In [ ]:
```
#load the data from website of matlab format, and save locally as a file
```

In [1]:
```
import requests
import zipfile
import tempfile


def get_data():
    url = "http://www.itl.nist.gov/iaui/vip/cs_links/EMNIST/matlab.zip"
    response = requests.get(url)
    return url, response.content


if __name__ == '__main__':
    url, data = get_data()  # data is byte type

    _tmp_file = tempfile.TemporaryFile()  #Create temporary files
    print(_tmp_file)

    _tmp_file.write(data)  # write byte data to temporary file

    zf = zipfile.ZipFile(_tmp_file, mode='r')
    for names in zf.namelist():
        f = zf.extract(names, 'EMNIST./zip')  #Unzip to the zip directory fil
        print(f)

    zf.close()
```

```
<_io.BufferedRandom name=57>
EMNIST./zip/matlab/emnist-balanced.mat
EMNIST./zip/matlab/emnist-byclass.mat
EMNIST./zip/matlab/emnist-bymerge.mat
EMNIST./zip/matlab/emnist-digits.mat
EMNIST./zip/matlab/emnist-letters.mat
EMNIST./zip/matlab/emnist-mnist.mat
```

In [ ]:
```
#load the file
```

In [2]:
```
from scipy import io as sio
file = sio.loadmat('./EMNIST./zip/matlab/emnist-byclass.mat')
```

In [ ]:
```
#load the data, seperate the data to train set and data set, then reshape
```

In [3]:
```
import numpy as np

print(file.keys())
train = file['dataset'][0][0][0]
test = file['dataset'][0][0][1]
data_train = train[0][0][0]
label_train = train[0][0][1].reshape(-1)
data_test = test[0][0][0]
label_test = test[0][0][1].reshape(-1)

mapping = file['dataset'][0][0][2]

print(data_train.shape)
print(label_train.shape)
```

```
print(data_test.shape)
print(label_test.shape)
```

```
dict_keys(['__header__', '__version__', '__globals__', 'dataset'])
(697932, 784)
(697932,)
(116323, 784)
(116323,)
```

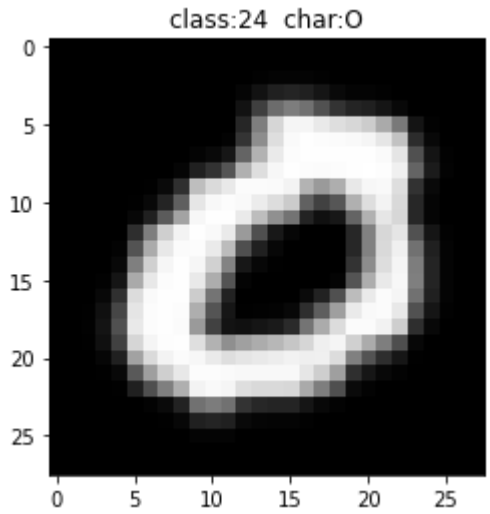
In [ ]:
```
#rotate the image by -90 degree and then flip horizontally
```

In [4]:
```
data_train = data_train.reshape([-1,28,28])
data_train = np.rot90(data_train, axes=[2,1])
data_train = np.flip(data_train, axis=2)
data_train = data_train.reshape([-1, 28 * 28])
data_test = data_test.reshape([-1,28,28])
data_test = np.rot90(data_test, axes=[2,1])
data_test = np.flip(data_test, axis=2)
data_test= data_test.reshape([-1, 28 * 28])

#randomly shuffle the data, and take 10% of the dataset
#1/10 for train and test respectively, 69793 train samples and 11632 test sam

train_sample_index = np.random.choice(data_train.shape[0], data_train.shape[0
data_train = data_train[train_sample_index]
label_train = label_train[train_sample_index]

test_sample_index = np.random.choice(data_test.shape[0], data_test.shape[0]//
data_test = data_test[test_sample_index]
label_test = label_test[test_sample_index]

print(data_train.shape)
print(label_train.shape)
print(data_test.shape)
print(label_test.shape)
```

```
(69793, 784)
(69793,)
(11632, 784)
(11632,)
```

In [ ]:
```
#show the original image in dataset
```

In [5]:
```
import matplotlib.pyplot as plt
img = data_train[0].reshape([28,28])
plt.imshow(img, cmap=plt.get_cmap('gray'))
plt.title("class:" +  str(label_train[0]) + "  char:" + chr(mapping[label_tra
plt.show()
```



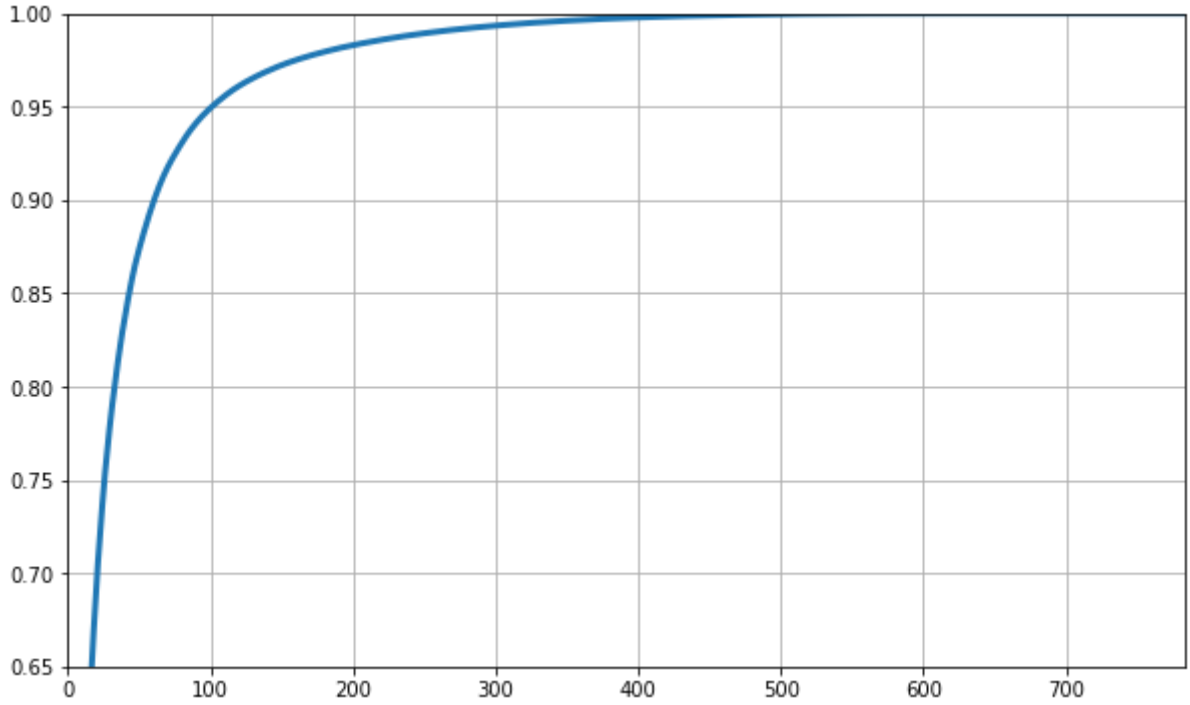
In [ ]:

In [6]:
```
# Pre-Processing Normaliazation
```

In [7]:
```
#all feature data are divided by 255 to scale all image pixels to 0-1.
data_train = data_train/255
data_test = data_test/255
```

In [8]:
```
# Pre-Processing PCA
```

In [9]:
```
from sklearn.decomposition import PCA

pca = PCA()
#train
pca.fit(data_train)

cumsum = np.cumsum(pca.explained_variance_ratio_)

#show the image of the variance occupied by each dimension
plt.figure(figsize = (10,6) )
plt.plot(cumsum, linewidth = 3)
plt.axis([0,784,0.65,1])
plt.grid(True)
plt.show()
```



In [10]:
```
# reduce the dimension 150, because when the dimension is 150, more than 95% (
pca = PCA(n_components=150)
pca.fit(data_train)


data_train = pca.transform(data_train)

data_test = pca.transform(data_test)
```

In [11]:
```
data_train.shape
```

Out[11]: (69793, 150)

In [ ]:
```

```

In [12]:
```
#Random forest classifier
```

In [13]:
```
from sklearn.ensemble import RandomForestClassifier
rf = RandomForestClassifier(random_state = 42)
from pprint import pprint

# Look at parameters used by current forest
pprint(rf.get_params())
```

```
{'bootstrap': True,
 'ccp_alpha': 0.0,
 'class_weight': None,
 'criterion': 'gini',
 'max_depth': None,
 'max_features': 'auto',
 'max_leaf_nodes': None,
 'max_samples': None,
 'min_impurity_decrease': 0.0,
 'min_samples_leaf': 1,
 'min_samples_split': 2,
```

```
'min_weight_fraction_leaf': 0.0,
'n_estimators': 100,
'n_jobs': None,
'oob_score': False,
'random_state': 42,
'verbose': 0,
'warm_start': False}
```

In [14]:

```
from sklearn.model_selection import RandomizedSearchCV

#set the parameters
n_estimators = [int(x) for x in np.linspace(start = 100, stop = 250, num = 50
max_features = ['auto', 'sqrt']
max_depth = [int(x) for x in np.linspace(10, 110, num = 11)]
min_samples_split = [2, 5, 10]
min_samples_leaf = [1, 2, 4]
bootstrap = [True, False]

#Create random search grid, create a RandomForestClassifier
random_grid = {'n_estimators': n_estimators,
               'max_features': max_features,
               'max_depth': max_depth,
               'min_samples_split': min_samples_split,
               'min_samples_leaf': min_samples_leaf,
               'bootstrap': bootstrap}
rf = RandomForestClassifier()

search = True

# Random search of parameters, using 5 fold cross validation, verbose=10
if search:
    rf_random = RandomizedSearchCV(estimator = rf, param_distributions = rand
    rf_random.fit(data_train, label_train)
    best_params_ = rf_random.best_params_
    cv_results = rf_random.cv_results_
```

In [18]:

```
#show the result and best params of random search
best_params
```

Out[18]:

```
{'n_estimators': 228,
 'min_samples_split': 2,
 'min_samples_leaf': 1,
 'max_features': 'auto',
 'max_depth': 110,
 'bootstrap': False}
```

In [ ]:

```
# show the accuracy and the running time of this random forest classifier bas
```

In [19]:

```
from matplotlib.patches import Polygon
import matplotlib.pyplot as plt

def plot_result(cv_results, title, x_label, y_label, param_name):
    accuracys = np.array(cv_results['mean_test_score'])
    cost_time = np.array(cv_results['mean_fit_time']) + np.array(cv_results['
    params = np.array(cv_results['param_' + param_name])
    index = params.argsort()
    print(params)
    accuracys = accuracys[index]
    params = params[index]
    cost_time = cost_time[index]
```

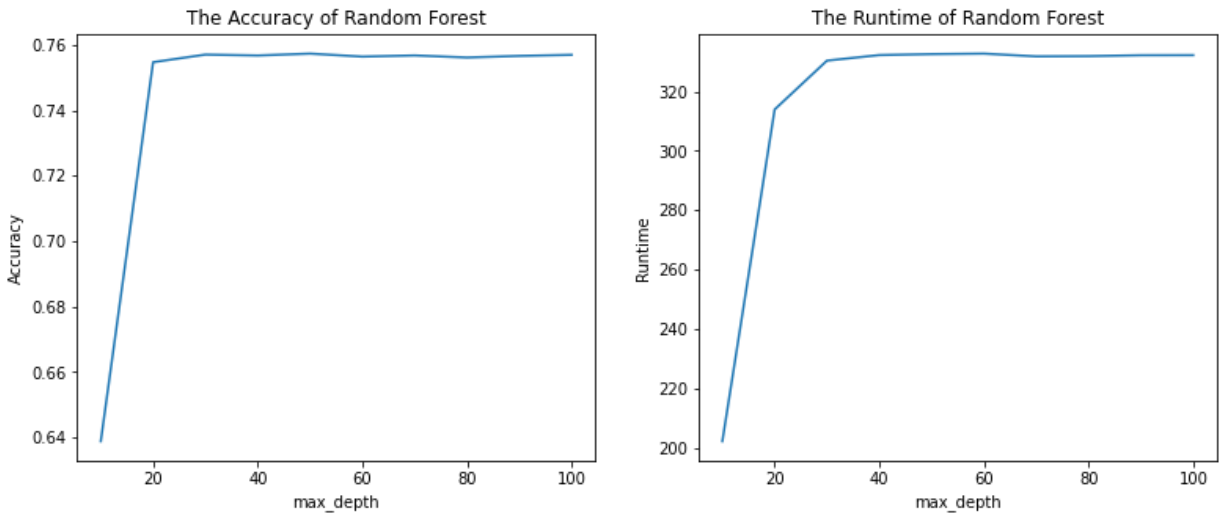
```
    plt.figure(figsize=(13, 5))
    plt.subplot(122)
    ax1 = plt.subplot(1, 2, 1)
    ax1.plot(params, accuracys)
    ax1.set_title(title[0])
    ax1.set_ylabel(y_label[0])
    ax1.set_xlabel(x_label[0])


    ax2 = plt.subplot(1, 2, 2)
    ax2.plot(params, cost_time)
    ax2.set_title(title[1])
    ax2.set_ylabel(y_label[1])
    ax2.set_xlabel(x_label[1])


    plt.show()
```

In [ ]:

```
from sklearn.model_selection import GridSearchCV

new_grid = {k: [v] for k, v in best_params.items()}
new_grid['max_depth'] = list(range(10, 110, 10))
rf = RandomForestClassifier()
rf_random = GridSearchCV(estimator = rf, param_grid = new_grid, cv = 5, verbos
rf_random.fit(data_train, label_train)

cv_result = rf_random.cv_results_
best_params_ = rf_random.best_params_
```

In [32]:

```
#Visualizations for Random Forest training result
#Graph of the accuracy vs. max_depth, the runtime vs. max_depth
title = ["The Accuracy of Random Forest", "The Runtime of Random Forest"]
x_label = ["max_depth", "max_depth"
y_label = ["Accuracy", "Runtime"]
cv_results = rf_random.cv_results_
plot_result(cv_results, title, x_label, y_label, 'max_depth')
```



In [24]:

```
print(rf_random.cv_results_)
```

```
{'mean_fit_time': array([202.33406577, 312.64495254, 328.91767397, 328.9607399
5,
       329.660428  , 330.1408514 , 330.15145097, 331.03753204,
       330.27580123, 332.08715453]), 'std_fit_time': array([0.56372705, 0.7625
6114, 0.75495402, 1.02589898, 0.23185053,
```

```
       0.68247326, 0.92473248, 1.44174524, 1.64170313, 1.15963759]), 'mean_sco
re_time': array([0.52534461, 1.7345015 , 2.48827758, 2.49332795, 2.48086028,
       2.50343399, 2.51019702, 2.49183116, 2.48673649, 2.46457839]), 'std_scor
e_time': array([0.00160155, 0.09574425, 0.0072807 , 0.03979533, 0.04396962,
       0.02355095, 0.00985752, 0.03385331, 0.03684181, 0.04478484]), 'param_bo
otstrap': masked_array(data=[False, False, False, False, False, False, False,
False,
                   False, False],
             mask=[False, False, False, False, False, False, False, False,
                   False, False],
       fill_value='?',
            dtype=object), 'param_max_depth': masked_array(data=[10, 20, 30, 4
0, 50, 60, 70, 80, 90, 100],
             mask=[False, False, False, False, False, False, False, False,
                   False, False],
       fill_value='?',
            dtype=object), 'param_max_features': masked_array(data=['auto', 'a
uto', 'auto', 'auto', 'auto', 'auto', 'auto',
                   'auto', 'auto', 'auto'],
             mask=[False, False, False, False, False, False, False, False,
                   False, False],
       fill_value='?',
            dtype=object), 'param_min_samples_leaf': masked_array(data=[1, 1,
1, 1, 1, 1, 1, 1, 1, 1],
             mask=[False, False, False, False, False, False, False, False,
                   False, False],
       fill_value='?',
            dtype=object), 'param_min_samples_split': masked_array(data=[2, 2,
2, 2, 2, 2, 2, 2, 2, 2],
             mask=[False, False, False, False, False, False, False, False,
                   False, False],
       fill_value='?',
            dtype=object), 'param_n_estimators': masked_array(data=[228, 228,
228, 228, 228, 228, 228, 228, 228, 228],
             mask=[False, False, False, False, False, False, False, False,
                   False, False],
       fill_value='?',
            dtype=object), 'params': [{'bootstrap': False, 'max_depth': 10, 'm
ax_features': 'auto', 'min_samples_leaf': 1, 'min_samples_split': 2, 'n_estima
tors': 228}, {'bootstrap': False, 'max_depth': 20, 'max_features': 'auto', 'mi
n_samples_leaf': 1, 'min_samples_split': 2, 'n_estimators': 228}, {'bootstra
p': False, 'max_depth': 30, 'max_features': 'auto', 'min_samples_leaf': 1, 'mi
n_samples_split': 2, 'n_estimators': 228}, {'bootstrap': False, 'max_depth': 4
0, 'max_features': 'auto', 'min_samples_leaf': 1, 'min_samples_split': 2, 'n_e
stimators': 228}, {'bootstrap': False, 'max_depth': 50, 'max_features': 'aut
o', 'min_samples_leaf': 1, 'min_samples_split': 2, 'n_estimators': 228}, {'boo
tstrap': False, 'max_depth': 60, 'max_features': 'auto', 'min_samples_leaf':
1, 'min_samples_split': 2, 'n_estimators': 228}, {'bootstrap': False, 'max_dep
th': 70, 'max_features': 'auto', 'min_samples_leaf': 1, 'min_samples_split':
2, 'n_estimators': 228}, {'bootstrap': False, 'max_depth': 80, 'max_features':
'auto', 'min_samples_leaf': 1, 'min_samples_split': 2, 'n_estimators': 228},
{'bootstrap': False, 'max_depth': 90, 'max_features': 'auto', 'min_samples_lea
f': 1, 'min_samples_split': 2, 'n_estimators': 228}, {'bootstrap': False, 'max
_depth': 100, 'max_features': 'auto', 'min_samples_leaf': 1, 'min_samples_spli
t': 2, 'n_estimators': 228}], 'split0_test_score': array([0.63736657, 0.754423
67, 0.75621463, 0.75549824, 0.7567161 ,
       0.75685937, 0.75277599, 0.75650118, 0.75607135, 0.75664446]), 'split1_t
est_score': array([0.6334981 , 0.75478186, 0.75779067, 0.7582205 , 0.75793395,
       0.75757576, 0.75635791, 0.75693101, 0.75506841, 0.75900852]), 'split2_t
est_score': array([0.63643527, 0.75184469, 0.75385056, 0.75377892, 0.7539222 ,
       0.75521169, 0.75628627, 0.75492514, 0.75599971, 0.75420875]), 'split3_t
est_score': array([0.63769881, 0.75562401, 0.7569136 , 0.75755839, 0.7569136 ,
       0.75548073, 0.75662702, 0.75648374, 0.75705688, 0.75483594]), 'split4_t
est_score': array([0.64142427, 0.75648374, 0.75999427, 0.75763003, 0.75934948,
       0.76078235, 0.76049577, 0.75934948, 0.75899126, 0.76092563]), 'mean_tes
t_score': array([0.63728461, 0.75463159, 0.75695275, 0.75653722, 0.75696706,
       0.75718198, 0.75650859, 0.75683811, 0.75663752, 0.75712466]), 'std_test
_score': array([0.00254457, 0.00156512, 0.00200613, 0.0016588 , 0.00178593,
```

```
       0.0019999 , 0.00244606, 0.00142928, 0.00133457, 0.00252855]), 'rank_tes
t_score': array([10,  9,  4,  7,  3,  1,  8,  5,  6,  2], dtype=int32)}
```

In [26]:

```
new_grid = {k: [v] for k, v in best_params.items()}
new_grid['n_estimators'] = list(range(50, 250, 20))
print(new_grid)
rf = RandomForestClassifier()
grid_search = GridSearchCV(estimator = rf, param_grid = new_grid, cv = 5, verl
grid_search.fit(data_train, label_train)
```

```
{'n_estimators': [50, 70, 90, 110, 130, 150, 170, 190, 210, 230], 'min_samples
_split': [2], 'min_samples_leaf': [1], 'max_features': ['auto'], 'max_depth':
[110], 'bootstrap': [False]}
Fitting 5 folds for each of 10 candidates, totalling 50 fits
[CV 1/5; 1/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=50
[CV 1/5; 1/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=50;, score=0.733 total time= 1.2
min
[CV 2/5; 1/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=50
[CV 2/5; 1/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=50;, score=0.735 total time= 1.2
min
[CV 3/5; 1/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=50
[CV 3/5; 1/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=50;, score=0.733 total time= 1.2
min
[CV 4/5; 1/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=50
[CV 4/5; 1/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=50;, score=0.738 total time= 1.2
min
[CV 5/5; 1/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=50
[CV 5/5; 1/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=50;, score=0.737 total time= 1.2
min
[CV 1/5; 2/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=70
[CV 1/5; 2/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=70;, score=0.741 total time= 1.7
min
[CV 2/5; 2/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=70
[CV 2/5; 2/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=70;, score=0.745 total time= 1.7
min
[CV 3/5; 2/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=70
[CV 3/5; 2/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=70;, score=0.743 total time= 1.7
min
[CV 4/5; 2/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=70
[CV 4/5; 2/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=70;, score=0.740 total time= 1.7
min
[CV 5/5; 2/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=70
[CV 5/5; 2/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=70;, score=0.743 total time= 1.7
min
[CV 1/5; 3/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=90
[CV 1/5; 3/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=90;, score=0.747 total time= 2.2
```

```
min
[CV 2/5; 3/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=90
[CV 2/5; 3/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=90;, score=0.747 total time= 2.2
min
[CV 3/5; 3/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=90
[CV 3/5; 3/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=90;, score=0.748 total time= 2.2
min
[CV 4/5; 3/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=90
[CV 4/5; 3/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=90;, score=0.748 total time= 2.2
min
[CV 5/5; 3/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=90
[CV 5/5; 3/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=90;, score=0.748 total time= 2.2
min
[CV 1/5; 4/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=110
[CV 1/5; 4/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=110;, score=0.750 total time= 2.
7min
[CV 2/5; 4/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=110
[CV 2/5; 4/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=110;, score=0.749 total time= 2.
7min
[CV 3/5; 4/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=110
[CV 3/5; 4/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=110;, score=0.748 total time= 2.
7min
[CV 4/5; 4/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=110
[CV 4/5; 4/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=110;, score=0.749 total time= 2.
7min
[CV 5/5; 4/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=110
[CV 5/5; 4/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=110;, score=0.753 total time= 2.
7min
[CV 1/5; 5/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=130
[CV 1/5; 5/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=130;, score=0.751 total time= 3.
2min
[CV 2/5; 5/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=130
[CV 2/5; 5/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=130;, score=0.754 total time= 3.
2min
[CV 3/5; 5/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=130
[CV 3/5; 5/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=130;, score=0.754 total time= 3.
2min
[CV 4/5; 5/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=130
[CV 4/5; 5/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=130;, score=0.753 total time= 3.
2min
[CV 5/5; 5/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=130
[CV 5/5; 5/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
```

```
les_leaf=1, min_samples_split=2, n_estimators=130;, score=0.752 total time= 3.
2min
[CV 1/5; 6/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=150
[CV 1/5; 6/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=150;, score=0.754 total time= 3.
6min
[CV 2/5; 6/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=150
[CV 2/5; 6/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=150;, score=0.752 total time= 3.
6min
[CV 3/5; 6/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=150
[CV 3/5; 6/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=150;, score=0.752 total time= 3.
6min
[CV 4/5; 6/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=150
[CV 4/5; 6/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=150;, score=0.755 total time= 3.
6min
[CV 5/5; 6/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=150
[CV 5/5; 6/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=150;, score=0.755 total time= 3.
6min
[CV 1/5; 7/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=170
[CV 1/5; 7/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=170;, score=0.756 total time= 4.
1min
[CV 2/5; 7/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=170
[CV 2/5; 7/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=170;, score=0.753 total time= 4.
1min
[CV 3/5; 7/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=170
[CV 3/5; 7/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=170;, score=0.753 total time= 4.
1min
[CV 4/5; 7/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=170
[CV 4/5; 7/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=170;, score=0.755 total time= 4.
1min
[CV 5/5; 7/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=170
[CV 5/5; 7/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=170;, score=0.755 total time= 4.
1min
[CV 1/5; 8/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=190
[CV 1/5; 8/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=190;, score=0.756 total time= 4.
6min
[CV 2/5; 8/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=190
[CV 2/5; 8/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=190;, score=0.756 total time= 4.
6min
[CV 3/5; 8/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=190
[CV 3/5; 8/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=190;, score=0.754 total time= 4.
6min
[CV 4/5; 8/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=190
```

```
[CV 4/5; 8/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=190;, score=0.755 total time= 4.
6min
[CV 5/5; 8/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=190
[CV 5/5; 8/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=190;, score=0.759 total time= 4.
6min
[CV 1/5; 9/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=210
[CV 1/5; 9/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=210;, score=0.756 total time= 5.
1min
[CV 2/5; 9/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=210
[CV 2/5; 9/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=210;, score=0.756 total time= 5.
1min
[CV 3/5; 9/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=210
[CV 3/5; 9/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=210;, score=0.755 total time= 5.
1min
[CV 4/5; 9/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=210
[CV 4/5; 9/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=210;, score=0.752 total time= 5.
1min
[CV 5/5; 9/10] START bootstrap=False, max_depth=110, max_features=auto, min_sa
mples_leaf=1, min_samples_split=2, n_estimators=210
[CV 5/5; 9/10] END bootstrap=False, max_depth=110, max_features=auto, min_samp
les_leaf=1, min_samples_split=2, n_estimators=210;, score=0.760 total time= 5.
1min
[CV 1/5; 10/10] START bootstrap=False, max_depth=110, max_features=auto, min_s
amples_leaf=1, min_samples_split=2, n_estimators=230
[CV 1/5; 10/10] END bootstrap=False, max_depth=110, max_features=auto, min_sam
ples_leaf=1, min_samples_split=2, n_estimators=230;, score=0.757 total time=
5.6min
[CV 2/5; 10/10] START bootstrap=False, max_depth=110, max_features=auto, min_s
amples_leaf=1, min_samples_split=2, n_estimators=230
[CV 2/5; 10/10] END bootstrap=False, max_depth=110, max_features=auto, min_sam
ples_leaf=1, min_samples_split=2, n_estimators=230;, score=0.755 total time=
5.6min
[CV 3/5; 10/10] START bootstrap=False, max_depth=110, max_features=auto, min_s
amples_leaf=1, min_samples_split=2, n_estimators=230
[CV 3/5; 10/10] END bootstrap=False, max_depth=110, max_features=auto, min_sam
ples_leaf=1, min_samples_split=2, n_estimators=230;, score=0.756 total time=
5.6min
[CV 4/5; 10/10] START bootstrap=False, max_depth=110, max_features=auto, min_s
amples_leaf=1, min_samples_split=2, n_estimators=230
[CV 4/5; 10/10] END bootstrap=False, max_depth=110, max_features=auto, min_sam
ples_leaf=1, min_samples_split=2, n_estimators=230;, score=0.757 total time=
5.6min
[CV 5/5; 10/10] START bootstrap=False, max_depth=110, max_features=auto, min_s
amples_leaf=1, min_samples_split=2, n_estimators=230
[CV 5/5; 10/10] END bootstrap=False, max_depth=110, max_features=auto, min_sam
ples_leaf=1, min_samples_split=2, n_estimators=230;, score=0.760 total time=
5.6min
```

Out[26]:

```
GridSearchCV(cv=5, estimator=RandomForestClassifier(),
             param_grid={'bootstrap': [False], 'max_depth': [110],
                         'max_features': ['auto'], 'min_samples_leaf': [1],
                         'min_samples_split': [2],
                         'n_estimators': [50, 70, 90, 110, 130, 150, 170, 190,
                                          210, 230]},
             verbose=10)
```

In [27]:

```
grid_search.cv_results_
```

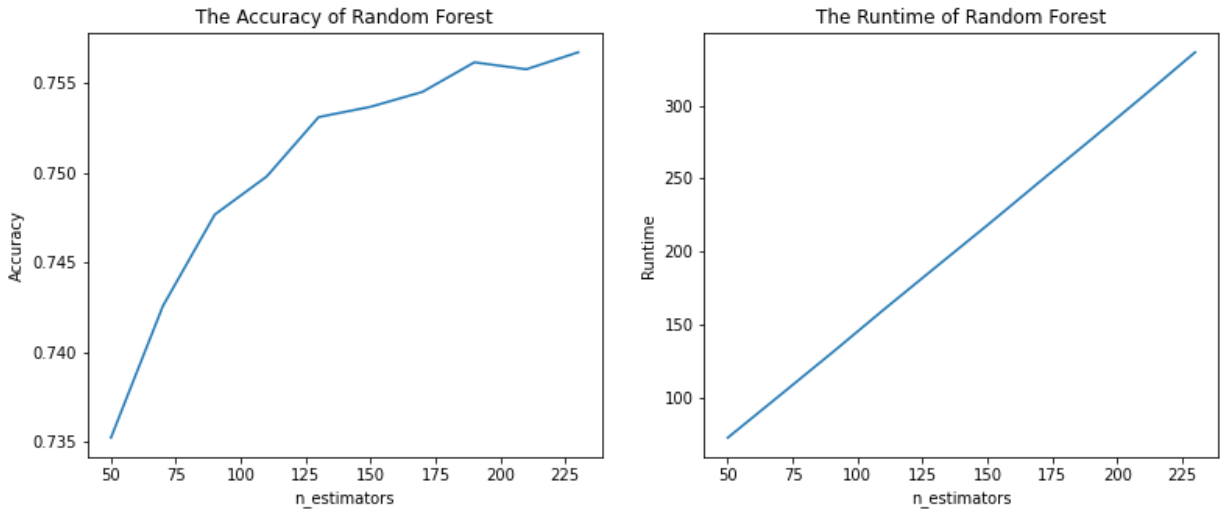
Out[27]:
```
{'mean_fit_time': array([ 72.3681623 , 101.11327324, 129.90426888, 159.34791288,
        188.18643961, 216.88711424, 246.00093136, 274.68320332,
        303.99210105, 333.82436976]),
 'std_fit_time': array([0.46534338, 0.37934914, 0.26098525, 0.37294882, 0.16138298,
        0.65261773, 0.70350817, 0.72842871, 0.45431816, 0.88843307]),
 'mean_score_time': array([0.28587465, 0.45116262, 0.66638412, 0.83311801, 1.04197478,
        1.19492078, 1.58325353, 2.06611991, 2.34407058, 2.57768245]),
 'std_score_time': array([0.01315074, 0.03801214, 0.02629902, 0.01505551, 0.04267864,
        0.00562566, 0.1382072 , 0.02362618, 0.0187399 , 0.03103009]),
 'param_bootstrap': masked_array(data=[False, False, False, False, False, False, False, False,
                    False, False],
              mask=[False, False, False, False, False, False, False, False,
                    False, False],
        fill_value='?',
             dtype=object),
 'param_max_depth': masked_array(data=[110, 110, 110, 110, 110, 110, 110, 110, 110, 110],
              mask=[False, False, False, False, False, False, False, False,
                    False, False],
        fill_value='?',
             dtype=object),
 'param_max_features': masked_array(data=['auto', 'auto', 'auto', 'auto', 'auto', 'auto', 'auto',
                    'auto', 'auto', 'auto'],
              mask=[False, False, False, False, False, False, False, False,
                    False, False],
        fill_value='?',
             dtype=object),
 'param_min_samples_leaf': masked_array(data=[1, 1, 1, 1, 1, 1, 1, 1, 1, 1],
              mask=[False, False, False, False, False, False, False, False,
                    False, False],
        fill_value='?',
             dtype=object),
 'param_min_samples_split': masked_array(data=[2, 2, 2, 2, 2, 2, 2, 2, 2, 2],
              mask=[False, False, False, False, False, False, False, False,
                    False, False],
        fill_value='?',
             dtype=object),
 'param_n_estimators': masked_array(data=[50, 70, 90, 110, 130, 150, 170, 190, 210, 230],
              mask=[False, False, False, False, False, False, False, False,
                    False, False],
        fill_value='?',
             dtype=object),
 'params': [{'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 50},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 70},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 90},
  {'bootstrap': False,
   'max_depth': 110,
```

```
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 110},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 130},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 150},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 170},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 190},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 210},
  {'bootstrap': False,
   'max_depth': 110,
   'max_features': 'auto',
   'min_samples_leaf': 1,
   'min_samples_split': 2,
   'n_estimators': 230}],
 'split0_test_score': array([0.73271724, 0.74117057, 0.74683   , 0.74955226,
0.75127158,
        0.75363565, 0.75592808, 0.75614299, 0.75571316, 0.75685937]),
 'split1_test_score': array([0.7354395 , 0.74475249, 0.74725983, 0.74912243,
0.75442367,
        0.75248943, 0.75327746, 0.75599971, 0.75585644, 0.75456695]),
 'split2_test_score': array([0.73286052, 0.74317645, 0.74826277, 0.74783294,
0.75406548,
        0.75234616, 0.75342073, 0.75413712, 0.75456695, 0.75556988]),
 'split3_test_score': array([0.73771314, 0.74043559, 0.74781487, 0.74896117,
0.75340307,
        0.75483594, 0.75505087, 0.75533744, 0.75232841, 0.75684195]),
 'split4_test_score': array([0.73742657, 0.74330133, 0.74817309, 0.75347471,
0.75232841,
        0.75505087, 0.75483594, 0.75913455, 0.76035249, 0.75970769]),
 'mean_test_score': array([0.73523139, 0.74256729, 0.74766811, 0.7497887 , 0.7
5309844,
        0.75367161, 0.75450261, 0.75615036, 0.75576349, 0.75670917]),
 'std_test_score': array([0.00214304, 0.00156077, 0.00054759, 0.00192854, 0.00
115884,
        0.00113258, 0.00101145, 0.00165179, 0.00261922, 0.00172734]),
 'rank_test_score': array([10,  9,  8,  7,  6,  5,  4,  2,  3,  1], dtype=int3
2)}
```

In [28]:

```
#Visualizations for Random Forest training result
#Graph of the accuracy vs. n_estimators, the runtime vs. n_estimators
cv_results = grid_search.cv_results_
title = ["The Accuracy of Random Forest", "The Runtime of Random Forest"]
```

```
x_label = ["n_estimators", "n_estimators"]
y_label = ["Accuracy", "Runtime"]
plot_result(cv_results, title, x_label, y_label, 'n_estimators')
```



In [34]:

```
from sklearn.ensemble import RandomForestClassifier
from sklearn.metrics import accuracy_score, precision_score, recall_score, co

best_esemble = RandomForestClassifier(**best_params)
best_esemble.fit(data_train, label_train)
```

Out[34]:

```
RandomForestClassifier(bootstrap=False, max_depth=110, n_estimators=228)
```

In [ ]:

```
#calculate the perfermance metric of RF model, including precision, recall, a
```

In [41]:

```
predict_data = best_esemble.predict(data_test)
precision = precision_score(label_test, predict_data, average = 'macro')
recall = recall_score(label_test, predict_data,average = 'macro')
accuracy = accuracy_score(label_test,predict_data)

print(predict_data)
print(label_test)

print("Accuracy: " + str(accuracy))
print("Recall: " + str(recall))
print("Precision: " + str(precision))

#show the confusion_matrix of this RF model
print(confusion_matrix(predict_data,label_test)[-1])
```

```
[ 5  0  2 ...  3 10  8]
[16  0  2 ...  3  0  8]
Accuracy: 0.7479367262723521
Recall: 0.48252830659431034
Precision: 0.6465831609757513
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9]
/Library/Frameworks/Python.framework/Versions/3.9/lib/python3.9/site-packages/
sklearn/metrics/_classification.py:1318: UndefinedMetricWarning: Precision is
ill-defined and being set to 0.0 in labels with no predicted samples. Use `zer
o_division` parameter to control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
```

In [43]:

```
#save the model
```

In [44]:
```
import joblib
joblib.dump(best_esemble,'./EMNIST./zip/matlab/random_forest.model')
best_esemble = joblib.load('./EMNIST./zip/matlab/random_forest.model')
```

In [ ]:
```

```