In [9]:

```python
weight0, weight1, weight2, bias0 ,bias1, bias2, loss_training_set ,loss_test_set = DNN()
```

```
0.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 2.5149347659670824
test loss is 1.6118094750958207
0.9 accuracy!
2.0 % proceeding
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-----------------------------------

training loss is 1.3611264849016464
test loss is 1.4140900466854691
0.912 accuracy!
4.0 % proceeding
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-----------------------------------

training loss is 1.0605172344904537
test loss is 1.2572120929347177
0.922 accuracy!
6.0 % proceeding
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-----------------------------------

training loss is 0.8422102388057583
test loss is 1.2231850932067416
0.923 accuracy!
8.0 % proceeding
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-----------------------------------

training loss is 0.726239135430163
test loss is 1.1626161206843304
0.927 accuracy!
10.0 % proceeding
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-----------------------------------

training loss is 0.6198121717872271
test loss is 1.160502795365448
0.928 accuracy!
12.0 % proceeding
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-----------------------------------

training loss is 0.5324898632013291
test loss is 1.0965966972596262
0.9319999999999999 accuracy!
14.000000000000002 % proceeding
-----------------------------------------------------------------------------------------------------------------
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```

```
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-----------------------------------

training loss is 0.46029361476551617
test loss is 1.0960243550167224
0.9319999999999999 accuracy!
16.0 % proceeding
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-----------------------------------

training loss is 0.4008714877695912
test loss is 1.0152999944723609
0.937 accuracy!
18.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.33506932505201975
test loss is 1.035664666375785
0.9339999999999999 accuracy!
20.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.3074991732074506
test loss is 1.0307298039992197
0.9359999999999999 accuracy!
22.0 % proceeding
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-----------------------------------

training loss is 0.26766254580996374
test loss is 1.0211479334231863
0.9359999999999999 accuracy!
24.0 % proceeding
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-----------------------------------

training loss is 0.22295709006632428
test loss is 1.0679271217540682
0.933 accuracy!
26.0 % proceeding
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training loss is 0.19941956402879477
test loss is 1.0503457755780874
0.9339999999999999 accuracy!
28.000000000000004 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.1780044230141076
```

```
test loss is 1.0155299987611037
0.937 accuracy!
30.0 % proceeding
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-----------------------------------

training loss is 0.14832513173285466
test loss is 1.0154413234487647
0.937 accuracy!
32.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.13286747904725585
test loss is 1.0533943647530484
0.9339999999999999 accuracy!
34.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.1144092205087674
test loss is 1.0462395127176412
0.9339999999999999 accuracy!
36.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.1073018462836586
test loss is 1.0631116470344022
0.9339999999999999 accuracy!
38.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.09659691666200783
test loss is 1.061376457379356
0.9339999999999999 accuracy!
40.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.08137558567803722
test loss is 1.0654026015723381
0.9319999999999999 accuracy!
42.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.06804135623211276
test loss is 1.031719379157748
0.9359999999999999 accuracy!
44.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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```

```
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training loss is 0.057715049082359256
test loss is 0.9699213937703438
0.9390000000000001 accuracy!
46.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.0492960273555089
test loss is 0.98439075728883
0.938 accuracy!
48.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.04890186231384991
test loss is 1.035957936108084
0.9339999999999999 accuracy!
50.0 % proceeding
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training loss is 0.041416323493454206
test loss is 0.9523526259382074
0.94 accuracy!
52.0 % proceeding
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-----------------------------------

training loss is 0.03893742072213069
test loss is 0.9836329667270168
0.938 accuracy!
54.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.03216594083755486
test loss is 1.0476570312153932
0.935 accuracy!
56.00000000000001 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.028319811179531116
test loss is 0.9348595398347663
0.942 accuracy!
57.99999999999999 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.024044030420369077
test loss is 0.9383687714946148
```

```
0.9410000000000001 accuracy!
60.0 % proceeding
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-----------------------------------

training loss is 0.01795469955199769
test loss is 0.9659495655732327
0.9390000000000001 accuracy!
62.0 % proceeding
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.016448282781528788
test loss is 0.9846731557335892
0.938 accuracy!
64.0 % proceeding
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.012488898017275946
test loss is 1.0424003746871906
0.935 accuracy!
66.0 % proceeding
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.016868747519025708
test loss is 1.020335244472253
0.9359999999999999 accuracy!
68.0 % proceeding
------------------------------------------------------------------------------------------------------------------
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------------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.012179407548810741
test loss is 0.9993177767089149
0.938 accuracy!
70.0 % proceeding
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
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------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.013001181330945898
test loss is 0.9997127270323134
0.938 accuracy!
72.0 % proceeding
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
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------------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.010252817346090556
test loss is 0.9670726722741555
0.94 accuracy!
74.0 % proceeding
------------------------------------------------------------------------------------------------------------------
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```

```
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-----------------------------------

training loss is 0.012148169288423466
test loss is 0.9619179961236524
0.94 accuracy!
76.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
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training loss is 0.010745262998210338
test loss is 1.003380833457053
0.937 accuracy!
78.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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training loss is 0.009490179483876504
test loss is 0.9358499302645163
0.9410000000000001 accuracy!
80.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.006396593196803525
test loss is 0.9991055675244346
0.938 accuracy!
82.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.007056705645462451
test loss is 0.9347761989165964
0.942 accuracy!
84.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.007406090936302602
test loss is 0.9049490159101365
0.943 accuracy!
86.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.005892544544452425
test loss is 0.9348808416467967
0.942 accuracy!
88.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.0024030067138877333
test loss is 0.9340942348970782
0.942 accuracy!
```

```
90.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.0010467341585904887
test loss is 0.9348460279372178
0.942 accuracy!
92.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------

training loss is 0.005186301831370774
test loss is 0.9031487629179922
0.944 accuracy!
94.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.006959105408398891
test loss is 0.9805674060457873
0.9390000000000001 accuracy!
96.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.0033000310162809806
test loss is 0.9509675600956976
0.9410000000000001 accuracy!
98.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------

training loss is 0.002779154419935798
test loss is 0.9683039815842942
0.938 accuracy!
```

In [13]:

```
confusionmatrix, top3matrix, top3matrix_index = ConfusionMatrix_n_top3(weight0, weight1, weight2, bias0 ,bias1, b
```

Module

In [3]:

```
import matplotlib.pyplot as plt
import pandas as pd
import seaborn as sns
```

Loader

In [4]:

```
import gzip
import numpy as np
from pathlib import Path
import math
import random

class Dataloader():
    def __init__(self, path, is_train=True, shuffle=True, batch_size=8):
```

```
        path = Path(path)
        imagePath = Path(path/'train-images-idx3-ubyte.gz') if is_train else Path(path/'t10k-images-idx3-ubyte.gz
        labelPath = Path(path/'train-labels-idx1-ubyte.gz') if is_train else Path(path/'t10k-labels-idx1-ubyte.gz

        self.batch_size = batch_size
        self.images = self.loadImages(imagePath)
        self.labels = self.loadLabels(labelPath)
        self.index = 0
        self.idx = np.arange(0, self.images.shape[0])
        if shuffle: np.random.shuffle(self.idx) # shuffle images

    def __len__(self):
        n_images, _, _, _ = self.images.shape
        n_images = math.ceil(n_images / self.batch_size)
        return n_images

    def __iter__(self):
        return datasetIterator(self)

    def __getitem__(self, index):
        image = self.images[self.idx[index * self.batch_size:(index + 1) * self.batch_size]]
        label = self.labels[self.idx[index * self.batch_size:(index + 1) * self.batch_size]]
        image = image/255.0
        return image, label

    def loadImages(self, path):
        with gzip.open(path) as f:
            images = np.frombuffer(f.read(), 'B', offset=16)
            images = images.reshape(-1, 1, 28, 28).astype(np.float32)
            return images

    def loadLabels(self, path):
        with gzip.open(path) as f:
            labels = np.frombuffer(f.read(), 'B', offset=8)
            rows = len(labels)
            cols = labels.max() + 1
            one_hot = np.zeros((rows, cols)).astype(np.uint8)
            one_hot[np.arange(rows), labels] = 1
            one_hot = one_hot.astype(np.float64)
            return one_hot

# for enumerate magic python function returns Iterator
class datasetIterator():
    def __init__(self, dataloader):
        self.index = 0
        self.dataloader = dataloader

    def __next__(self):
        if self.index < len(self.dataloader):
            item = self.dataloader[self.index]
            self.index += 1
            return item
        # end of iteration
        raise StopIteration
```

Function

In [5]:

```
def ReLU(value):
    return max(0, value)

def converter_ReLU(array):
    return np.array([ReLU(x) for x in array])

def zeroorone(value):
    if value > 0:
        return 1
    else:
        return 0

def converter_zeroorone_10(array):
    return np.array([zeroorone(x) for x in array.reshape(10)])

def converter_zeroorone_784(array):
    return np.array([zeroorone(x) for x in array.reshape(784)])

def SoftMax(z):
    c = np.max(z)
    exp_z = np.exp(z-c)
    sum_exp_z = np.sum(exp_z)
    y = exp_z / sum_exp_z
    return y

def Cross_entrophy_loss(y_label, y_prediction):
    return -np.sum(y_label*np.log(y_prediction+1e-7))
```

In [6]:

```
def DNN(batchsize=100, epoch=50, testing = 1000):
    #ready for dataset
    learning_rate = batchsize/60000
    iteration = math.ceil(60000/batchsize)
    loss_training_set = []
    loss_test_set = []

    training_data = Dataloader(
        path="./",
        shuffle=True,
        batch_size=batchsize
    )
    test_data = Dataloader(
        path="./",
        shuffle=True,
        is_train = False,
        batch_size = 1
    )
    #initialize function
    weight0 = np.random.randn(784,784)
    weight1 = np.random.randn(784,784)
    weight2 = np.random.randn(784,10)
    bias0 = np.random.randn(784)
    bias1 = np.random.randn(784)
    bias2 = np.random.randn(10)

    for k in range(0,epoch):
        print(100*(k/epoch),"% proceeding")
        training_loss = 0
        error = 0
        test_loss = 0
        for i in range(0,iteration):
            #foward porpagation
            print("-",end='')
            delta_3 = np.zeros(10).reshape(1,10)
            delta_2 = np.zeros(784).reshape(1,784)
            delta_1 = np.zeros(784).reshape(1,784)
            chain_delta_3 = np.zeros(7840).reshape(784,10)
            chain_delta_2 = np.zeros(614656).reshape(784,784)
            chain_delta_1 = np.zeros(614656).reshape(784,784)
            for j in range(0, batchsize):
                #foward porpagation
                y_label = training_data.__getitem__(i)[1][j]

                layer_input = converter_zeroorone_784(training_data.__getitem__(i)[0][j])
                layer_1 = np.dot(layer_input, weight0)+bias0
                layer_1_ReLU = converter_ReLU(layer_1)

                layer_2 = np.dot(layer_1_ReLU,weight1)+bias1
                layer_2_ReLU = converter_ReLU(layer_2)

                layer_3 = np.dot(layer_2_ReLU, weight2)+bias2
                y_prediction = SoftMax(layer_3)
                training_loss += Cross_entrophy_loss(y_label,y_prediction)
                #Backwardpropagation weight2

                delta_3_b = ((y_prediction - y_label)/batchsize)
                chain_delta_3_b = np.dot(layer_2_ReLU.reshape(784,1), delta_3_b.reshape(1,10))

                #Backwardpropagation weight1

                delta_2_b = np.dot(delta_3_b,weight2.T)*converter_zeroorone_784(layer_2)
                chain_delta_2_b= np.dot(layer_1_ReLU.reshape(784,1), delta_2_b.reshape(1,784))

                #Backwardpropagation weight0

                delta_1_b = np.dot(delta_2_b,weight1.T)*converter_zeroorone_784(layer_1)
                chain_delta_1_b= np.dot(layer_input.reshape(784,1), delta_1_b.reshape(1,784))


                delta_3 += delta_3_b
                delta_2 += delta_2_b
                delta_1 += delta_1_b
                chain_delta_3 += chain_delta_3_b
                chain_delta_2 += chain_delta_2_b
                chain_delta_1 += chain_delta_1_b
            weight2 -= (learning_rate * chain_delta_3)
            weight1 -= (learning_rate * chain_delta_2)
            weight0 -= (learning_rate * chain_delta_1)
            bias2 -= delta_3.reshape(10)*learning_rate
            bias1 -= delta_2.reshape(784)*learning_rate
            bias0 -= delta_1.reshape(784)*learning_rate
        print("\n")
        print("training loss is",training_loss/60000)
        loss_training_set.append(training_loss/60000)

        for i in range(0,testing):
```

```
            y_label = test_data.__getitem__(i)[1]
            layer_input = converter_zeroorone_784(test_data.__getitem__(i)[0])
            layer_1 = np.dot(layer_input, weight0)+bias0
            layer_1_ReLU = converter_ReLU(layer_1)
            layer_2 = np.dot(layer_1_ReLU,weight1)+bias1
            layer_2_ReLU = converter_ReLU(layer_2)
            layer_3 = np.dot(layer_2_ReLU, weight2)+bias2
            y_prediction = SoftMax(layer_3)
            test_loss += Cross_entrophy_loss(y_label,y_prediction)
            if(np.argmax(y_prediction)!=np.argmax(test_data.__getitem__(i)[1])):
                error += 1
        print("test loss is",test_loss/testing)
        print(1-(error/testing),"accuracy!")
        loss_test_set.append(test_loss/testing)
    return weight0, weight1, weight2, bias0 ,bias1, bias2, loss_training_set ,loss_test_set
```

In [12]:

```
test_data = Dataloader(
    path="./",
    shuffle=True,
    is_train = False,
    batch_size = 1
)
```

In [11]:

```
def ConfusionMatrix_n_top3(weight0, weight1, weight2, bias0 ,bias1, bias2, test_data):
    confusionmatrix = np.zeros(100).reshape(10,10)
    top3matrix = np.zeros(30).reshape(10,3)
    top3matrix_index = np.zeros(30).reshape(10,3)
    for i in range(0,10000):
        y_label = test_data.__getitem__(i)[1]
        layer_input = converter_zeroorone_784(test_data.__getitem__(i)[0])
        layer_1 = np.dot(layer_input, weight0)+bias0
        layer_1_ReLU = converter_ReLU(layer_1)
        layer_2 = np.dot(layer_1_ReLU,weight1)+bias1
        layer_2_ReLU = converter_ReLU(layer_2)
        layer_3 = np.dot(layer_2_ReLU, weight2)+bias2
        y_prediction = SoftMax(layer_3)

        #confusionmatrix
        confusionmatrix[np.argmax(y_label)][np.argmax(y_prediction)]+=1
        index = np.argmin(top3matrix[np.argmax(y_prediction)])
        if top3matrix[np.argmax(y_prediction)][index] <= y_prediction[np.argmax(y_prediction)]:
            top3matrix[np.argmax(y_prediction)][index] =  y_prediction[np.argmax(y_prediction)]
            top3matrix_index[np.argmax(y_prediction)][index] = i

    return confusionmatrix , top3matrix, top3matrix_index
```

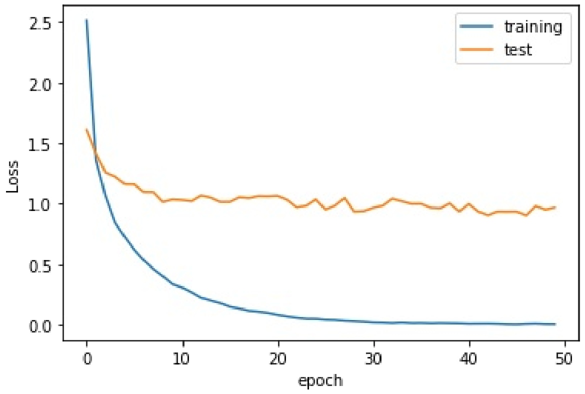
Loss graph

In [14]:

```
index = [x for x in range(50)]
```

In [15]:

```
plt.xlabel('epoch')
plt.ylabel("Loss")
plt.plot(index,loss_training_set)
plt.plot(index,loss_test_set)
plt.legend(['training', 'test'])
plt.show()
```



Confusion Matrix

In [16]:
```python
confusionmatrix_visualization = np.array([(100*x)/np.sum(x) for x in confusionmatrix])
```

In [17]:
```python
confusionmatrix_visualization = np.array([ np.fix(x) for x in confusionmatrix])
```

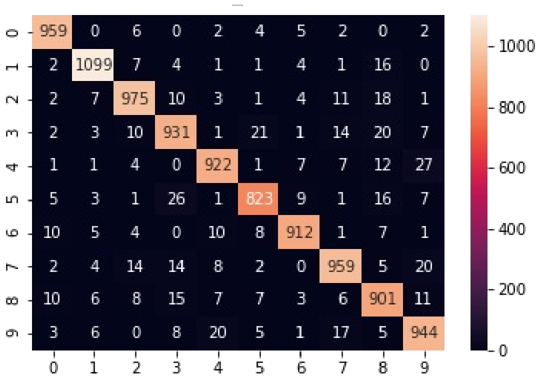
In [18]:
```python
confusionmatrix_visualization.astype(int)
```

Out[18]:
```
array([[ 959,    0,    6,    0,    2,    4,    5,    2,    0,    2],
       [   2, 1099,    7,    4,    1,    1,    4,    1,   16,    0],
       [   2,    7,  975,   10,    3,    1,    4,   11,   18,    1],
       [   2,    3,   10,  931,    1,   21,    1,   14,   20,    7],
       [   1,    1,    4,    0,  922,    1,    7,    7,   12,   27],
       [   5,    3,    1,   26,    1,  823,    9,    1,   16,    7],
       [  10,    5,    4,    0,   10,    8,  912,    1,    7,    1],
       [   2,    4,   14,   14,    8,    2,    0,  959,    5,   20],
       [  10,    6,    8,   15,    7,    7,    3,    6,  901,   11],
       [   3,    6,    0,    8,   20,    5,    1,   17,    5,  944]])
```

In [19]:
```python
sns.heatmap(confusionmatrix_visualization.astype(int), annot=True, fmt='d')

plt.title('confusionmatrix', fontsize=1)

plt.show()
```



Top-3 images with probability

In [20]:
```python
print(top3matrix)
```

```
[[1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]
 [1. 1. 1.]]
```

In [22]:
```python
fig, axes = plt.subplots(10,3, figsize=(3,10))
j=0
for i,ax in enumerate(axes.flat):
    index = math.ceil(top3matrix_index.reshape(30)[j])
    ax.imshow(test_data.__getitem__(index)[0].reshape(28,28))
    j+=1
```