Assignment 3

July 27, 2022

Computer vision 2022 assignment 3 deep learning for perception tasks

This is the coding part for the assignment 3. It is a very easy practice for the beginers to get familar with how to use deep learning frameworks.

1 Question 1: A simple classifier (60%)

For this exercise, we will provide a demo code showing how to train a network on a small dataset called FashionMinst. Please go through the following tutorials first. You will get a basic understanding about how to train an image classification network in pytorch. You can change the training scheme and the network structure. Please answer the following questions then. You can orginaze your own text and code cell to show the answer of each questions.

Note: Please plot the training and testing loss curve for each experiment (2 point).

Requirement:

Q1.1 (1 point) Change the learning rate and train for 10 epochs. Fill this table:

Lr	Accuracy
1	
0.1	
0.01	
0.001	

Q1.2 (2 point) Report the number of epochs when the accuracy reaches 90%. If the program can not reach 90% within 100 epochs, please fill in "not converged" in the Epoch blank. Fill this table:

Lr	Accuracy	Epoch
1		
0.1		
0.01		
0.001		

Q1.3 (2 points) Compare the results in table 1 and table 2, what is your observation and your understanding of the learning rate?

Q1.4 (3 point) Suppose the given network is a base network, please calculate the trainable parameters for this given network, and report its accuracy with lr = 0.01 and 40 epochs. Change the network structures by adding/removing layers/nodes. Report the accuracy and the parameters for each structure under the same training setting. Parameters represent the number of trainable parameters in your model, e.g. a 3 x 3 conv has 9 parameters, and a linear layer with n input nodes and m output nodes has n*m+m parameters for weights and bias.

Structures	Accuracy	Parameters
Remove nodes		
Remove layers		
Base		
Add layers		
Add nodes		

Q1.5 (2 points) Choose to do one of the following two tasks:

a. Write a code to calculate the parameter and expian the code.

OR

b. Write done the process of how to calculate the parameters by hand.

Q1.6 (1 points) What are your observations and conclusions for changing network structure?

Q1.7 (2 points) Calculate the mean of the gradients of all trainable parameters. Plot the gradients curve for the first 1000 training steps. Please use lr = 0.1. What are your observations? Note that this gradients will be saved with the training parameters automatically after you call loss.backwards(). Hint: https://pytorch.org/tutorials/beginner/basics/autogradqs_tutorial.html

[63]:
```
import numpy as np # This is for mathematical operations

# this is used in plotting
import matplotlib.pyplot as plt
import time
import pylab as pl
from IPython import display

%matplotlib inline

%load_ext autoreload
%autoreload 2
%reload_ext autoreload
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
```

[64]:
```python
#### Tutorial Code
####PyTorch has two primitives to work with data: torch.utils.data.DataLoader␣
↪and torch.utils.data.Dataset.
#####Dataset stores samples and their corresponding labels, and DataLoader wraps␣
↪an iterable around the Dataset.
import torch
from torch import nn
from torch.utils.data import DataLoader
from torchvision import datasets
from torchvision.transforms import ToTensor, Lambda, Compose
import matplotlib.pyplot as plt

# Download training data from open datasets.
##Every TorchVision Dataset includes two arguments:
##transform and target_transform to modify the samples and labels respectively.


training_data = datasets.FashionMNIST(
    root="data",
    train=True,
    download=True,
    transform=ToTensor(),
)

# Download test data from open datasets.
test_data = datasets.FashionMNIST(
    root="data",
    train=False,
    download=True,
    transform=ToTensor(),
)
```

We pass the Dataset as an argument to DataLoader. This wraps an iterable over our dataset and supports automatic batching, sampling, shuffling, and multiprocess data loading. Here we define a batch size of 64, i.e. each element in the dataloader iterable will return a batch of 64 features and labels.

[65]:
```python
batch_size = 64

# Create data loaders.
train_dataloader = DataLoader(training_data, batch_size=batch_size)
test_dataloader = DataLoader(test_data, batch_size=batch_size)

for X, y in test_dataloader:
    print("Shape of X [N, C, H, W]: ", X.shape)
    print("Shape of y: ", y.shape, y.dtype)
    break
```

```
Shape of X [N, C, H, W]:  torch.Size([64, 1, 28, 28])
Shape of y:  torch.Size([64]) torch.int64
```

To define a neural network in PyTorch, we create a class that inherits from nn.Module. We define the layers of the network in the init function and specify how data will pass through the network in the forward function. To accelerate operations in the neural network, we move it to the GPU if available.

[66]:
```
# Get cpu or gpu device for training.
device = "cuda" if torch.cuda.is_available() else "cpu"
print("Using {} device".format(device))

# Define model
class NeuralNetwork(nn.Module):
    def __init__(self):
        super(NeuralNetwork, self).__init__()
        self.flatten = nn.Flatten()
        self.linear_relu_stack = nn.Sequential(
            nn.Linear(28*28, 512),
            nn.ReLU(),
            nn.Linear(512, 512),
            nn.ReLU(),
            nn.Linear(512, 10)
        )

    def forward(self, x):
        x = self.flatten(x)
        logits = self.linear_relu_stack(x)
        return logits

model = NeuralNetwork().to(device)
print(model)
```

```
Using cpu device
NeuralNetwork(
  (flatten): Flatten(start_dim=1, end_dim=-1)
  (linear_relu_stack): Sequential(
    (0): Linear(in_features=784, out_features=512, bias=True)
    (1): ReLU()
    (2): Linear(in_features=512, out_features=512, bias=True)
    (3): ReLU()
    (4): Linear(in_features=512, out_features=10, bias=True)
  )
)
```

[67]:
```
###Define the loss function and the optimizer
loss_fn = nn.CrossEntropyLoss()
optimizer = torch.optim.SGD(model.parameters(), lr=1e-3) # 1, 0.1, 0.01, 0.001
```

In a single training loop, the model makes predictions on the training dataset (fed to it in batches), and backpropagates the prediction error to adjust the model's parameters.

[68]:
```python
def train(dataloader, model, loss_fn, optimizer, out=None):
    size = len(dataloader.dataset)
    model.train()

    losses = []
    grads = []

    num_batch = 0

    for batch, (X, y) in enumerate(dataloader):
        X, y = X.to(device), y.to(device)

        # Compute prediction error
        pred = model(X)
        loss = loss_fn(pred, y)

        # Backpropagation
        optimizer.zero_grad()
        loss.backward()

        # extract gradient, calculate mean, and store
        mean_grad = []
        for name, parameter in model.named_parameters():
          if not parameter.requires_grad: continue
          val = parameter.grad.mean().item()
          mean_grad.append(val)

        grads.append(np.mean(mean_grad))

        optimizer.step()

        if batch % 100 == 0:
            current = batch * len(X)
            # print(f"loss: {loss.item():>7f}  [{current:>5d}/{size:>5d}]")

        losses.append(loss.item())
    print('Training Error:', np.mean(losses))
    return losses, grads
```

[69]:
```python
##Define a test function
def test(dataloader, model, loss_fn):
    size = len(dataloader.dataset)
    num_batches = len(dataloader)
    model.eval()
    test_loss, correct = 0, 0
    with torch.no_grad():
        for X, y in dataloader:
            X, y = X.to(device), y.to(device)
            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(f"Test Error: \n Accuracy: {(100*correct):>0.1f}%, Avg loss:␣
 ↪{test_loss:>8f} \n")

    return test_loss, correct
```

[70]:
```
# Defining customisable Network
class NeuralNetworkv2(nn.Module):
    def __init__(self, num_nodes=512, num_layers=1):
        super(NeuralNetworkv2, self).__init__()
        self.flatten = nn.Flatten()

        layers = [nn.Linear(28*28, num_nodes), nn.ReLU()]

        for layer_idx in range(num_layers):
          layers.append(nn.Linear(num_nodes, num_nodes))
          layers.append(nn.ReLU())

        layers.append(nn.Linear(num_nodes, 10))

        self.linear_relu_stack = nn.Sequential(*layers)

    def forward(self, x):
        x = self.flatten(x)
        logits = self.linear_relu_stack(x)
        return logits
```

[71]:
```
#Helper Methods
#Method for getting the Average for a given learning rate and number of epochs
def getAverage(metric_list, lr, total_vals):
  values = getList(metric_list, lr, total_vals)
  average_value = sum(values)/total_vals
  return average_value

#Method to get a list of metric for given number of epochs
def getList(metric_list, lr, total_vals):
  return metric_list[lr][:total_vals]

#Method to plot the training and Test Curve
```

```
def plotTrainigTestCurve(first_list, second_list, first_label, second_label,␣
↪title):
  plt.plot(first_list, '--*b')
  plt.plot(second_list, '--*r')
  plt.title(title)
  plt.legend(['Training','Testing'], loc='upper right')
  plt.xlabel('epoch')
  plt.ylabel('loss')
  plt.show()
  return

#Method to plot the Accuracy Curve
def plotAccuracy(list_of_values, label, title):
  plt.plot(list_of_values, '--*g')
  plt.title(title)
  plt.legend(['Accuracy'], loc='upper left')
  plt.xlabel('epoch')
  plt.ylabel('Accuracy')
  plt.show()
  return

#Method to run different experiment with different learning rate, network␣
↪architecture and epochs
def RunExpirement(learning_rate_list, epochs, device, num_nodes = 512,␣
↪num_layers = 1):
  train_loss = {}
  test_loss = {}
  test_acc = {}
  train_grads = {}
  parameters = 0

  for lr in learning_rate_list:
    print('Running for Learning Rate', lr)
    model = NeuralNetworkv2(num_nodes=num_nodes, num_layers=num_layers).
↪to(device)
    optimizer = torch.optim.SGD(model.parameters(), lr=lr)
    parameters = sum(p.numel() for p in model.parameters() if p.requires_grad)
    print('Number of parameters', parameters)
    #Train and test the model
    train_loss[lr] = []
    test_loss[lr] = []
    test_acc[lr] = []
    train_grads[lr] = []

    for t in range(epochs):
      print(f"Epoch {t+1}\n-------------------------------")
```

```
        train_loss_epoch, mean_grads = train(train_dataloader, model, loss_fn,␣
 ↪optimizer)
        train_loss[lr].append(train_loss_epoch)
        train_grads[lr].extend(mean_grads)

        test_loss_epoch, test_acc_epoch = test(test_dataloader, model, loss_fn)
        test_loss[lr].append(test_loss_epoch)
        test_acc[lr].append(test_acc_epoch)

      train_loss[lr] = [sum(epoch_losses)/len(epoch_losses) for epoch_losses in␣
 ↪train_loss[lr]]

      print("Done for Learning Rate!", lr, '\n\n')
    return test_acc, parameters,train_loss, test_loss
```

[72]:
```
#Running Network for 100 Epochs for Learning Rates [1, 0.1, 0.01, 0.001] and 100␣
 ↪epochs
#Training the network for different learning rates
train_loss = {}
test_loss = {}
test_acc = {}
train_grads = {}

for lr in [1, 0.1, 0.01, 0.001]:
  print('Running for Learning Rate', lr)
  #Params for Base Network
  model = NeuralNetworkv2(num_nodes=512, num_layers=1).to(device)
  optimizer = torch.optim.SGD(model.parameters(), lr=lr)
  print('Number of parameters', sum(p.numel() for p in model.parameters() if p.
 ↪requires_grad))

  #Training for over 100 epochs and will retrieve the values for 10 epochs the␣
 ↪same
  epochs = 100
  train_loss[lr] = []
  test_loss[lr] = []
  test_acc[lr] = []
  train_grads[lr] = []

  for t in range(epochs):
    print(f"Epoch {t+1}\n-------------------------------")
    train_loss_epoch, mean_grads = train(train_dataloader, model, loss_fn,␣
 ↪optimizer)
    train_loss[lr].append(train_loss_epoch)
    train_grads[lr].extend(mean_grads)

    test_loss_epoch, test_acc_epoch = test(test_dataloader, model, loss_fn)
```

```
        test_loss[lr].append(test_loss_epoch)
        test_acc[lr].append(test_acc_epoch)

    train_loss[lr] = [sum(epoch_losses)/len(epoch_losses) for epoch_losses in␣
↪train_loss[lr]]

    print("Done for Learning Rate!", lr, '\n\n')
```

```
Running for Learning Rate 1
Number of parameters 669706
Epoch 1
-------------------------------
Training Error: 2.255376170566087
Test Error:
 Accuracy: 34.1%, Avg loss: 1.553257

Epoch 2
-------------------------------
Training Error: 2.016299335814234
Test Error:
 Accuracy: 19.9%, Avg loss: 2.125590

Epoch 3
-------------------------------
Training Error: 1.7631722781449748
Test Error:
 Accuracy: 19.9%, Avg loss: 1.722205

Epoch 4
-------------------------------
Training Error: 1.7280246339627165
Test Error:
 Accuracy: 26.7%, Avg loss: 1.660301

Epoch 5
-------------------------------
Training Error: 1.6948472774867565
Test Error:
 Accuracy: 25.3%, Avg loss: 1.661375

Epoch 6
-------------------------------
Training Error: 1.6669817416906865
Test Error:
 Accuracy: 23.9%, Avg loss: 1.682803

Epoch 7
-------------------------------
```

```
Training Error: 1.6240473434106628
Test Error:
 Accuracy: 26.2%, Avg loss: 1.631220

Epoch 8
-------------------------------
Training Error: 1.627462550012796
Test Error:
 Accuracy: 28.9%, Avg loss: 1.578095

Epoch 9
-------------------------------
Training Error: 1.5984512378157838
Test Error:
 Accuracy: 28.4%, Avg loss: 1.736664

Epoch 10
-------------------------------
Training Error: 1.695831680348687
Test Error:
 Accuracy: 19.9%, Avg loss: 1.724623

Epoch 11
-------------------------------
Training Error: 1.724713973653342
Test Error:
 Accuracy: 20.1%, Avg loss: 1.735343

Epoch 12
-------------------------------
Training Error: 1.726587321839607
Test Error:
 Accuracy: 19.9%, Avg loss: 1.717165

Epoch 13
-------------------------------
Training Error: 1.7209226966920945
Test Error:
 Accuracy: 19.9%, Avg loss: 1.714920

Epoch 14
-------------------------------
Training Error: 1.7215237309937792
Test Error:
 Accuracy: 19.8%, Avg loss: 1.722347

Epoch 15
-------------------------------
```

```
Training Error: 1.7168842369813655
Test Error:
 Accuracy: 19.8%, Avg loss: 1.718985

Epoch 16
-------------------------------
Training Error: 1.7246163388305127
Test Error:
 Accuracy: 19.9%, Avg loss: 1.708583

Epoch 17
-------------------------------
Training Error: 1.6894256492921793
Test Error:
 Accuracy: 20.0%, Avg loss: 1.706598

Epoch 18
-------------------------------
Training Error: 1.7764063603334082
Test Error:
 Accuracy: 25.2%, Avg loss: 1.663375

Epoch 19
-------------------------------
Training Error: 7.844585399637853
Test Error:
 Accuracy: 19.9%, Avg loss: 1.868884

Epoch 20
-------------------------------
Training Error: 2.4318757096587467
Test Error:
 Accuracy: 19.9%, Avg loss: 1.721839

Epoch 21
-------------------------------
Training Error: 1.7260141218903222
Test Error:
 Accuracy: 19.9%, Avg loss: 1.713389

Epoch 22
-------------------------------
Training Error: 2.0197673722116676
Test Error:
 Accuracy: 12.0%, Avg loss: 2.299574

Epoch 23
-------------------------------
```

```
Training Error: 1.88622315453568
Test Error:
 Accuracy: 19.9%, Avg loss: 1.709727

Epoch 24
-------------------------------
Training Error: 2.158084359885787
Test Error:
 Accuracy: 16.3%, Avg loss: 2.045715

Epoch 25
-------------------------------
Training Error: 1.8290159139297664
Test Error:
 Accuracy: 20.0%, Avg loss: 1.735985

Epoch 26
-------------------------------
Training Error: 1.7450911200631147
Test Error:
 Accuracy: 19.8%, Avg loss: 1.719922

Epoch 27
-------------------------------
Training Error: 1.7309987583140065
Test Error:
 Accuracy: 20.0%, Avg loss: 1.721059

Epoch 28
-------------------------------
Training Error: 1.7272024872714777
Test Error:
 Accuracy: 19.0%, Avg loss: 1.698937

Epoch 29
-------------------------------
Training Error: 1.7314357338175337
Test Error:
 Accuracy: 19.9%, Avg loss: 1.720935

Epoch 30
-------------------------------
Training Error: 1.7338684205053203
Test Error:
 Accuracy: 20.0%, Avg loss: 1.791063

Epoch 31
-------------------------------
```

```
Training Error: 1.7285532075713184
Test Error:
 Accuracy: 19.8%, Avg loss: 1.720372

Epoch 32
-------------------------------
Training Error: 2.2995914506759725
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305735

Epoch 33
-------------------------------
Training Error: 2.314214511975042
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305822

Epoch 34
-------------------------------
Training Error: 2.306041602386849
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305844

Epoch 35
-------------------------------
Training Error: 2.2974409354266836
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305798

Epoch 36
-------------------------------
Training Error: 2.3066544487023912
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305856

Epoch 37
-------------------------------
Training Error: 2.306075249907813
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305865

Epoch 38
-------------------------------
Training Error: 2.3060510763481483
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305842

Epoch 39
-------------------------------
```

```
Training Error: 2.305961592110998
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305417

Epoch 40
-------------------------------
Training Error: 1.8751766799863723
Test Error:
 Accuracy: 19.9%, Avg loss: 1.719460

Epoch 41
-------------------------------
Training Error: 1.7242662649927363
Test Error:
 Accuracy: 19.9%, Avg loss: 1.715463

Epoch 42
-------------------------------
Training Error: 1.720701662589238
Test Error:
 Accuracy: 19.9%, Avg loss: 1.714878

Epoch 43
-------------------------------
Training Error: 1.7188800134892657
Test Error:
 Accuracy: 20.0%, Avg loss: 1.713293

Epoch 44
-------------------------------
Training Error: 1.726115616018584
Test Error:
 Accuracy: 19.9%, Avg loss: 1.710924

Epoch 45
-------------------------------
Training Error: 1.7227720389488155
Test Error:
 Accuracy: 20.0%, Avg loss: 1.712027

Epoch 46
-------------------------------
Training Error: 1.7213039116056235
Test Error:
 Accuracy: 19.9%, Avg loss: 1.714618

Epoch 47
-------------------------------
```

```
Training Error: 1.7182910045835256
Test Error: 
 Accuracy: 20.0%, Avg loss: 1.713256 

Epoch 48
-------------------------------
Training Error: 1.7251341069685115
Test Error: 
 Accuracy: 20.0%, Avg loss: 1.718519 

Epoch 49
-------------------------------
Training Error: 1.7270103752740156
Test Error: 
 Accuracy: 19.9%, Avg loss: 1.715903 

Epoch 50
-------------------------------
Training Error: 1.7156107959462636
Test Error: 
 Accuracy: 27.1%, Avg loss: 1.607528 

Epoch 51
-------------------------------
Training Error: 1.7918131270134119
Test Error: 
 Accuracy: 19.8%, Avg loss: 1.725225 

Epoch 52
-------------------------------
Training Error: 1.728936874408966
Test Error: 
 Accuracy: 19.9%, Avg loss: 1.716008 

Epoch 53
-------------------------------
Training Error: 1.7234546102440433
Test Error: 
 Accuracy: 19.9%, Avg loss: 1.714467 

Epoch 54
-------------------------------
Training Error: 1.7208082787771977
Test Error: 
 Accuracy: 19.9%, Avg loss: 1.713597 

Epoch 55
-------------------------------
```

```
Training Error: 1.717089955232291
Test Error:
 Accuracy: 19.9%, Avg loss: 1.714446

Epoch 56
-------------------------------
Training Error: 1.7174616869070383
Test Error:
 Accuracy: 19.9%, Avg loss: 1.711407

Epoch 57
-------------------------------
Training Error: 1.7155108259939182
Test Error:
 Accuracy: 19.9%, Avg loss: 1.711843

Epoch 58
-------------------------------
Training Error: 1.7158920655626733
Test Error:
 Accuracy: 19.9%, Avg loss: 1.714858

Epoch 59
-------------------------------
Training Error: 1.7176292139584068
Test Error:
 Accuracy: 19.9%, Avg loss: 1.711453

Epoch 60
-------------------------------
Training Error: 1.746723928939559
Test Error:
 Accuracy: 19.9%, Avg loss: 1.715829

Epoch 61
-------------------------------
Training Error: 1.7233227058005993
Test Error:
 Accuracy: 19.9%, Avg loss: 1.715283

Epoch 62
-------------------------------
Training Error: 1.72059530350191
Test Error:
 Accuracy: 19.9%, Avg loss: 1.720051

Epoch 63
-------------------------------
```

```
Training Error: 1.7205607573360777
Test Error:
 Accuracy: 19.8%, Avg loss: 1.726334

Epoch 64
-------------------------------
Training Error: 1.7277612134591858
Test Error:
 Accuracy: 20.0%, Avg loss: 1.731669

Epoch 65
-------------------------------
Training Error: 1.717706434126856
Test Error:
 Accuracy: 20.0%, Avg loss: 1.715988

Epoch 66
-------------------------------
Training Error: 1.716296022380593
Test Error:
 Accuracy: 20.0%, Avg loss: 1.711887

Epoch 67
-------------------------------
Training Error: 1.7186319548438098
Test Error:
 Accuracy: 19.8%, Avg loss: 1.715544

Epoch 68
-------------------------------
Training Error: 1.7207856995464643
Test Error:
 Accuracy: 20.0%, Avg loss: 1.710402

Epoch 69
-------------------------------
Training Error: 1.7165727367533294
Test Error:
 Accuracy: 19.9%, Avg loss: 1.710619

Epoch 70
-------------------------------
Training Error: 1.714744277854464
Test Error:
 Accuracy: 19.9%, Avg loss: 1.709309

Epoch 71
-------------------------------
```

```
Training Error: 1.7154274227014228
Test Error:
 Accuracy: 20.0%, Avg loss: 1.713503

Epoch 72
-------------------------------
Training Error: 1.718282148782124
Test Error:
 Accuracy: 19.9%, Avg loss: 1.711652

Epoch 73
-------------------------------
Training Error: 1.7150568033078077
Test Error:
 Accuracy: 20.0%, Avg loss: 1.709222

Epoch 74
-------------------------------
Training Error: 1.7142554113605637
Test Error:
 Accuracy: 20.0%, Avg loss: 1.708872

Epoch 75
-------------------------------
Training Error: 1.714157818349948
Test Error:
 Accuracy: 19.9%, Avg loss: 1.709136

Epoch 76
-------------------------------
Training Error: 1.7142518333026342
Test Error:
 Accuracy: 19.9%, Avg loss: 1.709218

Epoch 77
-------------------------------
Training Error: 1.713621777639206
Test Error:
 Accuracy: 19.9%, Avg loss: 1.708462

Epoch 78
-------------------------------
Training Error: 1.7133947640085525
Test Error:
 Accuracy: 19.9%, Avg loss: 1.708043

Epoch 79
-------------------------------
```

```
Training Error: 1.7138974766995607
Test Error:
 Accuracy: 19.9%, Avg loss: 1.708427

Epoch 80
-------------------------------
Training Error: 1.7154052815457652
Test Error:
 Accuracy: 19.9%, Avg loss: 1.708408

Epoch 81
-------------------------------
Training Error: 1.7178896094944431
Test Error:
 Accuracy: 19.9%, Avg loss: 1.709382

Epoch 82
-------------------------------
Training Error: 1.7140201288245633
Test Error:
 Accuracy: 19.9%, Avg loss: 1.708291

Epoch 83
-------------------------------
Training Error: 1.7122838743714128
Test Error:
 Accuracy: 19.9%, Avg loss: 1.707525

Epoch 84
-------------------------------
Training Error: 1.7129995434014782
Test Error:
 Accuracy: 19.9%, Avg loss: 1.707564

Epoch 85
-------------------------------
Training Error: 1.713271484191992
Test Error:
 Accuracy: 19.9%, Avg loss: 1.707528

Epoch 86
-------------------------------
Training Error: 1.7125828761790098
Test Error:
 Accuracy: 19.9%, Avg loss: 1.707784

Epoch 87
-------------------------------
```

```
Training Error: 1.899639721109923
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 88
-------------------------------
Training Error: 2.3061229580246816
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 89
-------------------------------
Training Error: 2.306122957262149
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 90
-------------------------------
Training Error: 2.3061229562454386
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 91
-------------------------------
Training Error: 2.306122957262149
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 92
-------------------------------
Training Error: 2.3061229562454386
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 93
-------------------------------
Training Error: 2.306122957262149
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 94
-------------------------------
Training Error: 2.3061229562454386
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 95
-------------------------------
```

```
Training Error: 2.306122957262149
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 96
-------------------------------
Training Error: 2.3061229562454386
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 97
-------------------------------
Training Error: 2.306122957262149
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 98
-------------------------------
Training Error: 2.3061229562454386
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 99
-------------------------------
Training Error: 2.306122957262149
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Epoch 100
-------------------------------
Training Error: 2.3061229562454386
Test Error:
 Accuracy: 10.0%, Avg loss: 2.305845

Done for Learning Rate! 1


Running for Learning Rate 0.1
Number of parameters 669706
Epoch 1
-------------------------------
Training Error: 0.6577091144282681
Test Error:
 Accuracy: 78.3%, Avg loss: 0.567239

Epoch 2
-------------------------------
Training Error: 0.42484764305195577
```

```
Test Error:
 Accuracy: 81.4%, Avg loss: 0.488509

Epoch 3
-------------------------------
Training Error: 0.37568891626685413
Test Error:
 Accuracy: 83.3%, Avg loss: 0.451540

Epoch 4
-------------------------------
Training Error: 0.3455171389683986
Test Error:
 Accuracy: 85.0%, Avg loss: 0.417257

Epoch 5
-------------------------------
Training Error: 0.3231545064145568
Test Error:
 Accuracy: 85.4%, Avg loss: 0.404482

Epoch 6
-------------------------------
Training Error: 0.3051611215654594
Test Error:
 Accuracy: 86.0%, Avg loss: 0.387318

Epoch 7
-------------------------------
Training Error: 0.2904169270590043
Test Error:
 Accuracy: 86.5%, Avg loss: 0.374561

Epoch 8
-------------------------------
Training Error: 0.27682663678233305
Test Error:
 Accuracy: 87.2%, Avg loss: 0.359307

Epoch 9
-------------------------------
Training Error: 0.264697014173465
Test Error:
 Accuracy: 87.4%, Avg loss: 0.350789

Epoch 10
-------------------------------
Training Error: 0.2534424789758252
```

```
Test Error:
 Accuracy: 87.6%, Avg loss: 0.348286

Epoch 11
-------------------------------
Training Error: 0.2429788327738166
Test Error:
 Accuracy: 87.5%, Avg loss: 0.348162

Epoch 12
-------------------------------
Training Error: 0.23293255864461856
Test Error:
 Accuracy: 87.6%, Avg loss: 0.345156

Epoch 13
-------------------------------
Training Error: 0.22407401003229466
Test Error:
 Accuracy: 87.9%, Avg loss: 0.342687

Epoch 14
-------------------------------
Training Error: 0.215396716074744
Test Error:
 Accuracy: 88.2%, Avg loss: 0.338264

Epoch 15
-------------------------------
Training Error: 0.2065224451686083
Test Error:
 Accuracy: 87.8%, Avg loss: 0.343456

Epoch 16
-------------------------------
Training Error: 0.1984912425374934
Test Error:
 Accuracy: 88.0%, Avg loss: 0.344087

Epoch 17
-------------------------------
Training Error: 0.19071416242290407
Test Error:
 Accuracy: 87.6%, Avg loss: 0.352307

Epoch 18
-------------------------------
Training Error: 0.1831580922206137
```

```
Test Error:
 Accuracy: 88.1%, Avg loss: 0.341892

Epoch 19
-------------------------------
Training Error: 0.1754080681666446
Test Error:
 Accuracy: 88.1%, Avg loss: 0.348736

Epoch 20
-------------------------------
Training Error: 0.1684825749023319
Test Error:
 Accuracy: 87.5%, Avg loss: 0.370428

Epoch 21
-------------------------------
Training Error: 0.16125058443116735
Test Error:
 Accuracy: 88.0%, Avg loss: 0.368589

Epoch 22
-------------------------------
Training Error: 0.15487105902363815
Test Error:
 Accuracy: 87.5%, Avg loss: 0.376643

Epoch 23
-------------------------------
Training Error: 0.1477144381492091
Test Error:
 Accuracy: 87.7%, Avg loss: 0.382505

Epoch 24
-------------------------------
Training Error: 0.14075957656677154
Test Error:
 Accuracy: 87.5%, Avg loss: 0.390365

Epoch 25
-------------------------------
Training Error: 0.1354741152606285
Test Error:
 Accuracy: 87.0%, Avg loss: 0.410390

Epoch 26
-------------------------------
Training Error: 0.12869463270422873
```

```
Test Error:
 Accuracy: 87.0%, Avg loss: 0.430496

Epoch 27
-------------------------------
Training Error: 0.12212253403442819
Test Error:
 Accuracy: 86.6%, Avg loss: 0.437839

Epoch 28
-------------------------------
Training Error: 0.11717376788494302
Test Error:
 Accuracy: 87.4%, Avg loss: 0.427883

Epoch 29
-------------------------------
Training Error: 0.12843037396272236
Test Error:
 Accuracy: 87.1%, Avg loss: 0.426525

Epoch 30
-------------------------------
Training Error: 0.11147916154054277
Test Error:
 Accuracy: 87.6%, Avg loss: 0.436642

Epoch 31
-------------------------------
Training Error: 0.10377297743853094
Test Error:
 Accuracy: 87.7%, Avg loss: 0.447838

Epoch 32
-------------------------------
Training Error: 0.0997225817030808
Test Error:
 Accuracy: 87.3%, Avg loss: 0.459976

Epoch 33
-------------------------------
Training Error: 0.09474181969449527
Test Error:
 Accuracy: 86.7%, Avg loss: 0.486163

Epoch 34
-------------------------------
Training Error: 0.0897994247684156
```

```
Test Error:
 Accuracy: 86.7%, Avg loss: 0.485449

Epoch 35
-------------------------------
Training Error: 0.08675549719045793
Test Error:
 Accuracy: 87.3%, Avg loss: 0.504354

Epoch 36
-------------------------------
Training Error: 0.08453957535235136
Test Error:
 Accuracy: 87.8%, Avg loss: 0.472944

Epoch 37
-------------------------------
Training Error: 0.08824645040699763
Test Error:
 Accuracy: 87.8%, Avg loss: 0.498457

Epoch 38
-------------------------------
Training Error: 0.07867889578984395
Test Error:
 Accuracy: 88.0%, Avg loss: 0.492529

Epoch 39
-------------------------------
Training Error: 0.07675592126553135
Test Error:
 Accuracy: 88.2%, Avg loss: 0.486393

Epoch 40
-------------------------------
Training Error: 0.0740713533123276
Test Error:
 Accuracy: 87.9%, Avg loss: 0.503029

Epoch 41
-------------------------------
Training Error: 0.07003706097424126
Test Error:
 Accuracy: 88.1%, Avg loss: 0.507420

Epoch 42
-------------------------------
Training Error: 0.06713226526779041
```

```
Test Error:
 Accuracy: 87.5%, Avg loss: 0.545868

Epoch 43
-------------------------------
Training Error: 0.06882135307630782
Test Error:
 Accuracy: 85.0%, Avg loss: 0.609327

Epoch 44
-------------------------------
Training Error: 0.07447683644929785
Test Error:
 Accuracy: 87.7%, Avg loss: 0.549758

Epoch 45
-------------------------------
Training Error: 0.06509147065062164
Test Error:
 Accuracy: 88.0%, Avg loss: 0.529887

Epoch 46
-------------------------------
Training Error: 0.0612392401092374
Test Error:
 Accuracy: 88.5%, Avg loss: 0.559677

Epoch 47
-------------------------------
Training Error: 0.06431776202712725
Test Error:
 Accuracy: 88.7%, Avg loss: 0.548119

Epoch 48
-------------------------------
Training Error: 0.059287648460369054
Test Error:
 Accuracy: 88.4%, Avg loss: 0.570289

Epoch 49
-------------------------------
Training Error: 0.05350599081160179
Test Error:
 Accuracy: 88.2%, Avg loss: 0.563546

Epoch 50
-------------------------------
Training Error: 0.05195902979476993
```

```
Test Error:
 Accuracy: 87.7%, Avg loss: 0.561967

Epoch 51
-------------------------------
Training Error: 0.04904374110548179
Test Error:
 Accuracy: 87.9%, Avg loss: 0.546798

Epoch 52
-------------------------------
Training Error: 0.052634446752636926
Test Error:
 Accuracy: 88.5%, Avg loss: 0.541030

Epoch 53
-------------------------------
Training Error: 0.04681368887514821
Test Error:
 Accuracy: 88.8%, Avg loss: 0.542832

Epoch 54
-------------------------------
Training Error: 0.04530822623298684
Test Error:
 Accuracy: 88.6%, Avg loss: 0.544129

Epoch 55
-------------------------------
Training Error: 0.042624917526447426
Test Error:
 Accuracy: 87.3%, Avg loss: 0.602089

Epoch 56
-------------------------------
Training Error: 0.040842985383980575
Test Error:
 Accuracy: 89.0%, Avg loss: 0.586748

Epoch 57
-------------------------------
Training Error: 0.0404936998696831
Test Error:
 Accuracy: 88.8%, Avg loss: 0.560123

Epoch 58
-------------------------------
Training Error: 0.04852959115245838
```

```
Test Error:
 Accuracy: 88.2%, Avg loss: 0.649605

Epoch 59
-------------------------------
Training Error: 0.04098960544133603
Test Error:
 Accuracy: 88.9%, Avg loss: 0.554037

Epoch 60
-------------------------------
Training Error: 0.03906181744828042
Test Error:
 Accuracy: 88.6%, Avg loss: 0.628158

Epoch 61
-------------------------------
Training Error: 0.037282284163286106
Test Error:
 Accuracy: 88.6%, Avg loss: 0.588022

Epoch 62
-------------------------------
Training Error: 0.03888845983157947
Test Error:
 Accuracy: 88.8%, Avg loss: 0.609614

Epoch 63
-------------------------------
Training Error: 0.032281580538839415
Test Error:
 Accuracy: 88.8%, Avg loss: 0.621539

Epoch 64
-------------------------------
Training Error: 0.03481376918180705
Test Error:
 Accuracy: 88.6%, Avg loss: 0.644449

Epoch 65
-------------------------------
Training Error: 0.03166666776607079
Test Error:
 Accuracy: 88.8%, Avg loss: 0.605931

Epoch 66
-------------------------------
Training Error: 0.03454462326229064
```

```
Test Error:
 Accuracy: 89.0%, Avg loss: 0.617451

Epoch 67
-------------------------------
Training Error: 0.03669973922883973
Test Error:
 Accuracy: 87.9%, Avg loss: 0.681338

Epoch 68
-------------------------------
Training Error: 0.04042281874200838
Test Error:
 Accuracy: 89.2%, Avg loss: 0.616637

Epoch 69
-------------------------------
Training Error: 0.03720719548503755
Test Error:
 Accuracy: 87.7%, Avg loss: 0.708633

Epoch 70
-------------------------------
Training Error: 0.03070323470533629
Test Error:
 Accuracy: 89.1%, Avg loss: 0.651576

Epoch 71
-------------------------------
Training Error: 0.034094360577978135
Test Error:
 Accuracy: 88.9%, Avg loss: 0.631008

Epoch 72
-------------------------------
Training Error: 0.02652670994324278
Test Error:
 Accuracy: 88.5%, Avg loss: 0.687427

Epoch 73
-------------------------------
Training Error: 0.025576359660266394
Test Error:
 Accuracy: 89.2%, Avg loss: 0.664642

Epoch 74
-------------------------------
Training Error: 0.027171203441647834
```

```
Test Error:
 Accuracy: 88.5%, Avg loss: 0.688476

Epoch 75
-------------------------------
Training Error: 0.025725538209045946
Test Error:
 Accuracy: 89.3%, Avg loss: 0.660304

Epoch 76
-------------------------------
Training Error: 0.02875777381056024
Test Error:
 Accuracy: 88.4%, Avg loss: 0.728062

Epoch 77
-------------------------------
Training Error: 0.025625685479483015
Test Error:
 Accuracy: 88.7%, Avg loss: 0.690635

Epoch 78
-------------------------------
Training Error: 0.022129686210733423
Test Error:
 Accuracy: 89.2%, Avg loss: 0.684444

Epoch 79
-------------------------------
Training Error: 0.021495124969784337
Test Error:
 Accuracy: 88.5%, Avg loss: 0.707099

Epoch 80
-------------------------------
Training Error: 0.022695505201803155
Test Error:
 Accuracy: 88.9%, Avg loss: 0.684154

Epoch 81
-------------------------------
Training Error: 0.031666467559145595
Test Error:
 Accuracy: 89.1%, Avg loss: 0.688822

Epoch 82
-------------------------------
Training Error: 0.024350514248375154
```

```
Test Error:
 Accuracy: 88.2%, Avg loss: 0.719503

Epoch 83
-------------------------------
Training Error: 0.029868234425466926
Test Error:
 Accuracy: 88.6%, Avg loss: 0.728513

Epoch 84
-------------------------------
Training Error: 0.020506674659126665
Test Error:
 Accuracy: 89.2%, Avg loss: 0.695793

Epoch 85
-------------------------------
Training Error: 0.025562502573857875
Test Error:
 Accuracy: 89.1%, Avg loss: 0.745305

Epoch 86
-------------------------------
Training Error: 0.02586819138793674
Test Error:
 Accuracy: 88.9%, Avg loss: 0.696226

Epoch 87
-------------------------------
Training Error: 0.0272694272787195
Test Error:
 Accuracy: 88.7%, Avg loss: 0.715171

Epoch 88
-------------------------------
Training Error: 0.026401634475075778
Test Error:
 Accuracy: 86.7%, Avg loss: 0.853174

Epoch 89
-------------------------------
Training Error: 0.024789439356504336
Test Error:
 Accuracy: 89.1%, Avg loss: 0.728515

Epoch 90
-------------------------------
Training Error: 0.023951203270908644
```

```
Test Error:
 Accuracy: 89.1%, Avg loss: 0.715290

Epoch 91
-------------------------------
Training Error: 0.020960280127616835
Test Error:
 Accuracy: 89.3%, Avg loss: 0.713038

Epoch 92
-------------------------------
Training Error: 0.020443429796659113
Test Error:
 Accuracy: 89.2%, Avg loss: 0.709438

Epoch 93
-------------------------------
Training Error: 0.029734332870816373
Test Error:
 Accuracy: 88.5%, Avg loss: 0.695738

Epoch 94
-------------------------------
Training Error: 0.017338467551755714
Test Error:
 Accuracy: 89.2%, Avg loss: 0.742393

Epoch 95
-------------------------------
Training Error: 0.017078279491776087
Test Error:
 Accuracy: 88.9%, Avg loss: 0.730282

Epoch 96
-------------------------------
Training Error: 0.01732408264193928
Test Error:
 Accuracy: 89.2%, Avg loss: 0.734340

Epoch 97
-------------------------------
Training Error: 0.01347520039585174
Test Error:
 Accuracy: 89.3%, Avg loss: 0.739301

Epoch 98
-------------------------------
Training Error: 0.015497987439830118
```

```
Test Error:
 Accuracy: 89.0%, Avg loss: 0.808300

Epoch 99
-------------------------------
Training Error: 0.012749795523729162
Test Error:
 Accuracy: 89.0%, Avg loss: 0.775555

Epoch 100
-------------------------------
Training Error: 0.018864880534114073
Test Error:
 Accuracy: 89.0%, Avg loss: 0.746124

Done for Learning Rate! 0.1


Running for Learning Rate 0.01
Number of parameters 669706
Epoch 1
-------------------------------
Training Error: 1.3025766820160312
Test Error:
 Accuracy: 71.2%, Avg loss: 0.788043

Epoch 2
-------------------------------
Training Error: 0.6842773142399818
Test Error:
 Accuracy: 78.0%, Avg loss: 0.634276

Epoch 3
-------------------------------
Training Error: 0.5749518606327236
Test Error:
 Accuracy: 80.1%, Avg loss: 0.571338

Epoch 4
-------------------------------
Training Error: 0.5208489111364524
Test Error:
 Accuracy: 80.6%, Avg loss: 0.540348

Epoch 5
-------------------------------
Training Error: 0.4895395463241189
Test Error:
 Accuracy: 81.4%, Avg loss: 0.519681

Epoch 6
-------------------------------
Training Error: 0.46866841202796394
Test Error:
 Accuracy: 81.9%, Avg loss: 0.505027

Epoch 7
-------------------------------
Training Error: 0.45296149343442815
Test Error:
 Accuracy: 82.2%, Avg loss: 0.492451

Epoch 8
-------------------------------
Training Error: 0.44007895918670237
Test Error:
 Accuracy: 82.6%, Avg loss: 0.481303

Epoch 9
-------------------------------
Training Error: 0.4290199307268108
Test Error:
 Accuracy: 83.0%, Avg loss: 0.471427

Epoch 10
-------------------------------
Training Error: 0.4190923987166968
Test Error:
 Accuracy: 83.6%, Avg loss: 0.462631

Epoch 11
-------------------------------
Training Error: 0.41003214061133136
Test Error:
 Accuracy: 83.8%, Avg loss: 0.454363

Epoch 12
-------------------------------
Training Error: 0.4016102140646245
Test Error:
 Accuracy: 84.0%, Avg loss: 0.446164

Epoch 13
-------------------------------
Training Error: 0.3937715098325378
Test Error:
 Accuracy: 84.4%, Avg loss: 0.438822

Epoch 14
-------------------------------
Training Error: 0.3864075833165061
Test Error:
 Accuracy: 84.7%, Avg loss: 0.431908

Epoch 15
-------------------------------
Training Error: 0.3795446445947009
Test Error:
 Accuracy: 84.9%, Avg loss: 0.424960

Epoch 16
-------------------------------
Training Error: 0.3731024944102332
Test Error:
 Accuracy: 85.0%, Avg loss: 0.418595

Epoch 17
-------------------------------
Training Error: 0.3670148940991237
Test Error:
 Accuracy: 85.2%, Avg loss: 0.412632

Epoch 18
-------------------------------
Training Error: 0.36121963082091896
Test Error:
 Accuracy: 85.3%, Avg loss: 0.407415

Epoch 19
-------------------------------
Training Error: 0.3557447314357707
Test Error:
 Accuracy: 85.5%, Avg loss: 0.402404

Epoch 20
-------------------------------
Training Error: 0.35053885500949583
Test Error:
 Accuracy: 85.7%, Avg loss: 0.397818

Epoch 21
-------------------------------
Training Error: 0.3455673788529215
Test Error:
 Accuracy: 85.9%, Avg loss: 0.393731

Epoch 22
-------------------------------
Training Error: 0.34069364468680263
Test Error:
 Accuracy: 86.1%, Avg loss: 0.389709

Epoch 23
-------------------------------
Training Error: 0.33608082438836984
Test Error:
 Accuracy: 86.3%, Avg loss: 0.386161

Epoch 24
-------------------------------
Training Error: 0.33156952956147284
Test Error:
 Accuracy: 86.3%, Avg loss: 0.382457

Epoch 25
-------------------------------
Training Error: 0.32724351137241064
Test Error:
 Accuracy: 86.5%, Avg loss: 0.379802

Epoch 26
-------------------------------
Training Error: 0.3230525460531081
Test Error:
 Accuracy: 86.6%, Avg loss: 0.376916

Epoch 27
-------------------------------
Training Error: 0.31901206165901635
Test Error:
 Accuracy: 86.7%, Avg loss: 0.374158

Epoch 28
-------------------------------
Training Error: 0.31503383789870787
Test Error:
 Accuracy: 86.9%, Avg loss: 0.371158

Epoch 29
-------------------------------
Training Error: 0.3112067198797838
Test Error:
 Accuracy: 86.9%, Avg loss: 0.368515

Epoch 30
-------------------------------
Training Error: 0.307475147995232
Test Error:
 Accuracy: 86.9%, Avg loss: 0.366033

Epoch 31
-------------------------------
Training Error: 0.3038441600051643
Test Error:
 Accuracy: 87.0%, Avg loss: 0.364064

Epoch 32
-------------------------------
Training Error: 0.30029393164619705
Test Error:
 Accuracy: 87.1%, Avg loss: 0.362257

Epoch 33
-------------------------------
Training Error: 0.29682429565359025
Test Error:
 Accuracy: 87.2%, Avg loss: 0.359964

Epoch 34
-------------------------------
Training Error: 0.2934449733193241
Test Error:
 Accuracy: 87.2%, Avg loss: 0.358859

Epoch 35
-------------------------------
Training Error: 0.29012650943228174
Test Error:
 Accuracy: 87.2%, Avg loss: 0.357461

Epoch 36
-------------------------------
Training Error: 0.28685200124629523
Test Error:
 Accuracy: 87.2%, Avg loss: 0.355397

Epoch 37
-------------------------------
Training Error: 0.28368375749031366
Test Error:
 Accuracy: 87.3%, Avg loss: 0.353714

Epoch 38
-------------------------------
Training Error: 0.2805815073552289
Test Error:
 Accuracy: 87.4%, Avg loss: 0.352427

Epoch 39
-------------------------------
Training Error: 0.2775329745003282
Test Error:
 Accuracy: 87.5%, Avg loss: 0.350564

Epoch 40
-------------------------------
Training Error: 0.27456538552350834
Test Error:
 Accuracy: 87.7%, Avg loss: 0.349485

Epoch 41
-------------------------------
Training Error: 0.2716442654366051
Test Error:
 Accuracy: 87.7%, Avg loss: 0.347861

Epoch 42
-------------------------------
Training Error: 0.26877161881912237
Test Error:
 Accuracy: 87.7%, Avg loss: 0.346527

Epoch 43
-------------------------------
Training Error: 0.2659238945367113
Test Error:
 Accuracy: 87.7%, Avg loss: 0.345706

Epoch 44
-------------------------------
Training Error: 0.2631341429598042
Test Error:
 Accuracy: 87.8%, Avg loss: 0.344676

Epoch 45
-------------------------------
Training Error: 0.2604016207857554
Test Error:
 Accuracy: 87.9%, Avg loss: 0.343277

Epoch 46
-------------------------------
Training Error: 0.2576944071537396
Test Error:
 Accuracy: 87.9%, Avg loss: 0.343248

Epoch 47
-------------------------------
Training Error: 0.25505884680380697
Test Error:
 Accuracy: 87.9%, Avg loss: 0.342852

Epoch 48
-------------------------------
Training Error: 0.2524498444296785
Test Error:
 Accuracy: 88.0%, Avg loss: 0.341505

Epoch 49
-------------------------------
Training Error: 0.24993790381117417
Test Error:
 Accuracy: 88.0%, Avg loss: 0.340969

Epoch 50
-------------------------------
Training Error: 0.24737326894551198
Test Error:
 Accuracy: 88.0%, Avg loss: 0.340468

Epoch 51
-------------------------------
Training Error: 0.24482912460226874
Test Error:
 Accuracy: 88.0%, Avg loss: 0.338903

Epoch 52
-------------------------------
Training Error: 0.24235693835961158
Test Error:
 Accuracy: 88.0%, Avg loss: 0.339905

Epoch 53
-------------------------------
Training Error: 0.23991857479804996
Test Error:
 Accuracy: 88.0%, Avg loss: 0.337927

Epoch 54
-------------------------------
Training Error: 0.23743887230166114
Test Error:
 Accuracy: 88.1%, Avg loss: 0.336938

Epoch 55
-------------------------------
Training Error: 0.2350770061307434
Test Error:
 Accuracy: 88.2%, Avg loss: 0.337012

Epoch 56
-------------------------------
Training Error: 0.2327175448610902
Test Error:
 Accuracy: 88.1%, Avg loss: 0.336421

Epoch 57
-------------------------------
Training Error: 0.2303590963898437
Test Error:
 Accuracy: 88.2%, Avg loss: 0.335103

Epoch 58
-------------------------------
Training Error: 0.22801016534823598
Test Error:
 Accuracy: 88.2%, Avg loss: 0.335517

Epoch 59
-------------------------------
Training Error: 0.22572832170532328
Test Error:
 Accuracy: 88.2%, Avg loss: 0.334700

Epoch 60
-------------------------------
Training Error: 0.22338407580802308
Test Error:
 Accuracy: 88.3%, Avg loss: 0.334689

Epoch 61
-------------------------------
Training Error: 0.2210799084662565
Test Error:
 Accuracy: 88.2%, Avg loss: 0.334699

Epoch 62
-------------------------------
Training Error: 0.21882823818941105
Test Error:
 Accuracy: 88.2%, Avg loss: 0.335185

Epoch 63
-------------------------------
Training Error: 0.21658058365239008
Test Error:
 Accuracy: 88.3%, Avg loss: 0.333766

Epoch 64
-------------------------------
Training Error: 0.21436256029680847
Test Error:
 Accuracy: 88.2%, Avg loss: 0.334362

Epoch 65
-------------------------------
Training Error: 0.21218715792001563
Test Error:
 Accuracy: 88.3%, Avg loss: 0.333613

Epoch 66
-------------------------------
Training Error: 0.2100472361413337
Test Error:
 Accuracy: 88.4%, Avg loss: 0.333584

Epoch 67
-------------------------------
Training Error: 0.20785789122618337
Test Error:
 Accuracy: 88.4%, Avg loss: 0.333435

Epoch 68
-------------------------------
Training Error: 0.2057023091253632
Test Error:
 Accuracy: 88.4%, Avg loss: 0.332953

Epoch 69
-------------------------------
Training Error: 0.20352058333040937
Test Error:
 Accuracy: 88.4%, Avg loss: 0.331821

Epoch 70
-------------------------------
Training Error: 0.20153061809665612
Test Error:
 Accuracy: 88.5%, Avg loss: 0.331486

Epoch 71
-------------------------------
Training Error: 0.19939190239063712
Test Error:
 Accuracy: 88.4%, Avg loss: 0.333653

Epoch 72
-------------------------------
Training Error: 0.19736927675047536
Test Error:
 Accuracy: 88.5%, Avg loss: 0.332489

Epoch 73
-------------------------------
Training Error: 0.19539315938584204
Test Error:
 Accuracy: 88.5%, Avg loss: 0.333337

Epoch 74
-------------------------------
Training Error: 0.1932482026191726
Test Error:
 Accuracy: 88.4%, Avg loss: 0.332585

Epoch 75
-------------------------------
Training Error: 0.19124989640483978
Test Error:
 Accuracy: 88.4%, Avg loss: 0.333745

Epoch 76
-------------------------------
Training Error: 0.18923600481898545
Test Error:
 Accuracy: 88.4%, Avg loss: 0.334875

Epoch 77
-------------------------------
Training Error: 0.1872882597219906
Test Error:
 Accuracy: 88.3%, Avg loss: 0.335144

Epoch 78
-------------------------------
Training Error: 0.18529698432587993
Test Error:
 Accuracy: 88.4%, Avg loss: 0.335120

Epoch 79
-------------------------------
Training Error: 0.18332943505744562
Test Error:
 Accuracy: 88.3%, Avg loss: 0.336184

Epoch 80
-------------------------------
Training Error: 0.18146851605999825
Test Error:
 Accuracy: 88.5%, Avg loss: 0.333978

Epoch 81
-------------------------------
Training Error: 0.17938982753722527
Test Error:
 Accuracy: 88.5%, Avg loss: 0.334599

Epoch 82
-------------------------------
Training Error: 0.17755740069583661
Test Error:
 Accuracy: 88.5%, Avg loss: 0.335411

Epoch 83
-------------------------------
Training Error: 0.17563149473592163
Test Error:
 Accuracy: 88.4%, Avg loss: 0.338031

Epoch 84
-------------------------------
Training Error: 0.17371938347832352
Test Error:
 Accuracy: 88.7%, Avg loss: 0.334292

Epoch 85
-------------------------------
Training Error: 0.17196245219455217
Test Error:
 Accuracy: 88.5%, Avg loss: 0.338254

Epoch 86
-------------------------------
Training Error: 0.1701036959902437
Test Error:
 Accuracy: 88.7%, Avg loss: 0.336060

Epoch 87
-------------------------------
Training Error: 0.1681692923373505
Test Error:
 Accuracy: 88.6%, Avg loss: 0.336593

Epoch 88
-------------------------------
Training Error: 0.166293451586353
Test Error:
 Accuracy: 88.6%, Avg loss: 0.337443

Epoch 89
-------------------------------
Training Error: 0.1644888660673902
Test Error:
 Accuracy: 88.6%, Avg loss: 0.338276

Epoch 90
-------------------------------
Training Error: 0.16255649266196592
Test Error:
 Accuracy: 88.7%, Avg loss: 0.337513

Epoch 91
-------------------------------
Training Error: 0.16090018620321364
Test Error:
 Accuracy: 88.6%, Avg loss: 0.340791

Epoch 92
-------------------------------
Training Error: 0.15911456259058865
Test Error:
 Accuracy: 88.5%, Avg loss: 0.344365

Epoch 93
-------------------------------
Training Error: 0.15720299161525805
Test Error:
 Accuracy: 88.6%, Avg loss: 0.341492

Epoch 94
-------------------------------
Training Error: 0.1555942915824812
Test Error:
 Accuracy: 88.5%, Avg loss: 0.343948

Epoch 95
-------------------------------
Training Error: 0.15368412393353767
Test Error:
 Accuracy: 88.5%, Avg loss: 0.344467

Epoch 96
-------------------------------
Training Error: 0.1520794269118482
Test Error:
 Accuracy: 88.6%, Avg loss: 0.344972

Epoch 97
-------------------------------
Training Error: 0.15029333205794349
Test Error:
 Accuracy: 88.4%, Avg loss: 0.350210

Epoch 98
-------------------------------
Training Error: 0.14844706728021856
Test Error:
 Accuracy: 88.5%, Avg loss: 0.349216

Epoch 99
-------------------------------
Training Error: 0.14672236280765996
Test Error:
 Accuracy: 88.4%, Avg loss: 0.350131

Epoch 100
-------------------------------
Training Error: 0.1450241598199362
Test Error:
 Accuracy: 88.6%, Avg loss: 0.346492

Done for Learning Rate! 0.01


Running for Learning Rate 0.001
```

```
Number of parameters 669706
Epoch 1
-------------------------------
Training Error: 2.2479958099597046
Test Error: 
 Accuracy: 47.5%, Avg loss: 2.180335

Epoch 2
-------------------------------
Training Error: 2.075135699086098
Test Error: 
 Accuracy: 56.9%, Avg loss: 1.945329

Epoch 3
-------------------------------
Training Error: 1.759687049429554
Test Error: 
 Accuracy: 60.8%, Avg loss: 1.574462

Epoch 4
-------------------------------
Training Error: 1.4108837540469952
Test Error: 
 Accuracy: 62.7%, Avg loss: 1.281786

Epoch 5
-------------------------------
Training Error: 1.1776185562488621
Test Error: 
 Accuracy: 64.2%, Avg loss: 1.103942

Epoch 6
-------------------------------
Training Error: 1.034315725061685
Test Error: 
 Accuracy: 65.5%, Avg loss: 0.992056

Epoch 7
-------------------------------
Training Error: 0.9408896790384483
Test Error: 
 Accuracy: 67.0%, Avg loss: 0.916633

Epoch 8
-------------------------------
Training Error: 0.8757082927328691
Test Error: 
 Accuracy: 68.4%, Avg loss: 0.862434
```

```
Epoch 9
-------------------------------
Training Error: 0.8275327648181142
Test Error:
 Accuracy: 69.7%, Avg loss: 0.821388

Epoch 10
-------------------------------
Training Error: 0.7901418940471941
Test Error:
 Accuracy: 71.0%, Avg loss: 0.788777

Epoch 11
-------------------------------
Training Error: 0.7598557335608549
Test Error:
 Accuracy: 72.3%, Avg loss: 0.761844

Epoch 12
-------------------------------
Training Error: 0.7344263640802298
Test Error:
 Accuracy: 73.5%, Avg loss: 0.738811

Epoch 13
-------------------------------
Training Error: 0.712377923892251
Test Error:
 Accuracy: 74.2%, Avg loss: 0.718559

Epoch 14
-------------------------------
Training Error: 0.6927929703932582
Test Error:
 Accuracy: 75.1%, Avg loss: 0.700395

Epoch 15
-------------------------------
Training Error: 0.675099455121992
Test Error:
 Accuracy: 75.7%, Avg loss: 0.683894

Epoch 16
-------------------------------
Training Error: 0.6589518866178069
Test Error:
 Accuracy: 76.3%, Avg loss: 0.668818
```

```
Epoch 17
-------------------------------
Training Error: 0.6441332062424373
Test Error:
 Accuracy: 76.8%, Avg loss: 0.654991

Epoch 18
-------------------------------
Training Error: 0.630486348417522
Test Error:
 Accuracy: 77.3%, Avg loss: 0.642298

Epoch 19
-------------------------------
Training Error: 0.6179313732744026
Test Error:
 Accuracy: 77.9%, Avg loss: 0.630656

Epoch 20
-------------------------------
Training Error: 0.6063526518690561
Test Error:
 Accuracy: 78.2%, Avg loss: 0.619943

Epoch 21
-------------------------------
Training Error: 0.59565074331979
Test Error:
 Accuracy: 78.5%, Avg loss: 0.610071

Epoch 22
-------------------------------
Training Error: 0.5857458845066872
Test Error:
 Accuracy: 78.8%, Avg loss: 0.600956

Epoch 23
-------------------------------
Training Error: 0.5765645087146556
Test Error:
 Accuracy: 79.1%, Avg loss: 0.592533

Epoch 24
-------------------------------
Training Error: 0.5680505708654298
Test Error:
 Accuracy: 79.5%, Avg loss: 0.584740
```

```
Epoch 25
-------------------------------
Training Error: 0.5601466198338628
Test Error:
 Accuracy: 79.8%, Avg loss: 0.577518

Epoch 26
-------------------------------
Training Error: 0.5527971510185616
Test Error:
 Accuracy: 80.1%, Avg loss: 0.570819

Epoch 27
-------------------------------
Training Error: 0.5459558397277332
Test Error:
 Accuracy: 80.4%, Avg loss: 0.564589

Epoch 28
-------------------------------
Training Error: 0.5395725096212521
Test Error:
 Accuracy: 80.6%, Avg loss: 0.558783

Epoch 29
-------------------------------
Training Error: 0.5336083082883343
Test Error:
 Accuracy: 80.7%, Avg loss: 0.553361

Epoch 30
-------------------------------
Training Error: 0.5280295429326324
Test Error:
 Accuracy: 80.9%, Avg loss: 0.548299

Epoch 31
-------------------------------
Training Error: 0.5228047631760396
Test Error:
 Accuracy: 81.2%, Avg loss: 0.543563

Epoch 32
-------------------------------
Training Error: 0.5179007267519864
Test Error:
 Accuracy: 81.3%, Avg loss: 0.539123
```

```
Epoch 33
-------------------------------
Training Error: 0.51328885853926
Test Error:
 Accuracy: 81.4%, Avg loss: 0.534948

Epoch 34
-------------------------------
Training Error: 0.5089431474648559
Test Error:
 Accuracy: 81.5%, Avg loss: 0.531017

Epoch 35
-------------------------------
Training Error: 0.5048417535259017
Test Error:
 Accuracy: 81.6%, Avg loss: 0.527309

Epoch 36
-------------------------------
Training Error: 0.5009625040328325
Test Error:
 Accuracy: 81.6%, Avg loss: 0.523806

Epoch 37
-------------------------------
Training Error: 0.49728672978466254
Test Error:
 Accuracy: 81.7%, Avg loss: 0.520485

Epoch 38
-------------------------------
Training Error: 0.4937976372839291
Test Error:
 Accuracy: 81.9%, Avg loss: 0.517342

Epoch 39
-------------------------------
Training Error: 0.4904825025752409
Test Error:
 Accuracy: 81.8%, Avg loss: 0.514363

Epoch 40
-------------------------------
Training Error: 0.4873255715091854
Test Error:
 Accuracy: 81.9%, Avg loss: 0.511526
```

```
Epoch 41
-------------------------------
Training Error: 0.4843121675540135
Test Error:
 Accuracy: 82.0%, Avg loss: 0.508834

Epoch 42
-------------------------------
Training Error: 0.4814344451848124
Test Error:
 Accuracy: 82.1%, Avg loss: 0.506267

Epoch 43
-------------------------------
Training Error: 0.4786773630773335
Test Error:
 Accuracy: 82.2%, Avg loss: 0.503809

Epoch 44
-------------------------------
Training Error: 0.47603201507124054
Test Error:
 Accuracy: 82.2%, Avg loss: 0.501468

Epoch 45
-------------------------------
Training Error: 0.4734855716638982
Test Error:
 Accuracy: 82.3%, Avg loss: 0.499222

Epoch 46
-------------------------------
Training Error: 0.4710296488551697
Test Error:
 Accuracy: 82.4%, Avg loss: 0.497064

Epoch 47
-------------------------------
Training Error: 0.46867431917869207
Test Error:
 Accuracy: 82.6%, Avg loss: 0.495011

Epoch 48
-------------------------------
Training Error: 0.46641247350968784
Test Error:
 Accuracy: 82.7%, Avg loss: 0.493048
```

```
Epoch 49
-------------------------------
Training Error: 0.4642370678881592
Test Error:
 Accuracy: 82.7%, Avg loss: 0.491162

Epoch 50
-------------------------------
Training Error: 0.46213901900787596
Test Error:
 Accuracy: 82.8%, Avg loss: 0.489352

Epoch 51
-------------------------------
Training Error: 0.46011321221206236
Test Error:
 Accuracy: 82.8%, Avg loss: 0.487608

Epoch 52
-------------------------------
Training Error: 0.45815382298947904
Test Error:
 Accuracy: 82.8%, Avg loss: 0.485921

Epoch 53
-------------------------------
Training Error: 0.4562565246497644
Test Error:
 Accuracy: 82.9%, Avg loss: 0.484289

Epoch 54
-------------------------------
Training Error: 0.4544162962482428
Test Error:
 Accuracy: 82.9%, Avg loss: 0.482707

Epoch 55
-------------------------------
Training Error: 0.4526280800798046
Test Error:
 Accuracy: 83.0%, Avg loss: 0.481174

Epoch 56
-------------------------------
Training Error: 0.4508890182987205
Test Error:
 Accuracy: 83.1%, Avg loss: 0.479686
```

```
Epoch 57
-------------------------------
Training Error: 0.44919657094010923
Test Error:
 Accuracy: 83.1%, Avg loss: 0.478241

Epoch 58
-------------------------------
Training Error: 0.4475479903442265
Test Error:
 Accuracy: 83.1%, Avg loss: 0.476837

Epoch 59
-------------------------------
Training Error: 0.44593933844235917
Test Error:
 Accuracy: 83.1%, Avg loss: 0.475470

Epoch 60
-------------------------------
Training Error: 0.44437064541809596
Test Error:
 Accuracy: 83.2%, Avg loss: 0.474142

Epoch 61
-------------------------------
Training Error: 0.44283997278604936
Test Error:
 Accuracy: 83.2%, Avg loss: 0.472846

Epoch 62
-------------------------------
Training Error: 0.44134493888631815
Test Error:
 Accuracy: 83.3%, Avg loss: 0.471577

Epoch 63
-------------------------------
Training Error: 0.43988203489259364
Test Error:
 Accuracy: 83.3%, Avg loss: 0.470337

Epoch 64
-------------------------------
Training Error: 0.4384499589231477
Test Error:
 Accuracy: 83.3%, Avg loss: 0.469126
```

```
Epoch 65
-------------------------------
Training Error: 0.43704653620275097
Test Error:
 Accuracy: 83.4%, Avg loss: 0.467936

Epoch 66
-------------------------------
Training Error: 0.4356709793368891
Test Error:
 Accuracy: 83.5%, Avg loss: 0.466770

Epoch 67
-------------------------------
Training Error: 0.43431858847072635
Test Error:
 Accuracy: 83.5%, Avg loss: 0.465620

Epoch 68
-------------------------------
Training Error: 0.4329889956345436
Test Error:
 Accuracy: 83.5%, Avg loss: 0.464494

Epoch 69
-------------------------------
Training Error: 0.43168430124073903
Test Error:
 Accuracy: 83.6%, Avg loss: 0.463389

Epoch 70
-------------------------------
Training Error: 0.4304040872148359
Test Error:
 Accuracy: 83.7%, Avg loss: 0.462312

Epoch 71
-------------------------------
Training Error: 0.42914581762702225
Test Error:
 Accuracy: 83.8%, Avg loss: 0.461252

Epoch 72
-------------------------------
Training Error: 0.42790541068704396
Test Error:
 Accuracy: 83.8%, Avg loss: 0.460202
```

```
Epoch 73
-------------------------------
Training Error: 0.4266849603098847
Test Error:
 Accuracy: 83.8%, Avg loss: 0.459162

Epoch 74
-------------------------------
Training Error: 0.4254775638900586
Test Error:
 Accuracy: 83.9%, Avg loss: 0.458136

Epoch 75
-------------------------------
Training Error: 0.4242810729914891
Test Error:
 Accuracy: 84.0%, Avg loss: 0.457129

Epoch 76
-------------------------------
Training Error: 0.4231073281276963
Test Error:
 Accuracy: 84.0%, Avg loss: 0.456142

Epoch 77
-------------------------------
Training Error: 0.42195375584590156
Test Error:
 Accuracy: 84.0%, Avg loss: 0.455173

Epoch 78
-------------------------------
Training Error: 0.4208160180177516
Test Error:
 Accuracy: 84.0%, Avg loss: 0.454225

Epoch 79
-------------------------------
Training Error: 0.41969045319918125
Test Error:
 Accuracy: 84.0%, Avg loss: 0.453280

Epoch 80
-------------------------------
Training Error: 0.4185782888296571
Test Error:
 Accuracy: 84.0%, Avg loss: 0.452345
```

```
Epoch 81
-------------------------------
Training Error: 0.4174779343770257
Test Error:
 Accuracy: 84.0%, Avg loss: 0.451418

Epoch 82
-------------------------------
Training Error: 0.41639496746665633
Test Error:
 Accuracy: 84.0%, Avg loss: 0.450504

Epoch 83
-------------------------------
Training Error: 0.41533162800678564
Test Error:
 Accuracy: 84.1%, Avg loss: 0.449610

Epoch 84
-------------------------------
Training Error: 0.41428385012503116
Test Error:
 Accuracy: 84.1%, Avg loss: 0.448736

Epoch 85
-------------------------------
Training Error: 0.41324976326496615
Test Error:
 Accuracy: 84.2%, Avg loss: 0.447875

Epoch 86
-------------------------------
Training Error: 0.41222659919434773
Test Error:
 Accuracy: 84.2%, Avg loss: 0.447028

Epoch 87
-------------------------------
Training Error: 0.4112132046617933
Test Error:
 Accuracy: 84.3%, Avg loss: 0.446182

Epoch 88
-------------------------------
Training Error: 0.4102088919262896
Test Error:
 Accuracy: 84.3%, Avg loss: 0.445338
```

```
Epoch 89
-------------------------------
Training Error: 0.40921217320697395
Test Error:
 Accuracy: 84.4%, Avg loss: 0.444489

Epoch 90
-------------------------------
Training Error: 0.40822509846199295
Test Error:
 Accuracy: 84.4%, Avg loss: 0.443660

Epoch 91
-------------------------------
Training Error: 0.4072527984089689
Test Error:
 Accuracy: 84.4%, Avg loss: 0.442848

Epoch 92
-------------------------------
Training Error: 0.40629202370513984
Test Error:
 Accuracy: 84.4%, Avg loss: 0.442050

Epoch 93
-------------------------------
Training Error: 0.40534011066468284
Test Error:
 Accuracy: 84.5%, Avg loss: 0.441258

Epoch 94
-------------------------------
Training Error: 0.4043968279065608
Test Error:
 Accuracy: 84.5%, Avg loss: 0.440472

Epoch 95
-------------------------------
Training Error: 0.40346211703347246
Test Error:
 Accuracy: 84.5%, Avg loss: 0.439694

Epoch 96
-------------------------------
Training Error: 0.402536556569498
Test Error:
 Accuracy: 84.5%, Avg loss: 0.438927
```

```
Epoch 97
-------------------------------
Training Error: 0.40161715304927786
Test Error:
 Accuracy: 84.5%, Avg loss: 0.438155

Epoch 98
-------------------------------
Training Error: 0.4007054564318677
Test Error:
 Accuracy: 84.6%, Avg loss: 0.437394

Epoch 99
-------------------------------
Training Error: 0.39980318794436037
Test Error:
 Accuracy: 84.6%, Avg loss: 0.436640

Epoch 100
-------------------------------
Training Error: 0.39890487749439313
Test Error:
 Accuracy: 84.6%, Avg loss: 0.435899

Done for Learning Rate! 0.001
```

2 Explanations, Observations and Graphs

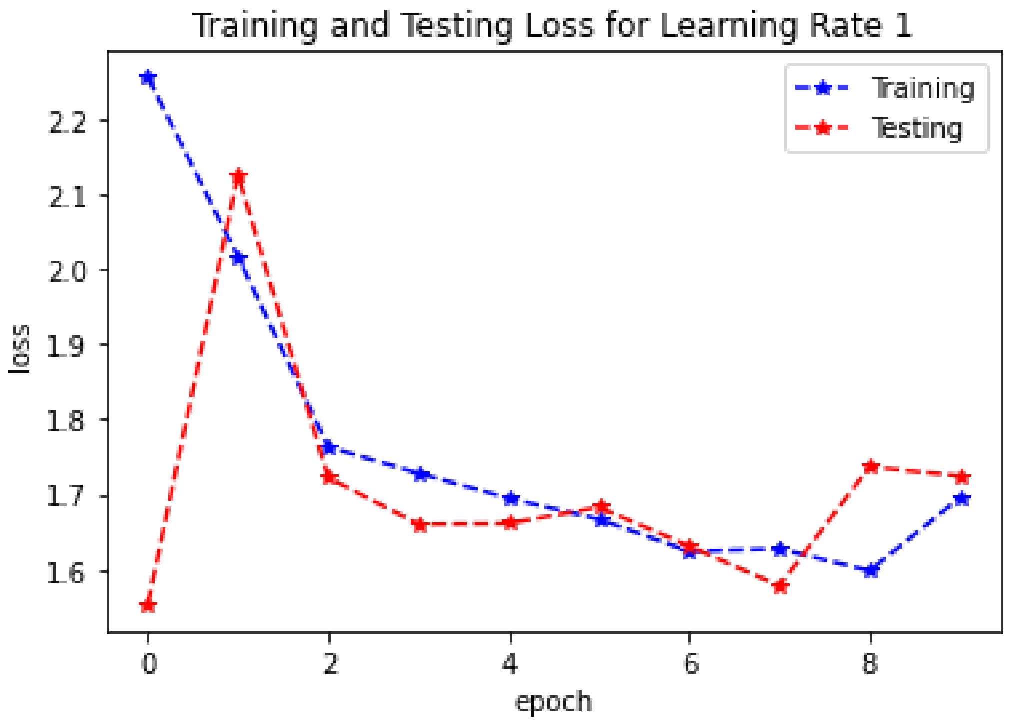
Q1.1 (1 point) Change the learning rate and train for 10 epochs. Fill this table:

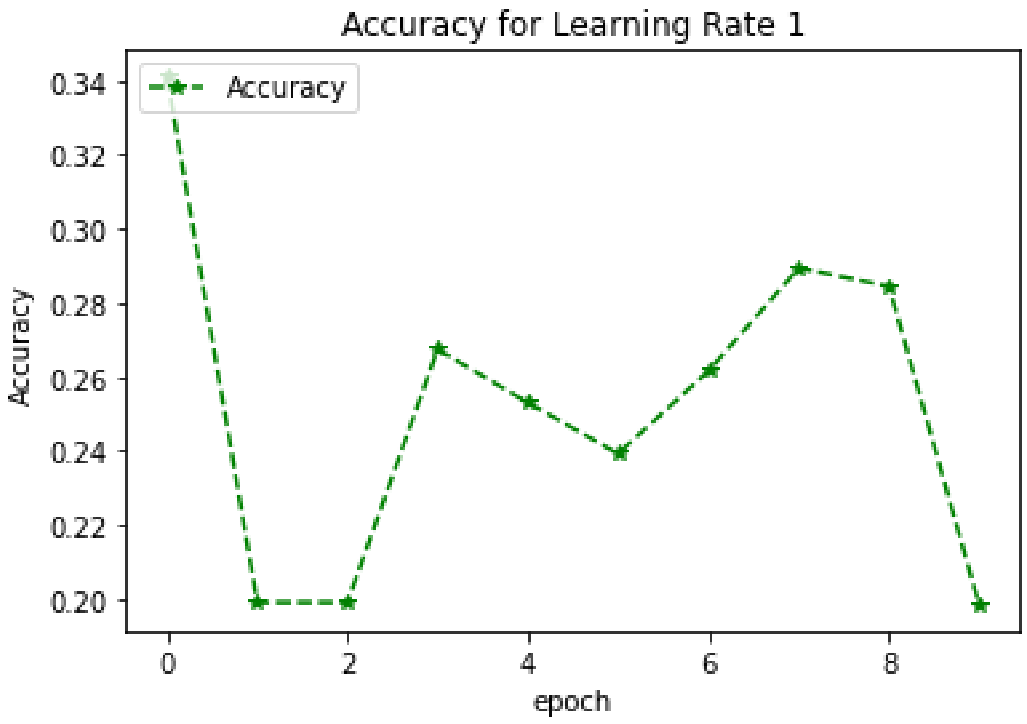
Lr	Accuracy (%)
1	25.33
0.1	84.79
0.01	80.46
0.001	63.36

[73]:
```
learning_rate = [1, 0.1, 0.01, 0.001]

#Getting train_error, test_error and accuracy
for lr in learning_rate:
   train_loss_list = getList(train_loss, lr, 10)
   test_loss_list = getList(test_loss, lr, 10)
```

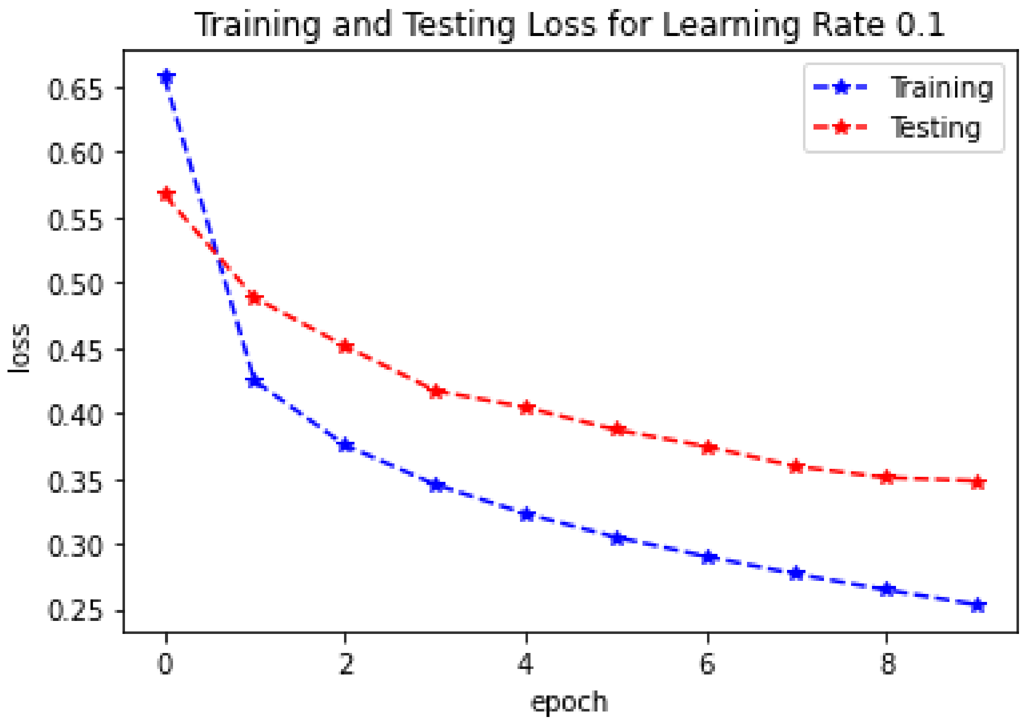
```
    accuracy = float("{:.2f}".format(getAverage(test_acc, lr, 10) * 100))␣
↪#format(getAverage(test_acc, lr, 10) * 100)
    print(f'Accuracy for Learning Rate {lr}, is {accuracy}')
    plotTrainigTestCurve(train_loss_list, test_loss_list, 'Training Loss',␣
↪'Testing Loss', f'Training and Testing Loss for Learning Rate {lr}')
    plotAccuracy(getList(test_acc, lr, 10), 'Accuracy' , f'Accuracy for Learning␣
↪Rate {lr}')
    print('\n\n')
```

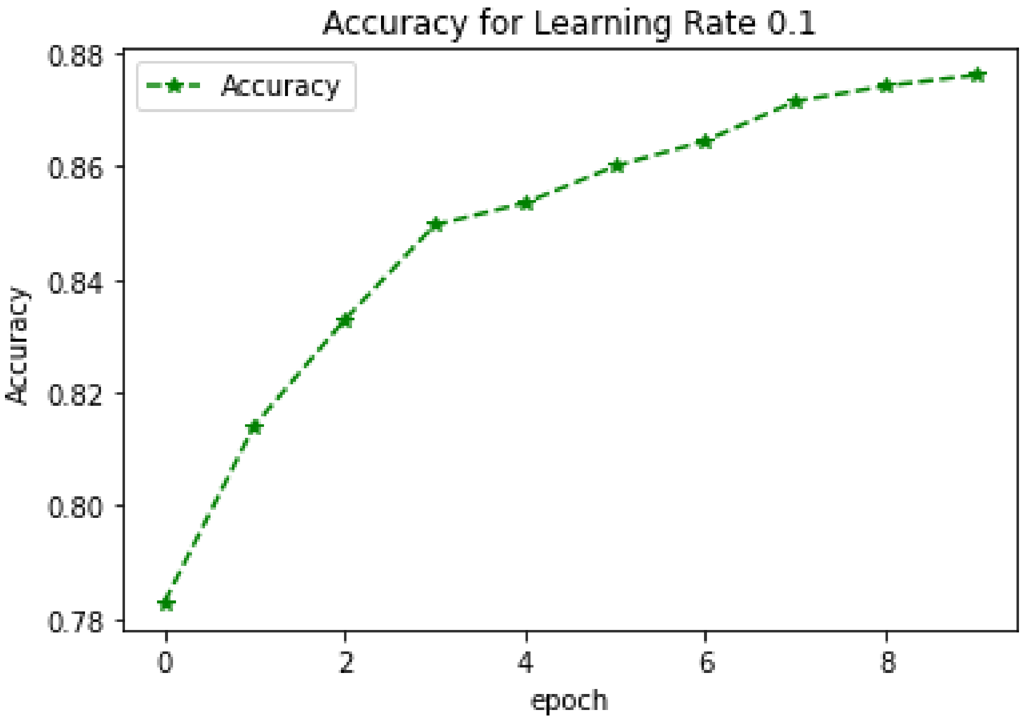
```
Accuracy for Learning Rate 1, is 25.33
```



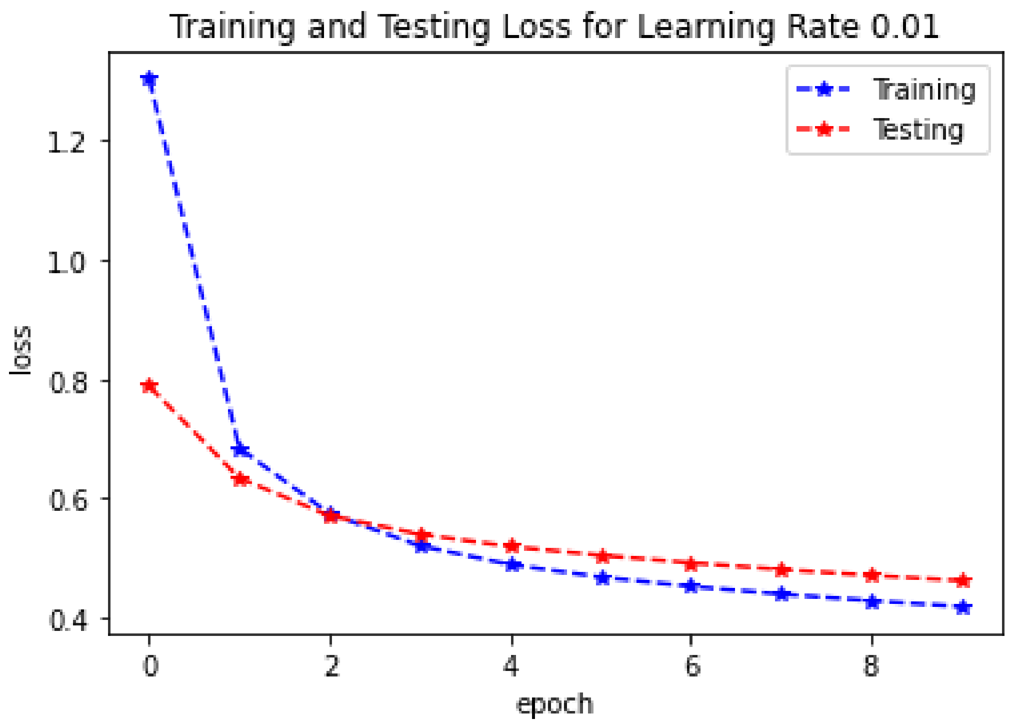


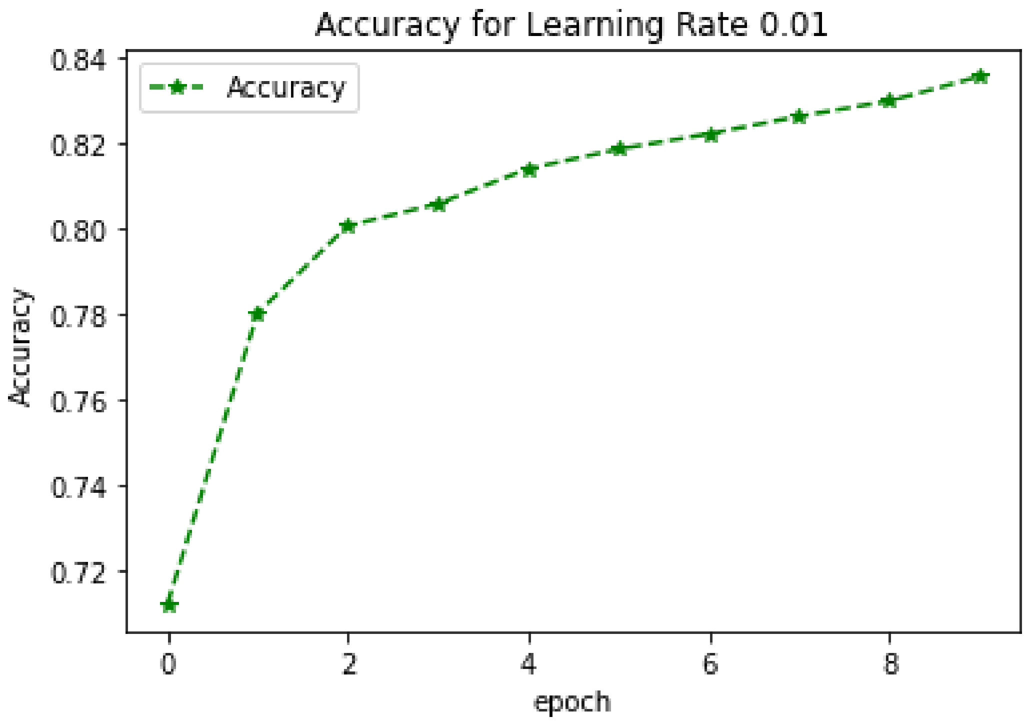
```
Accuracy for Learning Rate 0.1, is 84.79
```


Training and Testing Loss for Learning Rate 0.1
Training
Testing
loss
epoch
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0
2
4
6
8

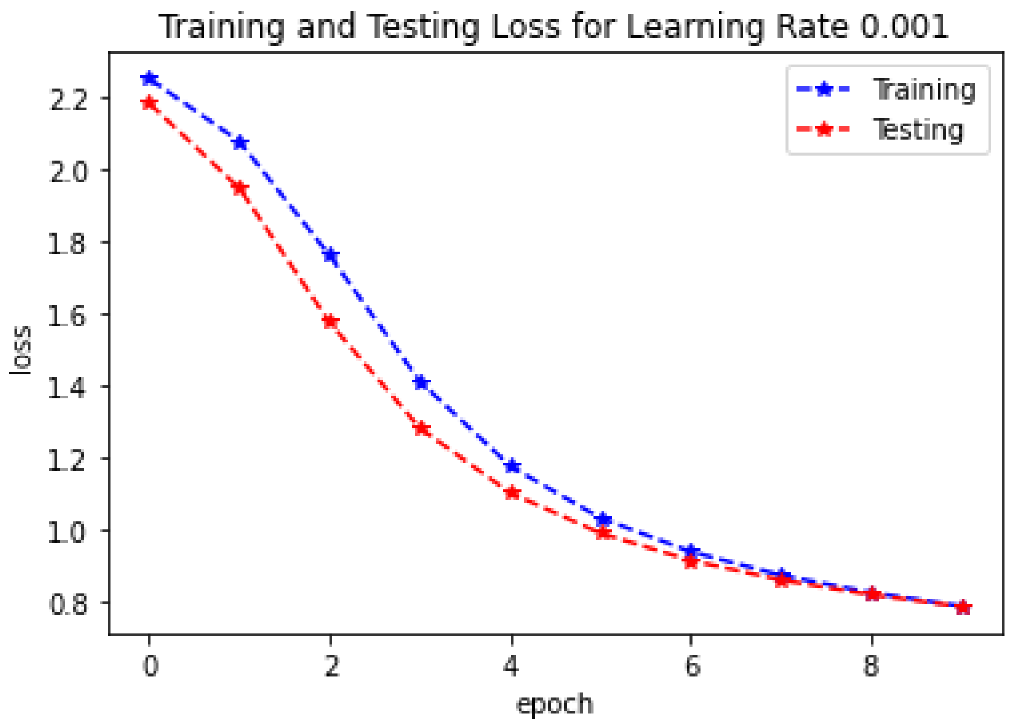

Accuracy for Learning Rate 0.1
Accuracy
Accuracy
epoch
0.88
0.86
0.84
0.82
0.80
0.78
0
2
4
6
8

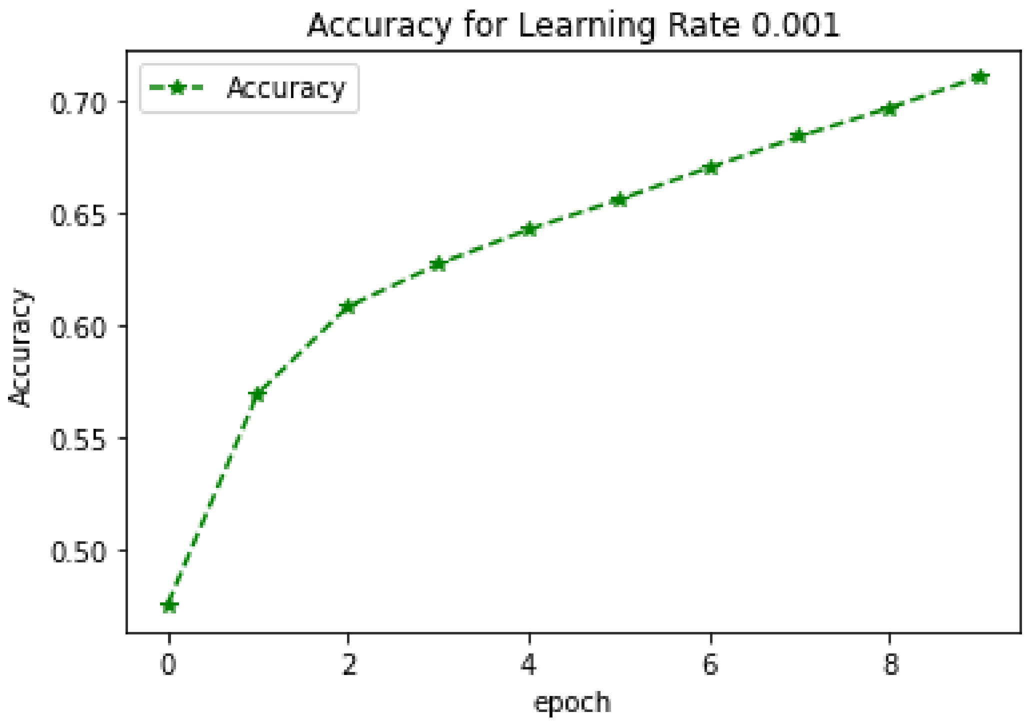
```
Accuracy for Learning Rate 0.01, is 80.46
```





```
Accuracy for Learning Rate 0.001, is 63.36
```


Training and Testing Loss for Learning Rate 0.001
Training
Testing
loss
epoch
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
2
4
6
8


Accuracy for Learning Rate 0.001
Accuracy
Accuracy
epoch
0.70
0.65
0.60
0.55
0.50
0
2
4
6
8

Observation from the above Testing and Training loss curve for Learning rates 1, 0.1, 0.01, 0.001

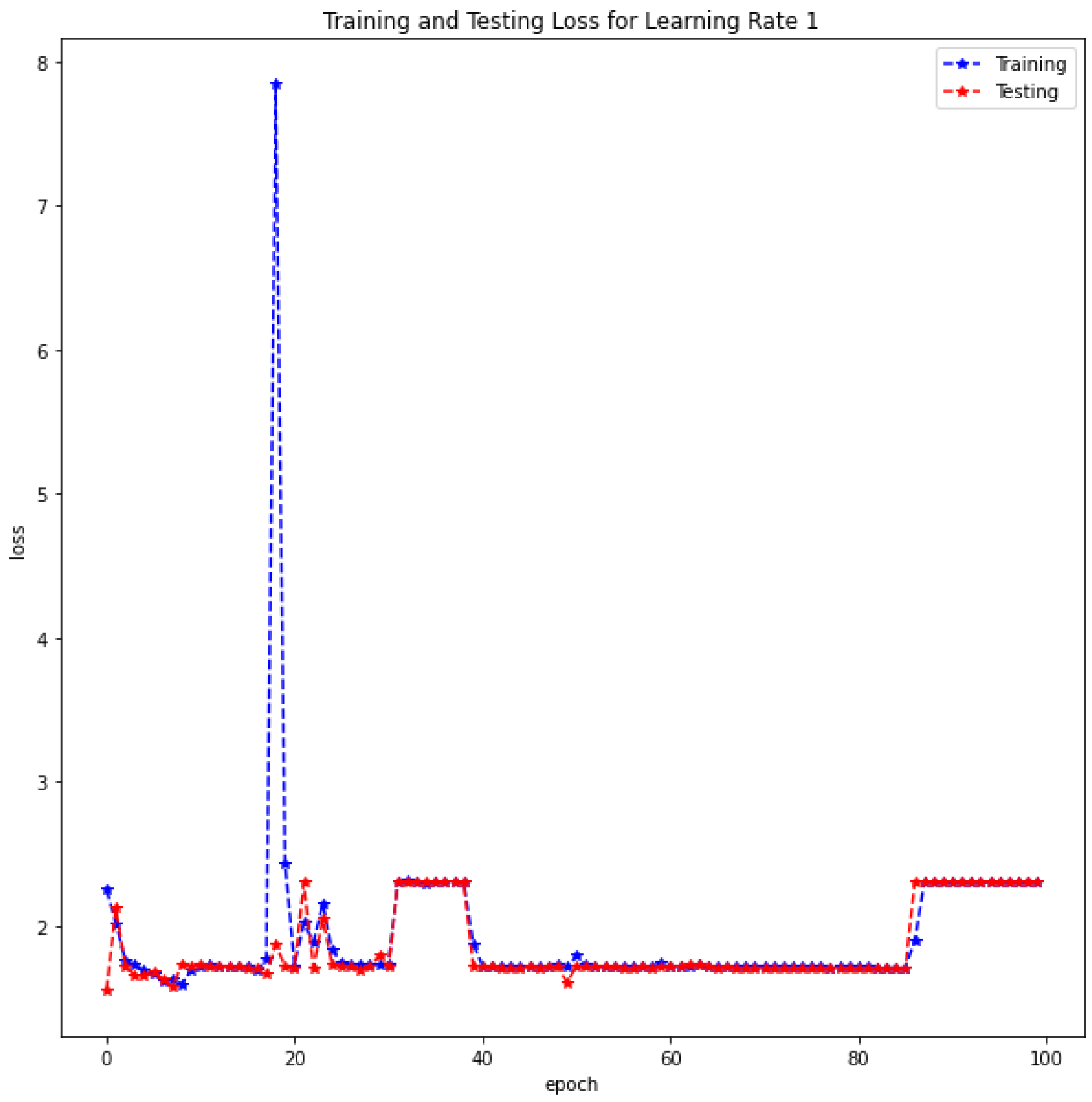
1. Garphs for Learning rate 1 - It can be seen that the learning rate is too large, which means that the models is not able to converge to an an optmial solution.
2. Graph for Learning rate 0.1 - The training and testing curve is has a bigger generalisation gap between the training and testing loss and with a better accuracy than other learning rates, it indicates that the model generalises better.
3. Graph for Learning rate 0.01 and 0.001 - The training and testing loss curves are still not stable after 100 epochs this means that the learning rate (Step sizse) is too small which implies that it will take longer (more than 100 epocsh) to converge.

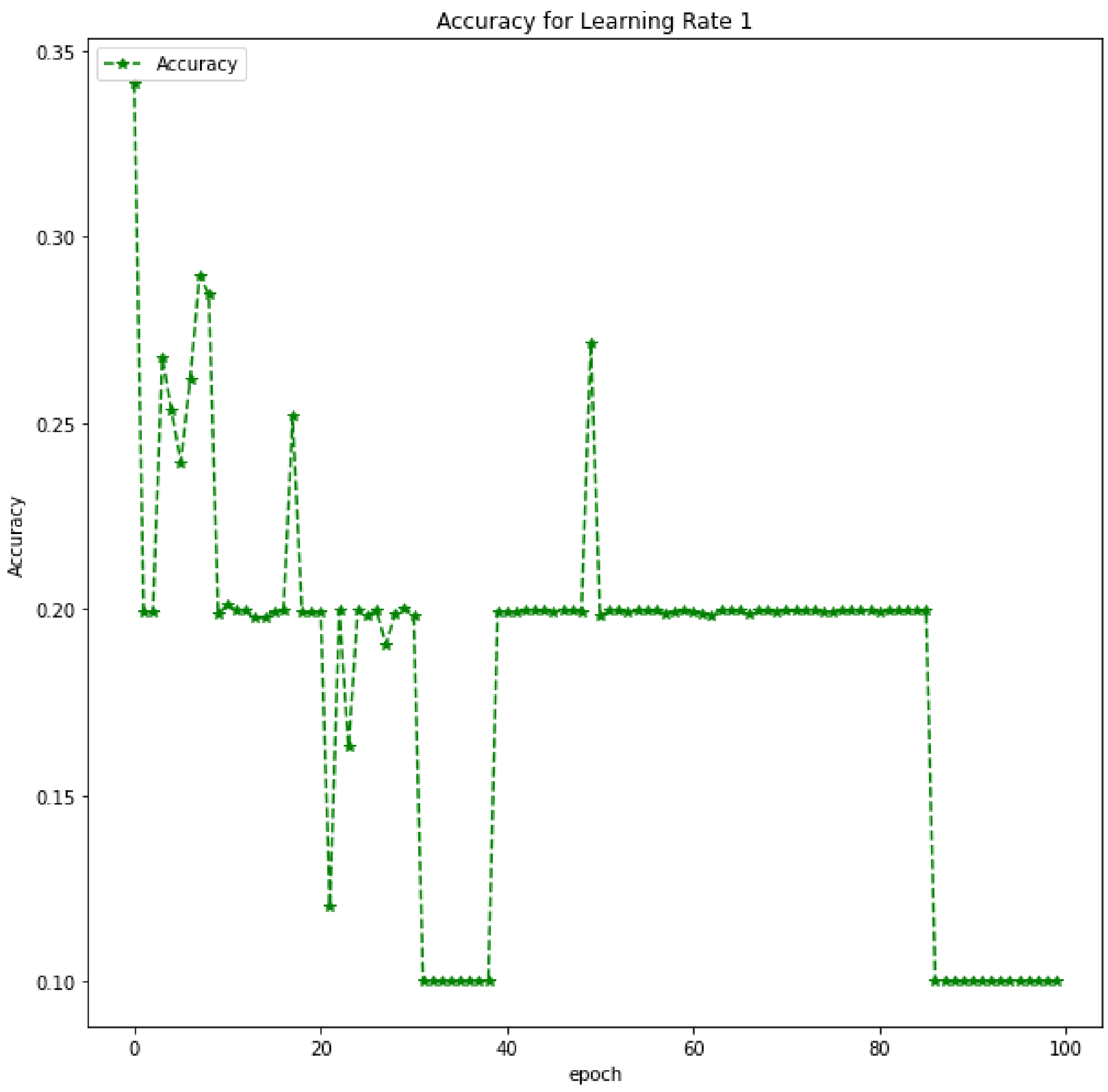
Q1.2 (2 point) Report the number of epochs when the accuracy reaches 90%. If the program can not reach 90% within 100 epochs, please fill in "not converged" in the Epoch blank. Fill this table:

Lr	Accuracy	Epoch
1	18.28	not converged
0.1	87.9	not converged
0.01	86.9	not converged
0.001	80.2	not converged

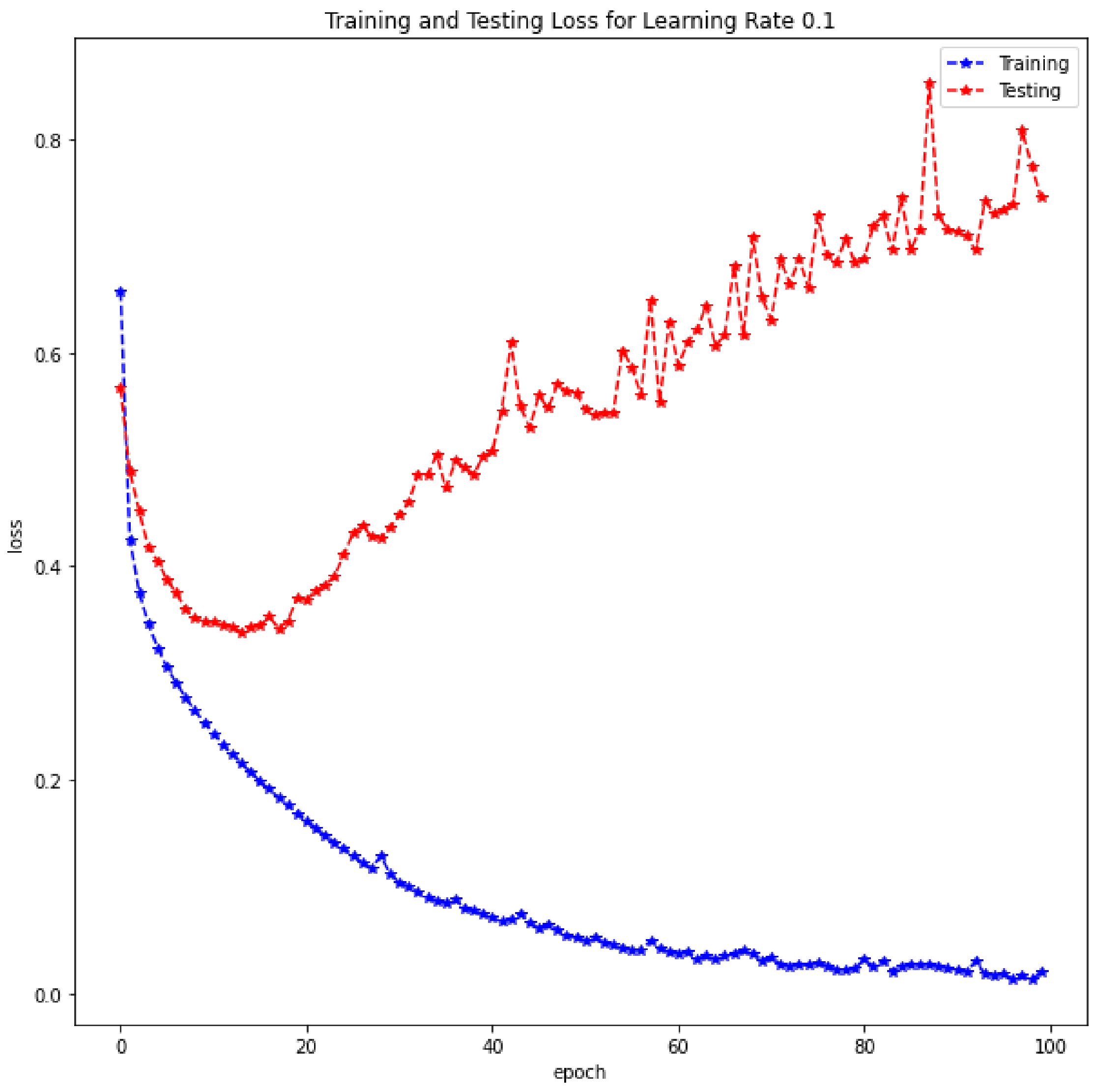
[92]:
```
# test_acc[0.01]
for lr in learning_rate:
    test_loss_list = getList(test_loss, lr, 100)
    train_loss_list = getList(train_loss, lr, 100)
    accuracy = float("{:.2f}".format(getAverage(test_acc, lr, 100) * 100))␣
 ↪#format(getAverage(test_acc, lr, 10) * 100)
    accuracy_list = getList(test_acc, lr, 100) * 100
    print(f'Accuracy for Learning Rate {lr}, is {accuracy}')
    plotTrainigTestCurve(train_loss_list, test_loss_list, 'Training Loss',␣
 ↪'Testing Loss', f'Training and Testing Loss for Learning Rate {lr}')
    plotAccuracy(getList(test_acc, lr, 100), 'Accuracy' , f'Accuracy for Learning␣
 ↪Rate {lr}')
    print('\n\n')
```

```
Accuracy for Learning Rate 1, is 18.28
```

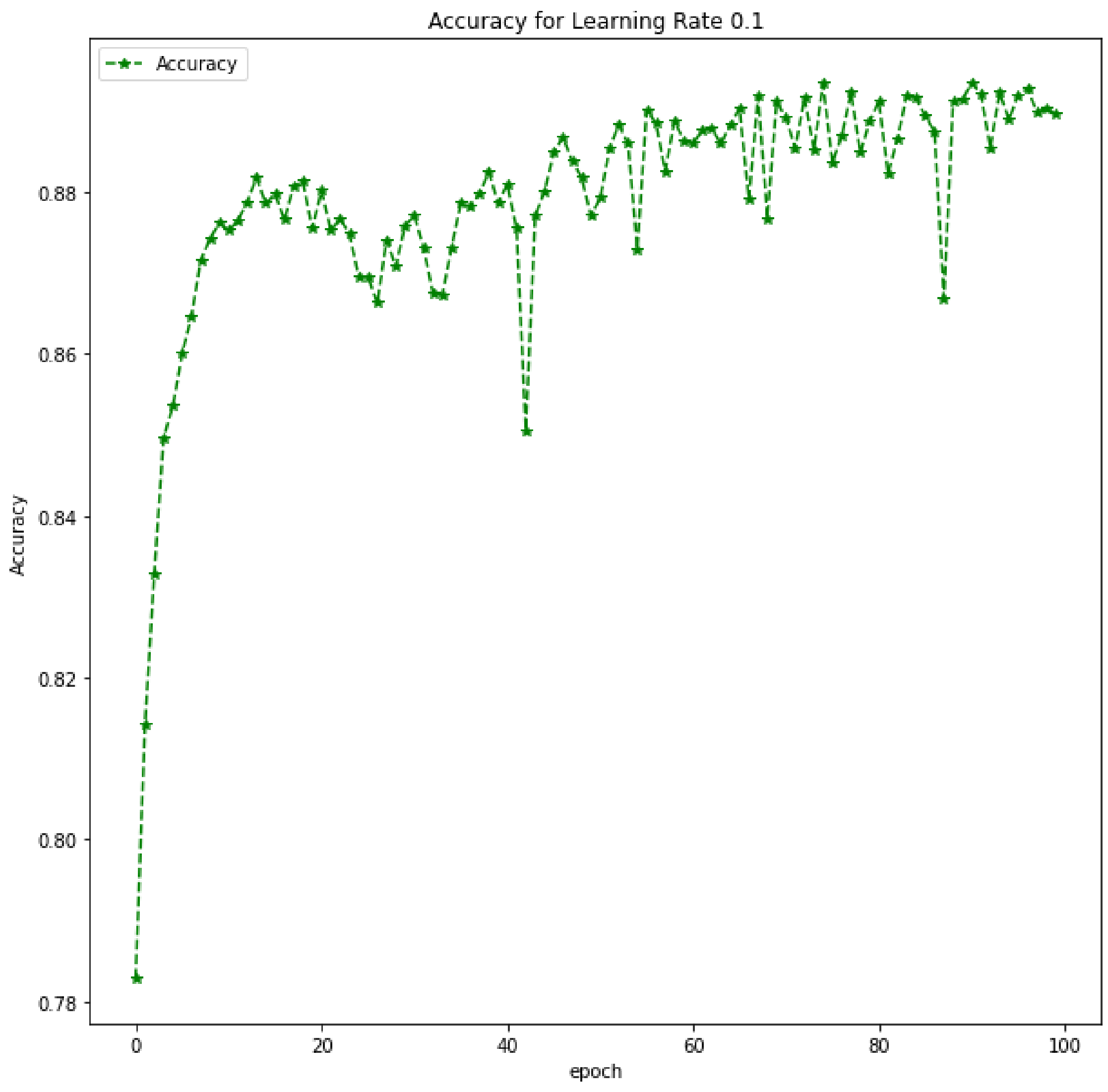

Training and Testing Loss for Learning Rate 1
loss
epoch
Training
Testing
8
7
6
5
4
3
2
0
20
40
60
80
100



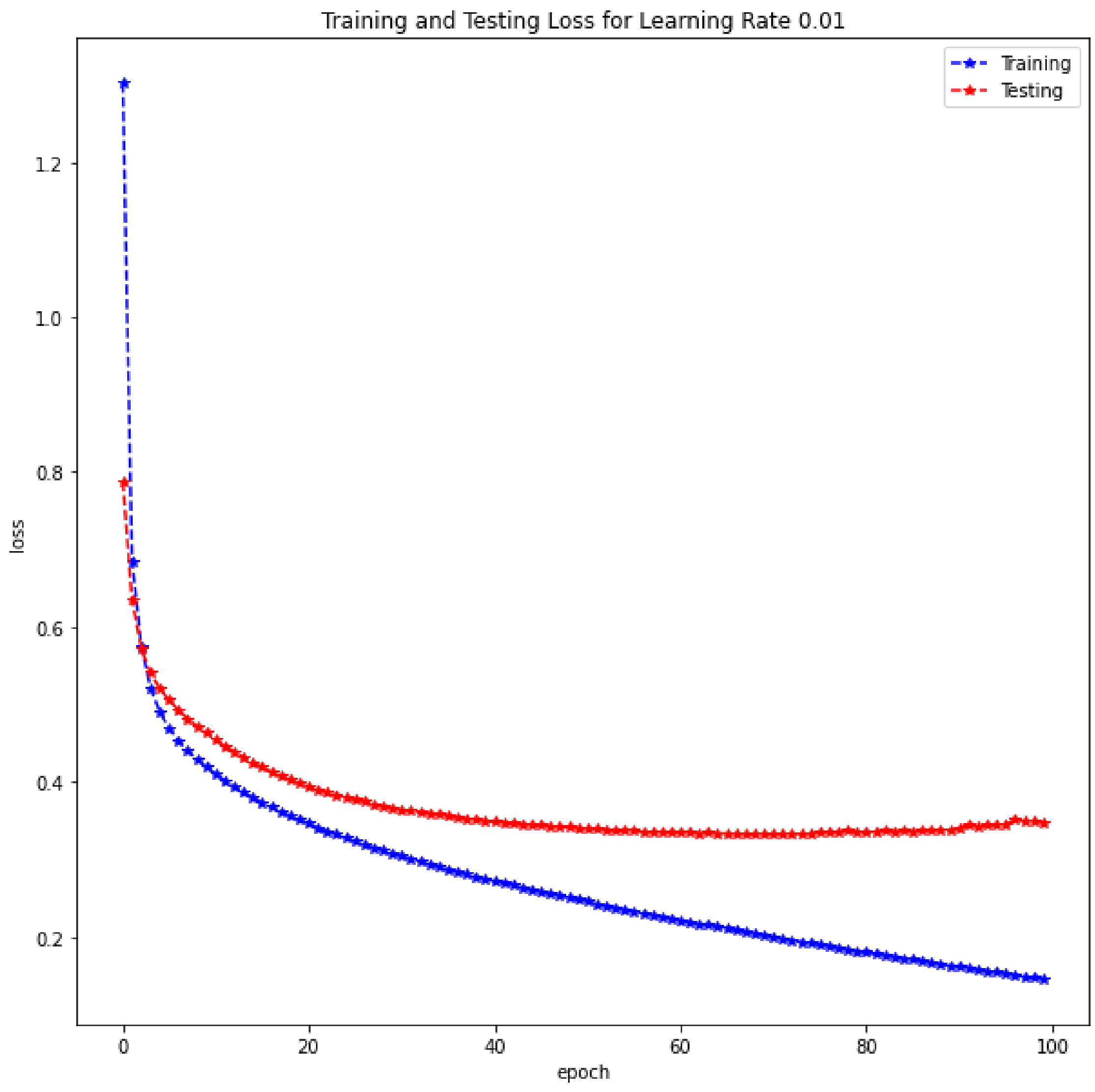
```
Accuracy for Learning Rate 0.1, is 87.9
```

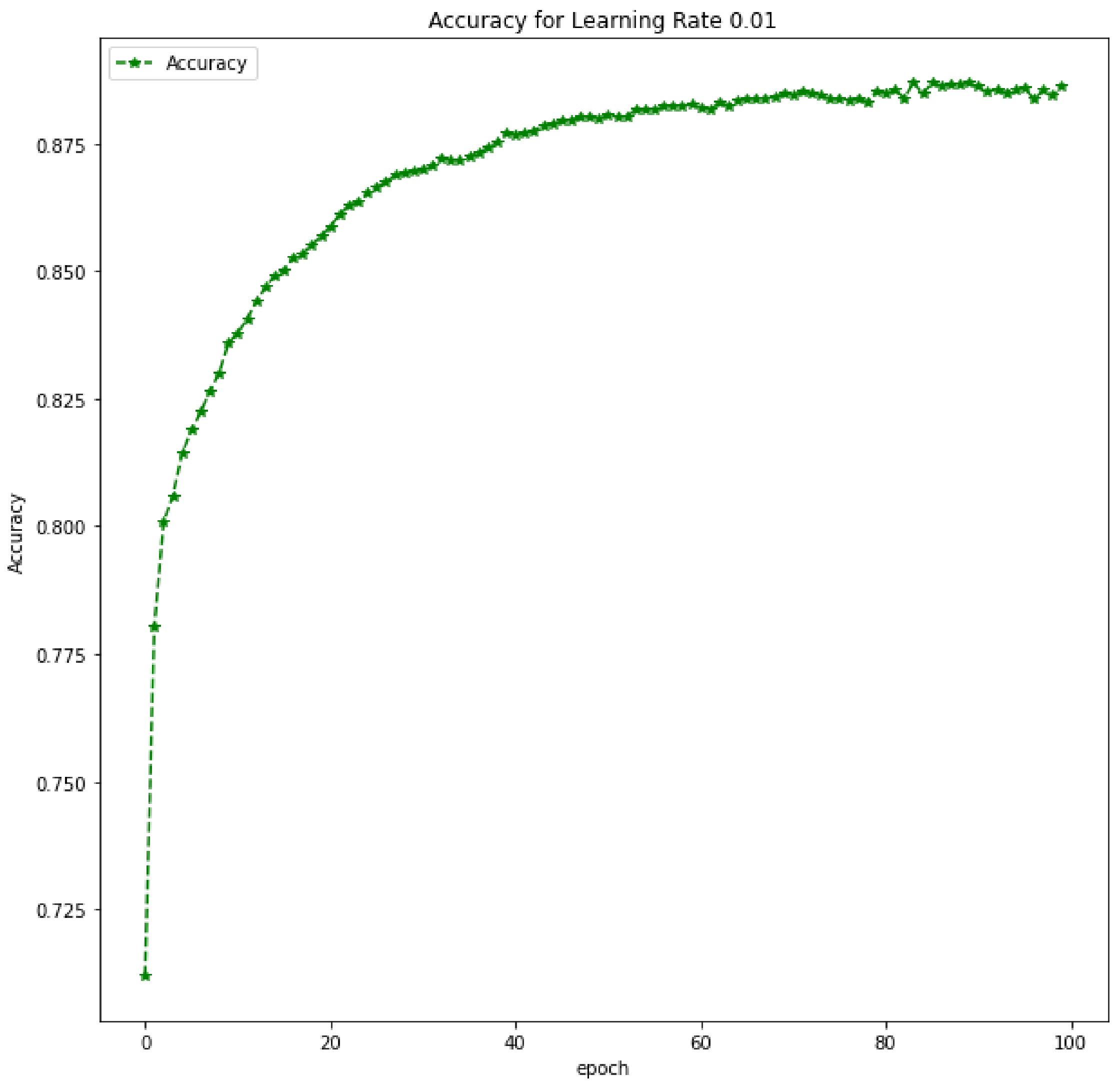


Training and Testing Loss for Learning Rate 0.1
Training
Testing
loss
0.0
0.2
0.4
0.6
0.8
epoch
0
20
40
60
80
100

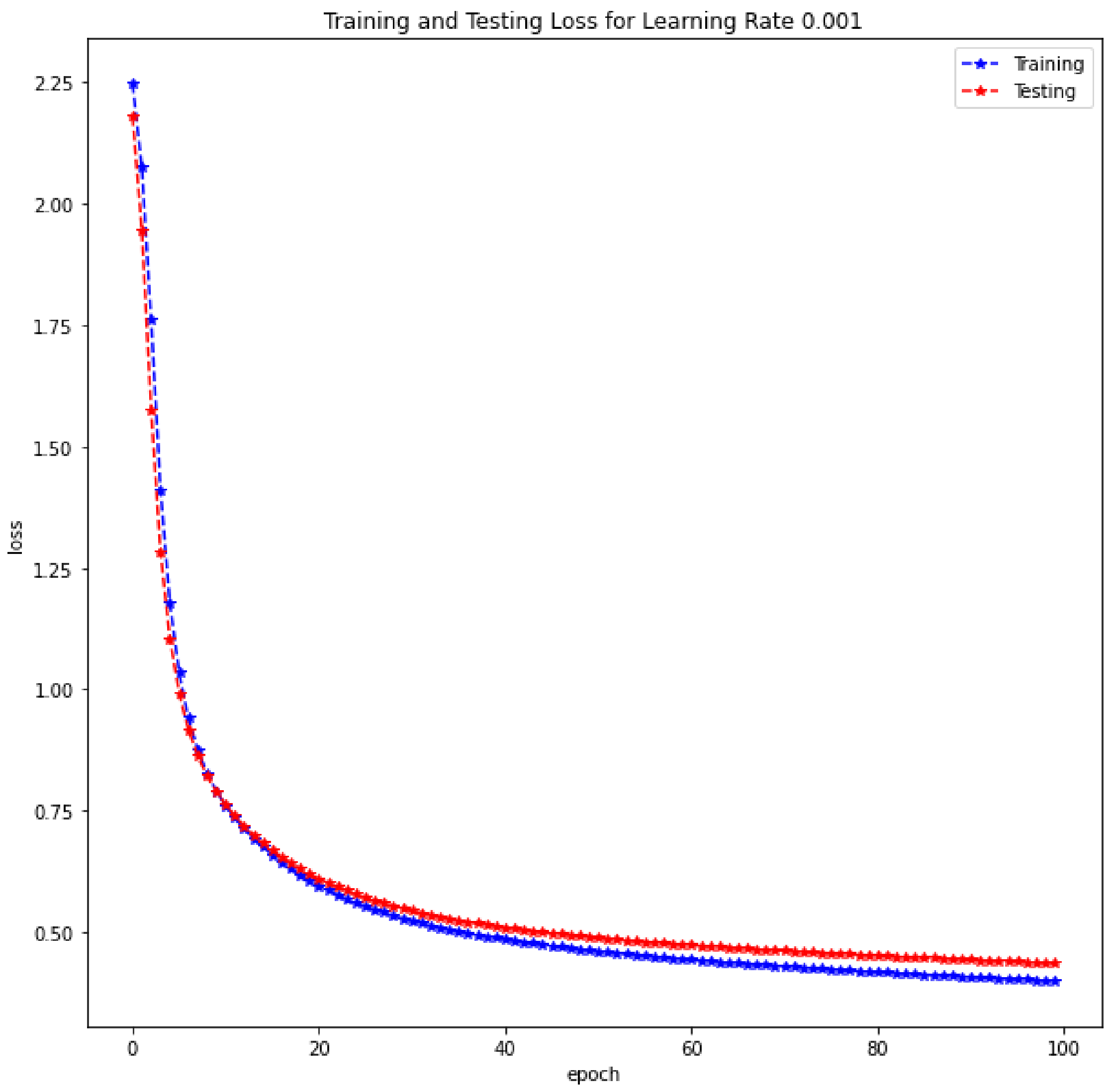


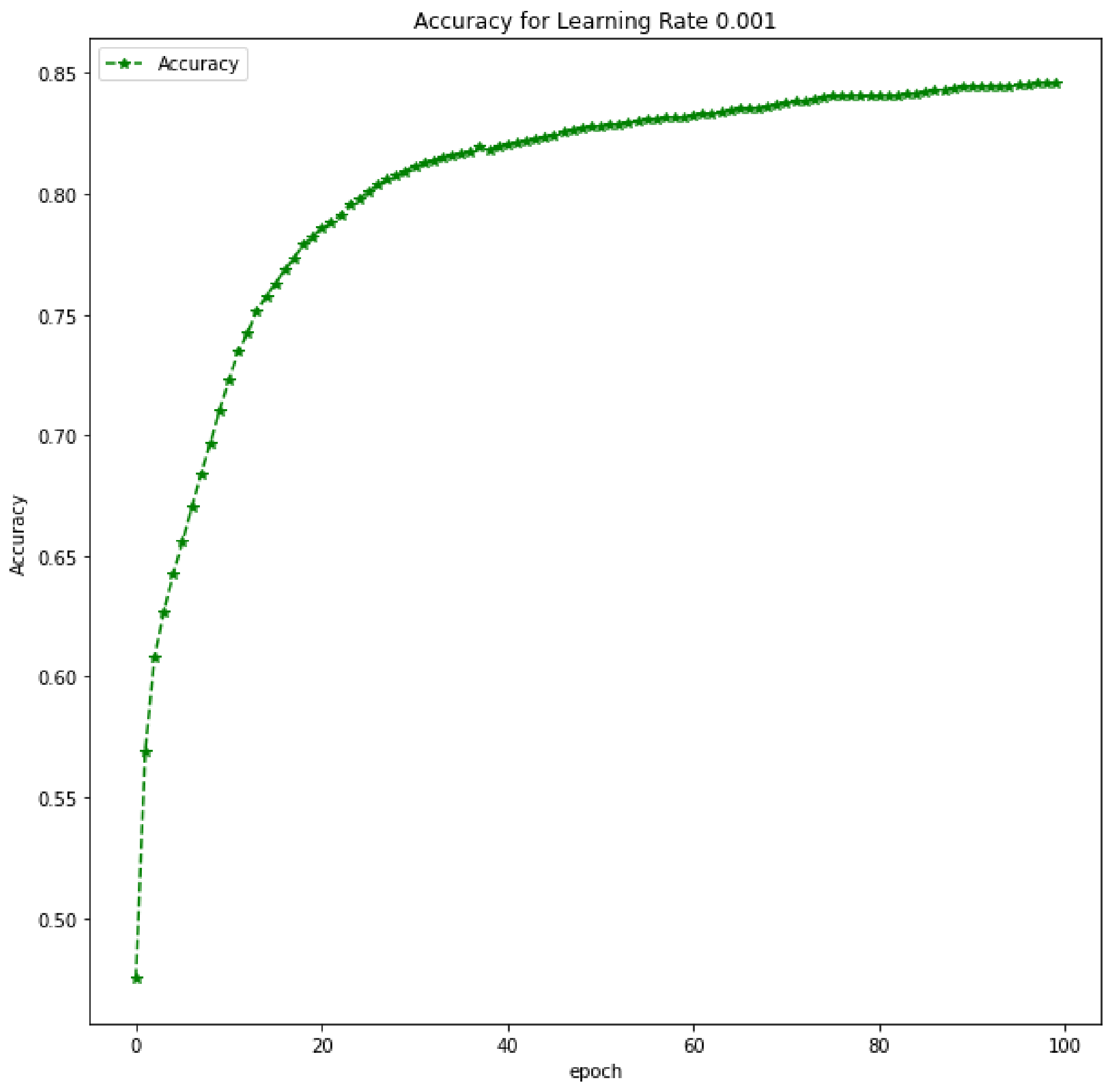
```
Accuracy for Learning Rate 0.01, is 86.9
```


Training and Testing Loss for Learning Rate 0.01
Training
Testing
1.2
1.0
0.8
0.6
0.4
0.2
loss
0
20
40
60
80
100
epoch



```
Accuracy for Learning Rate 0.001, is 80.2
```


Training and Testing Loss for Learning Rate 0.001
Training
Testing
loss
epoch
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0
20
40
60
80
100



Results for learning rate [1, 0.1, 0.01, 0.001] running over 100 epochs

1. None of the learning rate crossed 90% Accuracy within the 100 epochs.
2. Best accuracy was achieved for learning rate 0.1
3. The train and test loss curve for learning rate 0.1 shows that it was moving towards an optimal solution and achieved 88.17% accuracy. Accuracy could have been improved if the number of epochs would have been increased or a larger learning rate would have imporved the training time.

Q1.3 (2 points) Compare the results in table 1 and table 2, what is your observation and your understanding of the learning rate?

In neural netowrrks stochastic gradient descent is used for optimization that estimates the error and updates the weights of the model by using the back-propagation. The amount by which the weights are updated during training is known as the step size or the "learning rate." The learning rate is a configurable hyperparameter used in the training of neural networks. Smaller learning rates require more training epochs given the smaller changes made to the weights at each update this can cause the process to get stuck.Whereas, larger learning rates result in rapid changes and require fewer training epochs. However, learning rate which is too large can cause the model to converge too quickly to a suboptimal solution.

From the table 1 and 2 following observatoin can be made: 1. As the learning rate is decreased from 1 to 0.001 the accuracy increases and then decreases. The best accuracy in both the tables is at 0.1. This signifies that the learning rate of 0.1 gives a more optimal solution than other learning rates 2. It can be seen that as the number of epoch is increased from 10 to 100 the accuracy of learning rates for 0.1, 0.01 and 0.001 increases. This is becuase the updates made to the weights are smaller and therefore requires more epochs to converge to an optimal solution. However, decreasing learning rate too much is also not good as it would increase the training time. 3. For learning rate 1 it can be seen that the accuracy remains almost the same. This is because the step size is too large and we keep jumping around the minima (optimal solution). Having a large learning rate might help to jump out of a local minima and move towards a global minima but this has its own risk. If the learning rate is too high it might not be able to converge and give an optimal solution.

Q1.4 (3 point) Suppose the given network is a base network, please calculate the trainable parameters for this given network, and report its accuracy with lr = 0.01 and 40 epochs. Change the network structures by adding/removing layers/nodes. Report the accuracy and the parameters for each structure under the same training setting. Parameters represent the number of trainable parameters in your model, e.g. a 3 x 3 conv has 9 parameters, and a linear layer with n input nodes and m output nodes has n*m+m parameters for weights and bias.

Structures	Accuracy	Parameters
Remove nodes	84.34	269322
Remove layers	84.67	407050
Base	84.77	669706
Add layers	61.26	1720330
Add nodes	85.16	3581962

[75]:
```python
learning_rate_list = [0.01]
epochs = 40

average_acc_base = sum(getList(test_acc,0.01,epochs))/epochs
print(f'Accuracy for Base Network is {average_acc_base}')
```

```
Accuracy for Base Network is 0.8477675
```

Adding Nodes

[76]:
```python
#Adding Nodes
increased_nodes = 512 * 3
```

```
accuracy_add_nodes, params_add_noedes, train_add_nodes, test_add_nodes =␣
 ↪RunExpirement(learning_rate_list, epochs, device, num_nodes = increased_nodes,␣
 ↪num_layers = 1)
```

```
Running for Learning Rate 0.01
Number of parameters 3581962
Epoch 1
-------------------------------
Training Error: 1.1684784607084067
Test Error:
 Accuracy: 74.2%, Avg loss: 0.735505

Epoch 2
-------------------------------
Training Error: 0.6351586876393381
Test Error:
 Accuracy: 79.2%, Avg loss: 0.598637

Epoch 3
-------------------------------
Training Error: 0.5394703827178808
Test Error:
 Accuracy: 80.5%, Avg loss: 0.550071

Epoch 4
-------------------------------
Training Error: 0.4952989307357304
Test Error:
 Accuracy: 81.2%, Avg loss: 0.522990

Epoch 5
-------------------------------
Training Error: 0.46871908777939486
Test Error:
 Accuracy: 81.8%, Avg loss: 0.504160

Epoch 6
-------------------------------
Training Error: 0.4497640370401238
Test Error:
 Accuracy: 82.3%, Avg loss: 0.489144

Epoch 7
-------------------------------
Training Error: 0.4347197300653214
Test Error:
 Accuracy: 82.8%, Avg loss: 0.476513
```

```
Epoch 8
-------------------------------
Training Error: 0.42214727994284906
Test Error:
 Accuracy: 83.3%, Avg loss: 0.465441

Epoch 9
-------------------------------
Training Error: 0.41121625164742154
Test Error:
 Accuracy: 83.5%, Avg loss: 0.455436

Epoch 10
-------------------------------
Training Error: 0.4014581800746257
Test Error:
 Accuracy: 84.0%, Avg loss: 0.446400

Epoch 11
-------------------------------
Training Error: 0.39265965644929457
Test Error:
 Accuracy: 84.4%, Avg loss: 0.437988

Epoch 12
-------------------------------
Training Error: 0.3846048175303667
Test Error:
 Accuracy: 84.7%, Avg loss: 0.430393

Epoch 13
-------------------------------
Training Error: 0.3771423118105575
Test Error:
 Accuracy: 84.9%, Avg loss: 0.422734

Epoch 14
-------------------------------
Training Error: 0.3702001005156971
Test Error:
 Accuracy: 85.0%, Avg loss: 0.416381

Epoch 15
-------------------------------
Training Error: 0.36370419388386743
Test Error:
 Accuracy: 85.1%, Avg loss: 0.410353
```

```
Epoch 16
-------------------------------
Training Error: 0.35756867723678476
Test Error:
 Accuracy: 85.3%, Avg loss: 0.404803

Epoch 17
-------------------------------
Training Error: 0.3517627597871874
Test Error:
 Accuracy: 85.5%, Avg loss: 0.399541

Epoch 18
-------------------------------
Training Error: 0.346206882726282
Test Error:
 Accuracy: 85.8%, Avg loss: 0.394989

Epoch 19
-------------------------------
Training Error: 0.34088559486845665
Test Error:
 Accuracy: 86.0%, Avg loss: 0.390692

Epoch 20
-------------------------------
Training Error: 0.33577635393404504
Test Error:
 Accuracy: 86.1%, Avg loss: 0.386848

Epoch 21
-------------------------------
Training Error: 0.3308815312569838
Test Error:
 Accuracy: 86.2%, Avg loss: 0.383456

Epoch 22
-------------------------------
Training Error: 0.32615101169834515
Test Error:
 Accuracy: 86.3%, Avg loss: 0.380029

Epoch 23
-------------------------------
Training Error: 0.3215816221130428
Test Error:
 Accuracy: 86.5%, Avg loss: 0.376960
```

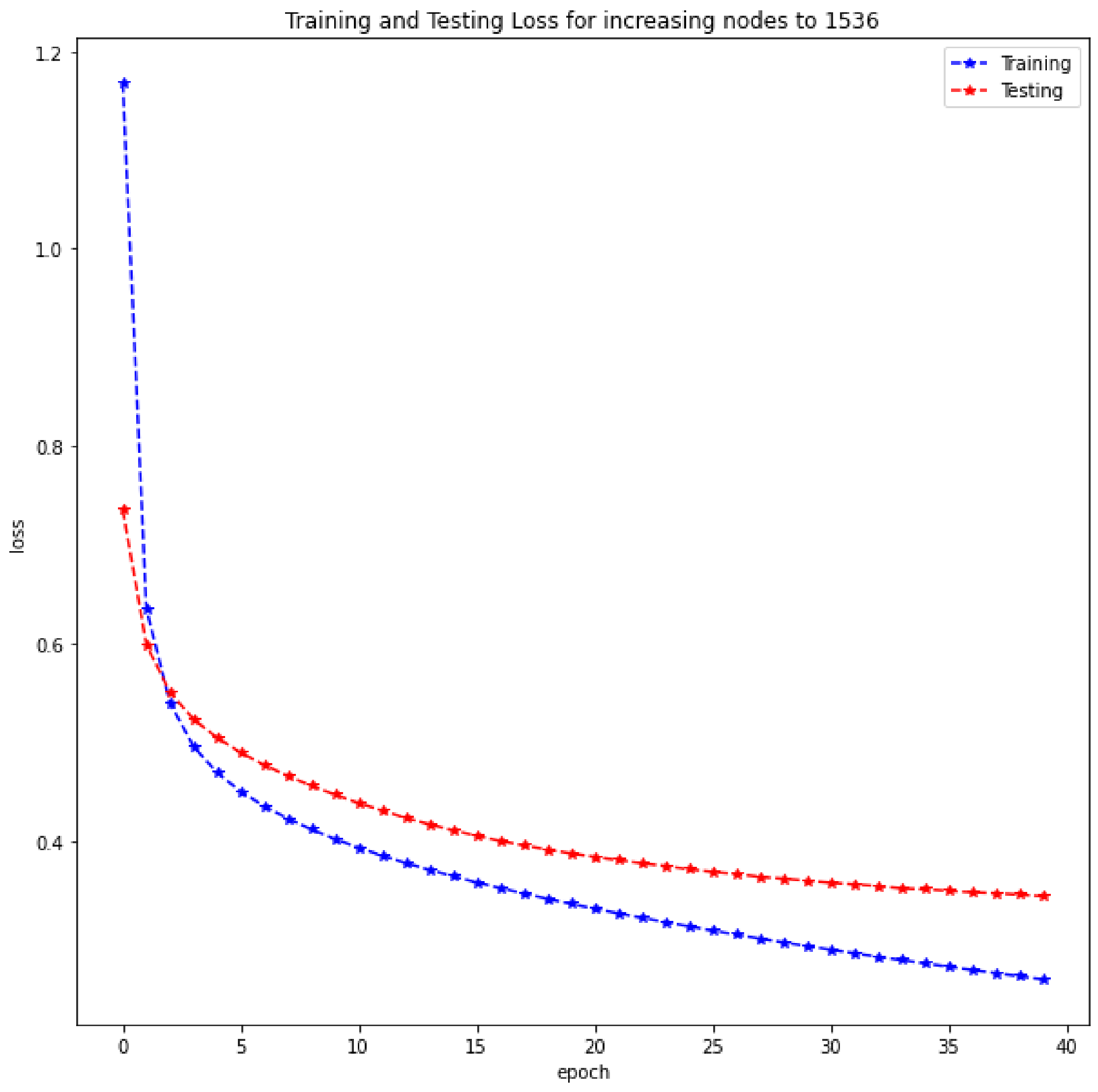
```
Epoch 24
-------------------------------
Training Error: 0.3171446102816286
Test Error: 
 Accuracy: 86.5%, Avg loss: 0.374106 

Epoch 25
-------------------------------
Training Error: 0.31282405844375266
Test Error: 
 Accuracy: 86.6%, Avg loss: 0.370744 

Epoch 26
-------------------------------
Training Error: 0.30861324801056117
Test Error: 
 Accuracy: 86.8%, Avg loss: 0.368138 

Epoch 27
-------------------------------
Training Error: 0.304550575993971
Test Error: 
 Accuracy: 86.9%, Avg loss: 0.365924 

Epoch 28
-------------------------------
Training Error: 0.30056615556671673
Test Error: 
 Accuracy: 87.0%, Avg loss: 0.363195 

Epoch 29
-------------------------------
Training Error: 0.29668272834723947
Test Error: 
 Accuracy: 87.0%, Avg loss: 0.361320 

Epoch 30
-------------------------------
Training Error: 0.2929147698684161
Test Error: 
 Accuracy: 87.0%, Avg loss: 0.359218 

Epoch 31
-------------------------------
Training Error: 0.2892505212712771
Test Error: 
 Accuracy: 87.1%, Avg loss: 0.357227 
```

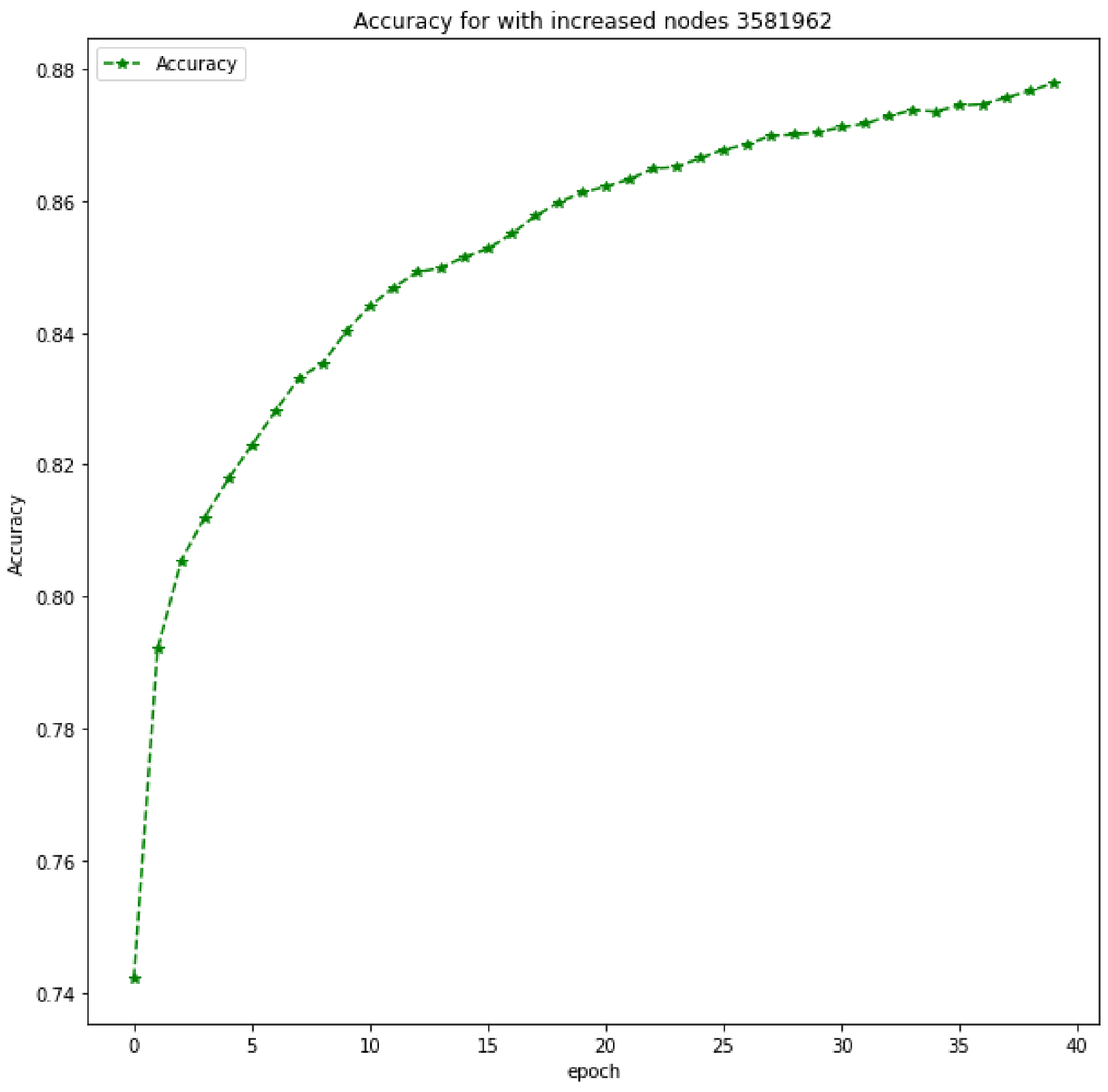
```
Epoch 32
-------------------------------
Training Error: 0.2856874888115473
Test Error: 
 Accuracy: 87.2%, Avg loss: 0.355574

Epoch 33
-------------------------------
Training Error: 0.2821736917503353
Test Error: 
 Accuracy: 87.3%, Avg loss: 0.353745

Epoch 34
-------------------------------
Training Error: 0.2787256909967231
Test Error: 
 Accuracy: 87.4%, Avg loss: 0.351556

Epoch 35
-------------------------------
Training Error: 0.27533966848559216
Test Error: 
 Accuracy: 87.4%, Avg loss: 0.350471

Epoch 36
-------------------------------
Training Error: 0.271992075719686
Test Error: 
 Accuracy: 87.4%, Avg loss: 0.348941

Epoch 37
-------------------------------
Training Error: 0.26871059645912543
Test Error: 
 Accuracy: 87.5%, Avg loss: 0.347518

Epoch 38
-------------------------------
Training Error: 0.26547609186216964
Test Error: 
 Accuracy: 87.6%, Avg loss: 0.346529

Epoch 39
-------------------------------
Training Error: 0.2623171204728867
Test Error: 
 Accuracy: 87.7%, Avg loss: 0.345032
```

```
Epoch 40
-------------------------------
Training Error: 0.2592182499386354
Test Error:
 Accuracy: 87.8%, Avg loss: 0.343356

Done for Learning Rate! 0.01
```

```
[84]: accuracy_mean_add_nodes = sum(accuracy_add_nodes[learning_rate_list[0]])/epochs
      print(f'Accuracy when increasing nodes to {increased_nodes} is␣
       ↪{accuracy_mean_add_nodes} with params {params_add_noedes} \n')
      plotTrainigTestCurve(train_add_nodes[0.01], test_add_nodes[0.01], 'Training␣
       ↪Loss', 'Testing Loss', f'Training and Testing Loss for increasing nodes to␣
       ↪{increased_nodes}')
      plotAccuracy(accuracy_add_nodes[learning_rate_list[0]], 'Accuracy' , f'Accuracy␣
       ↪for with increased nodes {params_add_noedes}')
```

```
Accuracy when increasing nodes to 1536 is 0.8516425000000002 with params 3581962
```


Training and Testing Loss for increasing nodes to 1536
Training
Testing
loss
epoch
1.2
1.0
0.8
0.6
0.4
0
5
10
15
20
25
30
35
40



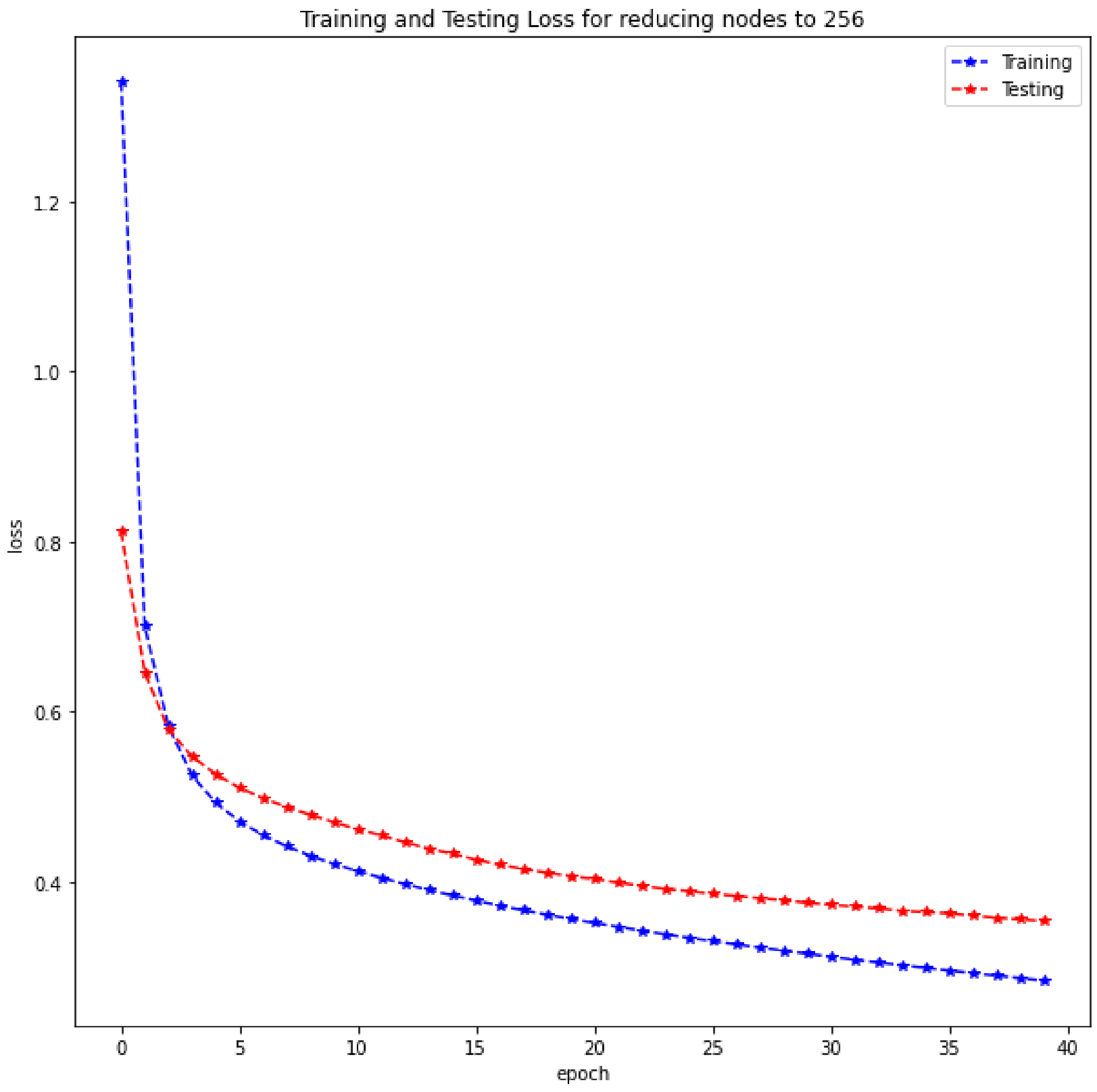
Removing Nodes

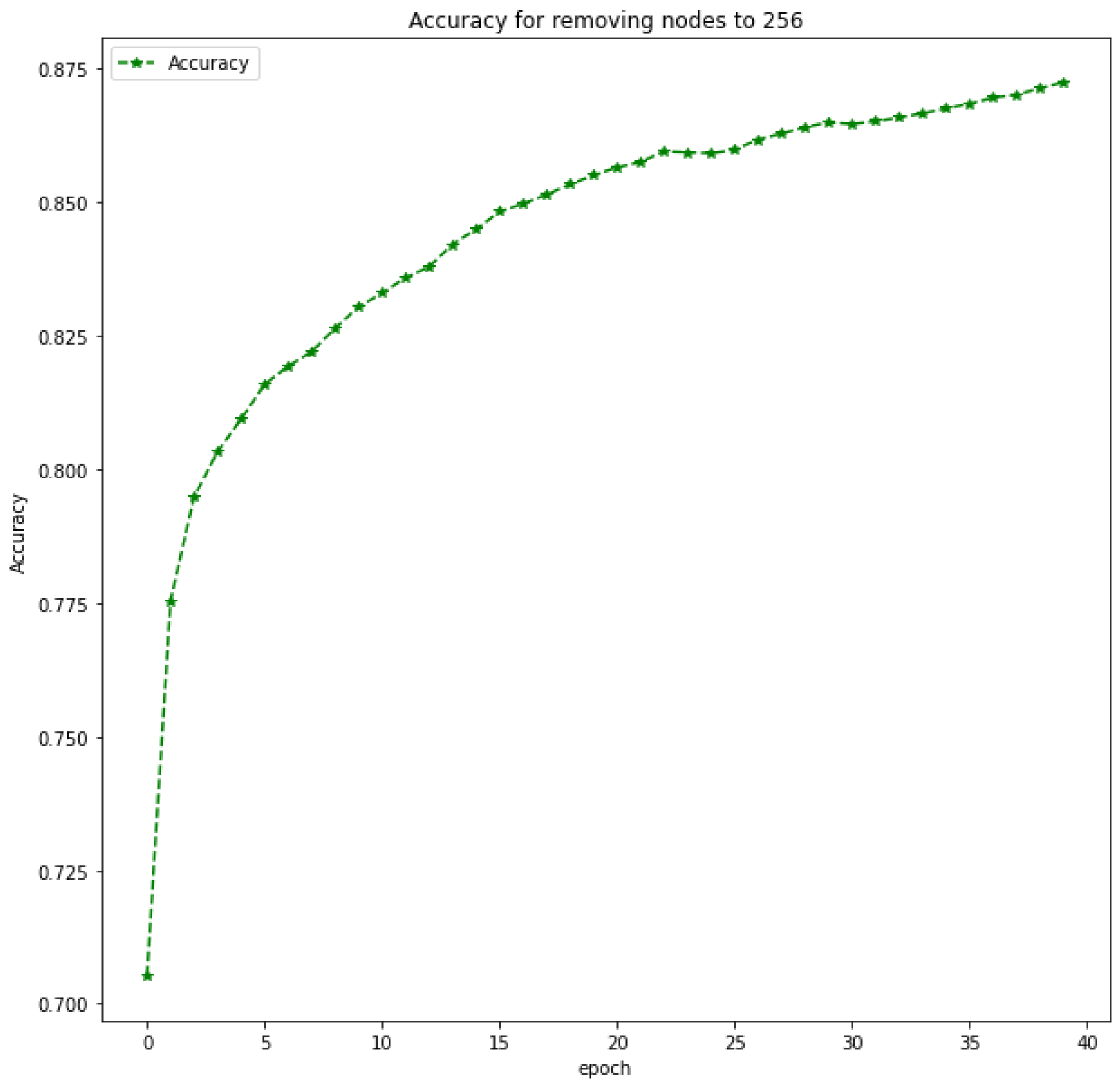
[85]:
```
#Remove Nodes
reduced_nodes = 256
acc_remove_nodes, params_remove_nodes, train_remove_nodes, test_remove_nodes =␣
↪RunExpirement(learning_rate_list, epochs, device, num_nodes = reduced_nodes,␣
↪num_layers = 1)
```

```
Running for Learning Rate 0.01
Number of parameters 269322
Epoch 1
-------------------------------
Training Error: 1.3416574306325364
Test Error:
 Accuracy: 70.5%, Avg loss: 0.812208

Epoch 2
-------------------------------
Training Error: 0.700541394987086
Test Error:
 Accuracy: 77.5%, Avg loss: 0.646135

Epoch 3
-------------------------------
Training Error: 0.5827143722886978
Test Error:
 Accuracy: 79.5%, Avg loss: 0.578784

Epoch 4
-------------------------------
Training Error: 0.5248314768139487
Test Error:
 Accuracy: 80.3%, Avg loss: 0.547352

Epoch 5
-------------------------------
Training Error: 0.49261769444258735
Test Error:
 Accuracy: 80.9%, Avg loss: 0.526362

Epoch 6
-------------------------------
Training Error: 0.4711527380544239
Test Error:
 Accuracy: 81.6%, Avg loss: 0.510423

Epoch 7
-------------------------------
Training Error: 0.45476838098024763
Test Error:
 Accuracy: 81.9%, Avg loss: 0.498184

Epoch 8
-------------------------------
Training Error: 0.4414710227582755
Test Error:
 Accuracy: 82.2%, Avg loss: 0.487843

Epoch 9
-------------------------------
Training Error: 0.4303570798814678
Test Error:
 Accuracy: 82.6%, Avg loss: 0.478598

Epoch 10
-------------------------------
Training Error: 0.4207983764567609
Test Error:
 Accuracy: 83.0%, Avg loss: 0.469847

Epoch 11
-------------------------------
Training Error: 0.4122739260607183
Test Error:
 Accuracy: 83.3%, Avg loss: 0.461840

Epoch 12
-------------------------------
Training Error: 0.40445537434648604
Test Error:
 Accuracy: 83.6%, Avg loss: 0.454424

Epoch 13
-------------------------------
Training Error: 0.39714930751430455
Test Error:
 Accuracy: 83.8%, Avg loss: 0.446415

Epoch 14
-------------------------------
Training Error: 0.3902833380265785
Test Error:
 Accuracy: 84.2%, Avg loss: 0.438703

Epoch 15
-------------------------------
Training Error: 0.38383145476264485
Test Error:
 Accuracy: 84.5%, Avg loss: 0.432955

Epoch 16
-------------------------------
Training Error: 0.37773801681837804
Test Error:
 Accuracy: 84.8%, Avg loss: 0.425900

Epoch 17
-------------------------------
Training Error: 0.3718512695767224
Test Error:
 Accuracy: 85.0%, Avg loss: 0.419875

Epoch 18
-------------------------------
Training Error: 0.366342711312049
Test Error:
 Accuracy: 85.1%, Avg loss: 0.414929

Epoch 19
-------------------------------
Training Error: 0.36110929112190376
Test Error:
 Accuracy: 85.3%, Avg loss: 0.410465

Epoch 20
-------------------------------
Training Error: 0.3561921154798221
Test Error:
 Accuracy: 85.5%, Avg loss: 0.406505

Epoch 21
-------------------------------
Training Error: 0.3513987884402021
Test Error:
 Accuracy: 85.6%, Avg loss: 0.403199

Epoch 22
-------------------------------
Training Error: 0.3467539850233206
Test Error:
 Accuracy: 85.7%, Avg loss: 0.398960

Epoch 23
-------------------------------
Training Error: 0.3422827374483985
Test Error:
 Accuracy: 85.9%, Avg loss: 0.395162

Epoch 24
-------------------------------
Training Error: 0.338078497553558
Test Error:
 Accuracy: 85.9%, Avg loss: 0.391504

Epoch 25
-------------------------------
Training Error: 0.3339858232959628
Test Error:
 Accuracy: 85.9%, Avg loss: 0.388941

Epoch 26
-------------------------------
Training Error: 0.3300022035598882
Test Error:
 Accuracy: 86.0%, Avg loss: 0.385670

Epoch 27
-------------------------------
Training Error: 0.32614860806002544
Test Error:
 Accuracy: 86.2%, Avg loss: 0.383139

Epoch 28
-------------------------------
Training Error: 0.3224587856150512
Test Error:
 Accuracy: 86.3%, Avg loss: 0.380404

Epoch 29
-------------------------------
Training Error: 0.31879741515813353
Test Error:
 Accuracy: 86.4%, Avg loss: 0.378232

Epoch 30
-------------------------------
Training Error: 0.31523607170848705
Test Error:
 Accuracy: 86.5%, Avg loss: 0.375270

Epoch 31
-------------------------------
Training Error: 0.31173655891945873
Test Error:
 Accuracy: 86.5%, Avg loss: 0.372833

Epoch 32
-------------------------------
Training Error: 0.30830655869708135
Test Error:
 Accuracy: 86.5%, Avg loss: 0.370878

Epoch 33
-------------------------------
Training Error: 0.3049641772866376
Test Error:
 Accuracy: 86.6%, Avg loss: 0.368555

Epoch 34
-------------------------------
Training Error: 0.3017416630806064
Test Error:
 Accuracy: 86.7%, Avg loss: 0.365704

Epoch 35
-------------------------------
Training Error: 0.29857051876117424
Test Error:
 Accuracy: 86.7%, Avg loss: 0.364393

Epoch 36
-------------------------------
Training Error: 0.29544574545740065
Test Error:
 Accuracy: 86.8%, Avg loss: 0.362652

Epoch 37
-------------------------------
Training Error: 0.29235064818152484
Test Error:
 Accuracy: 86.9%, Avg loss: 0.359947

Epoch 38
-------------------------------
Training Error: 0.2894077069564923
Test Error:
 Accuracy: 87.0%, Avg loss: 0.357559

Epoch 39
-------------------------------
Training Error: 0.28648466654995614
Test Error:
 Accuracy: 87.1%, Avg loss: 0.355618

Epoch 40
-------------------------------
Training Error: 0.2836850542408317
Test Error:
 Accuracy: 87.2%, Avg loss: 0.353485

Done for Learning Rate! 0.01
```

```
[86]: acc_averag_remove_nodes = sum(acc_remove_nodes[learning_rate_list[0]])/epochs
print(f'Accuracy for nodes reduced to {reduced_nodes} is␣
 ↪{acc_averag_remove_nodes}')
plotTrainigTestCurve(train_remove_nodes[0.01], test_remove_nodes[0.01],␣
 ↪'Training Loss', 'Testing Loss', f'Training and Testing Loss for reducing␣
 ↪nodes to {reduced_nodes}')
plotAccuracy(acc_remove_nodes[learning_rate_list[0]], 'Accuracy' , f'Accuracy␣
 ↪for removing nodes to {reduced_nodes}')
```

```
Accuracy for nodes reduced to 256 is 0.8433975
```





Removing Layers

[87]:
```
#Remove Layers
reduced_layers = 1 * 0
acc_remove_layers, params_remove_layers, train_remove_layers, test_remove_layers␣
 ↪= RunExpirement(learning_rate_list, epochs, device, num_nodes = 512,␣
 ↪num_layers = reduced_layers)
```

```
Running for Learning Rate 0.01
Number of parameters 407050
Epoch 1
-------------------------------
Training Error: 1.1019794021461056
Test Error:
 Accuracy: 74.5%, Avg loss: 0.742062
```

```
Epoch 2
-------------------------------
Training Error: 0.6523614588068493
Test Error:
 Accuracy: 79.0%, Avg loss: 0.613051

Epoch 3
-------------------------------
Training Error: 0.564571178766456
Test Error:
 Accuracy: 80.8%, Avg loss: 0.558196

Epoch 4
-------------------------------
Training Error: 0.5206007519002154
Test Error:
 Accuracy: 81.8%, Avg loss: 0.527591

Epoch 5
-------------------------------
Training Error: 0.49349676520585506
Test Error:
 Accuracy: 82.2%, Avg loss: 0.507564

Epoch 6
-------------------------------
Training Error: 0.47461345440733915
Test Error:
 Accuracy: 82.8%, Avg loss: 0.493117

Epoch 7
-------------------------------
Training Error: 0.4602979923457479
Test Error:
 Accuracy: 83.2%, Avg loss: 0.481930

Epoch 8
-------------------------------
Training Error: 0.44877331819869815
Test Error:
 Accuracy: 83.3%, Avg loss: 0.472749

Epoch 9
-------------------------------
Training Error: 0.43906777007366293
Test Error:
 Accuracy: 83.5%, Avg loss: 0.464884
```

```
Epoch 10
-------------------------------
Training Error: 0.4305969324669858
Test Error:
 Accuracy: 83.7%, Avg loss: 0.458000

Epoch 11
-------------------------------
Training Error: 0.4230069060410772
Test Error:
 Accuracy: 83.9%, Avg loss: 0.451773

Epoch 12
-------------------------------
Training Error: 0.4161697715076048
Test Error:
 Accuracy: 84.1%, Avg loss: 0.446124

Epoch 13
-------------------------------
Training Error: 0.4099471873438943
Test Error:
 Accuracy: 84.2%, Avg loss: 0.440949

Epoch 14
-------------------------------
Training Error: 0.4041881823082214
Test Error:
 Accuracy: 84.4%, Avg loss: 0.436091

Epoch 15
-------------------------------
Training Error: 0.3988021869522168
Test Error:
 Accuracy: 84.6%, Avg loss: 0.431395

Epoch 16
-------------------------------
Training Error: 0.3937744755766539
Test Error:
 Accuracy: 84.8%, Avg loss: 0.427179

Epoch 17
-------------------------------
Training Error: 0.3890231204058316
Test Error:
 Accuracy: 85.1%, Avg loss: 0.423174
```

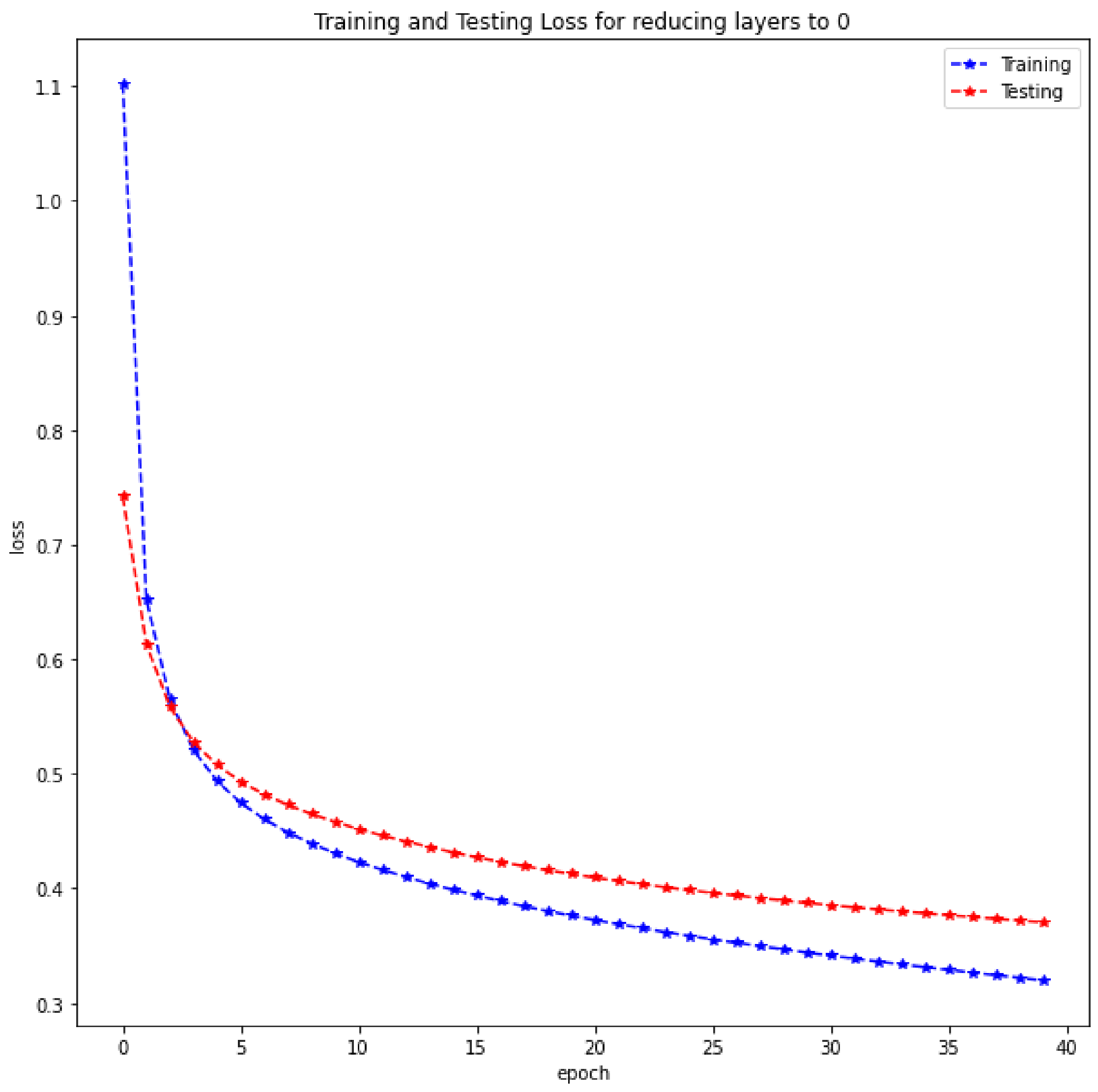
```
Epoch 18
-------------------------------
Training Error: 0.3845440052084323
Test Error:
 Accuracy: 85.2%, Avg loss: 0.419424

Epoch 19
-------------------------------
Training Error: 0.38029746018620186
Test Error:
 Accuracy: 85.3%, Avg loss: 0.415842

Epoch 20
-------------------------------
Training Error: 0.3762806224257453
Test Error:
 Accuracy: 85.5%, Avg loss: 0.412562

Epoch 21
-------------------------------
Training Error: 0.37244937943814915
Test Error:
 Accuracy: 85.5%, Avg loss: 0.409422

Epoch 22
-------------------------------
Training Error: 0.36877587493231045
Test Error:
 Accuracy: 85.6%, Avg loss: 0.406523

Epoch 23
-------------------------------
Training Error: 0.36527311163289206
Test Error:
 Accuracy: 85.7%, Avg loss: 0.403695

Epoch 24
-------------------------------
Training Error: 0.36189685401314103
Test Error:
 Accuracy: 85.8%, Avg loss: 0.401012

Epoch 25
-------------------------------
Training Error: 0.35867212569789847
Test Error:
 Accuracy: 85.9%, Avg loss: 0.398440
```

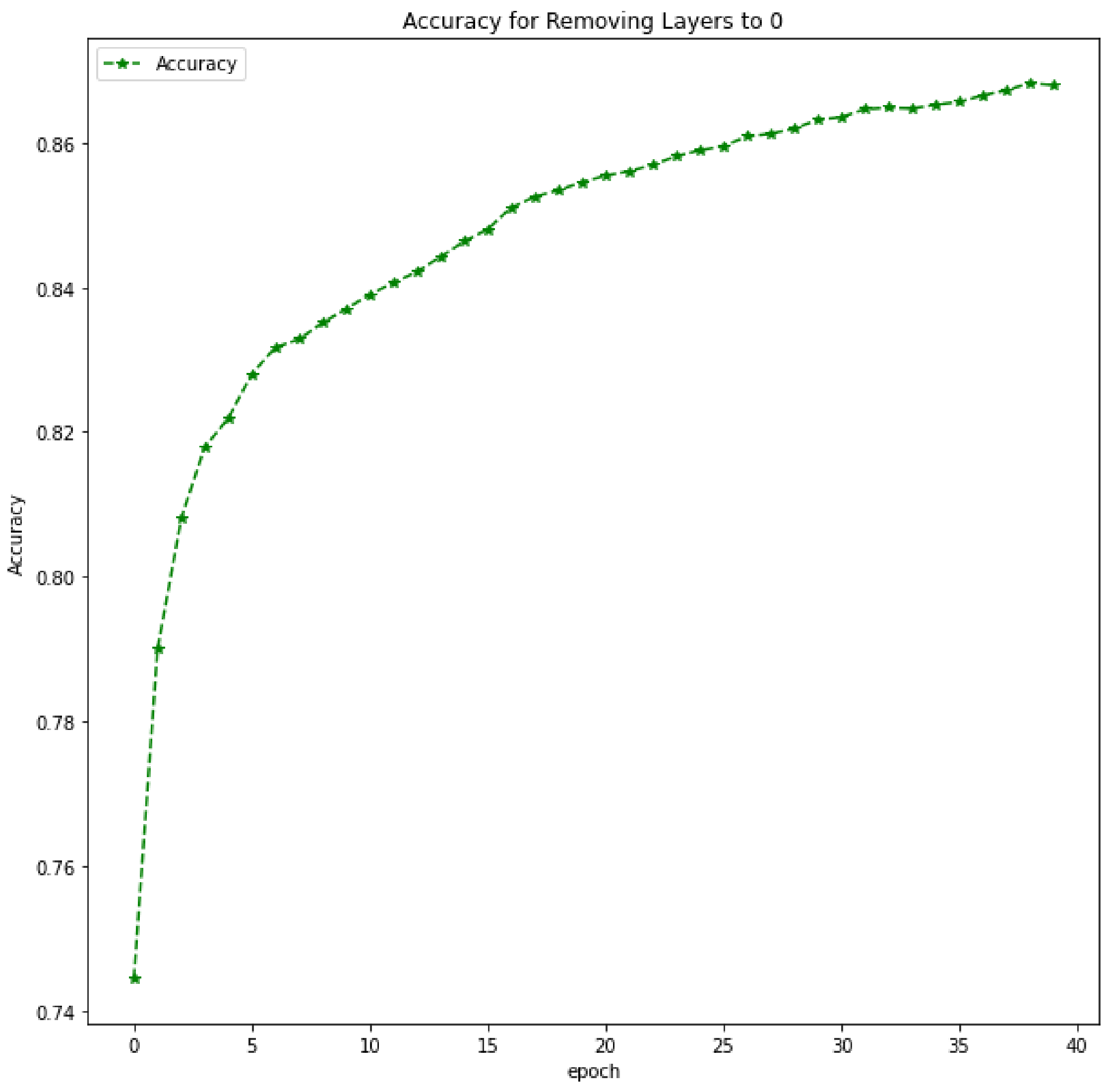
```
Epoch 26
-------------------------------
Training Error: 0.3555703474991103
Test Error:
 Accuracy: 86.0%, Avg loss: 0.396009

Epoch 27
-------------------------------
Training Error: 0.3525392808067773
Test Error:
 Accuracy: 86.1%, Avg loss: 0.393741

Epoch 28
-------------------------------
Training Error: 0.3496435743484543
Test Error:
 Accuracy: 86.1%, Avg loss: 0.391476

Epoch 29
-------------------------------
Training Error: 0.34679101524290756
Test Error:
 Accuracy: 86.2%, Avg loss: 0.389443

Epoch 30
-------------------------------
Training Error: 0.3440459537496572
Test Error:
 Accuracy: 86.3%, Avg loss: 0.387413

Epoch 31
-------------------------------
Training Error: 0.3413762546567393
Test Error:
 Accuracy: 86.4%, Avg loss: 0.385344

Epoch 32
-------------------------------
Training Error: 0.3387891478391726
Test Error:
 Accuracy: 86.5%, Avg loss: 0.383534

Epoch 33
-------------------------------
Training Error: 0.3362517288562331
Test Error:
 Accuracy: 86.5%, Avg loss: 0.381762
```

```
Epoch 34
-------------------------------
Training Error: 0.3337626964457508
Test Error:
 Accuracy: 86.5%, Avg loss: 0.379993

Epoch 35
-------------------------------
Training Error: 0.3313282653530523
Test Error:
 Accuracy: 86.5%, Avg loss: 0.378354

Epoch 36
-------------------------------
Training Error: 0.3289442817761954
Test Error:
 Accuracy: 86.6%, Avg loss: 0.376623

Epoch 37
-------------------------------
Training Error: 0.326589736587076
Test Error:
 Accuracy: 86.7%, Avg loss: 0.375132

Epoch 38
-------------------------------
Training Error: 0.3242839627952845
Test Error:
 Accuracy: 86.7%, Avg loss: 0.373511

Epoch 39
-------------------------------
Training Error: 0.32204416553889004
Test Error:
 Accuracy: 86.8%, Avg loss: 0.371943

Epoch 40
-------------------------------
Training Error: 0.31982639941102914
Test Error:
 Accuracy: 86.8%, Avg loss: 0.370471

Done for Learning Rate! 0.01
```

```
[88]: # acc_remove_layers, params_remove_layers
      average_acc_remove_layers = sum(acc_remove_layers[learning_rate_list[0]])/epochs
      print(f'Accuracy for reduced hidden Layers to {reduced_layers} is␣
       ↪{average_acc_remove_layers} with params {params_remove_layers}')
      plotTrainigTestCurve(train_remove_layers[0.01], test_remove_layers[0.01],␣
       ↪'Training Loss', 'Testing Loss', f'Training and Testing Loss for reducing␣
       ↪layers to {reduced_layers}')
      plotAccuracy(acc_remove_layers[learning_rate_list[0]], 'Accuracy' , f'Accuracy␣
       ↪for Removing Layers to {reduced_layers}')
```

```
Accuracy for reduced hidden Layers to 0 is 0.8467125 with params 407050
```





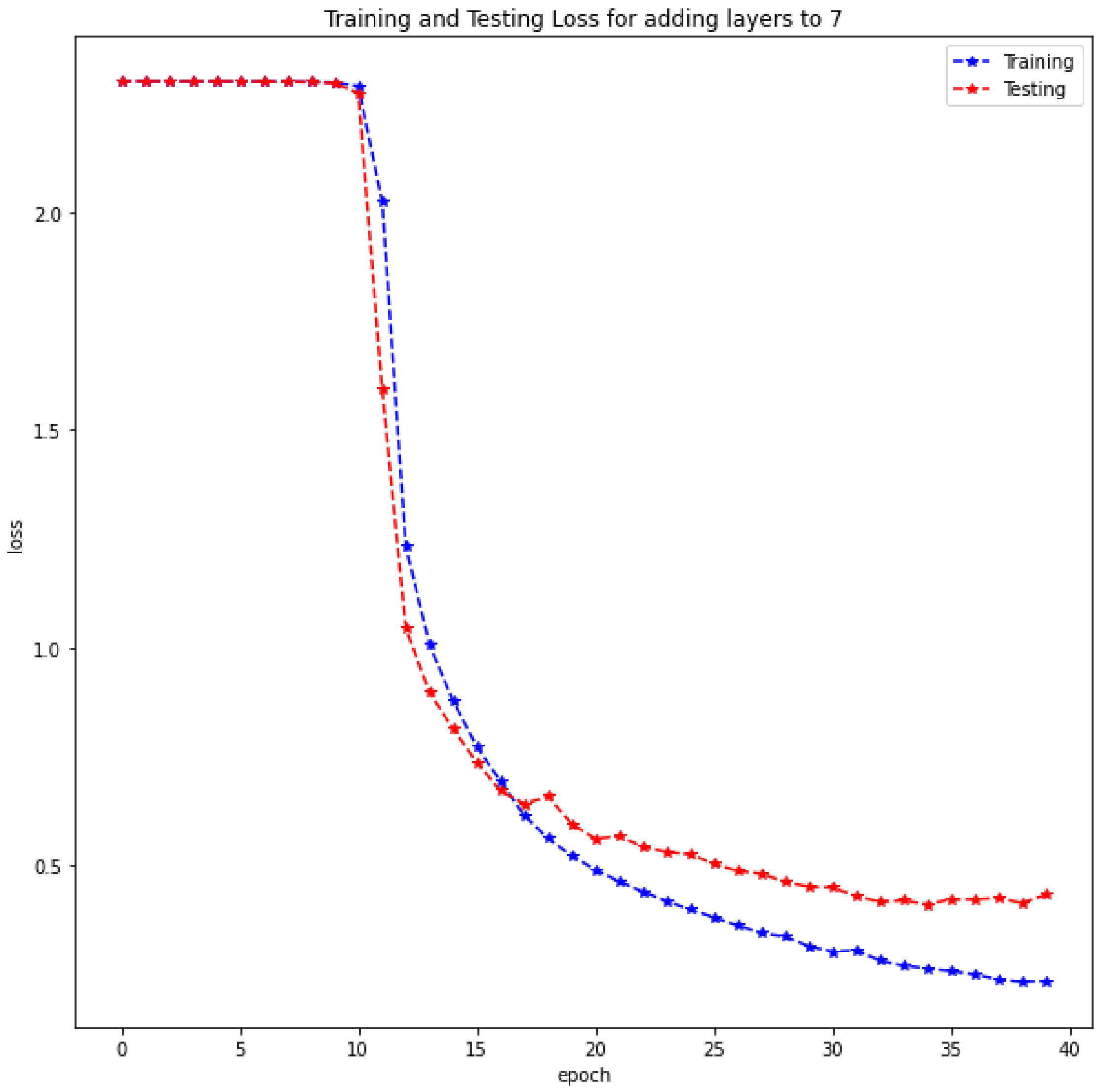
Adding Layers

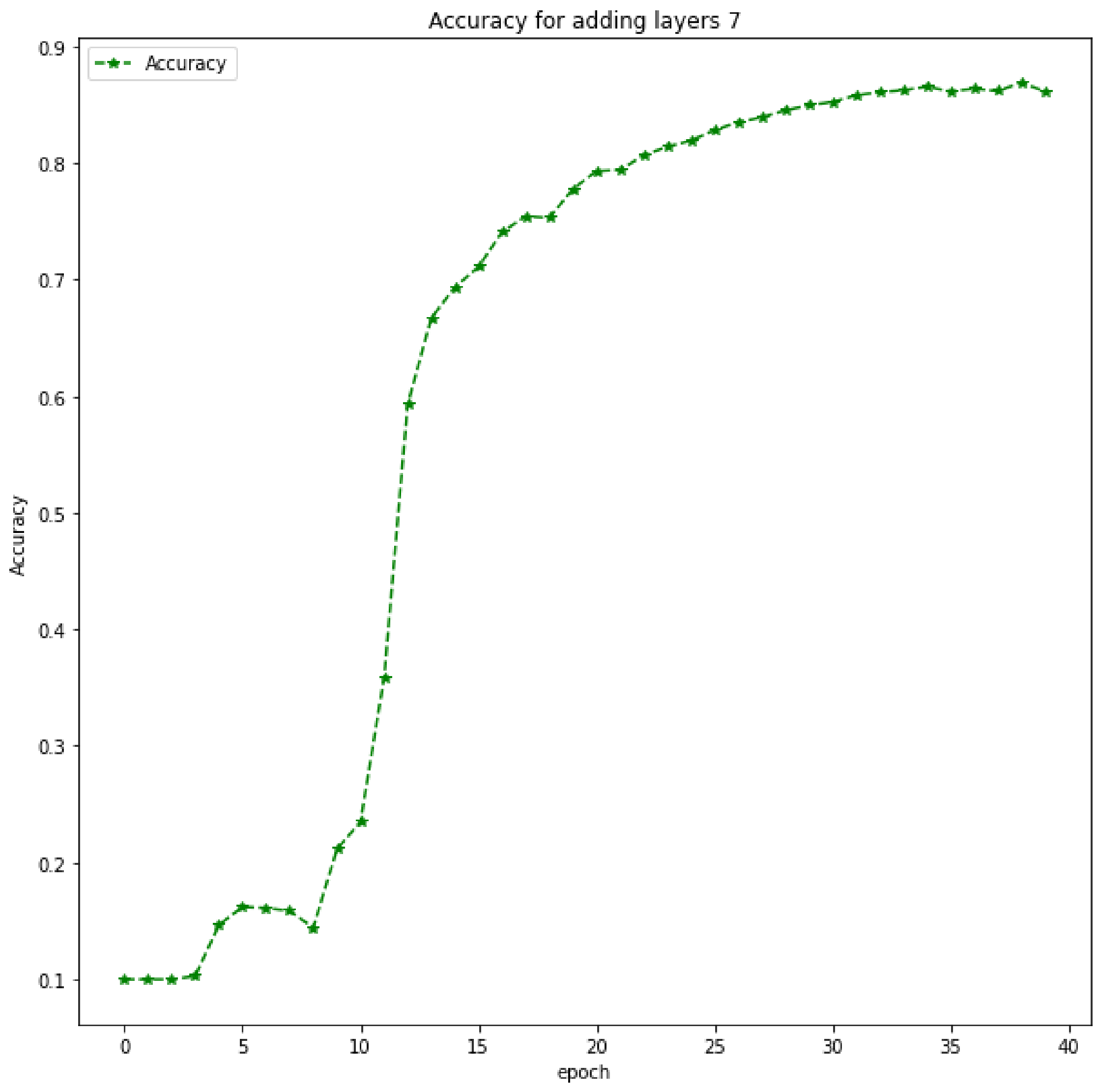
```
[93]: #Add Layers
increased_layers = 1 * 7
acc_add_layers, params_add_layers, train_add_layers, test_add_layers =␣
 ↪RunExpirement(learning_rate_list, epochs, device, num_nodes = 512, num_layers␣
 ↪= increased_layers)
```

```
Running for Learning Rate 0.01
Number of parameters 2245642
Epoch 1
-------------------------------
Training Error: 2.3027053883334974
Test Error:
 Accuracy: 10.0%, Avg loss: 2.302525

Epoch 2
-------------------------------
Training Error: 2.3025617846039568
Test Error:
 Accuracy: 10.0%, Avg loss: 2.302452

Epoch 3
-------------------------------
Training Error: 2.302489134802747
Test Error:
 Accuracy: 10.0%, Avg loss: 2.302379

Epoch 4
-------------------------------
Training Error: 2.3024082168587237
Test Error:
 Accuracy: 10.3%, Avg loss: 2.302289

Epoch 5
-------------------------------
Training Error: 2.3023066693531677
Test Error:
 Accuracy: 14.6%, Avg loss: 2.302174

Epoch 6
-------------------------------
Training Error: 2.3021639364360493
Test Error:
 Accuracy: 16.2%, Avg loss: 2.302004

Epoch 7
-------------------------------
Training Error: 2.3019600908385156
Test Error:
 Accuracy: 16.1%, Avg loss: 2.301751

Epoch 8
-------------------------------
Training Error: 2.3016236184248284
Test Error:
 Accuracy: 15.9%, Avg loss: 2.301313

Epoch 9
-------------------------------
Training Error: 2.300994236840368
Test Error:
 Accuracy: 14.4%, Avg loss: 2.300407

Epoch 10
-------------------------------
Training Error: 2.2993988207916716
Test Error:
 Accuracy: 21.1%, Avg loss: 2.297655

Epoch 11
-------------------------------
Training Error: 2.2911408082254408
Test Error:
 Accuracy: 23.5%, Avg loss: 2.274714

Epoch 12
-------------------------------
Training Error: 2.02629786056242
Test Error:
 Accuracy: 35.8%, Avg loss: 1.594661

Epoch 13
-------------------------------
Training Error: 1.2323196626294142
Test Error:
 Accuracy: 59.3%, Avg loss: 1.043725

Epoch 14
-------------------------------
Training Error: 1.006187989386414
Test Error:
 Accuracy: 66.7%, Avg loss: 0.896688

Epoch 15
-------------------------------
Training Error: 0.8764733409068224
Test Error:
 Accuracy: 69.3%, Avg loss: 0.812288

Epoch 16
-------------------------------
Training Error: 0.7713316251664782
Test Error:
 Accuracy: 71.1%, Avg loss: 0.734932

Epoch 17
-------------------------------
Training Error: 0.6912997061255645
Test Error:
 Accuracy: 74.1%, Avg loss: 0.669929

Epoch 18
-------------------------------
Training Error: 0.6132034680673054
Test Error:
 Accuracy: 75.4%, Avg loss: 0.639850

Epoch 19
-------------------------------
Training Error: 0.5603975696858566
Test Error:
 Accuracy: 75.3%, Avg loss: 0.656856

Epoch 20
-------------------------------
Training Error: 0.5208614870333976
Test Error:
 Accuracy: 77.7%, Avg loss: 0.593537

Epoch 21
-------------------------------
Training Error: 0.48875936014311655
Test Error:
 Accuracy: 79.3%, Avg loss: 0.560252

Epoch 22
-------------------------------
Training Error: 0.46183210886172904
Test Error:
 Accuracy: 79.4%, Avg loss: 0.565827

Epoch 23
-------------------------------
Training Error: 0.4375772916876685
Test Error:
 Accuracy: 80.6%, Avg loss: 0.541223

Epoch 24
-------------------------------
Training Error: 0.41654134519509417
Test Error:
 Accuracy: 81.4%, Avg loss: 0.529492

Epoch 25
-------------------------------
Training Error: 0.3970522204124089
Test Error:
 Accuracy: 81.9%, Avg loss: 0.523817

Epoch 26
-------------------------------
Training Error: 0.378638335334848
Test Error:
 Accuracy: 82.8%, Avg loss: 0.502320

Epoch 27
-------------------------------
Training Error: 0.35991807061154196
Test Error:
 Accuracy: 83.5%, Avg loss: 0.485396

Epoch 28
-------------------------------
Training Error: 0.34300167448739255
Test Error:
 Accuracy: 83.9%, Avg loss: 0.479565

Epoch 29
-------------------------------
Training Error: 0.3347756714105352
Test Error:
 Accuracy: 84.5%, Avg loss: 0.460705

Epoch 30
-------------------------------
Training Error: 0.3120384652540882
Test Error:
 Accuracy: 84.9%, Avg loss: 0.449179

Epoch 31
-------------------------------
Training Error: 0.30019995798942634
Test Error:
 Accuracy: 85.2%, Avg loss: 0.447593

Epoch 32
-------------------------------
Training Error: 0.302767700954541
Test Error:
 Accuracy: 85.8%, Avg loss: 0.427524

Epoch 33
-------------------------------
Training Error: 0.2799437780544829
Test Error:
 Accuracy: 86.0%, Avg loss: 0.414747

Epoch 34
-------------------------------
Training Error: 0.267875908232574
Test Error:
 Accuracy: 86.2%, Avg loss: 0.417870

Epoch 35
-------------------------------
Training Error: 0.26175700130461377
Test Error:
 Accuracy: 86.5%, Avg loss: 0.408825

Epoch 36
-------------------------------
Training Error: 0.25549344935301527
Test Error:
 Accuracy: 86.1%, Avg loss: 0.420529

Epoch 37
-------------------------------
Training Error: 0.24757362339399389
Test Error:
 Accuracy: 86.4%, Avg loss: 0.420360

Epoch 38
-------------------------------
Training Error: 0.23615325956361127
Test Error:
 Accuracy: 86.2%, Avg loss: 0.423272

Epoch 39
-------------------------------
Training Error: 0.23080136443077248
Test Error:
 Accuracy: 86.9%, Avg loss: 0.411842

Epoch 40
-------------------------------
Training Error: 0.23271408964639534
Test Error:
 Accuracy: 86.1%, Avg loss: 0.430768

Done for Learning Rate! 0.01
```

```
[95]: # acc_add_layers, params_add_layers
average_acc_add_layers = sum(acc_add_layers[learning_rate_list[0]])/epochs
print(f'Accuracy for increased hidden Layers to {increased_layers } is␣
 ↪{average_acc_add_layers} with params {params_add_layers}')
plotTrainigTestCurve(train_add_layers[0.01], test_add_layers[0.01], 'Training␣
 ↪Loss', 'Testing Loss', f'Training and Testing Loss for adding layers to␣
 ↪{increased_layers}')
plotAccuracy(acc_add_layers[learning_rate_list[0]], 'Accuracy' , f'Accuracy for␣
 ↪adding layers {increased_layers}')
```

```
Accuracy for increased hidden Layers to 7 is 0.6125825 with params 2245642
```





Q1.5 (2 points) Choose to do one of the following two tasks:

b. Write done the process of how to calculate the parameters by hand.

For a fully connected network the number of trainable parameteres can be be comptuted by (n + 1) * m. Where n is the number of input units and m is the number of output units and + 1 term in the equation takes care of the bias term. The number of trainable parameters are computed for input, output and all the hidden layers. For example calcuating the number of trainable parameters in the base network provided in this notebook, which has one input layer, one hidden layer and one output layer

Parameteres in 1. Input Layer: Input layer has 28x28 input and 512 output units => (28 x 28 + 1) * 512 = (784 + 1) * 512 =401920 2. Hidden Layer: Hidden layer has 512 input and 512 output units => (512 + 1) * 512 = 262656 3. Output Layer: Output Layer has 512 input and 10 output units => (512 + 1) * 10 = 5130

Layer	params (n +1) * m
input layer	401920
first hidden layer	262656
ouptut layer	5130

Total Trainable Parameters : 669706

In a simillar way trainable parameters can be calculated for fully connected networks with more than one hidden layer. Parameters for each hidden layer is computed separately and summed together with the input and output layer.

Q1.6 (1 points) What are your observations and conclusions for changing network structure?

A network with enough nodes in the single hidden layer can learn to approximate any mapping function and increasing the depth increases the capacity of the model. Training deep models can be computationally more efficient than training a single layer network with a vast number of nodes

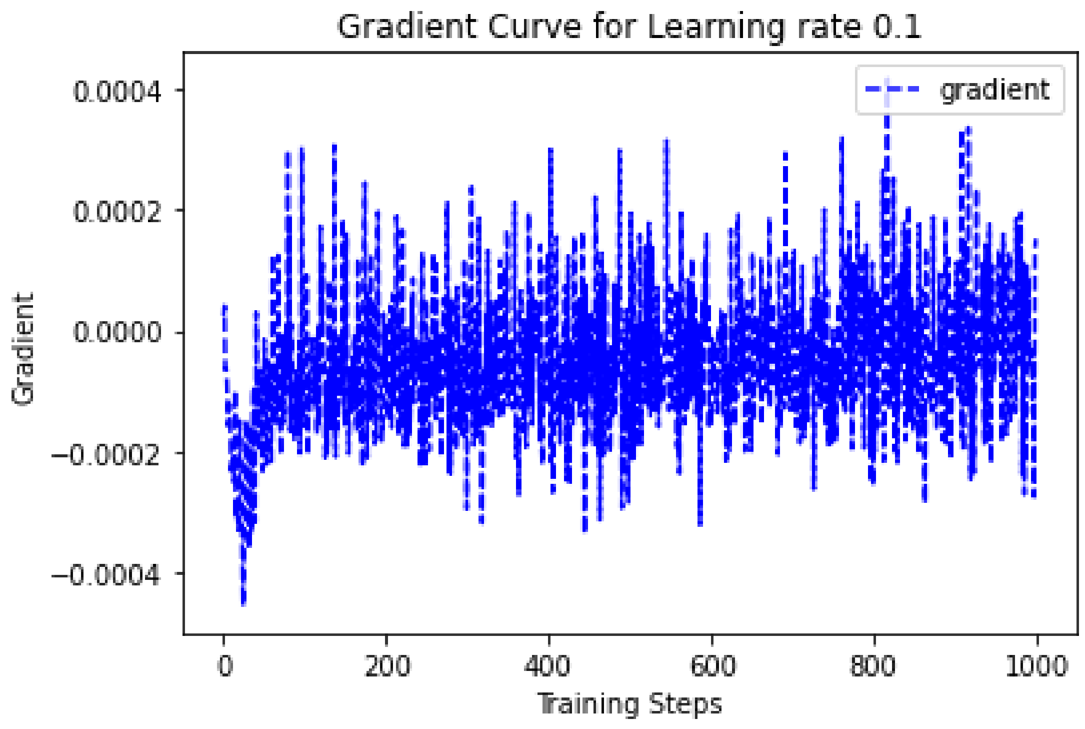
It can be seen from the experiments done in Q1.4 that as we increase the number of nodes and hidden layer the accuracy increases, this showcases that the base model is not able to understant the complete information presented in the dataset. It can be also seen from the training and testing loss curves that the models could still train for couple more epochs to get to the optimal solution. However, increasing the numbers of layers too much increases the complexity of the model which captures more details from the training data leading to overfitting as can be seen when increasing the number of hidden layers to 7.

On the contrary, as the nodes and layers are removed the prediction is comparable to the base network. This indicates that the network is still able to learn as much as the base network even with the a lower number of nodes or layers. This appears to underfit the dataset and therefore the width(nodes) and depth(layers) could be increased.

Q1.7 (2 points) Calculate the mean of the gradients of all trainable parameters. Plot the gradients curve for the first 1000 training steps. Please use lr = 0.1. What are your observations? Note that this gradients will be saved with the training parameters automatically after you call loss.backwards(). Hint: https://pytorch.org/tutorials/beginner/basics/autogradqs_tutorial.html

[80]:
```
def plotGradient(grad_list, title):
  plt.plot(grad_list, '--b')
  plt.rcParams["figure.figsize"] = (10,10)
  plt.title(title)
  plt.legend(['gradient'], loc='upper right')
  plt.xlabel('Training Steps')
  plt.ylabel('Gradient')
  plt.show()
  return
```

[81]:
```
gradient_list = train_grads[0.1][:1000]
plotGradient(gradient_list, 'Gradient Curve for Learning rate 0.1')
```

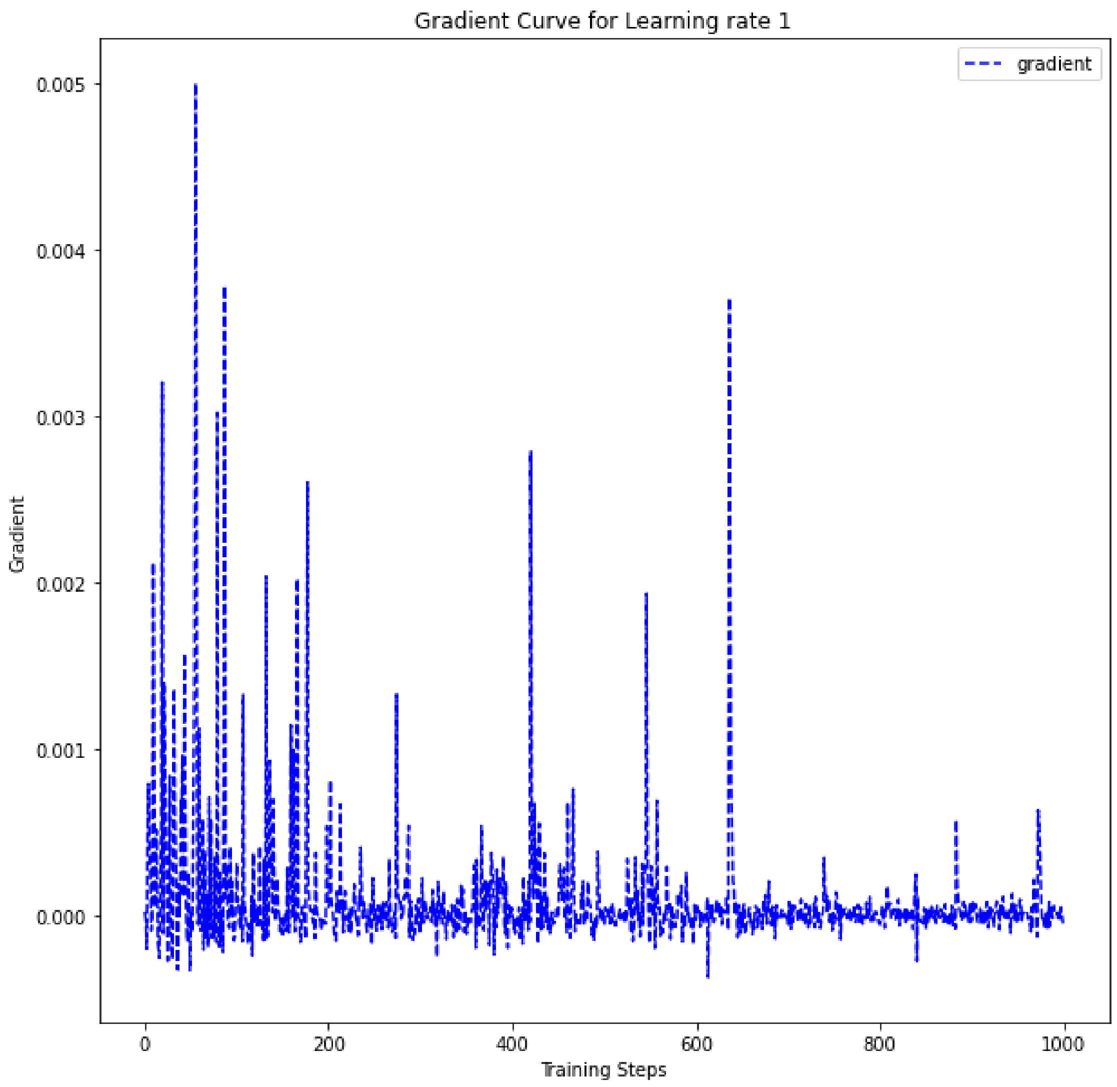


From the gradient curve it can be seen that the average gradient eventually decreases as the timestep increases. This indicates that the weights and bias values in the loss function are moving towards an optmial values. For comparison the gradient curve for learning rate 1 and 0.001 are showcased below.

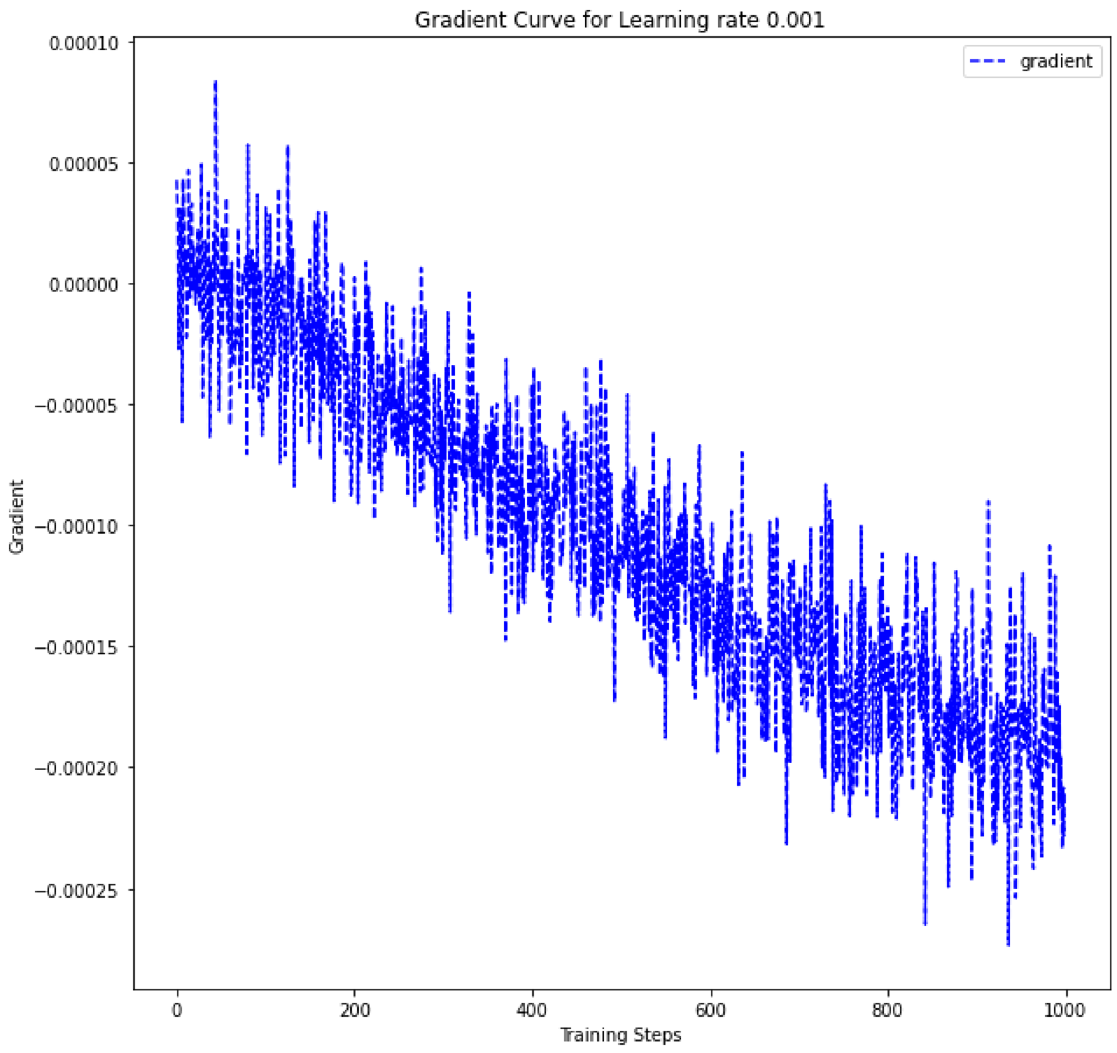
It can be seen that for learning rate 1 is too big as the average gradient shows sharp increase after certain invertals. This shows that the step size is too large and the step size is making the value of weight and bias jump around the minima.

For learning rate 0.001, it can be seen that the gradients are gradually decreasing but the rate is slower than the learning rate 0.1. This indicates that the step size 0.001 is too small and would take a longer time to converge.

[82]:
```
gradient_list_2 = train_grads[1][:1000]
plotGradient(gradient_list_2, 'Gradient Curve for Learning rate 1')
```



[83]:
```
gradient_list_3 = train_grads[0.001][:1000]
plotGradient(gradient_list_3, 'Gradient Curve for Learning rate 0.001')
```



3 Question 2: Presentation for Practical Applications (40%)

This is a group work. Each group needs to do a presentation at week 12. For each group, they will have around 15 minutes to present and 5 minutes to answer questions. Please submit your slides in myUni system.

Look for a typical computer vision problem, such as: a. removing noise on the image

b. increasing the resolution of the image

c. identifying objects in the image

d. segmenting the area to which the image belongs

e. estimating the depth of an object

f. estimating the motion of two object in different frames

g. generating colors for grey scale images

h. Others…

Discuss possible applications of this problem in life, e.g. image editing systems in your phone, improved quality of the old film, sweeping robot avoiding obstacles, unlocks the face of the mobile phone, identifies the cancer area according to the medical scan image, determines the identity according to the face, identifies the trash can on the road, and the detection system tracks the target object, etc.

Your presentation should include: 1. Introduction of this problem, e.g.,

```
The defination of the problem, the application of the problem and the research chanllenge of thi
```

2. Literature review

    a. Briefly describe a feasible solution from the literatures based on image processing and traditional machine learning algorithms.

    b. Briefly describe a feasible deep learning-based solution from the literatures.

3. Discussions

    Compare the advantages and disadvantages of the two options.

[ ]:

```

```