431205
Testing accuracy: 0.3434
Epoch 123
-----
Training loss: 2.113920974005011
Training accuracy: 0.3536
Testing loss: 2.3162633565678865
Testing accuracy: 0.347
Testing loss: 2.381146514130851
Testing accuracy: 0.3364
Epoch 124
-----
Training loss: 2.077420264570465
Training accuracy: 0.348
Testing loss: 2.3156650514351695
Testing accuracy: 0.339
Testing loss: 2.404959304787876
Testing accuracy: 0.3374
Epoch 125
-----
Training loss: 2.0642185451318205
Training accuracy: 0.3481
Testing loss: 2.2724270438616925
Testing accuracy: 0.3482
Testing loss: 2.4589605173226823
Testing accuracy: 0.3352
Epoch 126
-----
Training loss: 2.0714512749578096
Training accuracy: 0.3509
Testing loss: 2.3075780425477386
```

```

Testing accuracy: 0.3504
Testing loss: 2.307508055510205
Testing accuracy: 0.3454
Epoch 127
-----
Training loss: 2.037419477471951
Training accuracy: 0.35505
Testing loss: 2.286726704483625
Testing accuracy: 0.3548
Testing loss: 2.3564341112841594
Testing accuracy: 0.342
Epoch 128
-----
Training loss: 2.0414403763606845
Training accuracy: 0.35835
Testing loss: 2.2892610672527933
Testing accuracy: 0.3478
Testing loss: 2.3050375577922635
Testing accuracy: 0.335
Epoch 129
-----
Training loss: 2.0552794599552864
Training accuracy: 0.35755
Testing loss: 2.2319754306524375
Testing accuracy: 0.3594
Testing loss: 2.321574005041377
Testing accuracy: 0.3504
Epoch 130
-----
Training loss: 2.054425193848363
Training accuracy: 0.3554
Testing loss: 2.198988937545508
Testing accuracy: 0.3592
Testing loss: 2.298273954155765
Testing accuracy: 0.3438
Epoch 131
-----
Training loss: 2.04336620015576
Training accuracy: 0.3557
Testing loss: 2.255963917435075
Testing accuracy: 0.3532
Testing loss: 2.34175544570625
Testing accuracy: 0.3404
Epoch 132
-----
Training loss: 2.0135898178082936
Training accuracy: 0.3599
Testing loss: 2.2029025529897455

```

```
Testing accuracy: 0.3572
Testing loss: 2.3658753132071246
Testing accuracy: 0.351
Epoch 133
-----
Training loss: 2.0442096069152718
Training accuracy: 0.3566
Testing loss: 2.194439795862889
Testing accuracy: 0.3608
Testing loss: 2.3326179704706043
Testing accuracy: 0.348
Epoch 134
-----
Training loss: 2.01632892625675
Training accuracy: 0.3601
Testing loss: 2.238691112525493
Testing accuracy: 0.3616
Testing loss: 2.349154614856608
Testing accuracy: 0.3416
Epoch 135
-----
Training loss: 2.0015540971830887
Training accuracy: 0.36505
Testing loss: 2.2202340600266033
Testing accuracy: 0.3592
Testing loss: 2.340971340830371
Testing accuracy: 0.3586
Epoch 136
-----
Training loss: 2.0213446307305394
Training accuracy: 0.368
Testing loss: 2.2092655811581507
Testing accuracy: 0.3762
Testing loss: 2.2649516311358764
Testing accuracy: 0.3522
Epoch 137
-----
Training loss: 2.013391986427467
Training accuracy: 0.36715
Testing loss: 2.188031721618141
Testing accuracy: 0.3602
Testing loss: 2.2635496197909726
Testing accuracy: 0.3486
Epoch 138
-----
Training loss: 2.0043968298094215
Training accuracy: 0.3629
Testing loss: 2.2563730383445884
```



```
Testing accuracy: 0.3576
Testing loss: 2.287965842505667
Testing accuracy: 0.3408
Epoch 139
-----
Training loss: 1.9859944544402792
Training accuracy: 0.36435
Testing loss: 2.2305542053153795
Testing accuracy: 0.3686
Testing loss: 2.282251501682322
Testing accuracy: 0.3624
Epoch 140
-----
Training loss: 1.9854934395783796
Training accuracy: 0.366
Testing loss: 2.1956470019482572
Testing accuracy: 0.3566
Testing loss: 2.3245635288294553
Testing accuracy: 0.355
Epoch 141
-----
Training loss: 1.9763525041989356
Training accuracy: 0.3658
Testing loss: 2.1837229352167498
Testing accuracy: 0.3602
Testing loss: 2.225243134565207
Testing accuracy: 0.3498
Epoch 142
-----
Training loss: 1.9551362116894724
Training accuracy: 0.3714
Testing loss: 2.2265664699439194
Testing accuracy: 0.3652
Testing loss: 2.259747868281667
Testing accuracy: 0.3622
Epoch 143
-----
Training loss: 1.9485165751341793
Training accuracy: 0.37185
Testing loss: 2.159382228268657
Testing accuracy: 0.3528
Testing loss: 2.2065436211844576
Testing accuracy: 0.362
Epoch 144
-----
Training loss: 1.9543046056252567
Training accuracy: 0.36955
Testing loss: 2.2038649522024336
```

Testing accuracy: 0.3732  
Testing loss: 2.2115560645021093  
Testing accuracy: 0.3632  
Epoch 145

-----  
Training loss: 1.9552489090529446  
Training accuracy: 0.36955  
Testing loss: 2.202850603801979  
Testing accuracy: 0.3746  
Testing loss: 2.254580918259417  
Testing accuracy: 0.3576  
Epoch 146

-----  
Training loss: 1.9373356112749411  
Training accuracy: 0.3778  
Testing loss: 2.1241239178470694  
Testing accuracy: 0.361  
Testing loss: 2.2537493128176154  
Testing accuracy: 0.3444  
Epoch 147

-----  
Training loss: 1.9287828136790601  
Training accuracy: 0.3737  
Testing loss: 2.238199386041644  
Testing accuracy: 0.3694  
Testing loss: 2.282832151901198  
Testing accuracy: 0.3524  
Epoch 148

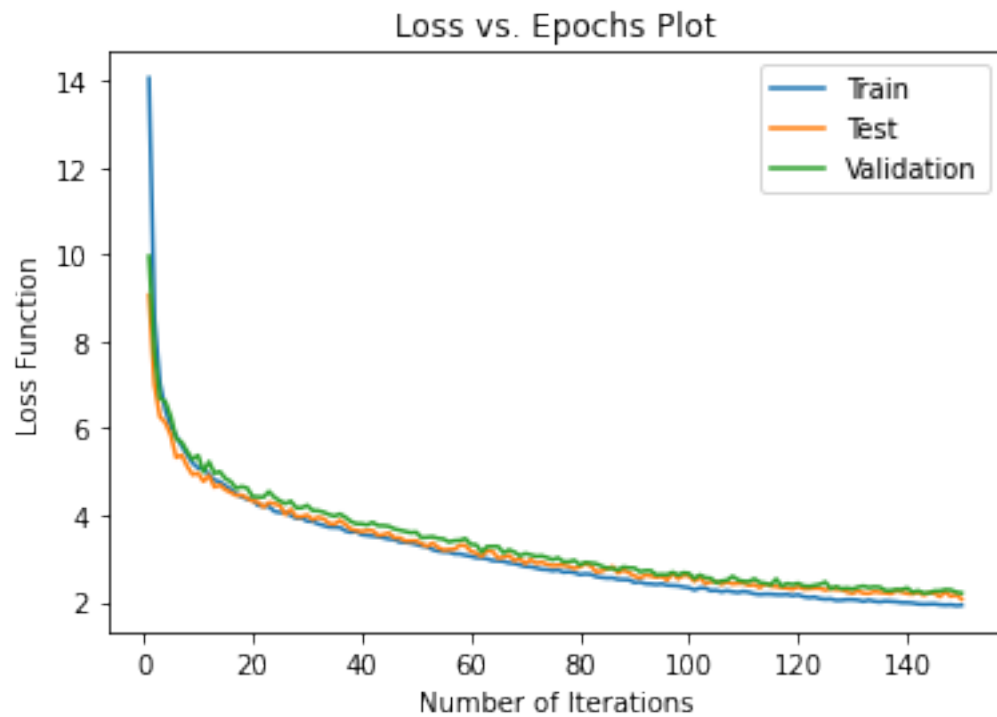
-----  
Training loss: 1.9360432429646757  
Training accuracy: 0.37545  
Testing loss: 2.131370086162839  
Testing accuracy: 0.371  
Testing loss: 2.277862370641435  
Testing accuracy: 0.3646  
Epoch 149

-----  
Training loss: 1.915450907403837  
Training accuracy: 0.3789  
Testing loss: 2.169809116827611  
Testing accuracy: 0.357  
Testing loss: 2.227242117685355  
Testing accuracy: 0.36  
Epoch 150

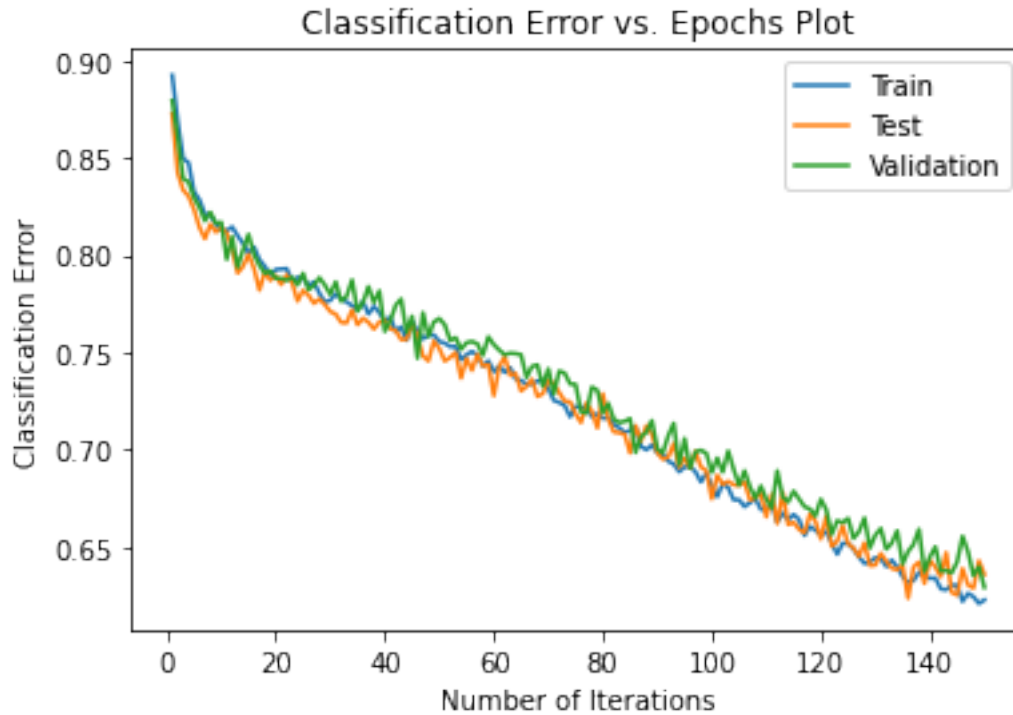
-----  
Training loss: 1.9252233488537804  
Training accuracy: 0.3771  
Testing loss: 2.067365791139967

Testing accuracy: 0.364  
Testing loss: 2.2057241589951935  
Testing accuracy: 0.3706  
Done  
Total Time Consumed: 13215.052844047546

```
[ ]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[ ]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



#### 6.3.4 Learning Rate = 2.5

```
[9]: # Define HyperParameters
learning_rate = 2.5
batch_size = 64
num_epochs = 150

sum_5 = sum_model().double()
optimizer = optim.Adadelta(sum_5.parameters(), lr = learning_rate, rho = 0.95,
    ↪eps = 1e-08, weight_decay = 0)
loss = nn.MSELoss()
```

```
[10]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.append(train_loop7(X_train,Y_train,sum_5,loss,optimizer))
    test_loss_record.append(test_loop7(X_test,Y_test,sum_5,loss))
    val_loss_record.append(test_loop7(X_val,Y_val,sum_5,loss))
print('Done')
```

```
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

-----

/usr/local/lib/python3.7/dist-packages/torch/nn/modules/loss.py:529:

UserWarning: Using a target size (torch.Size([])) that is different to the input size (torch.Size([1])). This will likely lead to incorrect results due to broadcasting. Please ensure they have the same size.

```
    return F.mse_loss(input, target, reduction=self.reduction)
```

Training loss: 7.914323465178954

Training accuracy: 0.1461

Testing loss: 6.277155181921705

Testing accuracy: 0.1662

Testing loss: 6.528202233510359

Testing accuracy: 0.1542

Epoch 2

-----

Training loss: 5.170067478299104

Training accuracy: 0.1853

Testing loss: 5.501395778148721

Testing accuracy: 0.1794

Testing loss: 5.6094114807468225

Testing accuracy: 0.1782

Epoch 3

-----

Training loss: 4.520066956337345

Training accuracy: 0.19965

Testing loss: 4.345092121105099

Testing accuracy: 0.209

Testing loss: 4.594819986177789

Testing accuracy: 0.2002

Epoch 4

-----

Training loss: 4.110619675028517

Training accuracy: 0.2126

Testing loss: 4.527076538301302

Testing accuracy: 0.2032

Testing loss: 4.7689084050972035

Testing accuracy: 0.2044

Epoch 5

-----

Training loss: 3.820491174327876

Training accuracy: 0.2202

Testing loss: 4.240535512814301

Testing accuracy: 0.2136

Testing loss: 4.470460114212921

```

Testing accuracy: 0.2038
Epoch 6
-----
Training loss: 3.6521853907428485
Training accuracy: 0.2271
Testing loss: 3.6845398929825177
Testing accuracy: 0.2276
Testing loss: 3.9195522195155994
Testing accuracy: 0.2176
Epoch 7
-----
Training loss: 3.5407219846528255
Training accuracy: 0.22915
Testing loss: 4.021863738176886
Testing accuracy: 0.2272
Testing loss: 4.190653083069694
Testing accuracy: 0.207
Epoch 8
-----
Training loss: 3.3924886705715807
Training accuracy: 0.23685
Testing loss: 3.717455321823311
Testing accuracy: 0.2346
Testing loss: 3.8288101528855956
Testing accuracy: 0.2192
Epoch 9
-----
Training loss: 3.2568099877264576
Training accuracy: 0.24395
Testing loss: 3.6759828498317133
Testing accuracy: 0.2428
Testing loss: 3.636101959481335
Testing accuracy: 0.2278
Epoch 10
-----
Training loss: 3.1115904496902984
Training accuracy: 0.25165
Testing loss: 3.5289909765541045
Testing accuracy: 0.2474
Testing loss: 3.6680379737828828
Testing accuracy: 0.251
Epoch 11
-----
Training loss: 3.03116414191647
Training accuracy: 0.2586
Testing loss: 3.3383575014806794
Testing accuracy: 0.2558
Testing loss: 3.443745184339636

```

```
Testing accuracy: 0.2404
Epoch 12
-----
Training loss: 2.877438023117671
Training accuracy: 0.25945
Testing loss: 3.0589088447982817
Testing accuracy: 0.2754
Testing loss: 3.244518893601465
Testing accuracy: 0.2544
Epoch 13
-----
Training loss: 2.8245555634073822
Training accuracy: 0.2705
Testing loss: 2.9165669418254794
Testing accuracy: 0.2806
Testing loss: 2.9381518013835204
Testing accuracy: 0.2768
Epoch 14
-----
Training loss: 2.772584551225299
Training accuracy: 0.2825
Testing loss: 2.989549809085431
Testing accuracy: 0.2798
Testing loss: 3.0427061666100537
Testing accuracy: 0.2796
Epoch 15
-----
Training loss: 2.66222397978519
Training accuracy: 0.28265
Testing loss: 2.8045473391751115
Testing accuracy: 0.2838
Testing loss: 2.918404598449428
Testing accuracy: 0.2814
Epoch 16
-----
Training loss: 2.64272966080527
Training accuracy: 0.2856
Testing loss: 2.8301558970120992
Testing accuracy: 0.2882
Testing loss: 2.836598772633557
Testing accuracy: 0.2768
Epoch 17
-----
Training loss: 2.554836151834766
Training accuracy: 0.30245
Testing loss: 2.874922768716297
Testing accuracy: 0.2878
Testing loss: 2.890848577527738
```

```
Testing accuracy: 0.2864
Epoch 18
-----
Training loss: 2.4626708052304114
Training accuracy: 0.3056
Testing loss: 2.6804658841364266
Testing accuracy: 0.3078
Testing loss: 2.8149262136789317
Testing accuracy: 0.3072
Epoch 19
-----
Training loss: 2.3879663625158862
Training accuracy: 0.3126
Testing loss: 2.5350682743413753
Testing accuracy: 0.3176
Testing loss: 2.707893770914297
Testing accuracy: 0.3056
Epoch 20
-----
Training loss: 2.346914106322638
Training accuracy: 0.31825
Testing loss: 2.5358265029172222
Testing accuracy: 0.3388
Testing loss: 2.59980822865185
Testing accuracy: 0.3228
Epoch 21
-----
Training loss: 2.3314168621061446
Training accuracy: 0.32255
Testing loss: 2.4633142537475847
Testing accuracy: 0.3352
Testing loss: 2.5909092797294737
Testing accuracy: 0.3342
Epoch 22
-----
Training loss: 2.2789506711040715
Training accuracy: 0.32795
Testing loss: 2.374235536090973
Testing accuracy: 0.3378
Testing loss: 2.5362868973426833
Testing accuracy: 0.3184
Epoch 23
-----
Training loss: 2.283532328150381
Training accuracy: 0.3436
Testing loss: 2.487488800327358
Testing accuracy: 0.3392
Testing loss: 2.5441607783358666
```



```

Testing accuracy: 0.3268
Epoch 24
-----
Training loss: 2.2353876130291566
Training accuracy: 0.33815
Testing loss: 2.3622440672262655
Testing accuracy: 0.3518
Testing loss: 2.5758906974157645
Testing accuracy: 0.3406
Epoch 25
-----
Training loss: 2.25638302462576
Training accuracy: 0.34235
Testing loss: 2.3012652306935837
Testing accuracy: 0.3472
Testing loss: 2.4238765985326447
Testing accuracy: 0.336
Epoch 26
-----
Training loss: 2.1893086492885696
Training accuracy: 0.34975
Testing loss: 2.4006671551885916
Testing accuracy: 0.3444
Testing loss: 2.4336862811076165
Testing accuracy: 0.3402
Epoch 27
-----
Training loss: 2.1592929573215343
Training accuracy: 0.34865
Testing loss: 2.3685080851779703
Testing accuracy: 0.365
Testing loss: 2.458152456301791
Testing accuracy: 0.342
Epoch 28
-----
Training loss: 2.1299507622789786
Training accuracy: 0.3581
Testing loss: 2.3168050709962498
Testing accuracy: 0.3614
Testing loss: 2.351068893949108
Testing accuracy: 0.3522
Epoch 29
-----
Training loss: 2.147287821649076
Training accuracy: 0.3572
Testing loss: 2.344236756932555
Testing accuracy: 0.3486
Testing loss: 2.5460125990343507

```

```
Testing accuracy: 0.3446
Epoch 30
-----
Training loss: 2.129804135362225
Training accuracy: 0.36225
Testing loss: 2.269414781182774
Testing accuracy: 0.38
Testing loss: 2.36921829561303
Testing accuracy: 0.3574
Epoch 31
-----
Training loss: 2.078996460556469
Training accuracy: 0.3637
Testing loss: 2.3093711509583548
Testing accuracy: 0.3702
Testing loss: 2.310914514290299
Testing accuracy: 0.361
Epoch 32
-----
Training loss: 2.0727466933417356
Training accuracy: 0.36575
Testing loss: 2.40284207916582
Testing accuracy: 0.3786
Testing loss: 2.4176841690011037
Testing accuracy: 0.3516
Epoch 33
-----
Training loss: 2.0713724080650406
Training accuracy: 0.37105
Testing loss: 2.2695849218360746
Testing accuracy: 0.3818
Testing loss: 2.2914640594368754
Testing accuracy: 0.366
Epoch 34
-----
Training loss: 2.0930085393370628
Training accuracy: 0.37105
Testing loss: 2.2305187867988843
Testing accuracy: 0.3934
Testing loss: 2.235323488823874
Testing accuracy: 0.3694
Epoch 35
-----
Training loss: 2.0467141498506067
Training accuracy: 0.37945
Testing loss: 2.1942333089737973
Testing accuracy: 0.3732
Testing loss: 2.2477541815270903
```

```
Testing accuracy: 0.3722
Epoch 36
-----
Training loss: 2.0272607420807036
Training accuracy: 0.38605
Testing loss: 2.2317908788070855
Testing accuracy: 0.3776
Testing loss: 2.2999840798757574
Testing accuracy: 0.3734
Epoch 37
-----
Training loss: 2.048540156176136
Training accuracy: 0.3759
Testing loss: 2.324636931655754
Testing accuracy: 0.3772
Testing loss: 2.3095393817501466
Testing accuracy: 0.372
Epoch 38
-----
Training loss: 1.9717353355995129
Training accuracy: 0.38015
Testing loss: 2.2322471566932878
Testing accuracy: 0.376
Testing loss: 2.33723674180131
Testing accuracy: 0.3646
Epoch 39
-----
Training loss: 2.000157878985626
Training accuracy: 0.38045
Testing loss: 2.258831547191281
Testing accuracy: 0.388
Testing loss: 2.2651084365757
Testing accuracy: 0.375
Epoch 40
-----
Training loss: 1.9437645575709823
Training accuracy: 0.3912
Testing loss: 2.184686043285812
Testing accuracy: 0.3848
Testing loss: 2.342363025604977
Testing accuracy: 0.3768
Epoch 41
-----
Training loss: 1.9464877574462867
Training accuracy: 0.3899
Testing loss: 2.138258207592356
Testing accuracy: 0.3972
Testing loss: 2.260464981475665
```

```
Testing accuracy: 0.3956
Epoch 42
-----
Training loss: 1.9269435809599516
Training accuracy: 0.3919
Testing loss: 2.0832434734476326
Testing accuracy: 0.4054
Testing loss: 2.2758414782489162
Testing accuracy: 0.3878
Epoch 43
-----
Training loss: 1.9125409592477285
Training accuracy: 0.39475
Testing loss: 2.1056393919964163
Testing accuracy: 0.4014
Testing loss: 2.205248485933471
Testing accuracy: 0.3816
Epoch 44
-----
Training loss: 1.9019406380171666
Training accuracy: 0.3934
Testing loss: 2.0878719554740997
Testing accuracy: 0.3844
Testing loss: 2.1878496274192036
Testing accuracy: 0.3898
Epoch 45
-----
Training loss: 1.9453558979537788
Training accuracy: 0.3968
Testing loss: 2.07117597869383
Testing accuracy: 0.4008
Testing loss: 2.2508346495519813
Testing accuracy: 0.385
Epoch 46
-----
Training loss: 1.9038914701894465
Training accuracy: 0.39555
Testing loss: 2.1516804323046514
Testing accuracy: 0.4008
Testing loss: 2.147160914093132
Testing accuracy: 0.3976
Epoch 47
-----
Training loss: 1.9022206281963518
Training accuracy: 0.40025
Testing loss: 2.1418967170075374
Testing accuracy: 0.384
Testing loss: 2.2066141753592006
```

```
Testing accuracy: 0.377
Epoch 48
-----
Training loss: 1.9530192634258046
Training accuracy: 0.3966
Testing loss: 2.0957285673228045
Testing accuracy: 0.3888
Testing loss: 2.2493240816975986
Testing accuracy: 0.385
Epoch 49
-----
Training loss: 1.905481639570844
Training accuracy: 0.40055
Testing loss: 2.0582888333189877
Testing accuracy: 0.4074
Testing loss: 2.219702987819824
Testing accuracy: 0.3912
Epoch 50
-----
Training loss: 1.9002058757360591
Training accuracy: 0.41
Testing loss: 2.1191475886996964
Testing accuracy: 0.3982
Testing loss: 2.288331722310256
Testing accuracy: 0.3804
Epoch 51
-----
Training loss: 1.8685503169999793
Training accuracy: 0.40575
Testing loss: 2.1813687538324915
Testing accuracy: 0.3968
Testing loss: 2.1788528638806492
Testing accuracy: 0.3986
Epoch 52
-----
Training loss: 1.9025142288840649
Training accuracy: 0.402
Testing loss: 2.059798991720057
Testing accuracy: 0.4116
Testing loss: 2.1751753124782076
Testing accuracy: 0.4082
Epoch 53
-----
Training loss: 1.8763945214190516
Training accuracy: 0.41395
Testing loss: 2.153478149545485
Testing accuracy: 0.4052
Testing loss: 2.0795665881350125
```

```
Testing accuracy: 0.402
Epoch 54
-----
Training loss: 1.9080309326015776
Training accuracy: 0.411
Testing loss: 2.034067472642585
Testing accuracy: 0.411
Testing loss: 2.1206335789775226
Testing accuracy: 0.397
Epoch 55
-----
Training loss: 1.8436568690709818
Training accuracy: 0.41735
Testing loss: 2.1800528463749766
Testing accuracy: 0.417
Testing loss: 2.1105565155203263
Testing accuracy: 0.4118
Epoch 56
-----
Training loss: 1.8785056715754351
Training accuracy: 0.4172
Testing loss: 2.053929848564998
Testing accuracy: 0.4076
Testing loss: 2.1652374221619173
Testing accuracy: 0.4122
Epoch 57
-----
Training loss: 1.9037650678125217
Training accuracy: 0.4131
Testing loss: 2.0934185141778685
Testing accuracy: 0.4246
Testing loss: 2.1295822970939224
Testing accuracy: 0.4146
Epoch 58
-----
Training loss: 1.8430060705342821
Training accuracy: 0.418
Testing loss: 1.9334554095137133
Testing accuracy: 0.422
Testing loss: 2.0107089674121044
Testing accuracy: 0.4228
Epoch 59
-----
Training loss: 1.8472403271374034
Training accuracy: 0.41965
Testing loss: 2.0384672930518843
Testing accuracy: 0.4276
Testing loss: 2.0954412551092934
```

```
Testing accuracy: 0.4066
Epoch 60
-----
Training loss: 1.835950719209238
Training accuracy: 0.423
Testing loss: 2.0733311075186838
Testing accuracy: 0.4098
Testing loss: 2.2306177635346436
Testing accuracy: 0.4032
Epoch 61
-----
Training loss: 1.8224212024219713
Training accuracy: 0.42325
Testing loss: 2.0848301039445536
Testing accuracy: 0.4096
Testing loss: 2.112183201810337
Testing accuracy: 0.4126
Epoch 62
-----
Training loss: 1.8718770395408977
Training accuracy: 0.41835
Testing loss: 1.9616696893493306
Testing accuracy: 0.4272
Testing loss: 2.0731650513617637
Testing accuracy: 0.413
Epoch 63
-----
Training loss: 1.8391219777314014
Training accuracy: 0.42115
Testing loss: 2.343043636482514
Testing accuracy: 0.4098
Testing loss: 2.403581433119775
Testing accuracy: 0.388
Epoch 64
-----
Training loss: 1.831257292955819
Training accuracy: 0.41945
Testing loss: 2.224534048942207
Testing accuracy: 0.4312
Testing loss: 2.1689236468271424
Testing accuracy: 0.405
Epoch 65
-----
Training loss: 1.8031288400849796
Training accuracy: 0.4218
Testing loss: 2.0479921510243453
Testing accuracy: 0.4128
Testing loss: 2.065719376105458
```

```
Testing accuracy: 0.4118
Epoch 66
-----
Training loss: 1.8535489098764464
Training accuracy: 0.42195
Testing loss: 2.236269788787153
Testing accuracy: 0.4076
Testing loss: 2.272044497467512
Testing accuracy: 0.3938
Epoch 67
-----
Training loss: 1.844058166576782
Training accuracy: 0.41935
Testing loss: 2.0890103049011928
Testing accuracy: 0.4204
Testing loss: 2.1714744546664235
Testing accuracy: 0.4034
Epoch 68
-----
Training loss: 1.8291972951878106
Training accuracy: 0.41965
Testing loss: 1.9606942369622034
Testing accuracy: 0.4096
Testing loss: 2.079507643469429
Testing accuracy: 0.4108
Epoch 69
-----
Training loss: 1.8262379470698666
Training accuracy: 0.42805
Testing loss: 2.1271823582847063
Testing accuracy: 0.4136
Testing loss: 2.0911279152704894
Testing accuracy: 0.416
Epoch 70
-----
Training loss: 1.8324447398440789
Training accuracy: 0.42885
Testing loss: 1.950008728368369
Testing accuracy: 0.4352
Testing loss: 1.994845207899785
Testing accuracy: 0.4264
Epoch 71
-----
Training loss: 1.8208085247076535
Training accuracy: 0.4312
Testing loss: 2.0893953793697158
Testing accuracy: 0.42
Testing loss: 2.19680446886964
```



```
Testing accuracy: 0.4004
Epoch 72
-----
Training loss: 1.8060748727150224
Training accuracy: 0.43435
Testing loss: 2.021458151560082
Testing accuracy: 0.439
Testing loss: 2.117146774204992
Testing accuracy: 0.432
Epoch 73
-----
Training loss: 1.81015279769857
Training accuracy: 0.4303
Testing loss: 2.087731498359359
Testing accuracy: 0.4276
Testing loss: 2.2202964081029735
Testing accuracy: 0.4146
Epoch 74
-----
Training loss: 1.8208253465950743
Training accuracy: 0.4331
Testing loss: 2.1194158724144194
Testing accuracy: 0.4392
Testing loss: 2.204882296928062
Testing accuracy: 0.4232
Epoch 75
-----
Training loss: 1.8416603904802986
Training accuracy: 0.4348
Testing loss: 2.087460530396064
Testing accuracy: 0.435
Testing loss: 2.151266594071257
Testing accuracy: 0.4166
Epoch 76
-----
Training loss: 1.7836819060923745
Training accuracy: 0.443
Testing loss: 2.0785755523807636
Testing accuracy: 0.4348
Testing loss: 2.1444903158197457
Testing accuracy: 0.4356
Epoch 77
-----
Training loss: 1.8150543681471514
Training accuracy: 0.43615
Testing loss: 1.9561548971481268
Testing accuracy: 0.426
Testing loss: 2.053255224234066
```

```

Testing accuracy: 0.4304
Epoch 78
-----
Training loss: 1.8026085805292191
Training accuracy: 0.4394
Testing loss: 1.9746091181008756
Testing accuracy: 0.4346
Testing loss: 2.2047141240479506
Testing accuracy: 0.4172
Epoch 79
-----
Training loss: 1.8388581775083788
Training accuracy: 0.43395
Testing loss: 2.085568946746697
Testing accuracy: 0.4342
Testing loss: 2.1643560255150356
Testing accuracy: 0.42
Epoch 80
-----
Training loss: 1.8301178155160902
Training accuracy: 0.43825
Testing loss: 2.021137448111642
Testing accuracy: 0.441
Testing loss: 2.085902281871984
Testing accuracy: 0.424
Epoch 81
-----
Training loss: 1.8105311865236593
Training accuracy: 0.44655
Testing loss: 1.9038152617912052
Testing accuracy: 0.4568
Testing loss: 2.046549105112963
Testing accuracy: 0.4108
Epoch 82
-----
Training loss: 1.8009852084489082
Training accuracy: 0.44485
Testing loss: 1.9669629883349142
Testing accuracy: 0.4452
Testing loss: 2.0618182482078957
Testing accuracy: 0.4244
Epoch 83
-----
Training loss: 1.8031556610989816
Training accuracy: 0.4466
Testing loss: 2.053499940741889
Testing accuracy: 0.4432
Testing loss: 2.0456552156117813

```

```

Testing accuracy: 0.4434
Epoch 84
-----
Training loss: 1.8077931964080973
Training accuracy: 0.44515
Testing loss: 1.9748444678567298
Testing accuracy: 0.4682
Testing loss: 2.01580605242856
Testing accuracy: 0.455
Epoch 85
-----
Training loss: 1.773740017752209
Training accuracy: 0.4448
Testing loss: 1.9199401409927115
Testing accuracy: 0.4364
Testing loss: 2.148555044770158
Testing accuracy: 0.4266
Epoch 86
-----
Training loss: 1.782668448155489
Training accuracy: 0.4465
Testing loss: 2.0513726225189624
Testing accuracy: 0.4394
Testing loss: 2.0338730747307654
Testing accuracy: 0.4434
Epoch 87
-----
Training loss: 1.796005180394495
Training accuracy: 0.4418
Testing loss: 2.0503651235554083
Testing accuracy: 0.44
Testing loss: 2.115729278356153
Testing accuracy: 0.4286
Epoch 88
-----
Training loss: 1.7479286928744633
Training accuracy: 0.44355
Testing loss: 2.0886769607345608
Testing accuracy: 0.4552
Testing loss: 2.155089348299237
Testing accuracy: 0.4486
Epoch 89
-----
Training loss: 1.7674611637285391
Training accuracy: 0.44885
Testing loss: 2.035266191515938
Testing accuracy: 0.432
Testing loss: 2.0584338596249103

```

```
Testing accuracy: 0.4166
Epoch 90
-----
Training loss: 1.7698278710036277
Training accuracy: 0.45065
Testing loss: 2.0460821704963443
Testing accuracy: 0.433
Testing loss: 2.051287273935502
Testing accuracy: 0.4424
Epoch 91
-----
Training loss: 1.7938122190620742
Training accuracy: 0.4484
Testing loss: 2.095016376311216
Testing accuracy: 0.431
Testing loss: 2.1982547396896845
Testing accuracy: 0.4242
Epoch 92
-----
Training loss: 1.791352137128339
Training accuracy: 0.45135
Testing loss: 2.1117809661718336
Testing accuracy: 0.4032
Testing loss: 2.19446032537748
Testing accuracy: 0.3884
Epoch 93
-----
Training loss: 1.8210758279460915
Training accuracy: 0.4417
Testing loss: 2.0534819150063743
Testing accuracy: 0.4546
Testing loss: 2.039837628855283
Testing accuracy: 0.44
Epoch 94
-----
Training loss: 1.7708272462633183
Training accuracy: 0.45285
Testing loss: 1.8951092955181232
Testing accuracy: 0.454
Testing loss: 1.9796952119449438
Testing accuracy: 0.4374
Epoch 95
-----
Training loss: 1.7531565124872697
Training accuracy: 0.45815
Testing loss: 1.9770279823056616
Testing accuracy: 0.4444
Testing loss: 2.0269469206250075
```

```
Testing accuracy: 0.4412
Epoch 96
-----
Training loss: 1.746922785768185
Training accuracy: 0.45895
Testing loss: 1.9935942798826818
Testing accuracy: 0.4612
Testing loss: 2.0782761725022803
Testing accuracy: 0.4522
Epoch 97
-----
Training loss: 1.789651169903433
Training accuracy: 0.45945
Testing loss: 1.974887478327896
Testing accuracy: 0.461
Testing loss: 1.9499034995822275
Testing accuracy: 0.4528
Epoch 98
-----
Training loss: 1.7609614109995277
Training accuracy: 0.4584
Testing loss: 1.9764779704419957
Testing accuracy: 0.4594
Testing loss: 2.002807161268993
Testing accuracy: 0.4384
Epoch 99
-----
Training loss: 1.7670747045543302
Training accuracy: 0.4552
Testing loss: 2.0317965826688202
Testing accuracy: 0.4446
Testing loss: 2.235543284855207
Testing accuracy: 0.4348
Epoch 100
-----
Training loss: 1.7731159711085172
Training accuracy: 0.45575
Testing loss: 1.9984707279779284
Testing accuracy: 0.4732
Testing loss: 2.074728503828098
Testing accuracy: 0.4584
Epoch 101
-----
Training loss: 1.7595869294692634
Training accuracy: 0.4665
Testing loss: 2.0029815795190764
Testing accuracy: 0.4558
Testing loss: 2.0127006807104495
```

```
Testing accuracy: 0.4384
Epoch 102
-----
Training loss: 1.7388997603111096
Training accuracy: 0.4604
Testing loss: 1.9481399236050263
Testing accuracy: 0.4784
Testing loss: 1.9627591981876313
Testing accuracy: 0.4668
Epoch 103
-----
Training loss: 1.7430931197528403
Training accuracy: 0.46175
Testing loss: 1.9486940014214218
Testing accuracy: 0.4552
Testing loss: 2.0590619585912795
Testing accuracy: 0.4414
Epoch 104
-----
Training loss: 1.7594538158116284
Training accuracy: 0.46075
Testing loss: 2.0141711212487787
Testing accuracy: 0.4648
Testing loss: 2.016954583158485
Testing accuracy: 0.4428
Epoch 105
-----
Training loss: 1.7213242085733163
Training accuracy: 0.46115
Testing loss: 1.9660143804717871
Testing accuracy: 0.4606
Testing loss: 1.9177283361296904
Testing accuracy: 0.4544
Epoch 106
-----
Training loss: 1.7160348773490117
Training accuracy: 0.4609
Testing loss: 1.9490517062789796
Testing accuracy: 0.4656
Testing loss: 2.0828012985422566
Testing accuracy: 0.4484
Epoch 107
-----
Training loss: 1.753122624587892
Training accuracy: 0.46485
Testing loss: 2.0309210255221064
Testing accuracy: 0.472
Testing loss: 2.006631493433622
```

```
Testing accuracy: 0.4598
Epoch 108
-----
Training loss: 1.7630072652811941
Training accuracy: 0.4662
Testing loss: 2.0461829166677608
Testing accuracy: 0.4636
Testing loss: 2.1972088648617083
Testing accuracy: 0.458
Epoch 109
-----
Training loss: 1.7789941332748374
Training accuracy: 0.46275
Testing loss: 2.0619686109003186
Testing accuracy: 0.445
Testing loss: 2.123195963452521
Testing accuracy: 0.4496
Epoch 110
-----
Training loss: 1.7420056324779662
Training accuracy: 0.4677
Testing loss: 2.0677879540824518
Testing accuracy: 0.4686
Testing loss: 2.0435728373562005
Testing accuracy: 0.4604
Epoch 111
-----
Training loss: 1.7882637787483542
Training accuracy: 0.46205
Testing loss: 1.8837810530181112
Testing accuracy: 0.4934
Testing loss: 1.948115196383384
Testing accuracy: 0.4812
Epoch 112
-----
Training loss: 1.7647762011001789
Training accuracy: 0.46355
Testing loss: 2.0447068268464204
Testing accuracy: 0.4568
Testing loss: 1.991154462141887
Testing accuracy: 0.4348
Epoch 113
-----
Training loss: 1.7776350349988257
Training accuracy: 0.47025
Testing loss: 1.9219299594595711
Testing accuracy: 0.485
Testing loss: 2.032176140513045
```

```
Testing accuracy: 0.4624
Epoch 114
-----
Training loss: 1.7063929999222338
Training accuracy: 0.46705
Testing loss: 1.9916680448147286
Testing accuracy: 0.4818
Testing loss: 2.129183207767617
Testing accuracy: 0.4694
Epoch 115
-----
Training loss: 1.7456195630465212
Training accuracy: 0.47045
Testing loss: 2.124253490074107
Testing accuracy: 0.4522
Testing loss: 2.1296989513387135
Testing accuracy: 0.448
Epoch 116
-----
Training loss: 1.7452900915237057
Training accuracy: 0.46745
Testing loss: 2.13786917778927
Testing accuracy: 0.4794
Testing loss: 2.1047747622046984
Testing accuracy: 0.4728
Epoch 117
-----
Training loss: 1.7714790044850564
Training accuracy: 0.4615
Testing loss: 1.96916997153118
Testing accuracy: 0.4852
Testing loss: 2.0185893403303226
Testing accuracy: 0.4666
Epoch 118
-----
Training loss: 1.7853815232255776
Training accuracy: 0.468
Testing loss: 1.9581583524148654
Testing accuracy: 0.454
Testing loss: 2.116887396921933
Testing accuracy: 0.456
Epoch 119
-----
Training loss: 1.7547382882067966
Training accuracy: 0.471
Testing loss: 2.0795665947373845
Testing accuracy: 0.4602
Testing loss: 2.117776385823458
```



```
Testing accuracy: 0.4472
Epoch 120
-----
Training loss: 1.7868581942915656
Training accuracy: 0.4717
Testing loss: 2.0182283686248863
Testing accuracy: 0.4778
Testing loss: 2.0647980709811145
Testing accuracy: 0.4588
Epoch 121
-----
Training loss: 1.719667154974161
Training accuracy: 0.47445
Testing loss: 2.0128726827827466
Testing accuracy: 0.484
Testing loss: 2.065433383976983
Testing accuracy: 0.4692
Epoch 122
-----
Training loss: 1.7969771832215338
Training accuracy: 0.46465
Testing loss: 1.9692177591597544
Testing accuracy: 0.4742
Testing loss: 2.1802094268254635
Testing accuracy: 0.4542
Epoch 123
-----
Training loss: 1.7669980789921476
Training accuracy: 0.4674
Testing loss: 1.9722799429785107
Testing accuracy: 0.4606
Testing loss: 2.131659269716026
Testing accuracy: 0.4534
Epoch 124
-----
Training loss: 1.7510272416690502
Training accuracy: 0.47535
Testing loss: 2.042742980126329
Testing accuracy: 0.4564
Testing loss: 2.096205302918118
Testing accuracy: 0.461
Epoch 125
-----
Training loss: 1.806854726827506
Training accuracy: 0.4688
Testing loss: 1.9809278591883162
Testing accuracy: 0.4862
Testing loss: 1.9829704563257369
```

```
Testing accuracy: 0.4774
Epoch 126
-----
Training loss: 1.7345710950563356
Training accuracy: 0.4775
Testing loss: 1.9407000967276065
Testing accuracy: 0.49
Testing loss: 2.080202463457479
Testing accuracy: 0.4762
Epoch 127
-----
Training loss: 1.693470669260605
Training accuracy: 0.47755
Testing loss: 1.9960230077092895
Testing accuracy: 0.4662
Testing loss: 2.021172948268255
Testing accuracy: 0.4674
Epoch 128
-----
Training loss: 1.7675104249565592
Training accuracy: 0.4749
Testing loss: 1.9800528616564061
Testing accuracy: 0.49
Testing loss: 2.0705938056033633
Testing accuracy: 0.4714
Epoch 129
-----
Training loss: 1.7478002272908133
Training accuracy: 0.48125
Testing loss: 1.8983734131315941
Testing accuracy: 0.477
Testing loss: 2.036585568503865
Testing accuracy: 0.467
Epoch 130
-----
Training loss: 1.6975495572329347
Training accuracy: 0.4804
Testing loss: 1.950426738709852
Testing accuracy: 0.4664
Testing loss: 2.068311447192158
Testing accuracy: 0.4714
Epoch 131
-----
Training loss: 1.7159972536938364
Training accuracy: 0.47655
Testing loss: 1.9750500425614246
Testing accuracy: 0.506
Testing loss: 2.01215138978481
```

```
Testing accuracy: 0.4782
Epoch 132
-----
Training loss: 1.7461562205787098
Training accuracy: 0.4785
Testing loss: 1.9897165521178157
Testing accuracy: 0.4814
Testing loss: 2.1275069601139034
Testing accuracy: 0.4672
Epoch 133
-----
Training loss: 1.7465083629947262
Training accuracy: 0.47955
Testing loss: 2.0360910240266117
Testing accuracy: 0.4782
Testing loss: 2.193022765228588
Testing accuracy: 0.4524
Epoch 134
-----
Training loss: 1.741969089878128
Training accuracy: 0.48045
Testing loss: 1.9749822053985575
Testing accuracy: 0.5056
Testing loss: 2.1552920475071304
Testing accuracy: 0.4804
Epoch 135
-----
Training loss: 1.7268149517328737
Training accuracy: 0.46995
Testing loss: 2.036506447451873
Testing accuracy: 0.4554
Testing loss: 2.203037868130194
Testing accuracy: 0.4684
Epoch 136
-----
Training loss: 1.6900759513753787
Training accuracy: 0.48195
Testing loss: 2.0532186303011373
Testing accuracy: 0.4702
Testing loss: 2.108354637734389
Testing accuracy: 0.4672
Epoch 137
-----
Training loss: 1.7014313677648574
Training accuracy: 0.47835
Testing loss: 2.0074101914919082
Testing accuracy: 0.4772
Testing loss: 2.073483833589796
```

```
Testing accuracy: 0.4814
Epoch 138
-----
Training loss: 1.7438159786015774
Training accuracy: 0.4787
Testing loss: 1.9586103014599314
Testing accuracy: 0.4916
Testing loss: 2.158291845646051
Testing accuracy: 0.471
Epoch 139
-----
Training loss: 1.755708316174494
Training accuracy: 0.4838
Testing loss: 1.9542889652990678
Testing accuracy: 0.4952
Testing loss: 2.1345912965741753
Testing accuracy: 0.4754
Epoch 140
-----
Training loss: 1.7918366882423764
Training accuracy: 0.47385
Testing loss: 1.9742100087752057
Testing accuracy: 0.5096
Testing loss: 2.064378301217956
Testing accuracy: 0.4954
Epoch 141
-----
Training loss: 1.6811221271034493
Training accuracy: 0.48095
Testing loss: 2.0413239537884817
Testing accuracy: 0.4284
Testing loss: 2.2069751443975854
Testing accuracy: 0.4384
Epoch 142
-----
Training loss: 1.6942652717979105
Training accuracy: 0.48945
Testing loss: 1.9511696400167788
Testing accuracy: 0.4758
Testing loss: 2.0697759923998187
Testing accuracy: 0.4726
Epoch 143
-----
Training loss: 1.699963909646697
Training accuracy: 0.4845
Testing loss: 1.9813350462515869
Testing accuracy: 0.4698
Testing loss: 2.101387265679216
```

```
Testing accuracy: 0.456
Epoch 144
-----
Training loss: 1.7373613278459525
Training accuracy: 0.48115
Testing loss: 2.006555806038378
Testing accuracy: 0.4918
Testing loss: 2.0632733063776465
Testing accuracy: 0.4832
Epoch 145
-----
Training loss: 1.734756952922951
Training accuracy: 0.48845
Testing loss: 2.039803196183619
Testing accuracy: 0.4814
Testing loss: 2.0753297536192816
Testing accuracy: 0.4724
Epoch 146
-----
Training loss: 1.7768669287311678
Training accuracy: 0.47935
Testing loss: 2.0301760239805344
Testing accuracy: 0.4906
Testing loss: 2.117918194197672
Testing accuracy: 0.4686
Epoch 147
-----
Training loss: 1.7174139992479083
Training accuracy: 0.48695
Testing loss: 1.887720522848859
Testing accuracy: 0.4718
Testing loss: 2.069661805425756
Testing accuracy: 0.4702
Epoch 148
-----
Training loss: 1.6970806376559173
Training accuracy: 0.48325
Testing loss: 2.103723257310436
Testing accuracy: 0.4438
Testing loss: 2.075331303613142
Testing accuracy: 0.4464
Epoch 149
-----
Training loss: 1.7347493559289047
Training accuracy: 0.47915
Testing loss: 2.0506410539199798
Testing accuracy: 0.4814
Testing loss: 1.999514969588998
```

Testing accuracy: 0.4802

Epoch 150

-----  
Training loss: 1.7134736359186746

Training accuracy: 0.48475

Testing loss: 1.9506760520943094

Testing accuracy: 0.4734

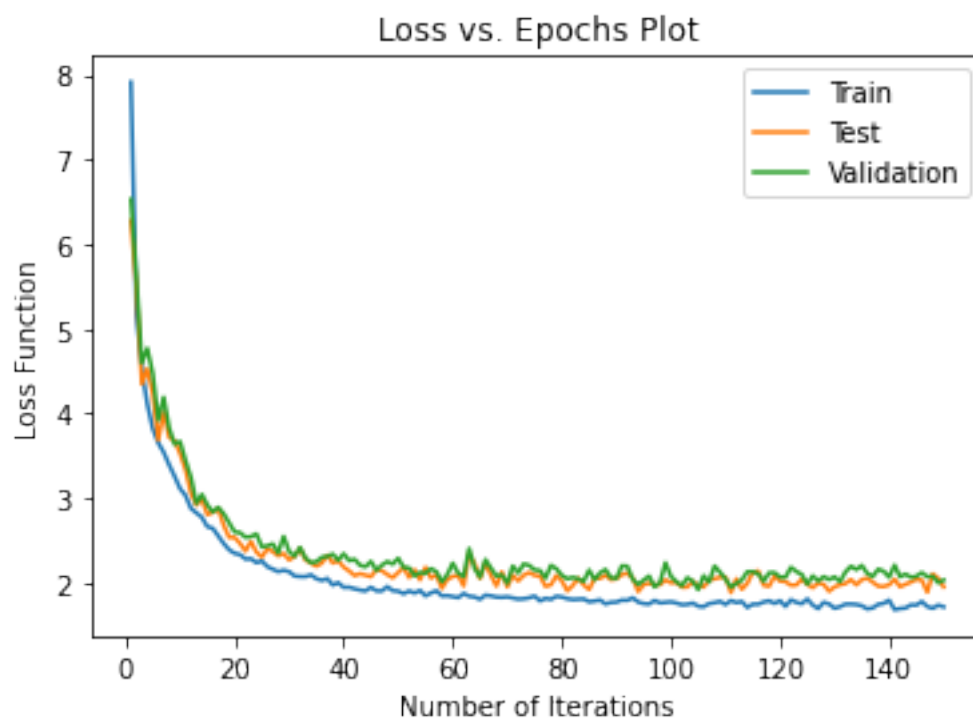
Testing loss: 2.0302226265399206

Testing accuracy: 0.4666

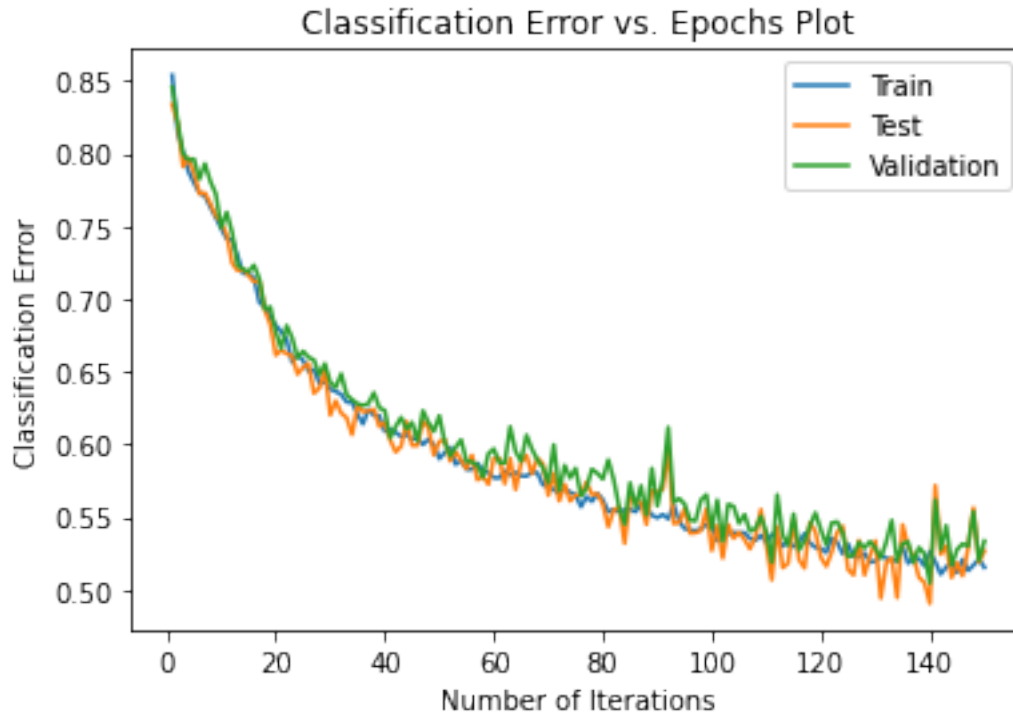
Done

Total Time Consumed: 12650.32956647873

```
[11]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[12]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



From above, we can observe the validation error as follow:

Learning Rate = 1: 50.66%;

Learning Rate = 0.2: 62.94%;

Learning Rate = 2.5: 53.34%.

Therefore, we choose the model with learning rate = 1. In addition, it can be observed that the loss function and misclassification keep decreasing with the number of epochs increasing. In another word, they do not suffer from the problem of overfitting and we can increase the number of epochs to obtain better result. However, due to the limited calculation power of my computer, I decide not to do it.

The testing error of our chosen model is 50.26% which is significantly larger than the test errors with respect to the original MNIST data. The bad performance is probably because I decrease the number of output channels of the second convolutional layer due to the limited calculation power of my computer. However, we can see that this algorithm replicated from paper is generalizable. Therefore, I believe we can train a good enough model with a better computer.

## 6.4 3-Layer 2D Convolutional Neural Network

```
[59]: def train_loop7(feature,label, model, loss_fn, optimizer):
    running_loss, correct = 0, 0
    size = len(feature.dataset)
    label = iter(label)
    for index, X in enumerate(feature):
        # Compute prediction and loss
        y = next(label)
```

```

    pred = model(X)
    loss = loss_fn(pred, y)
    running_loss += loss.item() * X.size(0)
    correct += (pred.argmax(1) == y).type(torch.float).sum().item()
    # Backpropagation
    optimizer.zero_grad()
    loss.backward()
    optimizer.step()
    running_loss = running_loss / size
    correct /= size
    print('Training loss: {}'.format(running_loss))
    print('Training accuracy: {}'.format(correct))
    return running_loss, correct

def test_loop7(feature, label, model, loss_fn):
    size = len(feature.dataset)
    test_loss, correct = 0, 0
    label = iter(label)
    with torch.no_grad():
        for index, X in enumerate(feature):
            pred = model(X)
            y = next(label)
            test_loss += loss_fn(pred, y).item() * X.size(0)
            correct += (pred.argmax(1) == y).type(torch.float).sum().item()

    test_loss /= size
    correct /= size
    print('Testing loss: {}'.format(test_loss))
    print('Testing accuracy: {}'.format(correct))
    return test_loss, correct

```

```

[60]: # Create a Convolutional Neural Network
class CNN1(nn.Module):
    def __init__(self, num_classes):
        super(CNN1, self).__init__() # Input Shape 1 * 28 * 56
        self.conv1 = nn.Sequential(
            nn.Conv2d(1, 32, 3),
            nn.BatchNorm2d(32),
            nn.ReLU(),
            nn.MaxPool2d(2)
        ) # Duput Shape 32 * 13 * 27
        self.conv2 = nn.Sequential(
            nn.Conv2d(32, 64, 3),
            nn.BatchNorm2d(64),
            nn.ReLU(),
            nn.MaxPool2d(2)

```



```

) # Output Shape 64 * 5 * 12
self.conv3 = nn.Conv2d(64,128,3) # Output Shape 128 * 3 * 10
self.fc1 = nn.Linear(3840, 800) # Output Shape 800
self.fc2 = nn.Linear(800, 256) # Output Shape 256
self.fc3 = nn.Linear(256, num_classes) # Output Shape: num_classes

def forward(self, x):
    x = self.conv1(x)
    x = self.conv2(x)
    x = F.relu(self.conv3(x))
    x = x.reshape(-1, 3840)
    x = F.relu(self.fc1(x))
    x = F.relu(self.fc2(x))
    x = self.fc3(x)
    return x

```

#### 6.4.1 Learning Rate = 0.1

```

[66]: # Define HyperParameters
# Number of Classes = 19
num_classes = 19
learning_rate = 0.1
batch_size = 64
num_epochs = 150
CNN_1 = CNN1(num_classes).double()

# Batch Data
train_loader = DataLoader(X_train, batch_size = batch_size)
train_loader_y = DataLoader(Y_train.type(torch.LongTensor), batch_size = ↵
    ↪batch_size)
test_loader = DataLoader(X_test, batch_size = batch_size)
test_loader_y = DataLoader(Y_test.type(torch.LongTensor), batch_size = ↵
    ↪batch_size)
val_loader = DataLoader(X_val, batch_size = batch_size)
val_loader_y = DataLoader(Y_val.type(torch.LongTensor), batch_size = batch_size)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_1.parameters(), lr = learning_rate)

```

```

[67]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")

```

```

    train_loss_record.
    ↪append(train_loop7(train_loader,train_loader_y,CNN_1,loss,optimizer))
    test_loss_record.append(test_loop7(test_loader,test_loader_y,CNN_1,loss))
    val_loss_record.append(test_loop7(val_loader,val_loader_y,CNN_1,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 2.222648693893431
Training accuracy: 0.23815
Testing loss: 1.2898517817829631
Testing accuracy: 0.572
Testing loss: 1.339690626509763
Testing accuracy: 0.5468

```

Epoch 2

```

-----
Training loss: 0.5660560619469733
Training accuracy: 0.825
Testing loss: 0.26429943028546293
Testing accuracy: 0.9214
Testing loss: 0.30331065234062976
Testing accuracy: 0.9134

```

Epoch 3

```

-----
Training loss: 0.19262644205312182
Training accuracy: 0.9427
Testing loss: 0.18791878109869548
Testing accuracy: 0.9396
Testing loss: 0.21953821264595227
Testing accuracy: 0.9382

```

Epoch 4

```

-----
Training loss: 0.09648740228151817
Training accuracy: 0.9713
Testing loss: 0.15263679436224498
Testing accuracy: 0.9548
Testing loss: 0.17970415721820523
Testing accuracy: 0.9528

```

Epoch 5

```

-----
Training loss: 0.04894115292633467
Training accuracy: 0.98585
Testing loss: 0.1442051474917266
Testing accuracy: 0.956
Testing loss: 0.17519108111234194
Testing accuracy: 0.9564

```

Epoch 6

-----  
Training loss: 0.03230804201389211  
Training accuracy: 0.99135  
Testing loss: 0.14719250808876239  
Testing accuracy: 0.9584  
Testing loss: 0.18746207614933577  
Testing accuracy: 0.9562  
Epoch 7

-----  
Training loss: 0.01596108522728049  
Training accuracy: 0.99595  
Testing loss: 0.15879767552444007  
Testing accuracy: 0.9582  
Testing loss: 0.1954330181358398  
Testing accuracy: 0.9574  
Epoch 8

-----  
Training loss: 0.011464372394182814  
Training accuracy: 0.9975  
Testing loss: 0.1507611840999589  
Testing accuracy: 0.9614  
Testing loss: 0.1944603387312608  
Testing accuracy: 0.9598  
Epoch 9

-----  
Training loss: 0.010512953033612323  
Training accuracy: 0.9975  
Testing loss: 0.14999772613165427  
Testing accuracy: 0.9618  
Testing loss: 0.18252862702664632  
Testing accuracy: 0.9602  
Epoch 10

-----  
Training loss: 0.004319674705551391  
Training accuracy: 0.99935  
Testing loss: 0.1269091869991763  
Testing accuracy: 0.9702  
Testing loss: 0.16643067648495447  
Testing accuracy: 0.9654  
Epoch 11

-----  
Training loss: 0.0010178223380239396  
Training accuracy: 1.0  
Testing loss: 0.12728508865510738  
Testing accuracy: 0.9702  
Testing loss: 0.17166925847933148  
Testing accuracy: 0.9658

Epoch 12

-----  
Training loss: 0.0005106267345983009  
Training accuracy: 1.0  
Testing loss: 0.13190756125173056  
Testing accuracy: 0.9692  
Testing loss: 0.1764230260021883  
Testing accuracy: 0.9668  
Epoch 13

-----  
Training loss: 0.0003804150550002237  
Training accuracy: 1.0  
Testing loss: 0.13532553874836128  
Testing accuracy: 0.9698  
Testing loss: 0.18008157628949484  
Testing accuracy: 0.9664  
Epoch 14

-----  
Training loss: 0.0003133443114959787  
Training accuracy: 1.0  
Testing loss: 0.1377859956204721  
Testing accuracy: 0.9692  
Testing loss: 0.18319002812279164  
Testing accuracy: 0.9664  
Epoch 15

-----  
Training loss: 0.00026904995009389445  
Training accuracy: 1.0  
Testing loss: 0.13978904212219703  
Testing accuracy: 0.969  
Testing loss: 0.18586071587043435  
Testing accuracy: 0.9662  
Epoch 16

-----  
Training loss: 0.000236622384191484  
Training accuracy: 1.0  
Testing loss: 0.14150597462774359  
Testing accuracy: 0.9684  
Testing loss: 0.18813934467619411  
Testing accuracy: 0.9662  
Epoch 17

-----  
Training loss: 0.0002118019188148954  
Training accuracy: 1.0  
Testing loss: 0.1430420530392172  
Testing accuracy: 0.9682  
Testing loss: 0.19015884181838433  
Testing accuracy: 0.9662

Epoch 18

-----  
Training loss: 0.0001919461573975125  
Training accuracy: 1.0  
Testing loss: 0.1443962760122344  
Testing accuracy: 0.9682  
Testing loss: 0.19195767527199104  
Testing accuracy: 0.9662  
Epoch 19

-----  
Training loss: 0.0001757095864775519  
Training accuracy: 1.0  
Testing loss: 0.14562544013482628  
Testing accuracy: 0.9684  
Testing loss: 0.19357432729039045  
Testing accuracy: 0.9662  
Epoch 20

-----  
Training loss: 0.0001621251304026199  
Training accuracy: 1.0  
Testing loss: 0.14674527925292807  
Testing accuracy: 0.9684  
Testing loss: 0.1950800208054958  
Testing accuracy: 0.9664  
Epoch 21

-----  
Training loss: 0.00015057622482329773  
Training accuracy: 1.0  
Testing loss: 0.14779301582142781  
Testing accuracy: 0.9688  
Testing loss: 0.19647532915269267  
Testing accuracy: 0.9664  
Epoch 22

-----  
Training loss: 0.00014060172480422152  
Training accuracy: 1.0  
Testing loss: 0.14874855234073373  
Testing accuracy: 0.9684  
Testing loss: 0.19777507830429455  
Testing accuracy: 0.9664  
Epoch 23

-----  
Training loss: 0.00013193033394785905  
Training accuracy: 1.0  
Testing loss: 0.1496677039855449  
Testing accuracy: 0.9684  
Testing loss: 0.19901347640696057  
Testing accuracy: 0.9664

Epoch 24

-----  
Training loss: 0.00012431438394387638  
Training accuracy: 1.0  
Testing loss: 0.15052845337918597  
Testing accuracy: 0.9684  
Testing loss: 0.2001608211907305  
Testing accuracy: 0.9664  
Epoch 25

-----  
Training loss: 0.00011755038838626098  
Training accuracy: 1.0  
Testing loss: 0.15132414809162886  
Testing accuracy: 0.9686  
Testing loss: 0.20125604645944076  
Testing accuracy: 0.9666  
Epoch 26

-----  
Training loss: 0.00011151892528227216  
Training accuracy: 1.0  
Testing loss: 0.15209687712178455  
Testing accuracy: 0.9684  
Testing loss: 0.20229246669870382  
Testing accuracy: 0.9666  
Epoch 27

-----  
Training loss: 0.0001060922429137215  
Training accuracy: 1.0  
Testing loss: 0.15281630871892185  
Testing accuracy: 0.9684  
Testing loss: 0.20327581271140055  
Testing accuracy: 0.9666  
Epoch 28

-----  
Training loss: 0.00010117723806047767  
Training accuracy: 1.0  
Testing loss: 0.15350458467351283  
Testing accuracy: 0.9684  
Testing loss: 0.20419994857589835  
Testing accuracy: 0.9666  
Epoch 29

-----  
Training loss: 9.67202695814285e-05  
Training accuracy: 1.0  
Testing loss: 0.15414924091571824  
Testing accuracy: 0.9684  
Testing loss: 0.20509242457324423  
Testing accuracy: 0.9666

Epoch 30

-----  
Training loss: 9.262290491932588e-05  
Training accuracy: 1.0  
Testing loss: 0.15476723831041844  
Testing accuracy: 0.9684  
Testing loss: 0.20592660354562445  
Testing accuracy: 0.9666  
Epoch 31

-----  
Training loss: 8.888859045473618e-05  
Training accuracy: 1.0  
Testing loss: 0.15536603212070044  
Testing accuracy: 0.968  
Testing loss: 0.20674117621180257  
Testing accuracy: 0.9666  
Epoch 32

-----  
Training loss: 8.543932995806661e-05  
Training accuracy: 1.0  
Testing loss: 0.15594383231467088  
Testing accuracy: 0.968  
Testing loss: 0.20750927490854923  
Testing accuracy: 0.9666  
Epoch 33

-----  
Training loss: 8.225125052537559e-05  
Training accuracy: 1.0  
Testing loss: 0.15649518750443864  
Testing accuracy: 0.9682  
Testing loss: 0.20826037030323183  
Testing accuracy: 0.9666  
Epoch 34

-----  
Training loss: 7.928725950853908e-05  
Training accuracy: 1.0  
Testing loss: 0.15703192685365522  
Testing accuracy: 0.9682  
Testing loss: 0.2089823263670201  
Testing accuracy: 0.9666  
Epoch 35

-----  
Training loss: 7.654553795591952e-05  
Training accuracy: 1.0  
Testing loss: 0.15755230010985707  
Testing accuracy: 0.9682  
Testing loss: 0.20966416030284626  
Testing accuracy: 0.9666

Epoch 36

-----  
Training loss: 7.397328022674409e-05  
Training accuracy: 1.0  
Testing loss: 0.15806001670647027  
Testing accuracy: 0.9682  
Testing loss: 0.2103239716667033  
Testing accuracy: 0.9666  
Epoch 37

-----  
Training loss: 7.157186987070255e-05  
Training accuracy: 1.0  
Testing loss: 0.15853463533550965  
Testing accuracy: 0.9682  
Testing loss: 0.21096080446945542  
Testing accuracy: 0.9666  
Epoch 38

-----  
Training loss: 6.932697741318517e-05  
Training accuracy: 1.0  
Testing loss: 0.15900197097420388  
Testing accuracy: 0.9682  
Testing loss: 0.21157723029536687  
Testing accuracy: 0.9668  
Epoch 39

-----  
Training loss: 6.721676930241069e-05  
Training accuracy: 1.0  
Testing loss: 0.1594531558918731  
Testing accuracy: 0.9682  
Testing loss: 0.21217294705748127  
Testing accuracy: 0.9668  
Epoch 40

-----  
Training loss: 6.523022955417046e-05  
Training accuracy: 1.0  
Testing loss: 0.15988263838111993  
Testing accuracy: 0.9682  
Testing loss: 0.2127455186612283  
Testing accuracy: 0.9672  
Epoch 41

-----  
Training loss: 6.33576429032418e-05  
Training accuracy: 1.0  
Testing loss: 0.1603085947957686  
Testing accuracy: 0.9682  
Testing loss: 0.213296974912725  
Testing accuracy: 0.9672



Epoch 42

-----  
Training loss: 6.159580832389718e-05  
Training accuracy: 1.0  
Testing loss: 0.16072023814746206  
Testing accuracy: 0.9682  
Testing loss: 0.2138361710054296  
Testing accuracy: 0.9672  
Epoch 43

-----  
Training loss: 5.9926393714046135e-05  
Training accuracy: 1.0  
Testing loss: 0.1611179590374601  
Testing accuracy: 0.9682  
Testing loss: 0.21435399509921818  
Testing accuracy: 0.9672  
Epoch 44

-----  
Training loss: 5.834221055612936e-05  
Training accuracy: 1.0  
Testing loss: 0.1615053214562319  
Testing accuracy: 0.9682  
Testing loss: 0.2148714879479307  
Testing accuracy: 0.9672  
Epoch 45

-----  
Training loss: 5.684660244083521e-05  
Training accuracy: 1.0  
Testing loss: 0.16188717153834267  
Testing accuracy: 0.9682  
Testing loss: 0.2153645940533965  
Testing accuracy: 0.9672  
Epoch 46

-----  
Training loss: 5.542110338884191e-05  
Training accuracy: 1.0  
Testing loss: 0.16225692091478552  
Testing accuracy: 0.9682  
Testing loss: 0.21585832392357238  
Testing accuracy: 0.9672  
Epoch 47

-----  
Training loss: 5.4067912803614605e-05  
Training accuracy: 1.0  
Testing loss: 0.16261649151268137  
Testing accuracy: 0.9682  
Testing loss: 0.2163292670485616  
Testing accuracy: 0.9672

Epoch 48

-----  
Training loss: 5.2776224779070104e-05  
Training accuracy: 1.0  
Testing loss: 0.16295925003431844  
Testing accuracy: 0.9682  
Testing loss: 0.21679535093325053  
Testing accuracy: 0.9672  
Epoch 49

-----  
Training loss: 5.154512107881428e-05  
Training accuracy: 1.0  
Testing loss: 0.16329966879866162  
Testing accuracy: 0.9684  
Testing loss: 0.2172467748508345  
Testing accuracy: 0.9672  
Epoch 50

-----  
Training loss: 5.036654532644276e-05  
Training accuracy: 1.0  
Testing loss: 0.16363845806346497  
Testing accuracy: 0.9684  
Testing loss: 0.21769364431872887  
Testing accuracy: 0.9672  
Epoch 51

-----  
Training loss: 4.92461303193444e-05  
Training accuracy: 1.0  
Testing loss: 0.16396575627907375  
Testing accuracy: 0.9684  
Testing loss: 0.21812487961735832  
Testing accuracy: 0.9672  
Epoch 52

-----  
Training loss: 4.816984592951746e-05  
Training accuracy: 1.0  
Testing loss: 0.16428432169101664  
Testing accuracy: 0.9684  
Testing loss: 0.21855033388010034  
Testing accuracy: 0.9672  
Epoch 53

-----  
Training loss: 4.713966324958718e-05  
Training accuracy: 1.0  
Testing loss: 0.1646070938038572  
Testing accuracy: 0.9684  
Testing loss: 0.21896771509530927  
Testing accuracy: 0.9672

Epoch 54

-----  
Training loss: 4.615103050958363e-05  
Training accuracy: 1.0  
Testing loss: 0.1649093725060708  
Testing accuracy: 0.9684  
Testing loss: 0.21937223264582786  
Testing accuracy: 0.9672  
Epoch 55

-----  
Training loss: 4.520816725423044e-05  
Training accuracy: 1.0  
Testing loss: 0.16521003655337743  
Testing accuracy: 0.9684  
Testing loss: 0.21976121754682426  
Testing accuracy: 0.9672  
Epoch 56

-----  
Training loss: 4.429338538017392e-05  
Training accuracy: 1.0  
Testing loss: 0.165511518508113  
Testing accuracy: 0.9684  
Testing loss: 0.2201551281891117  
Testing accuracy: 0.9672  
Epoch 57

-----  
Training loss: 4.342137881850921e-05  
Training accuracy: 1.0  
Testing loss: 0.16580139922877046  
Testing accuracy: 0.9682  
Testing loss: 0.22053389857044287  
Testing accuracy: 0.9672  
Epoch 58

-----  
Training loss: 4.2580963713410643e-05  
Training accuracy: 1.0  
Testing loss: 0.16608219243116906  
Testing accuracy: 0.968  
Testing loss: 0.220911638944829  
Testing accuracy: 0.9672  
Epoch 59

-----  
Training loss: 4.1770798234439195e-05  
Training accuracy: 1.0  
Testing loss: 0.1663621183684404  
Testing accuracy: 0.968  
Testing loss: 0.22127722918964815  
Testing accuracy: 0.9672

Epoch 60

-----  
Training loss: 4.09913908954615e-05  
Training accuracy: 1.0  
Testing loss: 0.16663985603680695  
Testing accuracy: 0.9678  
Testing loss: 0.2216344808816827  
Testing accuracy: 0.9672  
Epoch 61

-----  
Training loss: 4.0239164191008566e-05  
Training accuracy: 1.0  
Testing loss: 0.16690268589982626  
Testing accuracy: 0.9678  
Testing loss: 0.22199374302648595  
Testing accuracy: 0.9672  
Epoch 62

-----  
Training loss: 3.951447430825306e-05  
Training accuracy: 1.0  
Testing loss: 0.1671708168598863  
Testing accuracy: 0.9678  
Testing loss: 0.22233204264459913  
Testing accuracy: 0.9672  
Epoch 63

-----  
Training loss: 3.881203698218583e-05  
Training accuracy: 1.0  
Testing loss: 0.16742637992655565  
Testing accuracy: 0.9678  
Testing loss: 0.22267603549934228  
Testing accuracy: 0.9672  
Epoch 64

-----  
Training loss: 3.813729026305439e-05  
Training accuracy: 1.0  
Testing loss: 0.1676821998485577  
Testing accuracy: 0.9678  
Testing loss: 0.22300614369762306  
Testing accuracy: 0.9672  
Epoch 65

-----  
Training loss: 3.7485234250045316e-05  
Training accuracy: 1.0  
Testing loss: 0.16793427737370964  
Testing accuracy: 0.9678  
Testing loss: 0.2233312619092724  
Testing accuracy: 0.9674

Epoch 66

-----  
Training loss: 3.68540256002849e-05  
Training accuracy: 1.0  
Testing loss: 0.16817741059260083  
Testing accuracy: 0.9678  
Testing loss: 0.2236483620804474  
Testing accuracy: 0.9674  
Epoch 67

-----  
Training loss: 3.6241530356434294e-05  
Training accuracy: 1.0  
Testing loss: 0.1684204872821171  
Testing accuracy: 0.9676  
Testing loss: 0.22396723825916065  
Testing accuracy: 0.9674  
Epoch 68

-----  
Training loss: 3.5651350580451694e-05  
Training accuracy: 1.0  
Testing loss: 0.16865521079959866  
Testing accuracy: 0.9676  
Testing loss: 0.22427965022045737  
Testing accuracy: 0.9676  
Epoch 69

-----  
Training loss: 3.507929426643345e-05  
Training accuracy: 1.0  
Testing loss: 0.16888956186619083  
Testing accuracy: 0.9676  
Testing loss: 0.22458697222256374  
Testing accuracy: 0.9676  
Epoch 70

-----  
Training loss: 3.452419475569359e-05  
Training accuracy: 1.0  
Testing loss: 0.1691212194930349  
Testing accuracy: 0.9676  
Testing loss: 0.22488767195280565  
Testing accuracy: 0.9676  
Epoch 71

-----  
Training loss: 3.398587778558341e-05  
Training accuracy: 1.0  
Testing loss: 0.16934974868049496  
Testing accuracy: 0.9676  
Testing loss: 0.2251849762619956  
Testing accuracy: 0.9676

Epoch 72

-----  
Training loss: 3.346475127186176e-05  
Training accuracy: 1.0  
Testing loss: 0.16957380376598438  
Testing accuracy: 0.9674  
Testing loss: 0.22548127325679865  
Testing accuracy: 0.9676  
Epoch 73

-----  
Training loss: 3.2959096969246e-05  
Training accuracy: 1.0  
Testing loss: 0.16978723351740438  
Testing accuracy: 0.9674  
Testing loss: 0.22576991789877984  
Testing accuracy: 0.9676  
Epoch 74

-----  
Training loss: 3.246669236639747e-05  
Training accuracy: 1.0  
Testing loss: 0.17000630551625157  
Testing accuracy: 0.9674  
Testing loss: 0.22605795159703393  
Testing accuracy: 0.9676  
Epoch 75

-----  
Training loss: 3.1991689552141304e-05  
Training accuracy: 1.0  
Testing loss: 0.17021917229067982  
Testing accuracy: 0.9674  
Testing loss: 0.2263340085433127  
Testing accuracy: 0.9676  
Epoch 76

-----  
Training loss: 3.152711908392233e-05  
Training accuracy: 1.0  
Testing loss: 0.17042892271271978  
Testing accuracy: 0.9674  
Testing loss: 0.22661072905369184  
Testing accuracy: 0.9674  
Epoch 77

-----  
Training loss: 3.1077407735573455e-05  
Training accuracy: 1.0  
Testing loss: 0.1706352875822266  
Testing accuracy: 0.9674  
Testing loss: 0.22688557843045998  
Testing accuracy: 0.9674

Epoch 78

-----  
Training loss: 3.063891572814387e-05  
Training accuracy: 1.0  
Testing loss: 0.1708356686987826  
Testing accuracy: 0.9674  
Testing loss: 0.227150684326487  
Testing accuracy: 0.9674  
Epoch 79

-----  
Training loss: 3.0213338348364917e-05  
Training accuracy: 1.0  
Testing loss: 0.17103695658317378  
Testing accuracy: 0.9674  
Testing loss: 0.22741733547388576  
Testing accuracy: 0.9674  
Epoch 80

-----  
Training loss: 2.9798886418778214e-05  
Training accuracy: 1.0  
Testing loss: 0.1712331795140769  
Testing accuracy: 0.9674  
Testing loss: 0.2276756245239525  
Testing accuracy: 0.9674  
Epoch 81

-----  
Training loss: 2.9393818915308172e-05  
Training accuracy: 1.0  
Testing loss: 0.17142976977120838  
Testing accuracy: 0.9674  
Testing loss: 0.22793051857475372  
Testing accuracy: 0.9674  
Epoch 82

-----  
Training loss: 2.9000829400522376e-05  
Training accuracy: 1.0  
Testing loss: 0.17162598244344265  
Testing accuracy: 0.9674  
Testing loss: 0.22818582656990571  
Testing accuracy: 0.9674  
Epoch 83

-----  
Training loss: 2.861819737640637e-05  
Training accuracy: 1.0  
Testing loss: 0.17181758106188172  
Testing accuracy: 0.9674  
Testing loss: 0.22843518110799135  
Testing accuracy: 0.9674

Epoch 84

-----  
Training loss: 2.824475279748603e-05  
Training accuracy: 1.0  
Testing loss: 0.17200779853879256  
Testing accuracy: 0.9674  
Testing loss: 0.2286781829048928  
Testing accuracy: 0.9674  
Epoch 85

-----  
Training loss: 2.788124043929972e-05  
Training accuracy: 1.0  
Testing loss: 0.1721895220313306  
Testing accuracy: 0.9674  
Testing loss: 0.2289228823675066  
Testing accuracy: 0.9674  
Epoch 86

-----  
Training loss: 2.7525875214215474e-05  
Training accuracy: 1.0  
Testing loss: 0.17237566107629998  
Testing accuracy: 0.9674  
Testing loss: 0.22916382132344265  
Testing accuracy: 0.9674  
Epoch 87

-----  
Training loss: 2.7180742060162193e-05  
Training accuracy: 1.0  
Testing loss: 0.17255711375532368  
Testing accuracy: 0.9674  
Testing loss: 0.22939848134903887  
Testing accuracy: 0.9674  
Epoch 88

-----  
Training loss: 2.6843529963207762e-05  
Training accuracy: 1.0  
Testing loss: 0.1727361298241824  
Testing accuracy: 0.9674  
Testing loss: 0.22963280345888928  
Testing accuracy: 0.9674  
Epoch 89

-----  
Training loss: 2.65131742727297e-05  
Training accuracy: 1.0  
Testing loss: 0.17290895586147925  
Testing accuracy: 0.9674  
Testing loss: 0.2298625475285185  
Testing accuracy: 0.9672



Epoch 90

-----  
Training loss: 2.619157273868357e-05  
Training accuracy: 1.0  
Testing loss: 0.17308704042217932  
Testing accuracy: 0.9674  
Testing loss: 0.2300924697489353  
Testing accuracy: 0.9672  
Epoch 91

-----  
Training loss: 2.5877567567896076e-05  
Training accuracy: 1.0  
Testing loss: 0.17325614205679285  
Testing accuracy: 0.9674  
Testing loss: 0.23031858333613778  
Testing accuracy: 0.9672  
Epoch 92

-----  
Training loss: 2.557102569665586e-05  
Training accuracy: 1.0  
Testing loss: 0.17342911525853294  
Testing accuracy: 0.9674  
Testing loss: 0.23054090971406654  
Testing accuracy: 0.9672  
Epoch 93

-----  
Training loss: 2.5270506152163775e-05  
Training accuracy: 1.0  
Testing loss: 0.17359010205492972  
Testing accuracy: 0.9674  
Testing loss: 0.23076553981088677  
Testing accuracy: 0.9672  
Epoch 94

-----  
Training loss: 2.4976571505317303e-05  
Training accuracy: 1.0  
Testing loss: 0.17376119799356593  
Testing accuracy: 0.9674  
Testing loss: 0.2309831788122014  
Testing accuracy: 0.9672  
Epoch 95

-----  
Training loss: 2.469017729480585e-05  
Training accuracy: 1.0  
Testing loss: 0.17392747402376618  
Testing accuracy: 0.9674  
Testing loss: 0.2312002908659726  
Testing accuracy: 0.9672

Epoch 96

-----  
Training loss: 2.440981129579423e-05  
Training accuracy: 1.0  
Testing loss: 0.17408827099539106  
Testing accuracy: 0.9674  
Testing loss: 0.23141328591118376  
Testing accuracy: 0.9672  
Epoch 97

-----  
Training loss: 2.413507817025525e-05  
Training accuracy: 1.0  
Testing loss: 0.17425027684438815  
Testing accuracy: 0.9674  
Testing loss: 0.23162957275079388  
Testing accuracy: 0.9672  
Epoch 98

-----  
Training loss: 2.3866599546929825e-05  
Training accuracy: 1.0  
Testing loss: 0.17440772290955786  
Testing accuracy: 0.9674  
Testing loss: 0.23184147913404446  
Testing accuracy: 0.9672  
Epoch 99

-----  
Training loss: 2.3603726151297245e-05  
Training accuracy: 1.0  
Testing loss: 0.17456722691638643  
Testing accuracy: 0.9672  
Testing loss: 0.23204806341872636  
Testing accuracy: 0.9672  
Epoch 100

-----  
Training loss: 2.334641493583456e-05  
Training accuracy: 1.0  
Testing loss: 0.1747227435306043  
Testing accuracy: 0.9672  
Testing loss: 0.23225387352787316  
Testing accuracy: 0.9672  
Epoch 101

-----  
Training loss: 2.3094284484944966e-05  
Training accuracy: 1.0  
Testing loss: 0.17487928340630932  
Testing accuracy: 0.9672  
Testing loss: 0.23245801018320222  
Testing accuracy: 0.9672

Epoch 102

-----  
Training loss: 2.2847742276575644e-05  
Training accuracy: 1.0  
Testing loss: 0.17503186371183727  
Testing accuracy: 0.9672  
Testing loss: 0.23266001171626158  
Testing accuracy: 0.9672  
Epoch 103

-----  
Training loss: 2.2605827001912784e-05  
Training accuracy: 1.0  
Testing loss: 0.17518383708201193  
Testing accuracy: 0.9672  
Testing loss: 0.23285929547698414  
Testing accuracy: 0.9672  
Epoch 104

-----  
Training loss: 2.236918109743882e-05  
Training accuracy: 1.0  
Testing loss: 0.1753318174448075  
Testing accuracy: 0.9672  
Testing loss: 0.23306135827772556  
Testing accuracy: 0.967  
Epoch 105

-----  
Training loss: 2.2137391249441924e-05  
Training accuracy: 1.0  
Testing loss: 0.17547996636953045  
Testing accuracy: 0.9672  
Testing loss: 0.23325511300674817  
Testing accuracy: 0.967  
Epoch 106

-----  
Training loss: 2.190934841780291e-05  
Training accuracy: 1.0  
Testing loss: 0.17562622394168206  
Testing accuracy: 0.9672  
Testing loss: 0.23345158189890416  
Testing accuracy: 0.967  
Epoch 107

-----  
Training loss: 2.1686906527109918e-05  
Training accuracy: 1.0  
Testing loss: 0.1757756345248561  
Testing accuracy: 0.9672  
Testing loss: 0.23364353807212765  
Testing accuracy: 0.967

Epoch 108

-----  
Training loss: 2.1468371308858357e-05  
Training accuracy: 1.0  
Testing loss: 0.1759159192346929  
Testing accuracy: 0.9672  
Testing loss: 0.2338344901666891  
Testing accuracy: 0.967  
Epoch 109

-----  
Training loss: 2.1254094739100015e-05  
Training accuracy: 1.0  
Testing loss: 0.17605780997445505  
Testing accuracy: 0.9672  
Testing loss: 0.23402547584655312  
Testing accuracy: 0.967  
Epoch 110

-----  
Training loss: 2.104362327176958e-05  
Training accuracy: 1.0  
Testing loss: 0.17619595979214306  
Testing accuracy: 0.9672  
Testing loss: 0.23421251536710858  
Testing accuracy: 0.967  
Epoch 111

-----  
Training loss: 2.0837905449215985e-05  
Training accuracy: 1.0  
Testing loss: 0.17633743437531385  
Testing accuracy: 0.9672  
Testing loss: 0.23439881479155855  
Testing accuracy: 0.967  
Epoch 112

-----  
Training loss: 2.0635699029528246e-05  
Training accuracy: 1.0  
Testing loss: 0.17647285813514374  
Testing accuracy: 0.9672  
Testing loss: 0.23458445526516306  
Testing accuracy: 0.967  
Epoch 113

-----  
Training loss: 2.0436969786838354e-05  
Training accuracy: 1.0  
Testing loss: 0.17661221727132878  
Testing accuracy: 0.9672  
Testing loss: 0.23476539025191356  
Testing accuracy: 0.967

Epoch 114

-----  
Training loss: 2.0242463755544007e-05  
Training accuracy: 1.0  
Testing loss: 0.17674851159836782  
Testing accuracy: 0.9672  
Testing loss: 0.23494583125802193  
Testing accuracy: 0.967  
Epoch 115

-----  
Training loss: 2.0051311210021795e-05  
Training accuracy: 1.0  
Testing loss: 0.1768826952964345  
Testing accuracy: 0.9672  
Testing loss: 0.23512479246724788  
Testing accuracy: 0.967  
Epoch 116

-----  
Training loss: 1.9863705555377726e-05  
Training accuracy: 1.0  
Testing loss: 0.17701447472690737  
Testing accuracy: 0.9672  
Testing loss: 0.23530181519571752  
Testing accuracy: 0.967  
Epoch 117

-----  
Training loss: 1.9678705274387808e-05  
Training accuracy: 1.0  
Testing loss: 0.1771490227125156  
Testing accuracy: 0.9672  
Testing loss: 0.23547648950257458  
Testing accuracy: 0.967  
Epoch 118

-----  
Training loss: 1.9497845382449282e-05  
Training accuracy: 1.0  
Testing loss: 0.17728068970279603  
Testing accuracy: 0.9672  
Testing loss: 0.23565254856150167  
Testing accuracy: 0.967  
Epoch 119

-----  
Training loss: 1.9320085219303847e-05  
Training accuracy: 1.0  
Testing loss: 0.17741397257852967  
Testing accuracy: 0.9672  
Testing loss: 0.2358251958615467  
Testing accuracy: 0.967

Epoch 120

-----  
Training loss: 1.914545156859871e-05  
Training accuracy: 1.0  
Testing loss: 0.17754571348690434  
Testing accuracy: 0.9672  
Testing loss: 0.23599550675423775  
Testing accuracy: 0.967  
Epoch 121

-----  
Training loss: 1.8973432513403997e-05  
Training accuracy: 1.0  
Testing loss: 0.1776751309616012  
Testing accuracy: 0.9672  
Testing loss: 0.23616751633328809  
Testing accuracy: 0.967  
Epoch 122

-----  
Training loss: 1.8805009058985706e-05  
Training accuracy: 1.0  
Testing loss: 0.1778027218163401  
Testing accuracy: 0.9672  
Testing loss: 0.2363349419691363  
Testing accuracy: 0.967  
Epoch 123

-----  
Training loss: 1.863874620321145e-05  
Training accuracy: 1.0  
Testing loss: 0.1779311119329436  
Testing accuracy: 0.9672  
Testing loss: 0.2365036572658812  
Testing accuracy: 0.967  
Epoch 124

-----  
Training loss: 1.847534474354494e-05  
Training accuracy: 1.0  
Testing loss: 0.17805676358539269  
Testing accuracy: 0.9672  
Testing loss: 0.236669073690309  
Testing accuracy: 0.967  
Epoch 125

-----  
Training loss: 1.8315063693125166e-05  
Training accuracy: 1.0  
Testing loss: 0.17818047772638926  
Testing accuracy: 0.9672  
Testing loss: 0.23683525761661853  
Testing accuracy: 0.967

Epoch 126

-----  
Training loss: 1.8156859640497973e-05  
Training accuracy: 1.0  
Testing loss: 0.17830570017542996  
Testing accuracy: 0.9672  
Testing loss: 0.23700128317538557  
Testing accuracy: 0.967  
Epoch 127

-----  
Training loss: 1.800240464388534e-05  
Training accuracy: 1.0  
Testing loss: 0.17842963641045861  
Testing accuracy: 0.9672  
Testing loss: 0.23716006719333085  
Testing accuracy: 0.967  
Epoch 128

-----  
Training loss: 1.7849257642004683e-05  
Training accuracy: 1.0  
Testing loss: 0.17855139648693605  
Testing accuracy: 0.9672  
Testing loss: 0.2373220489360587  
Testing accuracy: 0.967  
Epoch 129

-----  
Training loss: 1.769940078448064e-05  
Training accuracy: 1.0  
Testing loss: 0.17867216035872946  
Testing accuracy: 0.9672  
Testing loss: 0.23748215979639276  
Testing accuracy: 0.967  
Epoch 130

-----  
Training loss: 1.755158516761425e-05  
Training accuracy: 1.0  
Testing loss: 0.17879267744307606  
Testing accuracy: 0.9672  
Testing loss: 0.23764201841538224  
Testing accuracy: 0.967  
Epoch 131

-----  
Training loss: 1.740662216678836e-05  
Training accuracy: 1.0  
Testing loss: 0.17890946286342652  
Testing accuracy: 0.9672  
Testing loss: 0.2377988699121031  
Testing accuracy: 0.967

Epoch 132

-----  
Training loss: 1.7262902189966884e-05  
Training accuracy: 1.0  
Testing loss: 0.17903296785184664  
Testing accuracy: 0.9672  
Testing loss: 0.23795503523681122  
Testing accuracy: 0.967  
Epoch 133

-----  
Training loss: 1.7122623325117202e-05  
Training accuracy: 1.0  
Testing loss: 0.1791478401654783  
Testing accuracy: 0.9672  
Testing loss: 0.23811274958748668  
Testing accuracy: 0.967  
Epoch 134

-----  
Training loss: 1.6983479159963714e-05  
Training accuracy: 1.0  
Testing loss: 0.17926444521089918  
Testing accuracy: 0.9672  
Testing loss: 0.23826722340282053  
Testing accuracy: 0.967  
Epoch 135

-----  
Training loss: 1.684725142762004e-05  
Training accuracy: 1.0  
Testing loss: 0.17938204863471513  
Testing accuracy: 0.9672  
Testing loss: 0.23842002379731517  
Testing accuracy: 0.967  
Epoch 136

-----  
Training loss: 1.6712809673011897e-05  
Training accuracy: 1.0  
Testing loss: 0.1794944929328928  
Testing accuracy: 0.967  
Testing loss: 0.23857256969971913  
Testing accuracy: 0.9672  
Epoch 137

-----  
Training loss: 1.6580088975331426e-05  
Training accuracy: 1.0  
Testing loss: 0.179607409242706  
Testing accuracy: 0.967  
Testing loss: 0.23872476737156217  
Testing accuracy: 0.9672



Epoch 138

-----  
Training loss: 1.645023303804245e-05  
Training accuracy: 1.0  
Testing loss: 0.17972349863122628  
Testing accuracy: 0.967  
Testing loss: 0.23887153847404674  
Testing accuracy: 0.9672  
Epoch 139

-----  
Training loss: 1.632163879970196e-05  
Training accuracy: 1.0  
Testing loss: 0.17983239542877397  
Testing accuracy: 0.967  
Testing loss: 0.23902178438267765  
Testing accuracy: 0.9672  
Epoch 140

-----  
Training loss: 1.6195538208942833e-05  
Training accuracy: 1.0  
Testing loss: 0.17994668607617273  
Testing accuracy: 0.967  
Testing loss: 0.23916780592574774  
Testing accuracy: 0.9672  
Epoch 141

-----  
Training loss: 1.6070939623326768e-05  
Training accuracy: 1.0  
Testing loss: 0.18005655282661406  
Testing accuracy: 0.967  
Testing loss: 0.23931565838298358  
Testing accuracy: 0.9672  
Epoch 142

-----  
Training loss: 1.59478522506003e-05  
Training accuracy: 1.0  
Testing loss: 0.18016662077145504  
Testing accuracy: 0.967  
Testing loss: 0.23945945721353737  
Testing accuracy: 0.9672  
Epoch 143

-----  
Training loss: 1.582747662189864e-05  
Training accuracy: 1.0  
Testing loss: 0.18027521902266078  
Testing accuracy: 0.967  
Testing loss: 0.23960442609247415  
Testing accuracy: 0.9672

Epoch 144

-----  
Training loss: 1.570827952939227e-05  
Training accuracy: 1.0  
Testing loss: 0.1803820623357023  
Testing accuracy: 0.967  
Testing loss: 0.2397486297368464  
Testing accuracy: 0.9672  
Epoch 145

-----  
Training loss: 1.5590773741985608e-05  
Training accuracy: 1.0  
Testing loss: 0.1804893900050439  
Testing accuracy: 0.967  
Testing loss: 0.23989062804890524  
Testing accuracy: 0.9672  
Epoch 146

-----  
Training loss: 1.5475428167408745e-05  
Training accuracy: 1.0  
Testing loss: 0.1805976394316588  
Testing accuracy: 0.967  
Testing loss: 0.24003342197149435  
Testing accuracy: 0.9672  
Epoch 147

-----  
Training loss: 1.53610136838124e-05  
Training accuracy: 1.0  
Testing loss: 0.18070404703363313  
Testing accuracy: 0.967  
Testing loss: 0.24017114964771719  
Testing accuracy: 0.9672  
Epoch 148

-----  
Training loss: 1.5248874900468967e-05  
Training accuracy: 1.0  
Testing loss: 0.18080850287314137  
Testing accuracy: 0.967  
Testing loss: 0.2403113443433458  
Testing accuracy: 0.9672  
Epoch 149

-----  
Training loss: 1.5137907471586151e-05  
Training accuracy: 1.0  
Testing loss: 0.18091068604196295  
Testing accuracy: 0.967  
Testing loss: 0.24045094027556974  
Testing accuracy: 0.9672

Epoch 150

-----  
Training loss: 1.5028482560705822e-05

Training accuracy: 1.0

Testing loss: 0.18101246743341018

Testing accuracy: 0.967

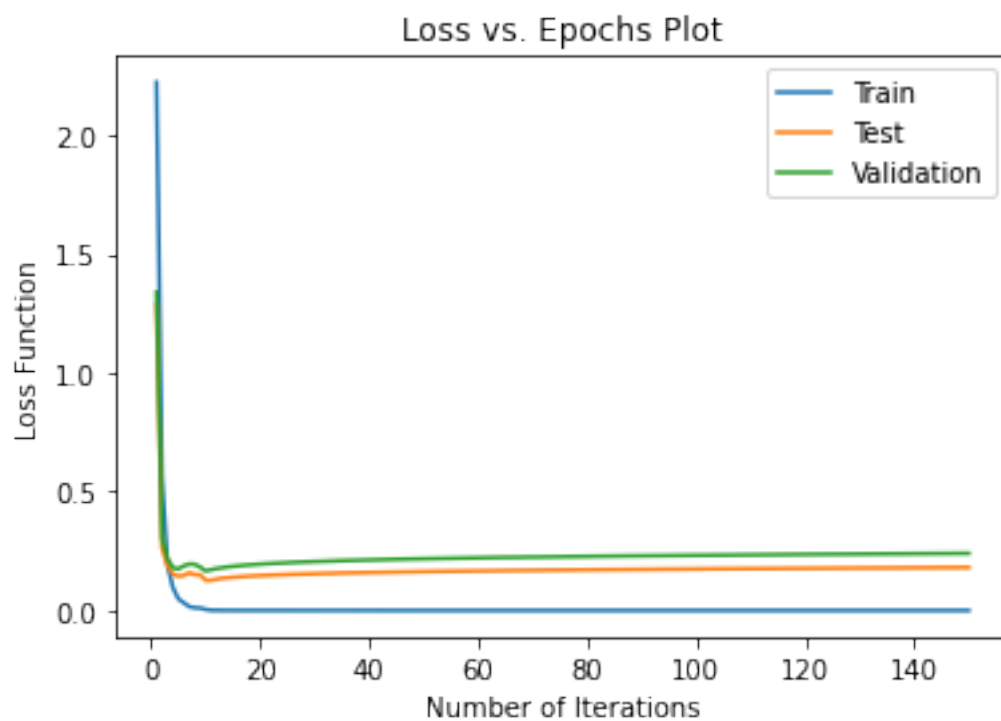
Testing loss: 0.2405865225491379

Testing accuracy: 0.9672

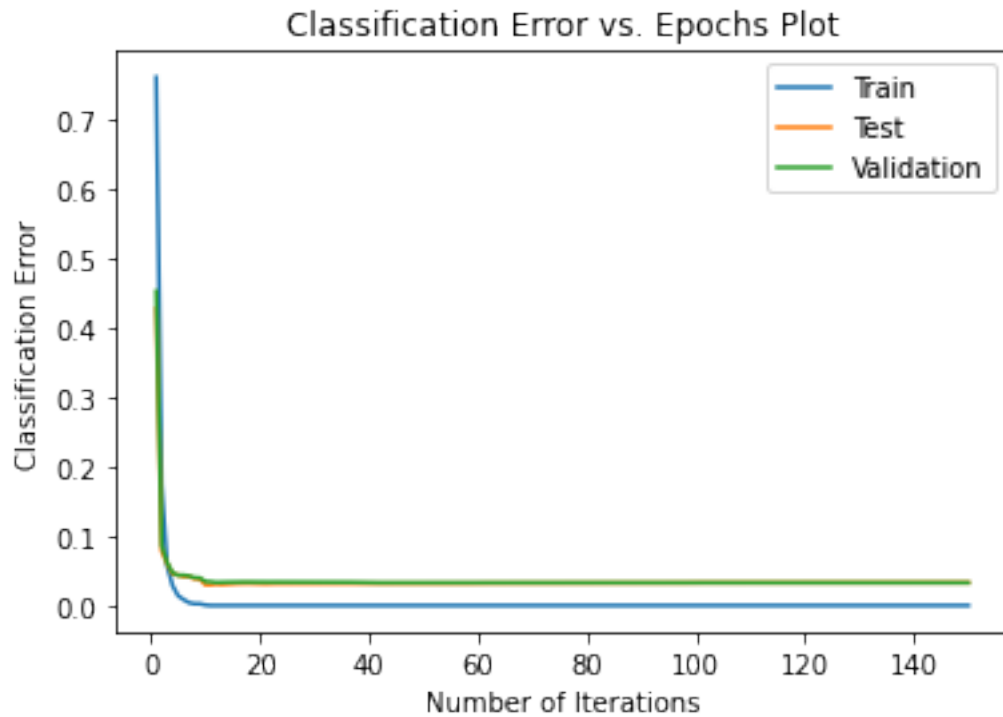
Done

Total Time Consumed: 7793.675707101822

```
[68]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```

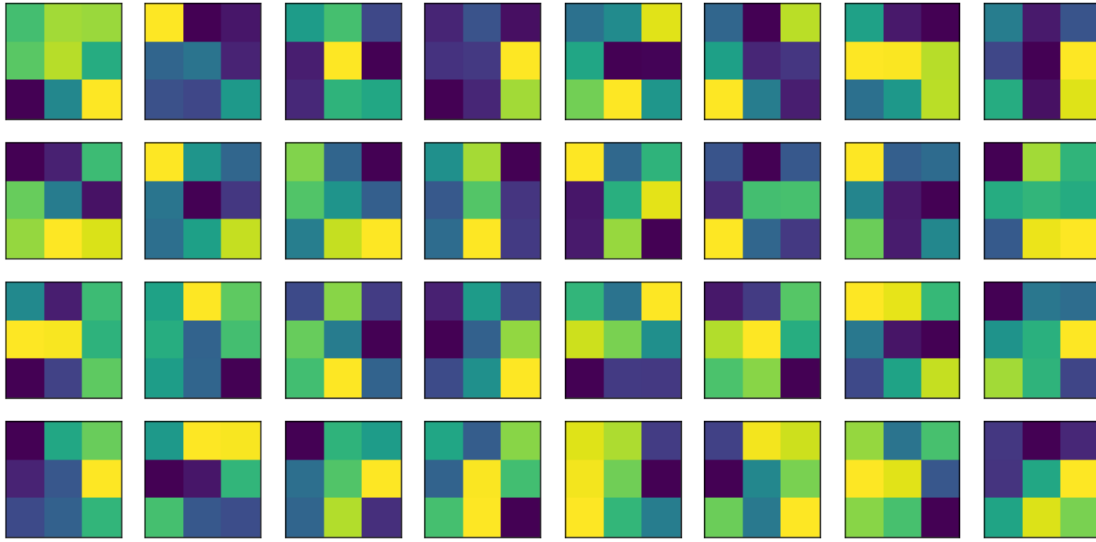


```
[69]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



#### 6.4.2 Weight Visualization

```
[75]: # Visualize the Weights from First Convolutional Network
weights = CNN_1.state_dict()['conv1.0.weight']
plt.figure(figsize = (12,6))
for i in range(len(weights)):
    plt.subplot(4,8,i+1)
    plt.imshow(weights[i].reshape(3,3))
    plt.xticks([])
    plt.yticks([])
```



### 6.4.3 Learning Rate = 0.01

```
[77]: # Define HyperParameters
# Number of Classes = 19
num_classes = 19
learning_rate = 0.01
batch_size = 64
num_epochs = 150
CNN_01 = CNN1(num_classes).double()

# Batch Datal
train_loader = DataLoader(X_train, batch_size = batch_size)
train_loader_y = DataLoader(Y_train.type(torch.LongTensor), batch_size = ↵
↪batch_size)
test_loader = DataLoader(X_test, batch_size = batch_size)
test_loader_y = DataLoader(Y_test.type(torch.LongTensor), batch_size = ↵
↪batch_size)
val_loader = DataLoader(X_val, batch_size = batch_size)
val_loader_y = DataLoader(Y_val.type(torch.LongTensor), batch_size = batch_size)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_01.parameters(), lr = learning_rate)

[78]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
```

```

for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.
    →append(train_loop7(train_loader,train_loader_y,CNN_01,loss,optimizer))
    test_loss_record.append(test_loop7(test_loader,test_loader_y,CNN_01,loss))
    val_loss_record.append(test_loop7(val_loader,val_loader_y,CNN_01,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))

```

Epoch 1

```

-----
Training loss: 2.7982280463455926
Training accuracy: 0.09995
Testing loss: 2.7335573703380227
Testing accuracy: 0.1116
Testing loss: 2.7489105041816377
Testing accuracy: 0.107

```

Epoch 2

```

-----
Training loss: 2.5758855677806483
Training accuracy: 0.1417
Testing loss: 2.4465241470184353
Testing accuracy: 0.1588
Testing loss: 2.491755502874469
Testing accuracy: 0.1622

```

Epoch 3

```

-----
Training loss: 2.249406127977174
Training accuracy: 0.21405
Testing loss: 2.3892735420996565
Testing accuracy: 0.1738
Testing loss: 2.4584518453663726
Testing accuracy: 0.1696

```

Epoch 4

```

-----
Training loss: 2.020702189402078
Training accuracy: 0.2914
Testing loss: 2.1791260177381404
Testing accuracy: 0.265
Testing loss: 2.251808186132121
Testing accuracy: 0.2552

```

Epoch 5

```

-----
Training loss: 1.766477831813971
Training accuracy: 0.40355
Testing loss: 1.9449788301003217
Testing accuracy: 0.3782

```

```
Testing loss: 2.0215180852290757
Testing accuracy: 0.357
Epoch 6
-----
Training loss: 1.3932739532114755
Training accuracy: 0.55255
Testing loss: 1.5226063766372266
Testing accuracy: 0.5216
Testing loss: 1.609286875817153
Testing accuracy: 0.4952
Epoch 7
-----
Training loss: 0.9553374543419102
Training accuracy: 0.7055
Testing loss: 1.0859375686171646
Testing accuracy: 0.662
Testing loss: 1.158524739811136
Testing accuracy: 0.6324
Epoch 8
-----
Training loss: 0.6363002657249259
Training accuracy: 0.81095
Testing loss: 0.7358261394638582
Testing accuracy: 0.7752
Testing loss: 0.7864096795582506
Testing accuracy: 0.7532
Epoch 9
-----
Training loss: 0.4512446539633351
Training accuracy: 0.8686
Testing loss: 0.48583130101233685
Testing accuracy: 0.8528
Testing loss: 0.5267949073554956
Testing accuracy: 0.8404
Epoch 10
-----
Training loss: 0.3441672524843716
Training accuracy: 0.89955
Testing loss: 0.3893409704475899
Testing accuracy: 0.8794
Testing loss: 0.4324371691642144
Testing accuracy: 0.864
Epoch 11
-----
Training loss: 0.2762881377115034
Training accuracy: 0.9189
Testing loss: 0.34777007977187896
Testing accuracy: 0.8894
```

Testing loss: 0.38980511267042073  
Testing accuracy: 0.8748  
Epoch 12

-----  
Training loss: 0.22947563384229291  
Training accuracy: 0.93465  
Testing loss: 0.3147495374962549  
Testing accuracy: 0.9026  
Testing loss: 0.354245835902391  
Testing accuracy: 0.8876  
Epoch 13

-----  
Training loss: 0.1947896078786307  
Training accuracy: 0.945  
Testing loss: 0.2897280327299635  
Testing accuracy: 0.9116  
Testing loss: 0.32531350583194074  
Testing accuracy: 0.898  
Epoch 14

-----  
Training loss: 0.16729443745704517  
Training accuracy: 0.95365  
Testing loss: 0.26755124525152635  
Testing accuracy: 0.9168  
Testing loss: 0.3009628858388814  
Testing accuracy: 0.9054  
Epoch 15

-----  
Training loss: 0.14494527992239975  
Training accuracy: 0.95945  
Testing loss: 0.24830634262615223  
Testing accuracy: 0.9222  
Testing loss: 0.28017126190945413  
Testing accuracy: 0.9134  
Epoch 16

-----  
Training loss: 0.1260804382936254  
Training accuracy: 0.96635  
Testing loss: 0.2313487713928491  
Testing accuracy: 0.928  
Testing loss: 0.2620455457196191  
Testing accuracy: 0.919  
Epoch 17

-----  
Training loss: 0.10974033355002939  
Training accuracy: 0.97085  
Testing loss: 0.21717357291232606  
Testing accuracy: 0.9336



```
Testing loss: 0.24788672999108663
Testing accuracy: 0.9246
Epoch 18
-----
Training loss: 0.09545606326956955
Training accuracy: 0.97585
Testing loss: 0.20645681134720958
Testing accuracy: 0.9376
Testing loss: 0.23818673099700954
Testing accuracy: 0.926
Epoch 19
-----
Training loss: 0.0829812144449609
Training accuracy: 0.97995
Testing loss: 0.2008792314559471
Testing accuracy: 0.9386
Testing loss: 0.23320879556238866
Testing accuracy: 0.928
Epoch 20
-----
Training loss: 0.07198524390506449
Training accuracy: 0.98425
Testing loss: 0.19625131679018276
Testing accuracy: 0.941
Testing loss: 0.2297418688593432
Testing accuracy: 0.9316
Epoch 21
-----
Training loss: 0.06238293583349878
Training accuracy: 0.98715
Testing loss: 0.1936197946597272
Testing accuracy: 0.9426
Testing loss: 0.2282693419667177
Testing accuracy: 0.9324
Epoch 22
-----
Training loss: 0.053869256870530555
Training accuracy: 0.98995
Testing loss: 0.19246954903781144
Testing accuracy: 0.9444
Testing loss: 0.2281478911840169
Testing accuracy: 0.9328
Epoch 23
-----
Training loss: 0.04635074701863993
Training accuracy: 0.992
Testing loss: 0.19117491055982427
Testing accuracy: 0.945
```

Testing loss: 0.22854856648458693  
Testing accuracy: 0.9332  
Epoch 24  
-----  
Training loss: 0.039863230101206994  
Training accuracy: 0.9939  
Testing loss: 0.19159218990720625  
Testing accuracy: 0.9448  
Testing loss: 0.23003176545882234  
Testing accuracy: 0.9334  
Epoch 25  
-----  
Training loss: 0.034197803954878515  
Training accuracy: 0.9954  
Testing loss: 0.19184687372016218  
Testing accuracy: 0.945  
Testing loss: 0.23199260868672514  
Testing accuracy: 0.9354  
Epoch 26  
-----  
Training loss: 0.029420402420402284  
Training accuracy: 0.997  
Testing loss: 0.19159747584346332  
Testing accuracy: 0.9446  
Testing loss: 0.2333593611996032  
Testing accuracy: 0.9352  
Epoch 27  
-----  
Training loss: 0.025396525741568907  
Training accuracy: 0.9981  
Testing loss: 0.19122178486023136  
Testing accuracy: 0.945  
Testing loss: 0.23497384970354696  
Testing accuracy: 0.935  
Epoch 28  
-----  
Training loss: 0.022027429472138205  
Training accuracy: 0.9984  
Testing loss: 0.1910163439781788  
Testing accuracy: 0.9454  
Testing loss: 0.23611794215601875  
Testing accuracy: 0.9356  
Epoch 29  
-----  
Training loss: 0.01920584119005758  
Training accuracy: 0.9989  
Testing loss: 0.19089838949361596  
Testing accuracy: 0.946

Testing loss: 0.237167365897512  
Testing accuracy: 0.9366  
Epoch 30  
-----  
Training loss: 0.016865342549368403  
Training accuracy: 0.99945  
Testing loss: 0.19057338444995958  
Testing accuracy: 0.9466  
Testing loss: 0.23780161460037139  
Testing accuracy: 0.9374  
Epoch 31  
-----  
Training loss: 0.014947379616417601  
Training accuracy: 0.99945  
Testing loss: 0.19052147634065836  
Testing accuracy: 0.9464  
Testing loss: 0.2385661086791619  
Testing accuracy: 0.9378  
Epoch 32  
-----  
Training loss: 0.013316568901471601  
Training accuracy: 0.9997  
Testing loss: 0.19050244480075906  
Testing accuracy: 0.9468  
Testing loss: 0.23930603593038377  
Testing accuracy: 0.9386  
Epoch 33  
-----  
Training loss: 0.011927706678016098  
Training accuracy: 0.99975  
Testing loss: 0.19055927933066724  
Testing accuracy: 0.947  
Testing loss: 0.24018208286760642  
Testing accuracy: 0.939  
Epoch 34  
-----  
Training loss: 0.010755288217763895  
Training accuracy: 0.99985  
Testing loss: 0.19047986602410125  
Testing accuracy: 0.9474  
Testing loss: 0.24086702253307996  
Testing accuracy: 0.9388  
Epoch 35  
-----  
Training loss: 0.009744592932783468  
Training accuracy: 0.99985  
Testing loss: 0.19069208749822586  
Testing accuracy: 0.9476

Testing loss: 0.24183801415610887

Testing accuracy: 0.939

Epoch 36

-----  
Training loss: 0.00888673799835276

Training accuracy: 0.9999

Testing loss: 0.19071339954559025

Testing accuracy: 0.9484

Testing loss: 0.2426719015529634

Testing accuracy: 0.9392

Epoch 37

-----  
Training loss: 0.008135382698629885

Training accuracy: 0.9999

Testing loss: 0.19084092900339955

Testing accuracy: 0.9488

Testing loss: 0.24342459217958645

Testing accuracy: 0.9394

Epoch 38

-----  
Training loss: 0.0074889980478408035

Training accuracy: 0.9999

Testing loss: 0.1911138773508868

Testing accuracy: 0.9504

Testing loss: 0.2443930691527123

Testing accuracy: 0.9398

Epoch 39

-----  
Training loss: 0.00692159305788677

Training accuracy: 0.9999

Testing loss: 0.19120843092880654

Testing accuracy: 0.9508

Testing loss: 0.24531249435908334

Testing accuracy: 0.94

Epoch 40

-----  
Training loss: 0.006422039176929692

Training accuracy: 0.99995

Testing loss: 0.19157426818554044

Testing accuracy: 0.9504

Testing loss: 0.2463091322427185

Testing accuracy: 0.94

Epoch 41

-----  
Training loss: 0.005975200890396556

Training accuracy: 0.99995

Testing loss: 0.1918298481031899

Testing accuracy: 0.9502

Testing loss: 0.24721683114752535  
Testing accuracy: 0.9406  
Epoch 42  
-----  
Training loss: 0.00558323806893869  
Training accuracy: 1.0  
Testing loss: 0.19222584777785617  
Testing accuracy: 0.9504  
Testing loss: 0.24818228400983275  
Testing accuracy: 0.9398  
Epoch 43  
-----  
Training loss: 0.005231253706826306  
Training accuracy: 1.0  
Testing loss: 0.19256340827118149  
Testing accuracy: 0.9506  
Testing loss: 0.2490348900894648  
Testing accuracy: 0.9396  
Epoch 44  
-----  
Training loss: 0.004916144914461866  
Training accuracy: 1.0  
Testing loss: 0.19290590865381937  
Testing accuracy: 0.9504  
Testing loss: 0.24999983860541455  
Testing accuracy: 0.9396  
Epoch 45  
-----  
Training loss: 0.004631778797519651  
Training accuracy: 1.0  
Testing loss: 0.19325087104107053  
Testing accuracy: 0.9502  
Testing loss: 0.25078850803660424  
Testing accuracy: 0.9406  
Epoch 46  
-----  
Training loss: 0.00437441692256177  
Training accuracy: 1.0  
Testing loss: 0.1937728478566878  
Testing accuracy: 0.9504  
Testing loss: 0.2517454701447482  
Testing accuracy: 0.9408  
Epoch 47  
-----  
Training loss: 0.0041395144082753375  
Training accuracy: 1.0  
Testing loss: 0.1941382548149868  
Testing accuracy: 0.9506

```
Testing loss: 0.25250823109004683
Testing accuracy: 0.9412
Epoch 48
-----
Training loss: 0.003925138324644879
Training accuracy: 1.0
Testing loss: 0.19459989213873607
Testing accuracy: 0.9504
Testing loss: 0.2533716446318301
Testing accuracy: 0.9412
Epoch 49
-----
Training loss: 0.0037299209794663525
Training accuracy: 1.0
Testing loss: 0.19511201836272787
Testing accuracy: 0.9502
Testing loss: 0.25424448262427773
Testing accuracy: 0.941
Epoch 50
-----
Training loss: 0.0035505675627658796
Training accuracy: 1.0
Testing loss: 0.1955625509958037
Testing accuracy: 0.95
Testing loss: 0.25510541840145196
Testing accuracy: 0.9406
Epoch 51
-----
Training loss: 0.003384092832691897
Training accuracy: 1.0
Testing loss: 0.19609333133143117
Testing accuracy: 0.9504
Testing loss: 0.25587447257524587
Testing accuracy: 0.9408
Epoch 52
-----
Training loss: 0.003232833560186125
Training accuracy: 1.0
Testing loss: 0.19660675160129396
Testing accuracy: 0.9502
Testing loss: 0.25675519225767585
Testing accuracy: 0.9406
Epoch 53
-----
Training loss: 0.0030916871734734622
Training accuracy: 1.0
Testing loss: 0.19702999659582193
Testing accuracy: 0.9502
```

```
Testing loss: 0.2575183362801965
Testing accuracy: 0.9408
Epoch 54
-----
Training loss: 0.002960519507595172
Training accuracy: 1.0
Testing loss: 0.1975238633114241
Testing accuracy: 0.95
Testing loss: 0.25829126624926596
Testing accuracy: 0.9408
Epoch 55
-----
Training loss: 0.0028390469764787477
Training accuracy: 1.0
Testing loss: 0.19806394964347832
Testing accuracy: 0.95
Testing loss: 0.2590951630832959
Testing accuracy: 0.9408
Epoch 56
-----
Training loss: 0.002726069609734712
Training accuracy: 1.0
Testing loss: 0.19852145414902675
Testing accuracy: 0.9504
Testing loss: 0.25984728964991066
Testing accuracy: 0.941
Epoch 57
-----
Training loss: 0.0026201267738855004
Training accuracy: 1.0
Testing loss: 0.19902243721913657
Testing accuracy: 0.9506
Testing loss: 0.2606458691171264
Testing accuracy: 0.9412
Epoch 58
-----
Training loss: 0.002520977556689117
Training accuracy: 1.0
Testing loss: 0.19953738314756883
Testing accuracy: 0.951
Testing loss: 0.2614003042015957
Testing accuracy: 0.9412
Epoch 59
-----
Training loss: 0.002428330645091147
Training accuracy: 1.0
Testing loss: 0.1999968838054779
Testing accuracy: 0.951
```

```
Testing loss: 0.26216182266469124
Testing accuracy: 0.9412
Epoch 60
-----
Training loss: 0.0023423035450396293
Training accuracy: 1.0
Testing loss: 0.20049508082871959
Testing accuracy: 0.9512
Testing loss: 0.2628968348148686
Testing accuracy: 0.9412
Epoch 61
-----
Training loss: 0.0022600975003333177
Training accuracy: 1.0
Testing loss: 0.20100810939527036
Testing accuracy: 0.951
Testing loss: 0.2636744605429848
Testing accuracy: 0.9414
Epoch 62
-----
Training loss: 0.002183701471223877
Training accuracy: 1.0
Testing loss: 0.20144080478770954
Testing accuracy: 0.9514
Testing loss: 0.26435624876842323
Testing accuracy: 0.9412
Epoch 63
-----
Training loss: 0.0021113995607551952
Training accuracy: 1.0
Testing loss: 0.2019259282615684
Testing accuracy: 0.9516
Testing loss: 0.26506696274939234
Testing accuracy: 0.9414
Epoch 64
-----
Training loss: 0.002043170415205817
Training accuracy: 1.0
Testing loss: 0.20240422421146917
Testing accuracy: 0.9514
Testing loss: 0.2657850407825582
Testing accuracy: 0.9414
Epoch 65
-----
Training loss: 0.001978871923851769
Training accuracy: 1.0
Testing loss: 0.20291459330163414
Testing accuracy: 0.9514
```



Testing loss: 0.2664895054145356  
Testing accuracy: 0.9414  
Epoch 66  
-----  
Training loss: 0.0019178995459333023  
Training accuracy: 1.0  
Testing loss: 0.20340184481092735  
Testing accuracy: 0.9514  
Testing loss: 0.2672004233040857  
Testing accuracy: 0.9414  
Epoch 67  
-----  
Training loss: 0.0018601086297418841  
Training accuracy: 1.0  
Testing loss: 0.20378443796619633  
Testing accuracy: 0.9512  
Testing loss: 0.2678036525364251  
Testing accuracy: 0.9414  
Epoch 68  
-----  
Training loss: 0.0018051114185316476  
Training accuracy: 1.0  
Testing loss: 0.2042359126132028  
Testing accuracy: 0.9514  
Testing loss: 0.2684743918492677  
Testing accuracy: 0.9416  
Epoch 69  
-----  
Training loss: 0.0017529477255117645  
Training accuracy: 1.0  
Testing loss: 0.20464810558077096  
Testing accuracy: 0.9512  
Testing loss: 0.26916943583799124  
Testing accuracy: 0.9422  
Epoch 70  
-----  
Training loss: 0.001703047105398812  
Training accuracy: 1.0  
Testing loss: 0.20505811144699052  
Testing accuracy: 0.9512  
Testing loss: 0.2697754966330045  
Testing accuracy: 0.9422  
Epoch 71  
-----  
Training loss: 0.0016563884409617263  
Training accuracy: 1.0  
Testing loss: 0.20549382447917455  
Testing accuracy: 0.9514

Testing loss: 0.27040426736158035  
Testing accuracy: 0.9422  
Epoch 72  
-----  
Training loss: 0.0016110453990796107  
Training accuracy: 1.0  
Testing loss: 0.20593509470718813  
Testing accuracy: 0.9514  
Testing loss: 0.2710404871579342  
Testing accuracy: 0.9422  
Epoch 73  
-----  
Training loss: 0.0015684040272038362  
Training accuracy: 1.0  
Testing loss: 0.20636090342058339  
Testing accuracy: 0.9512  
Testing loss: 0.2716539081867137  
Testing accuracy: 0.9422  
Epoch 74  
-----  
Training loss: 0.001527193106196683  
Training accuracy: 1.0  
Testing loss: 0.206744614220007  
Testing accuracy: 0.9514  
Testing loss: 0.2722636458537471  
Testing accuracy: 0.942  
Epoch 75  
-----  
Training loss: 0.0014885657897375853  
Training accuracy: 1.0  
Testing loss: 0.2071594359033664  
Testing accuracy: 0.9514  
Testing loss: 0.2728646853098544  
Testing accuracy: 0.942  
Epoch 76  
-----  
Training loss: 0.001450667178521215  
Training accuracy: 1.0  
Testing loss: 0.20758583138468062  
Testing accuracy: 0.9514  
Testing loss: 0.2734533667819485  
Testing accuracy: 0.942  
Epoch 77  
-----  
Training loss: 0.0014151801891578086  
Training accuracy: 1.0  
Testing loss: 0.20795604117645317  
Testing accuracy: 0.9514

```
Testing loss: 0.2740275845287655
Testing accuracy: 0.9418
Epoch 78
-----
Training loss: 0.0013810798817641403
Training accuracy: 1.0
Testing loss: 0.20838451592542587
Testing accuracy: 0.9514
Testing loss: 0.27462668819019026
Testing accuracy: 0.942
Epoch 79
-----
Training loss: 0.0013481096603175707
Training accuracy: 1.0
Testing loss: 0.20875006686508277
Testing accuracy: 0.9512
Testing loss: 0.2751962336592435
Testing accuracy: 0.942
Epoch 80
-----
Training loss: 0.001316673061342225
Training accuracy: 1.0
Testing loss: 0.20915559407285922
Testing accuracy: 0.951
Testing loss: 0.27574849688288494
Testing accuracy: 0.942
Epoch 81
-----
Training loss: 0.001286568241148175
Training accuracy: 1.0
Testing loss: 0.20952743695519102
Testing accuracy: 0.951
Testing loss: 0.27629843145043276
Testing accuracy: 0.9422
Epoch 82
-----
Training loss: 0.00125770761610277
Training accuracy: 1.0
Testing loss: 0.20992838943288783
Testing accuracy: 0.9508
Testing loss: 0.27686453884479334
Testing accuracy: 0.9422
Epoch 83
-----
Training loss: 0.001230008632877334
Training accuracy: 1.0
Testing loss: 0.2102871480801024
Testing accuracy: 0.9508
```

Testing loss: 0.27740075874906034

Testing accuracy: 0.9426

Epoch 84

-----  
Training loss: 0.001202911570426506

Training accuracy: 1.0

Testing loss: 0.21061577667063558

Testing accuracy: 0.9504

Testing loss: 0.2779292327970376

Testing accuracy: 0.9426

Epoch 85

-----  
Training loss: 0.0011769826582604473

Training accuracy: 1.0

Testing loss: 0.21098489832230558

Testing accuracy: 0.9504

Testing loss: 0.27840387043161097

Testing accuracy: 0.9426

Epoch 86

-----  
Training loss: 0.0011524663583641437

Training accuracy: 1.0

Testing loss: 0.21134052556185262

Testing accuracy: 0.9504

Testing loss: 0.27891789644424386

Testing accuracy: 0.9426

Epoch 87

-----  
Training loss: 0.0011284241225677511

Training accuracy: 1.0

Testing loss: 0.21172026531581614

Testing accuracy: 0.9504

Testing loss: 0.2794536840600598

Testing accuracy: 0.9426

Epoch 88

-----  
Training loss: 0.0011054307143496256

Training accuracy: 1.0

Testing loss: 0.21202292611876059

Testing accuracy: 0.9504

Testing loss: 0.2799257016377777

Testing accuracy: 0.9426

Epoch 89

-----  
Training loss: 0.0010831399244887166

Training accuracy: 1.0

Testing loss: 0.21238168281370245

Testing accuracy: 0.9506

Testing loss: 0.2804469162307184  
Testing accuracy: 0.9426  
Epoch 90  
-----  
Training loss: 0.0010617784009492018  
Training accuracy: 1.0  
Testing loss: 0.2127221463745825  
Testing accuracy: 0.9504  
Testing loss: 0.28096089572335436  
Testing accuracy: 0.9426  
Epoch 91  
-----  
Training loss: 0.0010407931018632957  
Training accuracy: 1.0  
Testing loss: 0.21305822048469994  
Testing accuracy: 0.9504  
Testing loss: 0.28140836892572657  
Testing accuracy: 0.9426  
Epoch 92  
-----  
Training loss: 0.0010210456060492368  
Training accuracy: 1.0  
Testing loss: 0.21339799344028537  
Testing accuracy: 0.9502  
Testing loss: 0.28192533894169486  
Testing accuracy: 0.9428  
Epoch 93  
-----  
Training loss: 0.0010014399471548361  
Training accuracy: 1.0  
Testing loss: 0.21369042274155967  
Testing accuracy: 0.9502  
Testing loss: 0.2823873945955845  
Testing accuracy: 0.9428  
Epoch 94  
-----  
Training loss: 0.0009827649771890746  
Training accuracy: 1.0  
Testing loss: 0.21404851378803363  
Testing accuracy: 0.9502  
Testing loss: 0.28284901285868896  
Testing accuracy: 0.9428  
Epoch 95  
-----  
Training loss: 0.0009648100584573579  
Training accuracy: 1.0  
Testing loss: 0.2143533599816701  
Testing accuracy: 0.9502

```
Testing loss: 0.2833401901940907
Testing accuracy: 0.9428
Epoch 96
-----
Training loss: 0.0009472669689557494
Training accuracy: 1.0
Testing loss: 0.21468288936477747
Testing accuracy: 0.9502
Testing loss: 0.28376953912113945
Testing accuracy: 0.943
Epoch 97
-----
Training loss: 0.000930217294923224
Training accuracy: 1.0
Testing loss: 0.21498110858202532
Testing accuracy: 0.9502
Testing loss: 0.28422335020304806
Testing accuracy: 0.9432
Epoch 98
-----
Training loss: 0.0009137379871729731
Training accuracy: 1.0
Testing loss: 0.21528710598028164
Testing accuracy: 0.9504
Testing loss: 0.2846664582459094
Testing accuracy: 0.9432
Epoch 99
-----
Training loss: 0.0008978961442730402
Training accuracy: 1.0
Testing loss: 0.21559636989533046
Testing accuracy: 0.9504
Testing loss: 0.2850846051437437
Testing accuracy: 0.9432
Epoch 100
-----
Training loss: 0.0008822832967288342
Training accuracy: 1.0
Testing loss: 0.21586983625445477
Testing accuracy: 0.9504
Testing loss: 0.2855459993488624
Testing accuracy: 0.9432
Epoch 101
-----
Training loss: 0.0008674278394350585
Training accuracy: 1.0
Testing loss: 0.2161907374631579
Testing accuracy: 0.9504
```

Testing loss: 0.28595688055027413  
Testing accuracy: 0.9432  
Epoch 102  
-----  
Training loss: 0.0008527516922829515  
Training accuracy: 1.0  
Testing loss: 0.21646289332536545  
Testing accuracy: 0.9504  
Testing loss: 0.2863672565317577  
Testing accuracy: 0.9432  
Epoch 103  
-----  
Training loss: 0.0008387538877774768  
Training accuracy: 1.0  
Testing loss: 0.21678273967988868  
Testing accuracy: 0.9504  
Testing loss: 0.28679526515269  
Testing accuracy: 0.9434  
Epoch 104  
-----  
Training loss: 0.0008250444422709894  
Training accuracy: 1.0  
Testing loss: 0.21705776927283582  
Testing accuracy: 0.9504  
Testing loss: 0.287197242408117  
Testing accuracy: 0.9434  
Epoch 105  
-----  
Training loss: 0.000811604725345243  
Training accuracy: 1.0  
Testing loss: 0.21732980080134454  
Testing accuracy: 0.9504  
Testing loss: 0.28759296641279797  
Testing accuracy: 0.9434  
Epoch 106  
-----  
Training loss: 0.0007987056867652517  
Training accuracy: 1.0  
Testing loss: 0.2176135929852947  
Testing accuracy: 0.9504  
Testing loss: 0.287991732523306  
Testing accuracy: 0.9434  
Epoch 107  
-----  
Training loss: 0.0007862092820541466  
Training accuracy: 1.0  
Testing loss: 0.21791828465913596  
Testing accuracy: 0.9504

Testing loss: 0.288401481164543  
Testing accuracy: 0.9434  
Epoch 108  
-----  
Training loss: 0.000773901341657394  
Training accuracy: 1.0  
Testing loss: 0.21816036867890126  
Testing accuracy: 0.9504  
Testing loss: 0.2887786058483754  
Testing accuracy: 0.9434  
Epoch 109  
-----  
Training loss: 0.0007620088484434941  
Training accuracy: 1.0  
Testing loss: 0.21844077617488475  
Testing accuracy: 0.9504  
Testing loss: 0.28917597240405907  
Testing accuracy: 0.9434  
Epoch 110  
-----  
Training loss: 0.0007504512849503921  
Training accuracy: 1.0  
Testing loss: 0.2187108269898074  
Testing accuracy: 0.9506  
Testing loss: 0.28954531869507344  
Testing accuracy: 0.9434  
Epoch 111  
-----  
Training loss: 0.0007391055050128486  
Training accuracy: 1.0  
Testing loss: 0.21897614679260283  
Testing accuracy: 0.9504  
Testing loss: 0.28992955977840973  
Testing accuracy: 0.9434  
Epoch 112  
-----  
Training loss: 0.0007281281405400973  
Training accuracy: 1.0  
Testing loss: 0.2192324598891764  
Testing accuracy: 0.9506  
Testing loss: 0.2903164512774646  
Testing accuracy: 0.9434  
Epoch 113  
-----  
Training loss: 0.0007174968766050792  
Training accuracy: 1.0  
Testing loss: 0.2195032210701886  
Testing accuracy: 0.9506



```

Testing loss: 0.2906744613506286
Testing accuracy: 0.9434
Epoch 114
-----
Training loss: 0.0007070578383092188
Training accuracy: 1.0
Testing loss: 0.2197366587046616
Testing accuracy: 0.9506
Testing loss: 0.2910562183663712
Testing accuracy: 0.9432
Epoch 115
-----
Training loss: 0.0006968780744266596
Training accuracy: 1.0
Testing loss: 0.22000713681297634
Testing accuracy: 0.9508
Testing loss: 0.2914369521494329
Testing accuracy: 0.9432
Epoch 116
-----
Training loss: 0.0006870191223463433
Training accuracy: 1.0
Testing loss: 0.22026294014846645
Testing accuracy: 0.9508
Testing loss: 0.2918055559936785
Testing accuracy: 0.9432
Epoch 117
-----
Training loss: 0.0006773364834423312
Training accuracy: 1.0
Testing loss: 0.22053779474507756
Testing accuracy: 0.9508
Testing loss: 0.2921584654667525
Testing accuracy: 0.9432
Epoch 118
-----
Training loss: 0.0006679731692158619
Training accuracy: 1.0
Testing loss: 0.22076425694755117
Testing accuracy: 0.9508
Testing loss: 0.29252303909905003
Testing accuracy: 0.943
Epoch 119
-----
Training loss: 0.0006588077832271007
Training accuracy: 1.0
Testing loss: 0.22100706473888512
Testing accuracy: 0.9508

```

```
Testing loss: 0.2928696162858747
Testing accuracy: 0.943
Epoch 120
-----
Training loss: 0.0006498398151577569
Training accuracy: 1.0
Testing loss: 0.22124170459193038
Testing accuracy: 0.9508
Testing loss: 0.2932067891711722
Testing accuracy: 0.943
Epoch 121
-----
Training loss: 0.0006410333339290026
Training accuracy: 1.0
Testing loss: 0.2215033769992072
Testing accuracy: 0.9508
Testing loss: 0.2935394327048019
Testing accuracy: 0.943
Epoch 122
-----
Training loss: 0.0006325012124009964
Training accuracy: 1.0
Testing loss: 0.22170941072014266
Testing accuracy: 0.9508
Testing loss: 0.29385028286172615
Testing accuracy: 0.9432
Epoch 123
-----
Training loss: 0.000624241705852796
Training accuracy: 1.0
Testing loss: 0.2219652310302311
Testing accuracy: 0.9508
Testing loss: 0.29424177231948134
Testing accuracy: 0.9432
Epoch 124
-----
Training loss: 0.0006161568531135071
Training accuracy: 1.0
Testing loss: 0.22220327420256544
Testing accuracy: 0.9508
Testing loss: 0.29454360598426493
Testing accuracy: 0.9432
Epoch 125
-----
Training loss: 0.0006081429915376677
Training accuracy: 1.0
Testing loss: 0.2224200224713823
Testing accuracy: 0.9508
```

Testing loss: 0.29487711239561265  
Testing accuracy: 0.9432  
Epoch 126  
-----  
Training loss: 0.0006002303369265371  
Training accuracy: 1.0  
Testing loss: 0.22264711614812427  
Testing accuracy: 0.9508  
Testing loss: 0.29521955321125115  
Testing accuracy: 0.9432  
Epoch 127  
-----  
Training loss: 0.0005927225888484148  
Training accuracy: 1.0  
Testing loss: 0.22288567947334478  
Testing accuracy: 0.9508  
Testing loss: 0.29554504130319353  
Testing accuracy: 0.9432  
Epoch 128  
-----  
Training loss: 0.0005853718136024144  
Training accuracy: 1.0  
Testing loss: 0.22311732915664984  
Testing accuracy: 0.9508  
Testing loss: 0.29586354483822663  
Testing accuracy: 0.943  
Epoch 129  
-----  
Training loss: 0.0005780622356259291  
Training accuracy: 1.0  
Testing loss: 0.2233430863136994  
Testing accuracy: 0.9508  
Testing loss: 0.2961886198379023  
Testing accuracy: 0.943  
Epoch 130  
-----  
Training loss: 0.0005709431972700875  
Training accuracy: 1.0  
Testing loss: 0.2235690668084601  
Testing accuracy: 0.9508  
Testing loss: 0.29650242952569217  
Testing accuracy: 0.9428  
Epoch 131  
-----  
Training loss: 0.0005640446837648097  
Training accuracy: 1.0  
Testing loss: 0.22380059648210773  
Testing accuracy: 0.9508

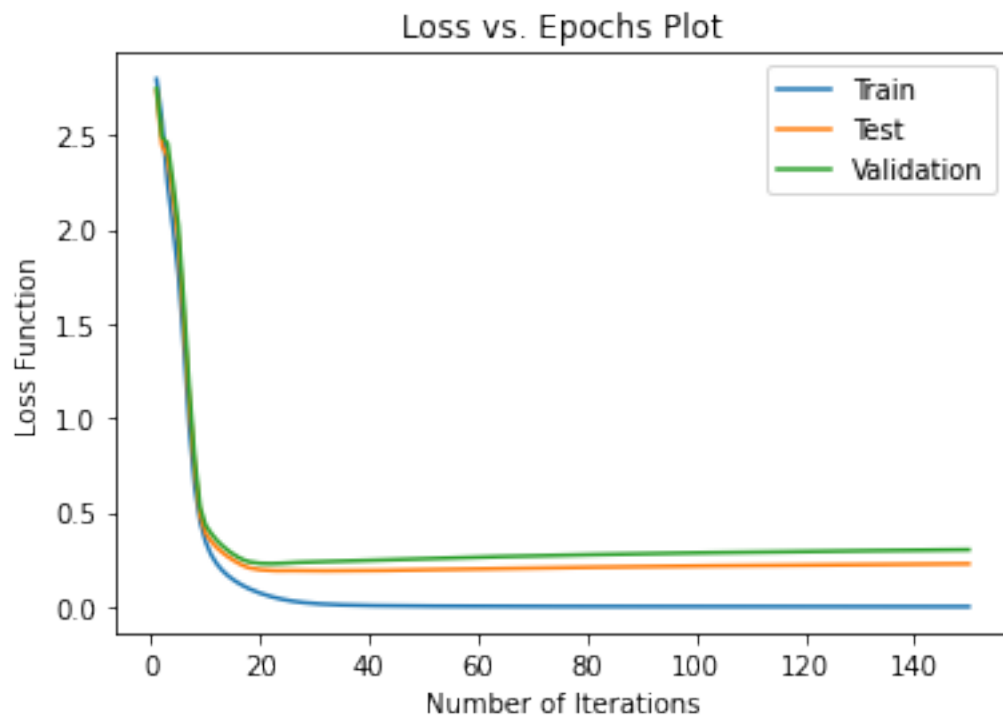
```
Testing loss: 0.29682162863585315
Testing accuracy: 0.9428
Epoch 132
-----
Training loss: 0.0005572443499356731
Training accuracy: 1.0
Testing loss: 0.2240189491487584
Testing accuracy: 0.9508
Testing loss: 0.2971337396072811
Testing accuracy: 0.9428
Epoch 133
-----
Training loss: 0.0005505748723640827
Training accuracy: 1.0
Testing loss: 0.22422157123450223
Testing accuracy: 0.9508
Testing loss: 0.29745418827050973
Testing accuracy: 0.9428
Epoch 134
-----
Training loss: 0.0005440749439152384
Training accuracy: 1.0
Testing loss: 0.22443773775003592
Testing accuracy: 0.951
Testing loss: 0.29773755577261735
Testing accuracy: 0.9428
Epoch 135
-----
Training loss: 0.0005377083769778386
Training accuracy: 1.0
Testing loss: 0.22467017919416615
Testing accuracy: 0.951
Testing loss: 0.2980403290216125
Testing accuracy: 0.9428
Epoch 136
-----
Training loss: 0.0005314749565054956
Training accuracy: 1.0
Testing loss: 0.22486577639814678
Testing accuracy: 0.9512
Testing loss: 0.29836161521636223
Testing accuracy: 0.9426
Epoch 137
-----
Training loss: 0.0005252378303123618
Training accuracy: 1.0
Testing loss: 0.22506759005131294
Testing accuracy: 0.9512
```

```
Testing loss: 0.29866653412426203
Testing accuracy: 0.9428
Epoch 138
-----
Training loss: 0.0005193700433345163
Training accuracy: 1.0
Testing loss: 0.2252891666309085
Testing accuracy: 0.9512
Testing loss: 0.2989720113214689
Testing accuracy: 0.9424
Epoch 139
-----
Training loss: 0.0005134519016209338
Training accuracy: 1.0
Testing loss: 0.22548745394963213
Testing accuracy: 0.9512
Testing loss: 0.29924619891705617
Testing accuracy: 0.9422
Epoch 140
-----
Training loss: 0.0005077410019601162
Training accuracy: 1.0
Testing loss: 0.22570833422136508
Testing accuracy: 0.9512
Testing loss: 0.2995523124039033
Testing accuracy: 0.9422
Epoch 141
-----
Training loss: 0.0005020285587975026
Training accuracy: 1.0
Testing loss: 0.2259081131349073
Testing accuracy: 0.9512
Testing loss: 0.2998515488170322
Testing accuracy: 0.942
Epoch 142
-----
Training loss: 0.0004965707165580536
Training accuracy: 1.0
Testing loss: 0.22610849130734265
Testing accuracy: 0.9512
Testing loss: 0.3001470996895753
Testing accuracy: 0.942
Epoch 143
-----
Training loss: 0.0004911418839832547
Training accuracy: 1.0
Testing loss: 0.2263123442468083
Testing accuracy: 0.9512
```

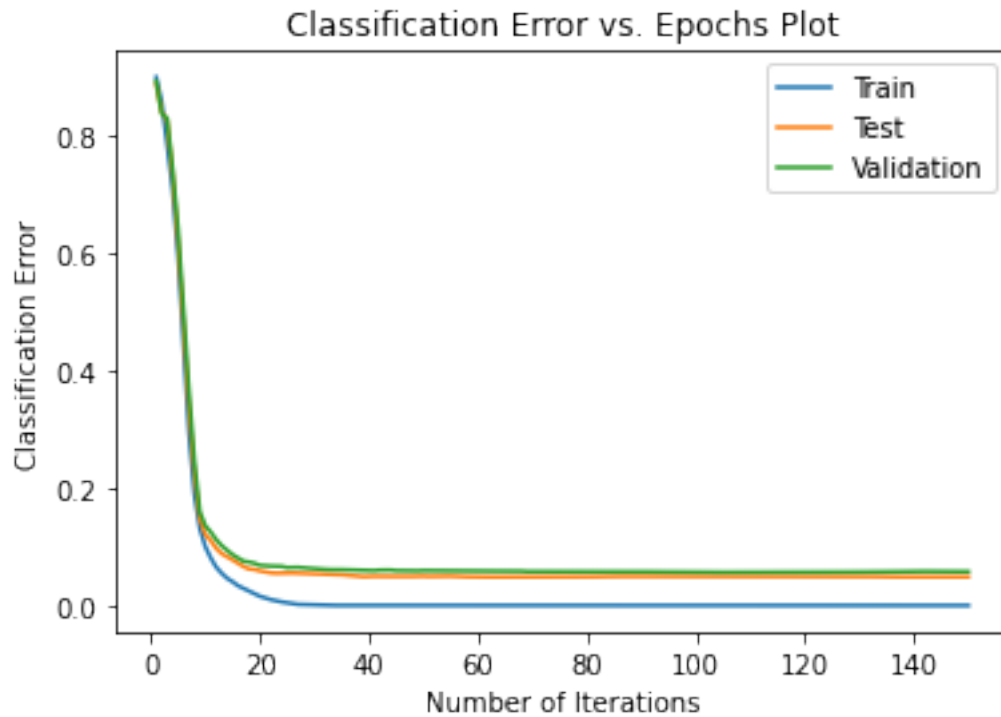
Testing loss: 0.30041575534518145  
Testing accuracy: 0.942  
Epoch 144  
-----  
Training loss: 0.00048580770697296947  
Training accuracy: 1.0  
Testing loss: 0.22652820623846437  
Testing accuracy: 0.9512  
Testing loss: 0.3007158461005619  
Testing accuracy: 0.942  
Epoch 145  
-----  
Training loss: 0.0004806471705972309  
Training accuracy: 1.0  
Testing loss: 0.22671546635439918  
Testing accuracy: 0.9512  
Testing loss: 0.3009931108206477  
Testing accuracy: 0.942  
Epoch 146  
-----  
Training loss: 0.0004755000640369493  
Training accuracy: 1.0  
Testing loss: 0.22690385139005598  
Testing accuracy: 0.9512  
Testing loss: 0.3012760967620613  
Testing accuracy: 0.942  
Epoch 147  
-----  
Training loss: 0.00047049252227470626  
Training accuracy: 1.0  
Testing loss: 0.22711516590909306  
Testing accuracy: 0.9512  
Testing loss: 0.3015607194211446  
Testing accuracy: 0.942  
Epoch 148  
-----  
Training loss: 0.00046552078795296213  
Training accuracy: 1.0  
Testing loss: 0.22729271958482022  
Testing accuracy: 0.9512  
Testing loss: 0.3018384567756428  
Testing accuracy: 0.9422  
Epoch 149  
-----  
Training loss: 0.00046073607073034075  
Training accuracy: 1.0  
Testing loss: 0.22748487918880436  
Testing accuracy: 0.9512

```
Testing loss: 0.3021137886931517
Testing accuracy: 0.942
Epoch 150
-----
Training loss: 0.000456034852323576
Training accuracy: 1.0
Testing loss: 0.22768085535008126
Testing accuracy: 0.9512
Testing loss: 0.3023824090082624
Testing accuracy: 0.9424
Done
Total Time Consumed: 8119.395992040634
```

```
[79]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[80]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



#### 6.4.4 Learning Rate = 0.2

```
[81]: # Define HyperParameters
# Number of Classes = 19
num_classes = 19
learning_rate = 0.2
batch_size = 64
num_epochs = 150
CNN_2 = CNN1(num_classes).double()

# Batch Dataloader
train_loader = DataLoader(X_train, batch_size = batch_size)
train_loader_y = DataLoader(Y_train.type(torch.LongTensor), batch_size = batch_size)
test_loader = DataLoader(X_test, batch_size = batch_size)
test_loader_y = DataLoader(Y_test.type(torch.LongTensor), batch_size = batch_size)
val_loader = DataLoader(X_val, batch_size = batch_size)
val_loader_y = DataLoader(Y_val.type(torch.LongTensor), batch_size = batch_size)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_2.parameters(), lr = learning_rate)
```



```
[82]: start_time = time.time()
      test_loss_record = []
      train_loss_record = []
      val_loss_record = []
      for i in range(num_epochs):
          print(f"Epoch {i+1}\n-----")
          train_loss_record.
          ↪append(train_loop7(train_loader,train_loader_y,CNN_2,loss,optimizer))
          test_loss_record.append(test_loop7(test_loader,test_loader_y,CNN_2,loss))
          val_loss_record.append(test_loop7(val_loader,val_loader_y,CNN_2,loss))
      print('Done')
      print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 1.8819665749575714
Training accuracy: 0.3654
Testing loss: 0.5782961348441121
Testing accuracy: 0.8116
Testing loss: 0.6366700513225486
Testing accuracy: 0.7984
Epoch 2
```

```
-----
Training loss: 0.32953013694323774
Training accuracy: 0.90105
Testing loss: 0.29098236962545687
Testing accuracy: 0.9058
Testing loss: 0.3286487615404689
Testing accuracy: 0.9012
Epoch 3
```

```
-----
Training loss: 0.13560839501911331
Training accuracy: 0.9586
Testing loss: 0.1642162605374861
Testing accuracy: 0.9502
Testing loss: 0.18011320673266693
Testing accuracy: 0.9516
Epoch 4
```

```
-----
Training loss: 0.06745339581008951
Training accuracy: 0.9798
Testing loss: 0.15789127551528626
Testing accuracy: 0.9556
Testing loss: 0.18153376724237538
Testing accuracy: 0.9546
Epoch 5
```

```
Training loss: 0.0451101654341834
Training accuracy: 0.98545
Testing loss: 0.1530002526951987
Testing accuracy: 0.958
Testing loss: 0.19182488683196888
Testing accuracy: 0.9544
Epoch 6
-----
Training loss: 0.03423601577830083
Training accuracy: 0.98945
Testing loss: 0.14961879185500684
Testing accuracy: 0.961
Testing loss: 0.17973421177028948
Testing accuracy: 0.9606
Epoch 7
-----
Training loss: 0.019277170703282012
Training accuracy: 0.9945
Testing loss: 0.16097191100763578
Testing accuracy: 0.961
Testing loss: 0.204422040902353
Testing accuracy: 0.9544
Epoch 8
-----
Training loss: 0.01776038093534667
Training accuracy: 0.995
Testing loss: 0.13309031136037106
Testing accuracy: 0.9658
Testing loss: 0.18234224774795874
Testing accuracy: 0.9636
Epoch 9
-----
Training loss: 0.013529061377440045
Training accuracy: 0.99635
Testing loss: 0.13207110509019368
Testing accuracy: 0.9654
Testing loss: 0.17349990545178906
Testing accuracy: 0.9642
Epoch 10
-----
Training loss: 0.014113801073744983
Training accuracy: 0.9955
Testing loss: 0.15758832019628627
Testing accuracy: 0.9608
Testing loss: 0.19397589724303335
Testing accuracy: 0.961
Epoch 11
-----
```

```

Training loss: 0.008398167517475023
Training accuracy: 0.998
Testing loss: 0.139551890631738
Testing accuracy: 0.9686
Testing loss: 0.197647746461824
Testing accuracy: 0.9618
Epoch 12
-----
Training loss: 0.0038972643353733815
Training accuracy: 0.99925
Testing loss: 0.1152868379166001
Testing accuracy: 0.9732
Testing loss: 0.1788977321941936
Testing accuracy: 0.9688
Epoch 13
-----
Training loss: 0.00035644740724099437
Training accuracy: 0.99995
Testing loss: 0.11960079631852116
Testing accuracy: 0.9738
Testing loss: 0.18098351123118261
Testing accuracy: 0.969
Epoch 14
-----
Training loss: 0.00011679982871690459
Training accuracy: 1.0
Testing loss: 0.12135240809084069
Testing accuracy: 0.9744
Testing loss: 0.18503898113871536
Testing accuracy: 0.9696
Epoch 15
-----
Training loss: 8.297808702459148e-05
Training accuracy: 1.0
Testing loss: 0.12300176784506081
Testing accuracy: 0.9746
Testing loss: 0.18780613037613034
Testing accuracy: 0.9696
Epoch 16
-----
Training loss: 6.848848515055711e-05
Training accuracy: 1.0
Testing loss: 0.12436766804215295
Testing accuracy: 0.9746
Testing loss: 0.19014734206804443
Testing accuracy: 0.9694
Epoch 17
-----

```

Training loss: 5.8969032071756835e-05  
Training accuracy: 1.0  
Testing loss: 0.12551470723662872  
Testing accuracy: 0.9748  
Testing loss: 0.19219827290761446  
Testing accuracy: 0.9692  
Epoch 18  
-----

Training loss: 5.2021616733693055e-05  
Training accuracy: 1.0  
Testing loss: 0.1265241442263141  
Testing accuracy: 0.9746  
Testing loss: 0.19398601785784578  
Testing accuracy: 0.9696  
Epoch 19  
-----

Training loss: 4.666697524171148e-05  
Training accuracy: 1.0  
Testing loss: 0.12742943779485916  
Testing accuracy: 0.9744  
Testing loss: 0.19559658372366617  
Testing accuracy: 0.9698  
Epoch 20  
-----

Training loss: 4.238557821986863e-05  
Training accuracy: 1.0  
Testing loss: 0.12824466556712985  
Testing accuracy: 0.9744  
Testing loss: 0.19706870680164285  
Testing accuracy: 0.97  
Epoch 21  
-----

Training loss: 3.8869982518712524e-05  
Training accuracy: 1.0  
Testing loss: 0.12898957885456225  
Testing accuracy: 0.9744  
Testing loss: 0.1984177675845605  
Testing accuracy: 0.9698  
Epoch 22  
-----

Training loss: 3.5931649687362e-05  
Training accuracy: 1.0  
Testing loss: 0.12967213018871923  
Testing accuracy: 0.9746  
Testing loss: 0.19966694677339525  
Testing accuracy: 0.9696  
Epoch 23  
-----

Training loss: 3.342756418238367e-05  
Training accuracy: 1.0  
Testing loss: 0.13030668260328276  
Testing accuracy: 0.9748  
Testing loss: 0.20082155517219752  
Testing accuracy: 0.9696  
Epoch 24  
-----

Training loss: 3.1273395839845206e-05  
Training accuracy: 1.0  
Testing loss: 0.13089761637898903  
Testing accuracy: 0.9748  
Testing loss: 0.2018950482056364  
Testing accuracy: 0.9696  
Epoch 25  
-----

Training loss: 2.9388884115897796e-05  
Training accuracy: 1.0  
Testing loss: 0.1314543710314446  
Testing accuracy: 0.9748  
Testing loss: 0.20290911546922902  
Testing accuracy: 0.9696  
Epoch 26  
-----

Training loss: 2.772746298871413e-05  
Training accuracy: 1.0  
Testing loss: 0.1319774989455176  
Testing accuracy: 0.9746  
Testing loss: 0.2038694469578293  
Testing accuracy: 0.9696  
Epoch 27  
-----

Training loss: 2.6246724717131097e-05  
Training accuracy: 1.0  
Testing loss: 0.13246846722795608  
Testing accuracy: 0.9746  
Testing loss: 0.2047841513436236  
Testing accuracy: 0.9694  
Epoch 28  
-----

Training loss: 2.492407765301622e-05  
Training accuracy: 1.0  
Testing loss: 0.13293324271644194  
Testing accuracy: 0.9746  
Testing loss: 0.2056422063401872  
Testing accuracy: 0.9696  
Epoch 29  
-----

Training loss: 2.3732896933122096e-05  
Training accuracy: 1.0  
Testing loss: 0.13337822731080148  
Testing accuracy: 0.9746  
Testing loss: 0.20646137904020698  
Testing accuracy: 0.9696  
Epoch 30  
-----

Training loss: 2.265430954614923e-05  
Training accuracy: 1.0  
Testing loss: 0.13380369664357697  
Testing accuracy: 0.9746  
Testing loss: 0.2072487881448566  
Testing accuracy: 0.9694  
Epoch 31  
-----

Training loss: 2.167055753763779e-05  
Training accuracy: 1.0  
Testing loss: 0.13421492599971566  
Testing accuracy: 0.9746  
Testing loss: 0.20799880102988458  
Testing accuracy: 0.9694  
Epoch 32  
-----

Training loss: 2.0771111181868604e-05  
Training accuracy: 1.0  
Testing loss: 0.13460938256028562  
Testing accuracy: 0.9746  
Testing loss: 0.20871903508966588  
Testing accuracy: 0.9694  
Epoch 33  
-----

Training loss: 1.994282971585952e-05  
Training accuracy: 1.0  
Testing loss: 0.13499096922159237  
Testing accuracy: 0.9746  
Testing loss: 0.2094150331376242  
Testing accuracy: 0.9694  
Epoch 34  
-----

Training loss: 1.9179208661110773e-05  
Training accuracy: 1.0  
Testing loss: 0.13535576740937474  
Testing accuracy: 0.9746  
Testing loss: 0.21008848986034973  
Testing accuracy: 0.9694  
Epoch 35  
-----

```
Training loss: 1.84725656812541e-05
Training accuracy: 1.0
Testing loss: 0.1357062403240565
Testing accuracy: 0.9746
Testing loss: 0.21073143657949045
Testing accuracy: 0.9694
Epoch 36
-----
Training loss: 1.7817213384432644e-05
Training accuracy: 1.0
Testing loss: 0.1360478856389906
Testing accuracy: 0.9746
Testing loss: 0.2113591139868835
Testing accuracy: 0.9694
Epoch 37
-----
Training loss: 1.7206292752604047e-05
Training accuracy: 1.0
Testing loss: 0.13637776095300955
Testing accuracy: 0.9746
Testing loss: 0.21196573411177427
Testing accuracy: 0.9694
Epoch 38
-----
Training loss: 1.6636294251289138e-05
Training accuracy: 1.0
Testing loss: 0.1366956662371063
Testing accuracy: 0.9746
Testing loss: 0.21255743695018636
Testing accuracy: 0.9694
Epoch 39
-----
Training loss: 1.6103005514666064e-05
Training accuracy: 1.0
Testing loss: 0.13700441830218768
Testing accuracy: 0.9746
Testing loss: 0.21313025913581615
Testing accuracy: 0.9694
Epoch 40
-----
Training loss: 1.560293560011643e-05
Training accuracy: 1.0
Testing loss: 0.13730200707495685
Testing accuracy: 0.9746
Testing loss: 0.21368559464967637
Testing accuracy: 0.9694
Epoch 41
-----
```

Training loss: 1.5132786733280903e-05  
Training accuracy: 1.0  
Testing loss: 0.13759165645219817  
Testing accuracy: 0.9746  
Testing loss: 0.21422172396592287  
Testing accuracy: 0.9694  
Epoch 42  
-----

Training loss: 1.4690652484858188e-05  
Training accuracy: 1.0  
Testing loss: 0.1378705646893243  
Testing accuracy: 0.9746  
Testing loss: 0.21474149846300755  
Testing accuracy: 0.9694  
Epoch 43  
-----

Training loss: 1.4274041588838251e-05  
Training accuracy: 1.0  
Testing loss: 0.13814227252612482  
Testing accuracy: 0.9746  
Testing loss: 0.21524670060393372  
Testing accuracy: 0.9694  
Epoch 44  
-----

Training loss: 1.3881330676344972e-05  
Training accuracy: 1.0  
Testing loss: 0.13840519715311217  
Testing accuracy: 0.9746  
Testing loss: 0.21573432174083693  
Testing accuracy: 0.9692  
Epoch 45  
-----

Training loss: 1.350973078978528e-05  
Training accuracy: 1.0  
Testing loss: 0.13865874954692833  
Testing accuracy: 0.9746  
Testing loss: 0.2162099657438742  
Testing accuracy: 0.9692  
Epoch 46  
-----

Training loss: 1.3158044834305454e-05  
Training accuracy: 1.0  
Testing loss: 0.13890750615767128  
Testing accuracy: 0.9746  
Testing loss: 0.21666926522102403  
Testing accuracy: 0.9692  
Epoch 47  
-----



Training loss: 1.282371603659899e-05  
Training accuracy: 1.0  
Testing loss: 0.1391479148341339  
Testing accuracy: 0.9748  
Testing loss: 0.2171185826727081  
Testing accuracy: 0.9692  
Epoch 48  
-----

Training loss: 1.2506710801648657e-05  
Training accuracy: 1.0  
Testing loss: 0.13938302987713422  
Testing accuracy: 0.9748  
Testing loss: 0.2175518613529593  
Testing accuracy: 0.9692  
Epoch 49  
-----

Training loss: 1.2204171807685109e-05  
Training accuracy: 1.0  
Testing loss: 0.13961020318928796  
Testing accuracy: 0.9748  
Testing loss: 0.2179783884732391  
Testing accuracy: 0.9692  
Epoch 50  
-----

Training loss: 1.191682888591679e-05  
Training accuracy: 1.0  
Testing loss: 0.13983076608062364  
Testing accuracy: 0.9748  
Testing loss: 0.21839542004388887  
Testing accuracy: 0.9692  
Epoch 51  
-----

Training loss: 1.1641841991809672e-05  
Training accuracy: 1.0  
Testing loss: 0.1400487838061136  
Testing accuracy: 0.9748  
Testing loss: 0.21880402573133287  
Testing accuracy: 0.9692  
Epoch 52  
-----

Training loss: 1.1379884054393497e-05  
Training accuracy: 1.0  
Testing loss: 0.14026159725095594  
Testing accuracy: 0.9748  
Testing loss: 0.21920405137237786  
Testing accuracy: 0.9692  
Epoch 53  
-----

Training loss: 1.1129162026816578e-05  
Training accuracy: 1.0  
Testing loss: 0.14046956518545908  
Testing accuracy: 0.9748  
Testing loss: 0.2195950832439046  
Testing accuracy: 0.9692  
Epoch 54  
-----

Training loss: 1.0889823156261883e-05  
Training accuracy: 1.0  
Testing loss: 0.1406742689090748  
Testing accuracy: 0.9748  
Testing loss: 0.21997730001628116  
Testing accuracy: 0.9694  
Epoch 55  
-----

Training loss: 1.0660516154168929e-05  
Training accuracy: 1.0  
Testing loss: 0.1408747048220671  
Testing accuracy: 0.9748  
Testing loss: 0.2203533305019138  
Testing accuracy: 0.9694  
Epoch 56  
-----

Training loss: 1.044066830301869e-05  
Training accuracy: 1.0  
Testing loss: 0.14107260322847168  
Testing accuracy: 0.9748  
Testing loss: 0.22072098254324432  
Testing accuracy: 0.9694  
Epoch 57  
-----

Training loss: 1.0229885404079504e-05  
Training accuracy: 1.0  
Testing loss: 0.1412641530784395  
Testing accuracy: 0.9748  
Testing loss: 0.2210813136344784  
Testing accuracy: 0.9694  
Epoch 58  
-----

Training loss: 1.0027398410743818e-05  
Training accuracy: 1.0  
Testing loss: 0.14145562043541232  
Testing accuracy: 0.9746  
Testing loss: 0.22143174914859232  
Testing accuracy: 0.9694  
Epoch 59  
-----

Training loss: 9.832776575086326e-06  
Training accuracy: 1.0  
Testing loss: 0.1416409912797751  
Testing accuracy: 0.9746  
Testing loss: 0.22177795069241502  
Testing accuracy: 0.9694  
Epoch 60  
-----

Training loss: 9.645748655607536e-06  
Training accuracy: 1.0  
Testing loss: 0.14182510506173823  
Testing accuracy: 0.9746  
Testing loss: 0.22211491661329225  
Testing accuracy: 0.9694  
Epoch 61  
-----

Training loss: 9.465307470329608e-06  
Training accuracy: 1.0  
Testing loss: 0.1420056074793781  
Testing accuracy: 0.9746  
Testing loss: 0.2224505071353709  
Testing accuracy: 0.9694  
Epoch 62  
-----

Training loss: 9.291641897835883e-06  
Training accuracy: 1.0  
Testing loss: 0.14218528027437555  
Testing accuracy: 0.9746  
Testing loss: 0.22277507479295713  
Testing accuracy: 0.9694  
Epoch 63  
-----

Training loss: 9.124053769769949e-06  
Training accuracy: 1.0  
Testing loss: 0.14236047188578696  
Testing accuracy: 0.9746  
Testing loss: 0.22309939511606514  
Testing accuracy: 0.9694  
Epoch 64  
-----

Training loss: 8.96236549367597e-06  
Training accuracy: 1.0  
Testing loss: 0.14253256020339442  
Testing accuracy: 0.9746  
Testing loss: 0.22341636040432986  
Testing accuracy: 0.9694  
Epoch 65  
-----

Training loss: 8.80646150511946e-06  
Training accuracy: 1.0  
Testing loss: 0.1427034989060182  
Testing accuracy: 0.9746  
Testing loss: 0.22372464257007124  
Testing accuracy: 0.9694  
Epoch 66  
-----

Training loss: 8.655604570057451e-06  
Training accuracy: 1.0  
Testing loss: 0.14286978807759354  
Testing accuracy: 0.9746  
Testing loss: 0.22403158953981164  
Testing accuracy: 0.9694  
Epoch 67  
-----

Training loss: 8.509892265318915e-06  
Training accuracy: 1.0  
Testing loss: 0.14303345392456418  
Testing accuracy: 0.9746  
Testing loss: 0.22433294682716517  
Testing accuracy: 0.9692  
Epoch 68  
-----

Training loss: 8.369281790703292e-06  
Training accuracy: 1.0  
Testing loss: 0.143196758522754  
Testing accuracy: 0.9746  
Testing loss: 0.22462928883713976  
Testing accuracy: 0.9692  
Epoch 69  
-----

Training loss: 8.23298615527994e-06  
Training accuracy: 1.0  
Testing loss: 0.1433560522250686  
Testing accuracy: 0.9746  
Testing loss: 0.22491970701990002  
Testing accuracy: 0.9692  
Epoch 70  
-----

Training loss: 8.101480234235952e-06  
Training accuracy: 1.0  
Testing loss: 0.143513674576889  
Testing accuracy: 0.9746  
Testing loss: 0.22520619306830664  
Testing accuracy: 0.9692  
Epoch 71  
-----

Training loss: 7.974094227999298e-06  
Training accuracy: 1.0  
Testing loss: 0.14366977480197127  
Testing accuracy: 0.9746  
Testing loss: 0.22549014166444636  
Testing accuracy: 0.9692  
Epoch 72

-----  
Training loss: 7.85041688030264e-06  
Training accuracy: 1.0  
Testing loss: 0.14382344550249188  
Testing accuracy: 0.9746  
Testing loss: 0.22576743214397874  
Testing accuracy: 0.9692  
Epoch 73

-----  
Training loss: 7.730346049803107e-06  
Training accuracy: 1.0  
Testing loss: 0.14397343795522144  
Testing accuracy: 0.9746  
Testing loss: 0.22604312975251828  
Testing accuracy: 0.9694  
Epoch 74

-----  
Training loss: 7.6139305831232905e-06  
Training accuracy: 1.0  
Testing loss: 0.14412320569706047  
Testing accuracy: 0.9746  
Testing loss: 0.22631341969306526  
Testing accuracy: 0.9694  
Epoch 75

-----  
Training loss: 7.5009836454071125e-06  
Training accuracy: 1.0  
Testing loss: 0.14427149626358285  
Testing accuracy: 0.9746  
Testing loss: 0.22657940130248475  
Testing accuracy: 0.9694  
Epoch 76

-----  
Training loss: 7.391085032254263e-06  
Training accuracy: 1.0  
Testing loss: 0.1444162353826241  
Testing accuracy: 0.9746  
Testing loss: 0.22684319427727814  
Testing accuracy: 0.9694  
Epoch 77

Training loss: 7.284505622082402e-06  
Training accuracy: 1.0  
Testing loss: 0.14456116051534673  
Testing accuracy: 0.9746  
Testing loss: 0.22710136387607555  
Testing accuracy: 0.9694  
Epoch 78  
-----

Training loss: 7.180840591614417e-06  
Training accuracy: 1.0  
Testing loss: 0.14470261809498822  
Testing accuracy: 0.9746  
Testing loss: 0.22735717553480717  
Testing accuracy: 0.9694  
Epoch 79  
-----

Training loss: 7.080049608405985e-06  
Training accuracy: 1.0  
Testing loss: 0.14484287073242139  
Testing accuracy: 0.9746  
Testing loss: 0.22761041436512625  
Testing accuracy: 0.9694  
Epoch 80  
-----

Training loss: 6.982240089095375e-06  
Training accuracy: 1.0  
Testing loss: 0.14498277631388481  
Testing accuracy: 0.9746  
Testing loss: 0.22785810827668046  
Testing accuracy: 0.9694  
Epoch 81  
-----

Training loss: 6.886947183577052e-06  
Training accuracy: 1.0  
Testing loss: 0.14511997840832078  
Testing accuracy: 0.9746  
Testing loss: 0.22810280993225734  
Testing accuracy: 0.9694  
Epoch 82  
-----

Training loss: 6.79428825111286e-06  
Training accuracy: 1.0  
Testing loss: 0.14525473784534712  
Testing accuracy: 0.9746  
Testing loss: 0.2283443220553195  
Testing accuracy: 0.9694  
Epoch 83  
-----

Training loss: 6.704097052282576e-06  
Training accuracy: 1.0  
Testing loss: 0.14538928784622834  
Testing accuracy: 0.9746  
Testing loss: 0.22858250912877734  
Testing accuracy: 0.9694  
Epoch 84

-----  
Training loss: 6.61626639413633e-06  
Training accuracy: 1.0  
Testing loss: 0.14552023024177677  
Testing accuracy: 0.9746  
Testing loss: 0.22881825481878526  
Testing accuracy: 0.9694  
Epoch 85

-----  
Training loss: 6.530638607262947e-06  
Training accuracy: 1.0  
Testing loss: 0.14565093336604204  
Testing accuracy: 0.9746  
Testing loss: 0.22904977444464802  
Testing accuracy: 0.9694  
Epoch 86

-----  
Training loss: 6.44722305565387e-06  
Training accuracy: 1.0  
Testing loss: 0.14577974206714292  
Testing accuracy: 0.9746  
Testing loss: 0.2292782280797571  
Testing accuracy: 0.9694  
Epoch 87

-----  
Training loss: 6.365879934883228e-06  
Training accuracy: 1.0  
Testing loss: 0.14590686084673343  
Testing accuracy: 0.9746  
Testing loss: 0.22950426351228775  
Testing accuracy: 0.9694  
Epoch 88

-----  
Training loss: 6.286610327791961e-06  
Training accuracy: 1.0  
Testing loss: 0.14603288643732573  
Testing accuracy: 0.9746  
Testing loss: 0.22972704421840484  
Testing accuracy: 0.9694  
Epoch 89

Training loss: 6.2092425759320485e-06  
Training accuracy: 1.0  
Testing loss: 0.14615828605497624  
Testing accuracy: 0.9746  
Testing loss: 0.2299478486043219  
Testing accuracy: 0.9694  
Epoch 90  
-----

Training loss: 6.133709618186502e-06  
Training accuracy: 1.0  
Testing loss: 0.1462812942475749  
Testing accuracy: 0.9746  
Testing loss: 0.23016831088465045  
Testing accuracy: 0.9694  
Epoch 91  
-----

Training loss: 6.0600806549553025e-06  
Training accuracy: 1.0  
Testing loss: 0.14640343033994793  
Testing accuracy: 0.9746  
Testing loss: 0.2303839600739002  
Testing accuracy: 0.9694  
Epoch 92  
-----

Training loss: 5.98810334684488e-06  
Training accuracy: 1.0  
Testing loss: 0.14652364399659024  
Testing accuracy: 0.9746  
Testing loss: 0.2305967228622203  
Testing accuracy: 0.9694  
Epoch 93  
-----

Training loss: 5.917832211431705e-06  
Training accuracy: 1.0  
Testing loss: 0.14664201695757914  
Testing accuracy: 0.9746  
Testing loss: 0.23080910427516893  
Testing accuracy: 0.9694  
Epoch 94  
-----

Training loss: 5.849240518088525e-06  
Training accuracy: 1.0  
Testing loss: 0.14675923519680328  
Testing accuracy: 0.9746  
Testing loss: 0.2310163484764213  
Testing accuracy: 0.9694  
Epoch 95  
-----



Training loss: 5.782158553845847e-06  
Training accuracy: 1.0  
Testing loss: 0.14687466509191963  
Testing accuracy: 0.9746  
Testing loss: 0.23122343807747303  
Testing accuracy: 0.9694  
Epoch 96  
-----

Training loss: 5.716625007489195e-06  
Training accuracy: 1.0  
Testing loss: 0.14698959297286385  
Testing accuracy: 0.9746  
Testing loss: 0.2314263595111257  
Testing accuracy: 0.9694  
Epoch 97  
-----

Training loss: 5.652562323096373e-06  
Training accuracy: 1.0  
Testing loss: 0.14710340752307824  
Testing accuracy: 0.9746  
Testing loss: 0.23162732045411272  
Testing accuracy: 0.9694  
Epoch 98  
-----

Training loss: 5.589919902201124e-06  
Training accuracy: 1.0  
Testing loss: 0.14721567798695417  
Testing accuracy: 0.9746  
Testing loss: 0.23182730537568663  
Testing accuracy: 0.9694  
Epoch 99  
-----

Training loss: 5.528687941011942e-06  
Training accuracy: 1.0  
Testing loss: 0.14732626209270344  
Testing accuracy: 0.9746  
Testing loss: 0.2320228557817104  
Testing accuracy: 0.9696  
Epoch 100  
-----

Training loss: 5.468806254401312e-06  
Training accuracy: 1.0  
Testing loss: 0.14743743184015562  
Testing accuracy: 0.9746  
Testing loss: 0.23221813703803715  
Testing accuracy: 0.9696  
Epoch 101  
-----

Training loss: 5.410076445885509e-06  
Training accuracy: 1.0  
Testing loss: 0.1475473042410507  
Testing accuracy: 0.9746  
Testing loss: 0.23241075769632266  
Testing accuracy: 0.9696  
Epoch 102  
-----

Training loss: 5.352655894923088e-06  
Training accuracy: 1.0  
Testing loss: 0.14765502173362577  
Testing accuracy: 0.9746  
Testing loss: 0.2326028521102924  
Testing accuracy: 0.9696  
Epoch 103  
-----

Training loss: 5.296434124178663e-06  
Training accuracy: 1.0  
Testing loss: 0.14776220204058368  
Testing accuracy: 0.9746  
Testing loss: 0.23279177288895067  
Testing accuracy: 0.9696  
Epoch 104  
-----

Training loss: 5.2413279863929765e-06  
Training accuracy: 1.0  
Testing loss: 0.14786774238257425  
Testing accuracy: 0.9746  
Testing loss: 0.23297952735330113  
Testing accuracy: 0.9696  
Epoch 105  
-----

Training loss: 5.187344757480541e-06  
Training accuracy: 1.0  
Testing loss: 0.14797196197327508  
Testing accuracy: 0.9746  
Testing loss: 0.23316593065974509  
Testing accuracy: 0.9696  
Epoch 106  
-----

Training loss: 5.134567543912131e-06  
Training accuracy: 1.0  
Testing loss: 0.1480760941034467  
Testing accuracy: 0.9746  
Testing loss: 0.23334859314575557  
Testing accuracy: 0.9696  
Epoch 107  
-----

Training loss: 5.082749461618144e-06  
Training accuracy: 1.0  
Testing loss: 0.1481786049092216  
Testing accuracy: 0.9746  
Testing loss: 0.23353122976942195  
Testing accuracy: 0.9696  
Epoch 108  
-----

Training loss: 5.031963338998636e-06  
Training accuracy: 1.0  
Testing loss: 0.14827921360432697  
Testing accuracy: 0.9746  
Testing loss: 0.2337122388580101  
Testing accuracy: 0.9696  
Epoch 109  
-----

Training loss: 4.982178645063343e-06  
Training accuracy: 1.0  
Testing loss: 0.1483799740616631  
Testing accuracy: 0.9746  
Testing loss: 0.23389147698959367  
Testing accuracy: 0.9696  
Epoch 110  
-----

Training loss: 4.933341763445958e-06  
Training accuracy: 1.0  
Testing loss: 0.14847982933643283  
Testing accuracy: 0.9746  
Testing loss: 0.23406913517142444  
Testing accuracy: 0.9696  
Epoch 111  
-----

Training loss: 4.885389424437849e-06  
Training accuracy: 1.0  
Testing loss: 0.14857773930808318  
Testing accuracy: 0.9746  
Testing loss: 0.2342452507530077  
Testing accuracy: 0.9696  
Epoch 112  
-----

Training loss: 4.838440205803327e-06  
Training accuracy: 1.0  
Testing loss: 0.14867589498683445  
Testing accuracy: 0.9746  
Testing loss: 0.23442088309829606  
Testing accuracy: 0.9696  
Epoch 113  
-----

Training loss: 4.792279541029092e-06  
Training accuracy: 1.0  
Testing loss: 0.14877350855312654  
Testing accuracy: 0.9746  
Testing loss: 0.23459575775093608  
Testing accuracy: 0.9696  
Epoch 114

-----  
Training loss: 4.747006904649112e-06  
Training accuracy: 1.0  
Testing loss: 0.14886857706037843  
Testing accuracy: 0.9746  
Testing loss: 0.23476835957482636  
Testing accuracy: 0.9696  
Epoch 115

-----  
Training loss: 4.7025259173509945e-06  
Training accuracy: 1.0  
Testing loss: 0.1489645745510762  
Testing accuracy: 0.9746  
Testing loss: 0.23494181971133313  
Testing accuracy: 0.9696  
Epoch 116

-----  
Training loss: 4.658840481724486e-06  
Training accuracy: 1.0  
Testing loss: 0.149058925483384  
Testing accuracy: 0.9746  
Testing loss: 0.23511347094988633  
Testing accuracy: 0.9696  
Epoch 117

-----  
Training loss: 4.6159847674334435e-06  
Training accuracy: 1.0  
Testing loss: 0.1491521513743571  
Testing accuracy: 0.9746  
Testing loss: 0.23528399754262322  
Testing accuracy: 0.9696  
Epoch 118

-----  
Training loss: 4.573854999131021e-06  
Training accuracy: 1.0  
Testing loss: 0.14924564275544314  
Testing accuracy: 0.9746  
Testing loss: 0.23545197996464157  
Testing accuracy: 0.9696  
Epoch 119

Training loss: 4.532495741746738e-06  
Training accuracy: 1.0  
Testing loss: 0.14933821946376613  
Testing accuracy: 0.9746  
Testing loss: 0.23561902733164697  
Testing accuracy: 0.9696  
Epoch 120  
-----

Training loss: 4.49179256666629e-06  
Training accuracy: 1.0  
Testing loss: 0.14942970789753607  
Testing accuracy: 0.9746  
Testing loss: 0.23578476323893202  
Testing accuracy: 0.9696  
Epoch 121  
-----

Training loss: 4.451896733598198e-06  
Training accuracy: 1.0  
Testing loss: 0.1495216801912937  
Testing accuracy: 0.9746  
Testing loss: 0.23594844616901378  
Testing accuracy: 0.9696  
Epoch 122  
-----

Training loss: 4.412588142379254e-06  
Training accuracy: 1.0  
Testing loss: 0.14961253091173718  
Testing accuracy: 0.9746  
Testing loss: 0.23611203591588067  
Testing accuracy: 0.9696  
Epoch 123  
-----

Training loss: 4.3740578704595976e-06  
Training accuracy: 1.0  
Testing loss: 0.1497022998246891  
Testing accuracy: 0.9746  
Testing loss: 0.2362733224006966  
Testing accuracy: 0.9696  
Epoch 124  
-----

Training loss: 4.336136523301522e-06  
Training accuracy: 1.0  
Testing loss: 0.14979098639802413  
Testing accuracy: 0.9746  
Testing loss: 0.23643341838035722  
Testing accuracy: 0.9696  
Epoch 125  
-----

Training loss: 4.2988423385499585e-06  
Training accuracy: 1.0  
Testing loss: 0.14987910012105138  
Testing accuracy: 0.9746  
Testing loss: 0.23659307078224642  
Testing accuracy: 0.9696  
Epoch 126  
-----

Training loss: 4.262227924248663e-06  
Training accuracy: 1.0  
Testing loss: 0.14996684459192203  
Testing accuracy: 0.9746  
Testing loss: 0.23675045572752443  
Testing accuracy: 0.9696  
Epoch 127  
-----

Training loss: 4.226116733564927e-06  
Training accuracy: 1.0  
Testing loss: 0.15005324858766148  
Testing accuracy: 0.9746  
Testing loss: 0.23690710917565488  
Testing accuracy: 0.9696  
Epoch 128  
-----

Training loss: 4.190728953108121e-06  
Training accuracy: 1.0  
Testing loss: 0.15013951297559996  
Testing accuracy: 0.9746  
Testing loss: 0.237062581784143  
Testing accuracy: 0.9696  
Epoch 129  
-----

Training loss: 4.155846290479775e-06  
Training accuracy: 1.0  
Testing loss: 0.15022524270048696  
Testing accuracy: 0.9746  
Testing loss: 0.2372166773937664  
Testing accuracy: 0.9696  
Epoch 130  
-----

Training loss: 4.121493373893701e-06  
Training accuracy: 1.0  
Testing loss: 0.1503089507076224  
Testing accuracy: 0.9746  
Testing loss: 0.23737049566393198  
Testing accuracy: 0.9698  
Epoch 131  
-----

Training loss: 4.087766771683328e-06  
Training accuracy: 1.0  
Testing loss: 0.15039368677164824  
Testing accuracy: 0.9746  
Testing loss: 0.23752154619010343  
Testing accuracy: 0.9698  
Epoch 132  
-----

Training loss: 4.054510074743001e-06  
Training accuracy: 1.0  
Testing loss: 0.1504773231152626  
Testing accuracy: 0.9746  
Testing loss: 0.23767173343062617  
Testing accuracy: 0.9698  
Epoch 133  
-----

Training loss: 4.021788991926282e-06  
Training accuracy: 1.0  
Testing loss: 0.15056146364088707  
Testing accuracy: 0.9746  
Testing loss: 0.23782262960811945  
Testing accuracy: 0.9698  
Epoch 134  
-----

Training loss: 3.989580540944747e-06  
Training accuracy: 1.0  
Testing loss: 0.15064319097721796  
Testing accuracy: 0.9746  
Testing loss: 0.23797113439961995  
Testing accuracy: 0.9698  
Epoch 135  
-----

Training loss: 3.957860503379264e-06  
Training accuracy: 1.0  
Testing loss: 0.15072531558956656  
Testing accuracy: 0.9746  
Testing loss: 0.23811971911825836  
Testing accuracy: 0.9698  
Epoch 136  
-----

Training loss: 3.926649833757773e-06  
Training accuracy: 1.0  
Testing loss: 0.1508075281433587  
Testing accuracy: 0.9746  
Testing loss: 0.238265967797179  
Testing accuracy: 0.9698  
Epoch 137  
-----

Training loss: 3.895936373131084e-06  
Training accuracy: 1.0  
Testing loss: 0.15088811090819432  
Testing accuracy: 0.9746  
Testing loss: 0.23841164947994303  
Testing accuracy: 0.9698  
Epoch 138  
-----

Training loss: 3.865681563494731e-06  
Training accuracy: 1.0  
Testing loss: 0.15096910317600562  
Testing accuracy: 0.9746  
Testing loss: 0.23855679503082716  
Testing accuracy: 0.9698  
Epoch 139  
-----

Training loss: 3.835866814604678e-06  
Training accuracy: 1.0  
Testing loss: 0.15104900704715274  
Testing accuracy: 0.9746  
Testing loss: 0.23870028649360717  
Testing accuracy: 0.9698  
Epoch 140  
-----

Training loss: 3.8064927718969613e-06  
Training accuracy: 1.0  
Testing loss: 0.15112850400313035  
Testing accuracy: 0.9746  
Testing loss: 0.23884246893270838  
Testing accuracy: 0.9698  
Epoch 141  
-----

Training loss: 3.777578756494529e-06  
Training accuracy: 1.0  
Testing loss: 0.1512074694815866  
Testing accuracy: 0.9746  
Testing loss: 0.23898356428236175  
Testing accuracy: 0.9698  
Epoch 142  
-----

Training loss: 3.7490603790756762e-06  
Training accuracy: 1.0  
Testing loss: 0.1512861153931906  
Testing accuracy: 0.9746  
Testing loss: 0.2391243725019658  
Testing accuracy: 0.9698  
Epoch 143  
-----



Training loss: 3.720957999990663e-06

Training accuracy: 1.0

Testing loss: 0.1513640782501737

Testing accuracy: 0.9746

Testing loss: 0.2392645439879494

Testing accuracy: 0.9698

Epoch 144

-----  
Training loss: 3.6932474351108816e-06

Training accuracy: 1.0

Testing loss: 0.15144139113245217

Testing accuracy: 0.9746

Testing loss: 0.23940335002124977

Testing accuracy: 0.9698

Epoch 145

-----  
Training loss: 3.6659910238015133e-06

Training accuracy: 1.0

Testing loss: 0.1515182896202463

Testing accuracy: 0.9746

Testing loss: 0.23954075766316854

Testing accuracy: 0.9698

Epoch 146

-----  
Training loss: 3.639040618508172e-06

Training accuracy: 1.0

Testing loss: 0.15159435826825698

Testing accuracy: 0.9746

Testing loss: 0.23967642318916088

Testing accuracy: 0.9698

Epoch 147

-----  
Training loss: 3.612525200355815e-06

Training accuracy: 1.0

Testing loss: 0.1516704600402855

Testing accuracy: 0.9746

Testing loss: 0.23981190787558682

Testing accuracy: 0.9698

Epoch 148

-----  
Training loss: 3.5863091445032477e-06

Training accuracy: 1.0

Testing loss: 0.15174471888241586

Testing accuracy: 0.9746

Testing loss: 0.23994708008114504

Testing accuracy: 0.9698

Epoch 149

Training loss: 3.560586198178135e-06

Training accuracy: 1.0

Testing loss: 0.15181937064921752

Testing accuracy: 0.9746

Testing loss: 0.24008043093902207

Testing accuracy: 0.9698

Epoch 150

-----  
Training loss: 3.535156837749547e-06

Training accuracy: 1.0

Testing loss: 0.1518931138303971

Testing accuracy: 0.9746

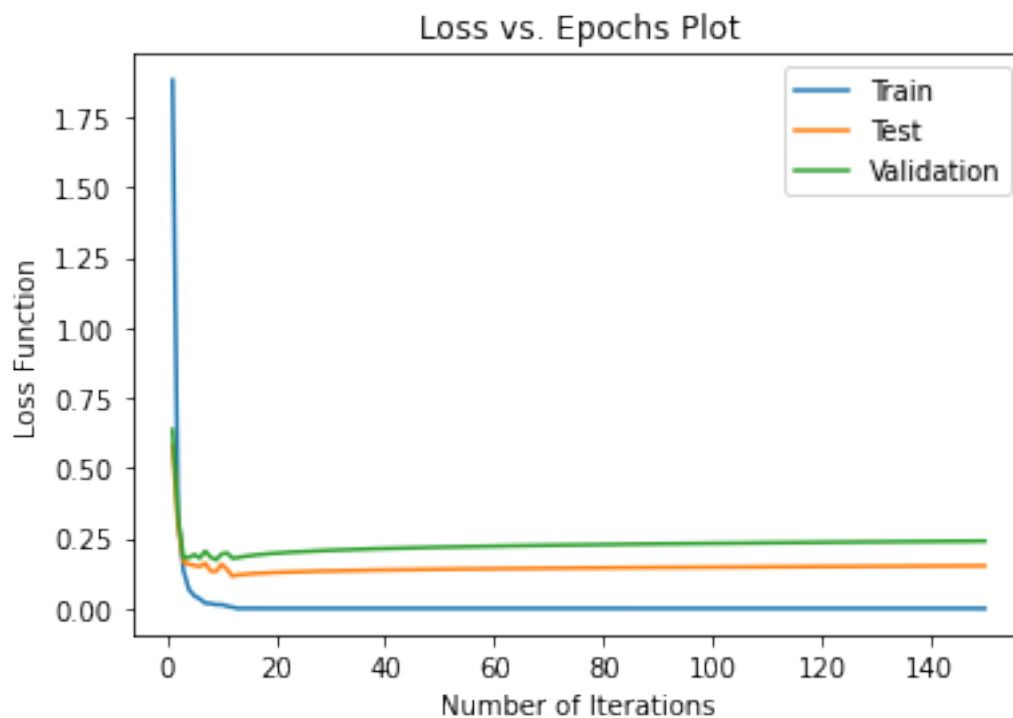
Testing loss: 0.2402129960273438

Testing accuracy: 0.9696

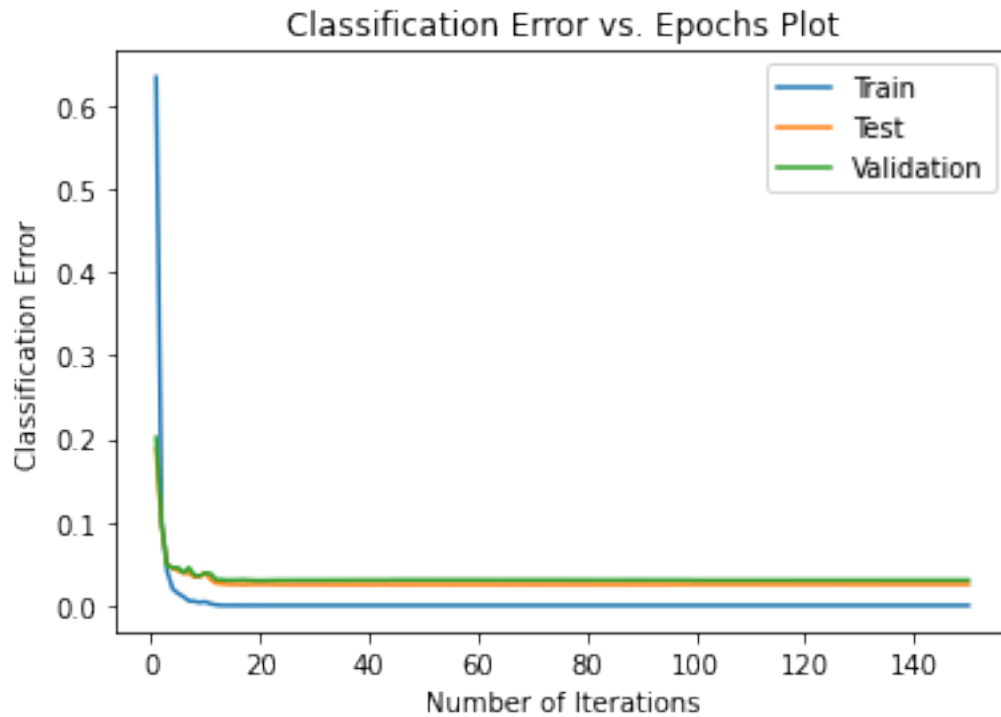
Done

Total Time Consumed: 8327.49877166748

```
[83]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[84]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



#### 6.4.5 Learning Rate = 0.5

```
[85]: # Define HyperParameters
# Number of Classes = 19
num_classes = 19
learning_rate = 0.5
batch_size = 64
num_epochs = 150
CNN_5 = CNN1(num_classes).double()

# Batch Dataloader
train_loader = DataLoader(X_train, batch_size = batch_size)
train_loader_y = DataLoader(Y_train.type(torch.LongTensor), batch_size = batch_size)
test_loader = DataLoader(X_test, batch_size = batch_size)
test_loader_y = DataLoader(Y_test.type(torch.LongTensor), batch_size = batch_size)
val_loader = DataLoader(X_val, batch_size = batch_size)
val_loader_y = DataLoader(Y_val.type(torch.LongTensor), batch_size = batch_size)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
optimizer = optim.SGD(CNN_5.parameters(), lr = learning_rate)
```

```
[86]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.
    ↪append(train_loop7(train_loader,train_loader_y,CNN_5,loss,optimizer))
    test_loss_record.append(test_loop7(test_loader,test_loader_y,CNN_5,loss))
    val_loss_record.append(test_loop7(val_loader,val_loader_y,CNN_5,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 2.2546351951514043
Training accuracy: 0.2434
Testing loss: 1.2123662931003962
Testing accuracy: 0.6684
Testing loss: 1.2616139588850737
Testing accuracy: 0.6478
Epoch 2
```

```
-----
Training loss: 0.5061800451384768
Training accuracy: 0.84755
Testing loss: 0.3094987507556903
Testing accuracy: 0.9068
Testing loss: 0.33035225385959643
Testing accuracy: 0.907
Epoch 3
```

```
-----
Training loss: 0.20505286249564675
Training accuracy: 0.9413
Testing loss: 0.23563692501858732
Testing accuracy: 0.937
Testing loss: 0.2631870177180386
Testing accuracy: 0.9348
Epoch 4
```

```
-----
Training loss: 0.12166823076685707
Training accuracy: 0.9629
Testing loss: 0.19931636035215214
Testing accuracy: 0.9458
Testing loss: 0.2280247592830067
Testing accuracy: 0.9458
Epoch 5
```

Training loss: 0.08397028312935195  
Training accuracy: 0.9743  
Testing loss: 0.24420885199643913  
Testing accuracy: 0.9412  
Testing loss: 0.2591591669487432  
Testing accuracy: 0.9392  
Epoch 6  
-----

Training loss: 0.07352680580172496  
Training accuracy: 0.97735  
Testing loss: 0.27487858271128845  
Testing accuracy: 0.9418  
Testing loss: 0.27949833819390435  
Testing accuracy: 0.9412  
Epoch 7  
-----

Training loss: 0.056282124789272824  
Training accuracy: 0.9834  
Testing loss: 0.2288916566681641  
Testing accuracy: 0.9482  
Testing loss: 0.2874111203222825  
Testing accuracy: 0.9384  
Epoch 8  
-----

Training loss: 0.056374190926824996  
Training accuracy: 0.9838  
Testing loss: 0.19269077546074043  
Testing accuracy: 0.9556  
Testing loss: 0.22858686527775934  
Testing accuracy: 0.9544  
Epoch 9  
-----

Training loss: 0.04852795375806019  
Training accuracy: 0.986  
Testing loss: 0.20019334793183774  
Testing accuracy: 0.9552  
Testing loss: 0.22446941731807774  
Testing accuracy: 0.9572  
Epoch 10  
-----

Training loss: 0.035320106371235185  
Training accuracy: 0.99035  
Testing loss: 0.17219546393667723  
Testing accuracy: 0.9626  
Testing loss: 0.21971709335798892  
Testing accuracy: 0.9568  
Epoch 11  
-----

Training loss: 0.027677915665429254  
Training accuracy: 0.9923  
Testing loss: 0.23344525370625324  
Testing accuracy: 0.9548  
Testing loss: 0.27843640466176595  
Testing accuracy: 0.9494  
Epoch 12

-----  
Training loss: 0.029269140851109956  
Training accuracy: 0.9915  
Testing loss: 0.24708702402342347  
Testing accuracy: 0.9502  
Testing loss: 0.3057559575383665  
Testing accuracy: 0.946  
Epoch 13

-----  
Training loss: 0.03472854565491883  
Training accuracy: 0.99065  
Testing loss: 0.19084766154687588  
Testing accuracy: 0.9598  
Testing loss: 0.25686917650014096  
Testing accuracy: 0.9528  
Epoch 14

-----  
Training loss: 0.03331540658643802  
Training accuracy: 0.9912  
Testing loss: 0.17088684035903495  
Testing accuracy: 0.9634  
Testing loss: 0.2011482176980057  
Testing accuracy: 0.9602  
Epoch 15

-----  
Training loss: 0.014985565399385715  
Training accuracy: 0.99565  
Testing loss: 0.16188430300188428  
Testing accuracy: 0.9696  
Testing loss: 0.23582219570479665  
Testing accuracy: 0.962  
Epoch 16

-----  
Training loss: 0.004678748529414482  
Training accuracy: 0.99835  
Testing loss: 0.1853051096819203  
Testing accuracy: 0.9676  
Testing loss: 0.2533758644957758  
Testing accuracy: 0.9636  
Epoch 17

Training loss: 0.02420802801431751  
Training accuracy: 0.99325  
Testing loss: 0.2558884598834402  
Testing accuracy: 0.9536  
Testing loss: 0.31406509825059753  
Testing accuracy: 0.9506  
Epoch 18  
-----

Training loss: 0.03198019868047164  
Training accuracy: 0.992  
Testing loss: 0.21854180902855438  
Testing accuracy: 0.9588  
Testing loss: 0.23841530888863172  
Testing accuracy: 0.9548  
Epoch 19  
-----

Training loss: 0.017734924541251283  
Training accuracy: 0.99515  
Testing loss: 0.2996651986528171  
Testing accuracy: 0.949  
Testing loss: 0.2890723049368173  
Testing accuracy: 0.9484  
Epoch 20  
-----

Training loss: 0.01908929346223139  
Training accuracy: 0.99555  
Testing loss: 0.16792475298048998  
Testing accuracy: 0.9678  
Testing loss: 0.20794687527769343  
Testing accuracy: 0.964  
Epoch 21  
-----

Training loss: 0.005062006055508097  
Training accuracy: 0.9983  
Testing loss: 0.17714934155608308  
Testing accuracy: 0.9686  
Testing loss: 0.2269548868432949  
Testing accuracy: 0.9656  
Epoch 22  
-----

Training loss: 0.005993924344687652  
Training accuracy: 0.9983  
Testing loss: 0.17007919993420417  
Testing accuracy: 0.9714  
Testing loss: 0.21856635422727563  
Testing accuracy: 0.9682  
Epoch 23  
-----

```
Training loss: 0.0054064166418896
Training accuracy: 0.9987
Testing loss: 0.18223138597368418
Testing accuracy: 0.9676
Testing loss: 0.21586457708900147
Testing accuracy: 0.966
Epoch 24
-----
Training loss: 0.001470713521321611
Training accuracy: 0.99975
Testing loss: 0.17352563682632918
Testing accuracy: 0.9724
Testing loss: 0.21871058190299786
Testing accuracy: 0.967
Epoch 25
-----
Training loss: 0.004995373305832815
Training accuracy: 0.99855
Testing loss: 0.20015273024817576
Testing accuracy: 0.966
Testing loss: 0.24218717404835974
Testing accuracy: 0.9636
Epoch 26
-----
Training loss: 0.018489449959614466
Training accuracy: 0.99565
Testing loss: 0.3369698367124854
Testing accuracy: 0.9452
Testing loss: 0.4663107829661245
Testing accuracy: 0.9324
Epoch 27
-----
Training loss: 0.024900817665427104
Training accuracy: 0.9935
Testing loss: 0.31416800410879103
Testing accuracy: 0.9552
Testing loss: 0.35018351338008763
Testing accuracy: 0.9512
Epoch 28
-----
Training loss: 0.028919653011332275
Training accuracy: 0.9914
Testing loss: 0.22250063028015823
Testing accuracy: 0.96
Testing loss: 0.2880376461881827
Testing accuracy: 0.9574
Epoch 29
-----
```



Training loss: 0.01629294694258969  
Training accuracy: 0.9963  
Testing loss: 0.18012382056099738  
Testing accuracy: 0.9638  
Testing loss: 0.2329486821192695  
Testing accuracy: 0.9618  
Epoch 30  
-----

Training loss: 0.006425970411220248  
Training accuracy: 0.9983  
Testing loss: 0.18778241897658624  
Testing accuracy: 0.9696  
Testing loss: 0.2365938748489988  
Testing accuracy: 0.9676  
Epoch 31  
-----

Training loss: 0.005600000331498557  
Training accuracy: 0.99835  
Testing loss: 0.18808964703017708  
Testing accuracy: 0.9702  
Testing loss: 0.25141034303941867  
Testing accuracy: 0.964  
Epoch 32  
-----

Training loss: 0.002925288046459326  
Training accuracy: 0.9993  
Testing loss: 0.19242693551750273  
Testing accuracy: 0.9696  
Testing loss: 0.2534370622639193  
Testing accuracy: 0.9648  
Epoch 33  
-----

Training loss: 0.00028359860738581794  
Training accuracy: 0.99995  
Testing loss: 0.18842882376626577  
Testing accuracy: 0.9704  
Testing loss: 0.24315881495886457  
Testing accuracy: 0.9682  
Epoch 34  
-----

Training loss: 3.731212271659184e-05  
Training accuracy: 1.0  
Testing loss: 0.18891328466304916  
Testing accuracy: 0.9704  
Testing loss: 0.24511476707783364  
Testing accuracy: 0.9686  
Epoch 35  
-----

Training loss: 2.8389140787397503e-05  
Training accuracy: 1.0  
Testing loss: 0.1895101627711612  
Testing accuracy: 0.971  
Testing loss: 0.24671936128524213  
Testing accuracy: 0.969  
Epoch 36  
-----

Training loss: 2.3331156772657136e-05  
Training accuracy: 1.0  
Testing loss: 0.19008244678812095  
Testing accuracy: 0.971  
Testing loss: 0.24808505044063073  
Testing accuracy: 0.969  
Epoch 37  
-----

Training loss: 1.9932831591372344e-05  
Training accuracy: 1.0  
Testing loss: 0.1906287880319803  
Testing accuracy: 0.971  
Testing loss: 0.2493067927959393  
Testing accuracy: 0.969  
Epoch 38  
-----

Training loss: 1.7464821329663248e-05  
Training accuracy: 1.0  
Testing loss: 0.19115045539844164  
Testing accuracy: 0.971  
Testing loss: 0.2503819897162332  
Testing accuracy: 0.9694  
Epoch 39  
-----

Training loss: 1.5527072491478253e-05  
Training accuracy: 1.0  
Testing loss: 0.19165906483986161  
Testing accuracy: 0.9712  
Testing loss: 0.2513799978785195  
Testing accuracy: 0.9694  
Epoch 40  
-----

Training loss: 1.4006952042949033e-05  
Training accuracy: 1.0  
Testing loss: 0.1921333644992855  
Testing accuracy: 0.9716  
Testing loss: 0.2523013963213343  
Testing accuracy: 0.9694  
Epoch 41  
-----

Training loss: 1.2768161994182076e-05  
Training accuracy: 1.0  
Testing loss: 0.19256903625303104  
Testing accuracy: 0.9718  
Testing loss: 0.2531489837432925  
Testing accuracy: 0.9696  
Epoch 42  
-----

Training loss: 1.1716906055294981e-05  
Training accuracy: 1.0  
Testing loss: 0.1929852503965116  
Testing accuracy: 0.972  
Testing loss: 0.2539591628396072  
Testing accuracy: 0.9696  
Epoch 43  
-----

Training loss: 1.0838246999773262e-05  
Training accuracy: 1.0  
Testing loss: 0.1933950986215077  
Testing accuracy: 0.972  
Testing loss: 0.254725026444189  
Testing accuracy: 0.9696  
Epoch 44  
-----

Training loss: 1.0089818474383433e-05  
Training accuracy: 1.0  
Testing loss: 0.19378599019966103  
Testing accuracy: 0.972  
Testing loss: 0.2554461662152814  
Testing accuracy: 0.9696  
Epoch 45  
-----

Training loss: 9.442117263249877e-06  
Training accuracy: 1.0  
Testing loss: 0.1941539401143885  
Testing accuracy: 0.9722  
Testing loss: 0.2561193769708899  
Testing accuracy: 0.9698  
Epoch 46  
-----

Training loss: 8.87197025658339e-06  
Training accuracy: 1.0  
Testing loss: 0.19450544241693996  
Testing accuracy: 0.9722  
Testing loss: 0.2567593475471796  
Testing accuracy: 0.97  
Epoch 47  
-----

Training loss: 8.369346184852476e-06  
Training accuracy: 1.0  
Testing loss: 0.1948449295503039  
Testing accuracy: 0.9722  
Testing loss: 0.2573683429188863  
Testing accuracy: 0.97  
Epoch 48  
-----

Training loss: 7.92243337260666e-06  
Training accuracy: 1.0  
Testing loss: 0.19517236174303276  
Testing accuracy: 0.972  
Testing loss: 0.2579509508652658  
Testing accuracy: 0.97  
Epoch 49  
-----

Training loss: 7.521227127218841e-06  
Training accuracy: 1.0  
Testing loss: 0.195492441174506  
Testing accuracy: 0.972  
Testing loss: 0.25850813348993623  
Testing accuracy: 0.97  
Epoch 50  
-----

Training loss: 7.160379555620719e-06  
Training accuracy: 1.0  
Testing loss: 0.19580274664078517  
Testing accuracy: 0.972  
Testing loss: 0.2590398050955975  
Testing accuracy: 0.97  
Epoch 51  
-----

Training loss: 6.832719264989794e-06  
Training accuracy: 1.0  
Testing loss: 0.19609991429455567  
Testing accuracy: 0.972  
Testing loss: 0.2595540159425498  
Testing accuracy: 0.9702  
Epoch 52  
-----

Training loss: 6.5347508896466204e-06  
Training accuracy: 1.0  
Testing loss: 0.19638762971862359  
Testing accuracy: 0.972  
Testing loss: 0.26004804221913363  
Testing accuracy: 0.9702  
Epoch 53  
-----

Training loss: 6.26243648573684e-06  
Training accuracy: 1.0  
Testing loss: 0.19666712512009807  
Testing accuracy: 0.972  
Testing loss: 0.2605254922162047  
Testing accuracy: 0.9702  
Epoch 54  
-----

Training loss: 6.012278100680559e-06  
Training accuracy: 1.0  
Testing loss: 0.196938876852528  
Testing accuracy: 0.9722  
Testing loss: 0.26099044586071857  
Testing accuracy: 0.9702  
Epoch 55  
-----

Training loss: 5.7816412062159185e-06  
Training accuracy: 1.0  
Testing loss: 0.19720131734062368  
Testing accuracy: 0.9726  
Testing loss: 0.26143846574150864  
Testing accuracy: 0.9702  
Epoch 56  
-----

Training loss: 5.568513775761287e-06  
Training accuracy: 1.0  
Testing loss: 0.1974572845973234  
Testing accuracy: 0.9726  
Testing loss: 0.26187230859363325  
Testing accuracy: 0.9704  
Epoch 57  
-----

Training loss: 5.370754253627315e-06  
Training accuracy: 1.0  
Testing loss: 0.19770670896579925  
Testing accuracy: 0.9726  
Testing loss: 0.26229323248074937  
Testing accuracy: 0.9704  
Epoch 58  
-----

Training loss: 5.187028685211742e-06  
Training accuracy: 1.0  
Testing loss: 0.19795104807679526  
Testing accuracy: 0.9726  
Testing loss: 0.2627006919481849  
Testing accuracy: 0.9704  
Epoch 59  
-----

Training loss: 5.015460062179586e-06  
Training accuracy: 1.0  
Testing loss: 0.19819082191032397  
Testing accuracy: 0.9726  
Testing loss: 0.2630958248676474  
Testing accuracy: 0.9704  
Epoch 60  
-----

Training loss: 4.854884539093784e-06  
Training accuracy: 1.0  
Testing loss: 0.19842574297790344  
Testing accuracy: 0.9726  
Testing loss: 0.26348106114295605  
Testing accuracy: 0.9708  
Epoch 61  
-----

Training loss: 4.704590019308517e-06  
Training accuracy: 1.0  
Testing loss: 0.198656282557532  
Testing accuracy: 0.9724  
Testing loss: 0.26385290940626455  
Testing accuracy: 0.9708  
Epoch 62  
-----

Training loss: 4.5631544334837295e-06  
Training accuracy: 1.0  
Testing loss: 0.19888080784836223  
Testing accuracy: 0.9724  
Testing loss: 0.264216705840093  
Testing accuracy: 0.9704  
Epoch 63  
-----

Training loss: 4.4297981309021825e-06  
Training accuracy: 1.0  
Testing loss: 0.19909986223877083  
Testing accuracy: 0.9724  
Testing loss: 0.26457023527890533  
Testing accuracy: 0.9704  
Epoch 64  
-----

Training loss: 4.303977405580925e-06  
Training accuracy: 1.0  
Testing loss: 0.19931511640905664  
Testing accuracy: 0.9724  
Testing loss: 0.26491411646422075  
Testing accuracy: 0.9704  
Epoch 65  
-----

Training loss: 4.185078760593628e-06  
Training accuracy: 1.0  
Testing loss: 0.19952496195608627  
Testing accuracy: 0.9726  
Testing loss: 0.2652515939092489  
Testing accuracy: 0.9706  
Epoch 66  
-----

Training loss: 4.072734323330015e-06  
Training accuracy: 1.0  
Testing loss: 0.199731302908263  
Testing accuracy: 0.9726  
Testing loss: 0.26557978798252524  
Testing accuracy: 0.9706  
Epoch 67  
-----

Training loss: 3.966181239161539e-06  
Training accuracy: 1.0  
Testing loss: 0.19993507162195798  
Testing accuracy: 0.9726  
Testing loss: 0.26590199109123186  
Testing accuracy: 0.9706  
Epoch 68  
-----

Training loss: 3.865210025954388e-06  
Training accuracy: 1.0  
Testing loss: 0.20013412312487738  
Testing accuracy: 0.9726  
Testing loss: 0.2662164405960364  
Testing accuracy: 0.9706  
Epoch 69  
-----

Training loss: 3.769262439098941e-06  
Training accuracy: 1.0  
Testing loss: 0.20032915458079728  
Testing accuracy: 0.9726  
Testing loss: 0.26652666578162715  
Testing accuracy: 0.9706  
Epoch 70  
-----

Training loss: 3.6779973487369194e-06  
Training accuracy: 1.0  
Testing loss: 0.2005202734551119  
Testing accuracy: 0.9724  
Testing loss: 0.26682975540484266  
Testing accuracy: 0.9706  
Epoch 71  
-----

Training loss: 3.5910700057885366e-06  
Training accuracy: 1.0  
Testing loss: 0.20070755725518802  
Testing accuracy: 0.9724  
Testing loss: 0.2671263636009914  
Testing accuracy: 0.9706  
Epoch 72  
-----

Training loss: 3.5083612915111217e-06  
Training accuracy: 1.0  
Testing loss: 0.20089237562322224  
Testing accuracy: 0.9724  
Testing loss: 0.26741622087741096  
Testing accuracy: 0.9706  
Epoch 73  
-----

Training loss: 3.4292369750801735e-06  
Training accuracy: 1.0  
Testing loss: 0.20107463704648376  
Testing accuracy: 0.9724  
Testing loss: 0.2677012684032683  
Testing accuracy: 0.9706  
Epoch 74  
-----

Training loss: 3.353510386072156e-06  
Training accuracy: 1.0  
Testing loss: 0.2012531315736797  
Testing accuracy: 0.9724  
Testing loss: 0.2679803940050127  
Testing accuracy: 0.9706  
Epoch 75  
-----

Training loss: 3.2811932557653267e-06  
Training accuracy: 1.0  
Testing loss: 0.2014285360016214  
Testing accuracy: 0.9724  
Testing loss: 0.268253460800117  
Testing accuracy: 0.9706  
Epoch 76  
-----

Training loss: 3.2119042677291023e-06  
Training accuracy: 1.0  
Testing loss: 0.20160148212376272  
Testing accuracy: 0.9724  
Testing loss: 0.2685213221504327  
Testing accuracy: 0.9706  
Epoch 77  
-----



Training loss: 3.1455354883695094e-06  
Training accuracy: 1.0  
Testing loss: 0.20177155537243738  
Testing accuracy: 0.9724  
Testing loss: 0.2687837667554004  
Testing accuracy: 0.9704  
Epoch 78  
-----

Training loss: 3.081890258568019e-06  
Training accuracy: 1.0  
Testing loss: 0.20193866125080812  
Testing accuracy: 0.9724  
Testing loss: 0.26904106570332925  
Testing accuracy: 0.9704  
Epoch 79  
-----

Training loss: 3.02062102534369e-06  
Training accuracy: 1.0  
Testing loss: 0.2021037663543038  
Testing accuracy: 0.9724  
Testing loss: 0.269294250127396  
Testing accuracy: 0.9704  
Epoch 80  
-----

Training loss: 2.961704841567136e-06  
Training accuracy: 1.0  
Testing loss: 0.2022662028531239  
Testing accuracy: 0.9724  
Testing loss: 0.26954301144784254  
Testing accuracy: 0.9708  
Epoch 81  
-----

Training loss: 2.905096205952307e-06  
Training accuracy: 1.0  
Testing loss: 0.20242557118555402  
Testing accuracy: 0.9724  
Testing loss: 0.26978729863733153  
Testing accuracy: 0.9708  
Epoch 82  
-----

Training loss: 2.850607952918367e-06  
Training accuracy: 1.0  
Testing loss: 0.20258222193424633  
Testing accuracy: 0.9724  
Testing loss: 0.2700276949601228  
Testing accuracy: 0.9708  
Epoch 83  
-----

Training loss: 2.798109952758954e-06  
Training accuracy: 1.0  
Testing loss: 0.20273677929672584  
Testing accuracy: 0.9724  
Testing loss: 0.270265013169256  
Testing accuracy: 0.9708  
Epoch 84  
-----

Training loss: 2.747488724992678e-06  
Training accuracy: 1.0  
Testing loss: 0.20288745755222307  
Testing accuracy: 0.9724  
Testing loss: 0.2704970248380675  
Testing accuracy: 0.9708  
Epoch 85  
-----

Training loss: 2.698602252422982e-06  
Training accuracy: 1.0  
Testing loss: 0.20303654116652084  
Testing accuracy: 0.9724  
Testing loss: 0.27072669232977364  
Testing accuracy: 0.9708  
Epoch 86  
-----

Training loss: 2.6513883870390567e-06  
Training accuracy: 1.0  
Testing loss: 0.20318304705775073  
Testing accuracy: 0.9722  
Testing loss: 0.2709531943737367  
Testing accuracy: 0.9708  
Epoch 87  
-----

Training loss: 2.6057868657633383e-06  
Training accuracy: 1.0  
Testing loss: 0.20332757774766588  
Testing accuracy: 0.9722  
Testing loss: 0.271176941661398  
Testing accuracy: 0.9708  
Epoch 88  
-----

Training loss: 2.5615649376397847e-06  
Training accuracy: 1.0  
Testing loss: 0.20347062886284364  
Testing accuracy: 0.9722  
Testing loss: 0.2713984287312084  
Testing accuracy: 0.9708  
Epoch 89  
-----

Training loss: 2.518864707693118e-06  
Training accuracy: 1.0  
Testing loss: 0.20361212236498266  
Testing accuracy: 0.9722  
Testing loss: 0.2716159730956851  
Testing accuracy: 0.9708  
Epoch 90  
-----

Training loss: 2.4775462966886325e-06  
Training accuracy: 1.0  
Testing loss: 0.20375135948479348  
Testing accuracy: 0.9722  
Testing loss: 0.27182998179210827  
Testing accuracy: 0.9708  
Epoch 91  
-----

Training loss: 2.4375390348890457e-06  
Training accuracy: 1.0  
Testing loss: 0.2038886251709866  
Testing accuracy: 0.9722  
Testing loss: 0.2720416653716646  
Testing accuracy: 0.9708  
Epoch 92  
-----

Training loss: 2.3987930511307435e-06  
Training accuracy: 1.0  
Testing loss: 0.20402482539198016  
Testing accuracy: 0.9722  
Testing loss: 0.2722504466773155  
Testing accuracy: 0.9708  
Epoch 93  
-----

Training loss: 2.361255687918122e-06  
Training accuracy: 1.0  
Testing loss: 0.2041597370036086  
Testing accuracy: 0.9722  
Testing loss: 0.27245553184078375  
Testing accuracy: 0.9708  
Epoch 94  
-----

Training loss: 2.324887746247531e-06  
Training accuracy: 1.0  
Testing loss: 0.2042924828760237  
Testing accuracy: 0.9722  
Testing loss: 0.27265869968147416  
Testing accuracy: 0.9708  
Epoch 95  
-----

```
Training loss: 2.28958098217709e-06
Training accuracy: 1.0
Testing loss: 0.2044232514351965
Testing accuracy: 0.9722
Testing loss: 0.2728585857721231
Testing accuracy: 0.9704
Epoch 96
-----
Training loss: 2.2553513974775523e-06
Training accuracy: 1.0
Testing loss: 0.2045520539720992
Testing accuracy: 0.972
Testing loss: 0.2730554518716623
Testing accuracy: 0.9704
Epoch 97
-----
Training loss: 2.222147919283263e-06
Training accuracy: 1.0
Testing loss: 0.2046791387344358
Testing accuracy: 0.972
Testing loss: 0.27324894470870675
Testing accuracy: 0.9704
Epoch 98
-----
Training loss: 2.189858847589551e-06
Training accuracy: 1.0
Testing loss: 0.20480465229392622
Testing accuracy: 0.972
Testing loss: 0.2734406849678499
Testing accuracy: 0.9704
Epoch 99
-----
Training loss: 2.1585023489914646e-06
Training accuracy: 1.0
Testing loss: 0.20492890625865348
Testing accuracy: 0.972
Testing loss: 0.27363023671836406
Testing accuracy: 0.9704
Epoch 100
-----
Training loss: 2.1280668771371724e-06
Training accuracy: 1.0
Testing loss: 0.205051194093228
Testing accuracy: 0.972
Testing loss: 0.2738165780679202
Testing accuracy: 0.9704
Epoch 101
-----
```

Training loss: 2.098447580292523e-06  
Training accuracy: 1.0  
Testing loss: 0.20517268972190908  
Testing accuracy: 0.972  
Testing loss: 0.27400025969258307  
Testing accuracy: 0.9706  
Epoch 102

-----  
Training loss: 2.0696216012625272e-06  
Training accuracy: 1.0  
Testing loss: 0.205292215871872  
Testing accuracy: 0.972  
Testing loss: 0.2741818961855568  
Testing accuracy: 0.9706  
Epoch 103

-----  
Training loss: 2.041555286253058e-06  
Training accuracy: 1.0  
Testing loss: 0.2054106634549043  
Testing accuracy: 0.972  
Testing loss: 0.2743608272606359  
Testing accuracy: 0.9706  
Epoch 104

-----  
Training loss: 2.0142478691156094e-06  
Training accuracy: 1.0  
Testing loss: 0.20552782824058663  
Testing accuracy: 0.972  
Testing loss: 0.27453798109215266  
Testing accuracy: 0.9706  
Epoch 105

-----  
Training loss: 1.987658605849673e-06  
Training accuracy: 1.0  
Testing loss: 0.20564355622788066  
Testing accuracy: 0.972  
Testing loss: 0.2747132419058389  
Testing accuracy: 0.9706  
Epoch 106

-----  
Training loss: 1.961768933150139e-06  
Training accuracy: 1.0  
Testing loss: 0.20575744581883693  
Testing accuracy: 0.972  
Testing loss: 0.27488635578242304  
Testing accuracy: 0.9706  
Epoch 107

Training loss: 1.936544550078657e-06  
Training accuracy: 1.0  
Testing loss: 0.20587039701918988  
Testing accuracy: 0.972  
Testing loss: 0.2750572204198286  
Testing accuracy: 0.9706  
Epoch 108  
-----

Training loss: 1.9119351009477834e-06  
Training accuracy: 1.0  
Testing loss: 0.20598213706090004  
Testing accuracy: 0.972  
Testing loss: 0.27522648907653546  
Testing accuracy: 0.9706  
Epoch 109  
-----

Training loss: 1.8879433543623638e-06  
Training accuracy: 1.0  
Testing loss: 0.20609258661725702  
Testing accuracy: 0.972  
Testing loss: 0.2753936683805131  
Testing accuracy: 0.9706  
Epoch 110  
-----

Training loss: 1.8645646008730767e-06  
Training accuracy: 1.0  
Testing loss: 0.20620173471669165  
Testing accuracy: 0.972  
Testing loss: 0.27555822946003183  
Testing accuracy: 0.9706  
Epoch 111  
-----

Training loss: 1.8417605742561908e-06  
Training accuracy: 1.0  
Testing loss: 0.20630978264842514  
Testing accuracy: 0.972  
Testing loss: 0.2757214393860085  
Testing accuracy: 0.9706  
Epoch 112  
-----

Training loss: 1.8195191099719295e-06  
Training accuracy: 1.0  
Testing loss: 0.20641762351965695  
Testing accuracy: 0.972  
Testing loss: 0.2758830815322375  
Testing accuracy: 0.9706  
Epoch 113  
-----

Training loss: 1.797790211487217e-06  
Training accuracy: 1.0  
Testing loss: 0.20652357247019318  
Testing accuracy: 0.972  
Testing loss: 0.27604316803262874  
Testing accuracy: 0.9706  
Epoch 114  
-----

Training loss: 1.7765942040555594e-06  
Training accuracy: 1.0  
Testing loss: 0.20662845977630753  
Testing accuracy: 0.9722  
Testing loss: 0.27620102957253195  
Testing accuracy: 0.9706  
Epoch 115  
-----

Training loss: 1.7558766413530563e-06  
Training accuracy: 1.0  
Testing loss: 0.2067324347265569  
Testing accuracy: 0.9722  
Testing loss: 0.2763576303718302  
Testing accuracy: 0.9706  
Epoch 116  
-----

Training loss: 1.735633536248165e-06  
Training accuracy: 1.0  
Testing loss: 0.20683541907649788  
Testing accuracy: 0.9722  
Testing loss: 0.2765126997640477  
Testing accuracy: 0.9706  
Epoch 117  
-----

Training loss: 1.7158326715464957e-06  
Training accuracy: 1.0  
Testing loss: 0.20693755991836169  
Testing accuracy: 0.9722  
Testing loss: 0.27666588497704203  
Testing accuracy: 0.9706  
Epoch 118  
-----

Training loss: 1.6964472602014595e-06  
Training accuracy: 1.0  
Testing loss: 0.20703872594405767  
Testing accuracy: 0.9724  
Testing loss: 0.2768182502011954  
Testing accuracy: 0.9706  
Epoch 119  
-----

Training loss: 1.6774968633486307e-06  
Training accuracy: 1.0  
Testing loss: 0.2071390730490894  
Testing accuracy: 0.9724  
Testing loss: 0.27696915891707596  
Testing accuracy: 0.9706  
Epoch 120

-----  
Training loss: 1.6589571847622393e-06  
Training accuracy: 1.0  
Testing loss: 0.20723867647739475  
Testing accuracy: 0.9724  
Testing loss: 0.27711851316408115  
Testing accuracy: 0.9706  
Epoch 121

-----  
Training loss: 1.640837781635866e-06  
Training accuracy: 1.0  
Testing loss: 0.2073370925786228  
Testing accuracy: 0.9724  
Testing loss: 0.27726631032939153  
Testing accuracy: 0.9706  
Epoch 122

-----  
Training loss: 1.6230990007309453e-06  
Training accuracy: 1.0  
Testing loss: 0.20743424487459033  
Testing accuracy: 0.9724  
Testing loss: 0.2774131663513944  
Testing accuracy: 0.9706  
Epoch 123

-----  
Training loss: 1.6057378798023994e-06  
Training accuracy: 1.0  
Testing loss: 0.2075310860444416  
Testing accuracy: 0.9724  
Testing loss: 0.27755860115131287  
Testing accuracy: 0.9706  
Epoch 124

-----  
Training loss: 1.5887299464027067e-06  
Training accuracy: 1.0  
Testing loss: 0.20762652828066458  
Testing accuracy: 0.9724  
Testing loss: 0.2777021767008796  
Testing accuracy: 0.9706  
Epoch 125



Training loss: 1.572078039696308e-06  
Training accuracy: 1.0  
Testing loss: 0.20772151679485037  
Testing accuracy: 0.9724  
Testing loss: 0.27784480228754277  
Testing accuracy: 0.9706  
Epoch 126  
-----

Training loss: 1.555764689729799e-06  
Training accuracy: 1.0  
Testing loss: 0.20781533330006463  
Testing accuracy: 0.9724  
Testing loss: 0.2779860230531786  
Testing accuracy: 0.9706  
Epoch 127  
-----

Training loss: 1.5397795306918092e-06  
Training accuracy: 1.0  
Testing loss: 0.20790865267265682  
Testing accuracy: 0.9724  
Testing loss: 0.27812630912642694  
Testing accuracy: 0.9706  
Epoch 128  
-----

Training loss: 1.5241157009303816e-06  
Training accuracy: 1.0  
Testing loss: 0.20800072651323617  
Testing accuracy: 0.9724  
Testing loss: 0.27826473712453054  
Testing accuracy: 0.9706  
Epoch 129  
-----

Training loss: 1.5087735667868135e-06  
Training accuracy: 1.0  
Testing loss: 0.20809205745740447  
Testing accuracy: 0.9724  
Testing loss: 0.2784023508569655  
Testing accuracy: 0.9706  
Epoch 130  
-----

Training loss: 1.4937254507046878e-06  
Training accuracy: 1.0  
Testing loss: 0.20818272566369023  
Testing accuracy: 0.9724  
Testing loss: 0.27853877903348684  
Testing accuracy: 0.9706  
Epoch 131  
-----

Training loss: 1.4789832924484448e-06  
Training accuracy: 1.0  
Testing loss: 0.20827277122993218  
Testing accuracy: 0.9724  
Testing loss: 0.278674037104299  
Testing accuracy: 0.9706  
Epoch 132  
-----

Training loss: 1.4645299993959032e-06  
Training accuracy: 1.0  
Testing loss: 0.20836171704655654  
Testing accuracy: 0.9724  
Testing loss: 0.27880751265973625  
Testing accuracy: 0.9706  
Epoch 133  
-----

Training loss: 1.4503469577855776e-06  
Training accuracy: 1.0  
Testing loss: 0.20845029209390722  
Testing accuracy: 0.9724  
Testing loss: 0.2789402006656136  
Testing accuracy: 0.9706  
Epoch 134  
-----

Training loss: 1.4364425603241465e-06  
Training accuracy: 1.0  
Testing loss: 0.20853804014081279  
Testing accuracy: 0.9724  
Testing loss: 0.27907175745001694  
Testing accuracy: 0.9706  
Epoch 135  
-----

Training loss: 1.4227974662496004e-06  
Training accuracy: 1.0  
Testing loss: 0.20862528570340588  
Testing accuracy: 0.9724  
Testing loss: 0.27920238791867247  
Testing accuracy: 0.9706  
Epoch 136  
-----

Training loss: 1.4094193048986096e-06  
Training accuracy: 1.0  
Testing loss: 0.20871156271492283  
Testing accuracy: 0.9724  
Testing loss: 0.27933139889718556  
Testing accuracy: 0.9706  
Epoch 137  
-----

Training loss: 1.3962791439218096e-06  
Training accuracy: 1.0  
Testing loss: 0.2087970146534454  
Testing accuracy: 0.9724  
Testing loss: 0.27946000488765294  
Testing accuracy: 0.9706  
Epoch 138  
-----

Training loss: 1.3833839931184836e-06  
Training accuracy: 1.0  
Testing loss: 0.20888167754030496  
Testing accuracy: 0.9724  
Testing loss: 0.27958781812816585  
Testing accuracy: 0.9706  
Epoch 139  
-----

Training loss: 1.370714730870247e-06  
Training accuracy: 1.0  
Testing loss: 0.2089660989677251  
Testing accuracy: 0.9724  
Testing loss: 0.2797142403850308  
Testing accuracy: 0.9706  
Epoch 140  
-----

Training loss: 1.3582568008692972e-06  
Training accuracy: 1.0  
Testing loss: 0.2090491390341514  
Testing accuracy: 0.9724  
Testing loss: 0.2798409857042157  
Testing accuracy: 0.9706  
Epoch 141  
-----

Training loss: 1.3460117993832335e-06  
Training accuracy: 1.0  
Testing loss: 0.20913157431887194  
Testing accuracy: 0.9724  
Testing loss: 0.2799664540924289  
Testing accuracy: 0.9706  
Epoch 142  
-----

Training loss: 1.3339814955247386e-06  
Training accuracy: 1.0  
Testing loss: 0.20921331198115628  
Testing accuracy: 0.9724  
Testing loss: 0.28009103961580634  
Testing accuracy: 0.9706  
Epoch 143  
-----

Training loss: 1.322158605890507e-06  
Training accuracy: 1.0  
Testing loss: 0.20929439324204022  
Testing accuracy: 0.9724  
Testing loss: 0.2802141437532742  
Testing accuracy: 0.9706  
Epoch 144  
-----

Training loss: 1.3105406247528573e-06  
Training accuracy: 1.0  
Testing loss: 0.20937517152594204  
Testing accuracy: 0.9724  
Testing loss: 0.2803366200153098  
Testing accuracy: 0.9708  
Epoch 145  
-----

Training loss: 1.2991272748126085e-06  
Training accuracy: 1.0  
Testing loss: 0.2094546978053936  
Testing accuracy: 0.9724  
Testing loss: 0.28045783466447366  
Testing accuracy: 0.9708  
Epoch 146  
-----

Training loss: 1.2879098683511396e-06  
Training accuracy: 1.0  
Testing loss: 0.20953392349468128  
Testing accuracy: 0.9724  
Testing loss: 0.28057786415691244  
Testing accuracy: 0.9708  
Epoch 147  
-----

Training loss: 1.2768836612392865e-06  
Training accuracy: 1.0  
Testing loss: 0.20961236084417387  
Testing accuracy: 0.9724  
Testing loss: 0.28069666275205873  
Testing accuracy: 0.9708  
Epoch 148  
-----

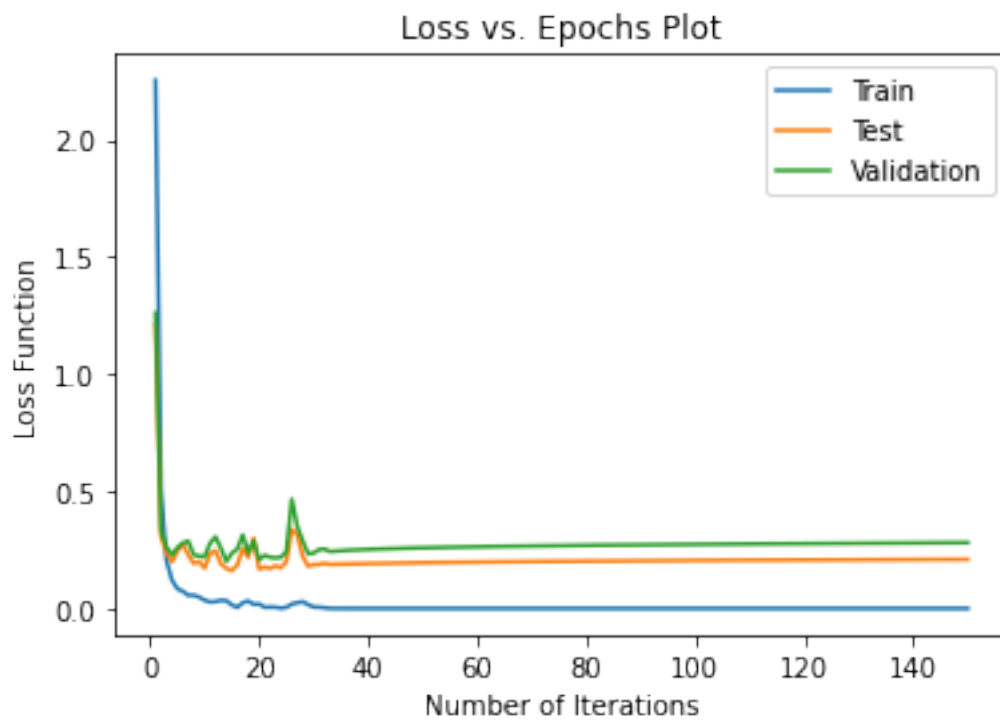
Training loss: 1.2660431091451478e-06  
Training accuracy: 1.0  
Testing loss: 0.20969012088165015  
Testing accuracy: 0.9722  
Testing loss: 0.280814785048372  
Testing accuracy: 0.9708  
Epoch 149  
-----

```

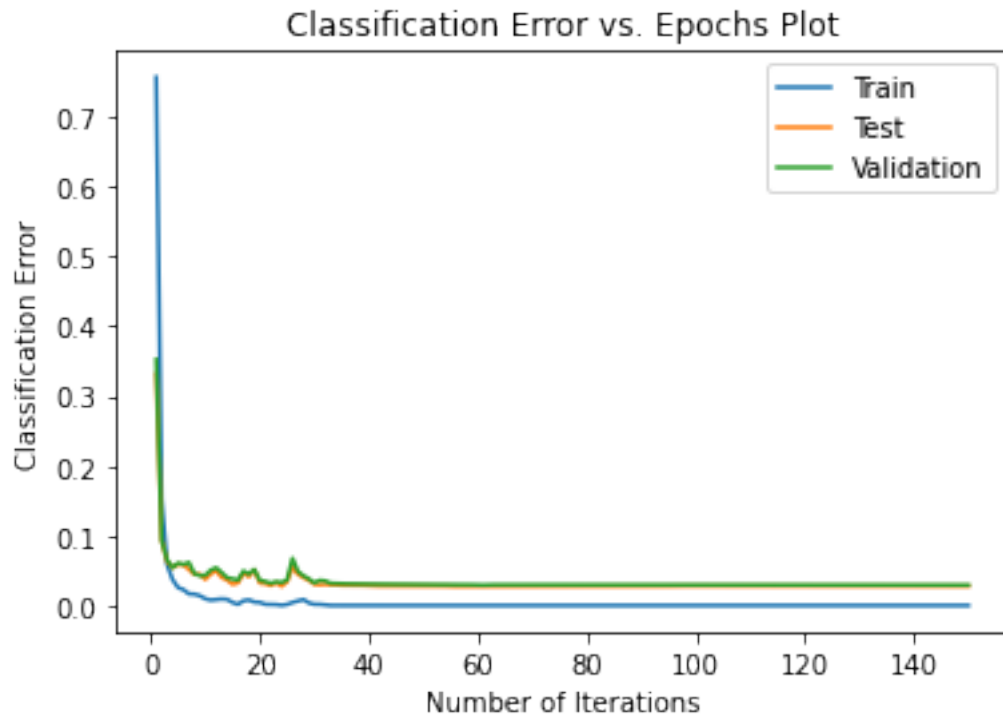
Training loss: 1.255385975098317e-06
Training accuracy: 1.0
Testing loss: 0.2097673280697776
Testing accuracy: 0.9722
Testing loss: 0.2809318979624158
Testing accuracy: 0.9708
Epoch 150
-----
Training loss: 1.244907202436711e-06
Training accuracy: 1.0
Testing loss: 0.20984385273177655
Testing accuracy: 0.9722
Testing loss: 0.2810479123956423
Testing accuracy: 0.9708
Done
Total Time Consumed: 8271.919256925583

```

```
[87]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[88]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



#### 6.4.6 Momentum = 0.5

```
[89]: # Define HyperParameters
# Number of Classes = 19
num_classes = 19
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.5
CNN_M5 = CNN1(num_classes).double()

# Batch Dataloader
train_loader = DataLoader(X_train, batch_size = batch_size)
train_loader_y = DataLoader(Y_train.type(torch.LongTensor), batch_size = batch_size)
test_loader = DataLoader(X_test, batch_size = batch_size)
test_loader_y = DataLoader(Y_test.type(torch.LongTensor), batch_size = batch_size)
val_loader = DataLoader(X_val, batch_size = batch_size)
val_loader_y = DataLoader(Y_val.type(torch.LongTensor), batch_size = batch_size)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
```

```
optimizer = optim.SGD(CNN_M5.parameters(), lr = learning_rate, momentum =  
↪momentum)
```

```
[90]: start_time = time.time()  
test_loss_record = []  
train_loss_record = []  
val_loss_record = []  
for i in range(num_epochs):  
    print(f"Epoch {i+1}\n-----")  
    train_loss_record.  
↪append(train_loop7(train_loader,train_loader_y,CNN_M5,loss,optimizer))  
    test_loss_record.append(test_loop7(test_loader,test_loader_y,CNN_M5,loss))  
    val_loss_record.append(test_loop7(val_loader,val_loader_y,CNN_M5,loss))  
print('Done')  
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----  
Training loss: 1.9095479911088613  
Training accuracy: 0.3466  
Testing loss: 0.6747865470522089  
Testing accuracy: 0.7826  
Testing loss: 0.7627325702547252  
Testing accuracy: 0.7504  
Epoch 2
```

```
-----  
Training loss: 0.34702036163966293  
Training accuracy: 0.89685  
Testing loss: 0.22728402353172675  
Testing accuracy: 0.9336  
Testing loss: 0.2682058225116405  
Testing accuracy: 0.9232  
Epoch 3
```

```
-----  
Training loss: 0.15095181281157213  
Training accuracy: 0.9542  
Testing loss: 0.17665663021880448  
Testing accuracy: 0.9456  
Testing loss: 0.21556594247722427  
Testing accuracy: 0.9384  
Epoch 4
```

```
-----  
Training loss: 0.08171036979738136  
Training accuracy: 0.97455  
Testing loss: 0.1738833452164396  
Testing accuracy: 0.9512  
Testing loss: 0.20157655749265826
```

```
Testing accuracy: 0.95
Epoch 5
-----
Training loss: 0.055641999168715574
Training accuracy: 0.9816
Testing loss: 0.16181525786762438
Testing accuracy: 0.959
Testing loss: 0.19151463113106892
Testing accuracy: 0.9552
Epoch 6
-----
Training loss: 0.03128042766943197
Training accuracy: 0.99
Testing loss: 0.15356328588570645
Testing accuracy: 0.9616
Testing loss: 0.17538486150960972
Testing accuracy: 0.9634
Epoch 7
-----
Training loss: 0.03862013482254902
Training accuracy: 0.98775
Testing loss: 0.1916503411133182
Testing accuracy: 0.9536
Testing loss: 0.18659143581464474
Testing accuracy: 0.9572
Epoch 8
-----
Training loss: 0.024727255290397553
Training accuracy: 0.9927
Testing loss: 0.17344078396214863
Testing accuracy: 0.9602
Testing loss: 0.23322864452977332
Testing accuracy: 0.9508
Epoch 9
-----
Training loss: 0.0176108452709162
Training accuracy: 0.99465
Testing loss: 0.21932750321997277
Testing accuracy: 0.956
Testing loss: 0.2298446254356235
Testing accuracy: 0.955
Epoch 10
-----
Training loss: 0.018100914157219622
Training accuracy: 0.9944
Testing loss: 0.15233503750936012
Testing accuracy: 0.9652
Testing loss: 0.19219648642136639
```



```
Testing accuracy: 0.9618
Epoch 11
-----
Training loss: 0.012153656051623482
Training accuracy: 0.996
Testing loss: 0.14152958062321816
Testing accuracy: 0.966
Testing loss: 0.20246068930928224
Testing accuracy: 0.9624
Epoch 12
-----
Training loss: 0.005053225243607377
Training accuracy: 0.99795
Testing loss: 0.16657326842230938
Testing accuracy: 0.9624
Testing loss: 0.20610032716652463
Testing accuracy: 0.9638
Epoch 13
-----
Training loss: 0.00219505838808087
Training accuracy: 0.99965
Testing loss: 0.14520146228664174
Testing accuracy: 0.9668
Testing loss: 0.19380597772549304
Testing accuracy: 0.9678
Epoch 14
-----
Training loss: 0.0037872910781657806
Training accuracy: 0.99885
Testing loss: 0.14720151029255613
Testing accuracy: 0.9698
Testing loss: 0.20672937156557392
Testing accuracy: 0.9662
Epoch 15
-----
Training loss: 0.002256427368621827
Training accuracy: 0.9995
Testing loss: 0.12477871433311359
Testing accuracy: 0.9738
Testing loss: 0.18144887728178238
Testing accuracy: 0.9698
Epoch 16
-----
Training loss: 0.00018100967190707882
Training accuracy: 1.0
Testing loss: 0.12729402415046026
Testing accuracy: 0.9736
Testing loss: 0.18292884883947277
```

```
Testing accuracy: 0.9704
Epoch 17
-----
Training loss: 8.199163868577954e-05
Training accuracy: 1.0
Testing loss: 0.12881659935016634
Testing accuracy: 0.974
Testing loss: 0.18490636018170833
Testing accuracy: 0.97
Epoch 18
-----
Training loss: 6.344217597526169e-05
Training accuracy: 1.0
Testing loss: 0.13010357256975577
Testing accuracy: 0.9742
Testing loss: 0.18674877534527928
Testing accuracy: 0.97
Epoch 19
-----
Training loss: 5.275683214308222e-05
Training accuracy: 1.0
Testing loss: 0.13119052411695958
Testing accuracy: 0.9738
Testing loss: 0.18830499182927507
Testing accuracy: 0.9702
Epoch 20
-----
Training loss: 4.551471640075164e-05
Training accuracy: 1.0
Testing loss: 0.13213936940572282
Testing accuracy: 0.9736
Testing loss: 0.18966894324530612
Testing accuracy: 0.9704
Epoch 21
-----
Training loss: 4.019049977982212e-05
Training accuracy: 1.0
Testing loss: 0.13299389618534227
Testing accuracy: 0.9738
Testing loss: 0.19089193064843488
Testing accuracy: 0.9704
Epoch 22
-----
Training loss: 3.607455695176603e-05
Training accuracy: 1.0
Testing loss: 0.13378046167012553
Testing accuracy: 0.974
Testing loss: 0.1920115557498686
```

```
Testing accuracy: 0.9704
Epoch 23
-----
Training loss: 3.277901827171201e-05
Training accuracy: 1.0
Testing loss: 0.13450680572976662
Testing accuracy: 0.9742
Testing loss: 0.1930487191431341
Testing accuracy: 0.9704
Epoch 24
-----
Training loss: 3.007863289252971e-05
Training accuracy: 1.0
Testing loss: 0.1351637114442772
Testing accuracy: 0.9744
Testing loss: 0.19401764079127534
Testing accuracy: 0.9704
Epoch 25
-----
Training loss: 2.781901500697046e-05
Training accuracy: 1.0
Testing loss: 0.13576217815934477
Testing accuracy: 0.9744
Testing loss: 0.19492627702938817
Testing accuracy: 0.9704
Epoch 26
-----
Training loss: 2.589274861997608e-05
Training accuracy: 1.0
Testing loss: 0.13632577652060895
Testing accuracy: 0.9744
Testing loss: 0.1957830686246763
Testing accuracy: 0.9702
Epoch 27
-----
Training loss: 2.4230401878539117e-05
Training accuracy: 1.0
Testing loss: 0.13685368922861224
Testing accuracy: 0.9744
Testing loss: 0.19659004275214892
Testing accuracy: 0.9704
Epoch 28
-----
Training loss: 2.278391599732656e-05
Training accuracy: 1.0
Testing loss: 0.1373536750509496
Testing accuracy: 0.9744
Testing loss: 0.1973601451947649
```

```
Testing accuracy: 0.97
Epoch 29
-----
Training loss: 2.1505698306254446e-05
Training accuracy: 1.0
Testing loss: 0.1378227081497716
Testing accuracy: 0.9744
Testing loss: 0.19809810025751326
Testing accuracy: 0.9698
Epoch 30
-----
Training loss: 2.037120244990303e-05
Training accuracy: 1.0
Testing loss: 0.13826761390365686
Testing accuracy: 0.9744
Testing loss: 0.19879274517808088
Testing accuracy: 0.9698
Epoch 31
-----
Training loss: 1.9357827567227235e-05
Training accuracy: 1.0
Testing loss: 0.1386831102936592
Testing accuracy: 0.9744
Testing loss: 0.19945572943890844
Testing accuracy: 0.9698
Epoch 32
-----
Training loss: 1.8447891875359486e-05
Training accuracy: 1.0
Testing loss: 0.13908528601276288
Testing accuracy: 0.9746
Testing loss: 0.2000940812634213
Testing accuracy: 0.9698
Epoch 33
-----
Training loss: 1.7623510651219413e-05
Training accuracy: 1.0
Testing loss: 0.1394726849506574
Testing accuracy: 0.9744
Testing loss: 0.20070430608972747
Testing accuracy: 0.9698
Epoch 34
-----
Training loss: 1.6872433647895127e-05
Training accuracy: 1.0
Testing loss: 0.139847894716383
Testing accuracy: 0.9746
Testing loss: 0.20129436848884308
```

Testing accuracy: 0.9698

Epoch 35

-----  
Training loss: 1.6185471396037254e-05

Training accuracy: 1.0

Testing loss: 0.14021288525104808

Testing accuracy: 0.9746

Testing loss: 0.20186585546770686

Testing accuracy: 0.9698

Epoch 36

-----  
Training loss: 1.5554547142914025e-05

Training accuracy: 1.0

Testing loss: 0.14056045309020107

Testing accuracy: 0.9746

Testing loss: 0.20241078469713017

Testing accuracy: 0.9698

Epoch 37

-----  
Training loss: 1.4973478253839153e-05

Training accuracy: 1.0

Testing loss: 0.1408966877206402

Testing accuracy: 0.9746

Testing loss: 0.2029345067142534

Testing accuracy: 0.9698

Epoch 38

-----  
Training loss: 1.4435680663175423e-05

Training accuracy: 1.0

Testing loss: 0.14121849172151252

Testing accuracy: 0.9746

Testing loss: 0.20344062467033394

Testing accuracy: 0.9698

Epoch 39

-----  
Training loss: 1.3936206740129117e-05

Training accuracy: 1.0

Testing loss: 0.14153203419828767

Testing accuracy: 0.9746

Testing loss: 0.2039289416906557

Testing accuracy: 0.97

Epoch 40

-----  
Training loss: 1.3471747032855663e-05

Training accuracy: 1.0

Testing loss: 0.14183413322196428

Testing accuracy: 0.9744

Testing loss: 0.2044047279068876

Testing accuracy: 0.9698

Epoch 41

-----  
Training loss: 1.303813058021676e-05

Training accuracy: 1.0

Testing loss: 0.14212330065247894

Testing accuracy: 0.9744

Testing loss: 0.20486617917517755

Testing accuracy: 0.9698

Epoch 42

-----  
Training loss: 1.2632043744012566e-05

Training accuracy: 1.0

Testing loss: 0.1424013633909009

Testing accuracy: 0.9744

Testing loss: 0.20531437392961638

Testing accuracy: 0.97

Epoch 43

-----  
Training loss: 1.225154561669592e-05

Training accuracy: 1.0

Testing loss: 0.14267268051797524

Testing accuracy: 0.9744

Testing loss: 0.20575079119214335

Testing accuracy: 0.97

Epoch 44

-----  
Training loss: 1.1893650712396534e-05

Training accuracy: 1.0

Testing loss: 0.1429346991282008

Testing accuracy: 0.9744

Testing loss: 0.20617196648428826

Testing accuracy: 0.97

Epoch 45

-----  
Training loss: 1.1556687414898869e-05

Training accuracy: 1.0

Testing loss: 0.14318933396185887

Testing accuracy: 0.9744

Testing loss: 0.2065860245995154

Testing accuracy: 0.9698

Epoch 46

-----  
Training loss: 1.1238562665109627e-05

Training accuracy: 1.0

Testing loss: 0.1434362287463849

Testing accuracy: 0.9744

Testing loss: 0.20698935681104116

Testing accuracy: 0.9698

Epoch 47

-----  
Training loss: 1.093822212531695e-05

Training accuracy: 1.0

Testing loss: 0.14367575874678312

Testing accuracy: 0.9744

Testing loss: 0.20737961552145426

Testing accuracy: 0.97

Epoch 48

-----  
Training loss: 1.0653996833255822e-05

Training accuracy: 1.0

Testing loss: 0.14391315185552955

Testing accuracy: 0.9744

Testing loss: 0.20775984337421918

Testing accuracy: 0.9702

Epoch 49

-----  
Training loss: 1.0384627289073377e-05

Training accuracy: 1.0

Testing loss: 0.14414495490087662

Testing accuracy: 0.9744

Testing loss: 0.20813042489211217

Testing accuracy: 0.9702

Epoch 50

-----  
Training loss: 1.0128323887455511e-05

Training accuracy: 1.0

Testing loss: 0.1443718977847003

Testing accuracy: 0.9744

Testing loss: 0.20849537807923565

Testing accuracy: 0.9702

Epoch 51

-----  
Training loss: 9.884428602156696e-06

Training accuracy: 1.0

Testing loss: 0.1445950948233866

Testing accuracy: 0.9744

Testing loss: 0.20885190491194894

Testing accuracy: 0.9702

Epoch 52

-----  
Training loss: 9.652096041597488e-06

Training accuracy: 1.0

Testing loss: 0.1448130296226902

Testing accuracy: 0.9744

Testing loss: 0.20920154370358338

Testing accuracy: 0.9702

Epoch 53

-----  
Training loss: 9.430772485495981e-06

Training accuracy: 1.0

Testing loss: 0.1450268918855383

Testing accuracy: 0.9744

Testing loss: 0.2095401352860863

Testing accuracy: 0.9702

Epoch 54

-----  
Training loss: 9.219388924554152e-06

Training accuracy: 1.0

Testing loss: 0.1452363854252307

Testing accuracy: 0.9744

Testing loss: 0.20987326050619937

Testing accuracy: 0.9702

Epoch 55

-----  
Training loss: 9.01750063450048e-06

Training accuracy: 1.0

Testing loss: 0.14544042431711338

Testing accuracy: 0.9742

Testing loss: 0.2101990915945271

Testing accuracy: 0.9704

Epoch 56

-----  
Training loss: 8.824401295756887e-06

Training accuracy: 1.0

Testing loss: 0.1456413893457124

Testing accuracy: 0.9742

Testing loss: 0.21052063210603475

Testing accuracy: 0.9704

Epoch 57

-----  
Training loss: 8.63962989875807e-06

Training accuracy: 1.0

Testing loss: 0.14583889695312316

Testing accuracy: 0.9742

Testing loss: 0.21083477873137896

Testing accuracy: 0.9704

Epoch 58

-----  
Training loss: 8.462519538351987e-06

Training accuracy: 1.0

Testing loss: 0.14603359574003133

Testing accuracy: 0.9742

Testing loss: 0.21114321356885124



Testing accuracy: 0.9702

Epoch 59

-----  
Training loss: 8.29274817495702e-06

Training accuracy: 1.0

Testing loss: 0.1462231500670568

Testing accuracy: 0.9742

Testing loss: 0.2114442545767997

Testing accuracy: 0.9702

Epoch 60

-----  
Training loss: 8.12961150923484e-06

Training accuracy: 1.0

Testing loss: 0.1464100233902694

Testing accuracy: 0.9742

Testing loss: 0.21174068678887498

Testing accuracy: 0.9702

Epoch 61

-----  
Training loss: 7.972922192060494e-06

Training accuracy: 1.0

Testing loss: 0.1465940147432617

Testing accuracy: 0.9742

Testing loss: 0.21203134919753083

Testing accuracy: 0.9702

Epoch 62

-----  
Training loss: 7.822367588272347e-06

Training accuracy: 1.0

Testing loss: 0.1467758921490308

Testing accuracy: 0.9742

Testing loss: 0.212314234952792

Testing accuracy: 0.9702

Epoch 63

-----  
Training loss: 7.677446793538078e-06

Training accuracy: 1.0

Testing loss: 0.146954343953407

Testing accuracy: 0.9742

Testing loss: 0.21259407298374777

Testing accuracy: 0.9702

Epoch 64

-----  
Training loss: 7.5381068158612255e-06

Training accuracy: 1.0

Testing loss: 0.14712695558160882

Testing accuracy: 0.9742

Testing loss: 0.21286750001021507

```
Testing accuracy: 0.9702
Epoch 65
-----
Training loss: 7.403855219429664e-06
Training accuracy: 1.0
Testing loss: 0.14729814105912079
Testing accuracy: 0.9742
Testing loss: 0.21313853849203465
Testing accuracy: 0.9702
Epoch 66
-----
Training loss: 7.274390900023019e-06
Training accuracy: 1.0
Testing loss: 0.14746699807513236
Testing accuracy: 0.9742
Testing loss: 0.21340501585329602
Testing accuracy: 0.9702
Epoch 67
-----
Training loss: 7.149056639911421e-06
Training accuracy: 1.0
Testing loss: 0.14763398162019098
Testing accuracy: 0.9742
Testing loss: 0.21366770618635575
Testing accuracy: 0.9702
Epoch 68
-----
Training loss: 7.028273906416294e-06
Training accuracy: 1.0
Testing loss: 0.14779683420567627
Testing accuracy: 0.9742
Testing loss: 0.21392493045312566
Testing accuracy: 0.9702
Epoch 69
-----
Training loss: 6.911542923196071e-06
Training accuracy: 1.0
Testing loss: 0.14795847510112944
Testing accuracy: 0.9744
Testing loss: 0.21417954724185057
Testing accuracy: 0.9702
Epoch 70
-----
Training loss: 6.7986975370278476e-06
Training accuracy: 1.0
Testing loss: 0.1481168252295065
Testing accuracy: 0.9744
Testing loss: 0.2144291138718316
```

Testing accuracy: 0.97  
Epoch 71  
-----  
Training loss: 6.68948531423173e-06  
Training accuracy: 1.0  
Testing loss: 0.14827462938730887  
Testing accuracy: 0.9744  
Testing loss: 0.2146750478520739  
Testing accuracy: 0.97  
Epoch 72  
-----  
Training loss: 6.5839099927703e-06  
Training accuracy: 1.0  
Testing loss: 0.14842880863679492  
Testing accuracy: 0.9744  
Testing loss: 0.2149181980340821  
Testing accuracy: 0.97  
Epoch 73  
-----  
Training loss: 6.481684290716002e-06  
Training accuracy: 1.0  
Testing loss: 0.1485814992717193  
Testing accuracy: 0.9744  
Testing loss: 0.21515704634053973  
Testing accuracy: 0.97  
Epoch 74  
-----  
Training loss: 6.3826541991280615e-06  
Training accuracy: 1.0  
Testing loss: 0.14873166908335433  
Testing accuracy: 0.9744  
Testing loss: 0.2153923464926395  
Testing accuracy: 0.97  
Epoch 75  
-----  
Training loss: 6.28661686613097e-06  
Training accuracy: 1.0  
Testing loss: 0.14887995709181293  
Testing accuracy: 0.9744  
Testing loss: 0.2156241950750718  
Testing accuracy: 0.97  
Epoch 76  
-----  
Training loss: 6.193634702844902e-06  
Training accuracy: 1.0  
Testing loss: 0.14902590054755455  
Testing accuracy: 0.9744  
Testing loss: 0.21585182757303634

Testing accuracy: 0.97  
Epoch 77  
-----  
Training loss: 6.103307446124561e-06  
Training accuracy: 1.0  
Testing loss: 0.1491700115223495  
Testing accuracy: 0.9744  
Testing loss: 0.21607585579361  
Testing accuracy: 0.97  
Epoch 78  
-----  
Training loss: 6.015604768107913e-06  
Training accuracy: 1.0  
Testing loss: 0.1493127332443124  
Testing accuracy: 0.9744  
Testing loss: 0.21629505863006124  
Testing accuracy: 0.97  
Epoch 79  
-----  
Training loss: 5.93027473295688e-06  
Training accuracy: 1.0  
Testing loss: 0.14945200516939458  
Testing accuracy: 0.9744  
Testing loss: 0.21651269740790036  
Testing accuracy: 0.97  
Epoch 80  
-----  
Training loss: 5.847395183579212e-06  
Training accuracy: 1.0  
Testing loss: 0.14959118395421722  
Testing accuracy: 0.9744  
Testing loss: 0.21672765233297747  
Testing accuracy: 0.97  
Epoch 81  
-----  
Training loss: 5.766731582761428e-06  
Training accuracy: 1.0  
Testing loss: 0.1497279425114362  
Testing accuracy: 0.9744  
Testing loss: 0.2169397554465864  
Testing accuracy: 0.97  
Epoch 82  
-----  
Training loss: 5.688281879406731e-06  
Training accuracy: 1.0  
Testing loss: 0.14986213089027994  
Testing accuracy: 0.9744  
Testing loss: 0.21715006704278525

Testing accuracy: 0.97  
Epoch 83  
-----  
Training loss: 5.611890836355107e-06  
Training accuracy: 1.0  
Testing loss: 0.14999492182108773  
Testing accuracy: 0.9746  
Testing loss: 0.21735783089920105  
Testing accuracy: 0.97  
Epoch 84  
-----  
Training loss: 5.537676035664878e-06  
Training accuracy: 1.0  
Testing loss: 0.15012600156941203  
Testing accuracy: 0.9746  
Testing loss: 0.2175640892667211  
Testing accuracy: 0.97  
Epoch 85  
-----  
Training loss: 5.465269666787564e-06  
Training accuracy: 1.0  
Testing loss: 0.15025452452499047  
Testing accuracy: 0.9746  
Testing loss: 0.2177682406722417  
Testing accuracy: 0.9698  
Epoch 86  
-----  
Training loss: 5.394854091269132e-06  
Training accuracy: 1.0  
Testing loss: 0.1503816417469197  
Testing accuracy: 0.9746  
Testing loss: 0.21796841545084553  
Testing accuracy: 0.9698  
Epoch 87  
-----  
Training loss: 5.32630705675271e-06  
Training accuracy: 1.0  
Testing loss: 0.1505072715025654  
Testing accuracy: 0.9746  
Testing loss: 0.21816687967264692  
Testing accuracy: 0.9698  
Epoch 88  
-----  
Training loss: 5.2594110671194626e-06  
Training accuracy: 1.0  
Testing loss: 0.15063220870069882  
Testing accuracy: 0.9746  
Testing loss: 0.21836283055957686

Testing accuracy: 0.9698

Epoch 89

-----  
Training loss: 5.194268930762317e-06

Training accuracy: 1.0

Testing loss: 0.15075488219659647

Testing accuracy: 0.9746

Testing loss: 0.2185562699465109

Testing accuracy: 0.9698

Epoch 90

-----  
Training loss: 5.130720494841484e-06

Training accuracy: 1.0

Testing loss: 0.1508757277496162

Testing accuracy: 0.9746

Testing loss: 0.2187455549011705

Testing accuracy: 0.9698

Epoch 91

-----  
Training loss: 5.068621669360971e-06

Training accuracy: 1.0

Testing loss: 0.1509956514281789

Testing accuracy: 0.9746

Testing loss: 0.21893482649447232

Testing accuracy: 0.9698

Epoch 92

-----  
Training loss: 5.008155907613105e-06

Training accuracy: 1.0

Testing loss: 0.1511149061805056

Testing accuracy: 0.9746

Testing loss: 0.21912073748721358

Testing accuracy: 0.9698

Epoch 93

-----  
Training loss: 4.9491165206053825e-06

Training accuracy: 1.0

Testing loss: 0.15123248204874074

Testing accuracy: 0.9744

Testing loss: 0.21930380135543323

Testing accuracy: 0.9698

Epoch 94

-----  
Training loss: 4.89136120280913e-06

Training accuracy: 1.0

Testing loss: 0.15134829527069185

Testing accuracy: 0.9744

Testing loss: 0.21948520727039655

```
Testing accuracy: 0.9698
Epoch 95
-----
Training loss: 4.835003963172076e-06
Training accuracy: 1.0
Testing loss: 0.15146348817635774
Testing accuracy: 0.9744
Testing loss: 0.21966390373760333
Testing accuracy: 0.9698
Epoch 96
-----
Training loss: 4.779901832488628e-06
Training accuracy: 1.0
Testing loss: 0.15157830432945016
Testing accuracy: 0.9744
Testing loss: 0.21984135809848449
Testing accuracy: 0.9698
Epoch 97
-----
Training loss: 4.726056657676129e-06
Training accuracy: 1.0
Testing loss: 0.15169135824270175
Testing accuracy: 0.9744
Testing loss: 0.2200169922075382
Testing accuracy: 0.9698
Epoch 98
-----
Training loss: 4.673399200629605e-06
Training accuracy: 1.0
Testing loss: 0.15180331184624257
Testing accuracy: 0.9744
Testing loss: 0.22019030250180457
Testing accuracy: 0.9698
Epoch 99
-----
Training loss: 4.621946392736827e-06
Training accuracy: 1.0
Testing loss: 0.15191368799866353
Testing accuracy: 0.9744
Testing loss: 0.2203611967179475
Testing accuracy: 0.9698
Epoch 100
-----
Training loss: 4.571603329288477e-06
Training accuracy: 1.0
Testing loss: 0.1520236913642987
Testing accuracy: 0.9744
Testing loss: 0.22053167288808054
```

```
Testing accuracy: 0.9698
Epoch 101
-----
Training loss: 4.522361873181017e-06
Training accuracy: 1.0
Testing loss: 0.15213308184214921
Testing accuracy: 0.9744
Testing loss: 0.22069919278436964
Testing accuracy: 0.9698
Epoch 102
-----
Training loss: 4.474188848346386e-06
Training accuracy: 1.0
Testing loss: 0.15224002043906082
Testing accuracy: 0.9742
Testing loss: 0.22086421730216224
Testing accuracy: 0.9698
Epoch 103
-----
Training loss: 4.42705438896634e-06
Training accuracy: 1.0
Testing loss: 0.15234762112868697
Testing accuracy: 0.974
Testing loss: 0.22102857256181224
Testing accuracy: 0.9698
Epoch 104
-----
Training loss: 4.3809192336345594e-06
Training accuracy: 1.0
Testing loss: 0.15245336474615773
Testing accuracy: 0.974
Testing loss: 0.22119042090371607
Testing accuracy: 0.9698
Epoch 105
-----
Training loss: 4.33572670936468e-06
Training accuracy: 1.0
Testing loss: 0.15255862527014635
Testing accuracy: 0.9738
Testing loss: 0.22135139069673287
Testing accuracy: 0.9698
Epoch 106
-----
Training loss: 4.291412517407436e-06
Training accuracy: 1.0
Testing loss: 0.15266286544569305
Testing accuracy: 0.9738
Testing loss: 0.22151021073589663
```



Testing accuracy: 0.9698  
Epoch 107  
-----  
Training loss: 4.248043357765676e-06  
Training accuracy: 1.0  
Testing loss: 0.15276629240108108  
Testing accuracy: 0.9738  
Testing loss: 0.22166887219020892  
Testing accuracy: 0.9698  
Epoch 108  
-----  
Training loss: 4.205501939536347e-06  
Training accuracy: 1.0  
Testing loss: 0.15286905069621806  
Testing accuracy: 0.9736  
Testing loss: 0.22182486584612685  
Testing accuracy: 0.9698  
Epoch 109  
-----  
Training loss: 4.1638517116484045e-06  
Training accuracy: 1.0  
Testing loss: 0.15297135606464943  
Testing accuracy: 0.9736  
Testing loss: 0.2219801669168756  
Testing accuracy: 0.9698  
Epoch 110  
-----  
Training loss: 4.122997928137269e-06  
Training accuracy: 1.0  
Testing loss: 0.15307290364037254  
Testing accuracy: 0.9736  
Testing loss: 0.2221329157849674  
Testing accuracy: 0.9698  
Epoch 111  
-----  
Training loss: 4.082876229184635e-06  
Training accuracy: 1.0  
Testing loss: 0.1531739545597102  
Testing accuracy: 0.9738  
Testing loss: 0.22228543750687357  
Testing accuracy: 0.9698  
Epoch 112  
-----  
Training loss: 4.043564464437252e-06  
Training accuracy: 1.0  
Testing loss: 0.15327278414939008  
Testing accuracy: 0.9738  
Testing loss: 0.22243708364404297

Testing accuracy: 0.9698  
Epoch 113  
-----  
Training loss: 4.0050408014621665e-06  
Training accuracy: 1.0  
Testing loss: 0.15337130337507987  
Testing accuracy: 0.9738  
Testing loss: 0.22258708189938556  
Testing accuracy: 0.9698  
Epoch 114  
-----  
Training loss: 3.967175022832969e-06  
Training accuracy: 1.0  
Testing loss: 0.15346837249789133  
Testing accuracy: 0.9738  
Testing loss: 0.22273586019201635  
Testing accuracy: 0.97  
Epoch 115  
-----  
Training loss: 3.93005112147668e-06  
Training accuracy: 1.0  
Testing loss: 0.15356540940973495  
Testing accuracy: 0.9738  
Testing loss: 0.2228840856242234  
Testing accuracy: 0.97  
Epoch 116  
-----  
Training loss: 3.893659451946703e-06  
Training accuracy: 1.0  
Testing loss: 0.15366011728365064  
Testing accuracy: 0.9738  
Testing loss: 0.22302868937874987  
Testing accuracy: 0.97  
Epoch 117  
-----  
Training loss: 3.857910871126038e-06  
Training accuracy: 1.0  
Testing loss: 0.15375516878743814  
Testing accuracy: 0.9738  
Testing loss: 0.22317391246728358  
Testing accuracy: 0.97  
Epoch 118  
-----  
Training loss: 3.822834775726606e-06  
Training accuracy: 1.0  
Testing loss: 0.15384840752232828  
Testing accuracy: 0.9738  
Testing loss: 0.22331690381702488

```
Testing accuracy: 0.97
Epoch 119
-----
Training loss: 3.7883863543136528e-06
Training accuracy: 1.0
Testing loss: 0.15394197779040342
Testing accuracy: 0.9738
Testing loss: 0.22345905560633778
Testing accuracy: 0.97
Epoch 120
-----
Training loss: 3.754566423162187e-06
Training accuracy: 1.0
Testing loss: 0.1540341691862787
Testing accuracy: 0.9738
Testing loss: 0.22360016580082015
Testing accuracy: 0.97
Epoch 121
-----
Training loss: 3.7214004976525958e-06
Training accuracy: 1.0
Testing loss: 0.15412573018281936
Testing accuracy: 0.9738
Testing loss: 0.2237396241915836
Testing accuracy: 0.97
Epoch 122
-----
Training loss: 3.688752017394242e-06
Training accuracy: 1.0
Testing loss: 0.15421644885894492
Testing accuracy: 0.974
Testing loss: 0.22387777372382262
Testing accuracy: 0.97
Epoch 123
-----
Training loss: 3.6567149110104385e-06
Training accuracy: 1.0
Testing loss: 0.1543065099237578
Testing accuracy: 0.974
Testing loss: 0.22401554900574802
Testing accuracy: 0.97
Epoch 124
-----
Training loss: 3.625205181501952e-06
Training accuracy: 1.0
Testing loss: 0.15439524393189946
Testing accuracy: 0.974
Testing loss: 0.22415123531948053
```

```
Testing accuracy: 0.97
Epoch 125
-----
Training loss: 3.5942290167785987e-06
Training accuracy: 1.0
Testing loss: 0.15448449134077064
Testing accuracy: 0.974
Testing loss: 0.22428688091683893
Testing accuracy: 0.97
Epoch 126
-----
Training loss: 3.5637767256969157e-06
Training accuracy: 1.0
Testing loss: 0.15457207424834862
Testing accuracy: 0.974
Testing loss: 0.22442099149112804
Testing accuracy: 0.97
Epoch 127
-----
Training loss: 3.5339024946873944e-06
Training accuracy: 1.0
Testing loss: 0.1546587907786048
Testing accuracy: 0.974
Testing loss: 0.2245538575983991
Testing accuracy: 0.97
Epoch 128
-----
Training loss: 3.504492433005396e-06
Training accuracy: 1.0
Testing loss: 0.15474393032852135
Testing accuracy: 0.974
Testing loss: 0.22468522305505206
Testing accuracy: 0.97
Epoch 129
-----
Training loss: 3.4755751548913646e-06
Training accuracy: 1.0
Testing loss: 0.15482907082241557
Testing accuracy: 0.974
Testing loss: 0.22481700711647132
Testing accuracy: 0.97
Epoch 130
-----
Training loss: 3.4471665520065315e-06
Training accuracy: 1.0
Testing loss: 0.15491392361681514
Testing accuracy: 0.974
Testing loss: 0.2249465927021331
```

Testing accuracy: 0.9698

Epoch 131

-----  
Training loss: 3.419169654370001e-06

Training accuracy: 1.0

Testing loss: 0.15499826425348529

Testing accuracy: 0.974

Testing loss: 0.2250757784112821

Testing accuracy: 0.9698

Epoch 132

-----  
Training loss: 3.3916328346551547e-06

Training accuracy: 1.0

Testing loss: 0.15508116340943454

Testing accuracy: 0.974

Testing loss: 0.2252035056527624

Testing accuracy: 0.9698

Epoch 133

-----  
Training loss: 3.364535822346623e-06

Training accuracy: 1.0

Testing loss: 0.15516420945823292

Testing accuracy: 0.974

Testing loss: 0.22533056994695025

Testing accuracy: 0.9698

Epoch 134

-----  
Training loss: 3.3378530604410118e-06

Training accuracy: 1.0

Testing loss: 0.15524725540709278

Testing accuracy: 0.974

Testing loss: 0.22545713889063776

Testing accuracy: 0.9698

Epoch 135

-----  
Training loss: 3.3115910774180433e-06

Training accuracy: 1.0

Testing loss: 0.15532877700255712

Testing accuracy: 0.974

Testing loss: 0.2255829831912623

Testing accuracy: 0.9698

Epoch 136

-----  
Training loss: 3.285769856961626e-06

Training accuracy: 1.0

Testing loss: 0.1554094415938246

Testing accuracy: 0.974

Testing loss: 0.2257066258957539

Testing accuracy: 0.9698

Epoch 137

-----  
Training loss: 3.2603435634733064e-06

Training accuracy: 1.0

Testing loss: 0.15548998479652607

Testing accuracy: 0.974

Testing loss: 0.22582939736042026

Testing accuracy: 0.9698

Epoch 138

-----  
Training loss: 3.235281618560374e-06

Training accuracy: 1.0

Testing loss: 0.15557133181151295

Testing accuracy: 0.974

Testing loss: 0.22595191598907996

Testing accuracy: 0.9698

Epoch 139

-----  
Training loss: 3.210640426311221e-06

Training accuracy: 1.0

Testing loss: 0.15565057198573815

Testing accuracy: 0.974

Testing loss: 0.22607282667238174

Testing accuracy: 0.9698

Epoch 140

-----  
Training loss: 3.1863047487879945e-06

Training accuracy: 1.0

Testing loss: 0.15572973442294716

Testing accuracy: 0.974

Testing loss: 0.22619383692014575

Testing accuracy: 0.9698

Epoch 141

-----  
Training loss: 3.162384765001585e-06

Training accuracy: 1.0

Testing loss: 0.15580793066564988

Testing accuracy: 0.9742

Testing loss: 0.22631279605254231

Testing accuracy: 0.9698

Epoch 142

-----  
Training loss: 3.1388162223144242e-06

Training accuracy: 1.0

Testing loss: 0.15588573638400527

Testing accuracy: 0.9742

Testing loss: 0.22643111226517

Testing accuracy: 0.9698

Epoch 143

-----  
Training loss: 3.1155477079619105e-06

Training accuracy: 1.0

Testing loss: 0.1559630136449625

Testing accuracy: 0.9742

Testing loss: 0.22654886966912435

Testing accuracy: 0.9698

Epoch 144

-----  
Training loss: 3.0926958165927944e-06

Training accuracy: 1.0

Testing loss: 0.1560400337771433

Testing accuracy: 0.9742

Testing loss: 0.2266654774682679

Testing accuracy: 0.9698

Epoch 145

-----  
Training loss: 3.070128838940919e-06

Training accuracy: 1.0

Testing loss: 0.15611637760085106

Testing accuracy: 0.9742

Testing loss: 0.22678163853589836

Testing accuracy: 0.9698

Epoch 146

-----  
Training loss: 3.0478784002686577e-06

Training accuracy: 1.0

Testing loss: 0.1561923428852103

Testing accuracy: 0.9742

Testing loss: 0.2268974901087393

Testing accuracy: 0.9698

Epoch 147

-----  
Training loss: 3.025994613701705e-06

Training accuracy: 1.0

Testing loss: 0.15626727050741784

Testing accuracy: 0.9742

Testing loss: 0.22701146327660354

Testing accuracy: 0.9698

Epoch 148

-----  
Training loss: 3.0044043115522672e-06

Training accuracy: 1.0

Testing loss: 0.15634214815354983

Testing accuracy: 0.9742

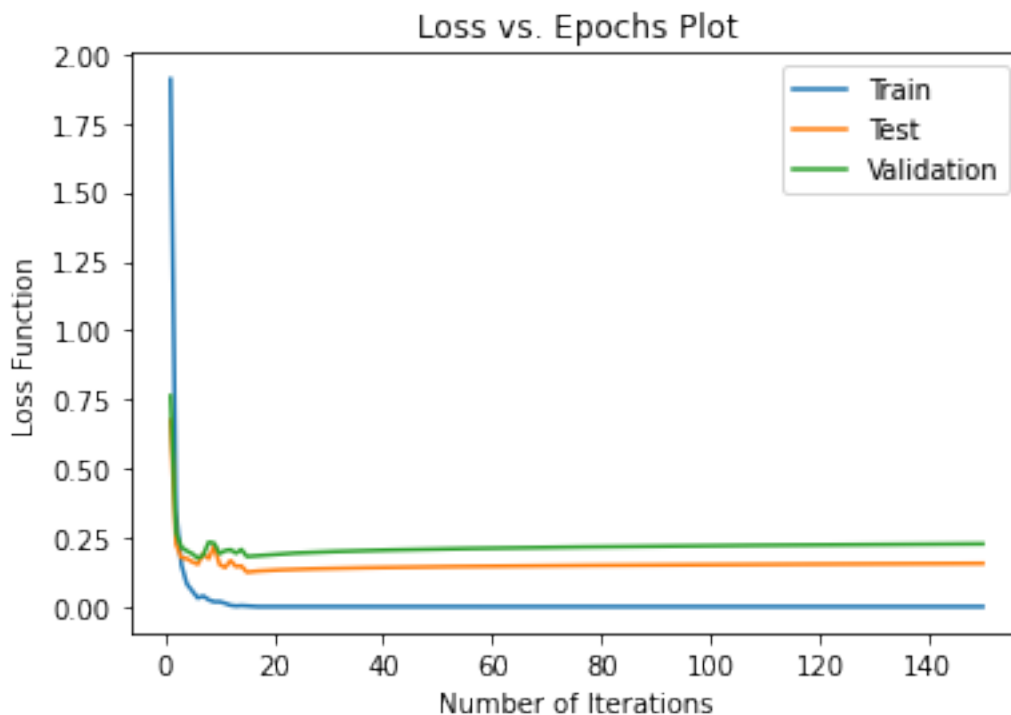
Testing loss: 0.22712462137897133

```

Testing accuracy: 0.9698
Epoch 149
-----
Training loss: 2.983106310434596e-06
Training accuracy: 1.0
Testing loss: 0.1564165929235425
Testing accuracy: 0.9742
Testing loss: 0.22723789037515818
Testing accuracy: 0.9698
Epoch 150
-----
Training loss: 2.9621048696217283e-06
Training accuracy: 1.0
Testing loss: 0.1564907914439718
Testing accuracy: 0.9742
Testing loss: 0.22735019396803371
Testing accuracy: 0.9698
Done
Total Time Consumed: 8456.383402109146

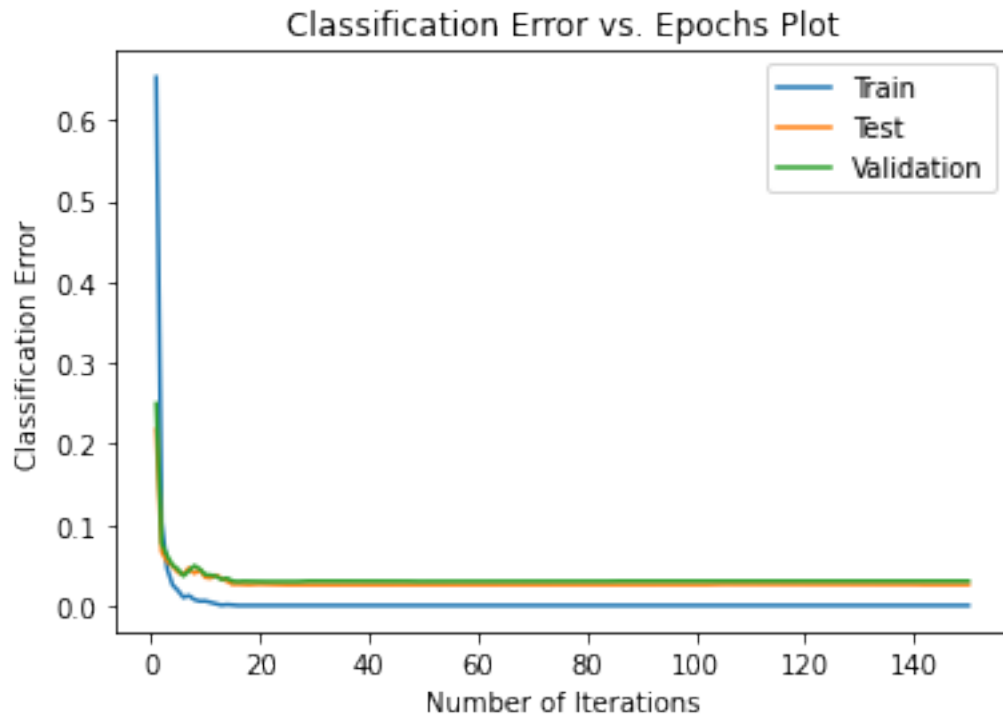
```

```
[91]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[92]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```





#### 6.4.7 Momentum = 0.9

```
[93]: # Define HyperParameters
# Number of Classes = 19
num_classes = 19
learning_rate = 0.1
batch_size = 64
num_epochs = 150
momentum = 0.9
CNN_M9 = CNN1(num_classes).double()

# Batch Dataloader
train_loader = DataLoader(X_train, batch_size = batch_size)
train_loader_y = DataLoader(Y_train.type(torch.LongTensor), batch_size = batch_size)
test_loader = DataLoader(X_test, batch_size = batch_size)
test_loader_y = DataLoader(Y_test.type(torch.LongTensor), batch_size = batch_size)
val_loader = DataLoader(X_val, batch_size = batch_size)
val_loader_y = DataLoader(Y_val.type(torch.LongTensor), batch_size = batch_size)

# Define Loss & Optimizer
loss = nn.CrossEntropyLoss()
```

```
optimizer = optim.SGD(CNN_M9.parameters(), lr = learning_rate, momentum = 0.9)
```

```
[94]: start_time = time.time()
test_loss_record = []
train_loss_record = []
val_loss_record = []
for i in range(num_epochs):
    print(f"Epoch {i+1}\n-----")
    train_loss_record.
    ↪append(train_loop7(train_loader,train_loader_y,CNN_M9,loss,optimizer))
    test_loss_record.append(test_loop7(test_loader,test_loader_y,CNN_M9,loss))
    val_loss_record.append(test_loop7(val_loader,val_loader_y,CNN_M9,loss))
print('Done')
print('Total Time Consumed: {}'.format(time.time() - start_time))
```

Epoch 1

```
-----
Training loss: 1.5410210219367797
Training accuracy: 0.49205
Testing loss: 0.49018420762581144
Testing accuracy: 0.8678
Testing loss: 0.5374604767267323
Testing accuracy: 0.848
Epoch 2
```

```
-----
Training loss: 0.4452177769619899
Training accuracy: 0.8762
Testing loss: 0.6788859315557288
Testing accuracy: 0.8304
Testing loss: 0.690787130137702
Testing accuracy: 0.8348
Epoch 3
```

```
-----
Training loss: 0.3582091936714985
Training accuracy: 0.90345
Testing loss: 0.35082074722223044
Testing accuracy: 0.911
Testing loss: 0.39611709609162965
Testing accuracy: 0.9056
Epoch 4
```

```
-----
Training loss: 0.313708302932222
Training accuracy: 0.91785
Testing loss: 0.29488731123114414
Testing accuracy: 0.9182
Testing loss: 0.3443763879100704
Testing accuracy: 0.916
```

Epoch 5

-----  
Training loss: 0.26955911857291426  
Training accuracy: 0.9283  
Testing loss: 0.4146247085989643  
Testing accuracy: 0.91  
Testing loss: 0.4153134863833924  
Testing accuracy: 0.9084  
Epoch 6

-----  
Training loss: 0.2918569123529157  
Training accuracy: 0.9228  
Testing loss: 0.26280492348093754  
Testing accuracy: 0.937  
Testing loss: 0.3213330535953152  
Testing accuracy: 0.9296  
Epoch 7

-----  
Training loss: 0.25501702866289233  
Training accuracy: 0.934  
Testing loss: 0.32929825578113503  
Testing accuracy: 0.9252  
Testing loss: 0.36972453233816566  
Testing accuracy: 0.9208  
Epoch 8

-----  
Training loss: 0.28600064593143354  
Training accuracy: 0.92715  
Testing loss: 0.42957078388633174  
Testing accuracy: 0.912  
Testing loss: 0.5067182533776785  
Testing accuracy: 0.8932  
Epoch 9

-----  
Training loss: 0.30852967532490155  
Training accuracy: 0.9242  
Testing loss: 0.5312515880972284  
Testing accuracy: 0.8994  
Testing loss: 0.5602543037214955  
Testing accuracy: 0.8978  
Epoch 10

-----  
Training loss: 0.29396341816244836  
Training accuracy: 0.92815  
Testing loss: 0.6553820518805833  
Testing accuracy: 0.8774  
Testing loss: 0.6961825975064506  
Testing accuracy: 0.8688

Epoch 11

-----  
Training loss: 0.29346702143195846  
Training accuracy: 0.92885  
Testing loss: 0.46628761954930614  
Testing accuracy: 0.912  
Testing loss: 0.5328454249251301  
Testing accuracy: 0.9018  
Epoch 12

-----  
Training loss: 0.3075448272935496  
Training accuracy: 0.9262  
Testing loss: 0.8996193645235723  
Testing accuracy: 0.8218  
Testing loss: 0.9366894480376086  
Testing accuracy: 0.8184  
Epoch 13

-----  
Training loss: 0.3363251202685739  
Training accuracy: 0.91915  
Testing loss: 0.574489148421385  
Testing accuracy: 0.8978  
Testing loss: 0.7195687806585734  
Testing accuracy: 0.8906  
Epoch 14

-----  
Training loss: 0.31353306109967044  
Training accuracy: 0.9298  
Testing loss: 0.7075927166497109  
Testing accuracy: 0.8982  
Testing loss: 0.7754948970053108  
Testing accuracy: 0.8976  
Epoch 15

-----  
Training loss: 0.3146467408918145  
Training accuracy: 0.9271  
Testing loss: 0.570862974331044  
Testing accuracy: 0.9042  
Testing loss: 0.7654493169348552  
Testing accuracy: 0.8994  
Epoch 16

-----  
Training loss: 0.36244452733950633  
Training accuracy: 0.9214  
Testing loss: 0.803510181961665  
Testing accuracy: 0.8604  
Testing loss: 0.8451011651081785  
Testing accuracy: 0.8528

Epoch 17

-----  
Training loss: 0.38655662497904897  
Training accuracy: 0.91325  
Testing loss: 0.6284536963165784  
Testing accuracy: 0.8748  
Testing loss: 0.6468718413984945  
Testing accuracy: 0.8698  
Epoch 18

-----  
Training loss: 0.35781828364379575  
Training accuracy: 0.91875  
Testing loss: 0.5326167488239968  
Testing accuracy: 0.9034  
Testing loss: 0.6231185500444312  
Testing accuracy: 0.8902  
Epoch 19

-----  
Training loss: 0.38622947456621937  
Training accuracy: 0.9169  
Testing loss: 0.8244773546309169  
Testing accuracy: 0.8624  
Testing loss: 0.8891086996555566  
Testing accuracy: 0.8482  
Epoch 20

-----  
Training loss: 0.47566039185359543  
Training accuracy: 0.8976  
Testing loss: 0.6938714749375625  
Testing accuracy: 0.8838  
Testing loss: 0.7376766913089428  
Testing accuracy: 0.875  
Epoch 21

-----  
Training loss: 0.4288863875291888  
Training accuracy: 0.9082  
Testing loss: 0.5751460868564874  
Testing accuracy: 0.8942  
Testing loss: 0.7067200521590441  
Testing accuracy: 0.877  
Epoch 22

-----  
Training loss: 0.5177511545239321  
Training accuracy: 0.88905  
Testing loss: 0.5168572179220191  
Testing accuracy: 0.8942  
Testing loss: 0.5805294760259258  
Testing accuracy: 0.8826

Epoch 23

-----  
Training loss: 0.48327789631221074  
Training accuracy: 0.896  
Testing loss: 0.5783444935034733  
Testing accuracy: 0.8838  
Testing loss: 0.6918349440349483  
Testing accuracy: 0.8656  
Epoch 24

-----  
Training loss: 0.4993307096342195  
Training accuracy: 0.8962  
Testing loss: 0.9898861001767442  
Testing accuracy: 0.8244  
Testing loss: 1.0165682825768025  
Testing accuracy: 0.8176  
Epoch 25

-----  
Training loss: 0.5322607540972109  
Training accuracy: 0.89245  
Testing loss: 0.8195538798699458  
Testing accuracy: 0.8412  
Testing loss: 0.9202031520046672  
Testing accuracy: 0.8242  
Epoch 26

-----  
Training loss: 0.48155662489365414  
Training accuracy: 0.90125  
Testing loss: 0.8029338495669163  
Testing accuracy: 0.8866  
Testing loss: 0.8808645154692034  
Testing accuracy: 0.8746  
Epoch 27

-----  
Training loss: 0.43924736023148736  
Training accuracy: 0.91285  
Testing loss: 0.938876456291216  
Testing accuracy: 0.8676  
Testing loss: 1.1271969776596704  
Testing accuracy: 0.853  
Epoch 28

-----  
Training loss: 0.7008663637210272  
Training accuracy: 0.8631  
Testing loss: 0.5950433302884589  
Testing accuracy: 0.8922  
Testing loss: 0.7275388747382301  
Testing accuracy: 0.8728

Epoch 29

-----  
Training loss: 0.6749020447856757  
Training accuracy: 0.87135  
Testing loss: 0.8257195468162212  
Testing accuracy: 0.87  
Testing loss: 0.9520600284823153  
Testing accuracy: 0.853  
Epoch 30

-----  
Training loss: 0.8214901580956036  
Training accuracy: 0.8386  
Testing loss: 0.7711413610405317  
Testing accuracy: 0.8322  
Testing loss: 0.8814546989084422  
Testing accuracy: 0.8178  
Epoch 31

-----  
Training loss: 0.8820603411054379  
Training accuracy: 0.8173  
Testing loss: 0.8792760297487503  
Testing accuracy: 0.8184  
Testing loss: 0.9873016810383035  
Testing accuracy: 0.7866  
Epoch 32

-----  
Training loss: 0.9242060993981206  
Training accuracy: 0.80895  
Testing loss: 1.0234795150086682  
Testing accuracy: 0.7792  
Testing loss: 1.1235391020771337  
Testing accuracy: 0.747  
Epoch 33

-----  
Training loss: 0.9409294488023584  
Training accuracy: 0.79685  
Testing loss: 1.0368188160307508  
Testing accuracy: 0.7738  
Testing loss: 1.1189863214658267  
Testing accuracy: 0.752  
Epoch 34

-----  
Training loss: 0.9129257170880369  
Training accuracy: 0.8041  
Testing loss: 1.3536399569283366  
Testing accuracy: 0.679  
Testing loss: 1.4518986607014772  
Testing accuracy: 0.6552

Epoch 35

-----  
Training loss: 1.2235894670024177  
Training accuracy: 0.72685  
Testing loss: 1.099818583476459  
Testing accuracy: 0.751  
Testing loss: 1.1266572190536719  
Testing accuracy: 0.737  
Epoch 36

-----  
Training loss: 0.9241142137060049  
Training accuracy: 0.79935  
Testing loss: 1.2460487031835947  
Testing accuracy: 0.7654  
Testing loss: 1.307701976024788  
Testing accuracy: 0.7482  
Epoch 37

-----  
Training loss: 1.0709795096824708  
Training accuracy: 0.7584  
Testing loss: 0.9130719553493993  
Testing accuracy: 0.8094  
Testing loss: 1.0081625033919244  
Testing accuracy: 0.7928  
Epoch 38

-----  
Training loss: 0.9214172424436063  
Training accuracy: 0.7958  
Testing loss: 1.5222442371531208  
Testing accuracy: 0.7598  
Testing loss: 1.583793421353284  
Testing accuracy: 0.7354  
Epoch 39

-----  
Training loss: 0.9082853126236814  
Training accuracy: 0.80015  
Testing loss: 1.3642056904079156  
Testing accuracy: 0.731  
Testing loss: 1.3344895800919008  
Testing accuracy: 0.7196  
Epoch 40

-----  
Training loss: 0.9793415340984868  
Training accuracy: 0.7916  
Testing loss: 1.6710469614962102  
Testing accuracy: 0.631  
Testing loss: 1.6668375664220871  
Testing accuracy: 0.6104



Epoch 41

-----  
Training loss: 1.1745005242396738  
Training accuracy: 0.7418  
Testing loss: 1.5003145202621821  
Testing accuracy: 0.7278  
Testing loss: 1.6569074729782243  
Testing accuracy: 0.7116  
Epoch 42

-----  
Training loss: 1.3338231836509962  
Training accuracy: 0.7094  
Testing loss: 1.7066741092466085  
Testing accuracy: 0.6768  
Testing loss: 1.822044690195065  
Testing accuracy: 0.6612  
Epoch 43

-----  
Training loss: 1.5859935820206459  
Training accuracy: 0.6271  
Testing loss: 2.821440365120237  
Testing accuracy: 0.1068  
Testing loss: 2.840897187675672  
Testing accuracy: 0.0936  
Epoch 44

-----  
Training loss: 2.801513195246151  
Training accuracy: 0.0971  
Testing loss: 2.7985601579197783  
Testing accuracy: 0.107  
Testing loss: 2.810923510116722  
Testing accuracy: 0.0936  
Epoch 45

-----  
Training loss: 2.800255588893602  
Training accuracy: 0.0969  
Testing loss: 2.7985599243080053  
Testing accuracy: 0.107  
Testing loss: 2.8109181983224394  
Testing accuracy: 0.0936  
Epoch 46

-----  
Training loss: 2.8002545303714945  
Training accuracy: 0.0969  
Testing loss: 2.798559903794129  
Testing accuracy: 0.107  
Testing loss: 2.8109179683273906  
Testing accuracy: 0.0936

Epoch 47

-----  
Training loss: 2.800254489044815  
Training accuracy: 0.0969  
Testing loss: 2.798559901765621  
Testing accuracy: 0.107  
Testing loss: 2.8109179575329777  
Testing accuracy: 0.0936  
Epoch 48

-----  
Training loss: 2.800254487280222  
Training accuracy: 0.0969  
Testing loss: 2.7985599016499365  
Testing accuracy: 0.107  
Testing loss: 2.8109179570529683  
Testing accuracy: 0.0936  
Epoch 49

-----  
Training loss: 2.8002544872057875  
Training accuracy: 0.0969  
Testing loss: 2.798559901644334  
Testing accuracy: 0.107  
Testing loss: 2.810917957032289  
Testing accuracy: 0.0936  
Epoch 50

-----  
Training loss: 2.80025448720268  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440816  
Testing accuracy: 0.107  
Testing loss: 2.8109179570314153  
Testing accuracy: 0.0936  
Epoch 51

-----  
Training loss: 2.800254487202551  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.8109179570313794  
Testing accuracy: 0.0936  
Epoch 52

-----  
Training loss: 2.8002544872025426  
Training accuracy: 0.0969  
Testing loss: 2.798559901644071  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 53

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 54

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 55

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 56

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 57

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 58

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 59

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 60

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 61

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 62

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 63

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 64

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 65

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 66

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 67

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 68

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 69

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 70

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 71

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 72

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 73

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 74

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 75

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 76

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 77

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 78

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 79

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 80

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 81

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 82

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 83

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 84

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 85

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 86

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 87

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 88

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936



Epoch 89

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 90

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 91

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 92

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 93

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 94

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 95

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 96

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 97

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 98

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 99

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 100

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 101

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 102

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 103

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 104

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 105

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 106

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 107

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 108

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 109

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 110

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 111

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 112

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 113

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 114

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 115

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 116

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 117

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 118

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 119

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 120

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 121

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 122

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 123

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 124

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 125

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 126

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 127

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 128

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 129

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 130

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 131

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 132

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 133

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 134

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 135

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 136

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936



Epoch 137

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 138

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 139

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 140

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 141

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 142

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 143

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 144

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 145

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 146

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 147

-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 148

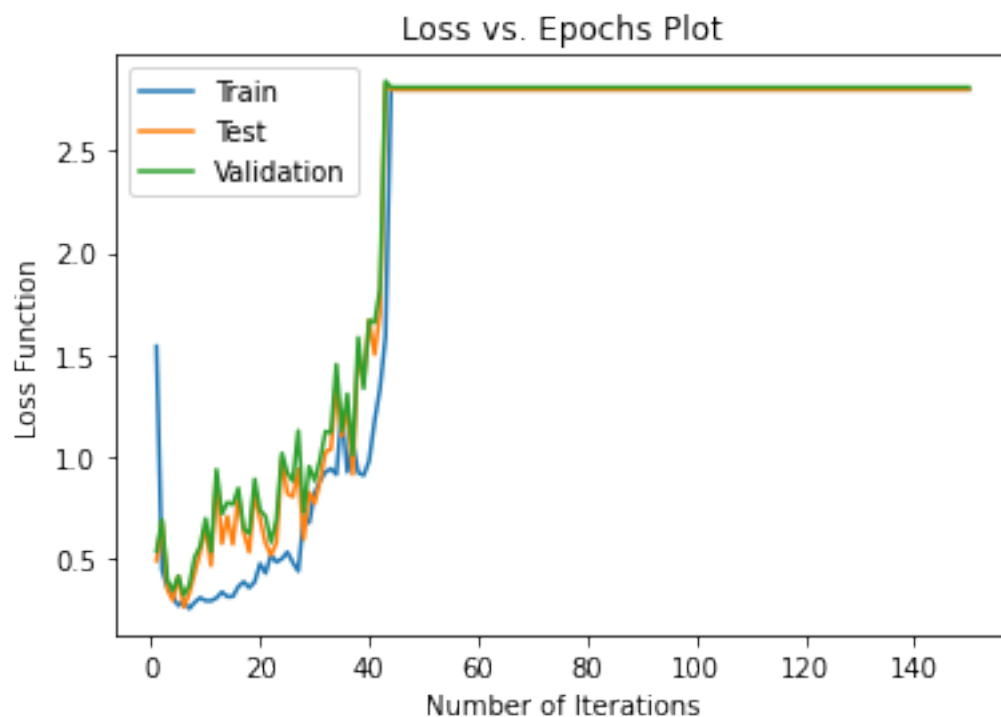
-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936

Epoch 149

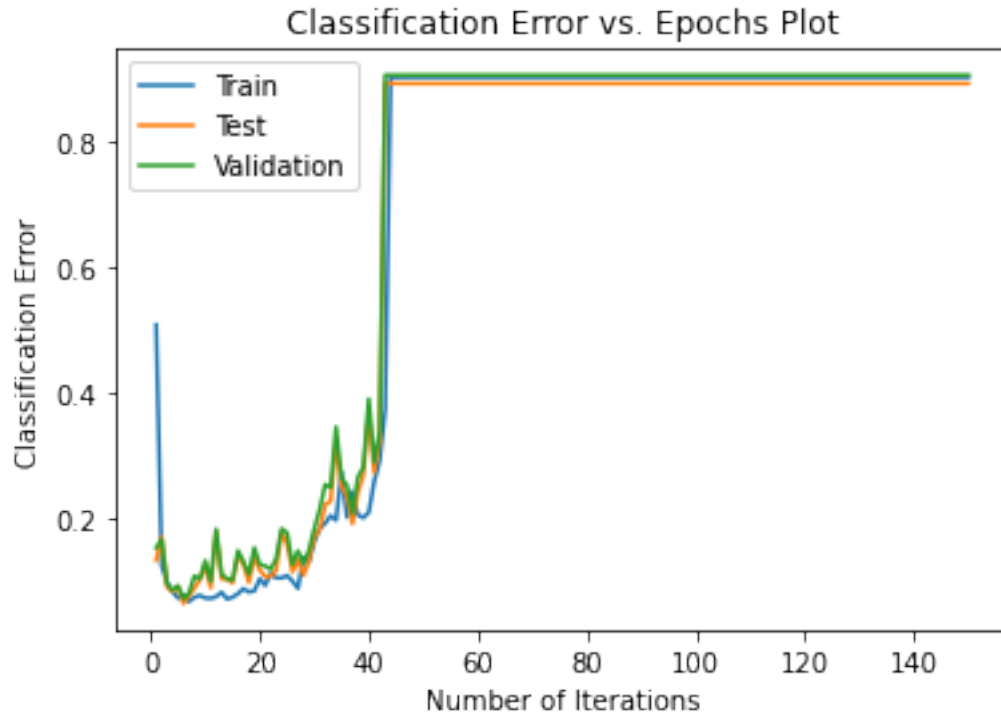
```
-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Epoch 150
```

```
-----  
Training loss: 2.800254487202543  
Training accuracy: 0.0969  
Testing loss: 2.7985599016440705  
Testing accuracy: 0.107  
Testing loss: 2.810917957031377  
Testing accuracy: 0.0936  
Done  
Total Time Consumed: 9804.940579414368
```

```
[95]: loss_plot1(train_loss_record, test_loss_record, val_loss_record)
```



```
[96]: error_plot1(train_loss_record, test_loss_record, val_loss_record)
```



## 6.5 7.(b)

From above, we can observe the validation error as follow:

Learning Rate = 0.1: 3.28%;

Learning Rate = 0.01: 5.76 %;

Learning Rate = 0.2: 3.04%;

Learning Rate = 0.5: 2.93%;

Momentum = 0.5 & Learning Rate = 0.1: 3.02%;

Momentum = 0.9 & Learning Rate = 0.1: 90.64%.

Therefore, we choose the model with Learning Rate = 0.5.

## 6.6 7.(c)

From above, we can observe the generalization error as follow:

Learning Rate = 0.1: 3.3%;

Learning Rate = 0.01: 4.88%;

Learning Rate = 0.2: 2.54%;

Learning Rate = 0.5: 2.98%;

Momentum = 0.5 & Learning Rate = 0.1: 2.58%;

Momentum = 0.9 & Learning Rate = 0.1: 89.3%.

Let's assume that the neural network perfectly figure out the summation relationship between the two image digits and label and there is no influence caused by the concatenation of two images. The highest generalization accuracy we can get is 99.3% from convolution neural network in part 4 with momentum = 0.5 & learning rate = 0.1. The probability of two correct classification is 0.993

\*  $0.993 = 0.986$ . Therefore, even if our above assumption hold, we still cannot obtain a test error lower than 1%.

## 7 Reference:

Bloice, M. D., Roth, P. M., & Holzinger, A. (2019, December 6). Performing arithmetic using a neural network trained on digit permutation pairs. arXiv.org. Retrieved April 26, 2022, from <https://arxiv.org/abs/1912.03035>