

# Prithvi\_Poddar\_17191\_Report\_1

June 22, 2020

## 1 Assignment 4

## 2 Prithvi Poddar 17191

### 2.1 Report: Neural Network

In this report, I'll be running a neural network based completely on numpy and inspired from <http://neuralnetworksanddeeplearning.com/index.html>

The codes can be found in the same directory as this python notebook is.

**P.S. Initially I'll be doing all the parameter tuning using train and test set splitting as this model converges quicker than Cross Validation. This will allow us to get better results in less number of epochs. Once we've decided our parameters, we'll finally use Cross validation to see if it gives better accuracy**

### 2.2 Part 1

#### 2.2.1 Importing the neural network module and the data loader

```
[1]: import matplotlib.pyplot as plt
import numpy as np
import network
import data_loader
%matplotlib inline
plt.rcParams['figure.figsize']=(20,10)
```

#### 2.2.2 Before starting, lets take a look at tunable parameters of this linear network model

weight\_initializer = 'default' or 'large'

cost = 'CrossEntropy' or 'Quadratic'

activation = 'sigmoid' or 'tanh' or 'relu'

size = [n1, n2, ...] {where n1=no. of neurons in first layer, n2=no. of neurons in second layer, and so on}

### 2.2.3 Parameters for training

training\_data, epochs, batch\_size, eta(learning rate), lambda(regularization factor), test\_data

### 2.2.4 Loading the training and testing data

We have total 3000 data entries. We'll be dividing it in 2500 for training and 500 for testing

```
[2]: training_data, testing_data = data_loader.load_full_data()
```

### 2.2.5 Now we call the neural network from the network.py file and start tuning our parameters

### 2.2.6 First, no hidden layer

Here we'll determine which cost function, activation function and weight initializer to use:

1. Choosing the weight initializer

'default' sets the weights randomly from gaussian distribution with mean 0 and standard deviation  $1/\sqrt{\text{number of training data}}$

'large' sets the weights randomly from gaussian distribution with mean 0 and standard deviation 1

```
[3]: net = network.Linear_Network([784,10], weight_initializer='default')
```

```
[4]: net.SGD(training_data, 30, 10, 0.5, lambda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 1.3272248517655656637

Training accuracy: 82.36%

Test accuracy: 76.4%

Epoch 2

Training loss: 0.71936398376920923024

Training accuracy: 90.88000000000001%

Test accuracy: 84.0%

Epoch 3

Training loss: 0.7287727998241616091

Training accuracy: 90.08%

Test accuracy: 81.6%

Epoch 4

Training loss: 0.8360652745009499089  
Training accuracy: 89.12%  
Test accuracy: 82.6%

Epoch 5  
Training loss: 0.6425745589650592904  
Training accuracy: 92.04%  
Test accuracy: 86.6%

Epoch 6  
Training loss: 0.6241366896945118083  
Training accuracy: 92.0%  
Test accuracy: 83.0%

Epoch 7  
Training loss: 0.59985113185178247337  
Training accuracy: 92.96%  
Test accuracy: 84.2%

Epoch 8  
Training loss: 0.68241411488689877727  
Training accuracy: 91.52%  
Test accuracy: 83.8%

Epoch 9  
Training loss: 0.6178573554240523534  
Training accuracy: 92.72%  
Test accuracy: 84.0%

Epoch 10  
Training loss: 0.76310250868291614135  
Training accuracy: 89.28%  
Test accuracy: 83.2%

Epoch 11  
Training loss: 0.625601111409811858  
Training accuracy: 91.60000000000001%  
Test accuracy: 84.0%

Epoch 12  
Training loss: 0.7855628262008626621  
Training accuracy: 87.88%  
Test accuracy: 82.8%

Epoch 13  
Training loss: 0.5769184174395629903  
Training accuracy: 93.56%  
Test accuracy: 85.0%

Epoch 14  
Training loss: 0.5563355127692802643  
Training accuracy: 93.67999999999999%  
Test accuracy: 85.39999999999999%

Epoch 15  
Training loss: 0.5379903095588351084  
Training accuracy: 93.2%  
Test accuracy: 87.0%

Epoch 16  
Training loss: 0.72949905138729781543  
Training accuracy: 90.64%  
Test accuracy: 83.2%

Epoch 17  
Training loss: 0.6482803319992067948  
Training accuracy: 91.64%  
Test accuracy: 83.2%

Epoch 18  
Training loss: 0.6061266507828651662  
Training accuracy: 92.67999999999999%  
Test accuracy: 85.8%

Epoch 19  
Training loss: 0.59069717762839155654  
Training accuracy: 92.4%  
Test accuracy: 85.2%

Epoch 20  
Training loss: 0.61283203722174617886  
Training accuracy: 92.2%  
Test accuracy: 84.39999999999999%

Epoch 21  
Training loss: 0.57973076543837441326  
Training accuracy: 93.56%  
Test accuracy: 85.6%

Epoch 22  
Training loss: 0.84151611942292329506  
Training accuracy: 88.36%  
Test accuracy: 81.8%

Epoch 23  
Training loss: 0.70880471330908518813

Training accuracy: 89.96%  
Test accuracy: 83.6%

Epoch 24  
Training loss: 0.5461793207742172807  
Training accuracy: 92.92%  
Test accuracy: 85.39999999999999%

Epoch 25  
Training loss: 0.5364074030537711383  
Training accuracy: 92.84%  
Test accuracy: 86.2%

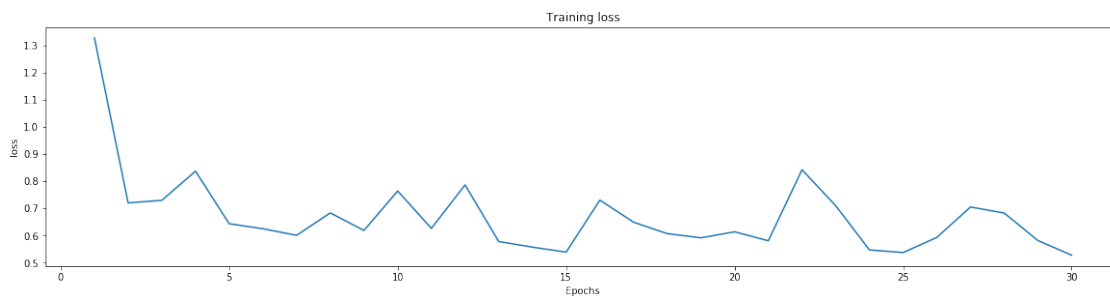
Epoch 26  
Training loss: 0.5921190950516245869  
Training accuracy: 92.47999999999999%  
Test accuracy: 85.0%

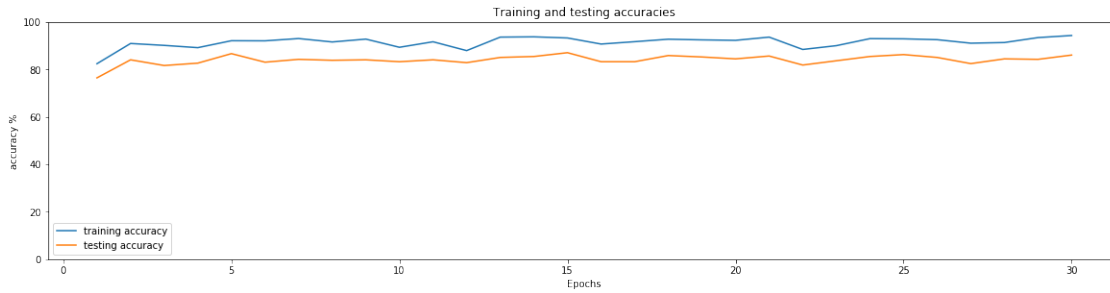
Epoch 27  
Training loss: 0.7042730509569844694  
Training accuracy: 91.0%  
Test accuracy: 82.39999999999999%

Epoch 28  
Training loss: 0.68189131938133071563  
Training accuracy: 91.28%  
Test accuracy: 84.39999999999999%

Epoch 29  
Training loss: 0.5808135480988476286  
Training accuracy: 93.36%  
Test accuracy: 84.2%

Epoch 30  
Training loss: 0.5267710394529381758  
Training accuracy: 94.24%  
Test accuracy: 86.0%





We get top training accuracy of 93% and test accuracy of 84%

Checking the large weight initializer

```
[5]: net = network.Linear_Network([784,10], weight_initializer='large')
```

```
[6]: net.SGD(training_data, 30, 10, 0.5, lambda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 1.4578713093857943548

Training accuracy: 83.56%

Test accuracy: 76.0%

Epoch 2

Training loss: 0.89294562377752571017

Training accuracy: 88.44%

Test accuracy: 81.2%

Epoch 3

Training loss: 0.6914466719289004403

Training accuracy: 90.72%

Test accuracy: 83.39999999999999%

Epoch 4

Training loss: 0.70416204213083758145

Training accuracy: 91.47999999999999%

Test accuracy: 82.0%

Epoch 5

Training loss: 0.6498968144804360314

Training accuracy: 91.32000000000001%

Test accuracy: 83.0%

Epoch 6

Training loss: 0.7011865655904408734

Training accuracy: 91.56%  
Test accuracy: 83.39999999999999%

Epoch 7  
Training loss: 0.70585561103012643816  
Training accuracy: 90.32%  
Test accuracy: 82.6%

Epoch 8  
Training loss: 0.7205639502113299712  
Training accuracy: 89.52%  
Test accuracy: 81.2%

Epoch 9  
Training loss: 0.601893005602259888  
Training accuracy: 92.92%  
Test accuracy: 84.6%

Epoch 10  
Training loss: 0.64886662271131890844  
Training accuracy: 91.4%  
Test accuracy: 83.8%

Epoch 11  
Training loss: 0.58694003587963932534  
Training accuracy: 92.24%  
Test accuracy: 84.8%

Epoch 12  
Training loss: 0.61938680469315643656  
Training accuracy: 92.12%  
Test accuracy: 84.0%

Epoch 13  
Training loss: 0.5812377080604218361  
Training accuracy: 92.47999999999999%  
Test accuracy: 84.2%

Epoch 14  
Training loss: 0.5568395041875347067  
Training accuracy: 93.16%  
Test accuracy: 87.0%

Epoch 15  
Training loss: 0.59555967628173598065  
Training accuracy: 93.04%  
Test accuracy: 84.8%

Epoch 16  
Training loss: 0.6654119533684015922  
Training accuracy: 91.52%  
Test accuracy: 82.0%

Epoch 17  
Training loss: 0.5900631852942883275  
Training accuracy: 92.88%  
Test accuracy: 85.2%

Epoch 18  
Training loss: 0.555863960001395426  
Training accuracy: 93.84%  
Test accuracy: 84.8%

Epoch 19  
Training loss: 0.57954733397477828925  
Training accuracy: 92.84%  
Test accuracy: 85.8%

Epoch 20  
Training loss: 0.59664816990770241906  
Training accuracy: 92.92%  
Test accuracy: 83.8%

Epoch 21  
Training loss: 0.61190289303504129405  
Training accuracy: 92.12%  
Test accuracy: 83.6%

Epoch 22  
Training loss: 0.7103513545524271277  
Training accuracy: 90.32%  
Test accuracy: 84.2%

Epoch 23  
Training loss: 0.61178790046544688855  
Training accuracy: 92.36%  
Test accuracy: 83.39999999999999%

Epoch 24  
Training loss: 0.60308399103683367525  
Training accuracy: 92.08%  
Test accuracy: 84.8%

Epoch 25  
Training loss: 0.5386263573189866411  
Training accuracy: 93.36%



Test accuracy: 84.0%

Epoch 26

Training loss: 0.601493377321824918

Training accuracy: 92.44%

Test accuracy: 83.6%

Epoch 27

Training loss: 0.5593667069569982776

Training accuracy: 92.96%

Test accuracy: 83.8%

Epoch 28

Training loss: 0.58097065791399862047

Training accuracy: 93.04%

Test accuracy: 86.6%

Epoch 29

Training loss: 0.63557041976418269966

Training accuracy: 91.2%

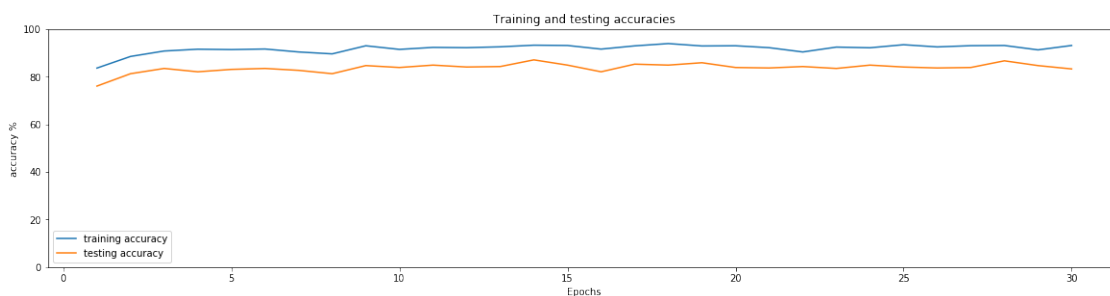
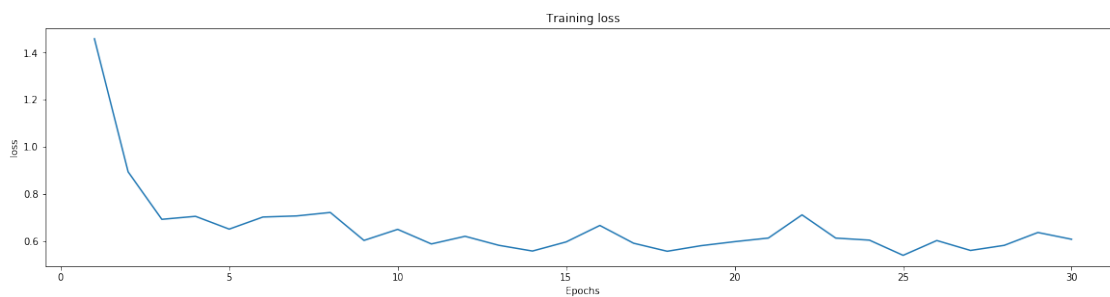
Test accuracy: 84.6%

Epoch 30

Training loss: 0.6067781788950730768

Training accuracy: 93.04%

Test accuracy: 83.2%



'large' weight initializer performs similar to the 'default' initializer with max test accuracy of 84% and training accuracy of 93%

**Hence we stick to 'default' weight initializer**

## 2. Choosing cost function

First we try out the 'Quadratic' cost

```
[7]: net = network.Linear_Network([784,10], weight_initializer='default',  
    ↪cost='Quadratic')
```

```
[8]: net.SGD(training_data, 30, 10, 0.5, lmbda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 0.14430774391452515734

Training accuracy: 87.12%

Test accuracy: 81.6%

Epoch 2

Training loss: 0.124346020914344430095

Training accuracy: 89.44%

Test accuracy: 83.2%

Epoch 3

Training loss: 0.115573315212080905765

Training accuracy: 89.96%

Test accuracy: 84.39999999999999%

Epoch 4

Training loss: 0.10971693140937655258

Training accuracy: 90.44%

Test accuracy: 84.39999999999999%

Epoch 5

Training loss: 0.10820816462001523951

Training accuracy: 90.4%

Test accuracy: 85.2%

Epoch 6

Training loss: 0.10918127544937454743

Training accuracy: 90.36%

Test accuracy: 84.2%

Epoch 7

Training loss: 0.10515369190497852874

Training accuracy: 91.24%  
Test accuracy: 85.39999999999999%

Epoch 8  
Training loss: 0.10510713413921377183  
Training accuracy: 91.12%  
Test accuracy: 84.8%

Epoch 9  
Training loss: 0.10571742606670785589  
Training accuracy: 90.8%  
Test accuracy: 85.39999999999999%

Epoch 10  
Training loss: 0.103638973411906549415  
Training accuracy: 91.28%  
Test accuracy: 86.0%

Epoch 11  
Training loss: 0.100888317744808204255  
Training accuracy: 92.08%  
Test accuracy: 84.39999999999999%

Epoch 12  
Training loss: 0.101918052915637961766  
Training accuracy: 91.0%  
Test accuracy: 84.8%

Epoch 13  
Training loss: 0.10527601839393982388  
Training accuracy: 90.84%  
Test accuracy: 84.8%

Epoch 14  
Training loss: 0.10327954535826308309  
Training accuracy: 91.72%  
Test accuracy: 85.39999999999999%

Epoch 15  
Training loss: 0.10295923682437099695  
Training accuracy: 91.60000000000001%  
Test accuracy: 84.2%

Epoch 16  
Training loss: 0.099238975557068284096  
Training accuracy: 91.60000000000001%  
Test accuracy: 85.6%

Epoch 17  
Training loss: 0.100934193076398050036  
Training accuracy: 91.64%  
Test accuracy: 84.2%

Epoch 18  
Training loss: 0.10092141939111313164  
Training accuracy: 91.64%  
Test accuracy: 84.2%

Epoch 19  
Training loss: 0.101285341750599067025  
Training accuracy: 91.72%  
Test accuracy: 86.0%

Epoch 20  
Training loss: 0.10120532614748231064  
Training accuracy: 91.28%  
Test accuracy: 85.0%

Epoch 21  
Training loss: 0.100735801236247800164  
Training accuracy: 91.56%  
Test accuracy: 85.39999999999999%

Epoch 22  
Training loss: 0.099846189579484215685  
Training accuracy: 91.08000000000001%  
Test accuracy: 85.6%

Epoch 23  
Training loss: 0.10024747364784468513  
Training accuracy: 91.4%  
Test accuracy: 85.39999999999999%

Epoch 24  
Training loss: 0.10022707787123517257  
Training accuracy: 91.92%  
Test accuracy: 85.0%

Epoch 25  
Training loss: 0.098565199902015944624  
Training accuracy: 91.88%  
Test accuracy: 85.39999999999999%

Epoch 26  
Training loss: 0.100775069707188423974  
Training accuracy: 91.60000000000001%

Test accuracy: 84.6%

Epoch 27

Training loss: 0.09849728591976504718

Training accuracy: 91.8%

Test accuracy: 85.6%

Epoch 28

Training loss: 0.102366198436458460494

Training accuracy: 91.4%

Test accuracy: 85.2%

Epoch 29

Training loss: 0.10038632306984616855

Training accuracy: 91.28%

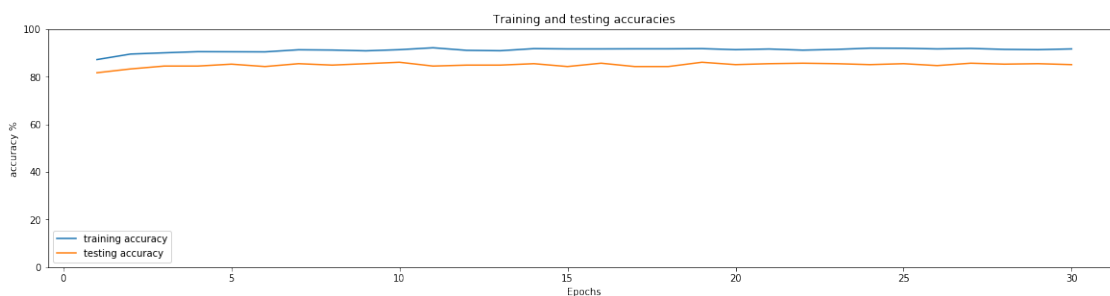
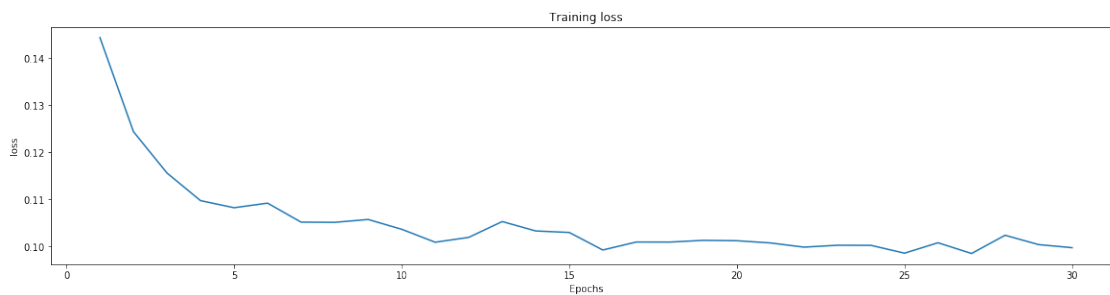
Test accuracy: 85.39999999999999%

Epoch 30

Training loss: 0.099725184937177996566

Training accuracy: 91.60000000000001%

Test accuracy: 85.0%



‘Quadratic’ cost gives training accuracy of 91% and test accuracy of 85%

Trying ‘CrossEntropy’

```
[9]: net = network.Linear_Network([784,10], weight_initializer='default',  
    ↪cost='CrossEntropy')
```

```
[10]: net.SGD(training_data, 30, 10, 0.5, lambda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 1.1400620321095680596

Training accuracy: 84.84%

Test accuracy: 78.8%

Epoch 2

Training loss: 1.1351648544076420024

Training accuracy: 81.72%

Test accuracy: 72.2%

Epoch 3

Training loss: 0.65034009401556294516

Training accuracy: 91.64%

Test accuracy: 85.0%

Epoch 4

Training loss: 0.7527512377906450604

Training accuracy: 90.32%

Test accuracy: 82.8%

Epoch 5

Training loss: 0.6661909609644937047

Training accuracy: 91.24%

Test accuracy: 84.2%

Epoch 6

Training loss: 0.63578586763901611236

Training accuracy: 92.60000000000001%

Test accuracy: 84.6%

Epoch 7

Training loss: 0.64226355571199650633

Training accuracy: 91.64%

Test accuracy: 81.39999999999999%

Epoch 8

Training loss: 0.5922074087873146851

Training accuracy: 92.56%

Test accuracy: 84.39999999999999%

Epoch 9

Training loss: 0.63043149207374716317

Training accuracy: 92.75999999999999%  
Test accuracy: 85.2%

Epoch 10  
Training loss: 0.8473234829533657159  
Training accuracy: 89.4%  
Test accuracy: 81.6%

Epoch 11  
Training loss: 0.60644628140989874333  
Training accuracy: 91.92%  
Test accuracy: 83.0%

Epoch 12  
Training loss: 1.0088905407902601304  
Training accuracy: 82.67999999999999%  
Test accuracy: 76.0%

Epoch 13  
Training loss: 0.54999673055911138666  
Training accuracy: 93.52000000000001%  
Test accuracy: 85.2%

Epoch 14  
Training loss: 0.5722264926432652073  
Training accuracy: 93.04%  
Test accuracy: 86.8%

Epoch 15  
Training loss: 0.65501607543581852203  
Training accuracy: 91.72%  
Test accuracy: 82.39999999999999%

Epoch 16  
Training loss: 0.5986362680342832776  
Training accuracy: 91.8%  
Test accuracy: 84.39999999999999%

Epoch 17  
Training loss: 0.5761357506820018151  
Training accuracy: 92.64%  
Test accuracy: 84.8%

Epoch 18  
Training loss: 0.56294678282739809406  
Training accuracy: 92.64%  
Test accuracy: 84.8%

Epoch 19  
Training loss: 0.7116680829999793707  
Training accuracy: 90.44%  
Test accuracy: 82.39999999999999%

Epoch 20  
Training loss: 0.61512079966337630707  
Training accuracy: 92.36%  
Test accuracy: 86.2%

Epoch 21  
Training loss: 0.8908456305872533953  
Training accuracy: 87.64%  
Test accuracy: 81.0%

Epoch 22  
Training loss: 0.5851243713355452483  
Training accuracy: 92.04%  
Test accuracy: 85.0%

Epoch 23  
Training loss: 0.55932565572145434823  
Training accuracy: 93.84%  
Test accuracy: 86.4%

Epoch 24  
Training loss: 0.73933033889102701497  
Training accuracy: 90.96%  
Test accuracy: 84.0%

Epoch 25  
Training loss: 0.5862781926799022349  
Training accuracy: 93.24%  
Test accuracy: 84.0%

Epoch 26  
Training loss: 0.63679211979251014507  
Training accuracy: 92.04%  
Test accuracy: 83.8%

Epoch 27  
Training loss: 0.5848565171300773471  
Training accuracy: 93.24%  
Test accuracy: 85.39999999999999%

Epoch 28  
Training loss: 0.5411677063095106016  
Training accuracy: 93.72%



Test accuracy: 86.0%

Epoch 29

Training loss: 0.7150090699505372132

Training accuracy: 89.52%

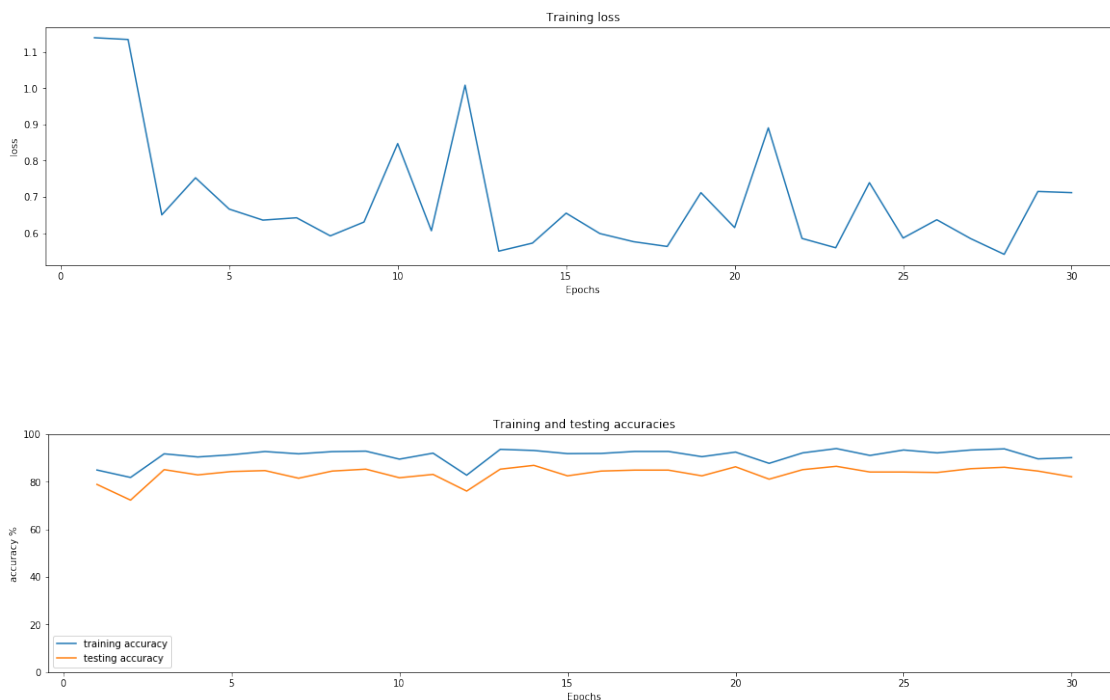
Test accuracy: 84.39999999999999%

Epoch 30

Training loss: 0.7116959135353462823

Training accuracy: 90.03999999999999%

Test accuracy: 82.0%



We see that 'CrossEntropy' gives a slightly better performance of 93% training and 85% testing accuracy.

But we notice from the loss graph that the drop in loss for Quadratic is much smoother than for CrossEntropy.

For now we'll stick to CrossEntropy and hope that the loss graph for the CrossEntropy function will smoothen out as we do further parameter tuning. If not then we'll visit this again and do another comparison between these two after the parameters have been set.

### 3. Choosing activation function

First we try 'sigmoid'

```
[11]: net = network.Linear_Network([784,10], weight_initializer='default',  
    ↪cost='Quadratic',  
        activation = 'sigmoid')
```

```
[12]: net.SGD(training_data, 30, 10, 0.5, lambda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 0.14122971164088507967

Training accuracy: 87.56%

Test accuracy: 81.6%

Epoch 2

Training loss: 0.12183825604439538239

Training accuracy: 89.88000000000001%

Test accuracy: 82.6%

Epoch 3

Training loss: 0.11069726174276199918

Training accuracy: 90.64%

Test accuracy: 84.6%

Epoch 4

Training loss: 0.111057099726467961

Training accuracy: 90.72%

Test accuracy: 84.0%

Epoch 5

Training loss: 0.10838269080122015666

Training accuracy: 90.32%

Test accuracy: 83.2%

Epoch 6

Training loss: 0.11343002714292998762

Training accuracy: 89.84%

Test accuracy: 83.6%

Epoch 7

Training loss: 0.105037625832915775505

Training accuracy: 91.24%

Test accuracy: 84.8%

Epoch 8

Training loss: 0.103404341202121716296

Training accuracy: 91.96%

Test accuracy: 84.8%

Epoch 9

Training loss: 0.10419560153325619538  
Training accuracy: 91.16%  
Test accuracy: 83.8%

Epoch 10  
Training loss: 0.10144401874467356361  
Training accuracy: 91.8%  
Test accuracy: 84.6%

Epoch 11  
Training loss: 0.102604120742263210374  
Training accuracy: 91.16%  
Test accuracy: 85.2%

Epoch 12  
Training loss: 0.102964981346572091526  
Training accuracy: 90.84%  
Test accuracy: 85.8%

Epoch 13  
Training loss: 0.1066126987253369264  
Training accuracy: 90.96%  
Test accuracy: 85.0%

Epoch 14  
Training loss: 0.10742839994708550137  
Training accuracy: 91.2%  
Test accuracy: 83.39999999999999%

Epoch 15  
Training loss: 0.101078667480840834095  
Training accuracy: 91.36%  
Test accuracy: 85.0%

Epoch 16  
Training loss: 0.10167868850154676023  
Training accuracy: 91.72%  
Test accuracy: 85.0%

Epoch 17  
Training loss: 0.10119786940045463477  
Training accuracy: 91.84%  
Test accuracy: 85.0%

Epoch 18  
Training loss: 0.10217698647409774651  
Training accuracy: 91.16%  
Test accuracy: 85.39999999999999%

Epoch 19  
Training loss: 0.10139874662149048952  
Training accuracy: 91.0%  
Test accuracy: 84.2%

Epoch 20  
Training loss: 0.0987169394456307345  
Training accuracy: 91.8%  
Test accuracy: 84.8%

Epoch 21  
Training loss: 0.103417567356149265744  
Training accuracy: 91.36%  
Test accuracy: 85.0%

Epoch 22  
Training loss: 0.1077361743222739469  
Training accuracy: 91.4%  
Test accuracy: 83.8%

Epoch 23  
Training loss: 0.098269939442113426556  
Training accuracy: 91.96%  
Test accuracy: 85.39999999999999%

Epoch 24  
Training loss: 0.10101376421813314317  
Training accuracy: 91.4%  
Test accuracy: 84.0%

Epoch 25  
Training loss: 0.10143763757343051315  
Training accuracy: 91.92%  
Test accuracy: 85.0%

Epoch 26  
Training loss: 0.09920781098870465662  
Training accuracy: 92.0%  
Test accuracy: 85.0%

Epoch 27  
Training loss: 0.101642044614305744825  
Training accuracy: 91.47999999999999%  
Test accuracy: 85.0%

Epoch 28  
Training loss: 0.102940995343994103054

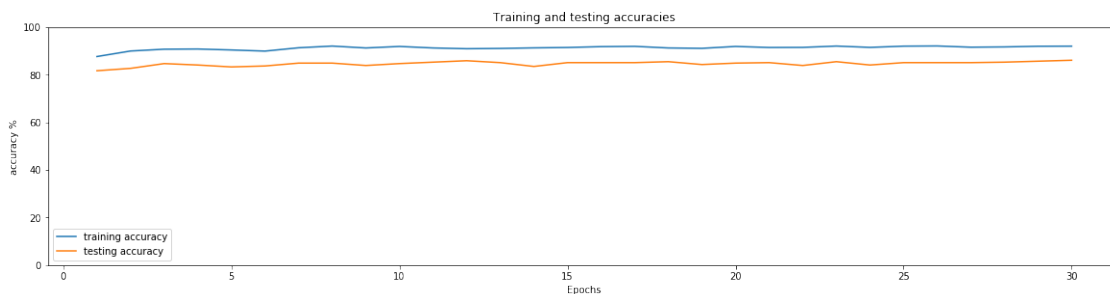
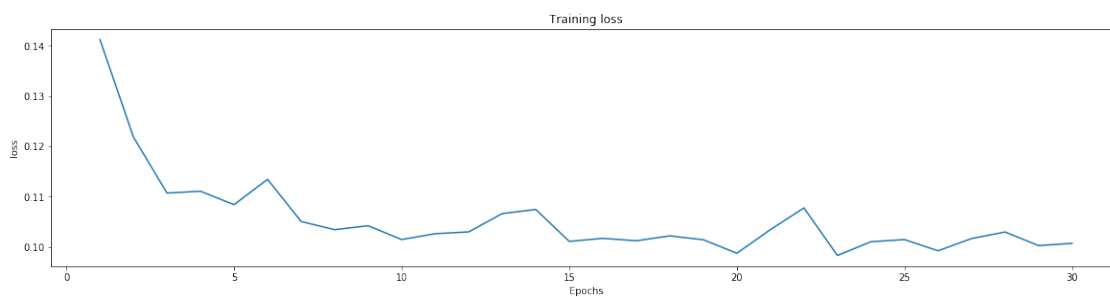
Training accuracy: 91.60000000000001%  
Test accuracy: 85.2%

Epoch 29

Training loss: 0.10024126340416166763  
Training accuracy: 91.88%  
Test accuracy: 85.6%

Epoch 30

Training loss: 0.1006897247175448399  
Training accuracy: 91.92%  
Test accuracy: 86.0%



Next we try 'tanh'

```
[13]: net = network.Linear_Network([784,10], weight_initializer='default',  
    ↪ cost='Quadratic',  
        activation = 'tanh')
```

```
[14]: net.SGD(training_data, 30, 10, 0.5, lambda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 3.2303686435523601016  
Training accuracy: 23.76%

Test accuracy: 25.8%

Epoch 2

Training loss: 2.8391497719870323316

Training accuracy: 51.519999999999996%

Test accuracy: 47.199999999999996%

Epoch 3

Training loss: 3.0352400608258571068

Training accuracy: 52.72%

Test accuracy: 54.6%

Epoch 4

Training loss: 2.935100450170637811

Training accuracy: 18.2%

Test accuracy: 18.6%

Epoch 5

Training loss: 3.1471953116887459011

Training accuracy: 37.6%

Test accuracy: 35.0%

Epoch 6

Training loss: 3.0969188531546436255

Training accuracy: 16.16%

Test accuracy: 16.2%

Epoch 7

Training loss: 2.8658553208136144576

Training accuracy: 45.4%

Test accuracy: 44.4%

Epoch 8

Training loss: 2.9958681236315074536

Training accuracy: 56.56%

Test accuracy: 53.2%

Epoch 9

Training loss: 2.8750594990381577432

Training accuracy: 40.64%

Test accuracy: 39.4%

Epoch 10

Training loss: 2.821630697405130503

Training accuracy: 54.120000000000005%

Test accuracy: 49.2%

Epoch 11

Training loss: 2.6034395529350308773  
Training accuracy: 61.040000000000006%  
Test accuracy: 56.00000000000001%

Epoch 12  
Training loss: 2.6777453698931522534  
Training accuracy: 58.32000000000001%  
Test accuracy: 54.6%

Epoch 13  
Training loss: 2.6481718717010123277  
Training accuracy: 57.24%  
Test accuracy: 55.2%

Epoch 14  
Training loss: 2.7441753971279190145  
Training accuracy: 22.6%  
Test accuracy: 22.2%

Epoch 15  
Training loss: 2.7118954620663923759  
Training accuracy: 39.36%  
Test accuracy: 34.0%

Epoch 16  
Training loss: 2.8885067015254884827  
Training accuracy: 24.279999999999998%  
Test accuracy: 23.599999999999998%

Epoch 17  
Training loss: 3.2009306612989373016  
Training accuracy: 40.48%  
Test accuracy: 41.0%

Epoch 18  
Training loss: 2.8446437104100511053  
Training accuracy: 50.239999999999995%  
Test accuracy: 46.0%

Epoch 19  
Training loss: 3.065784714651874284  
Training accuracy: 53.44%  
Test accuracy: 49.8%

Epoch 20  
Training loss: 2.762009200160105247  
Training accuracy: 51.2%  
Test accuracy: 46.2%

Epoch 21  
Training loss: 2.9784520175320587086  
Training accuracy: 51.04%  
Test accuracy: 48.0%

Epoch 22  
Training loss: 2.6870582312597372815  
Training accuracy: 52.32%  
Test accuracy: 43.4%

Epoch 23  
Training loss: 3.1708376953627454556  
Training accuracy: 44.84%  
Test accuracy: 39.4%

Epoch 24  
Training loss: 2.836906156888301584  
Training accuracy: 41.32%  
Test accuracy: 37.4%

Epoch 25  
Training loss: 3.015421873947301406  
Training accuracy: 41.199999999999996%  
Test accuracy: 38.4%

Epoch 26  
Training loss: 3.1471990475947490733  
Training accuracy: 31.319999999999997%  
Test accuracy: 28.799999999999997%

Epoch 27  
Training loss: 3.3073441086690658689  
Training accuracy: 51.6%  
Test accuracy: 45.2%

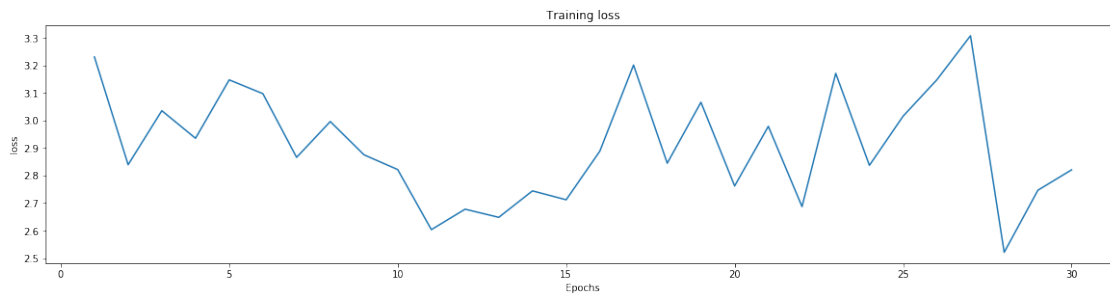
Epoch 28  
Training loss: 2.521124851750993633  
Training accuracy: 68.24%  
Test accuracy: 66.2%

Epoch 29  
Training loss: 2.7465482805800106004  
Training accuracy: 47.0%  
Test accuracy: 45.0%

Epoch 30  
Training loss: 2.8205753850486988596



Training accuracy: 57.04%  
Test accuracy: 53.800000000000004%



Next is 'relu'

```
[15]: net = network.Linear_Network([784,10], weight_initializer='default',  
    ↪cost='Quadratic',  
        activation = 'relu')
```

```
[16]: net.SGD(training_data, 30, 10, 0.5, lambda = 5.0, test_data=testing_data)
```

Epoch 1  
Training loss: 0.4998753750037329  
Training accuracy: 10.16%  
Test accuracy: 11.600000000000001%

Epoch 2  
Training loss: 0.5  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 3  
Training loss: 0.5  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 4  
Training loss: 0.49998475007594734  
Training accuracy: 10.280000000000001%  
Test accuracy: 11.600000000000001%

Epoch 5  
Training loss: 0.4999076350386032  
Training accuracy: 10.16%  
Test accuracy: 11.600000000000001%

Epoch 6  
Training loss: 0.4995488523378649  
Training accuracy: 10.24%  
Test accuracy: 11.600000000000001%

Epoch 7  
Training loss: 0.5000017563420155  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 8  
Training loss: 0.49999794468983255  
Training accuracy: 10.12%  
Test accuracy: 11.799999999999999%

Epoch 9  
Training loss: 0.500003075029748  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 10  
Training loss: 0.4995272756174767  
Training accuracy: 10.36%  
Test accuracy: 11.600000000000001%

Epoch 11  
Training loss: 0.4994626165659598  
Training accuracy: 10.4%  
Test accuracy: 11.600000000000001%

Epoch 12  
Training loss: 0.5000008708440793  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 13  
Training loss: 0.5000001957784715

Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 14  
Training loss: 0.5000006908692093  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 15  
Training loss: 0.5000002145128356  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 16  
Training loss: 0.5000022365878521  
Training accuracy: 10.08%  
Test accuracy: 11.600000000000001%

Epoch 17  
Training loss: 0.4996294796616622  
Training accuracy: 10.36%  
Test accuracy: 11.799999999999999%

Epoch 18  
Training loss: 0.49972734299694477  
Training accuracy: 10.2%  
Test accuracy: 11.600000000000001%

Epoch 19  
Training loss: 0.49960776562871306  
Training accuracy: 10.16%  
Test accuracy: 11.600000000000001%

Epoch 20  
Training loss: 0.4996009639194086  
Training accuracy: 10.2%  
Test accuracy: 11.600000000000001%

Epoch 21  
Training loss: 0.4987192194041874  
Training accuracy: 10.639999999999999%  
Test accuracy: 11.799999999999999%

Epoch 22  
Training loss: 0.5000006661991736  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 23  
Training loss: 0.5000005869100168  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 24  
Training loss: 0.49740447488982736  
Training accuracy: 10.92%  
Test accuracy: 12.4%

Epoch 25  
Training loss: 0.5000008572344935  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

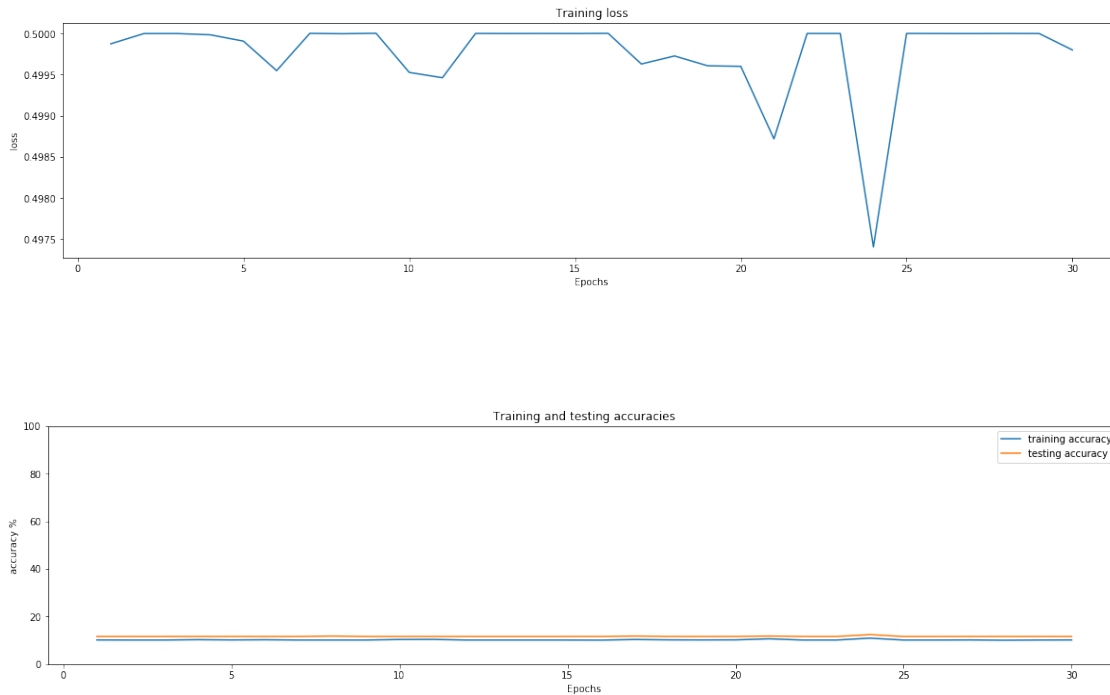
Epoch 26  
Training loss: 0.5000002644267925  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 27  
Training loss: 0.4999995713251814  
Training accuracy: 10.16%  
Test accuracy: 11.600000000000001%

Epoch 28  
Training loss: 0.5000008954464134  
Training accuracy: 10.040000000000001%  
Test accuracy: 11.600000000000001%

Epoch 29  
Training loss: 0.500000089223235  
Training accuracy: 10.12%  
Test accuracy: 11.600000000000001%

Epoch 30  
Training loss: 0.49980072677276055  
Training accuracy: 10.16%  
Test accuracy: 11.600000000000001%



Hence we can clearly see that 'sigmoid' is the best option we have

Since our initial parameters are set, we can move on to the number of layers and the stochastic gradient parameter tuning. I have already set the above parameters as default for our network so that we don't have to call them again and again

### 2.2.7 Now we decide the number of neurons and the number of hidden layers

1. 1 hidden layer. Testing for 15 to 50 neurons:

```
[22]: n = [15,20,25,30,35,40,45,50]
train_accuracies=[]
test_accuracies=[]
for neurons in n:
    net = network.Linear_Network([784, neurons, 10])
    tr_a, te_a = net.SGD(training_data, 30, 10, 0.5, lambda = 5.0,
    ↪test_data=testing_data,
        show_eval=False, show_graph=False, return_accuracies=True)
    train_accuracies.append(tr_a)
    test_accuracies.append(te_a)
    print(str(neurons)+" neurons:")
    print("Training acc.: "+str(tr_a)+"% Testing acc.: "+str(te_a)+"%")
    print()
```

```
plt.subplot(2, 1, 1)
plt.plot(n, train_accuracies, label='training accuracy')
plt.plot(n, test_accuracies, label='test accuracy')
plt.legend()
plt.title("Training and testing accuracies")
plt.xlabel("neurons")
plt.ylabel("accuracy %")
plt.ylim(0, 100)
plt.show()
```

15 neurons:

Training acc.: 94.096% Testing acc.: 85.83999999999999%

20 neurons:

Training acc.: 94.576% Testing acc.: 86.32%

25 neurons:

Training acc.: 95.47200000000001% Testing acc.: 87.16%

30 neurons:

Training acc.: 95.26400000000001% Testing acc.: 86.32%

35 neurons:

Training acc.: 95.58399999999999% Testing acc.: 87.16%

40 neurons:

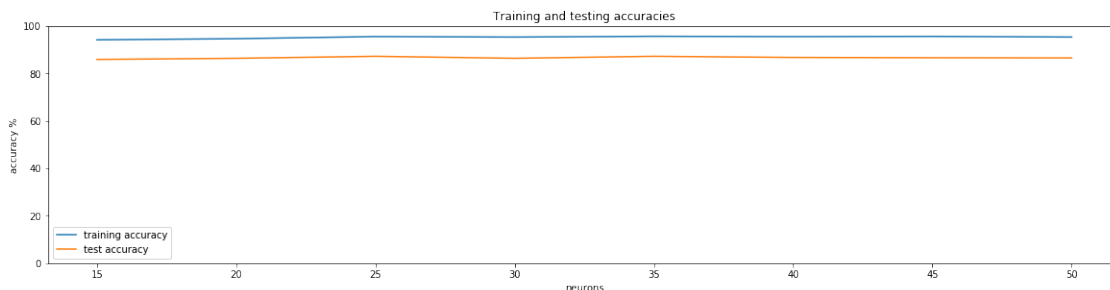
Training acc.: 95.44800000000001% Testing acc.: 86.68%

45 neurons:

Training acc.: 95.55199999999999% Testing acc.: 86.56%

50 neurons:

Training acc.: 95.27199999999999% Testing acc.: 86.47999999999999%



The result is pretty uniform. So lets stick to 35 neurons in the first layer.

Now we test the second hidden layer

```
[23]: n = [15,20,25,30]
train_accuracies=[]
test_accuracies=[]
for neurons in n:
    net = network.Linear_Network([784, 35, neurons, 10])
    tr_a, te_a = net.SGD(training_data, 30, 10, 0.5, lambda = 5.0,
    ↪test_data=testing_data,
        show_eval=False, show_graph=False, return_accuracies=True)
    train_accuracies.append(tr_a)
    test_accuracies.append(te_a)
    print(str(neurons)+" neurons:")
    print("Training acc.: "+str(tr_a)+"% Testing acc.: "+str(te_a)+"%")
    print()

plt.subplot(2, 1, 1)
plt.plot(n, train_accuracies, label='training accuracy')
plt.plot(n, test_accuracies, label='test accuracy')
plt.legend()
plt.title("Training and testing accuracies")
plt.xlabel("neurons")
plt.ylabel("accuracy %")
plt.ylim(0, 100)
plt.show()
```

15 neurons:

Training acc.: 95.84% Testing acc.: 87.44000000000001%

20 neurons:

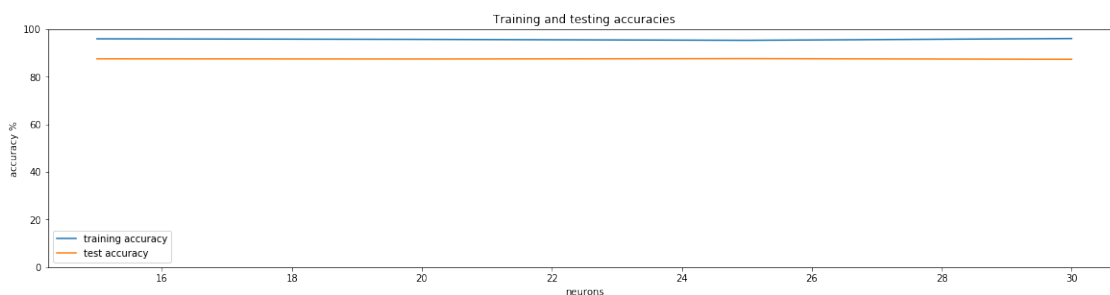
Training acc.: 95.6% Testing acc.: 87.36000000000001%

25 neurons:

Training acc.: 95.208% Testing acc.: 87.52000000000001%

30 neurons:

Training acc.: 95.96000000000001% Testing acc.: 87.24000000000001%



Here we stick to 25 neurons in 2nd layer

### Testing for 3rd hidden layer

```
[26]: n = [15,20]
train_accuracies=[]
test_accuracies=[]
for neurons in n:
    net = network.Linear_Network([784, 35, 25, neurons, 10])
    tr_a, te_a = net.SGD(training_data, 30, 10, 0.5, lambda = 5.0,
    ↪test_data=testing_data,
        show_eval=False, show_graph=False, return_accuracies=True)
    train_accuracies.append(tr_a)
    test_accuracies.append(te_a)
    print(str(neurons)+" neurons:")
    print("Training acc.: "+str(tr_a)+"% Testing acc.: "+str(te_a)+"%")
    print()

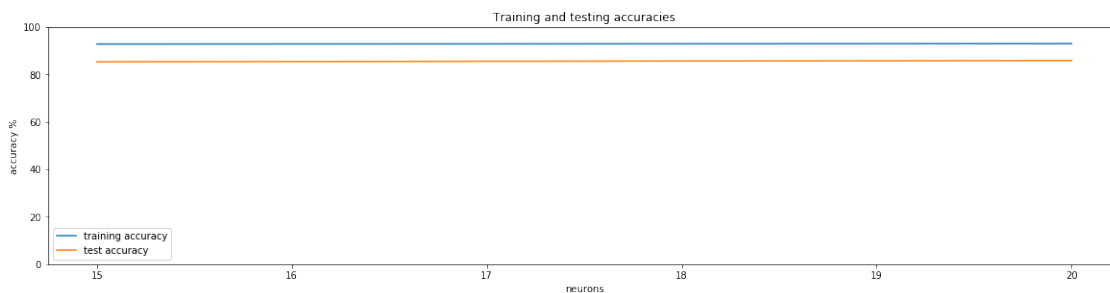
plt.subplot(2, 1, 1)
plt.plot(n, train_accuracies, label='training accuracy')
plt.plot(n, test_accuracies, label='test accuracy')
plt.legend()
plt.title("Training and testing accuracies")
plt.xlabel("neurons")
plt.ylabel("accuracy %")
plt.ylim(0, 100)
plt.show()
```

15 neurons:

Training acc.: 92.744% Testing acc.: 85.28%

20 neurons:

Training acc.: 92.92% Testing acc.: 85.8%





With a decrease in accuracies, we finally stick to 2 hidden layers.

First hidden layer has 35 neurons and second hidden layer has 25 neurons

**Checking the learning rate now. We increase the number of epochs and reduce the learning rate to see where the accuracies saturate** Initially we try 50 epochs with eta=0.1

```
[27]: net = network.Linear_Network([784, 35, 25, 10])
      net.SGD(training_data, 50, 10, 0.1, lambda = 5.0, test_data=testing_data)
```

Epoch 1

Training loss: 3.2032931311622133827

Training accuracy: 13.600000000000001%

Test accuracy: 13.8%

Epoch 2

Training loss: 2.979357053247336601

Training accuracy: 41.88%

Test accuracy: 43.8%

Epoch 3

Training loss: 2.3166261117557005891

Training accuracy: 64.96%

Test accuracy: 59.199999999999996%

Epoch 4

Training loss: 1.9229003357879172885

Training accuracy: 71.16%

Test accuracy: 65.4%

Epoch 5

Training loss: 1.6672206102524891513

Training accuracy: 72.64%

Test accuracy: 67.80000000000001%

Epoch 6

Training loss: 1.4578467746512805906

Training accuracy: 80.64%

Test accuracy: 78.4%

Epoch 7

Training loss: 1.3022954671634116282

Training accuracy: 79.03999999999999%

Test accuracy: 75.8%

Epoch 8

Training loss: 1.1923338158331425587

Training accuracy: 84.2%

Test accuracy: 81.39999999999999%

Epoch 9

Training loss: 1.104272894144313197

Training accuracy: 83.96000000000001%

Test accuracy: 79.2%

Epoch 10

Training loss: 1.0260431540807957934

Training accuracy: 88.2%

Test accuracy: 84.8%

Epoch 11

Training loss: 0.9518740348069485484

Training accuracy: 89.4%

Test accuracy: 85.6%

Epoch 12

Training loss: 0.9026574478291545418

Training accuracy: 89.36%

Test accuracy: 84.8%

Epoch 13

Training loss: 0.8368121554262523727

Training accuracy: 90.36%

Test accuracy: 85.8%

Epoch 14

Training loss: 0.8015666519443689536

Training accuracy: 90.56%

Test accuracy: 86.2%

Epoch 15

Training loss: 0.74793894548781152023

Training accuracy: 91.64%

Test accuracy: 86.8%

Epoch 16

Training loss: 0.7202715751531060989

Training accuracy: 92.32000000000001%

Test accuracy: 87.0%

Epoch 17

Training loss: 0.6819053678877821798

Training accuracy: 92.60000000000001%

Test accuracy: 87.8%

Epoch 18

Training loss: 0.6675191944689199315  
Training accuracy: 93.04%  
Test accuracy: 86.6%

Epoch 19  
Training loss: 0.6438959099241531791  
Training accuracy: 93.04%  
Test accuracy: 85.2%

Epoch 20  
Training loss: 0.6301744153544253214  
Training accuracy: 93.36%  
Test accuracy: 85.39999999999999%

Epoch 21  
Training loss: 0.6082534277698551203  
Training accuracy: 93.4%  
Test accuracy: 87.6%

Epoch 22  
Training loss: 0.5855477356087875859  
Training accuracy: 93.64%  
Test accuracy: 87.6%

Epoch 23  
Training loss: 0.58102895297055570987  
Training accuracy: 94.08%  
Test accuracy: 86.4%

Epoch 24  
Training loss: 0.56245226340447469743  
Training accuracy: 94.0%  
Test accuracy: 87.6%

Epoch 25  
Training loss: 0.5477023301539234164  
Training accuracy: 94.6%  
Test accuracy: 88.0%

Epoch 26  
Training loss: 0.54806605583476812615  
Training accuracy: 94.28%  
Test accuracy: 87.6%

Epoch 27  
Training loss: 0.53581361380082646775  
Training accuracy: 94.6%  
Test accuracy: 86.8%

Epoch 28  
Training loss: 0.52250660036221330485  
Training accuracy: 94.84%  
Test accuracy: 87.6%

Epoch 29  
Training loss: 0.5322095325667175552  
Training accuracy: 95.04%  
Test accuracy: 87.4%

Epoch 30  
Training loss: 0.5401955676587451312  
Training accuracy: 94.12%  
Test accuracy: 87.8%

Epoch 31  
Training loss: 0.50370827997148981316  
Training accuracy: 95.04%  
Test accuracy: 87.8%

Epoch 32  
Training loss: 0.5024204703821459328  
Training accuracy: 95.44%  
Test accuracy: 87.6%

Epoch 33  
Training loss: 0.48950475770784996677  
Training accuracy: 95.24000000000001%  
Test accuracy: 87.6%

Epoch 34  
Training loss: 0.49309646067488661992  
Training accuracy: 95.6%  
Test accuracy: 88.0%

Epoch 35  
Training loss: 0.4854083650874701685  
Training accuracy: 95.44%  
Test accuracy: 88.4%

Epoch 36  
Training loss: 0.48967493190505669443  
Training accuracy: 95.39999999999999%  
Test accuracy: 87.6%

Epoch 37  
Training loss: 0.47158326383664636035

Training accuracy: 95.96000000000001%  
Test accuracy: 88.2%

Epoch 38  
Training loss: 0.47664284314299774835  
Training accuracy: 95.84%  
Test accuracy: 87.0%

Epoch 39  
Training loss: 0.470897145197710012  
Training accuracy: 95.8%  
Test accuracy: 87.8%

Epoch 40  
Training loss: 0.48417765487660274814  
Training accuracy: 95.08%  
Test accuracy: 87.8%

Epoch 41  
Training loss: 0.46822515180435101073  
Training accuracy: 96.08%  
Test accuracy: 88.0%

Epoch 42  
Training loss: 0.4570609948228599176  
Training accuracy: 96.32%  
Test accuracy: 87.0%

Epoch 43  
Training loss: 0.44977651379688632152  
Training accuracy: 96.39999999999999%  
Test accuracy: 88.4%

Epoch 44  
Training loss: 0.45223173702288123118  
Training accuracy: 95.76%  
Test accuracy: 87.8%

Epoch 45  
Training loss: 0.45139669997598413754  
Training accuracy: 95.96000000000001%  
Test accuracy: 88.8%

Epoch 46  
Training loss: 0.45710616916202450057  
Training accuracy: 96.36%  
Test accuracy: 87.8%

Epoch 47

Training loss: 0.44614847732084361088

Training accuracy: 96.0%

Test accuracy: 87.8%

Epoch 48

Training loss: 0.44101348263886575344

Training accuracy: 96.39999999999999%

Test accuracy: 87.4%

Epoch 49

Training loss: 0.44976422677027937648

Training accuracy: 96.2%

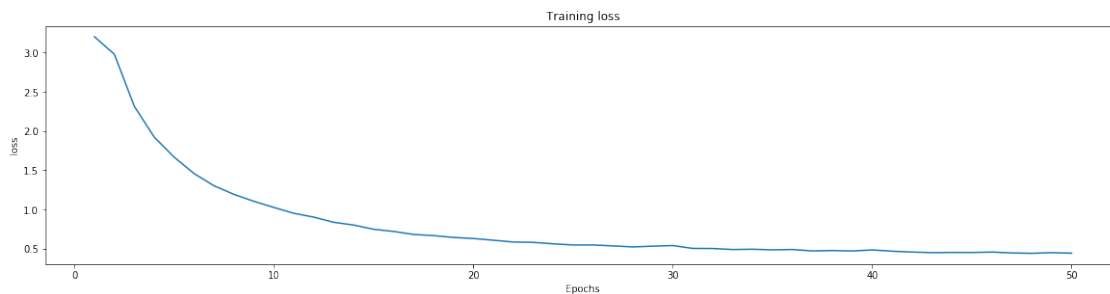
Test accuracy: 88.6%

Epoch 50

Training loss: 0.44304126623144652935

Training accuracy: 96.32%

Test accuracy: 88.6%



Trying eta=0.01 for 100 epochs

```
[28]: net = network.Linear_Network([784, 35, 25, 10])  
net.SGD(training_data, 100, 10, 0.01, lambda = 5.0, test_data=testing_data)
```

Epoch 1  
Training loss: 3.2460821917901008164  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 2  
Training loss: 3.239028594460498077  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 3  
Training loss: 3.235895415070075321  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 4  
Training loss: 3.232279988576710235  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 5  
Training loss: 3.2280075513184290456  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 6  
Training loss: 3.2248574488085505977  
Training accuracy: 11.200000000000001%  
Test accuracy: 8.799999999999999%

Epoch 7  
Training loss: 3.219469202006140357  
Training accuracy: 19.28%  
Test accuracy: 16.400000000000002%

Epoch 8  
Training loss: 3.2135988254186800164  
Training accuracy: 20.44%  
Test accuracy: 18.0%

Epoch 9  
Training loss: 3.20811834918552255  
Training accuracy: 19.88%  
Test accuracy: 21.4%

Epoch 10  
Training loss: 3.2010051766086239586  
Training accuracy: 12.0%

Test accuracy: 12.6%

Epoch 11

Training loss: 3.1922122905115274695

Training accuracy: 16.08%

Test accuracy: 14.799999999999999%

Epoch 12

Training loss: 3.1828051604763835975

Training accuracy: 22.0%

Test accuracy: 22.8%

Epoch 13

Training loss: 3.171549337209243616

Training accuracy: 20.48%

Test accuracy: 22.2%

Epoch 14

Training loss: 3.1579692570564938745

Training accuracy: 18.279999999999998%

Test accuracy: 19.6%

Epoch 15

Training loss: 3.142504897605991459

Training accuracy: 40.12%

Test accuracy: 37.6%

Epoch 16

Training loss: 3.122797757948355835

Training accuracy: 37.72%

Test accuracy: 35.199999999999996%

Epoch 17

Training loss: 3.1004062036062451215

Training accuracy: 38.76%

Test accuracy: 36.199999999999996%

Epoch 18

Training loss: 3.074397703183800599

Training accuracy: 41.92%

Test accuracy: 41.199999999999996%

Epoch 19

Training loss: 3.044349118716373748

Training accuracy: 40.2%

Test accuracy: 37.2%

Epoch 20



Training loss: 3.0091303008163201964  
Training accuracy: 46.6%  
Test accuracy: 45.4%

Epoch 21  
Training loss: 2.9684991816499108842  
Training accuracy: 46.44%  
Test accuracy: 46.0%

Epoch 22  
Training loss: 2.92469611200130771  
Training accuracy: 48.32%  
Test accuracy: 48.0%

Epoch 23  
Training loss: 2.8759409221530301218  
Training accuracy: 51.160000000000004%  
Test accuracy: 48.199999999999996%

Epoch 24  
Training loss: 2.8240886380030860686  
Training accuracy: 49.68%  
Test accuracy: 47.4%

Epoch 25  
Training loss: 2.7697902628774254458  
Training accuracy: 49.84%  
Test accuracy: 48.8%

Epoch 26  
Training loss: 2.7162277572661148433  
Training accuracy: 49.36%  
Test accuracy: 49.6%

Epoch 27  
Training loss: 2.6597446797016051545  
Training accuracy: 53.04%  
Test accuracy: 51.4%

Epoch 28  
Training loss: 2.6061288412169825428  
Training accuracy: 55.84%  
Test accuracy: 53.800000000000004%

Epoch 29  
Training loss: 2.5530383081132731824  
Training accuracy: 55.32%  
Test accuracy: 52.800000000000004%

Epoch 30  
Training loss: 2.5018998306884877557  
Training accuracy: 53.72%  
Test accuracy: 52.800000000000004%

Epoch 31  
Training loss: 2.4508792215258656015  
Training accuracy: 55.679999999999999%  
Test accuracy: 53.2%

Epoch 32  
Training loss: 2.4012865598298434712  
Training accuracy: 55.559999999999995%  
Test accuracy: 54.400000000000006%

Epoch 33  
Training loss: 2.3541694968697522428  
Training accuracy: 56.44%  
Test accuracy: 54.800000000000004%

Epoch 34  
Training loss: 2.3078569588949350783  
Training accuracy: 56.120000000000005%  
Test accuracy: 54.6%

Epoch 35  
Training loss: 2.2637557417282180897  
Training accuracy: 56.599999999999994%  
Test accuracy: 54.800000000000004%

Epoch 36  
Training loss: 2.221228771235827473  
Training accuracy: 58.199999999999996%  
Test accuracy: 57.599999999999994%

Epoch 37  
Training loss: 2.1798856352725289572  
Training accuracy: 58.320000000000001%  
Test accuracy: 56.99999999999999%

Epoch 38  
Training loss: 2.1404746908608168305  
Training accuracy: 59.96%  
Test accuracy: 57.8%

Epoch 39  
Training loss: 2.1037621162467799647

Training accuracy: 59.24%  
Test accuracy: 57.99999999999999%

Epoch 40  
Training loss: 2.0685769382234162049  
Training accuracy: 62.03999999999999%  
Test accuracy: 59.599999999999994%

Epoch 41  
Training loss: 2.0359159212131779585  
Training accuracy: 61.12%  
Test accuracy: 58.8%

Epoch 42  
Training loss: 2.0048847311586729329  
Training accuracy: 61.28%  
Test accuracy: 58.8%

Epoch 43  
Training loss: 1.974848235023085078  
Training accuracy: 63.160000000000004%  
Test accuracy: 60.4%

Epoch 44  
Training loss: 1.9473420165813056105  
Training accuracy: 63.63999999999999%  
Test accuracy: 61.6%

Epoch 45  
Training loss: 1.9208079851927383835  
Training accuracy: 63.63999999999999%  
Test accuracy: 61.199999999999996%

Epoch 46  
Training loss: 1.8957143576823315464  
Training accuracy: 64.28%  
Test accuracy: 60.8%

Epoch 47  
Training loss: 1.8717288913158866705  
Training accuracy: 64.52%  
Test accuracy: 61.199999999999996%

Epoch 48  
Training loss: 1.848219909449681893  
Training accuracy: 65.92%  
Test accuracy: 62.4%

Epoch 49  
Training loss: 1.8260729254400167509  
Training accuracy: 66.67999999999999%  
Test accuracy: 62.6%

Epoch 50  
Training loss: 1.8047938109639787926  
Training accuracy: 67.2%  
Test accuracy: 63.2%

```
Epoch 51
Training loss: 1.7834129408990705926
Training accuracy: 67.72%
Test accuracy: 63.2%
```

Epoch 52  
Training loss: 1.7629601038715065655  
Training accuracy: 67.88%  
Test accuracy: 63.4%

Epoch 53  
Training loss: 1.7434503943780405013  
Training accuracy: 69.08%  
Test accuracy: 65.4%

Epoch 54  
Training loss: 1.7237760193977251957  
Training accuracy: 69.56%  
Test accuracy: 65.8%

Epoch 55  
Training loss: 1.7055133364057228889  
Training accuracy: 70.52000000000001%  
Test accuracy: 67.4%

Epoch 56  
Training loss: 1.6856116623531849346  
Training accuracy: 71.12%  
Test accuracy: 67.60000000000001%

Epoch 57  
Training loss: 1.6670932176954086682  
Training accuracy: 71.36%  
Test accuracy: 67.60000000000001%

Epoch 58  
Training loss: 1.6490286058734865947  
Training accuracy: 71.28%

Test accuracy: 68.4%

Epoch 59

Training loss: 1.6305001383306866711

Training accuracy: 72.36%

Test accuracy: 68.2%

Epoch 60

Training loss: 1.6130062561568574205

Training accuracy: 73.24000000000001%

Test accuracy: 68.4%

Epoch 61

Training loss: 1.5946559071688159602

Training accuracy: 73.68%

Test accuracy: 69.19999999999999%

Epoch 62

Training loss: 1.5770382621481562106

Training accuracy: 73.8%

Test accuracy: 68.8%

Epoch 63

Training loss: 1.5588948405875222796

Training accuracy: 75.36%

Test accuracy: 70.19999999999999%

Epoch 64

Training loss: 1.5417844324714328183

Training accuracy: 75.16000000000001%

Test accuracy: 70.39999999999999%

Epoch 65

Training loss: 1.5241947466488462496

Training accuracy: 75.8%

Test accuracy: 71.6%

Epoch 66

Training loss: 1.5066104174884922006

Training accuracy: 77.08%

Test accuracy: 72.6%

Epoch 67

Training loss: 1.4899628374798290287

Training accuracy: 77.64%

Test accuracy: 73.6%

Epoch 68

Training loss: 1.4724902043963055593  
Training accuracy: 77.28%  
Test accuracy: 72.8%

Epoch 69  
Training loss: 1.4548622997156738217  
Training accuracy: 78.0%  
Test accuracy: 74.4%

Epoch 70  
Training loss: 1.4377368092651069656  
Training accuracy: 78.72%  
Test accuracy: 75.2%

Epoch 71  
Training loss: 1.4208452418719656946  
Training accuracy: 79.16%  
Test accuracy: 75.4%

Epoch 72  
Training loss: 1.4038049094047345091  
Training accuracy: 79.36%  
Test accuracy: 75.8%

Epoch 73  
Training loss: 1.3872365292509588534  
Training accuracy: 80.16%  
Test accuracy: 76.6%

Epoch 74  
Training loss: 1.3704860215398357733  
Training accuracy: 80.72%  
Test accuracy: 77.2%

Epoch 75  
Training loss: 1.3542485419195613612  
Training accuracy: 80.96%  
Test accuracy: 77.60000000000001%

Epoch 76  
Training loss: 1.3389831627064600793  
Training accuracy: 81.8%  
Test accuracy: 78.0%

Epoch 77  
Training loss: 1.3219832630852059864  
Training accuracy: 82.12%  
Test accuracy: 79.0%

Epoch 78  
Training loss: 1.3063851778332541608  
Training accuracy: 82.84%  
Test accuracy: 79.60000000000001%

Epoch 79  
Training loss: 1.291205768735197076  
Training accuracy: 83.2%  
Test accuracy: 79.60000000000001%

Epoch 80  
Training loss: 1.2756564658444705095  
Training accuracy: 83.76%  
Test accuracy: 80.80000000000001%

Epoch 81  
Training loss: 1.260856611725711458  
Training accuracy: 83.52000000000001%  
Test accuracy: 80.80000000000001%

Epoch 82  
Training loss: 1.2454534042063571398  
Training accuracy: 84.2%  
Test accuracy: 81.6%

Epoch 83  
Training loss: 1.2308656061274645392  
Training accuracy: 84.39999999999999%  
Test accuracy: 81.39999999999999%

Epoch 84  
Training loss: 1.2165548989951122977  
Training accuracy: 84.76%  
Test accuracy: 82.19999999999999%

Epoch 85  
Training loss: 1.2028314733363346907  
Training accuracy: 84.96000000000001%  
Test accuracy: 82.39999999999999%

Epoch 86  
Training loss: 1.1886340126235066866  
Training accuracy: 85.64%  
Test accuracy: 82.19999999999999%

Epoch 87  
Training loss: 1.1748772795262187512

Training accuracy: 86.04%

Test accuracy: 83.6%

Epoch 88

Training loss: 1.1616291866280881721

Training accuracy: 85.96000000000001%

Test accuracy: 82.8%

Epoch 89

Training loss: 1.1485587851601321016

Training accuracy: 86.08%

Test accuracy: 83.0%

Epoch 90

Training loss: 1.1357762153106187144

Training accuracy: 86.56%

Test accuracy: 84.0%

Epoch 91

Training loss: 1.1236120774360980917

Training accuracy: 86.32%

Test accuracy: 83.8%

Epoch 92

Training loss: 1.1112726251411067034

Training accuracy: 86.88%

Test accuracy: 83.8%

Epoch 93

Training loss: 1.0990041061046098446

Training accuracy: 86.92%

Test accuracy: 84.2%

Epoch 94

Training loss: 1.0874187265099264566

Training accuracy: 87.08%

Test accuracy: 84.0%

Epoch 95

Training loss: 1.0760050708785375866

Training accuracy: 87.44%

Test accuracy: 84.0%

Epoch 96

Training loss: 1.0646318248633173022

Training accuracy: 87.76%

Test accuracy: 84.39999999999999%



Epoch 97

Training loss: 1.0539327871630847478

Training accuracy: 88.2%

Test accuracy: 84.6%

Epoch 98

Training loss: 1.0437634386080763659

Training accuracy: 88.4%

Test accuracy: 84.39999999999999%

Epoch 99

Training loss: 1.0328500565623754981

Training accuracy: 88.03999999999999%

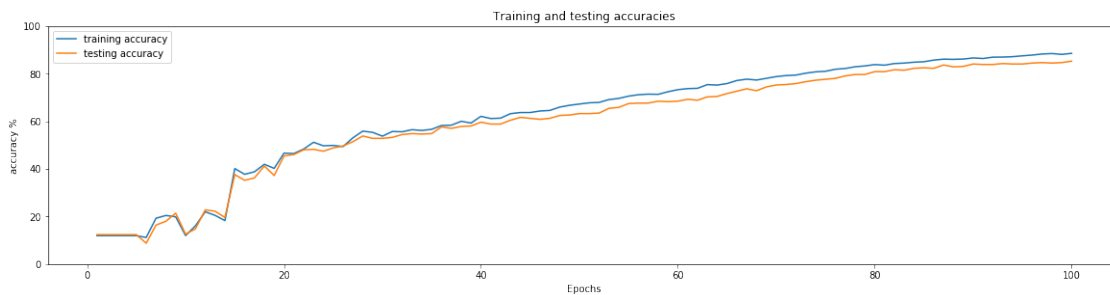
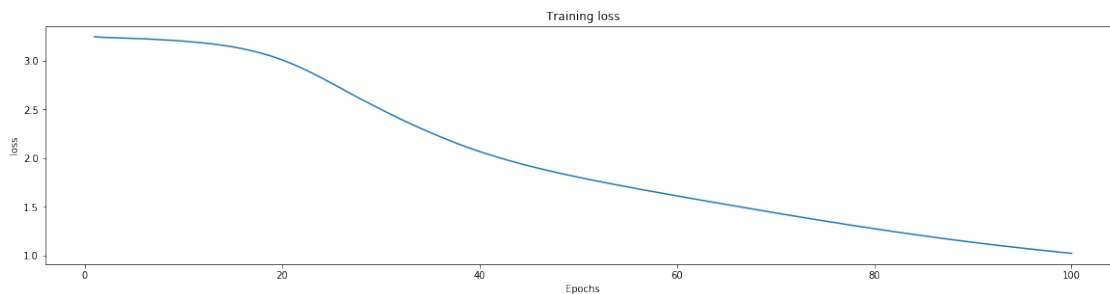
Test accuracy: 84.6%

Epoch 100

Training loss: 1.0225673635624652969

Training accuracy: 88.48%

Test accuracy: 85.2%



Since we didnt reach saturation, let's try with 200 epochs

```
[29]: net = network.Linear_Network([784, 35, 25, 10])  
net.SGD(training_data, 200, 10, 0.01, lambda = 5.0, test_data=testing_data)
```

Epoch 1  
Training loss: 3.2448648598402080197  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 2  
Training loss: 3.2373135604231627444  
Training accuracy: 11.959999999999999%  
Test accuracy: 12.4%

Epoch 3  
Training loss: 3.2316508006551143098  
Training accuracy: 18.4%  
Test accuracy: 15.2%

Epoch 4  
Training loss: 3.2263156506888010654  
Training accuracy: 18.240000000000002%  
Test accuracy: 15.4%

Epoch 5  
Training loss: 3.2183598531551415537  
Training accuracy: 16.400000000000002%  
Test accuracy: 17.0%

Epoch 6  
Training loss: 3.210233225292959681  
Training accuracy: 13.239999999999998%  
Test accuracy: 13.8%

Epoch 7  
Training loss: 3.2010835726235456465  
Training accuracy: 19.040000000000003%  
Test accuracy: 20.4%

Epoch 8  
Training loss: 3.1905204702988827826  
Training accuracy: 29.92%  
Test accuracy: 29.799999999999997%

Epoch 9  
Training loss: 3.17673840059719404  
Training accuracy: 28.360000000000003%  
Test accuracy: 28.000000000000004%

Epoch 10  
Training loss: 3.1617877300963245946  
Training accuracy: 29.080000000000002%

Test accuracy: 28.199999999999996%

Epoch 11

Training loss: 3.1439759453097912707

Training accuracy: 28.88%

Test accuracy: 28.000000000000004%

Epoch 12

Training loss: 3.1229978301627211515

Training accuracy: 32.28%

Test accuracy: 30.4%

Epoch 13

Training loss: 3.0981339858470488106

Training accuracy: 31.080000000000002%

Test accuracy: 31.2%

Epoch 14

Training loss: 3.0698266047872981837

Training accuracy: 27.48%

Test accuracy: 28.199999999999996%

Epoch 15

Training loss: 3.036665429925219199

Training accuracy: 29.720000000000002%

Test accuracy: 31.6%

Epoch 16

Training loss: 2.9997690267258597739

Training accuracy: 36.120000000000005%

Test accuracy: 34.2%

Epoch 17

Training loss: 2.9596269673826975566

Training accuracy: 35.36%

Test accuracy: 34.599999999999994%

Epoch 18

Training loss: 2.9154516722581708269

Training accuracy: 39.2%

Test accuracy: 36.6%

Epoch 19

Training loss: 2.8684099699877610638

Training accuracy: 44.04%

Test accuracy: 40.8%

Epoch 20

Training loss: 2.8189767979938176908  
Training accuracy: 42.32%  
Test accuracy: 37.8%

Epoch 21  
Training loss: 2.7675733086435321336  
Training accuracy: 44.72%  
Test accuracy: 40.400000000000006%

Epoch 22  
Training loss: 2.7131023592527464367  
Training accuracy: 44.64%  
Test accuracy: 39.6%

Epoch 23  
Training loss: 2.6567429832600327336  
Training accuracy: 48.72%  
Test accuracy: 43.8%

Epoch 24  
Training loss: 2.5985438096183832908  
Training accuracy: 48.76%  
Test accuracy: 42.0%

Epoch 25  
Training loss: 2.5375138751746777331  
Training accuracy: 54.04%  
Test accuracy: 47.4%

Epoch 26  
Training loss: 2.4755215038864055888  
Training accuracy: 52.959999999999994%  
Test accuracy: 47.4%

Epoch 27  
Training loss: 2.412296344343621339  
Training accuracy: 56.599999999999994%  
Test accuracy: 51.4%

Epoch 28  
Training loss: 2.349044874459079787  
Training accuracy: 58.68%  
Test accuracy: 53.400000000000006%

Epoch 29  
Training loss: 2.287425276675670176  
Training accuracy: 60.440000000000005%  
Test accuracy: 57.199999999999996%

Epoch 30  
Training loss: 2.227593976773718862  
Training accuracy: 61.519999999999996%  
Test accuracy: 56.8%

Epoch 31  
Training loss: 2.171830491115984002  
Training accuracy: 63.160000000000004%  
Test accuracy: 59.8%

Epoch 32  
Training loss: 2.118947942669142957  
Training accuracy: 63.480000000000004%  
Test accuracy: 59.0%

Epoch 33  
Training loss: 2.070304883854367748  
Training accuracy: 66.0%  
Test accuracy: 62.6%

Epoch 34  
Training loss: 2.0234420703287843942  
Training accuracy: 64.48%  
Test accuracy: 61.0%

Epoch 35  
Training loss: 1.9815780164013248907  
Training accuracy: 64.52%  
Test accuracy: 61.6%

Epoch 36  
Training loss: 1.9421671172035465943  
Training accuracy: 65.68%  
Test accuracy: 62.0%

Epoch 37  
Training loss: 1.9048386327800478276  
Training accuracy: 67.04%  
Test accuracy: 63.4%

Epoch 38  
Training loss: 1.870198086286800898  
Training accuracy: 67.84%  
Test accuracy: 63.0%

Epoch 39  
Training loss: 1.8371729189072062828

Training accuracy: 68.47999999999999%  
Test accuracy: 64.2%

Epoch 40  
Training loss: 1.8059812594806316281  
Training accuracy: 69.56%  
Test accuracy: 65.60000000000001%

Epoch 41  
Training loss: 1.7766110573477318171  
Training accuracy: 69.56%  
Test accuracy: 65.0%

Epoch 42  
Training loss: 1.7493029259867606846  
Training accuracy: 71.24000000000001%  
Test accuracy: 66.0%

Epoch 43  
Training loss: 1.7221326063389069891  
Training accuracy: 72.24000000000001%  
Test accuracy: 67.4%

Epoch 44  
Training loss: 1.6963154362727693296  
Training accuracy: 71.64%  
Test accuracy: 66.2%

Epoch 45  
Training loss: 1.6719976240586162215  
Training accuracy: 72.0%  
Test accuracy: 65.60000000000001%

Epoch 46  
Training loss: 1.6478905005764351338  
Training accuracy: 73.52%  
Test accuracy: 67.0%

Epoch 47  
Training loss: 1.625622332341793169  
Training accuracy: 72.92%  
Test accuracy: 67.0%

Epoch 48  
Training loss: 1.6026926432925977457  
Training accuracy: 74.72%  
Test accuracy: 68.2%

Epoch 49  
Training loss: 1.5810781387832224743  
Training accuracy: 74.92%  
Test accuracy: 68.2%

Epoch 50  
Training loss: 1.5602948782306045695  
Training accuracy: 75.76%  
Test accuracy: 68.8%

Epoch 51  
Training loss: 1.5401601152220052131  
Training accuracy: 75.84%  
Test accuracy: 69.8%

Epoch 52  
Training loss: 1.5201670845523957551  
Training accuracy: 76.2%  
Test accuracy: 68.8%

Epoch 53  
Training loss: 1.5009311419924430381  
Training accuracy: 77.24%  
Test accuracy: 70.19999999999999%

Epoch 54  
Training loss: 1.4819905806030879341  
Training accuracy: 77.60000000000001%  
Test accuracy: 69.8%

Epoch 55  
Training loss: 1.4638336856048307897  
Training accuracy: 77.56%  
Test accuracy: 71.8%

Epoch 56  
Training loss: 1.4451548647403959276  
Training accuracy: 78.68%  
Test accuracy: 72.0%

Epoch 57  
Training loss: 1.4273283430360277579  
Training accuracy: 78.56%  
Test accuracy: 71.8%

Epoch 58  
Training loss: 1.4097489279625173905  
Training accuracy: 78.64%

Test accuracy: 72.0%

Epoch 59

Training loss: 1.3927237857007958264

Training accuracy: 78.68%

Test accuracy: 71.39999999999999%

Epoch 60

Training loss: 1.3755970593340858997

Training accuracy: 79.28%

Test accuracy: 72.0%

Epoch 61

Training loss: 1.3593934381885453783

Training accuracy: 79.60000000000001%

Test accuracy: 73.2%

Epoch 62

Training loss: 1.3433029808291595912

Training accuracy: 79.72%

Test accuracy: 74.4%

Epoch 63

Training loss: 1.3270371784703640441

Training accuracy: 81.0%

Test accuracy: 76.0%

Epoch 64

Training loss: 1.3113332840049581442

Training accuracy: 81.36%

Test accuracy: 75.8%

Epoch 65

Training loss: 1.2970018796200158722

Training accuracy: 81.39999999999999%

Test accuracy: 76.8%

Epoch 66

Training loss: 1.2812429799740605171

Training accuracy: 82.12%

Test accuracy: 77.2%

Epoch 67

Training loss: 1.2666396076368702449

Training accuracy: 82.67999999999999%

Test accuracy: 78.2%

Epoch 68



Training loss: 1.2533590894455205921  
Training accuracy: 83.36%  
Test accuracy: 79.2%

Epoch 69  
Training loss: 1.2378935003378603682  
Training accuracy: 82.56%  
Test accuracy: 79.4%

Epoch 70  
Training loss: 1.2248447174763241473  
Training accuracy: 83.72%  
Test accuracy: 79.4%

Epoch 71  
Training loss: 1.2117561228666764345  
Training accuracy: 84.28%  
Test accuracy: 78.60000000000001%

Epoch 72  
Training loss: 1.1975948763352138132  
Training accuracy: 83.6%  
Test accuracy: 80.80000000000001%

Epoch 73  
Training loss: 1.1846408183400811487  
Training accuracy: 84.56%  
Test accuracy: 80.2%

Epoch 74  
Training loss: 1.1720948207842566809  
Training accuracy: 84.28%  
Test accuracy: 80.80000000000001%

Epoch 75  
Training loss: 1.1602747021176393314  
Training accuracy: 84.44%  
Test accuracy: 80.60000000000001%

Epoch 76  
Training loss: 1.1476667480533851068  
Training accuracy: 85.16%  
Test accuracy: 81.39999999999999%

Epoch 77  
Training loss: 1.1365720097217338381  
Training accuracy: 85.24000000000001%  
Test accuracy: 81.8%

Epoch 78  
Training loss: 1.1247255847502848179  
Training accuracy: 85.84%  
Test accuracy: 81.6%

Epoch 79  
Training loss: 1.1149158336767258999  
Training accuracy: 85.68%  
Test accuracy: 81.39999999999999%

Epoch 80  
Training loss: 1.1039917171596402458  
Training accuracy: 85.08%  
Test accuracy: 81.0%

Epoch 81  
Training loss: 1.0920787058580155763  
Training accuracy: 85.84%  
Test accuracy: 81.8%

Epoch 82  
Training loss: 1.081715399744579795  
Training accuracy: 86.56%  
Test accuracy: 82.19999999999999%

Epoch 83  
Training loss: 1.0724316371901005924  
Training accuracy: 86.64%  
Test accuracy: 82.0%

Epoch 84  
Training loss: 1.0618783918153546165  
Training accuracy: 86.4%  
Test accuracy: 82.19999999999999%

Epoch 85  
Training loss: 1.0523028605508784877  
Training accuracy: 86.56%  
Test accuracy: 82.19999999999999%

Epoch 86  
Training loss: 1.0428309317496282559  
Training accuracy: 86.72%  
Test accuracy: 82.39999999999999%

Epoch 87  
Training loss: 1.0335930147888180488

Training accuracy: 87.28%  
Test accuracy: 82.8%

Epoch 88  
Training loss: 1.0251894726401689612  
Training accuracy: 87.72%  
Test accuracy: 83.6%

Epoch 89  
Training loss: 1.0157816026483921518  
Training accuracy: 87.64%  
Test accuracy: 83.0%

Epoch 90  
Training loss: 1.0076949990941851434  
Training accuracy: 87.96000000000001%  
Test accuracy: 83.39999999999999%

Epoch 91  
Training loss: 0.9990189168665997991  
Training accuracy: 87.92%  
Test accuracy: 83.39999999999999%

Epoch 92  
Training loss: 0.9906598544992383033  
Training accuracy: 88.03999999999999%  
Test accuracy: 83.0%

Epoch 93  
Training loss: 0.9829733850150172254  
Training accuracy: 88.03999999999999%  
Test accuracy: 83.2%

Epoch 94  
Training loss: 0.9753109816219269748  
Training accuracy: 88.68%  
Test accuracy: 84.0%

Epoch 95  
Training loss: 0.9673540793529894392  
Training accuracy: 88.8%  
Test accuracy: 84.0%

Epoch 96  
Training loss: 0.9597514970576607972  
Training accuracy: 89.03999999999999%  
Test accuracy: 83.8%

```
Epoch 97
Training loss: 0.95234425147898404333
Training accuracy: 89.03999999999999%
Test accuracy: 84.2%
```

Epoch 98  
Training loss: 0.9451673288892534151  
Training accuracy: 88.96%  
Test accuracy: 84.39999999999999%

Epoch 99  
Training loss: 0.93805962067274864513  
Training accuracy: 88.88000000000001%  
Test accuracy: 84.2%

Epoch 100  
Training loss: 0.9315577093472887503  
Training accuracy: 89.28%  
Test accuracy: 83.8%

Epoch 101  
Training loss: 0.9241622647584131939  
Training accuracy: 89.12%  
Test accuracy: 84.0%

Epoch 102  
Training loss: 0.9180485451998891938  
Training accuracy: 89.36%  
Test accuracy: 83.8%

Epoch 103  
Training loss: 0.9109929078513542769  
Training accuracy: 89.44%  
Test accuracy: 83.8%

Epoch 104  
Training loss: 0.9048270072692862695  
Training accuracy: 89.75999999999999%  
Test accuracy: 84.0%

Epoch 105  
Training loss: 0.899356816572868636  
Training accuracy: 89.56%  
Test accuracy: 84.6%

Epoch 106  
Training loss: 0.89225139936257858846  
Training accuracy: 89.60000000000001%

Test accuracy: 84.39999999999999%

Epoch 107

Training loss: 0.886676226204396169

Training accuracy: 89.84%

Test accuracy: 84.0%

Epoch 108

Training loss: 0.88030074843402830335

Training accuracy: 89.8%

Test accuracy: 84.39999999999999%

Epoch 109

Training loss: 0.8746853764703772553

Training accuracy: 89.84%

Test accuracy: 84.6%

Epoch 110

Training loss: 0.86912751639407075734

Training accuracy: 89.92%

Test accuracy: 84.6%

Epoch 111

Training loss: 0.8632107469139967564

Training accuracy: 89.96%

Test accuracy: 84.6%

Epoch 112

Training loss: 0.8576764708850190823

Training accuracy: 90.08%

Test accuracy: 85.0%

Epoch 113

Training loss: 0.85230878540240242243

Training accuracy: 90.32%

Test accuracy: 85.2%

Epoch 114

Training loss: 0.84686883539164960715

Training accuracy: 90.52%

Test accuracy: 85.2%

Epoch 115

Training loss: 0.8416985475681299664

Training accuracy: 90.60000000000001%

Test accuracy: 85.0%

Epoch 116

Training loss: 0.83747999645107525774  
Training accuracy: 90.64%  
Test accuracy: 85.0%

Epoch 117  
Training loss: 0.8314217745867625897  
Training accuracy: 90.4%  
Test accuracy: 85.39999999999999%

Epoch 118  
Training loss: 0.82679126937779197115  
Training accuracy: 90.72%  
Test accuracy: 85.39999999999999%

Epoch 119  
Training loss: 0.82153390364633254014  
Training accuracy: 90.8%  
Test accuracy: 85.39999999999999%

Epoch 120  
Training loss: 0.81688116694402794596  
Training accuracy: 90.880000000000001%  
Test accuracy: 85.39999999999999%

Epoch 121  
Training loss: 0.81219536999729301344  
Training accuracy: 90.600000000000001%  
Test accuracy: 85.39999999999999%

Epoch 122  
Training loss: 0.8071922856760298857  
Training accuracy: 91.0%  
Test accuracy: 85.39999999999999%

Epoch 123  
Training loss: 0.80294261598008158837  
Training accuracy: 91.2%  
Test accuracy: 85.8%

Epoch 124  
Training loss: 0.7987991118468399861  
Training accuracy: 91.12%  
Test accuracy: 86.0%

Epoch 125  
Training loss: 0.79391852202519442157  
Training accuracy: 91.24%  
Test accuracy: 86.2%

Epoch 126  
Training loss: 0.7896756589047557638  
Training accuracy: 91.32000000000001%  
Test accuracy: 86.0%

Epoch 127  
Training loss: 0.78607630643014459924  
Training accuracy: 91.28%  
Test accuracy: 85.8%

Epoch 128  
Training loss: 0.7811274433262855312  
Training accuracy: 91.4%  
Test accuracy: 86.4%

Epoch 129  
Training loss: 0.7767869721471583545  
Training accuracy: 91.60000000000001%  
Test accuracy: 85.8%

Epoch 130  
Training loss: 0.77240243738995738434  
Training accuracy: 91.47999999999999%  
Test accuracy: 86.4%

Epoch 131  
Training loss: 0.7691039853575153948  
Training accuracy: 92.04%  
Test accuracy: 86.2%

Epoch 132  
Training loss: 0.7649061175713949493  
Training accuracy: 91.96%  
Test accuracy: 86.0%

Epoch 133  
Training loss: 0.7608901847267768064  
Training accuracy: 91.64%  
Test accuracy: 86.6%

Epoch 134  
Training loss: 0.75866994663786567374  
Training accuracy: 92.04%  
Test accuracy: 86.6%

Epoch 135  
Training loss: 0.752960017202732477

Training accuracy: 91.88%  
Test accuracy: 86.4%

Epoch 136  
Training loss: 0.75055359193349202644  
Training accuracy: 91.88%  
Test accuracy: 86.8%

Epoch 137  
Training loss: 0.7455113116188975216  
Training accuracy: 92.2%  
Test accuracy: 86.4%

Epoch 138  
Training loss: 0.7436768530742874325  
Training accuracy: 92.08%  
Test accuracy: 86.8%

Epoch 139  
Training loss: 0.7383576093752210722  
Training accuracy: 91.96%  
Test accuracy: 86.0%

Epoch 140  
Training loss: 0.7348899017214693404  
Training accuracy: 92.12%  
Test accuracy: 86.8%

Epoch 141  
Training loss: 0.73145469834716003417  
Training accuracy: 92.2%  
Test accuracy: 86.8%

Epoch 142  
Training loss: 0.728139260403335867  
Training accuracy: 92.36%  
Test accuracy: 86.4%

Epoch 143  
Training loss: 0.7246311330291147691  
Training accuracy: 92.24%  
Test accuracy: 86.4%

Epoch 144  
Training loss: 0.72155424234031550725  
Training accuracy: 92.47999999999999%  
Test accuracy: 87.0%



Epoch 145  
Training loss: 0.7183018109222813925  
Training accuracy: 92.24%  
Test accuracy: 86.8%

Epoch 146  
Training loss: 0.7156373309897406  
Training accuracy: 92.44%  
Test accuracy: 87.2%

Epoch 147  
Training loss: 0.71161071769414887205  
Training accuracy: 92.24%  
Test accuracy: 86.6%

Epoch 148  
Training loss: 0.70867872488624437607  
Training accuracy: 92.47999999999999%  
Test accuracy: 86.8%

Epoch 149  
Training loss: 0.70617170926885193717  
Training accuracy: 92.64%  
Test accuracy: 87.0%

Epoch 150  
Training loss: 0.70274955892325414786  
Training accuracy: 92.47999999999999%  
Test accuracy: 86.8%

Epoch 151  
Training loss: 0.6997328141277668819  
Training accuracy: 92.52%  
Test accuracy: 86.6%

Epoch 152  
Training loss: 0.69629242198541990857  
Training accuracy: 92.52%  
Test accuracy: 87.0%

Epoch 153  
Training loss: 0.6941443313843758697  
Training accuracy: 92.60000000000001%  
Test accuracy: 87.4%

Epoch 154  
Training loss: 0.6908471337415322669  
Training accuracy: 92.64%

Test accuracy: 86.8%

Epoch 155

Training loss: 0.68853430768362481034

Training accuracy: 92.64%

Test accuracy: 87.0%

Epoch 156

Training loss: 0.68514003060513119995

Training accuracy: 92.88%

Test accuracy: 87.0%

Epoch 157

Training loss: 0.6825781068075870057

Training accuracy: 92.84%

Test accuracy: 87.2%

Epoch 158

Training loss: 0.6802750108143772526

Training accuracy: 92.72%

Test accuracy: 86.8%

Epoch 159

Training loss: 0.6770158656481711667

Training accuracy: 92.96%

Test accuracy: 87.0%

Epoch 160

Training loss: 0.6746036332645691025

Training accuracy: 92.72%

Test accuracy: 87.4%

Epoch 161

Training loss: 0.6720427757983118415

Training accuracy: 92.88%

Test accuracy: 87.6%

Epoch 162

Training loss: 0.66940962661114800097

Training accuracy: 92.92%

Test accuracy: 87.4%

Epoch 163

Training loss: 0.6669632219010615594

Training accuracy: 93.08%

Test accuracy: 87.4%

Epoch 164

Training loss: 0.6648791954771500335  
Training accuracy: 92.96%  
Test accuracy: 87.4%

Epoch 165  
Training loss: 0.66190244500986940865  
Training accuracy: 93.08%  
Test accuracy: 87.4%

Epoch 166  
Training loss: 0.65944103395232555405  
Training accuracy: 93.04%  
Test accuracy: 87.4%

Epoch 167  
Training loss: 0.65691821273306173854  
Training accuracy: 93.2%  
Test accuracy: 87.8%

Epoch 168  
Training loss: 0.65498798182789156897  
Training accuracy: 93.16%  
Test accuracy: 87.6%

Epoch 169  
Training loss: 0.65238680611439229254  
Training accuracy: 93.28%  
Test accuracy: 87.4%

Epoch 170  
Training loss: 0.6501144064130033243  
Training accuracy: 93.32000000000001%  
Test accuracy: 87.8%

Epoch 171  
Training loss: 0.6483810013036173176  
Training accuracy: 93.32000000000001%  
Test accuracy: 87.4%

Epoch 172  
Training loss: 0.64608502843123692656  
Training accuracy: 93.24%  
Test accuracy: 87.4%

Epoch 173  
Training loss: 0.64436892396917374757  
Training accuracy: 93.28%  
Test accuracy: 87.6%

Epoch 174  
Training loss: 0.64165690900774034197  
Training accuracy: 93.24%  
Test accuracy: 87.6%

Epoch 175  
Training loss: 0.63952935322323386337  
Training accuracy: 93.36%  
Test accuracy: 87.6%

Epoch 176  
Training loss: 0.63837159085818753605  
Training accuracy: 93.47999999999999%  
Test accuracy: 87.6%

Epoch 177  
Training loss: 0.63519229436790445974  
Training accuracy: 93.28%  
Test accuracy: 87.4%

Epoch 178  
Training loss: 0.63332676032971372713  
Training accuracy: 93.52000000000001%  
Test accuracy: 87.4%

Epoch 179  
Training loss: 0.63094469646691017146  
Training accuracy: 93.44%  
Test accuracy: 87.6%

Epoch 180  
Training loss: 0.6292672903165051361  
Training accuracy: 93.56%  
Test accuracy: 87.6%

Epoch 181  
Training loss: 0.62713882196761277555  
Training accuracy: 93.4%  
Test accuracy: 87.4%

Epoch 182  
Training loss: 0.6253841666763890473  
Training accuracy: 93.44%  
Test accuracy: 87.4%

Epoch 183  
Training loss: 0.624090923552555987

Training accuracy: 93.64%  
Test accuracy: 87.4%

Epoch 184  
Training loss: 0.6214213639034449173  
Training accuracy: 93.52000000000001%  
Test accuracy: 87.8%

Epoch 185  
Training loss: 0.61996924809412455446  
Training accuracy: 93.56%  
Test accuracy: 87.4%

Epoch 186  
Training loss: 0.618022682014588171  
Training accuracy: 93.8%  
Test accuracy: 88.0%

Epoch 187  
Training loss: 0.616361126888142262  
Training accuracy: 93.52000000000001%  
Test accuracy: 87.6%

Epoch 188  
Training loss: 0.6143469426363560454  
Training accuracy: 93.76%  
Test accuracy: 87.8%

Epoch 189  
Training loss: 0.6131238347822947631  
Training accuracy: 93.72%  
Test accuracy: 87.6%

Epoch 190  
Training loss: 0.61127910880563941993  
Training accuracy: 93.84%  
Test accuracy: 88.0%

Epoch 191  
Training loss: 0.60890157521974988634  
Training accuracy: 93.92%  
Test accuracy: 87.4%

Epoch 192  
Training loss: 0.60758724443976687315  
Training accuracy: 93.8%  
Test accuracy: 87.6%

Epoch 193

Training loss: 0.6056600340362162441

Training accuracy: 93.84%

Test accuracy: 88.0%

Epoch 194

Training loss: 0.60412219758631545516

Training accuracy: 93.96%

Test accuracy: 87.8%

Epoch 195

Training loss: 0.602337904903135703

Training accuracy: 93.88%

Test accuracy: 88.0%

Epoch 196

Training loss: 0.60057651468884508877

Training accuracy: 93.84%

Test accuracy: 87.6%

Epoch 197

Training loss: 0.5990361561873028138

Training accuracy: 93.92%

Test accuracy: 87.6%

Epoch 198

Training loss: 0.597834502980628766

Training accuracy: 93.92%

Test accuracy: 87.6%

Epoch 199

Training loss: 0.5966503912371351327

Training accuracy: 94.16%

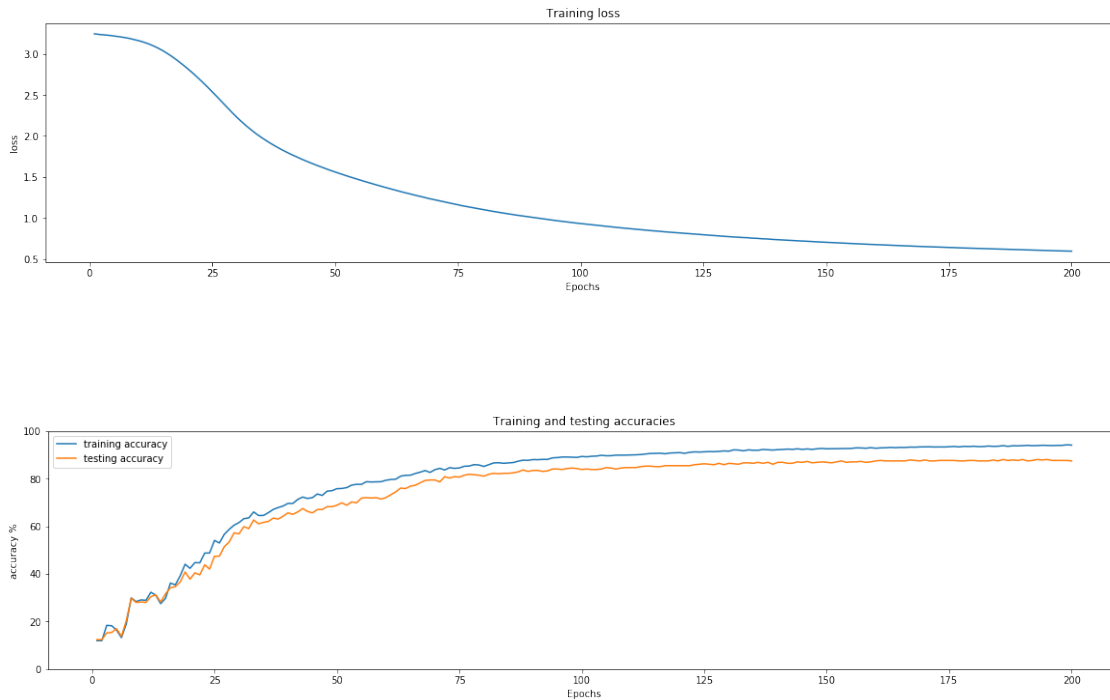
Test accuracy: 87.6%

Epoch 200

Training loss: 0.5945048589134503131

Training accuracy: 94.04%

Test accuracy: 87.4%



Since we tend to get similar results for both  $\eta=0.1$  and  $\eta=0.01$ , we continue with  $\eta=0.1$

**Finally we check if regularization is helpful or not** First with no regularization

```
[30]: net = network.Linear_Network([784, 35, 25, 10])
      net.SGD(training_data, 50, 10, 0.1, lambda = 0.0, test_data=testing_data)
```

Epoch 1

Training loss: 3.1566247878512270909

Training accuracy: 19.16%

Test accuracy: 19.2%

Epoch 2

Training loss: 2.638599112819415536

Training accuracy: 53.2%

Test accuracy: 48.8%

Epoch 3

Training loss: 1.9805994656752686879

Training accuracy: 63.56%

Test accuracy: 59.4%

Epoch 4

Training loss: 1.608633046737969135

Training accuracy: 76.84%

Test accuracy: 74.2%

Epoch 5

Training loss: 1.3345860039540976656

Training accuracy: 81.04%

Test accuracy: 77.8%

Epoch 6

Training loss: 1.1284489039738173178

Training accuracy: 83.52000000000001%

Test accuracy: 79.60000000000001%

Epoch 7

Training loss: 1.0026843595724710446

Training accuracy: 86.96000000000001%

Test accuracy: 83.0%

Epoch 8

Training loss: 0.86874549684692934

Training accuracy: 89.16%

Test accuracy: 84.6%

Epoch 9

Training loss: 0.7653506640010482795

Training accuracy: 90.48%

Test accuracy: 85.6%

Epoch 10

Training loss: 0.6954871826036289916

Training accuracy: 91.0%

Test accuracy: 86.4%

Epoch 11

Training loss: 0.635146010930845314

Training accuracy: 91.8%

Test accuracy: 87.0%

Epoch 12

Training loss: 0.57202693843374002706

Training accuracy: 93.36%

Test accuracy: 86.8%

Epoch 13

Training loss: 0.52869511146036359293

Training accuracy: 94.0%

Test accuracy: 86.8%

Epoch 14



Training loss: 0.49522335450114631322  
Training accuracy: 94.52000000000001%  
Test accuracy: 87.2%

Epoch 15  
Training loss: 0.4555449436507736489  
Training accuracy: 94.64%  
Test accuracy: 88.0%

Epoch 16  
Training loss: 0.42898493685530982074  
Training accuracy: 95.24000000000001%  
Test accuracy: 87.6%

Epoch 17  
Training loss: 0.399284533070007757  
Training accuracy: 95.56%  
Test accuracy: 87.4%

Epoch 18  
Training loss: 0.38202419382888428833  
Training accuracy: 95.76%  
Test accuracy: 87.0%

Epoch 19  
Training loss: 0.35723311841749348362  
Training accuracy: 96.24000000000001%  
Test accuracy: 87.0%

Epoch 20  
Training loss: 0.34810640722746674254  
Training accuracy: 96.16%  
Test accuracy: 87.6%

Epoch 21  
Training loss: 0.3231433343829978936  
Training accuracy: 96.28%  
Test accuracy: 87.8%

Epoch 22  
Training loss: 0.2905622877744582346  
Training accuracy: 97.0%  
Test accuracy: 88.2%

Epoch 23  
Training loss: 0.27556723798554143794  
Training accuracy: 97.28%  
Test accuracy: 88.0%

Epoch 24  
Training loss: 0.26657158046482363966  
Training accuracy: 97.39999999999999%  
Test accuracy: 87.6%

Epoch 25  
Training loss: 0.24837797672056164642  
Training accuracy: 97.84%  
Test accuracy: 87.4%

Epoch 26  
Training loss: 0.23185170300059365869  
Training accuracy: 97.96000000000001%  
Test accuracy: 88.0%

Epoch 27  
Training loss: 0.2204594919446421013  
Training accuracy: 98.04%  
Test accuracy: 87.0%

Epoch 28  
Training loss: 0.20808602338657359802  
Training accuracy: 98.16%  
Test accuracy: 87.8%

Epoch 29  
Training loss: 0.19481388368811271211  
Training accuracy: 98.32%  
Test accuracy: 87.6%

Epoch 30  
Training loss: 0.18746235075330992874  
Training accuracy: 98.52%  
Test accuracy: 87.8%

Epoch 31  
Training loss: 0.17624785879693008033  
Training accuracy: 98.68%  
Test accuracy: 88.2%

Epoch 32  
Training loss: 0.16684809755391320649  
Training accuracy: 98.83999999999999%  
Test accuracy: 87.8%

Epoch 33  
Training loss: 0.15794250167174995801

Training accuracy: 98.83999999999999%  
Test accuracy: 88.2%

Epoch 34  
Training loss: 0.14858422332373452581  
Training accuracy: 99.0%  
Test accuracy: 87.2%

Epoch 35  
Training loss: 0.14277124008601227345  
Training accuracy: 99.11999999999999%  
Test accuracy: 88.0%

Epoch 36  
Training loss: 0.13485401159964168761  
Training accuracy: 99.11999999999999%  
Test accuracy: 88.0%

Epoch 37  
Training loss: 0.12945302037582401789  
Training accuracy: 99.2%  
Test accuracy: 87.4%

Epoch 38  
Training loss: 0.12693830053463929211  
Training accuracy: 99.36%  
Test accuracy: 87.4%

Epoch 39  
Training loss: 0.12491073151483849345  
Training accuracy: 99.32%  
Test accuracy: 88.0%

Epoch 40  
Training loss: 0.11309156008954263679  
Training accuracy: 99.4%  
Test accuracy: 87.8%

Epoch 41  
Training loss: 0.10671730965437816927  
Training accuracy: 99.48%  
Test accuracy: 88.6%

Epoch 42  
Training loss: 0.10223956193534999181  
Training accuracy: 99.52%  
Test accuracy: 88.4%

Epoch 43  
Training loss: 0.098737920743430498724  
Training accuracy: 99.52%  
Test accuracy: 88.2%

Epoch 44  
Training loss: 0.096304470109465864944  
Training accuracy: 99.6%  
Test accuracy: 88.0%

Epoch 45  
Training loss: 0.09017947684613037218  
Training accuracy: 99.64%  
Test accuracy: 88.0%

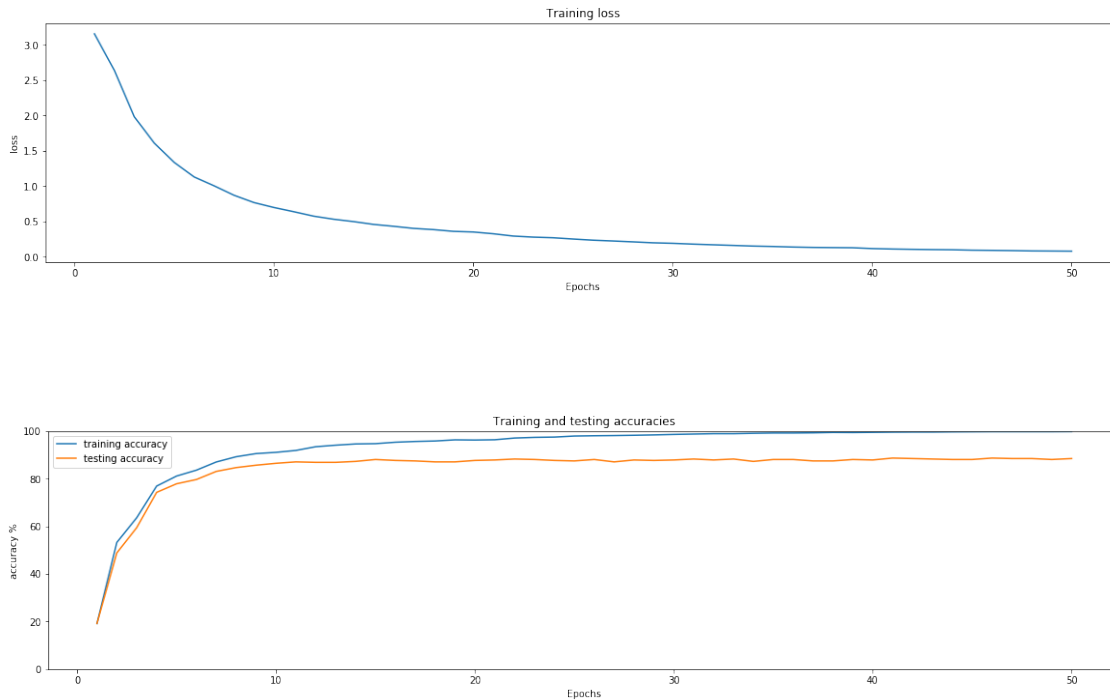
Epoch 46  
Training loss: 0.087573065413591265116  
Training accuracy: 99.68%  
Test accuracy: 88.6%

Epoch 47  
Training loss: 0.084378827461023778266  
Training accuracy: 99.68%  
Test accuracy: 88.4%

Epoch 48  
Training loss: 0.07969449837067826522  
Training accuracy: 99.68%  
Test accuracy: 88.4%

Epoch 49  
Training loss: 0.078168595932950542455  
Training accuracy: 99.68%  
Test accuracy: 88.0%

Epoch 50  
Training loss: 0.07624919357889873241  
Training accuracy: 99.72%  
Test accuracy: 88.4%



Clearly there has been over fitting as the training accuracy is 99%. It doesn't show up on the test accuracy as the testing set is too small. Hence we try different regularization factors to see which fits best

```
[34]: regs = [1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0]
train_accuracies=[]
test_accuracies=[]
for reg in regs:
    net = network.Linear_Network([784, 35, 25, 10])
    tr_a, te_a = net.SGD(training_data, 50, 10, 0.1, lambda = reg,
    ↪test_data=testing_data,
        show_eval=False, show_graph=False, return_accuracies=True)
    train_accuracies.append(tr_a)
    test_accuracies.append(te_a)
    print("regularization factor:"+str(reg))
    print("Training acc.: "+str(tr_a)+"% Testing acc.: "+str(te_a)+"%")
    print()

plt.subplot(2, 1, 1)
plt.plot(regs, train_accuracies, label='training accuracy')
plt.plot(regs, test_accuracies, label='test accuracy')
plt.legend()
plt.title("Training and testing accuracies")
plt.xlabel("neurons")
plt.ylabel("accuracy %")
```

```
plt.ylim(0, 100)
plt.show()
```

regularization factor:1.0

Training acc.: 99.512% Testing acc.: 88.67999999999999%

regularization factor:2.0

Training acc.: 99.02399999999999% Testing acc.: 88.67999999999999%

regularization factor:3.0

Training acc.: 98.016% Testing acc.: 87.67999999999999%

regularization factor:4.0

Training acc.: 97.088% Testing acc.: 87.24000000000001%

regularization factor:5.0

Training acc.: 96.48% Testing acc.: 87.80000000000001%

regularization factor:6.0

Training acc.: 95.64800000000001% Testing acc.: 87.36%

regularization factor:7.0

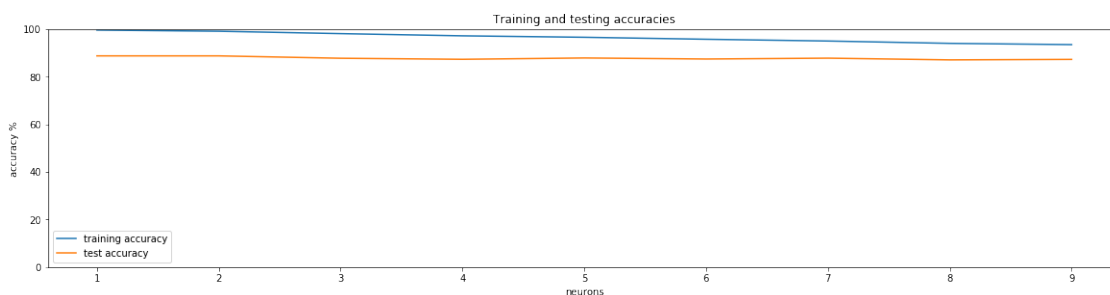
Training acc.: 94.912% Testing acc.: 87.72%

regularization factor:8.0

Training acc.: 93.928% Testing acc.: 87.0%

regularization factor:9.0

Training acc.: 93.4% Testing acc.: 87.2%



We see the training accuracy constantly dropping while the testing accuracy remained constant. This is indicative of over fitting. But we can't be too sure as the training and testing data is too small. We'd need atleast a bigger testing data to be entirely sure.

So for now, we stick to regularization of 7.0

**We'll revisit the regularization tuning when we look at Cross Validation** Now that we finally have all our parameters, let's take a list them down. Then we'll visualize the results on the testing data

1. size = [784, 35, 25, 10]
2. weight\_initializer = 'default'
3. cost = 'CrossEntropy'
4. activation = 'sigmoid'
5. epochs = 50
6. batch\_size = 10
7. eta = 0.1
8. lambda = 7.0

Final run of the mdoel

```
[3]: net = network.Linear_Network([784,35,25,10])
net.SGD(training_data, 50, 10, 0.1, lambda = 7.0, test_data = testing_data)
```

Epoch 1

Training loss: 3.2326841205725281342  
Training accuracy: 10.280000000000001%  
Test accuracy: 11.799999999999999%

Epoch 2

Training loss: 2.9537459618658661222  
Training accuracy: 39.04%  
Test accuracy: 36.199999999999996%

Epoch 3

Training loss: 2.4236604054472806506  
Training accuracy: 50.960000000000001%  
Test accuracy: 49.0%

Epoch 4

Training loss: 2.0560941779011762964  
Training accuracy: 61.760000000000005%  
Test accuracy: 58.4%

Epoch 5

Training loss: 1.7851758473356474966  
Training accuracy: 73.64%  
Test accuracy: 68.2%

Epoch 6

Training loss: 1.5828159690652832289  
Training accuracy: 75.48%  
Test accuracy: 71.2%

Epoch 7

```
Training loss: 1.4069334791200266226
Training accuracy: 79.75999999999999%
Test accuracy: 75.2%
```

```
Epoch 8
Training loss: 1.2701079597692875129
Training accuracy: 84.28%
Test accuracy: 81.2%
```

Epoch 9  
Training loss: 1.1523511466166390834  
Training accuracy: 86.88%  
Test accuracy: 83.6%

```
Epoch 10
Training loss: 1.0689898801611050113
Training accuracy: 88.36%
Test accuracy: 84.2%
```

```
Epoch 11
Training loss: 0.9958489060768214889
Training accuracy: 89.24%
Test accuracy: 85.6%
```

Epoch 12  
Training loss: 0.94237863925684892477  
Training accuracy: 89.24%  
Test accuracy: 85.2%

Epoch 13  
Training loss: 0.89018769680228264287  
Training accuracy: 90.8%  
Test accuracy: 85.8%

Epoch 14  
Training loss: 0.8528112852957638264  
Training accuracy: 91.08000000000001%  
Test accuracy: 86.0%

Epoch 15  
Training loss: 0.8458220951912395739  
Training accuracy: 91.56%  
Test accuracy: 85.2%

Epoch 16  
Training loss: 0.79749523820170468784  
Training accuracy: 90.92%  
Test accuracy: 86.2%



Epoch 17  
Training loss: 0.78889735394966301713  
Training accuracy: 90.64%  
Test accuracy: 86.6%

Epoch 18  
Training loss: 0.7622515288662194772  
Training accuracy: 91.92%  
Test accuracy: 87.4%

Epoch 19  
Training loss: 0.7348530839081167861  
Training accuracy: 91.92%  
Test accuracy: 87.2%

Epoch 20  
Training loss: 0.7299510551153513726  
Training accuracy: 92.16%  
Test accuracy: 87.6%

Epoch 21  
Training loss: 0.71238620434335595336  
Training accuracy: 92.96%  
Test accuracy: 87.8%

Epoch 22  
Training loss: 0.6891577904927793396  
Training accuracy: 93.28%  
Test accuracy: 87.4%

Epoch 23  
Training loss: 0.69107512165084638786  
Training accuracy: 93.12%  
Test accuracy: 87.4%

Epoch 24  
Training loss: 0.68156985734990621346  
Training accuracy: 93.36%  
Test accuracy: 87.0%

Epoch 25  
Training loss: 0.6626684695361602232  
Training accuracy: 93.16%  
Test accuracy: 88.0%

Epoch 26  
Training loss: 0.65078858219642967206

Training accuracy: 93.76%  
Test accuracy: 88.2%

Epoch 27  
Training loss: 0.6458221216025693004  
Training accuracy: 94.08%  
Test accuracy: 87.8%

Epoch 28  
Training loss: 0.63586314620361638754  
Training accuracy: 94.24%  
Test accuracy: 87.6%

Epoch 29  
Training loss: 0.63400881903736921677  
Training accuracy: 93.84%  
Test accuracy: 87.8%

Epoch 30  
Training loss: 0.6251042179150910963  
Training accuracy: 94.52000000000001%  
Test accuracy: 88.2%

Epoch 31  
Training loss: 0.61695678820882455173  
Training accuracy: 94.64%  
Test accuracy: 88.0%

Epoch 32  
Training loss: 0.6177354067088967172  
Training accuracy: 94.48%  
Test accuracy: 87.8%

Epoch 33  
Training loss: 0.61754338812817334466  
Training accuracy: 94.44%  
Test accuracy: 87.6%

Epoch 34  
Training loss: 0.6165443884876816758  
Training accuracy: 94.12%  
Test accuracy: 87.6%

Epoch 35  
Training loss: 0.6033791667883454335  
Training accuracy: 94.44%  
Test accuracy: 87.6%

Epoch 36  
Training loss: 0.6021970325391033135  
Training accuracy: 94.56%  
Test accuracy: 87.8%

Epoch 37  
Training loss: 0.5987250311007248646  
Training accuracy: 94.64%  
Test accuracy: 88.2%

Epoch 38  
Training loss: 0.6112678590840087999  
Training accuracy: 93.84%  
Test accuracy: 88.4%

Epoch 39  
Training loss: 0.60098091201283159623  
Training accuracy: 94.16%  
Test accuracy: 88.0%

Epoch 40  
Training loss: 0.5943690540855281772  
Training accuracy: 94.39999999999999%  
Test accuracy: 88.2%

Epoch 41  
Training loss: 0.59540718384031455964  
Training accuracy: 95.12%  
Test accuracy: 87.6%

Epoch 42  
Training loss: 0.5805668478565324346  
Training accuracy: 94.67999999999999%  
Test accuracy: 87.4%

Epoch 43  
Training loss: 0.59134911657571848293  
Training accuracy: 94.32000000000001%  
Test accuracy: 87.6%

Epoch 44  
Training loss: 0.58343780479105319026  
Training accuracy: 94.76%  
Test accuracy: 88.2%

Epoch 45  
Training loss: 0.5813726071401272093  
Training accuracy: 94.8%

Test accuracy: 88.6%

Epoch 46

Training loss: 0.5746104797288835689

Training accuracy: 95.12%

Test accuracy: 87.8%

Epoch 47

Training loss: 0.57736468906669823493

Training accuracy: 95.19999999999999%

Test accuracy: 87.4%

Epoch 48

Training loss: 0.57321975893967532943

Training accuracy: 95.19999999999999%

Test accuracy: 87.0%

Epoch 49

Training loss: 0.57746910449444494555

Training accuracy: 94.96%

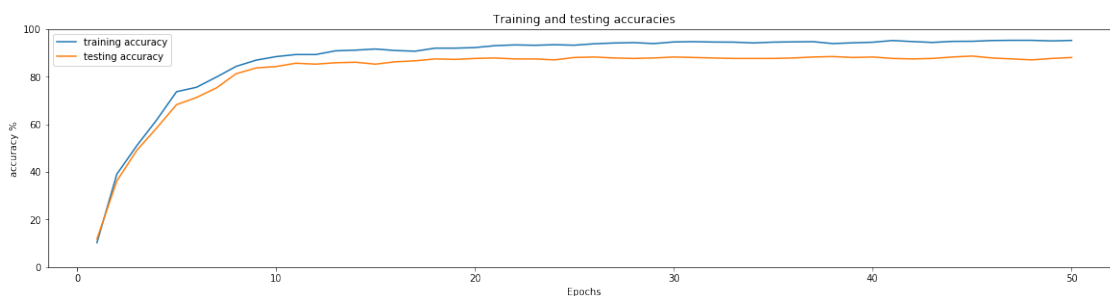
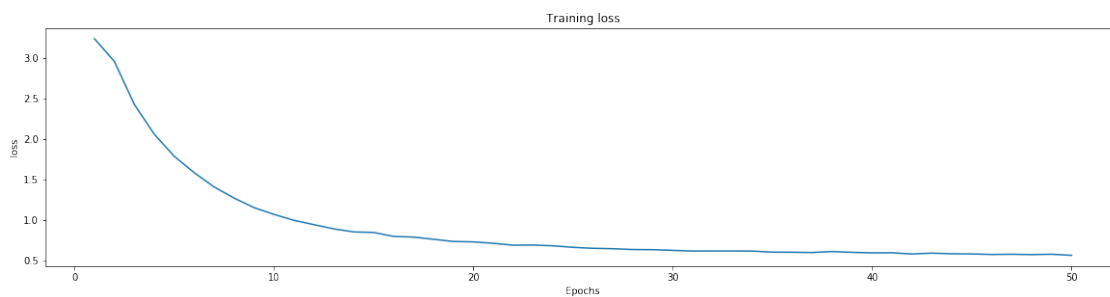
Test accuracy: 87.6%

Epoch 50

Training loss: 0.56415261698794610885

Training accuracy: 95.16%

Test accuracy: 88.0%

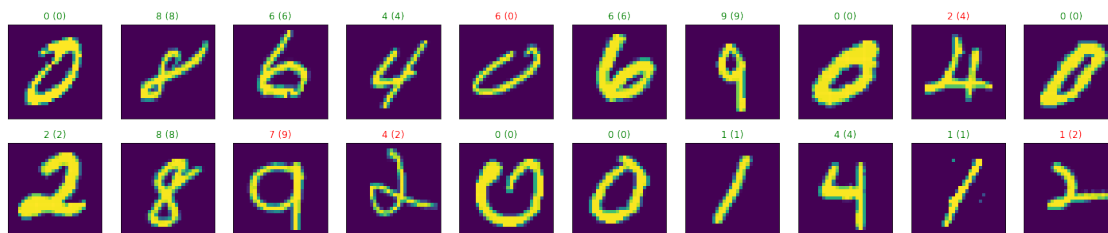


Now we are ready to visualize some results: Let's run it on 20 test datas

```
[22]: from PIL import Image
test_set = testing_data[:20]
prediction=[]
label=[]
images=[]
for (x,y) in test_set:
    prediction.append(np.argmax(net.feedforward(x)))
    label.append(y)
    image = x[0]
    image = x.reshape(28,28)*255
    images.append(image)

fig = plt.figure(figsize=(25, 5))

for idx in np.arange(20):
    ax = fig.add_subplot(2, 10, idx+1, xticks=[], yticks=[])
    plt.imshow(images[idx])
    ax.set_title("{} ({}).format(str(prediction[idx]), str(label[idx].item()))),
                color=("green" if prediction[idx]==label[idx] else "red"))
```



## 2.2.8 Now, finally lets use Cross validation to see if we get any improvement

We'll be using k-fold cross validation with k=10

```
[24]: training_data_CV = data_loader.load_full_data_cross_validate()
```

First, without any regularization

```
[28]: net2 = network.Linear_Network_CrossValidation([784,35,25,10])
```

```
[29]: net2.SGD(training_data_CV, 200, 10, 0.5, lmbda=0.0)
```

Epoch 1  
Training loss: 3.233537854495628635  
Training accuracy: 14.416666666666668%  
Test accuracy: 11.666666666666668%

Epoch 2  
Training loss: 3.2136444536432516718  
Training accuracy: 17.833333333333336%  
Test accuracy: 14.333333333333332%

Epoch 3  
Training loss: 3.1936151538179284432  
Training accuracy: 22.583333333333336%  
Test accuracy: 17.166666666666664%

Epoch 4  
Training loss: 3.1697761742039304717  
Training accuracy: 27.583333333333332%  
Test accuracy: 26.666666666666664%

Epoch 5  
Training loss: 3.1344249098431653114  
Training accuracy: 35.541666666666667%  
Test accuracy: 30.166666666666664%

Epoch 6  
Training loss: 3.0894104136105461755  
Training accuracy: 40.458333333333333%  
Test accuracy: 38.666666666666664%

Epoch 7  
Training loss: 3.0208982340898541958  
Training accuracy: 44.249999999999999%  
Test accuracy: 45.0%

Epoch 8  
Training loss: 2.924544118978684489  
Training accuracy: 45.958333333333333%  
Test accuracy: 43.666666666666667%

Epoch 9  
Training loss: 2.811105203930599877  
Training accuracy: 46.125%  
Test accuracy: 45.166666666666667%

Epoch 10  
Training loss: 2.6667257286226191304  
Training accuracy: 49.75%

Test accuracy: 48.00000000000001%

Epoch 11

Training loss: 2.5389568290337344732

Training accuracy: 52.83333333333336%

Test accuracy: 55.5%

Epoch 12

Training loss: 2.3855806663028148716

Training accuracy: 55.375%

Test accuracy: 51.5%

Epoch 13

Training loss: 2.271666654296425065

Training accuracy: 58.70833333333333%

Test accuracy: 61.0%

Epoch 14

Training loss: 2.163025813302426088

Training accuracy: 62.58333333333336%

Test accuracy: 61.6666666666667%

Epoch 15

Training loss: 2.0537074913546677784

Training accuracy: 65.20833333333334%

Test accuracy: 61.83333333333336%

Epoch 16

Training loss: 1.9638222763344113231

Training accuracy: 67.66666666666666%

Test accuracy: 67.0%

Epoch 17

Training loss: 1.8835723106574945352

Training accuracy: 68.75%

Test accuracy: 70.5%

Epoch 18

Training loss: 1.8045931964493152448

Training accuracy: 71.79166666666667%

Test accuracy: 72.0%

Epoch 19

Training loss: 1.7324466340130144214

Training accuracy: 73.12499999999999%

Test accuracy: 73.33333333333333%

Epoch 20

Training loss: 1.6648586208553211743  
Training accuracy: 75.541666666666666666%  
Test accuracy: 76.5%

Epoch 22  
Training loss: 1.535241905843814365  
Training accuracy: 77.54166666666667%  
Test accuracy: 76.16666666666667%

Epoch 24  
Training loss: 1.4430616623719659966  
Training accuracy: 79.58333333333334%  
Test accuracy: 82.5%

Epoch 26  
Training loss: 1.3301467053309693075  
Training accuracy: 82.91666666666667%  
Test accuracy: 81.0%

Epoch 28  
Training loss: 1.2445197852773281304  
Training accuracy: 84.37499999999999%  
Test accuracy: 82.83333333333334%



Epoch 30  
Training loss: 1.1489348588688546372  
Training accuracy: 86.95833333333333%  
Test accuracy: 81.83333333333334%

Epoch 31  
Training loss: 1.1161859154366940527  
Training accuracy: 86.33333333333333%  
Test accuracy: 83.83333333333333%

Epoch 32  
Training loss: 1.0884191005382822382  
Training accuracy: 86.95833333333333%  
Test accuracy: 83.33333333333333%

Epoch 33  
Training loss: 1.0557087938613798154  
Training accuracy: 87.0%  
Test accuracy: 86.66666666666666%

Epoch 34  
Training loss: 1.026124732991103635  
Training accuracy: 87.25%  
Test accuracy: 87.5%

Epoch 35  
Training loss: 0.99993741448852918466  
Training accuracy: 87.58333333333334%  
Test accuracy: 87.33333333333334%

Epoch 36  
Training loss: 0.9602884423170300631  
Training accuracy: 88.33333333333333%  
Test accuracy: 85.5%

Epoch 37  
Training loss: 0.94301490964553000794  
Training accuracy: 88.33333333333334%  
Test accuracy: 88.83333333333334%

Epoch 38  
Training loss: 0.9045795184717783384  
Training accuracy: 88.99999999999999%  
Test accuracy: 86.83333333333333%

Epoch 39  
Training loss: 0.8872087088640832861

Training accuracy: 88.33333333333333%  
Test accuracy: 88.5%

Epoch 40  
Training loss: 0.86917929699570480116  
Training accuracy: 89.16666666666667%  
Test accuracy: 88.33333333333334%

Epoch 41  
Training loss: 0.82985020283456606676  
Training accuracy: 89.95833333333333%  
Test accuracy: 85.0%

Epoch 42  
Training loss: 0.81448734432867398516  
Training accuracy: 89.875%  
Test accuracy: 87.66666666666666%

Epoch 43  
Training loss: 0.803156388806158129  
Training accuracy: 90.41666666666666%  
Test accuracy: 87.5%

Epoch 44  
Training loss: 0.80250260321638110917  
Training accuracy: 90.08333333333333%  
Test accuracy: 90.33333333333334%

Epoch 45  
Training loss: 0.7772046803427827947  
Training accuracy: 90.33333333333333%  
Test accuracy: 89.83333333333333%

Epoch 46  
Training loss: 0.7637192572759200975  
Training accuracy: 90.20833333333333%  
Test accuracy: 89.83333333333334%

Epoch 47  
Training loss: 0.7446162045200841144  
Training accuracy: 90.875%  
Test accuracy: 89.33333333333334%

Epoch 48  
Training loss: 0.7441090282189275952  
Training accuracy: 90.25000000000001%  
Test accuracy: 92.0%

Epoch 49  
Training loss: 0.71002135769709309786  
Training accuracy: 90.95833333333333%  
Test accuracy: 89.33333333333333%

Epoch 50  
Training loss: 0.70909111842985812345  
Training accuracy: 90.875%  
Test accuracy: 90.83333333333334%

Epoch 51  
Training loss: 0.68323298413620381093  
Training accuracy: 91.20833333333334%  
Test accuracy: 90.33333333333334%

Epoch 52  
Training loss: 0.66851598356334323447  
Training accuracy: 91.45833333333334%  
Test accuracy: 90.83333333333334%

Epoch 53  
Training loss: 0.64968153618653084574  
Training accuracy: 91.70833333333333%  
Test accuracy: 89.0%

Epoch 54  
Training loss: 0.6398616372196474671  
Training accuracy: 91.62500000000001%  
Test accuracy: 90.16666666666667%

Epoch 55  
Training loss: 0.6412475480804507115  
Training accuracy: 91.75%  
Test accuracy: 90.33333333333333%

Epoch 56  
Training loss: 0.62619662360283175393  
Training accuracy: 92.08333333333333%  
Test accuracy: 90.16666666666666%

Epoch 57  
Training loss: 0.614212794631739877  
Training accuracy: 92.25000000000001%  
Test accuracy: 91.0%

Epoch 58  
Training loss: 0.6136251767230409955  
Training accuracy: 92.0%

Test accuracy: 92.5%

Epoch 59

Training loss: 0.59304443407742042275

Training accuracy: 92.20833333333334%

Test accuracy: 91.49999999999999%

Epoch 60

Training loss: 0.57930135996502677673

Training accuracy: 92.41666666666667%

Test accuracy: 90.83333333333333%

Epoch 61

Training loss: 0.57294108257769131814

Training accuracy: 92.45833333333334%

Test accuracy: 92.0%

Epoch 62

Training loss: 0.5642136022420478326

Training accuracy: 92.58333333333334%

Test accuracy: 91.0%

Epoch 63

Training loss: 0.56422032895730070466

Training accuracy: 92.58333333333333%

Test accuracy: 92.16666666666666%

Epoch 64

Training loss: 0.5393062154227270558

Training accuracy: 93.0%

Test accuracy: 90.83333333333334%

Epoch 65

Training loss: 0.5346263021869130283

Training accuracy: 93.125%

Test accuracy: 91.5%

Epoch 66

Training loss: 0.53614029488283986713

Training accuracy: 93.20833333333334%

Test accuracy: 91.83333333333333%

Epoch 67

Training loss: 0.5238537524958866116

Training accuracy: 93.37499999999999%

Test accuracy: 92.16666666666666%

Epoch 68

Training loss: 0.5141374183858615948  
Training accuracy: 93.54166666666667%  
Test accuracy: 90.66666666666666%

Epoch 69  
Training loss: 0.5034502230425772184  
Training accuracy: 93.54166666666666%  
Test accuracy: 91.5%

Epoch 70  
Training loss: 0.49332982763752986497  
Training accuracy: 93.95833333333334%  
Test accuracy: 91.66666666666667%

Epoch 71  
Training loss: 0.4981555185247075186  
Training accuracy: 93.62500000000001%  
Test accuracy: 92.16666666666666%

Epoch 72  
Training loss: 0.4859485794092234187  
Training accuracy: 93.79166666666667%  
Test accuracy: 93.16666666666666%

Epoch 73  
Training loss: 0.49292245857212593703  
Training accuracy: 93.58333333333334%  
Test accuracy: 95.33333333333333%

Epoch 74  
Training loss: 0.48058538978474888274  
Training accuracy: 94.0%  
Test accuracy: 94.0%

Epoch 75  
Training loss: 0.46670350525377085426  
Training accuracy: 94.45833333333334%  
Test accuracy: 92.83333333333333%

Epoch 76  
Training loss: 0.46580880439297319  
Training accuracy: 94.04166666666667%  
Test accuracy: 94.5%

Epoch 77  
Training loss: 0.45025278126030846286  
Training accuracy: 94.41666666666666%  
Test accuracy: 93.83333333333333%

Epoch 78  
Training loss: 0.44568515329730115244  
Training accuracy: 94.625%  
Test accuracy: 93.16666666666666%

Epoch 79  
Training loss: 0.45728493769409120825  
Training accuracy: 94.04166666666666%  
Test accuracy: 95.0%

Epoch 80  
Training loss: 0.43893024364561242532  
Training accuracy: 94.41666666666666%  
Test accuracy: 94.16666666666666%

Epoch 81  
Training loss: 0.4350648032407386571  
Training accuracy: 94.95833333333333%  
Test accuracy: 94.83333333333334%

Epoch 82  
Training loss: 0.42379938359434590018  
Training accuracy: 94.95833333333333%  
Test accuracy: 92.83333333333333%

Epoch 83  
Training loss: 0.42013993720283877297  
Training accuracy: 94.66666666666666%  
Test accuracy: 94.5%

Epoch 84  
Training loss: 0.4110694180304460797  
Training accuracy: 94.95833333333333%  
Test accuracy: 94.50000000000001%

Epoch 85  
Training loss: 0.396175139717582081  
Training accuracy: 95.29166666666666%  
Test accuracy: 93.33333333333333%

Epoch 86  
Training loss: 0.40289144932859024913  
Training accuracy: 95.0%  
Test accuracy: 94.0%

Epoch 87  
Training loss: 0.3942100646964119145

Training accuracy: 95.41666666666666%  
Test accuracy: 93.66666666666667%

Epoch 88  
Training loss: 0.40213892306792189125  
Training accuracy: 95.00000000000001%  
Test accuracy: 95.00000000000001%

Epoch 89  
Training loss: 0.3930557160175613247  
Training accuracy: 95.54166666666667%  
Test accuracy: 94.16666666666666%

Epoch 90  
Training loss: 0.39824597951079950358  
Training accuracy: 95.29166666666667%  
Test accuracy: 95.49999999999999%

Epoch 91  
Training loss: 0.3860232166290985269  
Training accuracy: 95.33333333333333%  
Test accuracy: 95.5%

Epoch 92  
Training loss: 0.37552515954703147158  
Training accuracy: 95.66666666666667%  
Test accuracy: 94.16666666666666%

Epoch 93  
Training loss: 0.3674534473840604852  
Training accuracy: 95.625%  
Test accuracy: 95.16666666666666%

Epoch 94  
Training loss: 0.3760295920381473143  
Training accuracy: 95.29166666666667%  
Test accuracy: 96.0%

Epoch 95  
Training loss: 0.36306118467090412694  
Training accuracy: 95.79166666666667%  
Test accuracy: 94.66666666666667%

Epoch 96  
Training loss: 0.3668929916001822132  
Training accuracy: 95.83333333333334%  
Test accuracy: 95.5%

Epoch 97  
Training loss: 0.35835375228697677834  
Training accuracy: 95.70833333333334%  
Test accuracy: 96.33333333333333%

Epoch 98  
Training loss: 0.34991033829118221109  
Training accuracy: 95.95833333333334%  
Test accuracy: 95.5%

Epoch 99  
Training loss: 0.34653206556367312252  
Training accuracy: 96.16666666666666%  
Test accuracy: 95.49999999999999%

Epoch 100  
Training loss: 0.34749667747319227767  
Training accuracy: 96.12499999999999%  
Test accuracy: 96.16666666666666%

Epoch 101  
Training loss: 0.33248805795580390975  
Training accuracy: 96.50000000000001%  
Test accuracy: 94.5%

Epoch 102  
Training loss: 0.33296794195569076542  
Training accuracy: 96.41666666666666%  
Test accuracy: 95.50000000000001%

Epoch 103  
Training loss: 0.3230726531059142974  
Training accuracy: 96.5%  
Test accuracy: 95.16666666666666%

Epoch 104  
Training loss: 0.3186702769406441511  
Training accuracy: 96.70833333333334%  
Test accuracy: 95.0%

Epoch 105  
Training loss: 0.31552180475221269874  
Training accuracy: 96.37500000000001%  
Test accuracy: 96.33333333333333%

Epoch 106  
Training loss: 0.30715800825228927538  
Training accuracy: 96.70833333333334%



Test accuracy: 95.16666666666666%

Epoch 107

Training loss: 0.31372719525712916458

Training accuracy: 96.54166666666667%

Test accuracy: 96.33333333333334%

Epoch 108

Training loss: 0.31147468389433702747

Training accuracy: 96.58333333333334%

Test accuracy: 97.00000000000001%

Epoch 109

Training loss: 0.30401946100437874022

Training accuracy: 96.75000000000001%

Test accuracy: 95.33333333333333%

Epoch 110

Training loss: 0.29473213582329932522

Training accuracy: 97.04166666666666%

Test accuracy: 95.0%

Epoch 111

Training loss: 0.30458225851461759233

Training accuracy: 96.70833333333334%

Test accuracy: 96.66666666666667%

Epoch 112

Training loss: 0.3024291566177774124

Training accuracy: 96.83333333333334%

Test accuracy: 96.16666666666667%

Epoch 113

Training loss: 0.2959282481177537407

Training accuracy: 96.83333333333333%

Test accuracy: 96.33333333333333%

Epoch 114

Training loss: 0.29864434406749244862

Training accuracy: 96.45833333333333%

Test accuracy: 97.83333333333334%

Epoch 115

Training loss: 0.27537320018474425207

Training accuracy: 97.54166666666666%

Test accuracy: 94.99999999999999%

Epoch 116

Training loss: 0.28973314538900529308  
Training accuracy: 97.04166666666666%  
Test accuracy: 96.33333333333334%

Epoch 117  
Training loss: 0.27828360515138396428  
Training accuracy: 97.29166666666667%  
Test accuracy: 96.33333333333333%

Epoch 118  
Training loss: 0.2748774380718776696  
Training accuracy: 97.12499999999999%  
Test accuracy: 96.66666666666666%

Epoch 119  
Training loss: 0.27885319655724924705  
Training accuracy: 97.37500000000001%  
Test accuracy: 98.0%

Epoch 120  
Training loss: 0.2607242075577945485  
Training accuracy: 97.625%  
Test accuracy: 96.33333333333333%

Epoch 121  
Training loss: 0.27190881512309718004  
Training accuracy: 97.41666666666666%  
Test accuracy: 97.83333333333334%

Epoch 122  
Training loss: 0.27499029498764918783  
Training accuracy: 97.41666666666666%  
Test accuracy: 97.5%

Epoch 123  
Training loss: 0.26492011557657773056  
Training accuracy: 97.54166666666667%  
Test accuracy: 96.33333333333334%

Epoch 124  
Training loss: 0.26281708558338961248  
Training accuracy: 97.79166666666666%  
Test accuracy: 97.0%

Epoch 125  
Training loss: 0.2594877697893804848  
Training accuracy: 97.5%  
Test accuracy: 97.33333333333333%

Epoch 126  
Training loss: 0.24801046766115878418  
Training accuracy: 97.58333333333333%  
Test accuracy: 97.99999999999999%

Epoch 127  
Training loss: 0.2544819256691145019  
Training accuracy: 97.66666666666666%  
Test accuracy: 97.33333333333334%

Epoch 128  
Training loss: 0.2510110560142390494  
Training accuracy: 97.83333333333334%  
Test accuracy: 97.50000000000001%

Epoch 129  
Training loss: 0.24983823585143704555  
Training accuracy: 97.74999999999999%  
Test accuracy: 97.83333333333334%

Epoch 130  
Training loss: 0.23796188689254582613  
Training accuracy: 97.75%  
Test accuracy: 97.16666666666666%

Epoch 131  
Training loss: 0.24288715871391874937  
Training accuracy: 97.79166666666666%  
Test accuracy: 98.5%

Epoch 132  
Training loss: 0.23844946243967035447  
Training accuracy: 98.20833333333334%  
Test accuracy: 97.16666666666666%

Epoch 133  
Training loss: 0.23248424737769048774  
Training accuracy: 98.16666666666667%  
Test accuracy: 97.00000000000001%

Epoch 134  
Training loss: 0.23234957393184391429  
Training accuracy: 98.16666666666666%  
Test accuracy: 97.33333333333333%

Epoch 135  
Training loss: 0.23069132606995833797

Training accuracy: 98.16666666666666%  
Test accuracy: 97.66666666666666%

Epoch 136  
Training loss: 0.22076983262285283384  
Training accuracy: 98.25%  
Test accuracy: 98.0%

Epoch 137  
Training loss: 0.22856290434131055765  
Training accuracy: 98.25%  
Test accuracy: 97.99999999999999%

Epoch 138  
Training loss: 0.23152964668479385666  
Training accuracy: 98.375%  
Test accuracy: 98.33333333333334%

Epoch 139  
Training loss: 0.21639159129902917635  
Training accuracy: 98.5%  
Test accuracy: 96.99999999999999%

Epoch 140  
Training loss: 0.21353158560195480684  
Training accuracy: 98.375%  
Test accuracy: 97.83333333333334%

Epoch 141  
Training loss: 0.2068775154896613747  
Training accuracy: 98.66666666666666%  
Test accuracy: 97.0%

Epoch 142  
Training loss: 0.21651357599337643696  
Training accuracy: 98.25%  
Test accuracy: 98.66666666666666%

Epoch 143  
Training loss: 0.21344324591054655433  
Training accuracy: 98.29166666666666%  
Test accuracy: 98.33333333333333%

Epoch 144  
Training loss: 0.2050188983531804092  
Training accuracy: 98.375%  
Test accuracy: 98.33333333333334%

Epoch 145  
Training loss: 0.19500051027553397246  
Training accuracy: 98.83333333333334%  
Test accuracy: 97.66666666666667%

Epoch 146  
Training loss: 0.21241827381397513069  
Training accuracy: 98.375%  
Test accuracy: 98.66666666666667%

Epoch 147  
Training loss: 0.19445402009707637442  
Training accuracy: 98.58333333333334%  
Test accuracy: 97.99999999999999%

Epoch 148  
Training loss: 0.20635011804810885895  
Training accuracy: 98.58333333333333%  
Test accuracy: 98.99999999999999%

Epoch 149  
Training loss: 0.1964831167542076017  
Training accuracy: 98.45833333333333%  
Test accuracy: 98.66666666666666%

Epoch 150  
Training loss: 0.20080591498319494352  
Training accuracy: 98.41666666666667%  
Test accuracy: 99.33333333333334%

Epoch 151  
Training loss: 0.18069974580529949233  
Training accuracy: 98.95833333333333%  
Test accuracy: 97.33333333333334%

Epoch 152  
Training loss: 0.19249646562606721745  
Training accuracy: 98.54166666666666%  
Test accuracy: 98.83333333333334%

Epoch 153  
Training loss: 0.19488623774093451176  
Training accuracy: 98.58333333333333%  
Test accuracy: 99.0%

Epoch 154  
Training loss: 0.18104430865038142136  
Training accuracy: 98.62499999999999%

Test accuracy: 98.33333333333334%

Epoch 155

Training loss: 0.1800293033728428389

Training accuracy: 98.66666666666666%

Test accuracy: 98.5%

Epoch 156

Training loss: 0.17708346129552741228

Training accuracy: 98.95833333333334%

Test accuracy: 97.99999999999999%

Epoch 157

Training loss: 0.16836035965957944655

Training accuracy: 98.875%

Test accuracy: 98.16666666666666%

Epoch 158

Training loss: 0.17230847323947600167

Training accuracy: 98.91666666666666%

Test accuracy: 98.33333333333333%

Epoch 159

Training loss: 0.17912693189021032777

Training accuracy: 98.75%

Test accuracy: 98.49999999999999%

Epoch 160

Training loss: 0.17388458647384169331

Training accuracy: 98.83333333333333%

Test accuracy: 99.16666666666667%

Epoch 161

Training loss: 0.1730708292116527965

Training accuracy: 98.79166666666667%

Test accuracy: 98.83333333333333%

Epoch 162

Training loss: 0.17582647651474587496

Training accuracy: 98.79166666666666%

Test accuracy: 98.83333333333334%

Epoch 163

Training loss: 0.16697540169145183065

Training accuracy: 99.08333333333334%

Test accuracy: 98.33333333333333%

Epoch 164

Training loss: 0.17309629249206558117  
Training accuracy: 98.79166666666667%  
Test accuracy: 99.0%

Epoch 165  
Training loss: 0.1612094477521055103  
Training accuracy: 98.95833333333333%  
Test accuracy: 98.66666666666666%

Epoch 166  
Training loss: 0.16564558997883734772  
Training accuracy: 98.87499999999999%  
Test accuracy: 99.0%

Epoch 167  
Training loss: 0.16820310344190631736  
Training accuracy: 99.0%  
Test accuracy: 99.16666666666667%

Epoch 168  
Training loss: 0.1532430830000172007  
Training accuracy: 99.0%  
Test accuracy: 98.66666666666667%

Epoch 169  
Training loss: 0.15882823152176912601  
Training accuracy: 98.95833333333333%  
Test accuracy: 98.66666666666666%

Epoch 170  
Training loss: 0.1548341771018890666  
Training accuracy: 99.0%  
Test accuracy: 98.33333333333334%

Epoch 171  
Training loss: 0.15523995129799627125  
Training accuracy: 99.0%  
Test accuracy: 98.83333333333334%

Epoch 172  
Training loss: 0.14957948841058119952  
Training accuracy: 98.95833333333334%  
Test accuracy: 98.83333333333333%

Epoch 173  
Training loss: 0.14611684124963931899  
Training accuracy: 99.125%  
Test accuracy: 98.33333333333334%

Epoch 174  
Training loss: 0.15140465326693490838  
Training accuracy: 99.124999999999999999%  
Test accuracy: 98.6666666666666666%

Epoch 175  
Training loss: 0.14590294970227477  
Training accuracy: 99.125%  
Test accuracy: 98.8333333333333334%

Epoch 176  
Training loss: 0.15298028938280705454  
Training accuracy: 98.8333333333333334%  
Test accuracy: 99.6666666666666666%

Epoch 177  
Training loss: 0.14639683234569530505  
Training accuracy: 99.0416666666666666%  
Test accuracy: 99.5%

Epoch 178  
Training loss: 0.14749199265373726139  
Training accuracy: 99.1666666666666666%  
Test accuracy: 99.0%

Epoch 179  
Training loss: 0.14646913557516882468  
Training accuracy: 99.1666666666666667%  
Test accuracy: 99.3333333333333333%

Epoch 180  
Training loss: 0.14253620112813249294  
Training accuracy: 99.2500000000000001%  
Test accuracy: 99.1666666666666666%

Epoch 181  
Training loss: 0.14190517383155897439  
Training accuracy: 99.1666666666666667%  
Test accuracy: 99.5%

Epoch 182  
Training loss: 0.14018644935665947645  
Training accuracy: 99.2083333333333333%  
Test accuracy: 99.5%

Epoch 183  
Training loss: 0.14080945784592921594



Training accuracy: 99.29166666666667%  
Test accuracy: 98.83333333333333%

Epoch 184  
Training loss: 0.13775736094223302348  
Training accuracy: 99.25000000000001%  
Test accuracy: 99.16666666666666%

Epoch 185  
Training loss: 0.13406607285524639679  
Training accuracy: 99.375%  
Test accuracy: 98.83333333333333%

Epoch 186  
Training loss: 0.13258924166296546687  
Training accuracy: 99.29166666666666%  
Test accuracy: 99.16666666666666%

Epoch 187  
Training loss: 0.13080697710423674828  
Training accuracy: 99.25000000000001%  
Test accuracy: 99.0%

Epoch 188  
Training loss: 0.13426622844138323114  
Training accuracy: 99.33333333333333%  
Test accuracy: 98.99999999999999%

Epoch 189  
Training loss: 0.12549673862456182001  
Training accuracy: 99.45833333333334%  
Test accuracy: 98.83333333333334%

Epoch 190  
Training loss: 0.13033045967816450953  
Training accuracy: 99.20833333333334%  
Test accuracy: 99.5%

Epoch 191  
Training loss: 0.123998500961384386214  
Training accuracy: 99.45833333333333%  
Test accuracy: 98.66666666666667%

Epoch 192  
Training loss: 0.120301707585032027984  
Training accuracy: 99.41666666666667%  
Test accuracy: 98.83333333333333%

Epoch 193

Training loss: 0.12077861821056685112

Training accuracy: 99.375%

Test accuracy: 99.16666666666666%

Epoch 194

Training loss: 0.123122047850643746134

Training accuracy: 99.33333333333334%

Test accuracy: 99.33333333333334%

Epoch 195

Training loss: 0.1244189069402086804

Training accuracy: 99.50000000000001%

Test accuracy: 99.00000000000001%

Epoch 196

Training loss: 0.11702673569830103874

Training accuracy: 99.33333333333334%

Test accuracy: 99.5%

Epoch 197

Training loss: 0.12590261000093152491

Training accuracy: 99.16666666666666%

Test accuracy: 100.0%

Epoch 198

Training loss: 0.12202674122549884145

Training accuracy: 99.33333333333333%

Test accuracy: 99.33333333333333%

Epoch 199

Training loss: 0.10853645496922166513

Training accuracy: 99.54166666666666%

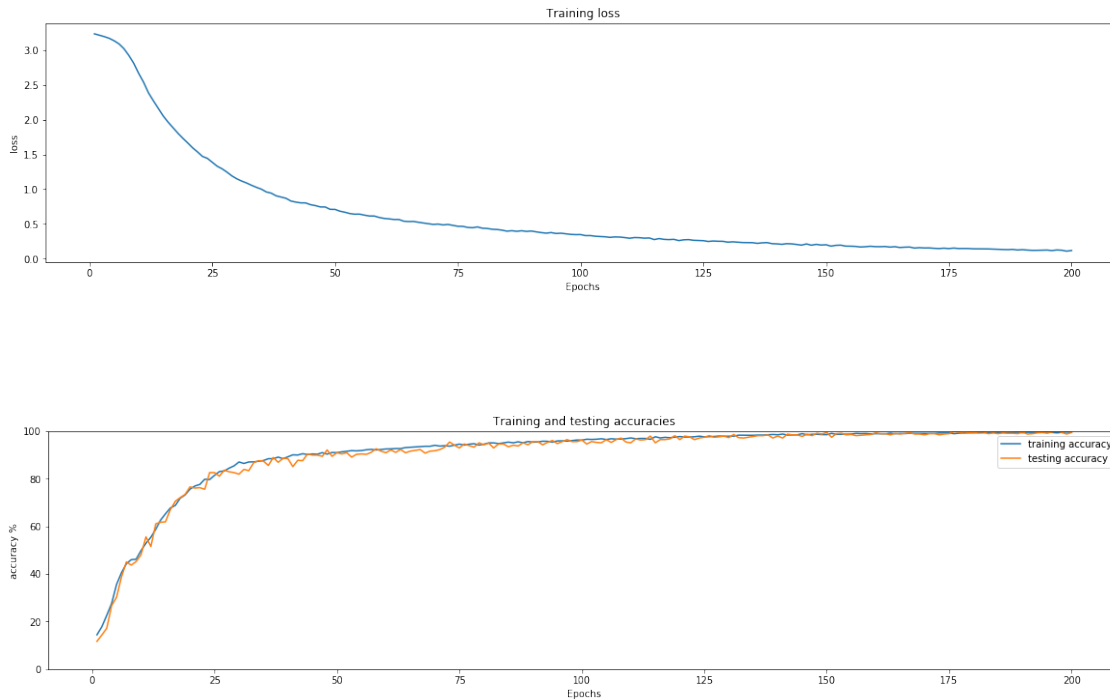
Test accuracy: 98.66666666666666%

Epoch 200

Training loss: 0.11863103602889296698

Training accuracy: 99.37500000000001%

Test accuracy: 99.33333333333333%



Now trying with a regularizatin factor:

```
[26]: net2 = network.Linear_Network_CrossValidation([784,35,25,10])
```

```
[27]: net2.SGD(training_data_CV, 200, 10, 0.5, lmbda=5.0)
```

Epoch 1

Training loss: 3.2479787792207839177

Training accuracy: 13.708333333333334%

Test accuracy: 13.0%

Epoch 2

Training loss: 3.2154712958092353582

Training accuracy: 16.083333333333336%

Test accuracy: 15.833333333333334%

Epoch 3

Training loss: 3.2042990612529214736

Training accuracy: 18.750000000000004%

Test accuracy: 17.166666666666664%

Epoch 4

Training loss: 3.182185956432032023

Training accuracy: 23.666666666666664%

Test accuracy: 19.000000000000004%

Epoch 5  
Training loss: 3.1563591483696204476  
Training accuracy: 26.5%  
Test accuracy: 23.499999999999996%

Epoch 6  
Training loss: 3.1190120285228041847  
Training accuracy: 30.958333333333332%  
Test accuracy: 30.0%

Epoch 7  
Training loss: 3.069249316275351229  
Training accuracy: 34.041666666666664%  
Test accuracy: 35.166666666666667%

Epoch 8  
Training loss: 2.9886785482640016581  
Training accuracy: 36.291666666666664%  
Test accuracy: 35.0%

Epoch 9  
Training loss: 2.8987725837657495876  
Training accuracy: 37.208333333333336%  
Test accuracy: 34.166666666666664%

Epoch 10  
Training loss: 2.7956088561542536055  
Training accuracy: 37.416666666666667%  
Test accuracy: 31.499999999999993%

Epoch 11  
Training loss: 2.7089090824446049124  
Training accuracy: 40.541666666666664%  
Test accuracy: 39.33333333333333%

Epoch 12  
Training loss: 2.6062313580128571404  
Training accuracy: 44.708333333333336%  
Test accuracy: 46.83333333333333%

Epoch 13  
Training loss: 2.5099035431732771692  
Training accuracy: 47.791666666666667%  
Test accuracy: 49.333333333333336%

Epoch 14  
Training loss: 2.4219925465016178784

Training accuracy: 48.541666666666664%  
Test accuracy: 42.333333333333336%

Epoch 15  
Training loss: 2.3499499555415663823  
Training accuracy: 52.083333333333333%  
Test accuracy: 48.333333333333336%

Epoch 16  
Training loss: 2.276330190651422131  
Training accuracy: 56.0%  
Test accuracy: 54.833333333333336%

Epoch 17  
Training loss: 2.2000531576148051117  
Training accuracy: 57.25%  
Test accuracy: 54.666666666666664%

Epoch 18  
Training loss: 2.1370256995314808892  
Training accuracy: 61.041666666666667%  
Test accuracy: 59.333333333333336%

Epoch 19  
Training loss: 2.0848511237533405892  
Training accuracy: 62.791666666666667%  
Test accuracy: 65.5%

Epoch 20  
Training loss: 2.0137205909015272482  
Training accuracy: 67.041666666666667%  
Test accuracy: 66.16666666666666%

Epoch 21  
Training loss: 1.9533093302620241818  
Training accuracy: 67.624999999999999%  
Test accuracy: 67.833333333333334%

Epoch 22  
Training loss: 1.8898338987303976112  
Training accuracy: 69.583333333333333%  
Test accuracy: 71.16666666666666%

Epoch 23  
Training loss: 1.8307328454711889418  
Training accuracy: 70.875000000000001%  
Test accuracy: 67.66666666666666%

Epoch 24  
Training loss: 1.7765021115508926877  
Training accuracy: 72.33333333333333%  
Test accuracy: 72.49999999999999%

Epoch 25  
Training loss: 1.7024188140817697199  
Training accuracy: 74.20833333333333%  
Test accuracy: 73.16666666666666%

Epoch 26  
Training loss: 1.6527680905120517129  
Training accuracy: 75.58333333333334%  
Test accuracy: 71.66666666666666%

Epoch 27  
Training loss: 1.5972874361736717142  
Training accuracy: 76.29166666666666%  
Test accuracy: 72.83333333333334%

Epoch 28  
Training loss: 1.5564497143070425788  
Training accuracy: 76.95833333333334%  
Test accuracy: 77.0%

Epoch 29  
Training loss: 1.5136278775985920208  
Training accuracy: 78.0%  
Test accuracy: 78.33333333333334%

Epoch 30  
Training loss: 1.4587659710007716225  
Training accuracy: 80.125%  
Test accuracy: 78.33333333333334%

Epoch 31  
Training loss: 1.4288245516540630599  
Training accuracy: 79.62499999999999%  
Test accuracy: 80.16666666666666%

Epoch 32  
Training loss: 1.3919085680526149597  
Training accuracy: 80.5%  
Test accuracy: 79.33333333333333%

Epoch 33  
Training loss: 1.3573732137636988203  
Training accuracy: 81.37500000000001%

Test accuracy: 80.66666666666666%

Epoch 34

Training loss: 1.3169464158206277386

Training accuracy: 82.33333333333334%

Test accuracy: 80.16666666666667%

Epoch 35

Training loss: 1.3033419912520667014

Training accuracy: 82.875%

Test accuracy: 83.5%

Epoch 36

Training loss: 1.2511141410983288981

Training accuracy: 83.20833333333333%

Test accuracy: 81.33333333333334%

Epoch 37

Training loss: 1.2312799379665704251

Training accuracy: 83.25%

Test accuracy: 83.0%

Epoch 38

Training loss: 1.1893164088582373971

Training accuracy: 84.20833333333334%

Test accuracy: 81.83333333333334%

Epoch 39

Training loss: 1.1833968778192231737

Training accuracy: 83.875%

Test accuracy: 85.0%

Epoch 40

Training loss: 1.1497179650784195005

Training accuracy: 84.375%

Test accuracy: 84.33333333333334%

Epoch 41

Training loss: 1.1216700277295455729

Training accuracy: 85.66666666666666%

Test accuracy: 83.16666666666666%

Epoch 42

Training loss: 1.0936943182485305148

Training accuracy: 85.16666666666666%

Test accuracy: 84.83333333333334%

Epoch 43

Training loss: 1.068147430165589693  
Training accuracy: 86.75%  
Test accuracy: 84.33333333333333%

Epoch 44  
Training loss: 1.0534425528084259783  
Training accuracy: 86.66666666666666%  
Test accuracy: 85.66666666666667%

Epoch 45  
Training loss: 1.036295909911595317  
Training accuracy: 86.95833333333334%  
Test accuracy: 84.66666666666666%

Epoch 46  
Training loss: 1.0191970198548043363  
Training accuracy: 87.29166666666666%  
Test accuracy: 86.16666666666666%

Epoch 47  
Training loss: 1.0244400105473987117  
Training accuracy: 86.91666666666666%  
Test accuracy: 89.50000000000001%

Epoch 48  
Training loss: 0.98375971192371858655  
Training accuracy: 87.70833333333334%  
Test accuracy: 87.49999999999999%

Epoch 49  
Training loss: 0.97154038585373679593  
Training accuracy: 87.54166666666666%  
Test accuracy: 89.33333333333334%

Epoch 50  
Training loss: 0.9463017908414572534  
Training accuracy: 88.625%  
Test accuracy: 87.66666666666667%

Epoch 51  
Training loss: 0.92899965423135429706  
Training accuracy: 88.20833333333334%  
Test accuracy: 89.0%

Epoch 52  
Training loss: 0.91672584990988335954  
Training accuracy: 89.29166666666666%  
Test accuracy: 88.16666666666666%



Epoch 53  
Training loss: 0.9005839156835550208  
Training accuracy: 89.12499999999999%  
Test accuracy: 88.33333333333333%

Epoch 55  
Training loss: 0.87706860489942942773  
Training accuracy: 89.625%  
Test accuracy: 89.66666666666667%

Epoch 57  
Training loss: 0.8433923231931204901  
Training accuracy: 90.08333333333333%  
Test accuracy: 88.5%

Epoch 59  
Training loss: 0.81998067367123828866  
Training accuracy: 90.25%  
Test accuracy: 88.83333333333333%

Epoch 61  
Training loss: 0.805538576371802753  
Training accuracy: 90.5%  
Test accuracy: 89.66666666666666%

Training accuracy: 90.625%  
Test accuracy: 89.5%

Epoch 63  
Training loss: 0.78104992318246836854  
Training accuracy: 90.66666666666666%  
Test accuracy: 90.33333333333333%

Epoch 64  
Training loss: 0.78488597126647265166  
Training accuracy: 90.70833333333333%  
Test accuracy: 91.66666666666666%

Epoch 65  
Training loss: 0.76586877184553158544  
Training accuracy: 91.04166666666666%  
Test accuracy: 91.0%

Epoch 66  
Training loss: 0.7627415076328802056  
Training accuracy: 90.70833333333334%  
Test accuracy: 91.5%

Epoch 67  
Training loss: 0.7394111681129755427  
Training accuracy: 91.12500000000001%  
Test accuracy: 89.0%

Epoch 68  
Training loss: 0.7414956570038536551  
Training accuracy: 90.99999999999999%  
Test accuracy: 92.00000000000001%

Epoch 69  
Training loss: 0.73016313568748646167  
Training accuracy: 91.33333333333334%  
Test accuracy: 91.66666666666666%

Epoch 70  
Training loss: 0.710853685886049901  
Training accuracy: 91.50000000000001%  
Test accuracy: 89.66666666666666%

Epoch 71  
Training loss: 0.7012255025330277849  
Training accuracy: 92.0%  
Test accuracy: 89.5%

Epoch 72  
Training loss: 0.69835240969558038207  
Training accuracy: 91.875%  
Test accuracy: 90.83333333333333%

Epoch 73  
Training loss: 0.7096119642473644569  
Training accuracy: 91.45833333333333%  
Test accuracy: 92.0%

Epoch 74  
Training loss: 0.68662704130133062606  
Training accuracy: 91.79166666666666%  
Test accuracy: 90.66666666666666%

Epoch 75  
Training loss: 0.6794407135588605874  
Training accuracy: 92.125%  
Test accuracy: 90.16666666666666%

Epoch 76  
Training loss: 0.6791475667787470243  
Training accuracy: 92.0%  
Test accuracy: 90.50000000000001%

Epoch 77  
Training loss: 0.6777194222773522526  
Training accuracy: 91.79166666666666%  
Test accuracy: 92.5%

Epoch 78  
Training loss: 0.66271087886373034666  
Training accuracy: 92.20833333333333%  
Test accuracy: 91.66666666666666%

Epoch 79  
Training loss: 0.67312596809601807346  
Training accuracy: 92.12500000000001%  
Test accuracy: 92.16666666666666%

Epoch 80  
Training loss: 0.66089598602693623737  
Training accuracy: 92.12499999999999%  
Test accuracy: 92.66666666666667%

Epoch 81  
Training loss: 0.63810989381418171766  
Training accuracy: 92.41666666666666%

Test accuracy: 90.16666666666667%

Epoch 82

Training loss: 0.64148968075877913587

Training accuracy: 92.33333333333334%

Test accuracy: 90.83333333333333%

Epoch 83

Training loss: 0.6265699034142066583

Training accuracy: 93.125%

Test accuracy: 89.0%

Epoch 84

Training loss: 0.6392864012220427994

Training accuracy: 92.66666666666666%

Test accuracy: 92.83333333333334%

Epoch 85

Training loss: 0.6266006267387549588

Training accuracy: 92.58333333333333%

Test accuracy: 92.0%

Epoch 86

Training loss: 0.62211655318230423104

Training accuracy: 92.95833333333333%

Test accuracy: 91.16666666666666%

Epoch 87

Training loss: 0.60962395522159163467

Training accuracy: 92.70833333333334%

Test accuracy: 92.0%

Epoch 88

Training loss: 0.61555908748795964784

Training accuracy: 92.66666666666666%

Test accuracy: 91.83333333333333%

Epoch 89

Training loss: 0.6206448106112517699

Training accuracy: 92.70833333333334%

Test accuracy: 94.0%

Epoch 90

Training loss: 0.62019830209994132966

Training accuracy: 92.75%

Test accuracy: 93.83333333333333%

Epoch 91

Training loss: 0.6065650652854656403  
Training accuracy: 93.124999999999999999%  
Test accuracy: 93.0%

Epoch 92  
Training loss: 0.58744448276939657263  
Training accuracy: 93.625%  
Test accuracy: 90.6666666666666666%

Epoch 93  
Training loss: 0.600956259946204607  
Training accuracy: 93.5%  
Test accuracy: 93.1666666666666666%

Epoch 94  
Training loss: 0.58942465346894128  
Training accuracy: 93.2083333333333334%  
Test accuracy: 91.8333333333333334%

Epoch 95  
Training loss: 0.5875020532472406944  
Training accuracy: 93.5%  
Test accuracy: 93.0000000000000001%

Epoch 96  
Training loss: 0.58659921324732605024  
Training accuracy: 93.3750000000000001%  
Test accuracy: 92.6666666666666666%

Epoch 97  
Training loss: 0.59270500196454628056  
Training accuracy: 93.3333333333333334%  
Test accuracy: 94.3333333333333333%

Epoch 98  
Training loss: 0.57404966506087506137  
Training accuracy: 93.5%  
Test accuracy: 93.1666666666666666%

Epoch 99  
Training loss: 0.5603962451653039363  
Training accuracy: 93.9583333333333333%  
Test accuracy: 92.0%

Epoch 100  
Training loss: 0.58139950112372748667  
Training accuracy: 93.6666666666666666%  
Test accuracy: 94.3333333333333334%

Epoch 101  
Training loss: 0.5504932939981991767  
Training accuracy: 94.33333333333334%  
Test accuracy: 90.66666666666667%

Epoch 102  
Training loss: 0.56695328661168041204  
Training accuracy: 93.875%  
Test accuracy: 93.33333333333333%

Epoch 103  
Training loss: 0.57478326237261645915  
Training accuracy: 93.75%  
Test accuracy: 94.5%

Epoch 104  
Training loss: 0.5490889575171057555  
Training accuracy: 94.41666666666666%  
Test accuracy: 93.33333333333333%

Epoch 105  
Training loss: 0.5546534616126897231  
Training accuracy: 93.91666666666666%  
Test accuracy: 93.16666666666667%

Epoch 106  
Training loss: 0.5520286629063114423  
Training accuracy: 94.04166666666666%  
Test accuracy: 94.83333333333334%

Epoch 107  
Training loss: 0.5460721922486810489  
Training accuracy: 94.50000000000001%  
Test accuracy: 93.0%

Epoch 108  
Training loss: 0.55054706705771070394  
Training accuracy: 94.25%  
Test accuracy: 94.33333333333334%

Epoch 109  
Training loss: 0.5269611817405436965  
Training accuracy: 95.04166666666666%  
Test accuracy: 92.16666666666666%

Epoch 110  
Training loss: 0.5317618483310746433

Training accuracy: 94.83333333333334%  
Test accuracy: 93.33333333333334%

Epoch 111  
Training loss: 0.5335269180206591611  
Training accuracy: 94.58333333333333%  
Test accuracy: 93.83333333333333%

Epoch 112  
Training loss: 0.53408761113067549655  
Training accuracy: 94.625%  
Test accuracy: 93.16666666666667%

Epoch 113  
Training loss: 0.5348281387170761161  
Training accuracy: 94.33333333333334%  
Test accuracy: 93.83333333333333%

Epoch 114  
Training loss: 0.5250364345596446813  
Training accuracy: 94.41666666666667%  
Test accuracy: 94.16666666666666%

Epoch 115  
Training loss: 0.5234101195985151651  
Training accuracy: 94.70833333333333%  
Test accuracy: 94.66666666666667%

Epoch 116  
Training loss: 0.5217382568419288064  
Training accuracy: 94.87499999999999%  
Test accuracy: 94.33333333333333%

Epoch 117  
Training loss: 0.51962051617765403315  
Training accuracy: 94.70833333333333%  
Test accuracy: 93.66666666666667%

Epoch 118  
Training loss: 0.52130206091476524255  
Training accuracy: 94.95833333333334%  
Test accuracy: 93.5%

Epoch 119  
Training loss: 0.51533498021104942084  
Training accuracy: 94.58333333333334%  
Test accuracy: 95.5%

Epoch 120  
Training loss: 0.51609079989613041383  
Training accuracy: 94.625%  
Test accuracy: 94.83333333333333%

Epoch 121  
Training loss: 0.50384150804798183155  
Training accuracy: 94.87500000000001%  
Test accuracy: 94.16666666666666%

Epoch 122  
Training loss: 0.50643285932262460805  
Training accuracy: 95.20833333333334%  
Test accuracy: 93.66666666666666%

Epoch 123  
Training loss: 0.51582140268006260186  
Training accuracy: 94.66666666666666%  
Test accuracy: 95.5%

Epoch 124  
Training loss: 0.5091117830962293215  
Training accuracy: 95.20833333333334%  
Test accuracy: 94.16666666666667%

Epoch 125  
Training loss: 0.50716910626601717537  
Training accuracy: 94.83333333333334%  
Test accuracy: 94.66666666666667%

Epoch 126  
Training loss: 0.5071110830179545531  
Training accuracy: 95.04166666666667%  
Test accuracy: 94.16666666666666%

Epoch 127  
Training loss: 0.5039549932007919334  
Training accuracy: 94.91666666666667%  
Test accuracy: 94.66666666666666%

Epoch 128  
Training loss: 0.50361859516030878464  
Training accuracy: 94.91666666666667%  
Test accuracy: 95.83333333333333%

Epoch 129  
Training loss: 0.49259359032396152932  
Training accuracy: 95.29166666666666%



Test accuracy: 94.66666666666666%

Epoch 130

Training loss: 0.4907284238405285068

Training accuracy: 95.45833333333334%

Test accuracy: 94.83333333333333%

Epoch 131

Training loss: 0.48310457404232942468

Training accuracy: 95.66666666666666%

Test accuracy: 93.0%

Epoch 132

Training loss: 0.48791446557895463304

Training accuracy: 95.41666666666666%

Test accuracy: 95.0%

Epoch 133

Training loss: 0.49101799830916978995

Training accuracy: 95.5%

Test accuracy: 94.16666666666666%

Epoch 134

Training loss: 0.49048526167185543665

Training accuracy: 95.45833333333334%

Test accuracy: 94.33333333333333%

Epoch 135

Training loss: 0.47997909318411970857

Training accuracy: 95.54166666666667%

Test accuracy: 95.16666666666666%

Epoch 136

Training loss: 0.47579368600119046465

Training accuracy: 95.45833333333333%

Test accuracy: 95.66666666666667%

Epoch 137

Training loss: 0.47108000085166319392

Training accuracy: 95.95833333333334%

Test accuracy: 94.16666666666666%

Epoch 138

Training loss: 0.47646555171408798445

Training accuracy: 95.66666666666667%

Test accuracy: 94.49999999999999%

Epoch 139



Epoch 149  
Training loss: 0.46718194888642835738  
Training accuracy: 95.875%  
Test accuracy: 95.5%

Epoch 150  
Training loss: 0.464452477329352695  
Training accuracy: 95.75%  
Test accuracy: 95.83333333333334%

Epoch 151  
Training loss: 0.4610188101660739184  
Training accuracy: 96.0%  
Test accuracy: 95.66666666666667%

Epoch 152  
Training loss: 0.45564314486874410524  
Training accuracy: 96.0%  
Test accuracy: 95.16666666666666%

Epoch 153  
Training loss: 0.4601041060101812616  
Training accuracy: 95.95833333333333%  
Test accuracy: 95.83333333333334%

Epoch 154  
Training loss: 0.46589302702050002682  
Training accuracy: 95.95833333333334%  
Test accuracy: 96.16666666666666%

Epoch 155  
Training loss: 0.45420338458819624095  
Training accuracy: 95.83333333333333%  
Test accuracy: 95.66666666666666%

Epoch 156  
Training loss: 0.44855392484374034855  
Training accuracy: 95.83333333333334%  
Test accuracy: 95.33333333333334%

Epoch 157  
Training loss: 0.46783527992994196118  
Training accuracy: 95.83333333333334%  
Test accuracy: 96.66666666666666%

Epoch 158  
Training loss: 0.44617249531030554245

Training accuracy: 96.08333333333334%  
Test accuracy: 95.50000000000001%

Epoch 159  
Training loss: 0.44695191723628128672  
Training accuracy: 96.16666666666667%  
Test accuracy: 95.33333333333334%

Epoch 160  
Training loss: 0.45036137108818487636  
Training accuracy: 96.125%  
Test accuracy: 96.0%

Epoch 161  
Training loss: 0.4580546348782063869  
Training accuracy: 96.04166666666667%  
Test accuracy: 96.83333333333334%

Epoch 162  
Training loss: 0.45555172418512725527  
Training accuracy: 96.16666666666666%  
Test accuracy: 96.66666666666667%

Epoch 163  
Training loss: 0.44272595571754029116  
Training accuracy: 96.41666666666666%  
Test accuracy: 94.83333333333333%

Epoch 164  
Training loss: 0.4442842545900404404  
Training accuracy: 96.20833333333334%  
Test accuracy: 95.66666666666666%

Epoch 165  
Training loss: 0.43802554099214790318  
Training accuracy: 96.37500000000001%  
Test accuracy: 95.16666666666667%

Epoch 166  
Training loss: 0.44936497505826862903  
Training accuracy: 96.5%  
Test accuracy: 95.5%

Epoch 167  
Training loss: 0.44641058052415321457  
Training accuracy: 96.25%  
Test accuracy: 95.83333333333333%

Epoch 168  
Training loss: 0.43520848574175497914  
Training accuracy: 96.62499999999999%  
Test accuracy: 94.66666666666666%

Epoch 169  
Training loss: 0.43161511494384770276  
Training accuracy: 96.5%  
Test accuracy: 95.33333333333334%

Epoch 170  
Training loss: 0.43887963752914026493  
Training accuracy: 96.66666666666667%  
Test accuracy: 95.5%

Epoch 171  
Training loss: 0.43442849268067308053  
Training accuracy: 96.5%  
Test accuracy: 95.66666666666666%

Epoch 172  
Training loss: 0.43207938416741564582  
Training accuracy: 96.45833333333333%  
Test accuracy: 95.5%

Epoch 173  
Training loss: 0.43798534118285132273  
Training accuracy: 96.375%  
Test accuracy: 95.49999999999999%

Epoch 174  
Training loss: 0.4395933946795436394  
Training accuracy: 96.375%  
Test accuracy: 96.49999999999999%

Epoch 175  
Training loss: 0.43344800167307012494  
Training accuracy: 96.66666666666667%  
Test accuracy: 96.0%

Epoch 176  
Training loss: 0.41954139758632181642  
Training accuracy: 96.41666666666667%  
Test accuracy: 95.66666666666666%

Epoch 177  
Training loss: 0.42110946009268479306  
Training accuracy: 97.08333333333333%

Test accuracy: 93.83333333333334%

Epoch 178

Training loss: 0.42806099112787142705

Training accuracy: 96.66666666666666%

Test accuracy: 95.16666666666666%

Epoch 179

Training loss: 0.41451573947503286447

Training accuracy: 97.08333333333333%

Test accuracy: 94.0%

Epoch 180

Training loss: 0.42837178988459138066

Training accuracy: 96.66666666666666%

Test accuracy: 96.0%

Epoch 181

Training loss: 0.41777400980930845076

Training accuracy: 96.625%

Test accuracy: 95.5%

Epoch 182

Training loss: 0.4300578992498257296

Training accuracy: 96.375%

Test accuracy: 96.83333333333334%

Epoch 183

Training loss: 0.42260262215924090161

Training accuracy: 96.58333333333333%

Test accuracy: 95.83333333333334%

Epoch 184

Training loss: 0.41978967039299038634

Training accuracy: 97.08333333333334%

Test accuracy: 95.66666666666667%

Epoch 185

Training loss: 0.4124393061934362509

Training accuracy: 97.20833333333334%

Test accuracy: 94.5%

Epoch 186

Training loss: 0.417288354227210665

Training accuracy: 97.0%

Test accuracy: 95.0%

Epoch 187

Training loss: 0.4206368764987213967  
Training accuracy: 96.91666666666666%  
Test accuracy: 94.5%

Epoch 188  
Training loss: 0.42209755188837812825  
Training accuracy: 96.83333333333333%  
Test accuracy: 95.66666666666667%

Epoch 189  
Training loss: 0.4145557828829357251  
Training accuracy: 96.50000000000001%  
Test accuracy: 96.5%

Epoch 190  
Training loss: 0.420670286377289013  
Training accuracy: 96.37500000000001%  
Test accuracy: 96.5%

Epoch 191  
Training loss: 0.43247128160499316018  
Training accuracy: 96.62500000000001%  
Test accuracy: 98.16666666666666%

Epoch 192  
Training loss: 0.41842589671255519542  
Training accuracy: 96.83333333333334%  
Test accuracy: 96.33333333333334%

Epoch 193  
Training loss: 0.42039387861725794484  
Training accuracy: 96.87499999999999%  
Test accuracy: 95.66666666666666%

Epoch 194  
Training loss: 0.41658119987596791442  
Training accuracy: 96.79166666666666%  
Test accuracy: 97.16666666666667%

Epoch 195  
Training loss: 0.4084725959622829171  
Training accuracy: 97.16666666666666%  
Test accuracy: 96.00000000000001%

Epoch 196  
Training loss: 0.41613037961262712774  
Training accuracy: 97.0%  
Test accuracy: 96.83333333333334%

Epoch 197

Training loss: 0.41428437566116258127

Training accuracy: 96.875%

Test accuracy: 96.33333333333334%

Epoch 198

Training loss: 0.4027377666574514209

Training accuracy: 96.91666666666667%

Test accuracy: 96.5%

Epoch 199

Training loss: 0.41719520111587007888

Training accuracy: 97.0%

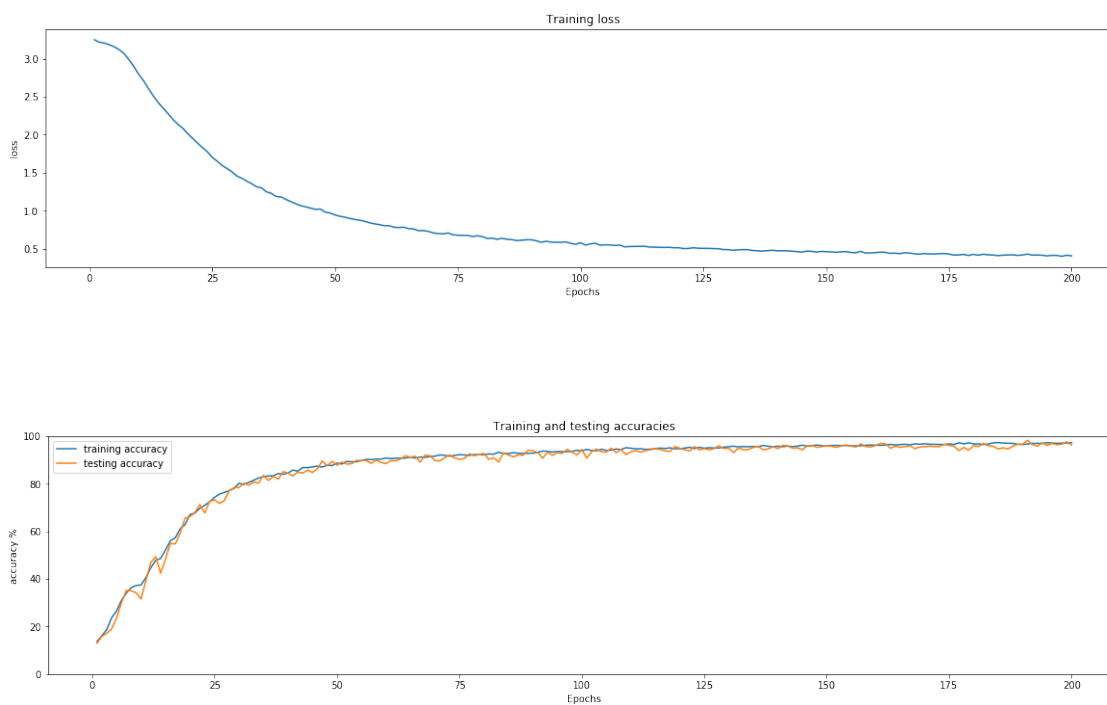
Test accuracy: 97.5%

Epoch 200

Training loss: 0.40886217833198734307

Training accuracy: 97.16666666666666%

Test accuracy: 96.16666666666666%



We see that there has been a little drop in both training and testing accuracy. But we can't be sure it's overfitting as the train and test accuracies are the same.



**2.2.9** So here I take the liberty to test my model using Cross Validation, on the entire MNIST data set.

```
[3]: import mnist_loader
```

```
[5]: training_data_MNIST, validation_data_MNIST, __ = mnist_loader.  
     ↪ load_data_wrapper()
```

```
[6]: net_mnist = network.Linear_Network_CrossValidation([784,35,25,10])
```

```
[7]: """No Regularization"""  
     net_mnist.SGD(training_data_MNIST, 200, 10, 0.5, lambda=0.0)
```

Epoch 1

Training loss: 3.2549137677927903634

Training accuracy: 12.0%

Test accuracy: 12.370000000000001%

Epoch 2

Training loss: 3.2303653631804196348

Training accuracy: 13.15%

Test accuracy: 13.62%

Epoch 3

Training loss: 3.21403511856918898

Training accuracy: 15.615%

Test accuracy: 15.780000000000001%

Epoch 4

Training loss: 3.1937961060341875327

Training accuracy: 26.5625%

Test accuracy: 27.370000000000005%

Epoch 5

Training loss: 3.1650126603191624968

Training accuracy: 29.375%

Test accuracy: 28.360000000000003%

Epoch 6

Training loss: 3.12670138108243522

Training accuracy: 39.94%

Test accuracy: 39.910000000000004%

Epoch 7

Training loss: 3.0709740305697261484

Training accuracy: 46.9375%

Test accuracy: 46.42999999999999%

```
Epoch 8
Training loss: 2.9931596486721955392
Training accuracy: 50.13999999999999%
Test accuracy: 49.290000000000006%
```

```
Epoch 9
Training loss: 2.891747902007158164
Training accuracy: 52.81750000000001%
Test accuracy: 52.08%
```

Epoch 10  
Training loss: 2.7685683583480938375  
Training accuracy: 54.3925%  
Test accuracy: 54.25%

Epoch 11  
Training loss: 2.630258383457266856  
Training accuracy: 56.735%  
Test accuracy: 56.48%

```
Epoch 12
Training loss: 2.4923512324388638832
Training accuracy: 58.602500000000006%
Test accuracy: 59.129999999999995%
```

Epoch 13  
Training loss: 2.3600355157016473136  
Training accuracy: 60.625%  
Test accuracy: 60.529999999999994%

Epoch 14  
Training loss: 2.240377761388976314  
Training accuracy: 62.4775%  
Test accuracy: 61.80999999999999%

Epoch 15  
Training loss: 2.1316149126602059413  
Training accuracy: 64.3875%  
Test accuracy: 64.59%

```
Epoch 16
Training loss: 2.0391558080466419735
Training accuracy: 65.94500000000001%
Test accuracy: 65.78999999999999%
```

Epoch 17  
Training loss: 1.9522488193406969867

Training accuracy: 67.2625%  
Test accuracy: 67.6%

Epoch 18  
Training loss: 1.8733498855591442873  
Training accuracy: 68.945%  
Test accuracy: 68.66999999999999%

Epoch 19  
Training loss: 1.805443993400869609  
Training accuracy: 70.2725%  
Test accuracy: 70.68%

Epoch 20  
Training loss: 1.7426149503634943496  
Training accuracy: 71.7375%  
Test accuracy: 71.74%

Epoch 21  
Training loss: 1.6820376008064805446  
Training accuracy: 73.07%  
Test accuracy: 73.28%

Epoch 22  
Training loss: 1.6244922816915998697  
Training accuracy: 74.365%  
Test accuracy: 74.14999999999999%

Epoch 23  
Training loss: 1.571081227523225908  
Training accuracy: 75.81750000000001%  
Test accuracy: 74.94000000000001%

Epoch 24  
Training loss: 1.5243752162732040671  
Training accuracy: 76.64500000000001%  
Test accuracy: 76.2%

Epoch 25  
Training loss: 1.480156117464390088  
Training accuracy: 77.7975%  
Test accuracy: 77.53%

Epoch 26  
Training loss: 1.4385026077754121182  
Training accuracy: 78.39750000000001%  
Test accuracy: 78.53%

Epoch 27  
Training loss: 1.3957791996356729744  
Training accuracy: 79.42750000000001%  
Test accuracy: 78.95%

Epoch 28  
Training loss: 1.3602404962390186127  
Training accuracy: 80.1%  
Test accuracy: 79.62%

Epoch 29  
Training loss: 1.3283987004161619605  
Training accuracy: 80.495%  
Test accuracy: 81.29%

Epoch 30  
Training loss: 1.2930813677184594752  
Training accuracy: 81.18749999999999%  
Test accuracy: 80.9%

Epoch 31  
Training loss: 1.261496540479844636  
Training accuracy: 81.775%  
Test accuracy: 81.5%

Epoch 32  
Training loss: 1.2327775380045271845  
Training accuracy: 82.3825%  
Test accuracy: 82.0%

Epoch 33  
Training loss: 1.2060662840206091873  
Training accuracy: 82.79999999999998%  
Test accuracy: 82.53999999999999%

Epoch 34  
Training loss: 1.1844482896911789679  
Training accuracy: 83.2775%  
Test accuracy: 83.1%

Epoch 35  
Training loss: 1.161595883817496025  
Training accuracy: 83.47749999999999%  
Test accuracy: 83.81%

Epoch 36  
Training loss: 1.1392114834219438607  
Training accuracy: 83.82249999999999%

Test accuracy: 84.04999999999998%

Epoch 37

Training loss: 1.1166716869641731766

Training accuracy: 84.32%

Test accuracy: 84.28%

Epoch 38

Training loss: 1.0979606377663168706

Training accuracy: 84.70750000000001%

Test accuracy: 84.82000000000001%

Epoch 39

Training loss: 1.0785392624043462338

Training accuracy: 85.02499999999999%

Test accuracy: 84.91999999999999%

Epoch 40

Training loss: 1.0612535013347289558

Training accuracy: 85.255%

Test accuracy: 85.05000000000001%

Epoch 41

Training loss: 1.0426605148625425263

Training accuracy: 85.54999999999998%

Test accuracy: 85.51%

Epoch 42

Training loss: 1.0284946224904879825

Training accuracy: 85.77000000000001%

Test accuracy: 85.67%

Epoch 43

Training loss: 1.0157374918889092406

Training accuracy: 85.975%

Test accuracy: 86.19999999999999%

Epoch 44

Training loss: 0.99515816367788840124

Training accuracy: 86.2475%

Test accuracy: 86.16%

Epoch 45

Training loss: 0.9801303680028433522

Training accuracy: 86.5325%

Test accuracy: 86.17999999999999%

Epoch 46

Training loss: 0.966785838606484092  
Training accuracy: 86.60749999999999%  
Test accuracy: 86.56%

Epoch 47  
Training loss: 0.95068921172750765465  
Training accuracy: 86.8925%  
Test accuracy: 86.65%

Epoch 48  
Training loss: 0.93652689937533321223  
Training accuracy: 87.05%  
Test accuracy: 86.9%

Epoch 49  
Training loss: 0.9254670877761319656  
Training accuracy: 87.3125%  
Test accuracy: 86.80000000000001%

Epoch 50  
Training loss: 0.9140372425036052727  
Training accuracy: 87.3675%  
Test accuracy: 87.57%

Epoch 51  
Training loss: 0.904290560709954509  
Training accuracy: 87.55749999999999%  
Test accuracy: 87.83%

Epoch 52  
Training loss: 0.8867661538703144436  
Training accuracy: 87.86000000000001%  
Test accuracy: 87.26%

Epoch 53  
Training loss: 0.875880878884457069  
Training accuracy: 87.9525%  
Test accuracy: 87.72%

Epoch 54  
Training loss: 0.8615725011764432524  
Training accuracy: 88.08749999999999%  
Test accuracy: 88.01%

Epoch 55  
Training loss: 0.85341504151270984396  
Training accuracy: 88.25%  
Test accuracy: 88.10999999999999%

Epoch 56  
Training loss: 0.8417671681075545337  
Training accuracy: 88.36%  
Test accuracy: 88.35%

Epoch 57  
Training loss: 0.8289953714605576363  
Training accuracy: 88.51750000000001%  
Test accuracy: 88.32%

Epoch 58  
Training loss: 0.81829261046099114  
Training accuracy: 88.695%  
Test accuracy: 88.36%

Epoch 59  
Training loss: 0.80942514720686124503  
Training accuracy: 88.75250000000001%  
Test accuracy: 88.91000000000001%

Epoch 60  
Training loss: 0.7956351261920827223  
Training accuracy: 88.9975%  
Test accuracy: 88.45%

Epoch 61  
Training loss: 0.78813499901126612214  
Training accuracy: 89.06249999999999%  
Test accuracy: 89.09%

Epoch 62  
Training loss: 0.7788519710412564244  
Training accuracy: 89.19500000000001%  
Test accuracy: 89.09%

Epoch 63  
Training loss: 0.7689662174097436863  
Training accuracy: 89.34%  
Test accuracy: 89.21000000000001%

Epoch 64  
Training loss: 0.7575235873248800461  
Training accuracy: 89.4525%  
Test accuracy: 89.13%

Epoch 65  
Training loss: 0.75145383160936609853

Training accuracy: 89.49%  
Test accuracy: 89.53%

Epoch 66  
Training loss: 0.7419267448887730292  
Training accuracy: 89.63%  
Test accuracy: 89.52000000000001%

Epoch 67  
Training loss: 0.7322442811956738567  
Training accuracy: 89.76750000000001%  
Test accuracy: 89.57000000000002%

Epoch 68  
Training loss: 0.72794642162758390637  
Training accuracy: 89.745%  
Test accuracy: 90.18%

Epoch 69  
Training loss: 0.7177915802939758386  
Training accuracy: 89.95000000000002%  
Test accuracy: 89.97999999999999%

Epoch 70  
Training loss: 0.70870041609145359397  
Training accuracy: 90.0925%  
Test accuracy: 89.88000000000001%

Epoch 71  
Training loss: 0.6999011838930103235  
Training accuracy: 90.09750000000001%  
Test accuracy: 90.38000000000001%

Epoch 72  
Training loss: 0.69583124688280737613  
Training accuracy: 90.2325%  
Test accuracy: 90.41%

Epoch 73  
Training loss: 0.68438552760432424946  
Training accuracy: 90.425%  
Test accuracy: 89.83%

Epoch 74  
Training loss: 0.67960758771305266126  
Training accuracy: 90.35249999999999%  
Test accuracy: 90.53%



Epoch 75  
Training loss: 0.66858719771266861184  
Training accuracy: 90.59%  
Test accuracy: 90.03%

Epoch 76  
Training loss: 0.66460862669553705126  
Training accuracy: 90.63250000000001%  
Test accuracy: 90.3%

Epoch 77  
Training loss: 0.65845408640708696067  
Training accuracy: 90.72999999999999%  
Test accuracy: 90.45%

Epoch 78  
Training loss: 0.654727499811937681  
Training accuracy: 90.675%  
Test accuracy: 90.84%

Epoch 79  
Training loss: 0.64757340471736984797  
Training accuracy: 90.75000000000001%  
Test accuracy: 90.92000000000002%

Epoch 80  
Training loss: 0.63996706109492308386  
Training accuracy: 90.9375%  
Test accuracy: 90.56%

Epoch 81  
Training loss: 0.6327073615411694417  
Training accuracy: 91.0225%  
Test accuracy: 90.63000000000001%

Epoch 82  
Training loss: 0.62732354312631060137  
Training accuracy: 91.00500000000001%  
Test accuracy: 90.86000000000001%

Epoch 83  
Training loss: 0.6256448658602083171  
Training accuracy: 91.00750000000001%  
Test accuracy: 91.3%

Epoch 84  
Training loss: 0.62019132893406158497  
Training accuracy: 91.14%

Test accuracy: 91.3%

Epoch 85

Training loss: 0.61244786160191979116

Training accuracy: 91.22749999999999%

Test accuracy: 91.36%

Epoch 86

Training loss: 0.60711826459307285323

Training accuracy: 91.3025%

Test accuracy: 91.20000000000002%

Epoch 87

Training loss: 0.600184055851650193

Training accuracy: 91.43%

Test accuracy: 91.08%

Epoch 88

Training loss: 0.5990108866896737519

Training accuracy: 91.27000000000001%

Test accuracy: 91.87000000000002%

Epoch 89

Training loss: 0.5900999045300778182

Training accuracy: 91.5375%

Test accuracy: 91.22%

Epoch 90

Training loss: 0.5852773988774215987

Training accuracy: 91.61250000000001%

Test accuracy: 91.27000000000001%

Epoch 91

Training loss: 0.58418047490896880857

Training accuracy: 91.58%

Test accuracy: 91.69000000000001%

Epoch 92

Training loss: 0.579592058875964512

Training accuracy: 91.66%

Test accuracy: 91.81000000000002%

Epoch 93

Training loss: 0.57360444315982017275

Training accuracy: 91.765%

Test accuracy: 91.62000000000002%

Epoch 94

Training loss: 0.56961162705048020506  
Training accuracy: 91.78%  
Test accuracy: 91.87%

Epoch 95  
Training loss: 0.56548790206478602877  
Training accuracy: 91.80749999999999%  
Test accuracy: 92.07%

Epoch 96  
Training loss: 0.5634193632574755771  
Training accuracy: 91.86%  
Test accuracy: 92.20000000000002%

Epoch 97  
Training loss: 0.55950622641808686315  
Training accuracy: 91.9875%  
Test accuracy: 91.98%

Epoch 98  
Training loss: 0.55115533455225003954  
Training accuracy: 92.145%  
Test accuracy: 91.75%

Epoch 99  
Training loss: 0.5471877368783312996  
Training accuracy: 92.155%  
Test accuracy: 91.88000000000001%

Epoch 100  
Training loss: 0.5448680766244118351  
Training accuracy: 92.13250000000001%  
Test accuracy: 92.16%

Epoch 101  
Training loss: 0.54243870365330319565  
Training accuracy: 92.06750000000001%  
Test accuracy: 92.45000000000002%

Epoch 102  
Training loss: 0.5370593625097435376  
Training accuracy: 92.2625%  
Test accuracy: 92.03999999999999%

Epoch 103  
Training loss: 0.53105385026293428397  
Training accuracy: 92.3125%  
Test accuracy: 92.09%

Epoch 104  
Training loss: 0.5297263652094429525  
Training accuracy: 92.31500000000001%  
Test accuracy: 92.32%

Epoch 105  
Training loss: 0.5263967963182853283  
Training accuracy: 92.43499999999999%  
Test accuracy: 91.94000000000001%

Epoch 106  
Training loss: 0.5274688864474547382  
Training accuracy: 92.365%  
Test accuracy: 92.72999999999999%

Epoch 107  
Training loss: 0.5235953992051184295  
Training accuracy: 92.405%  
Test accuracy: 92.7%

Epoch 108  
Training loss: 0.5175529612526807184  
Training accuracy: 92.52000000000001%  
Test accuracy: 92.65%

Epoch 109  
Training loss: 0.5158665966011020421  
Training accuracy: 92.50750000000002%  
Test accuracy: 92.85%

Epoch 110  
Training loss: 0.51481355013236593  
Training accuracy: 92.57750000000001%  
Test accuracy: 92.83%

Epoch 111  
Training loss: 0.50925440215825335324  
Training accuracy: 92.67750000000001%  
Test accuracy: 92.72%

Epoch 112  
Training loss: 0.50499963713168657606  
Training accuracy: 92.695%  
Test accuracy: 92.92%

Epoch 113  
Training loss: 0.50213016499462745574

Training accuracy: 92.765%  
Test accuracy: 92.73000000000002%

Epoch 114  
Training loss: 0.49810210946167742847  
Training accuracy: 92.7925%  
Test accuracy: 92.82000000000001%

Epoch 115  
Training loss: 0.49790211655841601942  
Training accuracy: 92.85249999999999%  
Test accuracy: 92.99000000000001%

Epoch 116  
Training loss: 0.48859874138618185173  
Training accuracy: 92.99500000000002%  
Test accuracy: 92.44999999999999%

Epoch 117  
Training loss: 0.48978641375085480393  
Training accuracy: 92.95%  
Test accuracy: 92.84%

Epoch 118  
Training loss: 0.48704454981115405631  
Training accuracy: 92.89%  
Test accuracy: 93.16%

Epoch 119  
Training loss: 0.484836892365944668  
Training accuracy: 93.0575%  
Test accuracy: 92.69000000000001%

Epoch 120  
Training loss: 0.48621767385332914264  
Training accuracy: 92.9225%  
Test accuracy: 93.35%

Epoch 121  
Training loss: 0.47850526845609744902  
Training accuracy: 93.065%  
Test accuracy: 93.0%

Epoch 122  
Training loss: 0.47659508450624067256  
Training accuracy: 93.07999999999998%  
Test accuracy: 93.06%

Epoch 123  
Training loss: 0.47475122446445212868  
Training accuracy: 93.16%  
Test accuracy: 93.02000000000001%

Epoch 124  
Training loss: 0.46808274880120322436  
Training accuracy: 93.24000000000001%  
Test accuracy: 92.87000000000002%

Epoch 125  
Training loss: 0.464224337508312318  
Training accuracy: 93.32%  
Test accuracy: 92.70000000000002%

Epoch 126  
Training loss: 0.46988140038887290812  
Training accuracy: 93.13500000000002%  
Test accuracy: 93.56%

Epoch 127  
Training loss: 0.46361561131306186644  
Training accuracy: 93.2775%  
Test accuracy: 93.21%

Epoch 128  
Training loss: 0.45892261712413412377  
Training accuracy: 93.33250000000001%  
Test accuracy: 93.01%

Epoch 129  
Training loss: 0.45826159034971505017  
Training accuracy: 93.37750000000001%  
Test accuracy: 93.01000000000002%

Epoch 130  
Training loss: 0.45846006918214342476  
Training accuracy: 93.41%  
Test accuracy: 93.14999999999999%

Epoch 131  
Training loss: 0.45815364481465175616  
Training accuracy: 93.3425%  
Test accuracy: 93.53999999999999%

Epoch 132  
Training loss: 0.45448285490169881536  
Training accuracy: 93.3575%

Test accuracy: 93.54%

Epoch 133

Training loss: 0.45174609817699773196

Training accuracy: 93.4075%

Test accuracy: 93.52000000000001%

Epoch 134

Training loss: 0.45057287792781927746

Training accuracy: 93.44249999999998%

Test accuracy: 93.62000000000002%

Epoch 135

Training loss: 0.4439435776773952469

Training accuracy: 93.5325%

Test accuracy: 93.25999999999999%

Epoch 136

Training loss: 0.44411678811575270052

Training accuracy: 93.525%

Test accuracy: 93.49%

Epoch 137

Training loss: 0.44324457879588654674

Training accuracy: 93.54249999999999%

Test accuracy: 93.49000000000001%

Epoch 138

Training loss: 0.44324319123878696525

Training accuracy: 93.5275%

Test accuracy: 93.71000000000001%

Epoch 139

Training loss: 0.43987613901745248817

Training accuracy: 93.5825%

Test accuracy: 93.78999999999999%

Epoch 140

Training loss: 0.436664713581823304

Training accuracy: 93.625%

Test accuracy: 93.77%

Epoch 141

Training loss: 0.4303227235650945576

Training accuracy: 93.68249999999999%

Test accuracy: 93.64%

Epoch 142

Training loss: 0.432802817843634215  
Training accuracy: 93.71499999999999%  
Test accuracy: 93.71000000000001%

Epoch 143  
Training loss: 0.4317384451137185207  
Training accuracy: 93.665%  
Test accuracy: 93.91%

Epoch 144  
Training loss: 0.43032012582326622176  
Training accuracy: 93.815%  
Test accuracy: 93.42%

Epoch 145  
Training loss: 0.42626187542228994367  
Training accuracy: 93.735%  
Test accuracy: 93.88999999999999%

Epoch 146  
Training loss: 0.42455500294497585572  
Training accuracy: 93.80250000000001%  
Test accuracy: 93.72%

Epoch 147  
Training loss: 0.42492543858901883044  
Training accuracy: 93.8%  
Test accuracy: 93.98%

Epoch 148  
Training loss: 0.41534818677721852632  
Training accuracy: 93.99749999999999%  
Test accuracy: 93.32000000000001%

Epoch 149  
Training loss: 0.42087038405811670627  
Training accuracy: 93.88749999999999%  
Test accuracy: 94.00000000000001%

Epoch 150  
Training loss: 0.41203653624302735985  
Training accuracy: 94.04499999999999%  
Test accuracy: 93.38%

Epoch 151  
Training loss: 0.41643164182219858093  
Training accuracy: 93.91499999999999%  
Test accuracy: 94.11%



Epoch 152  
Training loss: 0.41449397009616625697  
Training accuracy: 93.9975%  
Test accuracy: 93.89999999999999%

Epoch 153  
Training loss: 0.41173198523883212108  
Training accuracy: 94.0275%  
Test accuracy: 94.0%

Epoch 154  
Training loss: 0.41026183189993263158  
Training accuracy: 94.11999999999999%  
Test accuracy: 93.89%

Epoch 155  
Training loss: 0.4054492057734267452  
Training accuracy: 94.10499999999999%  
Test accuracy: 93.79999999999998%

Epoch 156  
Training loss: 0.40589666704218758153  
Training accuracy: 94.1725%  
Test accuracy: 93.77%

Epoch 157  
Training loss: 0.404836185027750019  
Training accuracy: 94.11500000000001%  
Test accuracy: 94.22%

Epoch 158  
Training loss: 0.402943400746825336  
Training accuracy: 94.1525%  
Test accuracy: 94.10999999999999%

Epoch 159  
Training loss: 0.40145288672166645096  
Training accuracy: 94.23999999999998%  
Test accuracy: 94.0%

Epoch 160  
Training loss: 0.40315426738565076397  
Training accuracy: 94.16%  
Test accuracy: 94.38%

Epoch 161  
Training loss: 0.39737144454527497956

Training accuracy: 94.33500000000001%  
Test accuracy: 94.03%

Epoch 162  
Training loss: 0.39719513921885937996  
Training accuracy: 94.2425%  
Test accuracy: 94.41%

Epoch 163  
Training loss: 0.3935560846615894485  
Training accuracy: 94.3075%  
Test accuracy: 94.1%

Epoch 164  
Training loss: 0.39344206609875944522  
Training accuracy: 94.3525%  
Test accuracy: 94.04%

Epoch 165  
Training loss: 0.39207711194504963484  
Training accuracy: 94.31250000000001%  
Test accuracy: 94.35%

Epoch 166  
Training loss: 0.39158693397253236702  
Training accuracy: 94.38250000000001%  
Test accuracy: 94.05000000000001%

Epoch 167  
Training loss: 0.3925627827420703906  
Training accuracy: 94.38%  
Test accuracy: 94.45%

Epoch 168  
Training loss: 0.39159753003450063319  
Training accuracy: 94.3%  
Test accuracy: 94.77%

Epoch 169  
Training loss: 0.3877796217170760142  
Training accuracy: 94.39%  
Test accuracy: 94.53%

Epoch 170  
Training loss: 0.38908044454082560282  
Training accuracy: 94.3375%  
Test accuracy: 94.85%

Epoch 171  
Training loss: 0.38192892321099931502  
Training accuracy: 94.54249999999999%  
Test accuracy: 94.28999999999999%

Epoch 172  
Training loss: 0.38199241506695650637  
Training accuracy: 94.53500000000001%  
Test accuracy: 94.35%

Epoch 173  
Training loss: 0.37985634652989393956  
Training accuracy: 94.53500000000001%  
Test accuracy: 94.39999999999999%

Epoch 174  
Training loss: 0.38163356179768788897  
Training accuracy: 94.49749999999999%  
Test accuracy: 94.58000000000001%

Epoch 175  
Training loss: 0.37882859869658468631  
Training accuracy: 94.56249999999999%  
Test accuracy: 94.48999999999998%

Epoch 176  
Training loss: 0.36935909014981529018  
Training accuracy: 94.7025%  
Test accuracy: 94.02000000000001%

Epoch 177  
Training loss: 0.37198621856431785004  
Training accuracy: 94.61999999999999%  
Test accuracy: 94.52%

Epoch 178  
Training loss: 0.3778492781379183282  
Training accuracy: 94.575%  
Test accuracy: 94.77%

Epoch 179  
Training loss: 0.3782577725950479073  
Training accuracy: 94.565%  
Test accuracy: 94.96000000000001%

Epoch 180  
Training loss: 0.37036794274279403324  
Training accuracy: 94.635%

Test accuracy: 94.68999999999998%

Epoch 181

Training loss: 0.36923994361741522622

Training accuracy: 94.68250000000002%

Test accuracy: 94.62%

Epoch 182

Training loss: 0.36914934109819437492

Training accuracy: 94.65%

Test accuracy: 94.74%

Epoch 183

Training loss: 0.36384758731292012377

Training accuracy: 94.79249999999999%

Test accuracy: 94.28999999999999%

Epoch 184

Training loss: 0.36348437821860411654

Training accuracy: 94.8%

Test accuracy: 94.45%

Epoch 185

Training loss: 0.36895496375140135573

Training accuracy: 94.6775%

Test accuracy: 95.08%

Epoch 186

Training loss: 0.36330459705155400798

Training accuracy: 94.79249999999999%

Test accuracy: 94.53999999999999%

Epoch 187

Training loss: 0.3606536572984903386

Training accuracy: 94.75249999999998%

Test accuracy: 94.78999999999999%

Epoch 188

Training loss: 0.361612120255389908

Training accuracy: 94.805%

Test accuracy: 94.80999999999999%

Epoch 189

Training loss: 0.35718861163897241737

Training accuracy: 94.88749999999999%

Test accuracy: 94.53%

Epoch 190

Training loss: 0.35862918062728819823  
Training accuracy: 94.8225%  
Test accuracy: 94.85%

Epoch 191  
Training loss: 0.35949735031136498877  
Training accuracy: 94.8125%  
Test accuracy: 94.96%

Epoch 192  
Training loss: 0.3563152715485924694  
Training accuracy: 94.885%  
Test accuracy: 94.64999999999999%

Epoch 193  
Training loss: 0.35137338075906334616  
Training accuracy: 95.005%  
Test accuracy: 94.34%

Epoch 194  
Training loss: 0.35013641888528973376  
Training accuracy: 94.91749999999999%  
Test accuracy: 94.67%

Epoch 195  
Training loss: 0.34952663293369294828  
Training accuracy: 94.9775%  
Test accuracy: 94.61999999999999%

Epoch 196  
Training loss: 0.35045629155387968004  
Training accuracy: 94.95%  
Test accuracy: 94.82000000000001%

Epoch 197  
Training loss: 0.34899207640514613688  
Training accuracy: 94.94749999999999%  
Test accuracy: 94.85%

Epoch 198  
Training loss: 0.34912806308276130186  
Training accuracy: 94.975%  
Test accuracy: 94.93999999999998%

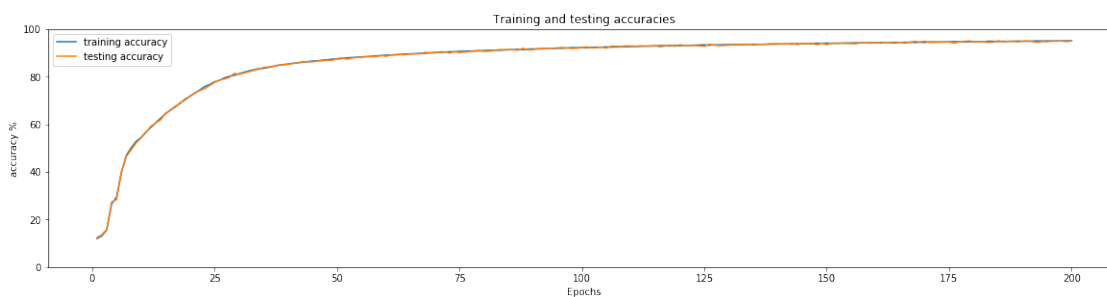
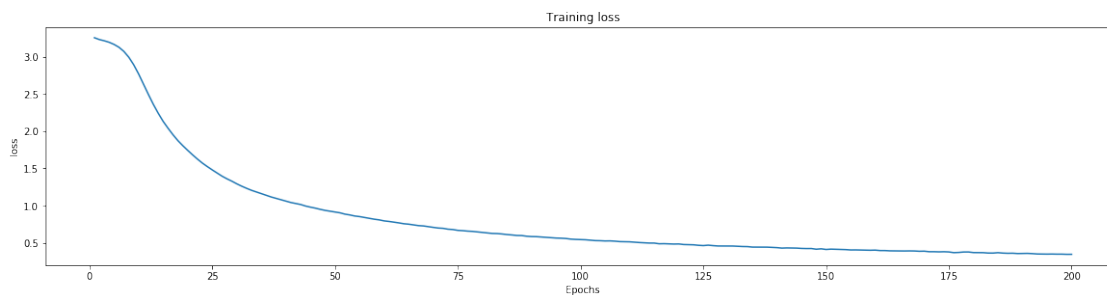
Epoch 199  
Training loss: 0.34675385339362467304  
Training accuracy: 95.03%  
Test accuracy: 94.66%

Epoch 200

Training loss: 0.347023505355116699

Training accuracy: 94.9725%

Test accuracy: 94.94%



We can see that the model performs considerably well on the larger dataset of 50000 entries with 95% accuracy. It seems we could get an higher accuracy if we continued for more epochs but considering the enormous time it takes to train the model on the entire data set, we will leave it to this.

Let us now look at the results on the validation data:

```
[10]: print ("Validation accuracy: "+str(net_mnist.  
    ↪ evaluate_validation_accuracy(validation_data_MNIST))+"%")
```

Validation accuracy: 94.87%

Hence we can see that the Cross Validation has clearly improved the performance.

## 2.3 Part 2

Now we test how well does the PCA data work compared to the normal image data. We'll use the same cost and activation here and play with the parameters of the Stochastic Gradient Descent to see which ones fit the best

Starting with no hidden layers:

```
[2]: training_data = data_loader.load_PCA()
```

```
[3]: net = network.Linear_Network_CrossValidation([25,10])
```

```
[4]: net.SGD(training_data, 200, 10, 0.1)
```

Epoch 1

Training loss: 9.22099801657356956

Training accuracy: 46.5%

Test accuracy: 45.000000000000001%

Epoch 2

Training loss: 5.6972104611961508326

Training accuracy: 64.29166666666666%

Test accuracy: 64.0%

Epoch 3

Training loss: 4.416983909376654337

Training accuracy: 69.66666666666666%

Test accuracy: 73.33333333333334%

Epoch 4

Training loss: 3.615743826552267308

Training accuracy: 73.87499999999999%

Test accuracy: 70.66666666666666%

Epoch 5

Training loss: 3.099086169043806279

Training accuracy: 76.91666666666666%

Test accuracy: 74.0%

Epoch 6

Training loss: 2.7268228464475887996

Training accuracy: 78.66666666666666%

Test accuracy: 76.83333333333334%

Epoch 7

Training loss: 2.4652329690654852014

Training accuracy: 79.20833333333334%

Test accuracy: 81.33333333333333%

Epoch 8

Training loss: 2.2423227203728069627

Training accuracy: 81.20833333333334%

Test accuracy: 81.16666666666667%

Epoch 9

Training loss: 2.0902640366876575906

Training accuracy: 81.875%

Test accuracy: 80.5%

Epoch 10

Training loss: 1.9570741335411768905

Training accuracy: 83.25000000000001%

Test accuracy: 81.33333333333334%

Epoch 11

Training loss: 1.8514596443420896478

Training accuracy: 83.16666666666666%

Test accuracy: 81.5%

Epoch 12

Training loss: 1.7771641398699509586

Training accuracy: 83.29166666666667%

Test accuracy: 82.50000000000001%

Epoch 13

Training loss: 1.6865713420050845176

Training accuracy: 83.87499999999999%

Test accuracy: 81.33333333333334%

Epoch 14

Training loss: 1.6438645911290386337

Training accuracy: 84.0%

Test accuracy: 80.66666666666667%

Epoch 15

Training loss: 1.5931499490888378794

Training accuracy: 84.04166666666666%

Test accuracy: 81.16666666666666%

Epoch 16

Training loss: 1.5275985931733456518

Training accuracy: 84.20833333333334%

Test accuracy: 81.33333333333334%

Epoch 17

Training loss: 1.5108335397047323175

Training accuracy: 83.45833333333334%

Test accuracy: 83.5%

Epoch 18

Training loss: 1.4578650939323272563

Training accuracy: 84.58333333333334%



Test accuracy: 81.83333333333334%

Epoch 19

Training loss: 1.4295217681960789051

Training accuracy: 84.33333333333334%

Test accuracy: 81.99999999999999%

Epoch 20

Training loss: 1.4023068684772099056

Training accuracy: 84.37499999999999%

Test accuracy: 82.16666666666667%

Epoch 21

Training loss: 1.393550409873582511

Training accuracy: 84.125%

Test accuracy: 83.83333333333334%

Epoch 22

Training loss: 1.3593415094239845594

Training accuracy: 84.58333333333334%

Test accuracy: 82.83333333333333%

Epoch 23

Training loss: 1.3367656897410729739

Training accuracy: 84.37500000000001%

Test accuracy: 83.16666666666666%

Epoch 24

Training loss: 1.3303301493884393016

Training accuracy: 84.08333333333333%

Test accuracy: 84.16666666666667%

Epoch 25

Training loss: 1.2997867553723576002

Training accuracy: 84.45833333333334%

Test accuracy: 83.5%

Epoch 26

Training loss: 1.2744088054515127466

Training accuracy: 85.08333333333333%

Test accuracy: 81.99999999999999%

Epoch 27

Training loss: 1.2643420714976450969

Training accuracy: 84.62499999999999%

Test accuracy: 82.66666666666666%

Epoch 28

Training loss: 1.2578427745448093097  
Training accuracy: 84.66666666666666%  
Test accuracy: 84.5%

Epoch 29  
Training loss: 1.248363277501828601  
Training accuracy: 85.0%  
Test accuracy: 83.5%

Epoch 30  
Training loss: 1.2087526776956383451  
Training accuracy: 85.29166666666666%  
Test accuracy: 82.66666666666667%

Epoch 31  
Training loss: 1.2247311884333820144  
Training accuracy: 84.91666666666666%  
Test accuracy: 84.0%

Epoch 32  
Training loss: 1.2078280365076548693  
Training accuracy: 85.12500000000001%  
Test accuracy: 83.16666666666666%

Epoch 33  
Training loss: 1.2043542942152072343  
Training accuracy: 84.95833333333333%  
Test accuracy: 84.50000000000001%

Epoch 34  
Training loss: 1.1901402066932745033  
Training accuracy: 85.04166666666667%  
Test accuracy: 83.66666666666666%

Epoch 35  
Training loss: 1.1893266877239534126  
Training accuracy: 85.125%  
Test accuracy: 84.33333333333334%

Epoch 36  
Training loss: 1.1753629308617575488  
Training accuracy: 85.00000000000001%  
Test accuracy: 83.50000000000001%

Epoch 37  
Training loss: 1.15785837871610086  
Training accuracy: 84.79166666666666%  
Test accuracy: 82.5%

Epoch 38  
Training loss: 1.1566425832193783563  
Training accuracy: 84.75%  
Test accuracy: 84.5%

Epoch 39  
Training loss: 1.1495045274817770896  
Training accuracy: 85.25%  
Test accuracy: 83.83333333333334%

Epoch 40  
Training loss: 1.1466338426937817961  
Training accuracy: 84.91666666666666%  
Test accuracy: 85.0%

Epoch 41  
Training loss: 1.131884816837323815  
Training accuracy: 85.16666666666666%  
Test accuracy: 83.5%

Epoch 42  
Training loss: 1.1207454266956132541  
Training accuracy: 85.20833333333334%  
Test accuracy: 84.66666666666667%

Epoch 43  
Training loss: 1.1151955116606021295  
Training accuracy: 85.04166666666666%  
Test accuracy: 85.0%

Epoch 44  
Training loss: 1.1286553414805337821  
Training accuracy: 85.0%  
Test accuracy: 85.5%

Epoch 45  
Training loss: 1.1231122970894174319  
Training accuracy: 84.70833333333334%  
Test accuracy: 86.16666666666667%

Epoch 46  
Training loss: 1.1006883708309570318  
Training accuracy: 85.25%  
Test accuracy: 84.33333333333334%

Epoch 47  
Training loss: 1.1063091023874119528

Training accuracy: 85.0%  
Test accuracy: 85.83333333333334%

Epoch 48  
Training loss: 1.1020724523413657304  
Training accuracy: 85.37499999999999%  
Test accuracy: 83.66666666666666%

Epoch 49  
Training loss: 1.1104249716803785487  
Training accuracy: 84.75000000000001%  
Test accuracy: 86.5%

Epoch 50  
Training loss: 1.0818069533600869779  
Training accuracy: 84.66666666666667%  
Test accuracy: 84.83333333333334%

Epoch 51  
Training loss: 1.0802805427946699336  
Training accuracy: 85.45833333333333%  
Test accuracy: 83.50000000000001%

Epoch 52  
Training loss: 1.0781572948084795707  
Training accuracy: 85.29166666666667%  
Test accuracy: 84.0%

Epoch 53  
Training loss: 1.0803223229246038665  
Training accuracy: 85.0%  
Test accuracy: 85.99999999999999%

Epoch 54  
Training loss: 1.0777593083232875224  
Training accuracy: 85.25%  
Test accuracy: 84.16666666666666%

Epoch 55  
Training loss: 1.0590637339114498695  
Training accuracy: 85.62499999999999%  
Test accuracy: 83.33333333333333%

Epoch 56  
Training loss: 1.0485721456538875736  
Training accuracy: 85.54166666666667%  
Test accuracy: 82.0%

Epoch 57  
Training loss: 1.0657101902259506693  
Training accuracy: 85.41666666666667%  
Test accuracy: 84.16666666666666%

Epoch 58  
Training loss: 1.0646789183573849475  
Training accuracy: 85.0%  
Test accuracy: 85.66666666666666%

Epoch 59  
Training loss: 1.0700191287991760078  
Training accuracy: 84.79166666666667%  
Test accuracy: 87.5%

Epoch 60  
Training loss: 1.0425749785778933251  
Training accuracy: 85.79166666666666%  
Test accuracy: 83.33333333333334%

Epoch 61  
Training loss: 1.0411661059297303879  
Training accuracy: 85.50000000000001%  
Test accuracy: 85.33333333333333%

Epoch 62  
Training loss: 1.0275679917544947195  
Training accuracy: 86.04166666666666%  
Test accuracy: 82.33333333333334%

Epoch 63  
Training loss: 1.0626175516479822297  
Training accuracy: 85.20833333333333%  
Test accuracy: 86.33333333333333%

Epoch 64  
Training loss: 1.0268900450835347518  
Training accuracy: 86.04166666666667%  
Test accuracy: 84.16666666666666%

Epoch 65  
Training loss: 1.0541205004489146379  
Training accuracy: 84.95833333333334%  
Test accuracy: 86.83333333333334%

Epoch 66  
Training loss: 1.0261506166687908975  
Training accuracy: 85.91666666666667%

Test accuracy: 84.33333333333333%

Epoch 67

Training loss: 1.0349572965866353538

Training accuracy: 85.5%

Test accuracy: 85.33333333333334%

Epoch 68

Training loss: 1.0230714984612415923

Training accuracy: 85.66666666666666%

Test accuracy: 84.16666666666667%

Epoch 69

Training loss: 1.0166117901239781439

Training accuracy: 85.87499999999999%

Test accuracy: 83.33333333333333%

Epoch 70

Training loss: 1.021026728780364924

Training accuracy: 85.79166666666667%

Test accuracy: 84.16666666666666%

Epoch 71

Training loss: 1.0259281825614258763

Training accuracy: 85.49999999999999%

Test accuracy: 85.00000000000001%

Epoch 72

Training loss: 1.0116180602894958048

Training accuracy: 85.875%

Test accuracy: 83.66666666666666%

Epoch 73

Training loss: 1.0080787574609261215

Training accuracy: 85.875%

Test accuracy: 83.83333333333334%

Epoch 74

Training loss: 1.0194721232291883708

Training accuracy: 85.5%

Test accuracy: 85.50000000000001%

Epoch 75

Training loss: 1.0048028661834067646

Training accuracy: 85.58333333333334%

Test accuracy: 83.33333333333334%

Epoch 76

Training loss: 1.0187854349289774013  
Training accuracy: 85.125%  
Test accuracy: 86.5%

Epoch 77  
Training loss: 1.0045413021616625495  
Training accuracy: 85.91666666666666%  
Test accuracy: 84.83333333333333%

Epoch 78  
Training loss: 0.9959548748476411365  
Training accuracy: 85.83333333333334%  
Test accuracy: 84.33333333333334%

Epoch 79  
Training loss: 1.0070186709150904116  
Training accuracy: 85.45833333333334%  
Test accuracy: 85.33333333333334%

Epoch 80  
Training loss: 0.987267135534026435  
Training accuracy: 86.125%  
Test accuracy: 82.66666666666666%

Epoch 81  
Training loss: 1.0089890770924260621  
Training accuracy: 85.50000000000001%  
Test accuracy: 85.66666666666666%

Epoch 82  
Training loss: 0.9950429323735696089  
Training accuracy: 85.95833333333333%  
Test accuracy: 85.0%

Epoch 83  
Training loss: 0.9976947280861072239  
Training accuracy: 85.91666666666666%  
Test accuracy: 85.50000000000001%

Epoch 84  
Training loss: 0.9936223070099521555  
Training accuracy: 86.20833333333334%  
Test accuracy: 84.16666666666667%

Epoch 85  
Training loss: 0.99902601892256380847  
Training accuracy: 85.45833333333333%  
Test accuracy: 86.50000000000001%

Epoch 86  
Training loss: 0.98890967583754411246  
Training accuracy: 86.16666666666667%  
Test accuracy: 85.49999999999999%

Epoch 87  
Training loss: 0.99209672280889362107  
Training accuracy: 85.75%  
Test accuracy: 84.5%

Epoch 88  
Training loss: 0.9953416496848202492  
Training accuracy: 85.875%  
Test accuracy: 85.83333333333334%

Epoch 89  
Training loss: 0.9801682297623016728  
Training accuracy: 85.95833333333333%  
Test accuracy: 83.83333333333334%

Epoch 90  
Training loss: 0.9941278286603629355  
Training accuracy: 85.45833333333334%  
Test accuracy: 85.5%

Epoch 91  
Training loss: 0.99759560550295738073  
Training accuracy: 85.875%  
Test accuracy: 85.5%

Epoch 92  
Training loss: 0.9942328126805559842  
Training accuracy: 85.75%  
Test accuracy: 86.0%

Epoch 93  
Training loss: 0.9649296148785307456  
Training accuracy: 86.33333333333334%  
Test accuracy: 83.66666666666666%

Epoch 94  
Training loss: 0.97775143639942753524  
Training accuracy: 86.25%  
Test accuracy: 85.83333333333333%

Epoch 95  
Training loss: 0.980758190177110446



Training accuracy: 85.70833333333333%  
Test accuracy: 85.66666666666666%

Epoch 96  
Training loss: 0.97627445855370527644  
Training accuracy: 86.12500000000001%  
Test accuracy: 84.83333333333334%

Epoch 97  
Training loss: 0.9694192008438162378  
Training accuracy: 86.24999999999999%  
Test accuracy: 84.66666666666667%

Epoch 98  
Training loss: 0.9643773562921801708  
Training accuracy: 86.41666666666666%  
Test accuracy: 83.33333333333333%

Epoch 99  
Training loss: 0.97539084866014406883  
Training accuracy: 86.08333333333334%  
Test accuracy: 85.16666666666666%

Epoch 100  
Training loss: 0.9671893405417292775  
Training accuracy: 85.58333333333334%  
Test accuracy: 85.5%

Epoch 101  
Training loss: 0.96451305736428271325  
Training accuracy: 85.91666666666666%  
Test accuracy: 86.00000000000001%

Epoch 102  
Training loss: 0.96011113968634111083  
Training accuracy: 85.91666666666666%  
Test accuracy: 85.5%

Epoch 103  
Training loss: 0.982912601711349907  
Training accuracy: 85.5%  
Test accuracy: 87.83333333333333%

Epoch 104  
Training loss: 0.97641935471151834443  
Training accuracy: 85.66666666666666%  
Test accuracy: 86.16666666666666%

Epoch 105  
Training loss: 0.9638803214258042194  
Training accuracy: 86.20833333333333%  
Test accuracy: 84.66666666666667%

Epoch 106  
Training loss: 0.95477579559118251834  
Training accuracy: 86.58333333333334%  
Test accuracy: 82.50000000000001%

Epoch 107  
Training loss: 0.9508399014948614521  
Training accuracy: 86.70833333333334%  
Test accuracy: 83.66666666666667%

Epoch 108  
Training loss: 0.97508097963701102843  
Training accuracy: 85.83333333333334%  
Test accuracy: 85.66666666666666%

Epoch 109  
Training loss: 0.97243272116623957773  
Training accuracy: 85.70833333333333%  
Test accuracy: 85.66666666666667%

Epoch 110  
Training loss: 0.9715200685240141046  
Training accuracy: 85.875%  
Test accuracy: 85.16666666666667%

Epoch 111  
Training loss: 0.9606236820461237213  
Training accuracy: 85.70833333333333%  
Test accuracy: 85.33333333333334%

Epoch 112  
Training loss: 0.9530854339547007519  
Training accuracy: 86.45833333333334%  
Test accuracy: 84.49999999999999%

Epoch 113  
Training loss: 0.9573774467594564696  
Training accuracy: 85.875%  
Test accuracy: 85.66666666666666%

Epoch 114  
Training loss: 0.9591036677244270033  
Training accuracy: 85.83333333333334%

Test accuracy: 85.33333333333333%

Epoch 115

Training loss: 0.96221566654308287756

Training accuracy: 85.83333333333334%

Test accuracy: 85.0%

Epoch 116

Training loss: 0.9620331650043036054

Training accuracy: 85.91666666666667%

Test accuracy: 86.0%

Epoch 117

Training loss: 0.9480083571309839313

Training accuracy: 86.0%

Test accuracy: 85.16666666666666%

Epoch 118

Training loss: 0.95891523401212553366

Training accuracy: 86.25%

Test accuracy: 83.33333333333333%

Epoch 119

Training loss: 0.9549137199912463951

Training accuracy: 86.16666666666667%

Test accuracy: 85.33333333333334%

Epoch 120

Training loss: 0.95152916914622130885

Training accuracy: 86.29166666666667%

Test accuracy: 85.16666666666666%

Epoch 121

Training loss: 0.9327393379310809832

Training accuracy: 86.625%

Test accuracy: 83.83333333333333%

Epoch 122

Training loss: 0.95170439636192179987

Training accuracy: 86.08333333333334%

Test accuracy: 86.16666666666666%

Epoch 123

Training loss: 0.9479719040540984737

Training accuracy: 86.04166666666666%

Test accuracy: 85.50000000000001%

Epoch 124

Training loss: 0.9485797780305012789  
Training accuracy: 85.70833333333334%  
Test accuracy: 84.33333333333333%

Epoch 125  
Training loss: 0.94987166012020494835  
Training accuracy: 86.45833333333334%  
Test accuracy: 84.83333333333334%

Epoch 126  
Training loss: 0.9465243238367845628  
Training accuracy: 86.20833333333333%  
Test accuracy: 85.33333333333334%

Epoch 127  
Training loss: 0.9532671469752907539  
Training accuracy: 86.16666666666666%  
Test accuracy: 85.99999999999999%

Epoch 128  
Training loss: 0.94637989040867940855  
Training accuracy: 85.95833333333334%  
Test accuracy: 86.66666666666666%

Epoch 129  
Training loss: 0.9536342726793946843  
Training accuracy: 86.20833333333333%  
Test accuracy: 85.66666666666666%

Epoch 130  
Training loss: 0.94773663383420461747  
Training accuracy: 86.125%  
Test accuracy: 86.5%

Epoch 131  
Training loss: 0.9381800498596907712  
Training accuracy: 86.375%  
Test accuracy: 85.49999999999999%

Epoch 132  
Training loss: 0.94838897112323895165  
Training accuracy: 86.37499999999999%  
Test accuracy: 86.33333333333334%

Epoch 133  
Training loss: 0.9475479501192993932  
Training accuracy: 86.125%  
Test accuracy: 86.5%

Epoch 134  
Training loss: 0.9403978357626282752  
Training accuracy: 85.95833333333333%  
Test accuracy: 86.99999999999999%

Epoch 135  
Training loss: 0.95148697735388235435  
Training accuracy: 85.75%  
Test accuracy: 86.66666666666667%

Epoch 136  
Training loss: 0.92213030598836386275  
Training accuracy: 86.54166666666666%  
Test accuracy: 84.83333333333333%

Epoch 137  
Training loss: 0.9483925306492080651  
Training accuracy: 86.08333333333334%  
Test accuracy: 85.83333333333333%

Epoch 138  
Training loss: 0.9318572029531691334  
Training accuracy: 86.16666666666666%  
Test accuracy: 84.33333333333333%

Epoch 139  
Training loss: 0.95558113786210473385  
Training accuracy: 85.875%  
Test accuracy: 86.83333333333334%

Epoch 140  
Training loss: 0.9426267645017579676  
Training accuracy: 85.91666666666666%  
Test accuracy: 87.83333333333334%

Epoch 141  
Training loss: 0.949690493423599071  
Training accuracy: 86.04166666666667%  
Test accuracy: 86.5%

Epoch 142  
Training loss: 0.9393803347845028423  
Training accuracy: 86.33333333333333%  
Test accuracy: 85.16666666666667%

Epoch 143  
Training loss: 0.9323541897388749656

Training accuracy: 86.74999999999999%  
Test accuracy: 84.5%

Epoch 144  
Training loss: 0.9239997508137448849  
Training accuracy: 86.54166666666666%  
Test accuracy: 84.00000000000001%

Epoch 145  
Training loss: 0.93210789341292852786  
Training accuracy: 86.08333333333333%  
Test accuracy: 85.00000000000001%

Epoch 146  
Training loss: 0.93173953082639658727  
Training accuracy: 86.58333333333333%  
Test accuracy: 84.16666666666666%

Epoch 147  
Training loss: 0.92290222671662442187  
Training accuracy: 86.75000000000001%  
Test accuracy: 85.16666666666667%

Epoch 148  
Training loss: 0.9564176076051543945  
Training accuracy: 85.83333333333334%  
Test accuracy: 87.66666666666667%

Epoch 149  
Training loss: 0.9348165774269013373  
Training accuracy: 86.41666666666667%  
Test accuracy: 85.49999999999999%

Epoch 150  
Training loss: 0.93596943290919236175  
Training accuracy: 86.33333333333334%  
Test accuracy: 85.50000000000001%

Epoch 151  
Training loss: 0.9339130674301683927  
Training accuracy: 86.50000000000001%  
Test accuracy: 85.66666666666667%

Epoch 152  
Training loss: 0.93320506152939738454  
Training accuracy: 86.375%  
Test accuracy: 85.16666666666666%

Epoch 153  
Training loss: 0.919140210195542701  
Training accuracy: 86.70833333333333%  
Test accuracy: 84.83333333333334%

Epoch 154  
Training loss: 0.92703292410881861713  
Training accuracy: 86.24999999999999%  
Test accuracy: 85.66666666666666%

Epoch 155  
Training loss: 0.94086879093074386434  
Training accuracy: 86.37500000000001%  
Test accuracy: 85.33333333333334%

Epoch 156  
Training loss: 0.95085953024332716234  
Training accuracy: 85.66666666666667%  
Test accuracy: 87.16666666666666%

Epoch 157  
Training loss: 0.9468469458793463968  
Training accuracy: 86.04166666666667%  
Test accuracy: 87.0%

Epoch 158  
Training loss: 0.94237196246204010477  
Training accuracy: 86.125%  
Test accuracy: 86.83333333333333%

Epoch 159  
Training loss: 0.9297184877123993287  
Training accuracy: 86.5%  
Test accuracy: 85.16666666666666%

Epoch 160  
Training loss: 0.9403964661932144125  
Training accuracy: 86.33333333333333%  
Test accuracy: 85.99999999999999%

Epoch 161  
Training loss: 0.91467708801819335243  
Training accuracy: 86.50000000000001%  
Test accuracy: 85.0%

Epoch 162  
Training loss: 0.9312914627904353087  
Training accuracy: 86.0%

Test accuracy: 86.00000000000001%

Epoch 163

Training loss: 0.9329994720909179408

Training accuracy: 86.25%

Test accuracy: 84.66666666666667%

Epoch 164

Training loss: 0.9070743203536967148

Training accuracy: 86.58333333333334%

Test accuracy: 84.5%

Epoch 165

Training loss: 0.92750206907822564087

Training accuracy: 86.04166666666666%

Test accuracy: 87.0%

Epoch 166

Training loss: 0.9314286658320047433

Training accuracy: 86.125%

Test accuracy: 86.5%

Epoch 167

Training loss: 0.9072719704957024541

Training accuracy: 86.83333333333334%

Test accuracy: 84.16666666666666%

Epoch 168

Training loss: 0.92819261146233053865

Training accuracy: 86.12499999999999%

Test accuracy: 87.0%

Epoch 169

Training loss: 0.91111359618094969504

Training accuracy: 87.08333333333333%

Test accuracy: 83.0%

Epoch 170

Training loss: 0.9205717767795343373

Training accuracy: 86.375%

Test accuracy: 85.33333333333333%

Epoch 171

Training loss: 0.91284131819120961345

Training accuracy: 86.54166666666666%

Test accuracy: 84.33333333333334%

Epoch 172



Training loss: 0.9034718972975628766  
Training accuracy: 86.375%  
Test accuracy: 85.0%

Epoch 173  
Training loss: 0.92236617145949156507  
Training accuracy: 86.20833333333333%  
Test accuracy: 85.83333333333333%

Epoch 174  
Training loss: 0.9163946539407847977  
Training accuracy: 86.95833333333334%  
Test accuracy: 84.00000000000001%

Epoch 175  
Training loss: 0.93817536546166749084  
Training accuracy: 86.0%  
Test accuracy: 87.66666666666666%

Epoch 176  
Training loss: 0.92294329129082237705  
Training accuracy: 86.45833333333333%  
Test accuracy: 85.16666666666667%

Epoch 177  
Training loss: 0.92206947596340459216  
Training accuracy: 86.83333333333334%  
Test accuracy: 84.33333333333334%

Epoch 178  
Training loss: 0.9445396987415937035  
Training accuracy: 85.625%  
Test accuracy: 87.83333333333333%

Epoch 179  
Training loss: 0.9225894754227977433  
Training accuracy: 86.66666666666666%  
Test accuracy: 84.16666666666666%

Epoch 180  
Training loss: 0.9300007719836669897  
Training accuracy: 86.08333333333334%  
Test accuracy: 86.83333333333334%

Epoch 181  
Training loss: 0.91691251941907935517  
Training accuracy: 86.5%  
Test accuracy: 85.16666666666666%

Epoch 182  
Training loss: 0.90995940583365245754  
Training accuracy: 86.79166666666666%  
Test accuracy: 83.66666666666667%

Epoch 183  
Training loss: 0.9402954934432730443  
Training accuracy: 85.95833333333334%  
Test accuracy: 87.66666666666666%

Epoch 184  
Training loss: 0.90597910009847618844  
Training accuracy: 86.58333333333333%  
Test accuracy: 84.83333333333333%

Epoch 185  
Training loss: 0.92376679380484247084  
Training accuracy: 86.16666666666666%  
Test accuracy: 86.33333333333333%

Epoch 186  
Training loss: 0.91151696468287896747  
Training accuracy: 86.62499999999999%  
Test accuracy: 84.49999999999999%

Epoch 187  
Training loss: 0.92396808072019166695  
Training accuracy: 86.04166666666666%  
Test accuracy: 86.66666666666666%

Epoch 188  
Training loss: 0.9155973874335843458  
Training accuracy: 86.33333333333334%  
Test accuracy: 86.16666666666667%

Epoch 189  
Training loss: 0.92769020484144148624  
Training accuracy: 85.87499999999999%  
Test accuracy: 87.0%

Epoch 190  
Training loss: 0.9288258499646736957  
Training accuracy: 86.16666666666666%  
Test accuracy: 86.0%

Epoch 191  
Training loss: 0.9207505904042493449

Training accuracy: 86.58333333333334%  
Test accuracy: 85.33333333333334%

Epoch 192  
Training loss: 0.92456407869531978565  
Training accuracy: 86.16666666666667%  
Test accuracy: 87.00000000000001%

Epoch 193  
Training loss: 0.9079855519680257943  
Training accuracy: 86.66666666666667%  
Test accuracy: 85.5%

Epoch 194  
Training loss: 0.91731855525541156624  
Training accuracy: 86.33333333333334%  
Test accuracy: 86.33333333333334%

Epoch 195  
Training loss: 0.9089417328397642065  
Training accuracy: 86.625%  
Test accuracy: 84.33333333333333%

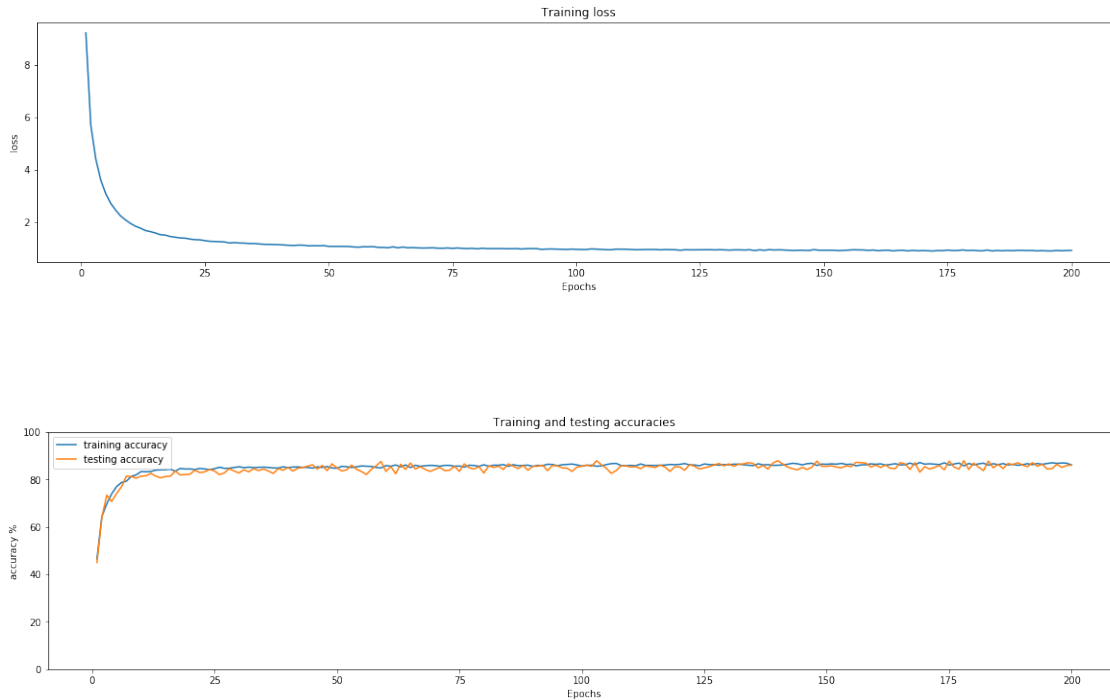
Epoch 196  
Training loss: 0.9057281808393979813  
Training accuracy: 86.95833333333333%  
Test accuracy: 84.5%

Epoch 197  
Training loss: 0.92285542674269693835  
Training accuracy: 86.70833333333333%  
Test accuracy: 86.33333333333333%

Epoch 198  
Training loss: 0.9128849809650571227  
Training accuracy: 86.87499999999999%  
Test accuracy: 85.0%

Epoch 199  
Training loss: 0.9224974515088569001  
Training accuracy: 86.79166666666666%  
Test accuracy: 85.83333333333333%

Epoch 200  
Training loss: 0.9262812921787709626  
Training accuracy: 86.0%  
Test accuracy: 86.0%



Now adding a hidden layer with 15 neurons:

```
[5]: net = network.Linear_Network_CrossValidation([25,15,10])
```

```
[6]: net.SGD(training_data, 200, 10, 0.1)
```

Epoch 1

Training loss: 4.792071241986174617

Training accuracy: 14.0%

Test accuracy: 14.166666666666666%

Epoch 2

Training loss: 3.3346337310360963358

Training accuracy: 33.041666666666667%

Test accuracy: 33.5%

Epoch 3

Training loss: 3.024566060762295849

Training accuracy: 44.791666666666664%

Test accuracy: 45.83333333333333%

Epoch 4

Training loss: 2.861589116469465267

Training accuracy: 51.75%

Test accuracy: 49.66666666666667%

Epoch 5  
Training loss: 2.755135437759301802  
Training accuracy: 55.25%  
Test accuracy: 57.83333333333336%

Epoch 6  
Training loss: 2.6496530787622441599  
Training accuracy: 59.375%  
Test accuracy: 57.83333333333336%

Epoch 7  
Training loss: 2.5734595082181430433  
Training accuracy: 61.75%  
Test accuracy: 64.9999999999999%

Epoch 8  
Training loss: 2.4751802065387753368  
Training accuracy: 65.70833333333333%  
Test accuracy: 61.66666666666667%

Epoch 9  
Training loss: 2.4047869776722956285  
Training accuracy: 66.875%  
Test accuracy: 66.16666666666666%

Epoch 10  
Training loss: 2.337064684430916995  
Training accuracy: 69.54166666666666%  
Test accuracy: 67.0%

Epoch 11  
Training loss: 2.2634988026305364562  
Training accuracy: 71.37500000000001%  
Test accuracy: 68.16666666666666%

Epoch 12  
Training loss: 2.2044487360756696262  
Training accuracy: 72.54166666666667%  
Test accuracy: 70.33333333333333%

Epoch 13  
Training loss: 2.1526844679981901808  
Training accuracy: 73.29166666666666%  
Test accuracy: 73.9999999999999%

Epoch 14  
Training loss: 2.0966026309364424907

Training accuracy: 74.25%  
Test accuracy: 74.6666666666667%

Epoch 15  
Training loss: 2.0494970646965249214  
Training accuracy: 75.16666666666666%  
Test accuracy: 76.83333333333334%

Epoch 16  
Training loss: 1.9914875619643344253  
Training accuracy: 76.79166666666666%  
Test accuracy: 73.99999999999999%

Epoch 17  
Training loss: 1.9422051684254647482  
Training accuracy: 76.83333333333334%  
Test accuracy: 77.16666666666667%

Epoch 18  
Training loss: 1.8955869939104049791  
Training accuracy: 77.79166666666667%  
Test accuracy: 76.83333333333333%

Epoch 19  
Training loss: 1.8665640969974049316  
Training accuracy: 78.08333333333333%  
Test accuracy: 77.33333333333334%

Epoch 20  
Training loss: 1.8381849444997990589  
Training accuracy: 78.41666666666667%  
Test accuracy: 81.5%

Epoch 21  
Training loss: 1.8003039329544767915  
Training accuracy: 79.25%  
Test accuracy: 81.16666666666667%

Epoch 22  
Training loss: 1.759474149049852692  
Training accuracy: 79.79166666666666%  
Test accuracy: 81.66666666666667%

Epoch 23  
Training loss: 1.7287966115834145813  
Training accuracy: 80.45833333333333%  
Test accuracy: 81.0%

Epoch 24  
Training loss: 1.6986172921309353453  
Training accuracy: 81.33333333333334%  
Test accuracy: 80.5%

Epoch 25  
Training loss: 1.664123405648994153  
Training accuracy: 81.95833333333334%  
Test accuracy: 80.0%

Epoch 26  
Training loss: 1.6397804306801896705  
Training accuracy: 81.91666666666666%  
Test accuracy: 80.83333333333333%

Epoch 27  
Training loss: 1.6170875797548805396  
Training accuracy: 82.125%  
Test accuracy: 81.5%

Epoch 28  
Training loss: 1.5896991525325337858  
Training accuracy: 82.37500000000001%  
Test accuracy: 82.16666666666666%

Epoch 29  
Training loss: 1.5642606610991159054  
Training accuracy: 83.25%  
Test accuracy: 80.0%

Epoch 30  
Training loss: 1.5455033895480043297  
Training accuracy: 82.58333333333334%  
Test accuracy: 83.5%

Epoch 31  
Training loss: 1.5125636832502982036  
Training accuracy: 83.20833333333333%  
Test accuracy: 81.83333333333334%

Epoch 32  
Training loss: 1.4874199918974025626  
Training accuracy: 83.79166666666667%  
Test accuracy: 80.33333333333334%

Epoch 33  
Training loss: 1.4943063733399869675  
Training accuracy: 82.125%

Test accuracy: 86.0%

Epoch 34

Training loss: 1.4753324177960314486

Training accuracy: 82.83333333333334%

Test accuracy: 84.83333333333334%

Epoch 35

Training loss: 1.4457634506661197761

Training accuracy: 83.62500000000001%

Test accuracy: 83.33333333333334%

Epoch 36

Training loss: 1.4265547282899436502

Training accuracy: 83.66666666666667%

Test accuracy: 84.50000000000001%

Epoch 37

Training loss: 1.4211053928843640298

Training accuracy: 83.95833333333334%

Test accuracy: 83.5%

Epoch 38

Training loss: 1.3952727323563335106

Training accuracy: 84.29166666666667%

Test accuracy: 84.33333333333333%

Epoch 39

Training loss: 1.3818687002725903815

Training accuracy: 84.625%

Test accuracy: 83.0%

Epoch 40

Training loss: 1.3673264963782815201

Training accuracy: 84.45833333333334%

Test accuracy: 84.33333333333334%

Epoch 41

Training loss: 1.3510860143272757518

Training accuracy: 84.41666666666667%

Test accuracy: 85.5%

Epoch 42

Training loss: 1.3412508966567629617

Training accuracy: 84.58333333333334%

Test accuracy: 84.66666666666667%

Epoch 43



Training loss: 1.3354592836216542951  
Training accuracy: 85.25%  
Test accuracy: 83.0%

Epoch 44  
Training loss: 1.3117213611373053009  
Training accuracy: 85.33333333333333%  
Test accuracy: 84.0%

Epoch 45  
Training loss: 1.2978819332558615382  
Training accuracy: 85.08333333333333%  
Test accuracy: 84.83333333333333%

Epoch 46  
Training loss: 1.2807342935883394653  
Training accuracy: 85.0%  
Test accuracy: 85.33333333333334%

Epoch 47  
Training loss: 1.2832940053815598599  
Training accuracy: 85.20833333333333%  
Test accuracy: 85.5%

Epoch 48  
Training loss: 1.2733372223314146567  
Training accuracy: 84.91666666666667%  
Test accuracy: 86.16666666666666%

Epoch 49  
Training loss: 1.2611978321538024588  
Training accuracy: 85.16666666666666%  
Test accuracy: 85.0%

Epoch 50  
Training loss: 1.2498402836722762714  
Training accuracy: 85.16666666666666%  
Test accuracy: 85.5%

Epoch 51  
Training loss: 1.2443737628992837575  
Training accuracy: 85.24999999999999%  
Test accuracy: 85.83333333333333%

Epoch 52  
Training loss: 1.2285847576162392171  
Training accuracy: 85.29166666666667%  
Test accuracy: 86.0%

Epoch 53  
Training loss: 1.2180203783985894354  
Training accuracy: 85.16666666666667%  
Test accuracy: 87.33333333333333%

Epoch 54  
Training loss: 1.2022887413734310714  
Training accuracy: 85.91666666666666%  
Test accuracy: 84.16666666666666%

Epoch 55  
Training loss: 1.2013132219519657333  
Training accuracy: 85.83333333333333%  
Test accuracy: 85.16666666666666%

Epoch 56  
Training loss: 1.1865733613617536035  
Training accuracy: 85.87500000000001%  
Test accuracy: 85.00000000000001%

Epoch 57  
Training loss: 1.1835710885031180698  
Training accuracy: 85.58333333333334%  
Test accuracy: 86.83333333333333%

Epoch 58  
Training loss: 1.1806409032128290632  
Training accuracy: 85.58333333333334%  
Test accuracy: 87.50000000000001%

Epoch 59  
Training loss: 1.1526536949425053005  
Training accuracy: 86.49999999999999%  
Test accuracy: 84.0%

Epoch 60  
Training loss: 1.1425263001911997493  
Training accuracy: 86.75%  
Test accuracy: 83.16666666666667%

Epoch 61  
Training loss: 1.1426443532326102506  
Training accuracy: 85.91666666666666%  
Test accuracy: 86.33333333333333%

Epoch 62  
Training loss: 1.1402445093914412693

Training accuracy: 86.29166666666666%  
Test accuracy: 85.83333333333334%

Epoch 63  
Training loss: 1.1205126387494043933  
Training accuracy: 86.75000000000001%  
Test accuracy: 83.33333333333334%

Epoch 64  
Training loss: 1.130712958249890276  
Training accuracy: 85.95833333333333%  
Test accuracy: 86.83333333333333%

Epoch 65  
Training loss: 1.1133509697931886723  
Training accuracy: 86.20833333333333%  
Test accuracy: 85.66666666666667%

Epoch 66  
Training loss: 1.110849579724731241  
Training accuracy: 86.125%  
Test accuracy: 87.00000000000001%

Epoch 67  
Training loss: 1.1086111833887634714  
Training accuracy: 86.00000000000001%  
Test accuracy: 87.0%

Epoch 68  
Training loss: 1.0782887914912924358  
Training accuracy: 86.66666666666667%  
Test accuracy: 84.50000000000001%

Epoch 69  
Training loss: 1.0784938539304441548  
Training accuracy: 86.625%  
Test accuracy: 85.16666666666667%

Epoch 70  
Training loss: 1.0753656220372738554  
Training accuracy: 86.41666666666666%  
Test accuracy: 85.83333333333333%

Epoch 71  
Training loss: 1.0869640692904350286  
Training accuracy: 86.33333333333334%  
Test accuracy: 87.0%

Epoch 72  
Training loss: 1.0583872441487163007  
Training accuracy: 87.08333333333333%  
Test accuracy: 83.83333333333334%

Epoch 73  
Training loss: 1.0583546080816946487  
Training accuracy: 86.29166666666667%  
Test accuracy: 86.5%

Epoch 74  
Training loss: 1.073400021566969035  
Training accuracy: 86.04166666666666%  
Test accuracy: 88.16666666666667%

Epoch 75  
Training loss: 1.0425174235419557928  
Training accuracy: 87.08333333333333%  
Test accuracy: 84.83333333333334%

Epoch 76  
Training loss: 1.0497942674656644374  
Training accuracy: 86.33333333333333%  
Test accuracy: 87.66666666666667%

Epoch 77  
Training loss: 1.0442352536381456231  
Training accuracy: 86.74999999999999%  
Test accuracy: 87.33333333333333%

Epoch 78  
Training loss: 1.0485822954776624642  
Training accuracy: 86.5%  
Test accuracy: 87.33333333333333%

Epoch 79  
Training loss: 1.0394737214361774839  
Training accuracy: 86.875%  
Test accuracy: 87.5%

Epoch 80  
Training loss: 1.0266713662968041834  
Training accuracy: 86.70833333333334%  
Test accuracy: 87.0%

Epoch 81  
Training loss: 1.0088097129781432113  
Training accuracy: 87.25000000000001%

Test accuracy: 85.5%

Epoch 82

Training loss: 1.0030700666534626408

Training accuracy: 87.25000000000001%

Test accuracy: 85.5%

Epoch 83

Training loss: 1.0251100498694718426

Training accuracy: 86.58333333333334%

Test accuracy: 88.66666666666667%

Epoch 84

Training loss: 1.0187122554295327413

Training accuracy: 86.45833333333333%

Test accuracy: 88.83333333333333%

Epoch 85

Training loss: 0.9916018921327679249

Training accuracy: 87.125%

Test accuracy: 86.00000000000001%

Epoch 86

Training loss: 0.986182765179135335

Training accuracy: 87.04166666666667%

Test accuracy: 86.16666666666666%

Epoch 87

Training loss: 1.0004127638505596296

Training accuracy: 86.58333333333333%

Test accuracy: 88.33333333333333%

Epoch 88

Training loss: 0.9903955685781764636

Training accuracy: 87.20833333333333%

Test accuracy: 86.16666666666667%

Epoch 89

Training loss: 0.98822047562277363285

Training accuracy: 87.37499999999999%

Test accuracy: 86.16666666666667%

Epoch 90

Training loss: 0.97857988628633842007

Training accuracy: 87.41666666666667%

Test accuracy: 85.83333333333333%

Epoch 91

Training loss: 0.96252298184761960555  
Training accuracy: 87.58333333333334%  
Test accuracy: 84.83333333333334%

Epoch 92  
Training loss: 0.97859248811936812914  
Training accuracy: 86.70833333333334%  
Test accuracy: 88.0%

Epoch 93  
Training loss: 0.9846400518195798965  
Training accuracy: 86.83333333333334%  
Test accuracy: 87.99999999999999%

Epoch 94  
Training loss: 0.9522857693034275841  
Training accuracy: 87.74999999999999%  
Test accuracy: 84.83333333333334%

Epoch 95  
Training loss: 0.9708674870452022016  
Training accuracy: 87.08333333333334%  
Test accuracy: 87.16666666666666%

Epoch 96  
Training loss: 0.9538011084673532119  
Training accuracy: 87.29166666666666%  
Test accuracy: 85.66666666666666%

Epoch 97  
Training loss: 0.9620743374461834331  
Training accuracy: 86.54166666666666%  
Test accuracy: 89.66666666666666%

Epoch 98  
Training loss: 0.9489315993769272317  
Training accuracy: 87.29166666666666%  
Test accuracy: 87.16666666666666%

Epoch 99  
Training loss: 0.95448517119208038895  
Training accuracy: 87.0%  
Test accuracy: 87.33333333333334%

Epoch 100  
Training loss: 0.9412384954137370943  
Training accuracy: 87.45833333333334%  
Test accuracy: 86.33333333333334%

Epoch 101  
Training loss: 0.93590102581430667376  
Training accuracy: 87.58333333333334%  
Test accuracy: 86.5%

Epoch 102  
Training loss: 0.9255851255313546605  
Training accuracy: 87.875%  
Test accuracy: 85.16666666666667%

Epoch 103  
Training loss: 0.93184329146338837677  
Training accuracy: 87.33333333333334%  
Test accuracy: 87.0%

Epoch 104  
Training loss: 0.9354958174191041429  
Training accuracy: 87.16666666666666%  
Test accuracy: 87.66666666666666%

Epoch 105  
Training loss: 0.9254144451295545146  
Training accuracy: 87.37499999999999%  
Test accuracy: 87.33333333333334%

Epoch 106  
Training loss: 0.93826832295926048354  
Training accuracy: 86.87500000000001%  
Test accuracy: 89.49999999999999%

Epoch 107  
Training loss: 0.92281230631242051356  
Training accuracy: 87.54166666666666%  
Test accuracy: 87.00000000000001%

Epoch 108  
Training loss: 0.92344866489474711907  
Training accuracy: 87.5%  
Test accuracy: 87.16666666666667%

Epoch 109  
Training loss: 0.9160526559781779713  
Training accuracy: 87.41666666666667%  
Test accuracy: 88.16666666666667%

Epoch 110  
Training loss: 0.9087690082938462748

Training accuracy: 87.91666666666666%  
Test accuracy: 86.33333333333333%

Epoch 111  
Training loss: 0.92184085554853523544  
Training accuracy: 87.16666666666666%  
Test accuracy: 89.16666666666666%

Epoch 112  
Training loss: 0.898667110554932874  
Training accuracy: 88.25%  
Test accuracy: 84.83333333333334%

Epoch 113  
Training loss: 0.8961106107936043808  
Training accuracy: 87.875%  
Test accuracy: 86.83333333333333%

Epoch 114  
Training loss: 0.9124922442581743497  
Training accuracy: 87.25%  
Test accuracy: 89.49999999999999%

Epoch 115  
Training loss: 0.90399932135205304806  
Training accuracy: 87.66666666666667%  
Test accuracy: 88.33333333333333%

Epoch 116  
Training loss: 0.89135088281432103255  
Training accuracy: 88.20833333333333%  
Test accuracy: 86.33333333333334%

Epoch 117  
Training loss: 0.8900109533701861539  
Training accuracy: 87.95833333333333%  
Test accuracy: 87.66666666666666%

Epoch 118  
Training loss: 0.8933366739458444653  
Training accuracy: 87.625%  
Test accuracy: 88.0%

Epoch 119  
Training loss: 0.8870837975972320764  
Training accuracy: 87.87499999999999%  
Test accuracy: 87.66666666666667%



Epoch 120  
Training loss: 0.8894478913205205831  
Training accuracy: 87.5%  
Test accuracy: 88.16666666666666%

Epoch 121  
Training loss: 0.8858634435667877942  
Training accuracy: 87.95833333333333%  
Test accuracy: 86.99999999999999%

Epoch 122  
Training loss: 0.88436532299397705635  
Training accuracy: 87.75%  
Test accuracy: 88.66666666666666%

Epoch 123  
Training loss: 0.87278278124390786723  
Training accuracy: 88.08333333333334%  
Test accuracy: 86.83333333333334%

Epoch 124  
Training loss: 0.86954010660260297146  
Training accuracy: 88.00000000000001%  
Test accuracy: 86.83333333333334%

Epoch 125  
Training loss: 0.8570596032470416318  
Training accuracy: 88.33333333333334%  
Test accuracy: 86.16666666666667%

Epoch 126  
Training loss: 0.84869443862327666504  
Training accuracy: 88.50000000000001%  
Test accuracy: 85.33333333333333%

Epoch 127  
Training loss: 0.8597267919683197739  
Training accuracy: 88.5%  
Test accuracy: 85.83333333333334%

Epoch 128  
Training loss: 0.86634196055481387433  
Training accuracy: 88.04166666666667%  
Test accuracy: 86.66666666666667%

Epoch 129  
Training loss: 0.8614274878274532961  
Training accuracy: 87.66666666666666%

Test accuracy: 88.16666666666666%

Epoch 130

Training loss: 0.8675033232795675226

Training accuracy: 88.0%

Test accuracy: 88.00000000000001%

Epoch 131

Training loss: 0.8597440581395520389

Training accuracy: 87.95833333333333%

Test accuracy: 87.83333333333334%

Epoch 132

Training loss: 0.8438763199028173909

Training accuracy: 88.58333333333333%

Test accuracy: 85.83333333333334%

Epoch 133

Training loss: 0.85488098176505648997

Training accuracy: 88.29166666666666%

Test accuracy: 87.66666666666667%

Epoch 134

Training loss: 0.8485277062289370063

Training accuracy: 88.20833333333333%

Test accuracy: 87.33333333333334%

Epoch 135

Training loss: 0.85430917042471805987

Training accuracy: 88.20833333333334%

Test accuracy: 87.66666666666667%

Epoch 136

Training loss: 0.86120212578860751336

Training accuracy: 87.58333333333333%

Test accuracy: 90.33333333333334%

Epoch 137

Training loss: 0.8421445363747444247

Training accuracy: 88.29166666666666%

Test accuracy: 87.83333333333333%

Epoch 138

Training loss: 0.84943022814370667287

Training accuracy: 87.95833333333333%

Test accuracy: 89.16666666666666%

Epoch 139

Training loss: 0.8349318309690698501  
Training accuracy: 88.29166666666667%  
Test accuracy: 87.33333333333334%

Epoch 140  
Training loss: 0.8438952523635520031  
Training accuracy: 88.0%  
Test accuracy: 88.66666666666667%

Epoch 141  
Training loss: 0.85058200704388999566  
Training accuracy: 87.625%  
Test accuracy: 89.99999999999999%

Epoch 142  
Training loss: 0.8473580652430164179  
Training accuracy: 87.95833333333334%  
Test accuracy: 89.0%

Epoch 143  
Training loss: 0.8288904536445277127  
Training accuracy: 88.29166666666666%  
Test accuracy: 88.33333333333333%

Epoch 144  
Training loss: 0.84502554239888817776  
Training accuracy: 88.20833333333333%  
Test accuracy: 88.66666666666666%

Epoch 145  
Training loss: 0.8249704041738632288  
Training accuracy: 88.70833333333334%  
Test accuracy: 86.83333333333334%

Epoch 146  
Training loss: 0.8101243845468566538  
Training accuracy: 88.87499999999999%  
Test accuracy: 85.5%

Epoch 147  
Training loss: 0.830451180332476665  
Training accuracy: 88.16666666666667%  
Test accuracy: 88.83333333333334%

Epoch 148  
Training loss: 0.8144032512335116481  
Training accuracy: 88.54166666666667%  
Test accuracy: 87.33333333333333%

Epoch 149  
Training loss: 0.8432930815210359316  
Training accuracy: 87.87500000000001%  
Test accuracy: 90.5%

Epoch 150  
Training loss: 0.825801178390405318  
Training accuracy: 88.375%  
Test accuracy: 88.5%

Epoch 151  
Training loss: 0.816428948408140164  
Training accuracy: 88.41666666666666%  
Test accuracy: 88.16666666666666%

Epoch 152  
Training loss: 0.8285413194550985597  
Training accuracy: 88.70833333333333%  
Test accuracy: 88.16666666666666%

Epoch 153  
Training loss: 0.8334283435540793537  
Training accuracy: 88.16666666666666%  
Test accuracy: 89.99999999999999%

Epoch 154  
Training loss: 0.8176348516876234481  
Training accuracy: 88.58333333333333%  
Test accuracy: 88.33333333333334%

Epoch 155  
Training loss: 0.80758688123256104613  
Training accuracy: 88.625%  
Test accuracy: 88.33333333333333%

Epoch 156  
Training loss: 0.8152647293477368018  
Training accuracy: 88.66666666666667%  
Test accuracy: 88.16666666666666%

Epoch 157  
Training loss: 0.8045939084748499149  
Training accuracy: 88.875%  
Test accuracy: 86.33333333333334%

Epoch 158  
Training loss: 0.80871380920139343095

Training accuracy: 88.41666666666667%  
Test accuracy: 89.00000000000001%

Epoch 159  
Training loss: 0.80862215258834086297  
Training accuracy: 88.54166666666667%  
Test accuracy: 88.5%

Epoch 160  
Training loss: 0.81109737952508566435  
Training accuracy: 88.58333333333334%  
Test accuracy: 88.5%

Epoch 161  
Training loss: 0.7968302857733810207  
Training accuracy: 89.08333333333333%  
Test accuracy: 87.16666666666667%

Epoch 162  
Training loss: 0.7887270445608660589  
Training accuracy: 89.16666666666666%  
Test accuracy: 86.16666666666666%

Epoch 163  
Training loss: 0.81079918934649637744  
Training accuracy: 88.41666666666666%  
Test accuracy: 90.0%

Epoch 164  
Training loss: 0.804321835729747886  
Training accuracy: 88.75%  
Test accuracy: 88.49999999999999%

Epoch 165  
Training loss: 0.80519862423734845074  
Training accuracy: 88.625%  
Test accuracy: 89.16666666666667%

Epoch 166  
Training loss: 0.79150341498594873225  
Training accuracy: 88.83333333333334%  
Test accuracy: 88.16666666666666%

Epoch 167  
Training loss: 0.8054933571248680998  
Training accuracy: 88.75%  
Test accuracy: 88.83333333333334%



Test accuracy: 88.5%

Epoch 178

Training loss: 0.7954524776762061021

Training accuracy: 88.75%

Test accuracy: 89.66666666666666%

Epoch 179

Training loss: 0.7894512102378247983

Training accuracy: 89.25%

Test accuracy: 88.33333333333334%

Epoch 180

Training loss: 0.7803963148911486146

Training accuracy: 88.75%

Test accuracy: 89.5%

Epoch 181

Training loss: 0.7864668859977220898

Training accuracy: 88.625%

Test accuracy: 90.33333333333334%

Epoch 182

Training loss: 0.78957837613564864484

Training accuracy: 88.74999999999999%

Test accuracy: 89.83333333333334%

Epoch 183

Training loss: 0.78553324971223383434

Training accuracy: 88.83333333333333%

Test accuracy: 89.33333333333334%

Epoch 184

Training loss: 0.77078406289936850167

Training accuracy: 88.91666666666666%

Test accuracy: 88.99999999999999%

Epoch 185

Training loss: 0.78671820398724182034

Training accuracy: 88.45833333333333%

Test accuracy: 90.66666666666666%

Epoch 186

Training loss: 0.7707891080309591755

Training accuracy: 89.00000000000001%

Test accuracy: 88.66666666666666%

Epoch 187

Training loss: 0.75172239125461242417  
Training accuracy: 89.33333333333334%  
Test accuracy: 87.66666666666666%

Epoch 188  
Training loss: 0.77231962397597780896  
Training accuracy: 88.79166666666667%  
Test accuracy: 89.49999999999999%

Epoch 189  
Training loss: 0.7669693061633796559  
Training accuracy: 89.16666666666666%  
Test accuracy: 88.33333333333333%

Epoch 190  
Training loss: 0.76702278147236339814  
Training accuracy: 89.20833333333334%  
Test accuracy: 88.16666666666666%

Epoch 191  
Training loss: 0.7727409459974207853  
Training accuracy: 89.08333333333334%  
Test accuracy: 89.16666666666667%

Epoch 192  
Training loss: 0.7540243424422010283  
Training accuracy: 89.20833333333333%  
Test accuracy: 88.5%

Epoch 193  
Training loss: 0.7655141737566350051  
Training accuracy: 89.16666666666666%  
Test accuracy: 89.16666666666667%

Epoch 194  
Training loss: 0.7833166390186084041  
Training accuracy: 88.20833333333334%  
Test accuracy: 91.99999999999999%

Epoch 195  
Training loss: 0.75936802310676597687  
Training accuracy: 89.04166666666666%  
Test accuracy: 89.0%

Epoch 196  
Training loss: 0.77347086182156473777  
Training accuracy: 88.70833333333333%  
Test accuracy: 90.0%



Epoch 197

Training loss: 0.7599821046214927405

Training accuracy: 88.95833333333334%

Test accuracy: 89.0%

Epoch 198

Training loss: 0.7664173272979356108

Training accuracy: 89.0%

Test accuracy: 89.83333333333333%

Epoch 199

Training loss: 0.7583545119896498101

Training accuracy: 89.25%

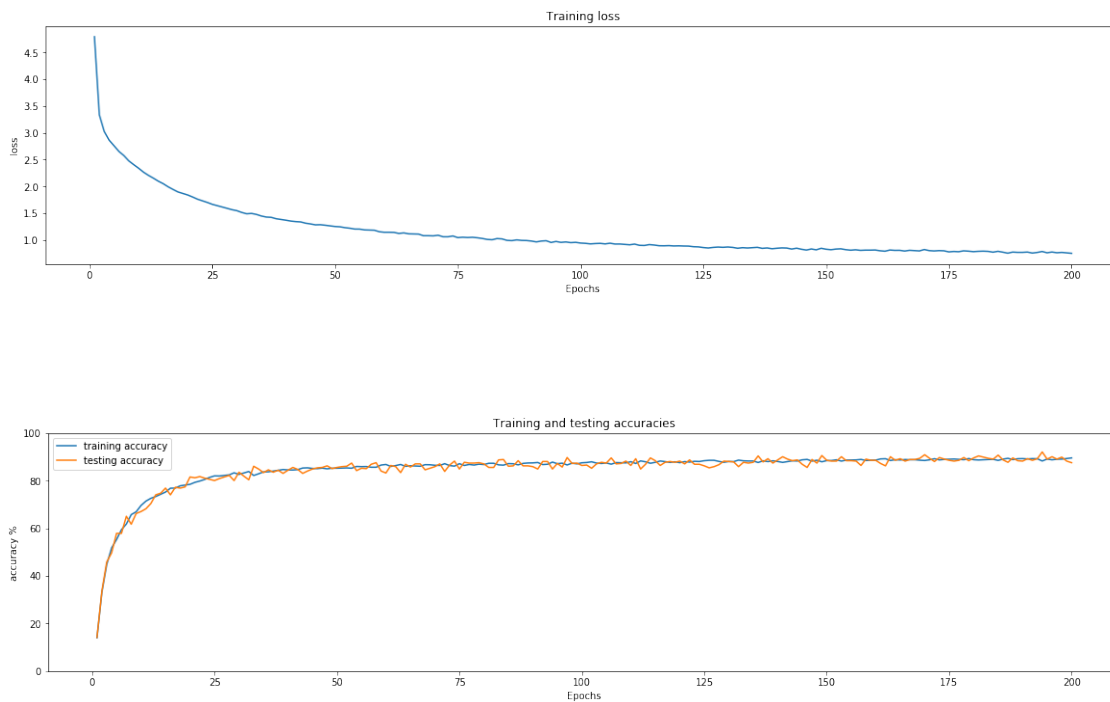
Test accuracy: 88.16666666666667%

Epoch 200

Training loss: 0.7491805327490448665

Training accuracy: 89.5%

Test accuracy: 87.50000000000001%



Here we see a slight increase in the accuracy reaching upto 90%

Finally let's try 2 hidden layers with 15 and 15 neurons in each respectively. We'll keep a regularization parameter to prevent overfitting.

```
[7]: net = network.Linear_Network_CrossValidation([25,15,15,10])
```

```
[8]: net.SGD(training_data, 200, 10, 0.1, lambda=1.0)
```

Epoch 1

Training loss: 4.4850064782964885078

Training accuracy: 9.916666666666668%

Test accuracy: 8.499999999999998%

Epoch 2

Training loss: 3.356805739666318296

Training accuracy: 14.666666666666668%

Test accuracy: 16.5%

Epoch 3

Training loss: 3.2432002048708097601

Training accuracy: 19.041666666666664%

Test accuracy: 19.499999999999996%

Epoch 4

Training loss: 3.216742481772191744

Training accuracy: 18.708333333333332%

Test accuracy: 19.833333333333332%

Epoch 5

Training loss: 3.2048485018208617062

Training accuracy: 22.333333333333336%

Test accuracy: 22.499999999999996%

Epoch 6

Training loss: 3.1970616176103365687

Training accuracy: 23.458333333333336%

Test accuracy: 22.333333333333336%

Epoch 7

Training loss: 3.1887496605536887408

Training accuracy: 22.375%

Test accuracy: 22.833333333333332%

Epoch 8

Training loss: 3.1825580041979554334

Training accuracy: 23.208333333333336%

Test accuracy: 22.499999999999996%

Epoch 9

Training loss: 3.170211927743147328

Training accuracy: 27.083333333333336%

Test accuracy: 22.33333333333332%

Epoch 10

Training loss: 3.160177211390351139

Training accuracy: 23.833333333333336%

Test accuracy: 21.333333333333336%

Epoch 11

Training loss: 3.1545633996040141993

Training accuracy: 30.458333333333336%

Test accuracy: 30.0%

Epoch 12

Training loss: 3.1468754136148765752

Training accuracy: 31.166666666666668%

Test accuracy: 30.83333333333332%

Epoch 13

Training loss: 3.138705717917055301

Training accuracy: 32.291666666666664%

Test accuracy: 33.333333333333336%

Epoch 14

Training loss: 3.1260554735067432575

Training accuracy: 34.54166666666667%

Test accuracy: 34.83333333333333%

Epoch 15

Training loss: 3.1148095681350496632

Training accuracy: 35.29166666666667%

Test accuracy: 37.66666666666667%

Epoch 16

Training loss: 3.0997341956324029333

Training accuracy: 34.25%

Test accuracy: 26.83333333333332%

Epoch 17

Training loss: 3.0928784680679185012

Training accuracy: 33.75%

Test accuracy: 32.5%

Epoch 18

Training loss: 3.0811709984576454067

Training accuracy: 35.458333333333336%

Test accuracy: 35.833333333333336%

Epoch 19

Training loss: 3.067233034350844062  
Training accuracy: 35.708333333333333%  
Test accuracy: 34.66666666666667%

Epoch 20  
Training loss: 3.0557381413786215698  
Training accuracy: 36.833333333333333%  
Test accuracy: 39.5%

Epoch 21  
Training loss: 3.0392835509045703535  
Training accuracy: 39.208333333333333%  
Test accuracy: 36.5%

Epoch 22  
Training loss: 3.024857649851178058  
Training accuracy: 39.16666666666667%  
Test accuracy: 39.5%

Epoch 23  
Training loss: 3.0095757197702931425  
Training accuracy: 39.333333333333336%  
Test accuracy: 38.66666666666667%

Epoch 24  
Training loss: 2.9968851175881324619  
Training accuracy: 40.333333333333333%  
Test accuracy: 40.66666666666664%

Epoch 25  
Training loss: 2.973875056258342664  
Training accuracy: 41.29166666666664%  
Test accuracy: 40.00000000000001%

Epoch 26  
Training loss: 2.9609351706824136642  
Training accuracy: 41.625%  
Test accuracy: 43.66666666666667%

Epoch 27  
Training loss: 2.9467658716130598624  
Training accuracy: 40.833333333333333%  
Test accuracy: 43.50000000000001%

Epoch 28  
Training loss: 2.9211061901704385986  
Training accuracy: 42.458333333333336%  
Test accuracy: 39.66666666666664%

Epoch 29  
Training loss: 2.9053420813347378279  
Training accuracy: 41.999999999999999%  
Test accuracy: 40.16666666666667%

Epoch 30  
Training loss: 2.8872881228682418546  
Training accuracy: 41.000000000000001%  
Test accuracy: 43.66666666666667%

Epoch 31  
Training loss: 2.8610202994739266263  
Training accuracy: 42.958333333333333%  
Test accuracy: 40.16666666666667%

Epoch 32  
Training loss: 2.8441363051991943155  
Training accuracy: 43.54166666666667%  
Test accuracy: 42.5%

Epoch 33  
Training loss: 2.8330324357810255972  
Training accuracy: 43.958333333333333%  
Test accuracy: 48.0%

Epoch 34  
Training loss: 2.8056650006215426841  
Training accuracy: 46.250000000000001%  
Test accuracy: 45.833333333333336%

Epoch 35  
Training loss: 2.7815924588915961059  
Training accuracy: 46.833333333333333%  
Test accuracy: 43.833333333333333%

Epoch 36  
Training loss: 2.7573104345573065113  
Training accuracy: 46.958333333333333%  
Test accuracy: 45.833333333333336%

Epoch 37  
Training loss: 2.7413646196354858639  
Training accuracy: 46.999999999999999%  
Test accuracy: 46.5%

Epoch 38  
Training loss: 2.7271742149533882565

Training accuracy: 47.20833333333333%  
Test accuracy: 51.5%

Epoch 39  
Training loss: 2.7001558407477445482  
Training accuracy: 48.125%  
Test accuracy: 46.0%

Epoch 40  
Training loss: 2.6861866865012374993  
Training accuracy: 49.0%  
Test accuracy: 50.33333333333333%

Epoch 41  
Training loss: 2.6583238320076925628  
Training accuracy: 50.083333333333336%  
Test accuracy: 48.83333333333333%

Epoch 42  
Training loss: 2.6317074658853856822  
Training accuracy: 51.04166666666667%  
Test accuracy: 46.833333333333336%

Epoch 43  
Training loss: 2.6138176654526768892  
Training accuracy: 50.416666666666664%  
Test accuracy: 49.83333333333333%

Epoch 44  
Training loss: 2.6044999991294236416  
Training accuracy: 50.33333333333333%  
Test accuracy: 52.16666666666667%

Epoch 45  
Training loss: 2.5793089454023069506  
Training accuracy: 52.5%  
Test accuracy: 51.833333333333336%

Epoch 46  
Training loss: 2.5632994127822610584  
Training accuracy: 52.125%  
Test accuracy: 53.333333333333336%

Epoch 47  
Training loss: 2.5347167003372911306  
Training accuracy: 52.25%  
Test accuracy: 50.66666666666667%

Epoch 48  
Training loss: 2.5081880780601504175  
Training accuracy: 53.125%  
Test accuracy: 50.66666666666667%

Epoch 49  
Training loss: 2.5019774462264822306  
Training accuracy: 52.625%  
Test accuracy: 55.333333333333336%

Epoch 50  
Training loss: 2.4764848894662325287  
Training accuracy: 54.041666666666664%  
Test accuracy: 53.5%

Epoch 51  
Training loss: 2.452226904106796056  
Training accuracy: 55.458333333333333%  
Test accuracy: 53.0%

Epoch 52  
Training loss: 2.4271786882900317133  
Training accuracy: 55.833333333333336%  
Test accuracy: 53.166666666666664%

Epoch 53  
Training loss: 2.4087328773039589653  
Training accuracy: 56.958333333333333%  
Test accuracy: 54.833333333333336%

Epoch 54  
Training loss: 2.3978986053310927494  
Training accuracy: 56.625%  
Test accuracy: 58.0%

Epoch 55  
Training loss: 2.3741816651786440753  
Training accuracy: 57.791666666666664%  
Test accuracy: 57.666666666666664%

Epoch 56  
Training loss: 2.3542260355808065624  
Training accuracy: 58.625%  
Test accuracy: 56.16666666666667%

Epoch 57  
Training loss: 2.335589776492270719  
Training accuracy: 59.791666666666664%

Test accuracy: 56.33333333333333%

Epoch 58

Training loss: 2.3231360258998368397

Training accuracy: 59.125%

Test accuracy: 59.833333333333336%

Epoch 59

Training loss: 2.3041447095744746758

Training accuracy: 60.20833333333333%

Test accuracy: 59.333333333333336%

Epoch 60

Training loss: 2.2830765835297399668

Training accuracy: 60.125000000000014%

Test accuracy: 62.0%

Epoch 61

Training loss: 2.2635407150988852269

Training accuracy: 61.708333333333336%

Test accuracy: 61.16666666666667%

Epoch 62

Training loss: 2.243757019773092045

Training accuracy: 62.54166666666667%

Test accuracy: 61.66666666666664%

Epoch 63

Training loss: 2.2319958972046281365

Training accuracy: 62.70833333333333%

Test accuracy: 64.83333333333333%

Epoch 64

Training loss: 2.2069541656405040695

Training accuracy: 63.958333333333336%

Test accuracy: 63.16666666666664%

Epoch 65

Training loss: 2.1899232454828515661

Training accuracy: 64.0%

Test accuracy: 64.66666666666666%

Epoch 66

Training loss: 2.1752786555805750444

Training accuracy: 64.70833333333334%

Test accuracy: 64.5%

Epoch 67



Training loss: 2.1423056912061856105  
Training accuracy: 65.1249999999999999%  
Test accuracy: 63.3333333333333333%

Epoch 68  
Training loss: 2.1407773707040331037  
Training accuracy: 65.3333333333333333%  
Test accuracy: 65.4999999999999999%

Epoch 69  
Training loss: 2.1057280311128920547  
Training accuracy: 66.7083333333333334%  
Test accuracy: 62.666666666666664%

Epoch 70  
Training loss: 2.0927274522981452404  
Training accuracy: 66.416666666666667%  
Test accuracy: 66.8333333333333333%

Epoch 71  
Training loss: 2.0839770262945515422  
Training accuracy: 66.291666666666666%  
Test accuracy: 68.000000000000001%

Epoch 72  
Training loss: 2.0677876537057070226  
Training accuracy: 67.3333333333333333%  
Test accuracy: 67.166666666666666%

Epoch 73  
Training loss: 2.0608752314827123479  
Training accuracy: 67.25%  
Test accuracy: 70.666666666666667%

Epoch 74  
Training loss: 2.0311699091818183954  
Training accuracy: 68.375000000000001%  
Test accuracy: 69.5%

Epoch 75  
Training loss: 2.0246517738084845745  
Training accuracy: 68.75%  
Test accuracy: 71.0%

Epoch 76  
Training loss: 1.9988725003135568018  
Training accuracy: 69.541666666666667%  
Test accuracy: 69.666666666666666%

Epoch 77  
Training loss: 1.9846538585974991995  
Training accuracy: 69.58333333333333%  
Test accuracy: 69.16666666666667%

Epoch 78  
Training loss: 1.9519214609644449316  
Training accuracy: 70.91666666666666%  
Test accuracy: 67.16666666666666%

Epoch 79  
Training loss: 1.9502124920417778286  
Training accuracy: 70.5%  
Test accuracy: 70.16666666666666%

Epoch 80  
Training loss: 1.9353559834261043355  
Training accuracy: 70.74999999999999%  
Test accuracy: 72.83333333333333%

Epoch 81  
Training loss: 1.9086712622242026586  
Training accuracy: 71.91666666666667%  
Test accuracy: 69.5%

Epoch 82  
Training loss: 1.8981191522404278106  
Training accuracy: 72.58333333333334%  
Test accuracy: 70.33333333333333%

Epoch 83  
Training loss: 1.8881939145386377953  
Training accuracy: 72.625%  
Test accuracy: 72.0%

Epoch 84  
Training loss: 1.8706959282181593679  
Training accuracy: 72.70833333333334%  
Test accuracy: 71.16666666666667%

Epoch 85  
Training loss: 1.8461974074922937936  
Training accuracy: 73.79166666666666%  
Test accuracy: 69.33333333333334%

Epoch 86  
Training loss: 1.8439941128404285996

Training accuracy: 73.45833333333334%  
Test accuracy: 73.5%

Epoch 87  
Training loss: 1.8333436000222114443  
Training accuracy: 73.83333333333334%  
Test accuracy: 74.5%

Epoch 88  
Training loss: 1.8197005523280204  
Training accuracy: 74.16666666666666%  
Test accuracy: 74.83333333333333%

Epoch 89  
Training loss: 1.8105139833816417727  
Training accuracy: 73.16666666666667%  
Test accuracy: 78.66666666666667%

Epoch 90  
Training loss: 1.792401468222083781  
Training accuracy: 74.45833333333334%  
Test accuracy: 75.5%

Epoch 91  
Training loss: 1.7810047174499233268  
Training accuracy: 74.625%  
Test accuracy: 75.33333333333333%

Epoch 92  
Training loss: 1.765299902122823938  
Training accuracy: 74.37500000000001%  
Test accuracy: 75.99999999999999%

Epoch 93  
Training loss: 1.7498873781278681779  
Training accuracy: 75.41666666666667%  
Test accuracy: 73.0%

Epoch 94  
Training loss: 1.726827081529860334  
Training accuracy: 75.45833333333333%  
Test accuracy: 75.0%

Epoch 95  
Training loss: 1.7295224553217010096  
Training accuracy: 75.29166666666667%  
Test accuracy: 75.66666666666667%

Epoch 96  
Training loss: 1.7246548127522062297  
Training accuracy: 75.70833333333333%  
Test accuracy: 77.66666666666666%

Epoch 97  
Training loss: 1.7032964189077534928  
Training accuracy: 75.875%  
Test accuracy: 76.16666666666666%

```
Epoch 98
Training loss: 1.6995911223933147227
Training accuracy: 76.29166666666666%
Test accuracy: 76.49999999999999%
```

Epoch 99  
Training loss: 1.6651640978227772287  
Training accuracy: 76.79166666666666%  
Test accuracy: 75.5%

Epoch 100  
Training loss: 1.6808723451918177181  
Training accuracy: 76.49999999999999%  
Test accuracy: 78.16666666666666%

Epoch 101  
Training loss: 1.6429320071485863347  
Training accuracy: 77.04166666666666%  
Test accuracy: 76.16666666666667%

Epoch 102  
Training loss: 1.6394109113463755749  
Training accuracy: 77.416666666666666666%  
Test accuracy: 75.499999999999999999%

Epoch 103  
Training loss: 1.6277586155694477767  
Training accuracy: 77.75%  
Test accuracy: 74.33333333333333%

Epoch 104  
Training loss: 1.6283481274764727302  
Training accuracy: 77.54166666666666%  
Test accuracy: 77.66666666666666%

Epoch 105  
Training loss: 1.6203712566662611195  
Training accuracy: 77.75000000000001%

Test accuracy: 78.16666666666667%

Epoch 106

Training loss: 1.6044070173546441207

Training accuracy: 78.54166666666667%

Test accuracy: 76.33333333333333%

Epoch 107

Training loss: 1.5839484847893517887

Training accuracy: 79.04166666666667%

Test accuracy: 75.33333333333333%

Epoch 108

Training loss: 1.5782264454868773425

Training accuracy: 78.75%

Test accuracy: 77.83333333333334%

Epoch 109

Training loss: 1.5807373960647599396

Training accuracy: 78.66666666666667%

Test accuracy: 78.33333333333334%

Epoch 110

Training loss: 1.5827687259254224922

Training accuracy: 78.375%

Test accuracy: 79.99999999999999%

Epoch 111

Training loss: 1.5682899960488519013

Training accuracy: 78.29166666666666%

Test accuracy: 81.33333333333334%

Epoch 112

Training loss: 1.5349081594944330439

Training accuracy: 79.70833333333334%

Test accuracy: 76.16666666666667%

Epoch 113

Training loss: 1.518288277049317607

Training accuracy: 79.83333333333333%

Test accuracy: 76.66666666666667%

Epoch 114

Training loss: 1.5281130021398682932

Training accuracy: 79.04166666666667%

Test accuracy: 79.0%

Epoch 115

Training loss: 1.522334181367994055  
Training accuracy: 79.125%  
Test accuracy: 79.83333333333333%

Epoch 116  
Training loss: 1.5117069466936084875  
Training accuracy: 78.87500000000001%  
Test accuracy: 81.66666666666667%

Epoch 117  
Training loss: 1.5090857267319704102  
Training accuracy: 79.33333333333333%  
Test accuracy: 81.66666666666666%

Epoch 118  
Training loss: 1.498418350903087802  
Training accuracy: 79.54166666666666%  
Test accuracy: 81.66666666666667%

Epoch 119  
Training loss: 1.4842821763492565848  
Training accuracy: 80.41666666666667%  
Test accuracy: 79.33333333333334%

Epoch 120  
Training loss: 1.4834437734570311832  
Training accuracy: 79.91666666666667%  
Test accuracy: 81.83333333333334%

Epoch 121  
Training loss: 1.4544172587766003447  
Training accuracy: 80.58333333333333%  
Test accuracy: 79.66666666666666%

Epoch 122  
Training loss: 1.4503141223089414038  
Training accuracy: 80.83333333333333%  
Test accuracy: 80.83333333333334%

Epoch 123  
Training loss: 1.4521998225408930161  
Training accuracy: 80.5%  
Test accuracy: 81.66666666666666%

Epoch 124  
Training loss: 1.4330439050394409963  
Training accuracy: 81.125%  
Test accuracy: 80.33333333333334%

Epoch 125  
Training loss: 1.4178019349950530134  
Training accuracy: 81.25%  
Test accuracy: 81.0%

Epoch 126  
Training loss: 1.4063413248700011705  
Training accuracy: 81.875%  
Test accuracy: 78.33333333333333%

Epoch 127  
Training loss: 1.4171777733106056664  
Training accuracy: 81.66666666666667%  
Test accuracy: 81.0%

Epoch 128  
Training loss: 1.4024362252603030789  
Training accuracy: 82.04166666666667%  
Test accuracy: 80.5%

Epoch 129  
Training loss: 1.3828547646318187213  
Training accuracy: 81.87499999999999%  
Test accuracy: 80.0%

Epoch 130  
Training loss: 1.3835596830702955788  
Training accuracy: 81.50000000000001%  
Test accuracy: 82.5%

Epoch 131  
Training loss: 1.3752081231646720192  
Training accuracy: 82.29166666666667%  
Test accuracy: 80.5%

Epoch 132  
Training loss: 1.3814652758042693465  
Training accuracy: 82.04166666666666%  
Test accuracy: 82.66666666666667%

Epoch 133  
Training loss: 1.3622488750226002483  
Training accuracy: 82.25%  
Test accuracy: 82.16666666666667%

Epoch 134  
Training loss: 1.3708993073272228599

Training accuracy: 81.91666666666666%  
Test accuracy: 83.66666666666667%

Epoch 135  
Training loss: 1.3451353839415193901  
Training accuracy: 82.875%  
Test accuracy: 80.5%

Epoch 136  
Training loss: 1.3326920537816569901  
Training accuracy: 83.08333333333333%  
Test accuracy: 79.83333333333333%

Epoch 137  
Training loss: 1.3385968511041070021  
Training accuracy: 83.08333333333334%  
Test accuracy: 82.5%

Epoch 138  
Training loss: 1.3337758253238553851  
Training accuracy: 83.04166666666666%  
Test accuracy: 82.33333333333334%

Epoch 139  
Training loss: 1.3259104316468697047  
Training accuracy: 82.91666666666667%  
Test accuracy: 84.00000000000001%

Epoch 140  
Training loss: 1.3087905092210158444  
Training accuracy: 83.66666666666667%  
Test accuracy: 81.0%

Epoch 141  
Training loss: 1.319660184317914443  
Training accuracy: 82.625%  
Test accuracy: 86.49999999999999%

Epoch 142  
Training loss: 1.3064673179315585598  
Training accuracy: 83.125%  
Test accuracy: 83.66666666666667%

Epoch 143  
Training loss: 1.2809365515009170014  
Training accuracy: 83.70833333333333%  
Test accuracy: 81.66666666666667%



Epoch 144  
Training loss: 1.2872712545188807299  
Training accuracy: 83.50000000000001%  
Test accuracy: 82.66666666666667%

Epoch 145  
Training loss: 1.2958660797949415038  
Training accuracy: 83.08333333333333%  
Test accuracy: 85.83333333333333%

Epoch 146  
Training loss: 1.2721159298840193667  
Training accuracy: 83.87499999999999%  
Test accuracy: 82.33333333333334%

Epoch 147  
Training loss: 1.2859210391615178577  
Training accuracy: 83.25%  
Test accuracy: 84.83333333333334%

Epoch 148  
Training loss: 1.2680142684812489846  
Training accuracy: 83.95833333333333%  
Test accuracy: 82.83333333333333%

Epoch 149  
Training loss: 1.2413955859140263797  
Training accuracy: 84.16666666666666%  
Test accuracy: 82.16666666666667%

Epoch 150  
Training loss: 1.2411662072628656659  
Training accuracy: 84.45833333333333%  
Test accuracy: 81.83333333333334%

Epoch 151  
Training loss: 1.2405623698211687882  
Training accuracy: 84.41666666666666%  
Test accuracy: 82.83333333333334%

Epoch 152  
Training loss: 1.2444146140355801715  
Training accuracy: 84.0%  
Test accuracy: 83.83333333333334%

Epoch 153  
Training loss: 1.2325377299862857082  
Training accuracy: 84.20833333333334%

Test accuracy: 83.66666666666667%

Epoch 154

Training loss: 1.22127167598089548

Training accuracy: 84.83333333333334%

Test accuracy: 82.16666666666666%

Epoch 155

Training loss: 1.2237970114797168009

Training accuracy: 84.16666666666666%

Test accuracy: 85.0%

Epoch 156

Training loss: 1.2202835807130927578

Training accuracy: 84.04166666666666%

Test accuracy: 85.33333333333333%

Epoch 157

Training loss: 1.2075148067370243655

Training accuracy: 84.54166666666666%

Test accuracy: 83.5%

Epoch 158

Training loss: 1.1986431462950857805

Training accuracy: 84.37499999999999%

Test accuracy: 84.16666666666666%

Epoch 159

Training loss: 1.2031189737939484987

Training accuracy: 84.875%

Test accuracy: 83.83333333333334%

Epoch 160

Training loss: 1.2032240720395311271

Training accuracy: 84.29166666666666%

Test accuracy: 85.33333333333334%

Epoch 161

Training loss: 1.1894628091619322769

Training accuracy: 84.375%

Test accuracy: 85.16666666666666%

Epoch 162

Training loss: 1.1763866716792061334

Training accuracy: 84.45833333333333%

Test accuracy: 84.83333333333333%

Epoch 163

Training loss: 1.1822431818465281286  
Training accuracy: 84.91666666666667%  
Test accuracy: 83.33333333333334%

Epoch 164  
Training loss: 1.1836099314217062288  
Training accuracy: 84.08333333333334%  
Test accuracy: 86.5%

Epoch 165  
Training loss: 1.1737219363981122391  
Training accuracy: 85.04166666666666%  
Test accuracy: 83.66666666666666%

Epoch 166  
Training loss: 1.1658452517535298158  
Training accuracy: 84.87499999999999%  
Test accuracy: 84.0%

Epoch 167  
Training loss: 1.1553331757552881924  
Training accuracy: 85.0%  
Test accuracy: 84.49999999999999%

Epoch 168  
Training loss: 1.1557910241415638655  
Training accuracy: 85.04166666666666%  
Test accuracy: 84.0%

Epoch 169  
Training loss: 1.1301753500787422925  
Training accuracy: 85.99999999999999%  
Test accuracy: 80.49999999999999%

Epoch 170  
Training loss: 1.1343607785122263982  
Training accuracy: 85.0%  
Test accuracy: 83.83333333333334%

Epoch 171  
Training loss: 1.1510424740460766448  
Training accuracy: 84.79166666666667%  
Test accuracy: 85.5%

Epoch 172  
Training loss: 1.1249354224349255202  
Training accuracy: 85.45833333333333%  
Test accuracy: 83.49999999999999%

Epoch 173  
Training loss: 1.1247047363009302611  
Training accuracy: 85.54166666666666%  
Test accuracy: 83.49999999999999%

Epoch 174  
Training loss: 1.1237967223888397194  
Training accuracy: 85.29166666666667%  
Test accuracy: 84.83333333333334%

Epoch 175  
Training loss: 1.1147545116480842052  
Training accuracy: 85.625%  
Test accuracy: 83.16666666666666%

Epoch 176  
Training loss: 1.1047748684328695884  
Training accuracy: 85.45833333333334%  
Test accuracy: 84.99999999999999%

Epoch 177  
Training loss: 1.1130921121547114152  
Training accuracy: 85.16666666666666%  
Test accuracy: 86.00000000000001%

Epoch 178  
Training loss: 1.1109414043932233156  
Training accuracy: 85.45833333333333%  
Test accuracy: 85.00000000000001%

Epoch 179  
Training loss: 1.1086664133032136249  
Training accuracy: 85.37499999999999%  
Test accuracy: 85.66666666666666%

Epoch 180  
Training loss: 1.1016285063092241905  
Training accuracy: 85.79166666666667%  
Test accuracy: 84.83333333333334%

Epoch 181  
Training loss: 1.0970076731483456799  
Training accuracy: 85.41666666666666%  
Test accuracy: 86.0%

Epoch 182  
Training loss: 1.0886376006681835261

Training accuracy: 85.58333333333333%  
Test accuracy: 85.33333333333333%

Epoch 183  
Training loss: 1.076965967019693096  
Training accuracy: 86.00000000000001%  
Test accuracy: 83.83333333333334%

Epoch 184  
Training loss: 1.0791030542458641371  
Training accuracy: 85.79166666666667%  
Test accuracy: 84.5%

Epoch 185  
Training loss: 1.086553503845163421  
Training accuracy: 85.5%  
Test accuracy: 86.33333333333334%

Epoch 186  
Training loss: 1.0757990159937518747  
Training accuracy: 86.00000000000001%  
Test accuracy: 85.5%

Epoch 187  
Training loss: 1.0621987199240161012  
Training accuracy: 86.16666666666666%  
Test accuracy: 84.5%

Epoch 188  
Training loss: 1.0637489190452939322  
Training accuracy: 86.5%  
Test accuracy: 84.49999999999999%

Epoch 189  
Training loss: 1.0705150586464930026  
Training accuracy: 85.16666666666667%  
Test accuracy: 88.83333333333334%

Epoch 190  
Training loss: 1.0476088977868649868  
Training accuracy: 86.25%  
Test accuracy: 84.66666666666666%

Epoch 191  
Training loss: 1.0530836098361415143  
Training accuracy: 86.16666666666666%  
Test accuracy: 85.66666666666667%

```
Epoch 192
Training loss: 1.0334311235185067992
Training accuracy: 86.74999999999999%
Test accuracy: 84.00000000000001%
```

Epoch 193  
Training loss: 1.0476885268063559933  
Training accuracy: 85.79166666666666%  
Test accuracy: 86.83333333333334%

Epoch 194  
Training loss: 1.0500284734024286511  
Training accuracy: 86.04166666666667%  
Test accuracy: 87.0%

Epoch 195  
Training loss: 1.0287267488290544034  
Training accuracy: 86.041666666666666666%  
Test accuracy: 86.833333333333333333%

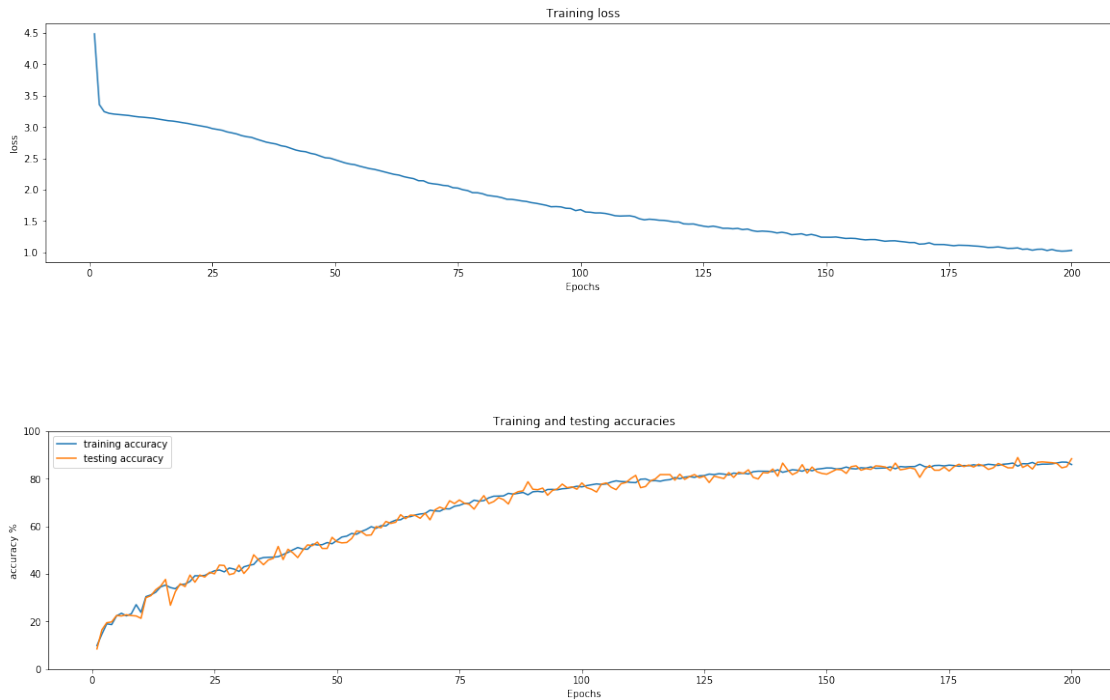
Epoch 196  
Training loss: 1.0452435175130006009  
Training accuracy: 86.16666666666666%  
Test accuracy: 86.66666666666666%

Epoch 197  
Training loss: 1.0254561796901198003  
Training accuracy: 86.54166666666666%  
Test accuracy: 86.33333333333333%

Epoch 198  
Training loss: 1.018080162968010525  
Training accuracy: 86.91666666666667%  
Test accuracy: 84.49999999999999%

Epoch 199  
Training loss: 1.0215660936076044658  
Training accuracy: 86.87500000000001%  
Test accuracy: 85.0%

Epoch 200  
Training loss: 1.0314826435002884537  
Training accuracy: 85.875%  
Test accuracy: 88.33333333333333%



We still don't get a result as good as the original images.

This might be because when reducing the dimensionality of the image, we may lose some spatial information of the image. This will make it tough for the neural network to learn some key spatial differences that separates one digit from another.

2.4 With this we end the 1st report. In the next report, we'll train a CNN using PyTorch to train on the entire MNIST dataset

[ ]: