# Main

November 8, 2019

```
In [1]: import numpy as np
        import pandas as pd
        from sklearn.neighbors import KNeighborsClassifier
        from sklearn.tree import DecisionTreeClassifier
        from sklearn.ensemble import RandomForestClassifier
        from keras import backend
        from keras.models import Sequential
        from keras.losses import categorical_crossentropy
        from keras.layers import Dense
        from keras.optimizers import SGD
        from keras.utils import to_categorical
        from keras.wrappers.scikit_learn import KerasClassifier
        from keras import metrics
        from keras import models, layers
        from sklearn.model_selection import cross_val_score, GridSearchCV
        from sklearn.model_selection import train_test_split, KFold
        from sklearn.metrics import f1_score, accuracy_score, confusion_matrix
        import matplotlib.pyplot as plt
        import warnings
```

```
C:\ProgramData\Anaconda3\lib\site-packages\sklearn\ensemble\weight_boosting.py:29: Deprecation
  from numpy.core.umath_tests import inner1d
Using TensorFlow backend.
```

## 1 1.1 Data

```
In [2]: # Import Data
        data_df = pd.read_csv('handwritten_digits_images.csv', header=None)
        labels_df = pd.read_csv('handwritten_digits_labels.csv', header=None)
        data = data_df.to_numpy()
        labels = labels_df.to_numpy()
```

```
In [3]: # descriptive statistics that summarize the central tendency, dispersion and shape of 
        data_df.describe()
```

```
Out[3]:             0        1        2        3        4        5        6        7    \
        count  70000.0  70000.0  70000.0  70000.0  70000.0  70000.0  70000.0  70000.0
```

```
mean      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
std       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
min       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
25%       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
50%       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
75%       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
max       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

            8        9  ...           774           775           776  \
count  70000.0  70000.0  ...  70000.000000  70000.000000  70000.000000
mean       0.0      0.0  ...      0.197414      0.099543      0.046629
std        0.0      0.0  ...      5.991206      4.256304      2.783732
min        0.0      0.0  ...      0.000000      0.000000      0.000000
25%        0.0      0.0  ...      0.000000      0.000000      0.000000
50%        0.0      0.0  ...      0.000000      0.000000      0.000000
75%        0.0      0.0  ...      0.000000      0.000000      0.000000
max        0.0      0.0  ...    254.000000    254.000000    253.000000

                777           778           779      780      781      782  \
count  70000.000000  70000.000000  70000.000000  70000.0  70000.0  70000.0
mean       0.016614      0.012957      0.001714      0.0      0.0      0.0
std        1.561822      1.553796      0.320889      0.0      0.0      0.0
min        0.000000      0.000000      0.000000      0.0      0.0      0.0
25%        0.000000      0.000000      0.000000      0.0      0.0      0.0
50%        0.000000      0.000000      0.000000      0.0      0.0      0.0
75%        0.000000      0.000000      0.000000      0.0      0.0      0.0
max      253.000000    254.000000     62.000000      0.0      0.0      0.0

            783
count  70000.0
mean       0.0
std        0.0
min        0.0
25%        0.0
50%        0.0
75%        0.0
max        0.0

[8 rows x 784 columns]
```

In [4]:
```
# print the first 5 rows of data
data_df.head(5)
```

Out[4]:
```
   0    1    2    3    4    5    6    7    8    9    ...  774  775  776  777  \
0    0    0    0    0    0    0    0    0    0    0  ...    0    0    0    0
1    0    0    0    0    0    0    0    0    0    0  ...    0    0    0    0
2    0    0    0    0    0    0    0    0    0    0  ...    0    0    0    0
3    0    0    0    0    0    0    0    0    0    0  ...    0    0    0    0
```

```
4    0    0    0    0    0    0    0    0    0    0  ...    0    0    0    0

   778  779  780  781  782  783
0    0    0    0    0    0    0
1    0    0    0    0    0    0
2    0    0    0    0    0    0
3    0    0    0    0    0    0
4    0    0    0    0    0    0

[5 rows x 784 columns]
```

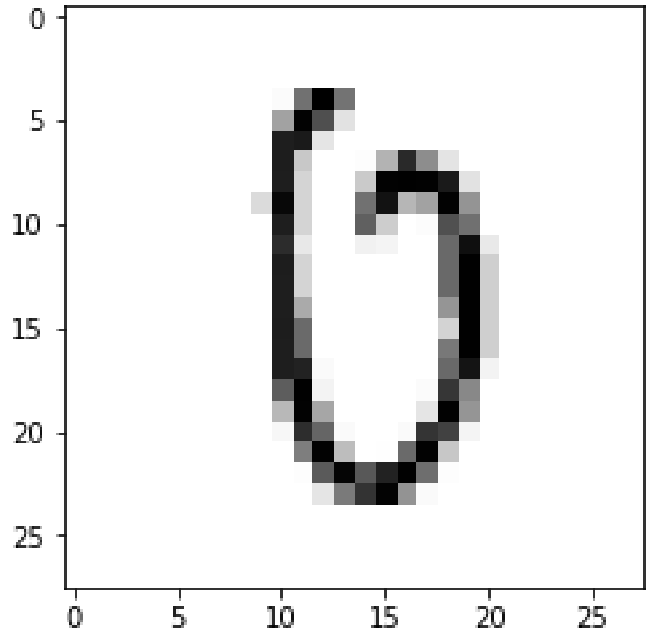
In [5]:
```
# Ratios of number of samples with respect to their classes
unique_nums, counts = np.unique(labels, return_counts=True)

print("Class Labels: \n", unique_nums)
print("Num of samples for each class respectively: \n", counts)
print("Ratio of samples for each class respectively: \n", counts/sum(counts))
```

```
Class Labels:
 [0 1 2 3 4 5 6 7 8 9]
Num of samples for each class respectively:
 [6903 7877 6990 7141 6824 6313 6876 7293 6825 6958]
Ratio of samples for each class respectively:
 [0.09861429 0.11252857 0.09985714 0.10201429 0.09748571 0.09018571
 0.09822857 0.10418571 0.0975     0.0994    ]
```

In [6]:
```
# Visualizing one of the samples
ax = plt.axes()
ax.imshow(data[0].reshape(28,28),cmap="Greys")
```

Out[6]: <matplotlib.image.AxesImage at 0x1ac3f433e48>




## 2 1.2 Code

In [7]:
```
# Stop showing warnings
warnings.filterwarnings('ignore')
# warnings.filterwarnings(action='once')
```

In [8]:
```
# define a function for selecting best k
def KNN_select(X, Y, possible_ks=[3, 5, 10, 20]):
    acc_list = []
    for k in possible_ks:
        print("training for k = %d"%k)
        clf = KNeighborsClassifier(n_neighbors=k)
        scores = cross_val_score(clf, X, Y, scoring='f1_macro', cv=5)
        acc_list.append(np.mean(scores))
        print("for k = %d scores are :"%k,scores)
        print("=========================================")
    Best_k = possible_ks[np.argmax(acc_list)]
    return Best_k
```

In [9]:
```
# define a function for selecting best number of trees for our decision tree alg.
def DT_select(X, Y, possible_depths=[10,20]):
    acc_list = []
    for d in possible_depths:
        print("training for depth = %d"%d)
        clf = DecisionTreeClassifier(random_state=0, max_depth=d)
```

```
            scores = cross_val_score(clf, X, Y, scoring='f1_macro', cv=5)
            acc_list.append(np.mean(scores))
            print("for depth = %d scores are :"%d,scores)
            print("========================================")
        Best_depth = possible_depths[np.argmax(acc_list)]
        return Best_depth
```

In [10]:
```
# define a function for selecting best number of trees for our random forest alg.
def RF_select(X, Y, possible_num_of_trees=[100, 300, 500, 1000]):
    acc_list = []
    for num in possible_num_of_trees:
        print("training for %d trees"%num)
        clf = RandomForestClassifier(n_estimators=num)
        scores = cross_val_score(clf, X, Y, scoring='f1_macro', cv=5)
        acc_list.append(np.mean(scores))
        print("for %d trees scores are :"%num,scores)
        print("========================================")
    Best_num_of_trees = possible_num_of_trees[np.argmax(acc_list)]
    return Best_num_of_trees
```

In [18]:
```
seed = 1000
np.random.seed(seed)

def KFold_split(X, Y, num_folds, seed):
    KFold_splitter = KFold(n_splits=num_folds, shuffle=True, random_state=seed)
    X_train_folds = []
    X_val_folds = []
    Y_train_folds = []
    Y_val_folds = []
    for (kth_fold_train_idxs, kth_fold_val_idxs) in KFold_splitter.split(X, Y):
        X_train_folds.append(X[kth_fold_train_idxs])
        X_val_folds.append(X[kth_fold_val_idxs])
        Y_train_folds.append(Y[kth_fold_train_idxs])
        Y_val_folds.append(Y[kth_fold_val_idxs])
    return X_train_folds, X_val_folds, Y_train_folds, Y_val_folds

### Construct a simple fully-connected MLP with SGD:
def build_MLP(input_shape, num_classes, activation_type, network_depth):
    MLP = Sequential()
    # Hidden layers (fully connected):
    MLP.add(Dense(input_shape=input_shape, units=30, activation=activation_type))
    if network_depth > 1:
        for i in range(1,network_depth):
            MLP.add(Dense(units=60, activation=activation_type))
    # Output layer (fully-connected):
    MLP.add(Dense(units=num_classes,
                  activation='softmax'))
    MLP.compile(loss=categorical_crossentropy,
```

```
                optimizer='SGD',
                metrics=['accuracy'])
    return MLP

def MLP_select(X, Y, possible_depths=[1,2,3,4,5],
               possible_activation_functions=["sigmoid", "relu"],
               batch_sizes=[50,100,200,500],
               num_epochs=[50,100,200,500]):
    acc_list = [[[[0 for b in range(len(batch_sizes))]
                  for e in range(len(num_epochs))]
                 for a in range(len(possible_activation_functions))]
                for d in range(len(possible_depths))]
    input_shape = (X.shape[1], )
    num_classes = 10
    Y = to_categorical(Y, num_classes)
    num_folds = 5
    X_train_folds, X_val_folds, Y_train_folds, Y_val_folds = KFold_split(X, Y, num_fo

    depth_index = 0
    for depth in possible_depths:
        activation_function_index = 0
        for activation_function in possible_activation_functions:
            epoch_index = 0
            for epoch in num_epochs:
                batch_size_index = 0
                for batch_size in batch_sizes:
                    model = KerasClassifier(build_fn=build_MLP, input_shape=input_sha
                         activation_type=activation_function, network_depth=depth, ep

                    print("training for Number of Hidden Layers:{}, Activation Functi
                         .format(depth, activation_function,epoch,batch_size))

                    for X_train_fold, X_val_fold, Y_train_fold, Y_val_fold in zip(X_t
                        model.fit(X_train_fold, Y_train_fold)
                        prediction = model.predict(X_val_fold)
                        acc_list[depth_index][activation_function_index][epoch_index]
                            f1_score(np.argmax(Y_val_fold,axis=1), prediction, averag
                    print("for Depth:{}, Activation Function:{}, Num of Epocs:{}, Bat
                         .format(depth, activation_function,epoch,batch_size),
                         acc_list[depth_index][activation_function_index][epoch_index]
                    print("==========================================")
                    batch_size_index = batch_size_index + 1
                epoch_index = epoch_index + 1
            activation_function_index = activation_function_index + 1
        depth_index = depth_index + 1
```

```
        acc_list = np.array(acc_list)
        best_depth_i, best_activation_function_i, best_num_epoch_i, best_batch_size_i = \
            np.unravel_index(acc_list.argmax(), acc_list.shape)
        best_depth, best_activation_function, best_num_epoch, best_batch_size = \
            possible_depths[best_depth_i],\
            possible_activation_functions[best_activation_function_i],\
            num_epochs[best_num_epoch_i],\
            batch_sizes[best_batch_size_i]

        return best_depth, best_activation_function, best_num_epoch, best_batch_size
```

```
In [12]: def final_model_select(X, Y):
    #     print("###############____KNN____################")
    #     #  Find the best model with respect to different values of K
    #     Best_k = KNN_select(X, Y, possible_ks=[5, 10])
    #     print("The best k is: ", Best_k)

        print("################____DT____#################")
        #  Find the best model with respect to different values of depth
        Best_depth = DT_select(X, Y, possible_depths=[8, 15])
        print("The best depth is: ", Best_depth)

        print("################____RF____#################")
        # Find the best model with respect to different number of trees
        Best_num_of_trees = RF_select(X, Y, possible_num_of_trees=[100, 500])
        print("The best num of trees is: ", Best_num_of_trees)

        print("################____MLP____################")
        Best_num_of_hidden_layers, Best_activation_function, best_num_epoch, best_batch_si
                                                                         MLP_select(X, Y,
                                                                         possible_depths=[(
                                                                         possible_activatio
                                                                         batch_sizes=[15,30
                                                                         num_epochs=[25,50]
        print("The best number of hidden layers is: ", Best_num_of_hidden_layers)
        print("The best activation function is: ", Best_activation_function)
        print("The best number of epocs is: ", best_num_epoch)
        print("The best batchsize is: ", best_batch_size)

        print("======================Selection Between DT, RF, and MLP================
        acc_list = [0 for i in range(3)]

    #     #KNN
    #     clf = KNeighborsClassifier(n_neighbors=Best_k)
    #     scores = cross_val_score(clf, X, Y, scoring='f1_macro', cv=5)
    #     acc_list[0] = np.mean(scores)
    #     print("K Neighbors Classifier Classification Performance: ",acc_list[0])
    #     print("========================================")
```

```
    #DT
    clf = DecisionTreeClassifier(random_state=0, max_depth=Best_depth)
    scores = cross_val_score(clf, X, Y, scoring='f1_macro', cv=5)
    acc_list[0] = np.mean(scores)
    print("Decision Tree Classification Performance: ",acc_list[0])
    print("==========================================")

    # RF
    clf = RandomForestClassifier(n_estimators=Best_num_of_trees)
    scores = cross_val_score(clf, X, Y, scoring='f1_macro', cv=5)
    acc_list[1] = np.mean(scores)
    print("Random Forest Classifier Classification Performance: ",acc_list[1])
    print("==========================================")

    #MLP
    input_shape = (X.shape[1], )
    num_classes = 10
    Y = to_categorical(Y, num_classes)
    num_folds = 5
    clf = KerasClassifier(build_fn=build_MLP, input_shape=input_shape, num_classes=nu
            activation_type=Best_activation_function, network_depth=Best_num_of_hidde
                           epochs=best_num_epoch, batch_size=best_batch_size, verbose=
    X_train_folds, X_val_folds, Y_train_folds, Y_val_folds = KFold_split(X, Y, num_fo
    for X_train_fold, X_val_fold, Y_train_fold, Y_val_fold in zip(X_train_folds, X_va
        clf.fit(X_train_fold, Y_train_fold)
        prediction = clf.predict(X_val_fold)
        acc_list [2] += f1_score(np.argmax(Y_val_fold,axis=1), prediction, average='m
    print("MLP Classifier Classification Performance: ",acc_list[2])
    print("==========================================")

    model_index = np.argmax(acc_list)

    if model_index==0:
#         print("The best model is learnt by K Neighbors Classifier!")
#         model = KNeighborsClassifier(n_neighbors=Best_k)
        print("The best model is learnt by Decision Tree Classifier!")
        model = DecisionTreeClassifier(random_state=0, max_depth=Best_depth)
    elif model_index==1:
        print("The best model is learnt by Random Forest Classifier!")
        model = RandomForestClassifier(n_estimators=Best_num_of_trees)
    else:
        print("The best model is learnt by MLP Classifier!")
        model = KerasClassifier(build_fn=build_MLP, input_shape=input_shape, num_clas
                    activation_type=Best_activation_function, network_depth=Best_num_
                    epochs=best_num_epoch, batch_size=best_batch_size, verbose=0)

    return model_index, model
```

In [13]:
```python
# A preprocessing of data can be needed as the dimentionality of data and number of s
# A model selection for dimentionality reduction
def preprocess_data(X, Y):

    def dim_red_ae(data,n_dims_encoded=20):
        input_layer = layers.Input(shape=(data.shape[1], ))
        encoding_layer = layers.Dense(n_dims_encoded,activation='tanh')(input_layer)
        decoding_layer = layers.Dense(data.shape[1],activation='tanh') (encoding_laye
        autoencoder = models.Model(input_layer, decoding_layer)
        autoencoder.compile('adam', loss='mse')
        autoencoder.fit(x = data, y = data, epochs=5)
        encoder = models.Model(input_layer, encoding_layer)
        return encoder,autoencoder

    acc_list = []
    possible_dims = [300,400,500]
    for dims in possible_dims:
        print("training for %d dimensions"%dims)
        encoder,_ = dim_red_ae(X,dims)
        encodings = encoder.predict(X)
        clf = RandomForestClassifier().fit(encodings,Y)
        scores = cross_val_score(clf, encodings, Y, cv=5)
        acc_list.append(np.mean(scores))
        print("for %d dims scores are :"%dims,scores)
        print("=========================================")
    best_dim = possible_dims[np.argmax(acc_list)]

    encoder,_ = dim_red_ae(X,best_dim)
    processed_data = encoder.predict(X)
    return processed_data
```

In [14]:
```python
# # preprocess the data
# processed_data = preprocess_data(data, labels)
# Devide data to train and test
X_train, X_test, Y_train, Y_test = train_test_split(data, labels, test_size = 0.3, ra
```

In [15]:
```python
'''
The best model will be selected among {DT, Decision Tree, and MLP}
However, beforehand:
(-For KNN the best model with respect to different values of K will be selected)
-For DT the best model with respect to different values of max depth will be selected
-For DT the best model with respect to different number of trees will be selected
-For MLP the best model with respect to "different number of hidden layes",
"types of activation functions" , "number of epocs", and "batchsize" will be selected

'''
# Model Selection
model_index, model = final_model_select(X_train, Y_train)
```

```
################____DT____#################
training for depth = 8
for depth = 8 scores are : [0.80025981 0.80975031 0.79846313 0.80527481 0.80632002]
=========================================
training for depth = 15
for depth = 15 scores are : [0.86058851 0.86452152 0.85933953 0.86518803 0.85727826]
=========================================
The depth is:  15
################____RF____#################
training for 100 trees
for 100 trees scores are : [0.96571259 0.9635131  0.96440118 0.96285871 0.96681695]
=========================================
training for 500 trees
for 500 trees scores are : [0.9668079  0.96708214 0.96672265 0.96455033 0.9696471 ]
=========================================
The best num of trees is:  500
################____MLP____#################
training for Depth:0, Activation Function:sigmoid, Num of Epocs:25, Batch Size:15
for Depth:0, Activation Function:sigmoid, Num of Epocs:25, Batch Size:15 mean score is : 0.8724
=========================================
training for Depth:0, Activation Function:sigmoid, Num of Epocs:25, Batch Size:30
for Depth:0, Activation Function:sigmoid, Num of Epocs:25, Batch Size:30 mean score is : 0.8890
=========================================
training for Depth:0, Activation Function:sigmoid, Num of Epocs:50, Batch Size:15
for Depth:0, Activation Function:sigmoid, Num of Epocs:50, Batch Size:15 mean score is : 0.8897
=========================================
training for Depth:0, Activation Function:sigmoid, Num of Epocs:50, Batch Size:30
for Depth:0, Activation Function:sigmoid, Num of Epocs:50, Batch Size:30 mean score is : 0.9045
=========================================
training for Depth:0, Activation Function:relu, Num of Epocs:25, Batch Size:15
for Depth:0, Activation Function:relu, Num of Epocs:25, Batch Size:15 mean score is : 0.0354769
=========================================
training for Depth:0, Activation Function:relu, Num of Epocs:25, Batch Size:30
for Depth:0, Activation Function:relu, Num of Epocs:25, Batch Size:30 mean score is : 0.068411
=========================================
training for Depth:0, Activation Function:relu, Num of Epocs:50, Batch Size:15
for Depth:0, Activation Function:relu, Num of Epocs:50, Batch Size:15 mean score is : 0.020338
=========================================
training for Depth:0, Activation Function:relu, Num of Epocs:50, Batch Size:30
for Depth:0, Activation Function:relu, Num of Epocs:50, Batch Size:30 mean score is : 0.0524736
=========================================
training for Depth:1, Activation Function:sigmoid, Num of Epocs:25, Batch Size:15
for Depth:1, Activation Function:sigmoid, Num of Epocs:25, Batch Size:15 mean score is : 0.8715
=========================================
training for Depth:1, Activation Function:sigmoid, Num of Epocs:25, Batch Size:30
for Depth:1, Activation Function:sigmoid, Num of Epocs:25, Batch Size:30 mean score is : 0.8926
=========================================
training for Depth:1, Activation Function:sigmoid, Num of Epocs:50, Batch Size:15
```

```
for Depth:1, Activation Function:sigmoid, Num of Epocs:50, Batch Size:15 mean score is : 0.8889
===========================================
training for Depth:1, Activation Function:sigmoid, Num of Epocs:50, Batch Size:30
for Depth:1, Activation Function:sigmoid, Num of Epocs:50, Batch Size:30 mean score is : 0.9053
===========================================
training for Depth:1, Activation Function:relu, Num of Epocs:25, Batch Size:15
for Depth:1, Activation Function:relu, Num of Epocs:25, Batch Size:15 mean score is : 0.0203406
===========================================
training for Depth:1, Activation Function:relu, Num of Epocs:25, Batch Size:30
for Depth:1, Activation Function:relu, Num of Epocs:25, Batch Size:30 mean score is : 0.0523229
===========================================
training for Depth:1, Activation Function:relu, Num of Epocs:50, Batch Size:15
for Depth:1, Activation Function:relu, Num of Epocs:50, Batch Size:15 mean score is : 0.0205376
===========================================
training for Depth:1, Activation Function:relu, Num of Epocs:50, Batch Size:30
for Depth:1, Activation Function:relu, Num of Epocs:50, Batch Size:30 mean score is : 0.0207075
===========================================
training for Depth:7, Activation Function:sigmoid, Num of Epocs:25, Batch Size:15
for Depth:7, Activation Function:sigmoid, Num of Epocs:25, Batch Size:15 mean score is : 0.020
===========================================
training for Depth:7, Activation Function:sigmoid, Num of Epocs:25, Batch Size:30
for Depth:7, Activation Function:sigmoid, Num of Epocs:25, Batch Size:30 mean score is : 0.0194
===========================================
training for Depth:7, Activation Function:sigmoid, Num of Epocs:50, Batch Size:15
for Depth:7, Activation Function:sigmoid, Num of Epocs:50, Batch Size:15 mean score is : 0.0192
===========================================
training for Depth:7, Activation Function:sigmoid, Num of Epocs:50, Batch Size:30
for Depth:7, Activation Function:sigmoid, Num of Epocs:50, Batch Size:30 mean score is : 0.0200
===========================================
training for Depth:7, Activation Function:relu, Num of Epocs:25, Batch Size:15
for Depth:7, Activation Function:relu, Num of Epocs:25, Batch Size:15 mean score is : 0.9507402
===========================================
training for Depth:7, Activation Function:relu, Num of Epocs:25, Batch Size:30
for Depth:7, Activation Function:relu, Num of Epocs:25, Batch Size:30 mean score is : 0.9485595
===========================================
training for Depth:7, Activation Function:relu, Num of Epocs:50, Batch Size:15
for Depth:7, Activation Function:relu, Num of Epocs:50, Batch Size:15 mean score is : 0.9527279
===========================================
training for Depth:7, Activation Function:relu, Num of Epocs:50, Batch Size:30
for Depth:7, Activation Function:relu, Num of Epocs:50, Batch Size:30 mean score is : 0.9519217
===========================================
The best number of hidden layers is:  7
The best activation function is:  relu
The best number of epocs is:  50
The best batchsize is:  15
========================Selection Between DT, RF, and MLP=========================
Decision Tree Classification Performance:  0.8613831716103608
===========================================
```

```
Random Forest Classifier Classification Performance:  0.9665362143782851
=========================================
MLP Classifier Classification Performance:  0.93859088418216
=========================================
The best model is learnt by Random Forest Classifier!
```

```
In [16]: # Model Evaluation

         if model_index==0: #DT
             model.fit(X_train, Y_train)
             pred_Y = model.predict(X_test)
             Classification_Performance = f1_score(Y_test, pred_Y, average='macro')
         elif model_index==1: #RF
             model.fit(X_train, Y_train)
             pred_Y = model.predict(X_test)
             Classification_Performance = f1_score(Y_test, pred_Y, average='macro')
         else: #MLP
             num_classes = 10
             Y_train_cat = to_categorical(Y_train, num_classes)
             Y_test_cat = to_categorical(Y_test, num_classes)
             model.fit(X_train, Y_train_cat)
             pred_Y = model.predict(Y_test_cat)
             Classification_Performance = f1_score(Y_test, pred_Y, average='macro')

         print("The Classification Performance for test set is: ", Classification_Performance)
```

```
The Classification Performance for test set is:  0.9708338999042571
```

```
In [17]: # Train the selected model on the whole data (there will be no evaluation)
         if model_index==0: #DT
             model.fit(data, labels)
         elif model_index==1: #RF
             model.fit(data, labels)
         else: #MLP
             num_classes = 10
             labels_cat = to_categorical(labels, num_classes)
             model.fit(data, labels_cat)

         print("=========================================")
         print("THE FINAL MODEL IS GENERATED!")
         print("=========================================")
```

```
=========================================
THE FINAL MODEL IS GENERATED!
=========================================
```