assign3_q1

April 3, 2020

[0]:
```
from google.colab import drive
drive.mount('/content/drive')
```

[0]:
```
import numpy as np
import math
import pandas as pd
import matplotlib.pyplot as plt
import random
import glob
import cv2
import os
from numpy import mean
from numpy import cov
from numpy.linalg import eig
```

[0]:
```
def rgb2gray(rgb):
    return np.dot(rgb[...,:3], [0.2989, 0.5870, 0.1140])
```

0.1 We read the files using OpenCV and store them in a list after downscaling the images and flattening them. We also create a dictionary mapping the file labels to the image matrix.

[4]:
```
faces = []
path= '/content/drive/My Drive/SMAI_Assignment3_Dataset/dataset/'
data_path = os.path.join(path,'*g')
files = glob.glob(data_path)
index = path.rindex('/')
labels_dict = {}
for f1 in files:
  file_name = f1[index+1:]
  file_label, name = file_name.split('_')
  img = cv2.imread(f1)
  img = rgb2gray(img)
  gray = cv2.resize(img, (100,100), interpolation = cv2.INTER_AREA)
  face = gray.flatten()
  faces.append(face)
```

```
  if file_label in labels_dict:
    labels_dict[file_label].append(face)
  else:
    labels_dict[file_label] = [face]

faces = np.array(faces)
print(faces)
faces.shape
```

```
[[185.95189282 121.08736387  37.61438748 ... 203.2247     203.2247
  203.2247    ]
 [ 21.91588271  21.55999863  22.24398713 ...  24.78532952  17.35223347
   14.73619512]
 [117.47369971 114.98464094 110.30165815 ...  85.38188735  92.14534858
   95.64598513]
 ...
 [253.366      253.366      253.366      ...  27.06021174  27.00406501
   28.86154526]
 [148.88045857 149.38309385 151.88990161 ... 179.7612002  175.46599707
  169.82343428]
 [113.22766084 121.90593501 129.71078774 ...  34.62707827  34.05039351
   44.23473982]]
```

[4]: (520, 10000)

0.1.1 We calculate the mean of each column and center the values in each column of the matrix by subtracting the mean column value. We also find the covariance matrix of the centered matrix.

[0]:
```
img_mean = mean(faces)
temp = faces - img_mean
covariance = cov(temp.T)
```

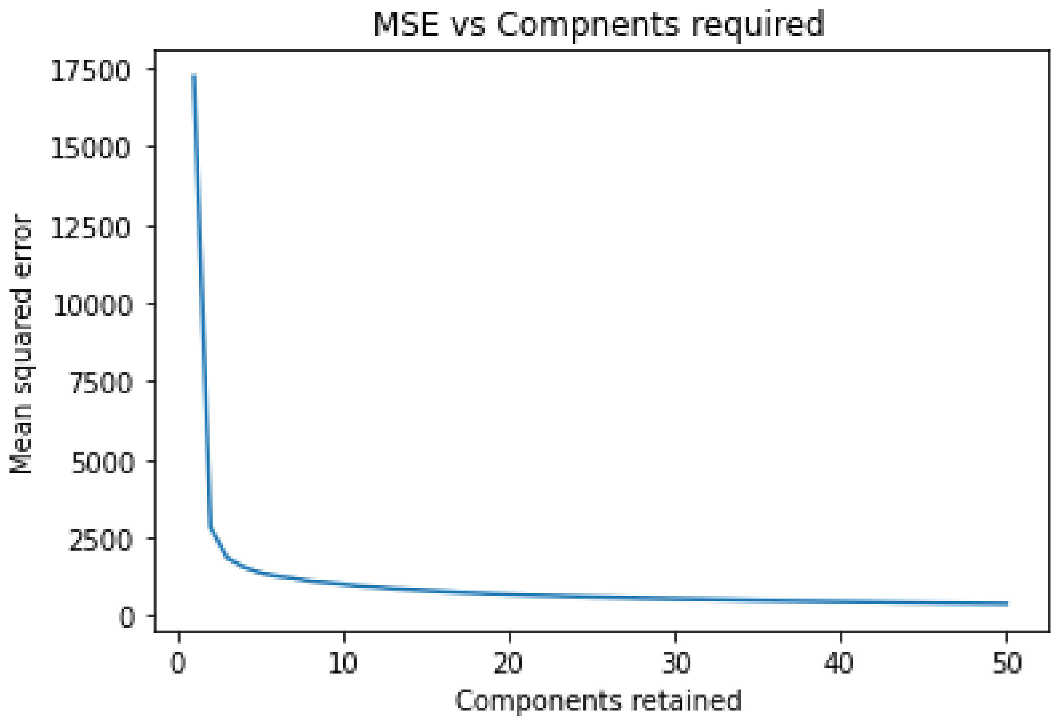
0.1.2 We calculate the eigen decomposition of the covariance matrix, thus resulting in a list of eigenvalues and a list of eigenvectors. We sort the eigen values in descending order and accordingly store the eigen vectors.

[0]:
```
e, v = eig(covariance)
indexes = e.argsort()[::-1]
eigen_values = e[indexes]
eigen_vectors = v[:,indexes]
```

0.2 Plot showing how mean squared error varies by increasing the number of components retained.

[0]:
```python
from sklearn.metrics import mean_squared_error

total_components = faces.shape[1]
number_of_images = faces.shape[0]
allowed_components = 50
mse_list = list()

for components in range(allowed_components):
  vectors = eigen_vectors[:,:components]
  transformation_matrix = np.real(vectors)
  pca_projections = np.dot(faces, transformation_matrix)
  reconstruction_matrix = np.dot(pca_projections, transformation_matrix.T)
  mse = 0
  for i in range(total_components):
    mse = mse + (mean_squared_error(faces[:,i], reconstruction_matrix[:,i]))

  mse = mse / total_components
  mse_list.append(mse)
```

[0]:
```python
plt.plot([i+1 for i in range(len(mse_list))], mse_list)
plt.xlabel('Components retained')
plt.ylabel('Mean squared error')
plt.title("MSE vs Compnents required")
plt.show()
```

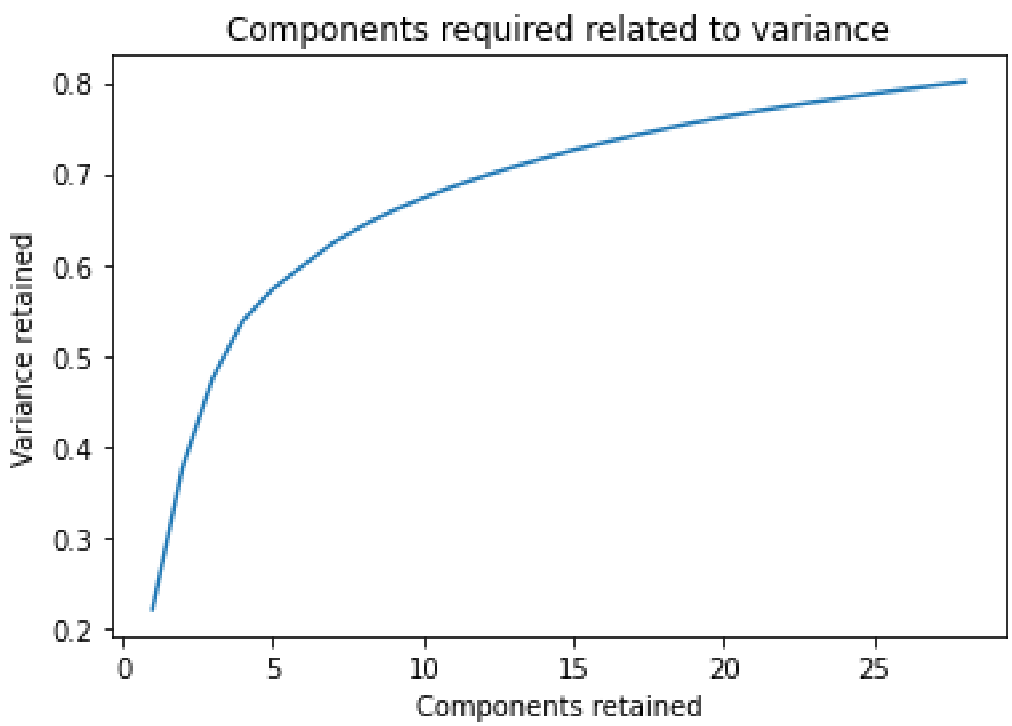


0.3 Plot showing how variance varies by increasing the number of components retained.

[0]:
```
total = np.sum(eigen_values)
variance_reqd = 0.8
var_list = list()
no_of_components = 0
components_reqd = 0
sum1 = 0
while True:
  sum1 += eigen_values[no_of_components]
  var = sum1/total
  var_list.append(var)
  var_achieved = np.real(var)
  if var_achieved >= variance_reqd:
      components_reqd = no_of_components + 1
      break
  no_of_components += 1


print("No. of components required to achieve less than 20% error: ",␣
 ↪components_reqd)
```

```
No. of components required to achieve less than 20% error:  28
```

[0]:
```
plt.plot([i+1 for i in range(len(var_list))], np.real(var_list))
plt.xlabel('Components retained')
plt.ylabel('Variance retained')
plt.title("Components required related to variance")
plt.show()
```



0.3.1 We perform PCA on the number of components as found out from above and then form the reconstruction matrix, which is used to reconstruct the images. The plots of the original images and the one reconstructed after applying PCA are displayed.

[0]:
```
transformation_matrix = np.real(eigen_vectors[:,0:components_reqd])

no_of_faces = 20
faces_plot = []
for i in range(no_of_faces):
  index = np.random.randint(0,faces.shape[0]+1)
  face =  faces[index]
  faces_plot.append(face.reshape(100,100))
  face1 = reconstruction_matrix[index]
  faces_plot.append(face1.reshape(100,100))
```

[0]:
```
fig, axes = plt.subplots(no_of_faces, 2,  figsize=(50,50), subplot_kw={'xticks':
 ↪[], 'yticks':[]}, gridspec_kw=dict(hspace=0.1, wspace=0.1))
for i, ax in enumerate(axes.flat):
    ax.imshow(faces_plot[i],cmap='gray')
```

0.4 Here we show a comparison of 100 such images.

0.5 The original images are shown below

[0]:
```
fig, axes = plt.subplots(10,10,figsize=(10,10),subplot_kw={'xticks':[], 'yticks':
 →[]},gridspec_kw=dict(hspace=0.2, wspace=0.2))
for i, ax in enumerate(axes.flat):
 ax.imshow(faces[i].reshape(100,100),cmap='gray')
```

0.6 The images reconstructed after applying PCA are shown below.

[0]:
```
fig, axes = plt.subplots(10,10,figsize=(10,10), subplot_kw={'xticks':[],␣
 ↪'yticks':[]},gridspec_kw=dict(hspace=0.2, wspace=0.2))
for i, ax in enumerate(axes.flat):
    ax.imshow(reconstruction_matrix[i].reshape(100,100),cmap="gray")
```

1 Using PCA of sklearn

1.1 In this section, we apply PCA from the sklearn module. The reconstructed images after applying PCA are displayed below.

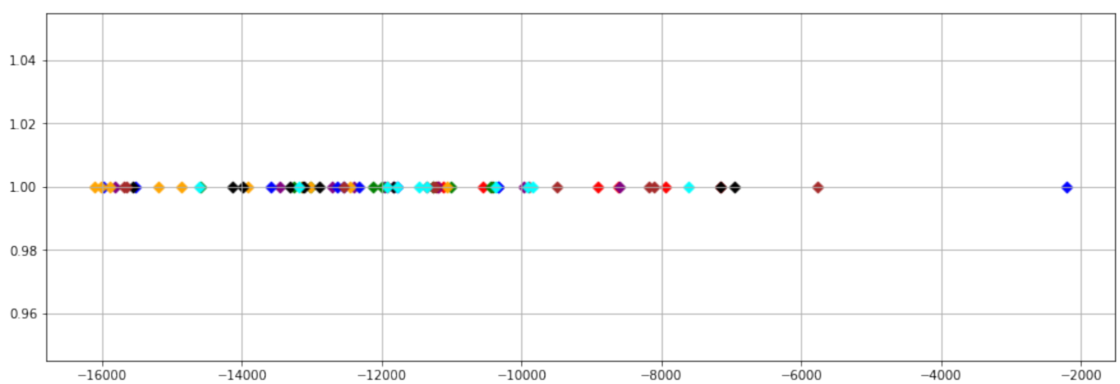
[0]:
```
from sklearn.decomposition import PCA
faces_pca = PCA(n_components=0.8)
faces_pca.fit(faces)
```

[0]:
```
components = faces_pca.transform(faces)
projected = faces_pca.inverse_transform(components)
```

[0]:
```
fig, axes = plt.subplots(10,10,figsize=(10,10), subplot_kw={'xticks':[],
 ↪'yticks':[]},gridspec_kw=dict(hspace=0.2, wspace=0.2))
for i, ax in enumerate(axes.flat):
    ax.imshow(projected[i].reshape(100,100),cmap="gray")
```

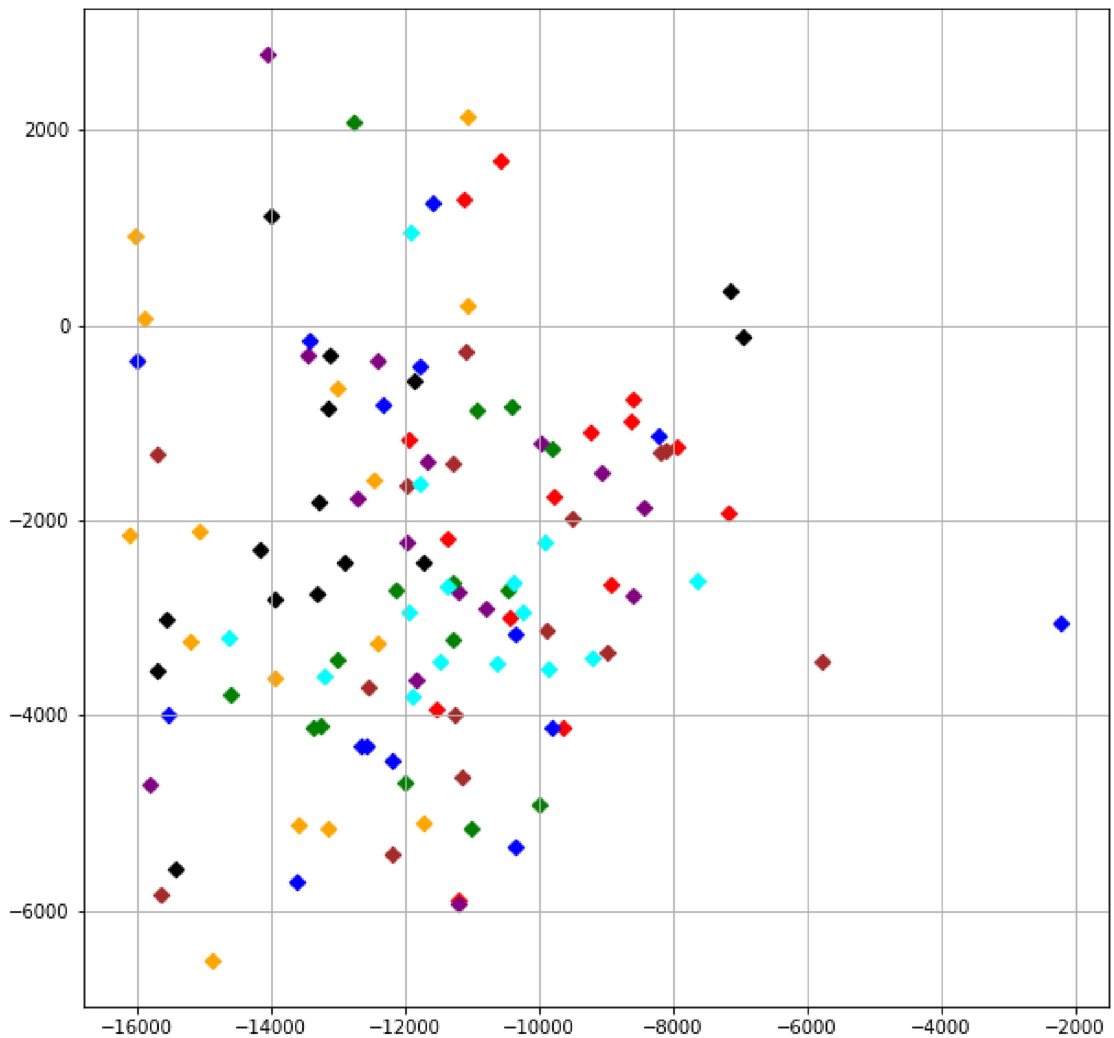
2 Scatterplot to examine how the images are clustered in the 1D space

[28]:
```
transformation_matrix = np.real(eigen_vectors[:,0]).reshape((-1,1))
d1 = {'000':[], '001':[], '002':[], '003':[], '004':[], '005':[], '006':[],␣
 ↪'007':[]}

for label in labels_dict.keys():
    for i in range(10):
        d1[label].append(np.dot(np.array(labels_dict[label][i]).reshape((1,-1)),␣
 ↪transformation_matrix))

plt.figure(figsize=(15,5))
plt.grid()
plt.scatter(d1['000'], np.ones_like(d1['000']), c='red', marker='D')
plt.scatter(d1['001'], np.ones_like(d1['001']), c='purple', marker='D')
plt.scatter(d1['002'], np.ones_like(d1['002']), c='green', marker='D')
plt.scatter(d1['003'], np.ones_like(d1['003']), c='blue', marker='D')
plt.scatter(d1['004'], np.ones_like(d1['004']), c='orange', marker='D')
plt.scatter(d1['005'], np.ones_like(d1['005']), c='black', marker='D')
plt.scatter(d1['006'], np.ones_like(d1['006']), c='brown', marker='D')
plt.scatter(d1['007'], np.ones_like(d1['007']), c='cyan', marker='D')
plt.show()
```



3 Scatterplot to examine how the images are clustered in the 2D space

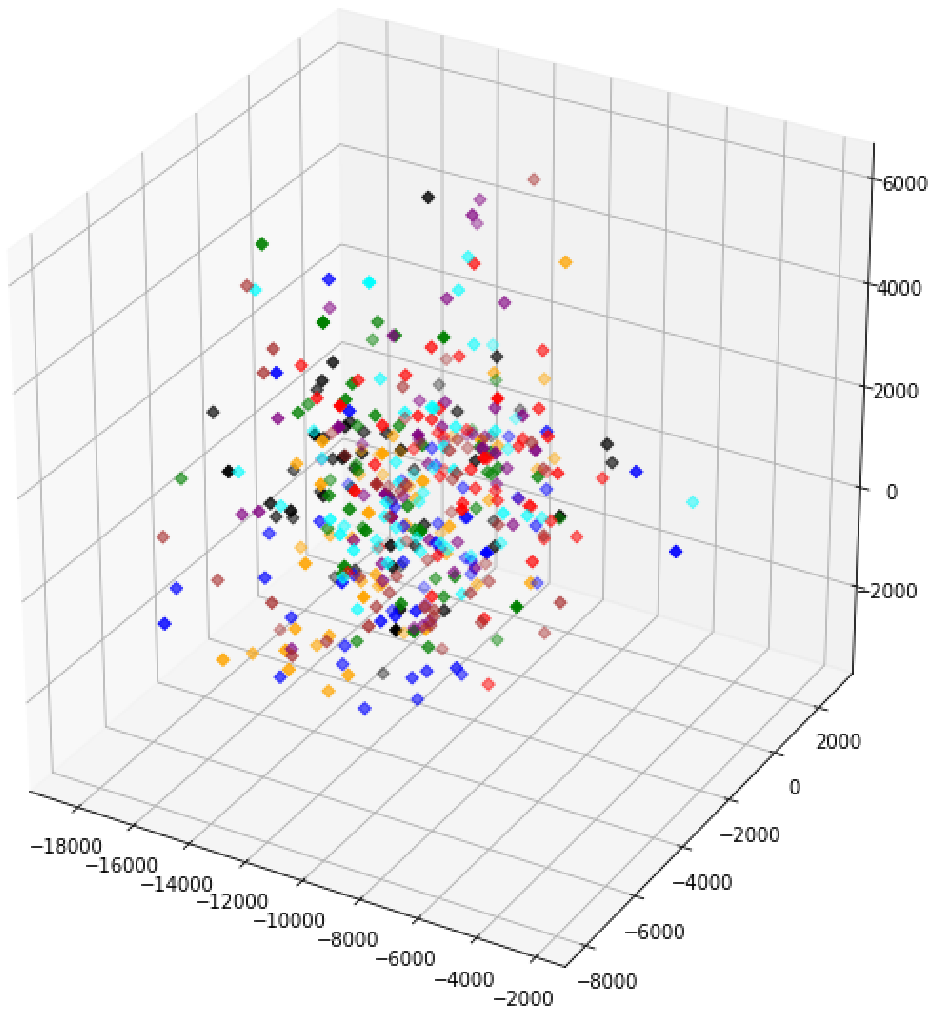
[35]:
```
transformation_matrix = np.real(eigen_vectors[:,0:2]).reshape((10000,2))
d1 = {'000':np.array([0,0]), '001':np.array([0,0]), '002':np.array([0,0]), '003':
↪np.array([0,0]), '004':np.array([0,0]), '005':np.array([0,0]), '006':np.
↪array([0,0]), '007':np.array([0,0]) }

for label in labels_dict.keys():
    for i in range(15):
        d1[label] = np.vstack((d1[label],(np.dot(np.array(labels_dict[label][i]).
↪reshape((1,-1)), transformation_matrix))))

for label in labels_dict.keys():
    d1[label] = d1[label][1:,:]

plt.figure(figsize=(10,10))
plt.grid()
plt.scatter(d1['000'][:,0], d1['000'][:,1], c='red', marker='D')
plt.scatter(d1['001'][:,0], d1['001'][:,1], c='purple', marker='D')
plt.scatter(d1['002'][:,0], d1['002'][:,1], c='green', marker='D')
plt.scatter(d1['003'][:,0], d1['003'][:,1], c='blue', marker='D')
plt.scatter(d1['004'][:,0], d1['004'][:,1], c='orange', marker='D')
plt.scatter(d1['005'][:,0], d1['005'][:,1], c='black', marker='D')
plt.scatter(d1['006'][:,0], d1['006'][:,1], c='brown', marker='D')
plt.scatter(d1['007'][:,0], d1['007'][:,1], c='cyan', marker='D')
plt.show()
```



4 Scatterplot to examine how the images are clustered in the 3D space

[55]:
```
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
fig = plt.figure()
plt1 = Axes3D(fig)

transformation_matrix = np.real(eigen_vectors[:,0:3]).reshape((10000,3))
d1 = {'000':np.array([0,0,0]), '001':np.array([0,0,0]), '002':np.array([0,0,0]),␣
 ↪'003':np.array([0,0,0]), '004':np.array([0,0,0]), '005':np.array([0,0,0]),␣
 ↪'006':np.array([0,0,0]), '007':np.array([0,0,0]) }

for label in labels_dict.keys():
```

```
    for i in range(50):
        d1[label] = np.vstack((d1[label],(np.dot(np.array(labels_dict[label][i]).
 ↪reshape((1,-1)), transformation_matrix))))

for label in labels_dict.keys():
    d1[label] = d1[label][1:,:]

plt1.scatter(d1['000'][:,0], d1['000'][:,1], d1['000'][:,2], c='red', marker='D')
plt1.scatter(d1['001'][:,0], d1['001'][:,1], d1['001'][:,2], c='purple',␣
 ↪marker='D')
plt1.scatter(d1['002'][:,0], d1['002'][:,1], d1['002'][:,2], c='green',␣
 ↪marker='D')
plt1.scatter(d1['003'][:,0], d1['003'][:,1], d1['003'][:,2], c='blue',␣
 ↪marker='D')
plt1.scatter(d1['004'][:,0], d1['004'][:,1], d1['004'][:,2], c='orange',␣
 ↪marker='D')
plt1.scatter(d1['005'][:,0], d1['005'][:,1], d1['005'][:,2], c='black',␣
 ↪marker='D')
plt1.scatter(d1['006'][:,0], d1['006'][:,1], d1['006'][:,2], c='brown',␣
 ↪marker='D')
plt1.scatter(d1['007'][:,0], d1['007'][:,1], d1['007'][:,2], c='cyan',␣
 ↪marker='D')
plt.rcParams["figure.figsize"] = (8,8)
plt.show()
```


6000
4000
2000
0
−2000
2000
0
−2000
−4000
−6000
−8000
−18000
−16000
−14000
−12000
−10000
−8000
−6000
−4000
−2000

assign3_q2

April 3, 2020

[0]:
```
from google.colab import drive
drive.mount('/content/drive')
```

[0]:
```
import numpy as np
import math
import pandas as pd
import matplotlib.pyplot as plt
import random
import glob
import cv2
import os
from numpy import mean
from numpy import cov
from numpy.linalg import eig
```

[0]:
```
def rgb2gray(rgb):
    return np.dot(rgb[...,:3], [0.2989, 0.5870, 0.1140])
```

0.1 We read the files using OpenCV and store them in a list after downscaling the images and flattening them. We also create a dictionary mapping the file labels to the image matrix.

[4]:
```
faces = []
path= '/content/drive/My Drive/SMAI_Assignment3_Dataset/dataset/'
data_path = os.path.join(path,'*g')
files = glob.glob(data_path)
index = path.rindex('/')
labels = []
# print(index)
labels_dict = {}
for f1 in files:
    # print(f1)
    file_name = f1[index+1:]
    file_label, name = file_name.split('_')
    labels.append(file_label)
    img = cv2.imread(f1)
```

```
    img = rgb2gray(img)
    img = cv2.resize(img, (100,100), interpolation = cv2.INTER_AREA)
    face = img.flatten()
    faces.append(face)
    if file_label in labels_dict:
        labels_dict[file_label].append(face)
    else:
        labels_dict[file_label] = [face]

faces = np.array(faces)
print(faces)
faces.shape
```

```
[[185.95189282 121.08736387  37.61438748 ... 203.2247     203.2247
  203.2247    ]
 [ 21.91588271  21.55999863  22.24398713 ...  24.78532952  17.35223347
   14.73619512]
 [117.47369971 114.98464094 110.30165815 ...  85.38188735  92.14534858
   95.64598513]
 ...
 [253.366      253.366      253.366      ...  27.06021174  27.00406501
   28.86154526]
 [148.88045857 149.38309385 151.88990161 ... 179.7612002  175.46599707
  169.82343428]
 [113.22766084 121.90593501 129.71078774 ...  34.62707827  34.05039351
   44.23473982]]
```

[4]: (520, 10000)

0.1.1 We calculate the mean of each column and center the values in each column of the matrix by subtracting the mean column value. We also find the covariance matrix of the centered matrix.

[0]:
```
img_mean = mean(faces)
temp = faces - img_mean
covariance = cov(temp.T)
```

0.1.2 We calculate the eigen decomposition of the covariance matrix, thus resulting in a list of eigenvalues and a list of eigenvectors. We sort the eigen values in descending order and accordingly store the eigen vectors.

[0]:
```
e, v = eig(covariance)
indexes = e.argsort()[::-1]
eigen_values = e[indexes]
eigen_vectors = v[:,indexes]
```

0.1.3 We calculate the number of components required by keeping a variance of atleast 90%.

[7]:
```
total = np.sum(eigen_values)
variance_reqd = 0.90
var_list = list()
no_of_components = 0
components_reqd = 0
sum1 = 0
while True:
  sum1 += eigen_values[no_of_components]
  var = sum1/total
  var_list.append(var)
  var_achieved = np.real(var)
  if var_achieved >= variance_reqd:
      components_reqd = no_of_components + 1
      break
  no_of_components += 1


print("No. of components required to achieve less than 10% error: ",␣
 ↪components_reqd)
```

```
No. of components required to achieve less than 10% error:  76
```

0.1.4 We perform PCA on the number of components as found out from above and then form the reconstruction matrix, which will be used to reconstruct the images.

[51]:
```
components = components_reqd

vectors = eigen_vectors[:,:components]
transformation_matrix = np.real(vectors)
pca_projections = np.dot(faces, transformation_matrix)
reconstruction_matrix = np.dot(pca_projections, transformation_matrix.T)

print(faces.shape)
print(reconstruction_matrix.shape)
```

```
(520, 10000)
(520, 10000)
```

[0]:
```
i=0
labels_dict1 = {}
for i in range(reconstruction_matrix.shape[0]):
    face = reconstruction_matrix[i]
    if labels[i] in labels_dict1:
        labels_dict1[labels[i]].append(face)
    else:
```

```
        labels_dict1[labels[i]] = [face]

faces = np.array(faces)
# print(faces)
# faces.shape
```

0.2 We create the training and testing sets by splitting the data

[0]:
```
num_of_classes = len(labels_dict1)

def one_hot_encoding(label):
  one_hot_label = []
  one_hot_label = [0 for i in range(num_of_classes)]
  one_hot_label[label] = 1
  return one_hot_label

X_train = [0 for i in range(10000)]
y_train = [0 for i in range(8)]

X_test = [0 for i in range(10000)]
y_test = []

for key,value in labels_dict1.items():
  label = int(key)
  one_hot_label = one_hot_encoding(label)
  data = np.array(value)
  train = data[:55,:]
  test = data[55:,:]
  X_train = np.vstack((X_train, train))
  X_test = np.vstack((X_test, test))
  y_train = np.vstack((y_train,np.array([one_hot_label]*55)))
  for i in range(10):
    y_test.append(label)

X_train = X_train[1:,:]
y_train = y_train[1:,:]
X_test = X_test[1:,:]
y_test = np.array(y_test)
```

[81]:
```
print("X_train: ", X_train)
print(X_train.shape)
print("y_train: ", y_train)
print(y_train.shape)
print("X_test: ",X_test)
print(X_test.shape)
print("y_test: ",y_test)
```

```python
print(y_test.shape)
```

```
X_train:  [[ 88.56927781  60.48447453  39.67597814 ... 175.91652011 172.65047621
  169.69305176]
 [ 80.38395073  84.20208715  93.71392165 ...  29.26699876  11.28317832
    4.76091264]
 [136.43542408 136.38232086 134.32948553 ...  21.72405066  12.16232683
   10.67998468]
 ...
 [ 59.59654217  54.72678781  60.70654822 ...  60.04973391  56.8864315
   56.6746354 ]
 [ 73.16343614  75.15448327  86.35760386 ...  33.36448489  23.38114963
   21.56224291]
 [ 36.21543214  41.64532623  55.21922415 ...  -5.36950512 -18.40673183
  -21.90512786]]
(440, 10000)
y_train:  [[0 0 0 ... 1 0 0]
 [0 0 0 ... 1 0 0]
 [0 0 0 ... 1 0 0]
 ...
 [0 0 0 ... 0 0 0]
 [0 0 0 ... 0 0 0]
 [0 0 0 ... 0 0 0]]
(440, 8)
X_test:  [[164.20163881 155.5613513  149.05479844 ... 126.52310893 112.71742891
  113.37109021]
 [102.12939368 104.82414833 113.81462122 ...  53.32925053  56.92219685
   51.43530175]
 [ 76.45425393  64.73479722  60.08819013 ...  26.97986477  30.31276687
   28.07977395]
 ...
 [139.32908525 134.44852789 134.47059502 ... 137.9037959  125.31631188
  119.40645791]
 [ 26.56415586  23.14043589  29.50851895 ...  74.05287196  62.52661559
   62.7795406 ]
 [111.60304478 117.67176096 128.23828298 ...  47.49116121  47.85164105
   53.09630908]]
(80, 10000)
y_test:  [5 5 5 5 5 5 5 5 5 5 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 0 0 0 0 0 2 2 2 2 2
2 2
 2 2 2 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 7 7 7 7 7 7 7 7 7 7 4 4 4 4
 4 4 4 4 4 4]
(80,)
```

0.3 We scale the data and then add the bias column.

[0]:
```
from sklearn.preprocessing import MinMaxScaler
scaler = MinMaxScaler()
scaler.fit(X_train)
X_train=scaler.transform(X_train)
scaler.fit(X_test)
X_test=scaler.transform(X_test)
```

[0]:
```
print(X_train.shape[0])
ones = np.ones([X_train.shape[0],1])
X_train = np.concatenate((ones,X_train),axis=1)
ones = np.ones([X_test.shape[0],1])
X_test = np.concatenate((ones,X_test),axis=1)
```

0.4 Logistic regression function

[0]:
```
def sigmoid(z):
  return 1 / (1 + np.exp(-z))

def loss_func(h, y):
  return (-y * np.log(h) - (1 - y) * np.log(1 - h)).mean()


def logistic_regression(X_train, y_train, iter, alpha):
  theta = np.random.rand(X_train.shape[1])
  count = 1
  while(count<=iter):
    temp = np.dot(X_train, theta)
    h = sigmoid(temp)
    # print(h.dtype)
    count = count+1

    error = h-y_train


    gradient = np.dot(X_train.T, error)/y_train.shape[0]
    theta = theta - alpha*gradient
    # print(count)
    # z = np.dot(X_train, theta)
    # h = sigmoid(z)
    # loss = loss_func(h, y_train)

    # print(loss)

  return theta
```

0.5 We run the logistic regression function using learning rate as 0.001 for 10000 iterations

[0]:
```
weights = [[0 for i in range(10001)]]
for i in range(num_of_classes):
  weights = np.vstack((weights,logistic_regression(X_train, y_train[:,i], 10000,
 ↪0.001)))


weights = weights[1:]
```

0.6 We make the predictions.

[0]:
```
predictions = sigmoid(np.dot(X_test, weights.T))
print(predictions)
print(predictions.shape)

y_pred=[]

for i in range(predictions.shape[0]):
  maxElement = np.amax(predictions[i])
  for j in range(8):
    if(predictions[i][j] == maxElement):
      ind = j
      break
  y_pred.append(j)

# print(len(y_pred))
# print(y_pred)
# print(y_test)
```

0.7 The accuracy is found out to be 0.65

0.7.1 Due the random initialization of weights, the accuracy may vary slightly in different trials.

[160]:
```
a_1 = (y_pred == y_test).mean()
print("Accuracy: ", a_1)
```

```
Accuracy:  0.65
```

0.8 The confusion matrix and f1 score obtained are printed below

[157]:
```
from sklearn.metrics import confusion_matrix
print(confusion_matrix(y_test,y_pred))
```

```
[[ 5  2  0  0  2  0  0  1]
 [ 2  3  1  2  1  0  1  0]
 [ 0  1  5  2  0  1  1  0]
 [ 0  0  0 10  0  0  0  0]
 [ 0  0  1  0  8  1  0  0]
 [ 0  0  2  0  0  8  0  0]
 [ 2  2  1  1  0  0  4  0]
 [ 0  0  0  0  0  1  0  9]]
```

[159]:
```
from sklearn.metrics import f1_score
f1_1 = f1_score(y_test,y_pred, average='weighted')
print("f1 score: ", f1_1)
```

```
f1 score:  0.6354323308270677
```

1 Without PCA

1.1 In this section we test our model without applying PCA

1.2 First we create the training and testing sets by splitting the data

[0]:
```
num_of_classes = len(labels_dict)

def one_hot_encoding(label):
  one_hot_label = []
  one_hot_label = [0 for i in range(num_of_classes)]
  one_hot_label[label] = 1
  return one_hot_label

X_train = [0 for i in range(10000)]
y_train = [0 for i in range(8)]

X_test = [0 for i in range(10000)]
y_test = []

for key,value in labels_dict.items():
  label = int(key)
  one_hot_label = one_hot_encoding(label)
  # print(label, one_hot_label)
  data = np.array(value)
  train = data[:55,:]
  test = data[55:,:]
  X_train = np.vstack((X_train, train))
  X_test = np.vstack((X_test, test))
  y_train = np.vstack((y_train,np.array([one_hot_label]*55)))
  for i in range(10):
    y_test.append(label)
```

```
X_train = X_train[1:,:]
y_train = y_train[1:,:]
X_test = X_test[1:,:]
y_test = np.array(y_test)
```

[123]:
```
print("X_train: ", X_test)
print(X_train.shape)
print("y_train: ", y_test)
print(y_train.shape)
print("X_test: ",X_test)
print(X_test.shape)
print("y_test: ",y_test)
print(y_test.shape)
```

```
X_train:  [[172.53145771 167.32714421 161.14392471 ... 150.16182234 134.43501411
  129.77947385]
 [118.13704026 133.97492222 113.70451284 ...  40.85465188  48.04985459
   62.89469478]
 [112.25209609  90.92810178  82.84142327 ...  43.17035171  58.4476136
   73.92792783]
 ...
 [145.45533286 141.51235273 139.80773499 ... 142.6336812  147.81163015
  150.99954375]
 [ 38.65265625  30.5749011   39.24424138 ...  37.72947388  39.60180354
   29.15661482]
 [113.22766084 121.90593501 129.71078774 ...  34.62707827  34.05039351
   44.23473982]]
(440, 10000)
y_train:  [5 5 5 5 5 5 5 5 5 5 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 0 0 0 0 0 2 2 2 2 2
2 2
 2 2 2 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 7 7 7 7 7 7 7 7 7 7 4 4 4 4
 4 4 4 4 4 4]
(440, 8)
X_test:  [[172.53145771 167.32714421 161.14392471 ... 150.16182234 134.43501411
  129.77947385]
 [118.13704026 133.97492222 113.70451284 ...  40.85465188  48.04985459
   62.89469478]
 [112.25209609  90.92810178  82.84142327 ...  43.17035171  58.4476136
   73.92792783]
 ...
 [145.45533286 141.51235273 139.80773499 ... 142.6336812  147.81163015
  150.99954375]
 [ 38.65265625  30.5749011   39.24424138 ...  37.72947388  39.60180354
   29.15661482]
 [113.22766084 121.90593501 129.71078774 ...  34.62707827  34.05039351
   44.23473982]]
```

```
(80, 10000)
y_test:  [5 5 5 5 5 5 5 5 5 5 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 0 0 0 0 0 2 2 2 2 2
2 2
 2 2 2 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 7 7 7 7 7 7 7 7 7 7 4 4 4 4
 4 4 4 4 4 4]
(80,)
```

1.3 We scale the data and then add the bias column.

[0]:
```
from sklearn.preprocessing import MinMaxScaler
scaler = MinMaxScaler()
scaler.fit(X_train)
X_train=scaler.transform(X_train)
scaler.fit(X_test)
X_test=scaler.transform(X_test)
```

[0]:
```
print(X_train.shape[0])
ones = np.ones([X_train.shape[0],1])
X_train = np.concatenate((ones,X_train),axis=1)
ones = np.ones([X_test.shape[0],1])
X_test = np.concatenate((ones,X_test),axis=1)
```

1.4 Logistic regression function

[0]:
```
def sigmoid(z):
  return 1 / (1 + np.exp(-z))

def loss_func(h, y):
  return (-y * np.log(h) - (1 - y) * np.log(1 - h)).mean()


def logistic_regression(X_train, y_train, iter, alpha):
  theta = np.random.rand(X_train.shape[1])
  count = 1
  while(count<=iter):
    temp = np.dot(X_train, theta)
    h = sigmoid(temp)
    # print(h.dtype)
    count = count+1

    error = h-y_train


    gradient = np.dot(X_train.T, error)/y_train.shape[0]
    theta = theta - alpha*gradient
    # print(count)
    # z = np.dot(X_train, theta)
```

```
    # h = sigmoid(z)
    # loss = loss_func(h, y_train)

    # print(loss)

  return theta
```

1.5 We run the logistic regression function using learning rate as 0.01 for 10000 iterations

[0]:
```
weights = [[0 for i in range(10001)]]
for i in range(num_of_classes):
  weights = np.vstack((weights,logistic_regression(X_train, y_train[:,i], 10000,␣
 ↪0.01)))


weights = weights[1:]
```

1.6 We make the predictions

[0]:
```
predictions = sigmoid(np.dot(X_test, weights.T))
print(predictions)
print(predictions.shape)

y_pred=[]

for i in range(predictions.shape[0]):
  maxElement = np.amax(predictions[i])
  for j in range(8):
    if(predictions[i][j] == maxElement):
      ind = j
      break
  y_pred.append(j)

# print(len(y_pred))
# print(y_pred)
# print(y_test)
```

1.7 The accuracy is found out to be 0.65

1.7.1 Due the random initialization of weights, the accuracy may vary slightly in different trials.

[162]:
```
a_2 = (y_pred == y_test).mean()
print("Accuracy: ", a_2)
```

```
Accuracy:  0.6875
```

1.8 The confusion matrix and f1 score obtained are printed below

[0]:
```python
from sklearn.metrics import confusion_matrix
print(confusion_matrix(y_test,y_pred))
```

```
[[7 0 1 1 1 0 0 0]
 [1 6 0 1 0 0 2 0]
 [1 0 8 0 0 0 1 0]
 [0 2 0 7 0 1 0 0]
 [0 1 0 0 4 4 1 0]
 [0 0 2 0 0 8 0 0]
 [0 1 2 0 0 0 6 1]
 [0 0 0 0 0 1 0 9]]
```

[163]:
```python
from sklearn.metrics import f1_score
f1_2 = f1_score(y_test,y_pred, average='weighted')
print("f1 score: ", f1_2)
```

```
f1 score:  0.6836670480549198
```

2 Summary

[164]:
```python
without_pca = ["Model without PCA", a_1, f1_1]
with_pca = ["Model without PCA", a_2, f1_2]
data = [without_pca, with_pca]
df = pd.DataFrame(data, columns = ['Model', 'Accuracy', 'f1 score'])
df
```

[164]:

	Model	Accuracy	f1 score
0	Model without PCA	0.6500	0.635432
1	Model without PCA	0.6875	0.683667

2.1 Thus we see that our model performed relatively well on applying PCA, getting an accuracy score comparable to that of the model where PCA is not applied.

assign3_q3

April 3, 2020

[1]:
```
from google.colab import drive
drive.mount('/content/drive')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call
drive.mount("/content/drive", force_remount=True).
```

[0]:
```
!pip install python-mnist
```

[0]:
```
import keras
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from tensorflow.keras.utils import to_categorical
from mnist import MNIST
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.metrics import accuracy_score
from sklearn.metrics import confusion_matrix
from sklearn.metrics import classification_report
from sklearn.metrics import f1_score
from sklearn.metrics import precision_score
from sklearn.metrics import recall_score
```

0.1 We load the MNIST data into the training and testing sets

[0]:
```
mndata = MNIST('/content/drive/My Drive/SMAI_Assignment3_Dataset/dataset_q3')
mndata.gz = True
X_train, y_train = mndata.load_training()
```

[125]:
```
X_test, y_test = mndata.load_testing()
print(len(X_test))
print(len(y_test))
print(len(X_test[0]))
y_test = list(y_test)
```

```
10000
10000
```

784

[126]:
```
X_train = np.array(X_train)
y_train = np.array(y_train)
X_test = np.array(X_test)
y_test = np.array(y_test)
print(X_train.shape)
print(y_train.shape)
```

```
(60000, 784)
(60000,)
```

1 Support Vector Machine (SVM)

1.1 SVM model 1 using C=2 and the default kernel = 'rbf'

[0]:
```
from sklearn.svm import SVC
clf = SVC(C=2.0)
clf.fit(X_train, y_train)
y_pred = clf.predict(X_test)
accuracy = accuracy_score(y_test, y_pred)
```

1.1.1 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[128]:
```
a_svm1 = accuracy
f1_svm1 = f1_score(y_test, y_pred, average='weighted')
p_svm1 = precision_score(y_test, y_pred, average='weighted')
r_svm1 = recall_score(y_test, y_pred, average='weighted')
print("Accuracy: ", a_svm1)
print("f1 score: ",f1_svm1)
print("Precision score: ",p_svm1)
print("Recall score: ",r_svm1)
print("Confusion matrix: \n", confusion_matrix(y_test, y_pred))
```

```
Accuracy:  0.9831
f1 score:  0.9830916493531652
Precision score:  0.9830983682809287
Recall score:  0.9831
Confusion matrix:
 [[ 973    0    1    0    0    3    0    1    2    0]
 [    0 1127    3    1    0    1    1    1    1    0]
 [    6    1 1012    0    1    0    1    7    3    1]
 [    0    0    1  997    0    3    0    4    3    2]
 [    0    0    4    0  966    0    3    0    1    8]
 [    2    0    0    6    1  876    3    0    3    1]
 [    4    2    0    0    2    3  946    0    1    0]
```

```
 [   0    5   10    2    1    0    0 1005    0    5]
 [   3    0    2    3    4    3    1    2  951    5]
 [   2    2    0    7   10    1    1    7    1  978]]
```

1.2 SVM model 2 using C=2 and kernel = 'poly'

[0]:
```
clf = SVC(C=2.0, kernel='poly')
clf.fit(X_train, y_train)
y_pred1 = clf.predict(X_test)
accuracy1 = accuracy_score(y_test, y_pred1)
```

1.2.1 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[130]:
```
a_svm2 = accuracy1
f1_svm2 = f1_score(y_test, y_pred1, average='weighted')
p_svm2 = precision_score(y_test, y_pred1, average='weighted')
r_svm2 = recall_score(y_test, y_pred1, average='weighted')
print("Accuracy: ", a_svm2)
print("f1 score: ",f1_svm2)
print("Precision score: ",p_svm2)
print("Recall score: ",r_svm2)
print("Confusion matrix: \n", confusion_matrix(y_test, y_pred1))
```

```
Accuracy:  0.9785
f1 score:  0.9784814949100687
Precision score:  0.9785009643261748
Recall score:  0.9785
Confusion matrix:
 [[ 971    0    1    1    0    3    1    1    2    0]
 [   0 1128    2    1    0    0    3    0    1    0]
 [   7    3 1006    0    2    0    4    8    2    0]
 [   0    2    2  986    0    6    0    5    5    4]
 [   2    0    2    0  965    0    4    0    0    9]
 [   2    0    1    9    1  867    4    1    5    2]
 [   4    5    2    0    3    4  938    0    2    0]
 [   0   11    8    1    1    0    0  999    0    8]
 [   3    0    1    4    4    3    1    3  953    2]
 [   2    6    1    4   12    5    1    4    2  972]]
```

1.3 SVM model 3 using LinearSVC module and C=1.

1.3.1 The maximum number of iterations allowed is set as 10000 because of which we see a drop in the accuracy as it did not converge in 10000 iterations.

[131]:
```
from sklearn.svm import LinearSVC
clf_c1 = LinearSVC(C=1.0, max_iter=10000)
clf_c1.fit(X_train, y_train)
y_pred_c1 = clf_c1.predict(X_test)
accuracy_c1 = accuracy_score(y_test, y_pred_c1)
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/svm/_base.py:947:
ConvergenceWarning: Liblinear failed to converge, increase the number of
iterations.
  "the number of iterations.", ConvergenceWarning)
```

1.3.2 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[132]:
```
a_svm3 = accuracy_c1
f1_svm3 = f1_score(y_test, y_pred_c1, average='weighted')
p_svm3 = precision_score(y_test, y_pred_c1, average='weighted')
r_svm3 = recall_score(y_test, y_pred_c1, average='weighted')
print("Accuracy: ", a_svm3)
print("f1 score: ",f1_svm3)
print("Precision score: ",p_svm3)
print("Recall score: ",r_svm3)
print("Confusion matrix: \n", confusion_matrix(y_test, y_pred_c1))
```

```
Accuracy:  0.8782
f1 score:  0.8786973405507397
Precision score:  0.8847569307948001
Recall score:  0.8782
Confusion matrix:
 [[ 905    1   15    2    2   19    7    9   10   10]
 [   0 1102   15    2    0    1    4    0   11    0]
 [   3   13  937   12   13    3   11   11   25    4]
 [   3    4   49  850    3   28    2    8   35   28]
 [   0    5   11    1  906    0    3    1    4   51]
 [   4    6   10   29   21  750   17    4   31   20]
 [   8    5   43    1    6   20  867    0    7    1]
 [   0   17   29    2   17    2    1  788    4  168]
 [   3    8   52   22   15   32   14   10  758   60]
 [   1   10   11    8   39    7    0    6    8  919]]
```

2 Summary of the SVM models

[146]:
```
svm_l1 = ["SVM model 1", a_svm1, f1_svm1, p_svm1, r_svm1]
svm_l2 = ["SVM model 2", a_svm2, f1_svm2, p_svm2, r_svm2]
svm_l3 = ["SVM model 3", a_svm3, f1_svm3, p_svm3, r_svm3]
data = [svm_l1, svm_l2, svm_l3]
df1 = pd.DataFrame(data, columns = ['Model', 'Accuracy', 'F1 score', 'Precision␣
↪score', 'Recall score'])
df1
```

[146]:

	Model	Accuracy	F1 score	Precision score	Recall score
0	SVM model 1	0.9831	0.983092	0.983098	0.9831
1	SVM model 2	0.9785	0.978481	0.978501	0.9785
2	SVM model 3	0.8782	0.878697	0.884757	0.8782

3 Multi Layer Perceptron (MLP)

3.0.1 First we change our labels to categorical data.

[0]:
```
y_train = keras.utils.to_categorical(y_train, 10)
y_test = keras.utils.to_categorical(y_test, 10)
```

3.1 MLP model 1 with 1 hidden layer of 30 nodes using activation function 'sigmoid'

3.1.1 We use the 'sgd' optimizer.

[100]:
```
model1 = Sequential()
model1.add(Dense(30, activation = "sigmoid", input_shape=(784,)))
model1.add(Dense(10, activation="softmax"))
model1.compile(loss="categorical_crossentropy", optimizer="sgd",␣
↪metrics=['accuracy'])
model1.fit(X_train, y_train, epochs=40)
```

```
Epoch 1/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.9490 -
acc: 0.7679
Epoch 2/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.5411 -
acc: 0.8651
Epoch 3/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.4671 -
acc: 0.8752
Epoch 4/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.4268 -
acc: 0.8831
Epoch 5/40
```

```
60000/60000 [==============================] - 2s 41us/sample - loss: 0.3981 -
acc: 0.8874
Epoch 6/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.3898 -
acc: 0.8892
Epoch 7/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.3642 -
acc: 0.8959
Epoch 8/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.3613 -
acc: 0.8955
Epoch 9/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.3553 -
acc: 0.8992
Epoch 10/40
60000/60000 [==============================] - 2s 40us/sample - loss: 0.3439 -
acc: 0.9007
Epoch 11/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.3351 -
acc: 0.9025
Epoch 12/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.3321 -
acc: 0.9040
Epoch 13/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.3213 -
acc: 0.9058
Epoch 14/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.3283 -
acc: 0.9071
Epoch 15/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.3166 -
acc: 0.9071
Epoch 16/40
60000/60000 [==============================] - 2s 40us/sample - loss: 0.3155 -
acc: 0.9064
Epoch 17/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.3080 -
acc: 0.9100
Epoch 18/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.3039 -
acc: 0.9098
Epoch 19/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.3063 -
acc: 0.9087
Epoch 20/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.3066 -
acc: 0.9078
Epoch 21/40
```

```
60000/60000 [==============================] - 2s 41us/sample - loss: 0.2941 -
acc: 0.9135
Epoch 22/40
60000/60000 [==============================] - 2s 41us/sample - loss: 0.2921 -
acc: 0.9136
Epoch 23/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.3021 -
acc: 0.9117
Epoch 24/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2918 -
acc: 0.9132
Epoch 25/40
60000/60000 [==============================] - 3s 44us/sample - loss: 0.2893 -
acc: 0.9125
Epoch 26/40
60000/60000 [==============================] - 3s 44us/sample - loss: 0.2900 -
acc: 0.9131
Epoch 27/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2899 -
acc: 0.9142
Epoch 28/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.2838 -
acc: 0.9160
Epoch 29/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2853 -
acc: 0.9168
Epoch 30/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.2774 -
acc: 0.9180
Epoch 31/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2793 -
acc: 0.9163
Epoch 32/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.2885 -
acc: 0.9150
Epoch 33/40
60000/60000 [==============================] - 3s 44us/sample - loss: 0.2779 -
acc: 0.9190
Epoch 34/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2821 -
acc: 0.9179
Epoch 35/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2808 -
acc: 0.9182
Epoch 36/40
60000/60000 [==============================] - 3s 42us/sample - loss: 0.2744 -
acc: 0.9185
Epoch 37/40
```

```
60000/60000 [==============================] - 3s 42us/sample - loss: 0.2819 -
acc: 0.9163
Epoch 38/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2746 -
acc: 0.9198
Epoch 39/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2754 -
acc: 0.9183
Epoch 40/40
60000/60000 [==============================] - 3s 43us/sample - loss: 0.2652 -
acc: 0.9214
```

[100]:
```
<tensorflow.python.keras.callbacks.History at 0x7f606e923b70>
```

3.1.2 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[104]:
```
score1 = model1.evaluate(X_test, y_test)
print('Loss = ', score1[0], ' Accuracy = ', score1[1])
a_nn1 = score1[1]
```

```
10000/10000 [==============================] - 0s 26us/sample - loss: 0.2613 -
acc: 0.9248
Loss =  0.26132565671801566  Accuracy =  0.9248
```

[117]:
```
y_pred1 = model1.predict(X_test)
pred1 = []
for i in range(len(y_pred1)):
    pred1.append(np.argmax(y_pred1[i]))

f1_nn1 = f1_score(y_test, pred1, average='weighted')
p_nn1 = precision_score(y_test, pred1, average='weighted')
r_nn1 = recall_score(y_test, pred1, average='weighted')
print("f1 score: ",f1_nn1)
print("Precision score: ",p_nn1)
print("Recall score: ",r_nn1)
print("Confusion matrix: \n", confusion_matrix(y_test, pred1))
```

```
f1 score:  0.924704902567081
Precision score:  0.9249559572143476
Recall score:  0.9248
Confusion matrix:
 [[ 953    0    1    3    0    5    9    5    3    1]
 [   0 1114    3    4    0    2    2    0   10    0]
 [  13    3  924   18   10    1   19   16   24    4]
 [   5    1   23  914    0   20    3   12   23    9]
 [   3    1    2    0  902    1    7    8    6   52]
```

```
[   8    1    3   43    7  784   12    8   18    8]
[  16    3    6    1    9   11  898    3   11    0]
[   3   12   19    8    6    2    0  948    9   21]
[   3   11    3   16    5   15   10   11  890   10]
[   5    7    2    7   24    6    1   21   15  921]]
```

3.2 MLP model 2 with 1 hidden layer of 100 nodes using activation function 'sigmoid'

3.2.1 We use the 'sgd' optimizer.

3.2.2 Thus in this model we test by increasing the number of nodes in the hidden layer.

[105]:
```
model2 = Sequential()
model2.add(Dense(100, activation = "sigmoid", input_shape=(784,)))
model2.add(Dense(10, activation="softmax"))
model2.compile(loss="categorical_crossentropy", optimizer="sgd",␣
 ↪metrics=['accuracy'])
model2.fit(X_train, y_train, epochs=40)
```

```
Epoch 1/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.6909 -
acc: 0.8233
Epoch 2/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.3925 -
acc: 0.8944
Epoch 3/40
60000/60000 [==============================] - 4s 59us/sample - loss: 0.3351 -
acc: 0.9075
Epoch 4/40
60000/60000 [==============================] - 4s 60us/sample - loss: 0.3113 -
acc: 0.9123
Epoch 5/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2859 -
acc: 0.9189
Epoch 6/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2759 -
acc: 0.9218
Epoch 7/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.2608 -
acc: 0.9258
Epoch 8/40
60000/60000 [==============================] - 4s 60us/sample - loss: 0.2497 -
acc: 0.9294
Epoch 9/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2409 -
acc: 0.9319
Epoch 10/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2384 -
```

```
acc: 0.9320
Epoch 11/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.2414 -
acc: 0.9320
Epoch 12/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.2295 -
acc: 0.9341
Epoch 13/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2281 -
acc: 0.9341
Epoch 14/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2155 -
acc: 0.9379
Epoch 15/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.2159 -
acc: 0.9382
Epoch 16/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.2137 -
acc: 0.9379
Epoch 17/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.2111 -
acc: 0.9404
Epoch 18/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2040 -
acc: 0.9410
Epoch 19/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.2004 -
acc: 0.9422
Epoch 20/40
60000/60000 [==============================] - 4s 60us/sample - loss: 0.1940 -
acc: 0.9426
Epoch 21/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1933 -
acc: 0.9446
Epoch 22/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1968 -
acc: 0.9432
Epoch 23/40
60000/60000 [==============================] - 4s 67us/sample - loss: 0.1873 -
acc: 0.9455
Epoch 24/40
60000/60000 [==============================] - 4s 67us/sample - loss: 0.1841 -
acc: 0.9468
Epoch 25/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.1839 -
acc: 0.9465
Epoch 26/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1881 -
```

```
acc: 0.9453
Epoch 27/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.1819 -
acc: 0.9460
Epoch 28/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.1777 -
acc: 0.9475
Epoch 29/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.1756 -
acc: 0.9485
Epoch 30/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1705 -
acc: 0.9500
Epoch 31/40
60000/60000 [==============================] - 4s 59us/sample - loss: 0.1684 -
acc: 0.9498
Epoch 32/40
60000/60000 [==============================] - 4s 60us/sample - loss: 0.1676 -
acc: 0.9506
Epoch 33/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.1676 -
acc: 0.9508
Epoch 34/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1656 -
acc: 0.9507
Epoch 35/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1637 -
acc: 0.9513
Epoch 36/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1615 -
acc: 0.9517
Epoch 37/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.1554 -
acc: 0.9531
Epoch 38/40
60000/60000 [==============================] - 4s 62us/sample - loss: 0.1608 -
acc: 0.9512
Epoch 39/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1593 -
acc: 0.9523
Epoch 40/40
60000/60000 [==============================] - 4s 61us/sample - loss: 0.1614 -
acc: 0.9512
```

```
[105]: <tensorflow.python.keras.callbacks.History at 0x7f60652cedd8>
```

3.2.3 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[106]:
```
score2 = model2.evaluate(X_test, y_test)
print('Loss = ', score2[0], ' Accuracy = ', score2[1])
a_nn2 = score2[1]
```

```
10000/10000 [==============================] - 0s 40us/sample - loss: 0.1761 -
acc: 0.9472
Loss =  0.1761124474093318  Accuracy =  0.9472
```

[118]:
```
y_pred2 = model2.predict(X_test)
pred2 = []
for i in range(len(y_pred2)):
    pred2.append(np.argmax(y_pred2[i]))

f1_nn2 = f1_score(y_test, pred2, average='weighted')
p_nn2 = precision_score(y_test, pred2, average='weighted')
r_nn2 = recall_score(y_test, pred2, average='weighted')
print("f1 score: ",f1_nn2)
print("Precision score: ",p_nn2)
print("Recall score: ",r_nn2)
print("Confusion matrix: \n", confusion_matrix(y_test, pred2))
```

```
f1 score:  0.9471341905677948
Precision score:  0.9472052295536872
Recall score:  0.9472
Confusion matrix:
 [[ 965    0    0    1    0    4    6    2    2    0]
 [   0 1115    2    3    1    1    4    2    7    0]
 [   6    1  965   12    8    6    9   11   10    4]
 [   2    2   12  935    1   31    0   11   12    4]
 [   1    0    3    1  926    1   12    1    3   34]
 [   4    1    4   26    1  825   14    4    7    6]
 [  10    2    1    2    5    8  926    0    4    0]
 [   1    7   21    4    1    0    0  976    2   16]
 [   7    5    5   14    8   14   14   10  892    5]
 [   6    5    1    6   15    5    1   17    6  947]]
```

3.3 MLP model 3 with 1 hidden layer of 100 nodes using activation function 'relu'

3.3.1 We use the 'adam' optimizer.

3.3.2 In this model, we test by changing our activation function as well as the optimizer.

[107]:
```
model3 = Sequential()
model3.add(Dense(100, activation = "relu", input_shape=(784,)))
model3.add(Dense(10, activation="softmax"))
```

```
model3.compile(loss="categorical_crossentropy", optimizer="adam",␣
 ↪metrics=['accuracy'])
model3.fit(X_train, y_train, epochs=40)
```

```
Epoch 1/40
60000/60000 [==============================] - 4s 67us/sample - loss: 2.4593 -
acc: 0.8508
Epoch 2/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.3895 -
acc: 0.9066
Epoch 3/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.3033 -
acc: 0.9226
Epoch 4/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2546 -
acc: 0.9340
Epoch 5/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2383 -
acc: 0.9392
Epoch 6/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.2172 -
acc: 0.9447
Epoch 7/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.2120 -
acc: 0.9465
Epoch 8/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1984 -
acc: 0.9501
Epoch 9/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1943 -
acc: 0.9512
Epoch 10/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1844 -
acc: 0.9533
Epoch 11/40
60000/60000 [==============================] - 4s 67us/sample - loss: 0.1799 -
acc: 0.9559
Epoch 12/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1787 -
acc: 0.9559
Epoch 13/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1731 -
acc: 0.9574
Epoch 14/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1706 -
acc: 0.9577
Epoch 15/40
```

```
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1758 -
acc: 0.9574
Epoch 16/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1760 -
acc: 0.9581
Epoch 17/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1644 -
acc: 0.9607
Epoch 18/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1575 -
acc: 0.9607
Epoch 19/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1599 -
acc: 0.9602
Epoch 20/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1589 -
acc: 0.9613
Epoch 21/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1589 -
acc: 0.9615
Epoch 22/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1598 -
acc: 0.9626
Epoch 23/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1541 -
acc: 0.9627
Epoch 24/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1528 -
acc: 0.9631
Epoch 25/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1484 -
acc: 0.9631
Epoch 26/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1530 -
acc: 0.9633
Epoch 27/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1492 -
acc: 0.9638
Epoch 28/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1470 -
acc: 0.9646
Epoch 29/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1517 -
acc: 0.9638
Epoch 30/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1451 -
acc: 0.9652
Epoch 31/40
```

```
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1442 -
acc: 0.9659
Epoch 32/40
60000/60000 [==============================] - 4s 68us/sample - loss: 0.1456 -
acc: 0.9657
Epoch 33/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1419 -
acc: 0.9666
Epoch 34/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.1361 -
acc: 0.9661
Epoch 35/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1409 -
acc: 0.9662
Epoch 36/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1445 -
acc: 0.9666
Epoch 37/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1375 -
acc: 0.9673
Epoch 38/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1317 -
acc: 0.9679
Epoch 39/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1411 -
acc: 0.9674
Epoch 40/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1345 -
acc: 0.9683
```

[107]:
```
<tensorflow.python.keras.callbacks.History at 0x7f606512c780>
```

3.3.3 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[108]:
```
score3 = model3.evaluate(X_test, y_test)
print('Loss = ', score3[0], ' Accuracy = ', score3[1])
a_nn3 = score3[1]
```

```
10000/10000 [==============================] - 0s 40us/sample - loss: 0.4870 -
acc: 0.9459
Loss =  0.4869805608151073  Accuracy =  0.9459
```

[119]:
```
y_pred3 = model3.predict(X_test)
pred3 = []
for i in range(len(y_pred3)):
    pred3.append(np.argmax(y_pred3[i]))
```

```
f1_nn3 = f1_score(y_test, pred3, average='weighted')
p_nn3 = precision_score(y_test, pred3, average='weighted')
r_nn3 = recall_score(y_test, pred3, average='weighted')
print("f1 score: ",f1_nn3)
print("Precision score: ",p_nn3)
print("Recall score: ",r_nn3)
print("Confusion matrix: \n", confusion_matrix(y_test, pred3))
```

```
f1 score:  0.946497887611948
Precision score:  0.948777620415543
Recall score:  0.9459
Confusion matrix:
 [[ 958    0    2    1    0    2    2    1   14    0]
 [   0 1106    3    2    0    2    1    0   21    0]
 [   5    3  971    5    1    1    3    8   34    1]
 [   1    1   10  952    0   14    0    4   25    3]
 [   2    1    3    0  902    0    3    5   26   40]
 [   3    0    1   28    2  809    7    1   38    3]
 [   7    4    3    0    4   10  904    0   26    0]
 [   0    6   13   12    5    2    0  974    6   10]
 [   3    0    3    8    2    6    3    0  944    5]
 [   3    3    0   12   15    7    0    4   26  939]]
```

3.4 MLP model 4 with 1 hidden layer of 100 nodes using activation function 'sigmoid'

3.4.1 We use the 'adam' optimizer.

[109]:
```
model4 = Sequential()
model4.add(Dense(100, input_dim=784, activation='sigmoid'))
model4.add(Dense(10, activation = "softmax"))
model4.compile(loss='categorical_crossentropy', optimizer='adam',␣
 ↪metrics=['accuracy'])
model4.fit(X_train, y_train, epochs=40)
```

```
Epoch 1/40
60000/60000 [==============================] - 4s 67us/sample - loss: 0.5491 -
acc: 0.8504
Epoch 2/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.3590 -
acc: 0.8960
Epoch 3/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.3279 -
acc: 0.9050
Epoch 4/40
60000/60000 [==============================] - 4s 67us/sample - loss: 0.2997 -
acc: 0.9109
Epoch 5/40
```

```
60000/60000 [==============================] - 4s 63us/sample - loss: 0.2808 -
acc: 0.9144
Epoch 6/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2813 -
acc: 0.9136
Epoch 7/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.2656 -
acc: 0.9202
Epoch 8/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.2585 -
acc: 0.9215
Epoch 9/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2562 -
acc: 0.9216
Epoch 10/40
60000/60000 [==============================] - 4s 68us/sample - loss: 0.2536 -
acc: 0.9220
Epoch 11/40
60000/60000 [==============================] - 4s 69us/sample - loss: 0.2439 -
acc: 0.9262
Epoch 12/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.2389 -
acc: 0.9261
Epoch 13/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2399 -
acc: 0.9263
Epoch 14/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2264 -
acc: 0.9305
Epoch 15/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2210 -
acc: 0.9322
Epoch 16/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2141 -
acc: 0.9348
Epoch 17/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2149 -
acc: 0.9348
Epoch 18/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2034 -
acc: 0.9384
Epoch 19/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2036 -
acc: 0.9374
Epoch 20/40
60000/60000 [==============================] - 4s 63us/sample - loss: 0.2029 -
acc: 0.9369
Epoch 21/40
```

```
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2079 -
acc: 0.9355
Epoch 22/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2167 -
acc: 0.9339
Epoch 23/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2132 -
acc: 0.9355
Epoch 24/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1965 -
acc: 0.9401
Epoch 25/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.2028 -
acc: 0.9376
Epoch 26/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1964 -
acc: 0.9403
Epoch 27/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1888 -
acc: 0.9423
Epoch 28/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.2001 -
acc: 0.9388
Epoch 29/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1874 -
acc: 0.9431
Epoch 30/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1955 -
acc: 0.9411
Epoch 31/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1798 -
acc: 0.9450
Epoch 32/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1824 -
acc: 0.9448
Epoch 33/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1759 -
acc: 0.9469
Epoch 34/40
60000/60000 [==============================] - 4s 66us/sample - loss: 0.1768 -
acc: 0.9463
Epoch 35/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1775 -
acc: 0.9449
Epoch 36/40
60000/60000 [==============================] - 4s 65us/sample - loss: 0.1827 -
acc: 0.9433
Epoch 37/40
```

```
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1791 -
acc: 0.9445
Epoch 38/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1680 -
acc: 0.9485
Epoch 39/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1714 -
acc: 0.9476
Epoch 40/40
60000/60000 [==============================] - 4s 64us/sample - loss: 0.1705 -
acc: 0.9481
```

[109]: <tensorflow.python.keras.callbacks.History at 0x7f6064e21160>

3.4.2 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[110]:
```
score4 = model4.evaluate(X_test, y_test)
print('Loss = ', score4[0], ' Accuracy = ', score4[1])
a_nn4 = score4[1]
```

```
10000/10000 [==============================] - 0s 44us/sample - loss: 0.1691 -
acc: 0.9482
Loss =  0.16905173732340337  Accuracy =  0.9482
```

[120]:
```
y_pred4 = model4.predict(X_test)
pred4 = []
for i in range(len(y_pred4)):
    pred4.append(np.argmax(y_pred4[i]))

f1_nn4 = f1_score(y_test, pred4, average='weighted')
p_nn4 = precision_score(y_test, pred4, average='weighted')
r_nn4 = recall_score(y_test, pred4, average='weighted')
print("f1 score: ",f1_nn4)
print("Precision score: ",p_nn4)
print("Recall score: ",r_nn4)
print("Confusion matrix: \n", confusion_matrix(y_test, pred4))
```

```
f1 score:  0.9481685590783149
Precision score:  0.9482358568300188
Recall score:  0.9482
Confusion matrix:
 [[ 962    0    1    2    0    3    7    2    3    0]
 [    0 1110    3    4    0    2    3    2   11    0]
 [    8    1  979    6    5    3    4   11   13    2]
 [    1    0   13  950    0   16    0   13   14    3]
 [    1    2    6    0  923    1   10    3    3   33]
```

```
[  10    0    1   23    2  824   10    1   19    2]
[   7    4    5    0    5    7  922    0    8    0]
[   0    4   27    5    1    0    0  974    2   15]
[  11    3    4    8    4   10    8    6  908   12]
[   8    6    4   12   28    5    1    8    7  930]]
```

3.5 MLP model 5 with 2 hidden layers of 100 nodes each using activation function 'sigmoid'

3.5.1 We use the 'adam' optimizer.

3.5.2 In this model we increase the number of hidden layers.

[111]:

```
model5 = Sequential()
model5.add(Dense(100, input_dim=784, activation='sigmoid'))
model5.add(Dense(100, input_dim=784, activation='sigmoid'))
model5.add(Dense(10, activation = "softmax"))
model5.compile(loss='categorical_crossentropy', optimizer='adam',␣
 ↪metrics=['accuracy'])
model5.fit(X_train, y_train, epochs=40)
```

```
Epoch 1/40
60000/60000 [==============================] - 5s 76us/sample - loss: 0.5871 -
acc: 0.8440
Epoch 2/40
60000/60000 [==============================] - 4s 71us/sample - loss: 0.3646 -
acc: 0.8894
Epoch 3/40
60000/60000 [==============================] - 4s 74us/sample - loss: 0.3282 -
acc: 0.8985
Epoch 4/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2948 -
acc: 0.9102
Epoch 5/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2836 -
acc: 0.9128
Epoch 6/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2623 -
acc: 0.9186
Epoch 7/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2489 -
acc: 0.9233
Epoch 8/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2318 -
acc: 0.9286
Epoch 9/40
60000/60000 [==============================] - 4s 71us/sample - loss: 0.2259 -
acc: 0.9297
```

```
Epoch 10/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2213 -
acc: 0.9315
Epoch 11/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2140 -
acc: 0.9326
Epoch 12/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2102 -
acc: 0.9350
Epoch 13/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1969 -
acc: 0.9379
Epoch 14/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.2049 -
acc: 0.9353
Epoch 15/40
60000/60000 [==============================] - 4s 71us/sample - loss: 0.1888 -
acc: 0.9407
Epoch 16/40
60000/60000 [==============================] - 4s 71us/sample - loss: 0.1842 -
acc: 0.9414
Epoch 17/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1940 -
acc: 0.9399
Epoch 18/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1927 -
acc: 0.9399
Epoch 19/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1814 -
acc: 0.9433
Epoch 20/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1659 -
acc: 0.9473
Epoch 21/40
60000/60000 [==============================] - 4s 73us/sample - loss: 0.1700 -
acc: 0.9468
Epoch 22/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1733 -
acc: 0.9453
Epoch 23/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1670 -
acc: 0.9469
Epoch 24/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1632 -
acc: 0.9490
Epoch 25/40
60000/60000 [==============================] - 4s 74us/sample - loss: 0.1541 -
acc: 0.9513
```

```
Epoch 26/40
60000/60000 [==============================] - 4s 73us/sample - loss: 0.1559 -
acc: 0.9515
Epoch 27/40
60000/60000 [==============================] - 4s 75us/sample - loss: 0.1522 -
acc: 0.9523
Epoch 28/40
60000/60000 [==============================] - 4s 73us/sample - loss: 0.1526 -
acc: 0.9513
Epoch 29/40
60000/60000 [==============================] - 5s 75us/sample - loss: 0.1439 -
acc: 0.9539
Epoch 30/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1365 -
acc: 0.9569
Epoch 31/40
60000/60000 [==============================] - 4s 74us/sample - loss: 0.1353 -
acc: 0.9577
Epoch 32/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1332 -
acc: 0.9577
Epoch 33/40
60000/60000 [==============================] - 5s 76us/sample - loss: 0.1362 -
acc: 0.9575
Epoch 34/40
60000/60000 [==============================] - 4s 71us/sample - loss: 0.1378 -
acc: 0.9569
Epoch 35/40
60000/60000 [==============================] - 4s 73us/sample - loss: 0.1441 -
acc: 0.9540
Epoch 36/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1372 -
acc: 0.9567
Epoch 37/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1347 -
acc: 0.9576
Epoch 38/40
60000/60000 [==============================] - 4s 72us/sample - loss: 0.1365 -
acc: 0.9570
Epoch 39/40
60000/60000 [==============================] - 4s 71us/sample - loss: 0.1337 -
acc: 0.9579
Epoch 40/40
60000/60000 [==============================] - 4s 73us/sample - loss: 0.1259 -
acc: 0.9600
```

```
[111]: <tensorflow.python.keras.callbacks.History at 0x7f6064b57470>
```

3.5.3 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[112]:
```
score5 = model5.evaluate(X_test, y_test)
print('Loss = ', score5[0], ' Accuracy = ', score5[1])
a_nn5 = score5[1]
```

```
10000/10000 [==============================] - 0s 46us/sample - loss: 0.1464 -
acc: 0.9543
Loss =  0.14642892222478987  Accuracy =  0.9543
```

[121]:
```
y_pred5 = model5.predict(X_test)
pred5 = []
for i in range(len(y_pred5)):
    pred5.append(np.argmax(y_pred5[i]))

f1_nn5 = f1_score(y_test, pred5, average='weighted')
p_nn5 = precision_score(y_test, pred5, average='weighted')
r_nn5 = recall_score(y_test, pred5, average='weighted')
print("f1 score: ",f1_nn5)
print("Precision score: ",p_nn5)
print("Recall score: ",r_nn5)
print("Confusion matrix: \n", confusion_matrix(y_test, pred5))
```

```
f1 score:  0.9542756426779866
Precision score:  0.9544382887107254
Recall score:  0.9543
Confusion matrix:
 [[ 965    1    1    0    0    3    3    2    2    3]
 [   0 1121    3    4    0    0    2    1    4    0]
 [  10    2  987    8    3    2    4    8    7    1]
 [   1    0   15  950    0   15    0    9   12    8]
 [   1    1    6    0  928    1    4    2    2   37]
 [   5    0    2   25    2  836    7    4    7    4]
 [  10    3    3    0    6   14  917    0    5    0]
 [   2    9   15    8    1    0    0  980    0   13]
 [  11    3   10   14    5   10    4    7  897   13]
 [   1    5    0    7   11    6    1    9    7  962]]
```

3.6 MLP model 6 with 3 hidden layers of 100 nodes each using activation function 'sigmoid'

3.6.1 We use the 'adam' optimizer.

3.6.2 In this model we further increase the number of hidden layers by 1.

[113]:
```
model6 = Sequential()
model6.add(Dense(100, input_dim=784, activation='sigmoid'))
model6.add(Dense(100, input_dim=784, activation='sigmoid'))
model6.add(Dense(100, input_dim=784, activation='sigmoid'))
model6.add(Dense(10, activation = "softmax"))
model6.compile(loss='categorical_crossentropy', optimizer='adam',␣
 ↪metrics=['accuracy'])
model6.fit(X_train, y_train, epochs=40)
```

```
Epoch 1/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.6930 -
acc: 0.7980
Epoch 2/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.3864 -
acc: 0.8786
Epoch 3/40
60000/60000 [==============================] - 5s 82us/sample - loss: 0.3507 -
acc: 0.8907
Epoch 4/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.3225 -
acc: 0.8990
Epoch 5/40
60000/60000 [==============================] - 5s 81us/sample - loss: 0.3008 -
acc: 0.9059
Epoch 6/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.2815 -
acc: 0.9112
Epoch 7/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.2752 -
acc: 0.9129
Epoch 8/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.2534 -
acc: 0.9197
Epoch 9/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.2514 -
acc: 0.9201
Epoch 10/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.2394 -
acc: 0.9244
Epoch 11/40
60000/60000 [==============================] - 5s 81us/sample - loss: 0.2311 -
```

```
acc: 0.9266
Epoch 12/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.2349 -
acc: 0.9252
Epoch 13/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.2252 -
acc: 0.9296
Epoch 14/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.2177 -
acc: 0.9319
Epoch 15/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.2078 -
acc: 0.9342
Epoch 16/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.1959 -
acc: 0.9386
Epoch 17/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.1901 -
acc: 0.9392
Epoch 18/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.1836 -
acc: 0.9409
Epoch 19/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.1828 -
acc: 0.9422
Epoch 20/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.1777 -
acc: 0.9434
Epoch 21/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.1705 -
acc: 0.9451
Epoch 22/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1733 -
acc: 0.9449
Epoch 23/40
60000/60000 [==============================] - 5s 80us/sample - loss: 0.1678 -
acc: 0.9464
Epoch 24/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1661 -
acc: 0.9474
Epoch 25/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.1640 -
acc: 0.9484
Epoch 26/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1558 -
acc: 0.9503
Epoch 27/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.1614 -
```

```
acc: 0.9485
Epoch 28/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1516 -
acc: 0.9515
Epoch 29/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.1525 -
acc: 0.9510
Epoch 30/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.1502 -
acc: 0.9520
Epoch 31/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.1526 -
acc: 0.9512
Epoch 32/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1511 -
acc: 0.9513
Epoch 33/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1460 -
acc: 0.9526
Epoch 34/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1446 -
acc: 0.9535
Epoch 35/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.1395 -
acc: 0.9552
Epoch 36/40
60000/60000 [==============================] - 5s 77us/sample - loss: 0.1364 -
acc: 0.9559
Epoch 37/40
60000/60000 [==============================] - 5s 79us/sample - loss: 0.1375 -
acc: 0.9554
Epoch 38/40
60000/60000 [==============================] - 5s 75us/sample - loss: 0.1361 -
acc: 0.9569
Epoch 39/40
60000/60000 [==============================] - 5s 78us/sample - loss: 0.1362 -
acc: 0.9559
Epoch 40/40
60000/60000 [==============================] - 5s 75us/sample - loss: 0.1295 -
acc: 0.9590
```

```
[113]: <tensorflow.python.keras.callbacks.History at 0x7f60647d57f0>
```

3.6.3 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[114]:
```
score6 = model6.evaluate(X_test, y_test)
print('Loss = ', score6[0], ' Accuracy = ', score6[1])
a_nn6 = score6[1]
```

```
10000/10000 [==============================] - 0s 43us/sample - loss: 0.1419 -
acc: 0.9527
Loss =  0.14187228043526412  Accuracy =  0.9527
```

[122]:
```
y_pred6 = model6.predict(X_test)
pred6 = []
for i in range(len(y_pred6)):
    pred6.append(np.argmax(y_pred6[i]))

f1_nn6 = f1_score(y_test, pred6, average='weighted')
p_nn6 = precision_score(y_test, pred6, average='weighted')
r_nn6 = recall_score(y_test, pred6, average='weighted')
print("f1 score: ",f1_nn6)
print("Precision score: ",p_nn6)
print("Recall score: ",r_nn6)
print("Confusion matrix: \n", confusion_matrix(y_test, pred6))
```

```
f1 score:  0.952713292371295
Precision score:  0.9528063644041739
Recall score:  0.9527
Confusion matrix:
 [[ 957    0    0    2    0    1    8    2    4    6]
 [   0 1117    5    1    0    1    1    0    9    1]
 [   7    3  984   14    1    2    3    9    8    1]
 [   0    1    9  960    0   10    0   11   18    1]
 [   2    0    4    0  936    2    7    3    3   25]
 [   6    2    0   23    2  838    9    1    8    3]
 [   6    4    4    0    6   11  921    0    5    1]
 [   1    9   13    4    3    0    0  970    1   27]
 [   0    2    7   21    7    7    4    3  913   10]
 [   7    7    0   10   14    9    1   10   20  931]]
```

4 Summary of the MLP models

[136]:
```
nn_l1 = ["MLP model 1", a_nn1, f1_nn1, p_nn1, r_nn1]
nn_l2 = ["MLP model 2", a_nn2, f1_nn2, p_nn2, r_nn2]
nn_l3 = ["MLP model 3", a_nn3, f1_nn3, p_nn3, r_nn3]
nn_l4 = ["MLP model 4", a_nn4, f1_nn4, p_nn4, r_nn4]
nn_l5 = ["MLP model 5", a_nn5, f1_nn5, p_nn5, r_nn5]
nn_l6 = ["MLP model 6", a_nn6, f1_nn6, p_nn6, r_nn6]
```

```
data = [nn_l1, nn_l2, nn_l3, nn_l4, nn_l5, nn_l6]
df = pd.DataFrame(data, columns = ['Model', 'Accuracy', 'F1 score', 'Precision␣
↪score', 'Recall score'])
df
```

[136]:

	Model	Accuracy	F1 score	Precision score	Recall score
0	MLP model 1	0.9248	0.924705	0.924956	0.9248
1	MLP model 2	0.9472	0.947134	0.947205	0.9472
2	MLP model 3	0.9459	0.946498	0.948778	0.9459
3	MLP model 4	0.9482	0.948169	0.948236	0.9482
4	MLP model 5	0.9543	0.954276	0.954438	0.9543
5	MLP model 6	0.9527	0.952713	0.952806	0.9527

5 Covolutional Neural Network (CNN)

[0]:
```
!pip install tensorflow==1.14
```

[0]:
```
from keras.models import Sequential
from keras.layers import Dense, Conv2D, Dropout, Flatten, MaxPooling2D
```

[0]:
```
X_train = X_train.reshape(X_train.shape[0], 28, 28, 1)
X_test = X_test.reshape(X_test.shape[0], 28, 28, 1)
input_shape = (28, 28, 1)
# X_train.dtype
X_train = X_train.astype('float32')
# X_train.dtype
X_test = X_test.astype('float32')
X_train = X_train/255
X_test = X_test/255
```

[9]:
```
print(X_train.shape)
print(y_train.shape)
print(X_test.shape)
print(y_test.shape)
```

```
(60000, 28, 28, 1)
(60000, 10)
(10000, 28, 28, 1)
(10000, 10)
```

5.1 CNN model 1 using 1 Conv2D layer using activation function 'sigmoid'

[16]:
```
model1 = Sequential()
model1.add(Conv2D(28, kernel_size=(3,3), activation = 'sigmoid',␣
↪input_shape=input_shape))
model1.add(MaxPooling2D(pool_size=(2, 2)))
```

```
model1.add(Flatten())
model1.add(Dense(10,activation='softmax'))
model1.compile(optimizer='adam', loss='categorical_crossentropy',␣
 ↪metrics=['accuracy'])
model1.fit(X_train, y_train, batch_size=128, epochs=10)
```

```
Epoch 1/10
60000/60000 [==============================] - 20s 338us/step - loss: 1.1379 -
acc: 0.6494
Epoch 2/10
60000/60000 [==============================] - 20s 330us/step - loss: 0.3952 -
acc: 0.8832
Epoch 3/10
60000/60000 [==============================] - 20s 330us/step - loss: 0.3400 -
acc: 0.8976
Epoch 4/10
60000/60000 [==============================] - 19s 321us/step - loss: 0.3143 -
acc: 0.9053
Epoch 5/10
60000/60000 [==============================] - 19s 325us/step - loss: 0.2936 -
acc: 0.9126
Epoch 6/10
60000/60000 [==============================] - 19s 323us/step - loss: 0.2700 -
acc: 0.9207
Epoch 7/10
60000/60000 [==============================] - 19s 319us/step - loss: 0.2479 -
acc: 0.9275
Epoch 8/10
60000/60000 [==============================] - 19s 322us/step - loss: 0.2286 -
acc: 0.9325
Epoch 9/10
60000/60000 [==============================] - 19s 322us/step - loss: 0.2077 -
acc: 0.9408
Epoch 10/10
60000/60000 [==============================] - 20s 325us/step - loss: 0.1912 -
acc: 0.9435
```

```
[16]: <keras.callbacks.History at 0x7f6067fc9470>
```

5.1.1 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

```
[71]: score1 = model1.evaluate(X_test, y_test)
print('Loss = ', score1[0], ' Accuracy = ', score1[1])
a_cnn1 = score1[1]
```

```
10000/10000 [==============================] - 2s 198us/step
```

```
Loss =  0.18071984765529633  Accuracy =  0.948
```

[65]:
```
y_pred1 = model1.predict(X_test)
pred1 = []
for i in range(len(y_pred1)):
    pred1.append(np.argmax(y_pred1[i]))

f1_cnn1 = f1_score(y_test, pred1, average='weighted')
p_cnn1 = precision_score(y_test, pred1, average='weighted')
r_cnn1 = recall_score(y_test, pred1, average='weighted')
print("f1 score: ",f1_cnn1)
print("Precision score: ",p_cnn1)
print("Recall score: ",r_cnn1)
print("Confusion matrix: \n", confusion_matrix(y_test, pred1))
```

```
f1 score:  0.9478929253148535
Precision score:  0.9487443580517673
Recall score:  0.948
Confusion matrix:
 [[ 974    0    1    1    0    1    0    2    1    0]
 [   0 1124    4    1    1    1    1    0    3    0]
 [  10    4  963   10   13    0    1   12   16    3]
 [   2    0   14  944    2   15    0   14   14    5]
 [   3    0    5    0  952    0    0    3    4   15]
 [  10    2    3   12    4  839    2    5   13    2]
 [  25    4   14    0   26   25  855    2    7    0]
 [   3    9   19    5    6    0    0  978    0    8]
 [   7    2    8   10    7    5    0    5  919   11]
 [   9    6    1    5   26    2    0   18   10  932]]
```

5.2 CNN model 2 using 2 Conv2D layers using activation function 'relu'

5.2.1 Thus in this model we test by adding another convolutional layer, increasing the number of nodes in one of the convolutional layers and changing the activation function.

[19]:
```
model2 = Sequential()
model2.add(Conv2D(32, kernel_size=(3,3), activation='relu',␣
 ↪input_shape=input_shape))
model2.add(Conv2D(64, (3, 3), activation='relu'))
model2.add(MaxPooling2D(pool_size=(2, 2)))
model2.add(Flatten())
model2.add(Dense(10,activation='softmax'))
model2.compile(optimizer='adam', loss='categorical_crossentropy',␣
 ↪metrics=['accuracy'])
model2.fit(X_train, y_train, batch_size=128, epochs=10)
```

```
Epoch 1/10
60000/60000 [==============================] - 103s 2ms/step - loss: 0.2124 -
```

```
acc: 0.9386
Epoch 2/10
60000/60000 [==============================] - 101s 2ms/step - loss: 0.0608 -
acc: 0.9818
Epoch 3/10
60000/60000 [==============================] - 101s 2ms/step - loss: 0.0433 -
acc: 0.9868
Epoch 4/10
60000/60000 [==============================] - 100s 2ms/step - loss: 0.0331 -
acc: 0.9898
Epoch 5/10
60000/60000 [==============================] - 100s 2ms/step - loss: 0.0267 -
acc: 0.9916
Epoch 6/10
60000/60000 [==============================] - 99s 2ms/step - loss: 0.0222 -
acc: 0.9929
Epoch 7/10
60000/60000 [==============================] - 99s 2ms/step - loss: 0.0171 -
acc: 0.9944
Epoch 8/10
60000/60000 [==============================] - 99s 2ms/step - loss: 0.0130 -
acc: 0.9958
Epoch 9/10
60000/60000 [==============================] - 99s 2ms/step - loss: 0.0118 -
acc: 0.9961
Epoch 10/10
60000/60000 [==============================] - 100s 2ms/step - loss: 0.0098 -
acc: 0.9968
```

[19]:
```
<keras.callbacks.History at 0x7f6067c78b38>
```

5.2.2 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[70]:
```
score2 = model2.evaluate(X_test, y_test)
print('Loss = ', score2[0], ' Accuracy = ', score2[1])
a_cnn2 = score2[1]
```

```
10000/10000 [==============================] - 5s 515us/step
Loss =  0.04824989859047273  Accuracy =  0.988
```

[64]:
```
y_pred2 = model2.predict(X_test)
pred2 = []
for i in range(len(y_pred2)):
    pred2.append(np.argmax(y_pred2[i]))

f1_cnn2 = f1_score(y_test, pred2, average='weighted')
```

```
p_cnn2 = precision_score(y_test, pred2, average='weighted')
r_cnn2 = recall_score(y_test, pred2, average='weighted')
print("f1 score: ",f1_cnn2)
print("Precision score: ",p_cnn2)
print("Recall score: ",r_cnn2)
print("Confusion matrix: \n", confusion_matrix(y_test, pred2))
```

```
f1 score:  0.9880025565099859
Precision score:  0.9880673420408137
Recall score:  0.988
Confusion matrix:
 [[ 970    0    0    1    0    0    5    0    1    3]
 [   0 1128    1    2    0    0    2    0    2    0]
 [   1    1 1017    6    0    0    1    5    1    0]
 [   0    0    0 1008    0    2    0    0    0    0]
 [   0    1    0    0  976    0    1    0    0    4]
 [   1    0    0   10    0  879    1    0    0    1]
 [   2    2    0    1    1    1  950    0    1    0]
 [   0    4    7    3    0    0    0 1010    1    3]
 [   4    0    3    3    0    2    2    2  956    2]
 [   0    3    0    7    5    3    0    2    3  986]]
```

5.3 CNN model 3 using 2 Conv2D layers using activation function 'relu' and another layer of 128 nodes.

5.3.1 Thus in this model we test by adding another layer.

[21]:
```
model3 = Sequential()
model3.add(Conv2D(32, kernel_size=(3,3), activation='relu',␣
 ↪input_shape=input_shape))
model3.add(Dense(64, activation='relu'))
model3.add(MaxPooling2D(pool_size=(2, 2)))
model3.add(Flatten())
model3.add(Dense(128, activation='relu'))
model3.add(Dense(10,activation='softmax'))
model3.compile(optimizer='adam', loss='categorical_crossentropy',␣
 ↪metrics=['accuracy'])
model3.fit(X_train, y_train, batch_size=128, epochs=10)
```

```
Epoch 1/10
60000/60000 [==============================] - 59s 981us/step - loss: 0.1972 -
acc: 0.9420
Epoch 2/10
60000/60000 [==============================] - 58s 960us/step - loss: 0.0543 -
acc: 0.9841
Epoch 3/10
60000/60000 [==============================] - 57s 946us/step - loss: 0.0347 -
acc: 0.9895
```

```
Epoch 4/10
60000/60000 [==============================] - 57s 942us/step - loss: 0.0253 -
acc: 0.9921
Epoch 5/10
60000/60000 [==============================] - 56s 933us/step - loss: 0.0171 -
acc: 0.9945
Epoch 6/10
60000/60000 [==============================] - 56s 925us/step - loss: 0.0125 -
acc: 0.9959
Epoch 7/10
60000/60000 [==============================] - 55s 922us/step - loss: 0.0088 -
acc: 0.9973
Epoch 8/10
60000/60000 [==============================] - 56s 926us/step - loss: 0.0070 -
acc: 0.9978
Epoch 9/10
60000/60000 [==============================] - 55s 918us/step - loss: 0.0056 -
acc: 0.9982
Epoch 10/10
60000/60000 [==============================] - 55s 919us/step - loss: 0.0063 -
acc: 0.9980
```

[21]: <keras.callbacks.History at 0x7f60677c9eb8>

5.3.2 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

[69]:
```
score3 = model3.evaluate(X_test, y_test)
print('Loss = ', score3[0], ' Accuracy = ', score3[1])
a_cnn3 = score3[1]
```

```
10000/10000 [==============================] - 3s 316us/step
Loss =  0.04637024184245347  Accuracy =  0.9887
```

[63]:
```
y_pred3 = model3.predict(X_test)
pred3 = []
for i in range(len(y_pred3)):
    pred3.append(np.argmax(y_pred3[i]))

f1_cnn3 = f1_score(y_test, pred3, average='weighted')
p_cnn3 = precision_score(y_test, pred3, average='weighted')
r_cnn3 = recall_score(y_test, pred3, average='weighted')
print("f1 score: ",f1_cnn3)
print("Precision score: ",p_cnn3)
print("Recall score: ",r_cnn3)
print("Confusion matrix: \n", confusion_matrix(y_test, pred3))
```

```
f1 score:  0.9886963829908504
Precision score:  0.9887282417107286
Recall score:  0.9887
Confusion matrix:
 [[ 979    0    0    0    0    0    0    1    0    0]
 [   0 1131    2    1    0    0    0    0    1    0]
 [   2    2 1019    1    1    0    0    4    3    0]
 [   0    0    1 1005    0    1    0    1    2    0]
 [   1    1    2    0  963    0    2    0    2   11]
 [   1    0    0    6    0  882    2    0    0    1]
 [   7    2    1    0    2    1  944    0    1    0]
 [   0    2    7    4    0    0    0 1012    1    2]
 [   3    0    1    3    0    1    1    1  960    4]
 [   2    1    1    2    3    5    0    1    2  992]]
```

5.4 CNN model 4 using 2 Conv2D layers using activation function 'relu' and another layer of 128 nodes.

5.4.1 We also add dropout layers.

[23]:
```
model4 = Sequential()
model4.add(Conv2D(32, kernel_size=(3, 3), activation='relu',␣
 ↪input_shape=input_shape))
model4.add(Conv2D(64, (3, 3), activation='relu'))
model4.add(MaxPooling2D(pool_size=(2, 2)))
model4.add(Dropout(0.25))
model4.add(Flatten())
model4.add(Dense(128, activation='relu'))
model4.add(Dropout(0.5))
model4.add(Dense(10, activation='softmax'))
model4.compile(optimizer=keras.optimizers.Adadelta(),␣
 ↪loss='categorical_crossentropy', metrics=['accuracy'])
model4.fit(X_train, y_train, batch_size=128, epochs=10)
```

```
Epoch 1/10
60000/60000 [==============================] - 121s 2ms/step - loss: 0.2621 -
acc: 0.9181
Epoch 2/10
60000/60000 [==============================] - 118s 2ms/step - loss: 0.0891 -
acc: 0.9737
Epoch 3/10
60000/60000 [==============================] - 118s 2ms/step - loss: 0.0688 -
acc: 0.9798
Epoch 4/10
60000/60000 [==============================] - 120s 2ms/step - loss: 0.0570 -
acc: 0.9835
Epoch 5/10
60000/60000 [==============================] - 116s 2ms/step - loss: 0.0486 -
```

```
acc: 0.9855
Epoch 6/10
60000/60000 [==============================] - 121s 2ms/step - loss: 0.0420 -
acc: 0.9874
Epoch 7/10
60000/60000 [==============================] - 121s 2ms/step - loss: 0.0381 -
acc: 0.9887
Epoch 8/10
60000/60000 [==============================] - 121s 2ms/step - loss: 0.0344 -
acc: 0.9896
Epoch 9/10
60000/60000 [==============================] - 121s 2ms/step - loss: 0.0314 -
acc: 0.9899
Epoch 10/10
60000/60000 [==============================] - 120s 2ms/step - loss: 0.0312 -
acc: 0.9903
```

```
[23]: <keras.callbacks.History at 0x7f60672e0048>
```

5.4.2 The accuracy, f1 score, precision score, recall score and confusion matrix obtained by running the model is shown below

```
[67]: score4 = model4.evaluate(X_test, y_test)
      print('Loss = ', score4[0], ' Accuracy = ', score4[1])
      a_cnn4 = score4[1]
```

```
10000/10000 [==============================] - 5s 504us/step
Loss =  0.027261577927844338  Accuracy =  0.9904
```

```
[62]: y_pred4 = model4.predict(X_test)
      pred4 = []
      for i in range(len(y_pred4)):
          pred4.append(np.argmax(y_pred4[i]))

      f1_cnn4 = f1_score(y_test, pred4, average='weighted')
      p_cnn4 = precision_score(y_test, pred4, average='weighted')
      r_cnn4 = recall_score(y_test, pred4, average='weighted')
      print("f1 score: ",f1_cnn4)
      print("Precision score: ",p_cnn4)
      print("Recall score: ",r_cnn4)
      print("Confusion matrix: \n", confusion_matrix(y_test, pred4))
```

```
f1 score:  0.9903989674914703
Precision score:  0.9904144613900989
Recall score:  0.9904
Confusion matrix:
 [[ 974    0    0    0    0    0    4    1    1    0]
```

```
[   0 1130    1    1    0    1    2    0    0    0]
[   1    1 1022    1    1    0    2    2    2    0]
[   0    0    3 1002    0    4    0    0    1    0]
[   0    0    0    0  974    0    3    0    2    3]
[   2    0    0    4    0  883    3    0    0    0]
[   3    1    0    0    1    1  951    0    1    0]
[   0    2    6    1    0    0    0 1017    1    1]
[   4    0    1    0    0    0    3    1  962    3]
[   2    1    0    1    6    5    0    3    2  989]]
```

6 Summary of the CNN models

[144]:
```
cnn_l1 = ["CNN model 1", a_cnn1, f1_cnn1, p_cnn1, r_cnn1]
cnn_l2 = ["CNN model 2", a_cnn2, f1_cnn2, p_cnn2, r_cnn2]
cnn_l3 = ["CNN model 3", a_cnn3, f1_cnn3, p_cnn3, r_cnn3]
cnn_l4 = ["CNN model 4", a_cnn4, f1_cnn4, p_cnn4, r_cnn4]
data = [cnn_l1, cnn_l2, cnn_l3, cnn_l4]
df = pd.DataFrame(data, columns = ['Model', 'Accuracy', 'F1 score', 'Precision␣
↪score', 'Recall score'])
df
```

[144]:

	Model	Accuracy	F1 score	Precision score	Recall score
0	CNN model 1	0.9480	0.947893	0.948744	0.9480
1	CNN model 2	0.9880	0.988003	0.988067	0.9880
2	CNN model 3	0.9887	0.988696	0.988728	0.9887
3	CNN model 4	0.9904	0.990399	0.990414	0.9904

7 Overall Summary of all the models

[147]:
```
data = [svm_l1, svm_l2, svm_l3, nn_l1, nn_l2, nn_l3, nn_l4, nn_l5, nn_l6,␣
↪cnn_l1, cnn_l2, cnn_l3, cnn_l4]
df = pd.DataFrame(data, columns = ['Model', 'Accuracy', 'F1 score', 'Precision␣
↪score', 'Recall score'])
df
```

[147]:

	Model	Accuracy	F1 score	Precision score	Recall score
0	SVM model 1	0.9831	0.983092	0.983098	0.9831
1	SVM model 2	0.9785	0.978481	0.978501	0.9785
2	SVM model 3	0.8782	0.878697	0.884757	0.8782
3	MLP model 1	0.9248	0.924705	0.924956	0.9248
4	MLP model 2	0.9472	0.947134	0.947205	0.9472
5	MLP model 3	0.9459	0.946498	0.948778	0.9459
6	MLP model 4	0.9482	0.948169	0.948236	0.9482
7	MLP model 5	0.9543	0.954276	0.954438	0.9543
8	MLP model 6	0.9527	0.952713	0.952806	0.9527

9	CNN model 1	0.9480	0.947893	0.948744	0.9480
10	CNN model 2	0.9880	0.988003	0.988067	0.9880
11	CNN model 3	0.9887	0.988696	0.988728	0.9887
12	CNN model 4	0.9904	0.990399	0.990414	0.9904

assign3_q4

April 3, 2020

[0]:
```
from google.colab import drive
drive.mount('/content/drive')
```

[0]:
```
import pandas as pd
import numpy as np
import random
from sklearn.metrics import mean_squared_error, r2_score
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from tensorflow.keras.utils import to_categorical
```

0.1 We read the data from the given csv file

[0]:
```
data = pd.read_csv("/content/drive/My Drive/SMAI_Assignment3_Dataset/dataset_q4/
 ↪household_power_consumption.txt", sep=';')
data
X = pd.DataFrame()
X['row_no'] = np.arange(len(data))
X['data'] = data['Global_active_power']
```

1 Window size = 60

1.1 We train our dataset for 50,000 samples using a window size of 60. In this phase, we ignore the rows having missing values.

[0]:
```
window_size = 60
X2 = np.array([0] * (window_size + 1))

count = 1
while(count<=50000):
  row = random.randrange(len(X) - window_size - 1)
  temp = X[row:row+window_size+1]['data'].tolist()
  if('?' not in temp):
    temp = [float(item) for item in temp]
    X2 = np.vstack((X2,temp))
```

```
    count = count + 1

X2 = X2[1:,:]
print(X2)
print(X2.shape)
```

```
[[0.4   0.4   0.4   ... 0.428 0.43  0.428]
 [0.292 0.29  0.288 ... 0.43  0.434 0.528]
 [0.302 0.242 0.232 ... 0.212 0.212 0.212]
 ...
 [0.264 0.266 0.266 ... 1.656 1.76  2.688]
 [2.26  2.266 2.448 ... 2.412 2.338 2.31 ]
 [0.32  0.314 0.316 ... 0.422 0.42  0.418]]
(50000, 61)
```

1.2 We split our data into train and test sets.

[0]:
```
X_train = X2[0:35000,0:60]
y_train = X2[0:35000,60]

X_test = X2[35000:,0:60]
y_test = X2[35000:,60]
print(X_train)
print(y_train)
```

```
[[0.4   0.4   0.4   ... 0.432 0.428 0.43 ]
 [0.292 0.29  0.288 ... 0.424 0.43  0.434]
 [0.302 0.242 0.232 ... 0.212 0.212 0.212]
 ...
 [2.024 2.282 2.282 ... 1.88  1.888 1.876]
 [0.358 2.434 2.57  ... 2.902 3.882 4.952]
 [1.384 1.384 1.384 ... 0.292 0.252 0.22 ]]
[0.428 0.528 0.212 ... 1.876 4.946 0.22 ]
```

1.3 Linear Regression model 1

[0]:
```
from sklearn.linear_model import LinearRegression

model_reg = LinearRegression()
model_reg.fit(X_train, y_train)
y_pred_reg = model_reg.predict(X_test)

mse_reg = mean_squared_error(y_test, y_pred_reg)
print('Mean squared error: ', mse_reg)
```

```python
r2_reg = r2_score(y_test, y_pred_reg)
print('r2 score: ', r2_reg)
```

```
Mean squared error:  0.0653094713737575
r2 score:  0.9429255892493377
```

1.4 Multi Layer Perceptron (MLP)

1.5 MLP model 1

1.6 In this model, we use MLP having one hidden layer of 100 nodes using activation function 'relu'

[0]:
```python
model_nn = Sequential()
model_nn.add(Dense(100, input_dim=60, activation='relu'))
model_nn.add(Dense(1))
model_nn.compile(optimizer='adam', loss='mse', metrics=['mse'])
model_nn.fit(X_train, y_train, epochs=30)
```

```
Epoch 1/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.1208 - mse:
0.1208
Epoch 2/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0867 - mse:
0.0867
Epoch 3/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0802 - mse:
0.0801
Epoch 4/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0767 - mse:
0.0767
Epoch 5/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0765 - mse:
0.0764
Epoch 6/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0734 - mse:
0.0734
Epoch 7/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0731 - mse:
0.0731
Epoch 8/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0744 - mse:
0.0744
Epoch 9/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0720 - mse:
0.0720
Epoch 10/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0719 - mse:
```

```
0.0720
Epoch 11/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0709 - mse:
0.0709
Epoch 12/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0710 - mse:
0.0710
Epoch 13/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0692 - mse:
0.0692
Epoch 14/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0692 - mse:
0.0692
Epoch 15/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0682 - mse:
0.0682
Epoch 16/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0671 - mse:
0.0671
Epoch 17/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0677 - mse:
0.0677
Epoch 18/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0687 - mse:
0.0687
Epoch 19/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0672 - mse:
0.0671
Epoch 20/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0668 - mse:
0.0668
Epoch 21/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0662 - mse:
0.0662
Epoch 22/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0662 - mse:
0.0661
Epoch 23/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0663 - mse:
0.0663
Epoch 24/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0648 - mse:
0.0648
Epoch 25/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0654 - mse:
0.0653
Epoch 26/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0659 - mse:
```

```
0.0659
Epoch 27/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0658 - mse:
0.0658
Epoch 28/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0651 - mse:
0.0651
Epoch 29/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0647 - mse:
0.0647
Epoch 30/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0648 - mse:
0.0648
```

[0]: <tensorflow.python.keras.callbacks.History at 0x7f27259bc320>

[0]:
```
y_pred_nn1 = model_nn.predict(X_test)
mse_nn1 = mean_squared_error(y_test, y_pred_nn1)
print('Mean squared error: ', mse_nn1)

r2_nn1 = r2_score(y_test, y_pred_nn1)
print('r2 score: ', r2_nn1)
```

```
Mean squared error:  0.06743341996900627
r2 score:  0.941069455491268
```

1.7 MLP model 2

1.7.1 In this model we add another hidden layer in our model and test the data.

[0]:
```
model_nn1 = Sequential()
model_nn1.add(Dense(100, input_dim=60, activation='relu'))
model_nn1.add(Dense(100, input_dim=60, activation='relu'))
model_nn1.add(Dense(1))
model_nn1.compile(optimizer='adam', loss='mse', metrics=['mse'])
model_nn1.fit(X_train, y_train, epochs=30)
```

```
Epoch 1/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.1194 - mse:
0.1194
Epoch 2/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0816 - mse:
0.0816
Epoch 3/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0768 - mse:
0.0768
Epoch 4/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0747 - mse:
```

```
0.0747
Epoch 5/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0730 - mse:
0.0730
Epoch 6/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0713 - mse:
0.0713
Epoch 7/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0703 - mse:
0.0703
Epoch 8/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0697 - mse:
0.0698
Epoch 9/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0702 - mse:
0.0702
Epoch 10/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0682 - mse:
0.0682
Epoch 11/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0694 - mse:
0.0694
Epoch 12/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0678 - mse:
0.0678
Epoch 13/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0687 - mse:
0.0686
Epoch 14/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0667 - mse:
0.0667
Epoch 15/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0656 - mse:
0.0656
Epoch 16/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0669 - mse:
0.0669
Epoch 17/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0658 - mse:
0.0658
Epoch 18/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0659 - mse:
0.0658
Epoch 19/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0652 - mse:
0.0652
Epoch 20/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0652 - mse:
```

```
0.0652
Epoch 21/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0644 - mse:
0.0644
Epoch 22/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0637 - mse:
0.0636
Epoch 23/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0636 - mse:
0.0636
Epoch 24/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0638 - mse:
0.0638
Epoch 25/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0625 - mse:
0.0625
Epoch 26/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0628 - mse:
0.0628
Epoch 27/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0632 - mse:
0.0632
Epoch 28/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0621 - mse:
0.0621
Epoch 29/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0617 - mse:
0.0617
Epoch 30/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0619 - mse:
0.0618
```

[0]: <tensorflow.python.keras.callbacks.History at 0x7f273bcccd68>

[0]:
```
y_pred_nn2 = model_nn1.predict(X_test)
mse_nn2 = mean_squared_error(y_test, y_pred_nn2)
print('Mean squared error: ', mse_nn2)

r2_nn2 = r2_score(y_test, y_pred_nn2)
print('r2 score: ', r2_nn2)
```

```
Mean squared error:  0.069224194734125
r2 score:  0.9395044847089845
```

1.8 MLP model 3

1.8.1 In this model we change the activation function to 'sigmoid'

[0]:
```
model_nn3 = Sequential()
model_nn3.add(Dense(100, input_dim=60, activation='sigmoid'))
model_nn3.add(Dense(1))
model_nn3.compile(optimizer='adam', loss='mse', metrics=['mse'])
model_nn3.fit(X_train, y_train, epochs=30)
```

```
Epoch 1/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.1363 - mse:
0.1363
Epoch 2/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0831 - mse:
0.0831
Epoch 3/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0772 - mse:
0.0772
Epoch 4/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0745 - mse:
0.0745
Epoch 5/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0735 - mse:
0.0735
Epoch 6/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0739 - mse:
0.0739
Epoch 7/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0735 - mse:
0.0735
Epoch 8/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0739 - mse:
0.0739
Epoch 9/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0735 - mse:
0.0735
Epoch 10/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0738 - mse:
0.0737
Epoch 11/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0732 - mse:
0.0732
Epoch 12/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0727 - mse:
0.0727
Epoch 13/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0731 - mse:
```

```
0.0731
Epoch 14/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0731 - mse:
0.0730
Epoch 15/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0719 - mse:
0.0719
Epoch 16/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0719 - mse:
0.0719
Epoch 17/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0718 - mse:
0.0718
Epoch 18/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0727 - mse:
0.0727
Epoch 19/30
1094/1094 [==============================] - 2s 2ms/step - loss: 0.0718 - mse:
0.0718
Epoch 20/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0710 - mse:
0.0710
Epoch 21/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0714 - mse:
0.0714
Epoch 22/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0710 - mse:
0.0710
Epoch 23/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0719 - mse:
0.0719
Epoch 24/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0716 - mse:
0.0716
Epoch 25/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0707 - mse:
0.0707
Epoch 26/30
1094/1094 [==============================] - 1s 1ms/step - loss: 0.0708 - mse:
0.0708
Epoch 27/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0706 - mse:
0.0706
Epoch 28/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0729 - mse:
0.0729
Epoch 29/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0704 - mse:
```

```
0.0704
Epoch 30/30
1094/1094 [==============================] - 2s 1ms/step - loss: 0.0709 - mse:
0.0709
```

[0]: <tensorflow.python.keras.callbacks.History at 0x7f272cd9f400>

[0]:
```
y_pred_nn3 = model_nn3.predict(X_test)
mse_nn3 = mean_squared_error(y_test, y_pred_nn3)
print('Mean squared error: ', mse_nn3)

r2_nn3 = r2_score(y_test, y_pred_nn3)
print('r2 score: ', r2_nn3)
```

```
Mean squared error:  0.076219229660009
r2 score:  0.9314961160221193
```

2 Summary of the three models

[0]:
```
lr_l1 = ["Linear Regression model 1", mse_reg, r2_reg]
mlp_l2 = ["MLP model 1", mse_nn1, r2_nn1]
mlp_l3 = ["MLP model 2", mse_nn2, r2_nn2]
mlp_l4 = ["MLP model 3", mse_nn3, r2_nn3]
data = [lr_l1, mlp_l2, mlp_l3, mlp_l4]
df = pd.DataFrame(data, columns = ['Model', 'Mean squared error', 'r2 score'])
df
```

[0]:

	Model	Mean squared error	r2 score
0	Linear Regression model 1	0.065309	0.942926
1	MLP model 1	0.067433	0.941069
2	MLP model 2	0.069224	0.939504
3	MLP model 3	0.076219	0.931496

3 Window size = 120

3.1 We train our dataset for 50,000 samples using a window size of 120. In this phase, we ignore the rows having missing values.

[0]:
```
window_size = 120
X2 = np.array([0] * (window_size + 1))

count = 1
while(count<=30000):
  row = random.randrange(len(X) - window_size - 1)
  temp = X[row:row+window_size+1]['data'].tolist()
  if('?' not in temp):
```

```
    temp = [float(item) for item in temp]
    X2 = np.vstack((X2,temp))
    count = count + 1

X2 = X2[1:,:]
print(X2)
print(X2.shape)
```

```
[[1.396 1.394 1.396 ... 1.188 1.186 1.184]
 [1.64  1.636 1.64  ... 1.414 1.41  1.412]
 [0.966 0.984 1.018 ... 0.236 0.236 0.236]
 ...
 [0.222 0.23  0.21  ... 1.234 1.24  1.238]
 [0.4   0.328 0.306 ... 0.39  0.388 0.43 ]
 [0.516 1.702 2.514 ... 1.502 1.422 1.412]]
(30000, 121)
```

3.2 We split our data into train and test sets.

[0]:
```
X_train = X2[0:21000,0:120]
y_train = X2[0:21000,120]

X_test = X2[21000:,0:120]
y_test = X2[21000:,120]
print(X_train)
print(y_train)
```

```
[[1.396 1.394 1.396 ... 1.188 1.188 1.186]
 [1.64  1.636 1.64  ... 1.406 1.414 1.41 ]
 [0.966 0.984 1.018 ... 0.254 0.236 0.236]
 ...
 [3.542 3.522 3.522 ... 1.814 1.79  1.806]
 [0.37  0.386 0.348 ... 0.326 0.306 0.322]
 [0.746 0.752 0.756 ... 1.772 1.882 1.936]]
[1.184 1.412 0.236 ... 1.792 0.302 1.932]
```

3.3 Linear Regression model 2

[0]:
```
from sklearn.linear_model import LinearRegression

model_reg2 = LinearRegression()
model_reg2.fit(X_train, y_train)
y_pred_reg2 = model_reg2.predict(X_test)

mse_reg2 = mean_squared_error(y_test, y_pred_reg2)
print('Mean squared error: ', mse_reg2)
```

```
r2_reg2 = r2_score(y_test, y_pred_reg2)
print('r2 score: ', r2_reg2)
```

```
Mean squared error:  0.0737459290811239
r2 score:  0.9337122808870182
```

3.4 Multi Layer Perceptron (MLP)

3.5 MLP model 4

3.6 In this model, we use MLP having one hidden layer of 100 nodes using activation function 'relu'

[0]:
```
model_nn4 = Sequential()
model_nn4.add(Dense(100, input_dim=120, activation='relu'))
model_nn4.add(Dense(1))
model_nn4.compile(optimizer='adam', loss='mse', metrics=['mse'])
model_nn4.fit(X_train, y_train, epochs=30)
```

```
Epoch 1/30
657/657 [==============================] - 1s 1ms/step - loss: 0.2022 - mse:
0.2022
Epoch 2/30
657/657 [==============================] - 1s 1ms/step - loss: 0.1123 - mse:
0.1117
Epoch 3/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0989 - mse:
0.0988
Epoch 4/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0953 - mse:
0.0953
Epoch 5/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0928 - mse:
0.0927
Epoch 6/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0861 - mse:
0.0861
Epoch 7/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0848 - mse:
0.0847
Epoch 8/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0957 - mse:
0.0958
Epoch 9/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0834 - mse:
0.0834
Epoch 10/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0837 - mse:
```

```
0.0838
Epoch 11/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0826 - mse:
0.0826
Epoch 12/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0824 - mse:
0.0823
Epoch 13/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0836 - mse:
0.0837
Epoch 14/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0818 - mse:
0.0812
Epoch 15/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0833 - mse:
0.0834
Epoch 16/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0781 - mse:
0.0782
Epoch 17/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0788 - mse:
0.0789
Epoch 18/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0770 - mse:
0.0770
Epoch 19/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0741 - mse:
0.0742
Epoch 20/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0752 - mse:
0.0753
Epoch 21/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0744 - mse:
0.0743
Epoch 22/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0722 - mse:
0.0722
Epoch 23/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0722 - mse:
0.0723
Epoch 24/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0731 - mse:
0.0731
Epoch 25/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0725 - mse:
0.0725
Epoch 26/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0713 - mse:
```

```
0.0713
Epoch 27/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0711 - mse:
0.0712
Epoch 28/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0709 - mse:
0.0709
Epoch 29/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0720 - mse:
0.0720
Epoch 30/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0703 - mse:
0.0704
```

[0]: <tensorflow.python.keras.callbacks.History at 0x7f273aec0240>

[0]:
```
y_pred_nn4 = model_nn4.predict(X_test)
mse_nn4 = mean_squared_error(y_test, y_pred_nn4)
print('Mean squared error: ', mse_nn4)

r2_nn4 = r2_score(y_test, y_pred_nn4)
print('r2 score: ', r2_nn4)
```

```
Mean squared error:  0.07395400051487365
r2 score:  0.9335252525191111
```

3.7 MLP model 5

3.7.1 In this model we add another hidden layer in our model and test the data.

[0]:
```
model_nn5 = Sequential()
model_nn5.add(Dense(100, input_dim=120, activation='relu'))
model_nn5.add(Dense(100, input_dim=120, activation='relu'))
model_nn5.add(Dense(1))
model_nn5.compile(optimizer='adam', loss='mse', metrics=['mse'])
model_nn5.fit(X_train, y_train, epochs=30)
```

```
Epoch 1/30
657/657 [==============================] - 1s 2ms/step - loss: 0.1632 - mse:
0.1634
Epoch 2/30
657/657 [==============================] - 1s 2ms/step - loss: 0.1075 - mse:
0.1076
Epoch 3/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0920 - mse:
0.0921
Epoch 4/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0877 - mse:
```

```
0.0878
Epoch 5/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0863 - mse:
0.0863
Epoch 6/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0827 - mse:
0.0828
Epoch 7/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0812 - mse:
0.0813
Epoch 8/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0818 - mse:
0.0819
Epoch 9/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0787 - mse:
0.0785
Epoch 10/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0808 - mse:
0.0809
Epoch 11/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0801 - mse:
0.0800
Epoch 12/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0760 - mse:
0.0760
Epoch 13/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0756 - mse:
0.0757
Epoch 14/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0771 - mse:
0.0772
Epoch 15/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0750 - mse:
0.0750
Epoch 16/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0747 - mse:
0.0748
Epoch 17/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0731 - mse:
0.0731
Epoch 18/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0740 - mse:
0.0740
Epoch 19/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0716 - mse:
0.0717
Epoch 20/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0729 - mse:
```

```
0.0730
Epoch 21/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0701 - mse:
0.0702
Epoch 22/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0724 - mse:
0.0725
Epoch 23/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0721 - mse:
0.0722
Epoch 24/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0699 - mse:
0.0698
Epoch 25/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0700 - mse:
0.0700
Epoch 26/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0686 - mse:
0.0684
Epoch 27/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0712 - mse:
0.0713
Epoch 28/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0671 - mse:
0.0672
Epoch 29/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0671 - mse:
0.0669
Epoch 30/30
657/657 [==============================] - 1s 2ms/step - loss: 0.0670 - mse:
0.0671
```

[0]: <tensorflow.python.keras.callbacks.History at 0x7f272d0d60f0>

[0]:
```
y_pred_nn5 = model_nn5.predict(X_test)
mse_nn5 = mean_squared_error(y_test, y_pred_nn5)
print('Mean squared error: ', mse_nn5)

r2_nn5 = r2_score(y_test, y_pred_nn5)
print('r2 score: ', r2_nn5)
```

```
Mean squared error:  0.08150738651148945
r2 score:  0.9267357695532811
```

3.8 MLP model 6

3.8.1 In this model we change the activation function to 'sigmoid'

[0]:
```
model_nn6 = Sequential()
model_nn6.add(Dense(100, input_dim=120, activation='sigmoid'))
model_nn6.add(Dense(1))
model_nn6.compile(optimizer='adam', loss='mse', metrics=['mse'])
model_nn6.fit(X_train, y_train, epochs=30)
```

```
Epoch 1/30
657/657 [==============================] - 1s 1ms/step - loss: 0.2167 - mse:
0.2169
Epoch 2/30
657/657 [==============================] - 1s 1ms/step - loss: 0.1117 - mse:
0.1118
Epoch 3/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0960 - mse:
0.0961
Epoch 4/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0920 - mse:
0.0918
Epoch 5/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0895 - mse:
0.0894
Epoch 6/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0878 - mse:
0.0879
Epoch 7/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0854 - mse:
0.0852
Epoch 8/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0833 - mse:
0.0831
Epoch 9/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0846 - mse:
0.0847
Epoch 10/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0852 - mse:
0.0849
Epoch 11/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0817 - mse:
0.0818
Epoch 12/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0810 - mse:
0.0811
Epoch 13/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0850 - mse:
```

```
0.0851
Epoch 14/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0817 - mse:
0.0818
Epoch 15/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0820 - mse:
0.0821
Epoch 16/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0807 - mse:
0.0807
Epoch 17/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0821 - mse:
0.0821
Epoch 18/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0813 - mse:
0.0813
Epoch 19/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0815 - mse:
0.0815
Epoch 20/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0820 - mse:
0.0818
Epoch 21/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0797 - mse:
0.0798
Epoch 22/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0802 - mse:
0.0803
Epoch 23/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0790 - mse:
0.0791
Epoch 24/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0777 - mse:
0.0778
Epoch 25/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0788 - mse:
0.0788
Epoch 26/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0795 - mse:
0.0796
Epoch 27/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0795 - mse:
0.0796
Epoch 28/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0791 - mse:
0.0792
Epoch 29/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0782 - mse:
```

```
0.0783
Epoch 30/30
657/657 [==============================] - 1s 1ms/step - loss: 0.0762 - mse:
0.0763
```

[0]: <tensorflow.python.keras.callbacks.History at 0x7f2736d9ceb8>

[0]:
```
y_pred_nn6 = model_nn6.predict(X_test)
mse_nn6 = mean_squared_error(y_test, y_pred_nn6)
print('Mean squared error: ', mse_nn6)

r2_nn6 = r2_score(y_test, y_pred_nn6)
print('r2 score: ', r2_nn6)
```

```
Mean squared error:  0.08456300210476338
r2 score:  0.9239891801389505
```

4 Summary of the three models having window size = 120

[0]:
```
lr_l5 = ["Linear Regression model 2", mse_reg, r2_reg]
mlp_l6 = ["MLP model 4", mse_nn4, r2_nn4]
mlp_l7 = ["MLP model 5", mse_nn5, r2_nn5]
mlp_l8 = ["MLP model 6", mse_nn6, r2_nn6]
data = [lr_l5, mlp_l6, mlp_l7, mlp_l8]
df = pd.DataFrame(data, columns = ['Model', 'Mean squared error', 'r2 score'])
df
```

[0]:

	Model	Mean squared error	r2 score
0	Linear Regression model 2	0.065309	0.942926
1	MLP model 4	0.073954	0.933525
2	MLP model 5	0.081507	0.926736
3	MLP model 6	0.084563	0.923989

5 Overall Summary

5.0.1 Here the first four rows displays the results by the models using window size = 60 and the next four rows displays the results by the models using window size = 120.

[0]:
```
data = [lr_l1, mlp_l2, mlp_l3, mlp_l4, lr_l5, mlp_l6, mlp_l7, mlp_l8]
df = pd.DataFrame(data, columns = ['Model', 'Mean squared error', 'r2 score'])
df
```

[0]:

	Model	Mean squared error	r2 score
0	Linear Regression model 1	0.065309	0.942926
1	MLP model 1	0.067433	0.941069
2	MLP model 2	0.069224	0.939504

```
3                MLP model 3           0.076219  0.931496
4  Linear Regression model 2           0.065309  0.942926
5                MLP model 4           0.073954  0.933525
6                MLP model 5           0.081507  0.926736
7                MLP model 6           0.084563  0.923989
```

5.1 From the above summary chart, we can see that we got comparable results using different kinds of models. Among them, we choose *linear regression model using window size = 60* to proceed further in our experiment.

6 Predicting the missing values in the given file

[0]:
```
window_size = 60
X2 = np.array([0] * (window_size + 1))

count = 1
while(count<=50000):
  row = random.randrange(len(X) - window_size - 1)
  temp = X[row:row+window_size+1]['data'].tolist()
  if('?' not in temp):
    temp = [float(item) for item in temp]
    X2 = np.vstack((X2,temp))
    count = count + 1

X2 = X2[1:,:]
print(X2)
print(X2.shape)
```

```
[[0.266 0.176 0.176 ... 0.08  0.126 0.158]
 [0.31  0.308 0.312 ... 0.22  0.22  0.22 ]
 [3.82  2.648 1.736 ... 1.614 1.638 1.684]
 ...
 [0.504 0.5   0.498 ... 0.958 0.958 0.954]
 [0.282 0.244 0.228 ... 2.552 2.542 2.534]
 [0.234 0.234 0.234 ... 0.308 0.256 0.256]]
(50000, 61)
```

6.1 We train our data using window size of 60

[0]:
```
X_train = X2[:,0:60]
y_train = X2[:,60]
print(X_train)
print(X_train.shape)
print(y_train)
print(y_train.shape)
```

```
[[0.266 0.176 0.176 ... 0.1   0.08  0.126]
 [0.31  0.308 0.312 ... 0.22  0.22  0.22 ]
 [3.82  2.648 1.736 ... 1.62  1.614 1.638]
 ...
 [0.504 0.5   0.498 ... 0.96  0.958 0.958]
 [0.282 0.244 0.228 ... 2.554 2.552 2.542]
 [0.234 0.234 0.234 ... 0.328 0.308 0.256]]
(50000, 60)
[0.158 0.22  1.684 ... 0.954 2.534 0.256]
(50000,)
```

6.2 Linear Regression model

[0]:
```
model = LinearRegression()
model.fit(X_train, y_train)
```

[0]:
```
LinearRegression(copy_X=True, fit_intercept=True, n_jobs=None, normalize=False)
```

6.3 We predict the labels of the missing values. The list of all the predicted values are printed below.

[0]:
```
X1 = X
X1 = np.array(X['data'])
count = 0
predictions = []
for i in range(len(data)):
  temp = X1[i]
  if(temp == '?'):
    if(i < window_size):
      pred1 = np.nanmean()
      X1[i] = pred1
    else:
      temp1 = np.array(X1[i-60:i].tolist())
      temp1 = temp1.astype('float32')
      test = temp1.reshape((1,-1))
      pred1 = model.predict(test)
      predictions.append(pred1[0])
      X1[i] = pred1[0]
    count = count + 1
```

[0]:
```
print(predictions)
print(len(predictions))
```

```
[0.2768042389679501, 0.32089765062589926, 6.153626816158928, 6.115620740789014,
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