Import Libraries

First, we need to import matplotlib libraries as well as numpy library.

```
from matplotlib import pyplot as plt
from matplotlib.image import imread
import numpy as np
import os
```

Data loading

```
TRAIN_IMG_FOLDER = (r"/content/sample_data/Training images")
TEST_IMG_FOLDER =  (r"/content/sample_data/TEST")

train_set_files = os.listdir(TRAIN_IMG_FOLDER)
test_set_files = os.listdir(TEST_IMG_FOLDER)

width  = 128
height = 128
```

Check: All data from 'train' is included in 'test'?

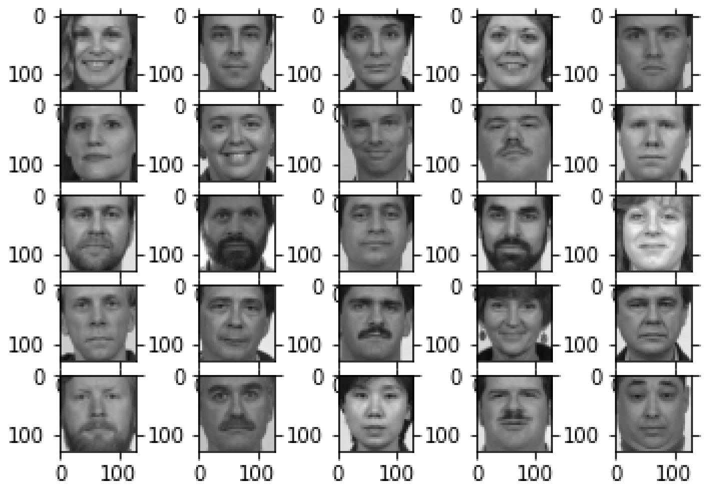
```
train_id_file = set([f.split('_')[0] for f in train_set_files])
test_id_file = set([f.split('_')[0] for f in train_set_files])
print(train_id_file <= test_id_file)
```

```
     True
```

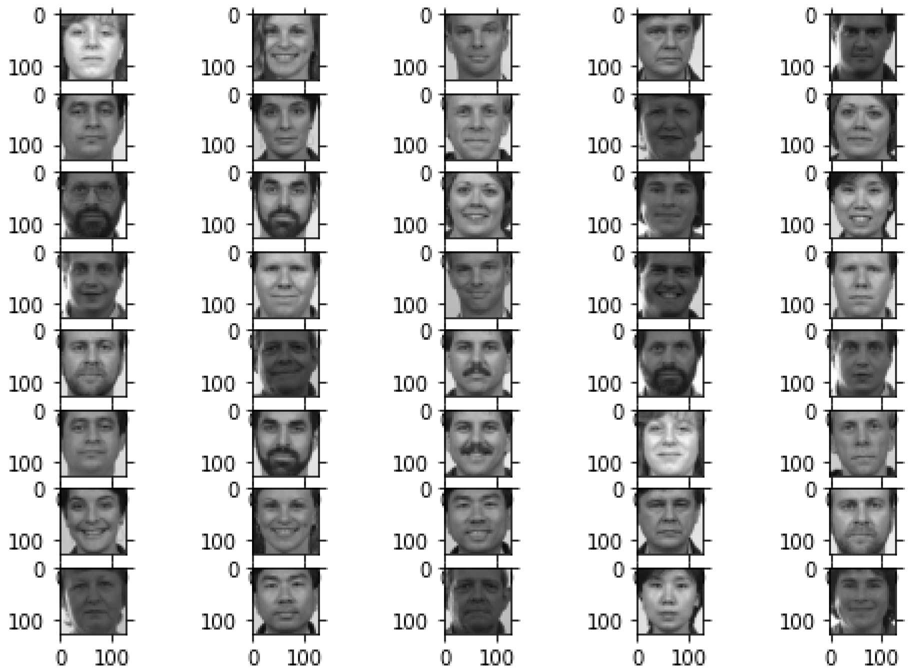
```
print('Train Images:')

train_image_names = os.listdir(TRAIN_IMG_FOLDER)
training_tensor   = np.ndarray(shape=(len(train_image_names), height*width), dtype=np.floa

for i in range(len(train_image_names)):
    img = plt.imread(os.path.join(TRAIN_IMG_FOLDER, train_image_names[i]))
    training_tensor[i,:] = np.array(img, dtype='float64').flatten()
    plt.subplot(5,5,1+i)
    plt.imshow(img, cmap='gray')
    plt.tick_params(labelleft='off', labelbottom='off', bottom='off',top='off',right='off'
plt.show()
```

```
print('Test Images:')
test_image_names = os.listdir(TEST_IMG_FOLDER)#[i for i in dataset_dir if i not in train_i
testing_tensor   = np.ndarray(shape=(len(test_image_names), height*width), dtype=np.float6

for i in range(len(test_image_names)):
    img = imread(os.path.join(TEST_IMG_FOLDER, test_image_names[i]))
    testing_tensor[i,:] = np.array(img, dtype='float64').flatten()
    plt.subplot(8,5,1+i)
    plt.imshow(img, cmap='gray')
    plt.subplots_adjust(right=1.2, top=1.2)
    plt.tick_params(labelleft='off', labelbottom='off', bottom='off',top='off',right='off'
plt.show()
```

```
Train Images:
```



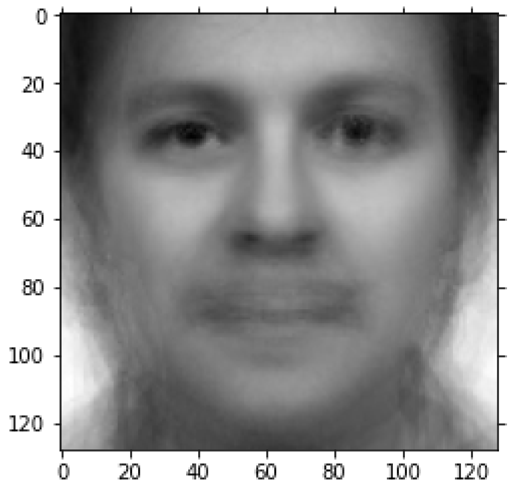
```
Test Images:
```



Calculate the mean face

The mean is just the sum of all of the pictures divided by the number of pictures. As a result, we

```
mean_face = np.zeros((1,height*width))

for i in training_tensor:
    mean_face = np.add(mean_face,i)

mean_face = np.divide(mean_face,float(len(train_image_names))).flatten()

plt.imshow(mean_face.reshape(height, width), cmap='gray')
plt.tick_params(labelleft='off', labelbottom='off', bottom='off',top='off',right='off',lef
plt.show()
```



Calculation of difference between training vector and mean vector

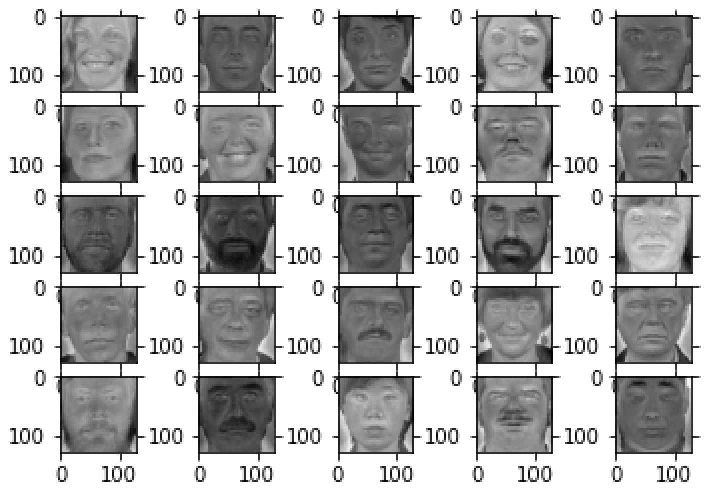
To normalize the training set, we just simply need to subtract for each picture in the training set the mean that was calculated in the previous step.

The reason why this is necessary is because we want to create a system that is able to represent any face. Therefore, we calculated the elements that all faces have in common (the mean). If we extract this average from the pictures, the features that distinguish each picture from the rest of the set are visible.

```
normalised_training_tensor = np.ndarray(shape=(len(train_image_names), height*width))

for i in range(len(train_image_names)):
    normalised_training_tensor[i] = np.subtract(training_tensor[i],mean_face)
```

Display normalised faces

```
for·i·in·range(len(train_image_names)):
····img·=·normalised_training_tensor[i].reshape(height,width)
····plt.subplot(5,5,1+i)
····plt.imshow(img,·cmap='gray')
····plt.tick_params(labelleft='off',·labelbottom='off',·bottom='off',top='off',right='off'
plt.show()
```



Converience Matrix

The covariance represents how two variables change together. After the previous step, we have a set of images that have different features, so now we want to see how these features for each individual picture change in relation to the rest of the pictures.

```
cov_matrix=np.cov(normalised_training_tensor)
cov_matrix = np.divide(cov_matrix,25.0)
print('Covariance Matrix Shape:', cov_matrix.shape)
#print('Covariance matrix of X: \n%s' %cov_matrix)
```

```
Covariance Matrix Shape: (25, 25)
```

Eigenvector of covariance

From the covariance we can extract the eigenvectors. Fortunately, there is a function that helps us in this step. There is plenty of information in the internet about eigenvectors but the general idea is that eigenvectors are the vectors of the covariance that describe the direction of the data.

```
#eigenvalues and eigenvectors
eigenvalues, eigenvectors, = np.linalg.eig(cov_matrix)
print('eigenvalues.shape: {} eigenvectors.shape: {}'.format(eigenvalues.shape, eigenvector
```

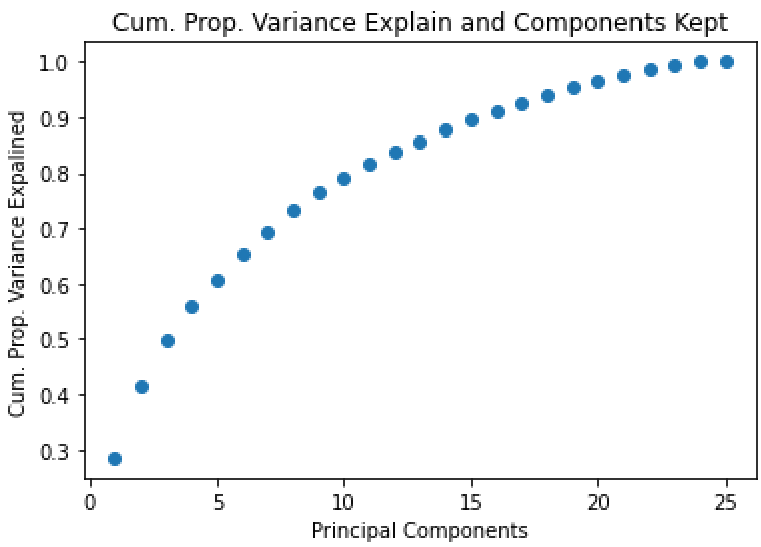
```
eigenvalues.shape: (25,) eigenvectors.shape: (25, 25)
```

```
eig_pairs = [(eigenvalues[index], eigenvectors[:,index]) for index in range(len(eigenvalue

# Sort the eigen pairs in descending order:
eig_pairs.sort(reverse=True)
eigvalues_sort  = [eig_pairs[index][0] for index in range(len(eigenvalues))]
eigvectors_sort = [eig_pairs[index][1] for index in range(len(eigenvalues))]

sorted_ind = sorted(range(eigenvalues.shape[0]), key=lambda k: eigenvalues[k], reverse=Tru

eigvalues_sort = eigenvalues[sorted_ind]
eigvectors_sort = eigenvectors[sorted_ind]
train_set_files_sort = np.array(train_set_files)[sorted_ind]
```

Find cumulative variance of each principle component

```
var_comp_sum = np.cumsum(eigvalues_sort)/sum(eigvalues_sort)

# Show cumulative proportion of varaince with respect to components
print("Cumulative proportion of variance explained vector: \n%s" %var_comp_sum)

# x-axis for number of principal components kept
num_comp = range(1,len(eigvalues_sort)+1)
plt.title('Cum. Prop. Variance Explain and Components Kept')
plt.xlabel('Principal Components')
plt.ylabel('Cum. Prop. Variance Expalined')

plt.scatter(num_comp, var_comp_sum)
plt.show()
```

```
Cumulative proportion of variance explained vector:
[0.28481989 0.41576165 0.49714907 0.55777059 0.60785024 0.65427472
 0.69489721 0.73168527 0.7641529  0.7916646  0.81546473 0.83669985
 0.85752859 0.87642433 0.89418977 0.91069532 0.92659352 0.94017913
 0.95309028 0.96500642 0.97612862 0.98491526 0.99275274 1.
 1.        ]
```



Choose the necessary of principal components:

```
reduced_data = np.array(eigvectors_sort[:25]).transpose()
reduced_data.shape
```

```
(25, 25)
```

```
print(training_tensor.transpose().shape, reduced_data.shape)
```

```
(16384, 25) (25, 25)
```

Calculate eigenfaces

Each eigenvector is multiplied by the whole normalized training set matrix and as a result, we will have the same amount of eigenfaces as images in our training set.

```
proj_data = np.dot(training_tensor.transpose(),reduced_data)
proj_data = proj_data.transpose()
proj_data.shape
```

```
(25, 16384)
```

Plot eigen faces

```
for i in range(proj_data.shape[0]):
    img = proj_data[i].reshape(height,width)
    plt.subplot(5,5,1+i)
    plt.imshow(img, cmap='gray')
    plt.tick_params(labelleft='off', labelbottom='off', bottom='off',top='off',right='off'
plt.show()
```

Finding weights for each traning image

Each normalized face in the training set multiplies each eigenface. Consequently, there will be N set of weights with M elements (N = amount of pictures in the training set, M = number of eigenfaces).

```
w = np.array([np.dot(proj_data,i) for i in normalised_training_tensor])
print(w.shape)
```

```
(25, 25)
```

Reconizing all test images

```
def recogniser(test_image_names, train_image_names,proj_data,w, t0=2e8, prn=False):

    count        = 0
    num_images   = 0
    correct_pred = 0

    result = []
    wts = []

    #False match rate (FMR)
    FMR_count = 0

    #False non-match rate (FNMR)
    FNMR_count = 0


    test_image_names2 = sorted(test_image_names)

    for img in test_image_names2:
        #img = imread(os.path.join(TEST_IMG_FOLDER, test_image_names[i]))
        unknown_face = plt.imread(os.path.join(TEST_IMG_FOLDER, img))
        num_images += 1

        unknown_face_vector = np.array(unknown_face, dtype='float64').flatten()
        normalised_uface_vector = np.subtract(unknown_face_vector,mean_face)

        w_unknown = np.dot(proj_data, normalised_uface_vector)
        diff  = w - w_unknown
        norms = np.linalg.norm(diff, axis=1)
        index = np.argmin(norms)

        wts.append([count, norms[index]])
```

```
        if prn: print('Input:'+'.'.join(img.split('.')[:2]), end='\t')
        count+=1

        match = img.split('_')[0] == train_image_names[index].split('_')[0]
        if norms[index] < t0: # It's a face
            if match:
                if prn: print('Matched:' + train_image_names[index], end = '\t')
                correct_pred += 1
                result.append(1)
            else:
                if prn: print('F/Matched:'+train_image_names[index], end = '\t')
                result.append(0)
                FMR_count += 1
        else:
            if match:
                if prn: print('Unknown face!'+train_image_names[index], end = '\t')
                FNMR_count +=1

            else:
                pass
                correct_pred += 1



        if prn: print(norms[index], end=' ')
        if prn: print()



    FMR = FMR_count/num_images
    FNMR = FNMR_count/num_images


    print('Correct predictions: {}/{} = {} \t\t'.format(correct_pred, num_images, correct_
    print('FMR: {} \t'.format(FMR), end=' ')
    print('FNMR: {} \t'.format(FNMR))



    return wts, result, correct_pred, num_images, FMR, FNMR


wts, result, correct_pred, num_images, FMR, FNMR =recogniser(test_image_names, train_image
```

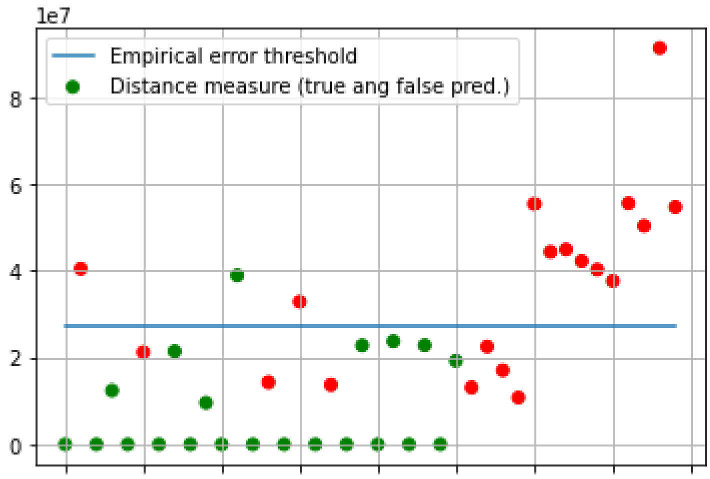
```
Input:00770_960530_fa.jpg       Matched:00770_960530_fa.jpg     0.0
Input:00770_960530_fa_a.jpg     F/Matched:00744_941201_fa.jpg   40443667.46730239
Input:00771_941205_fa.jpg       Matched:00771_941205_fa.jpg     0.0
Input:00771_941205_fb.jpg       Matched:00771_941205_fa.jpg     12411902.370116899
Input:00772_941201_fa.jpg       Matched:00772_941201_fa.jpg     0.0
Input:00772_941201_fb.jpg       F/Matched:00763_941201_fa.jpg   21167349.76704071
Input:00773_941201_fa.jpg       Matched:00773_941201_fa.jpg     0.0
Input:00773_941201_fb.jpg       Matched:00773_941201_fa.jpg     21385298.89308537
Input:00775_941205_fa.jpg       Matched:00775_941205_fa.jpg     0.0
Input:00775_941205_fb.jpg       Matched:00775_941205_fa.jpg     9590985.449027391
Input:00779_941205_fa.jpg       Matched:00779_941205_fa.jpg     0.0
Input:00779_941205_fb.jpg       Matched:00779_941205_fa.jpg     38922068.40712187
```

```
Input:00781_941205_fa.jpg       Matched:00781_941205_fa.jpg     0.0
Input:00781_941205_fb.jpg       F/Matched:00804_941205_fa.jpg   14277462.667984817
Input:00787_941205_fa.jpg       Matched:00787_941205_fa.jpg     0.0
Input:00787_941205_fb.jpg       F/Matched:00744_941201_fa.jpg   32827038.492167294
Input:00794_941205_fa.jpg       Matched:00794_941205_fa.jpg     0.0
Input:00794_941205_fb.jpg       F/Matched:00775_941205_fa.jpg   13696831.306772253
Input:00797_941205_fa.jpg       Matched:00797_941205_fa.jpg     0.0
Input:00797_941205_fb.jpg       Matched:00797_941205_fa.jpg     22738402.814766455
Input:00804_941205_fa.jpg       Matched:00804_941205_fa.jpg     0.0
Input:00804_941205_fb.jpg       Matched:00804_941205_fa.jpg     23695586.06549764
Input:00806_941205_fa.jpg       Matched:00806_941205_fa.jpg     0.0
Input:00806_941205_fb.jpg       Matched:00806_941205_fa.jpg     22783423.946304098
Input:00807_941205_fa.jpg       Matched:00807_941205_fa.jpg     0.0
Input:00807_941205_fb.jpg       Matched:00807_941205_fa.jpg     19176199.709934838
Input:00809_941205_fa.jpg       F/Matched:00761_941201_fa.jpg   13086008.769753514
Input:00809_941205_fb.jpg       F/Matched:00761_941201_fa.jpg   22463983.150025796
Input:00816_941205_fa.jpg       F/Matched:00766_941201_fa.jpg   16977907.094737023
Input:00816_941205_fb.jpg       F/Matched:00794_941205_fa.jpg   10808932.965668758
Input:00876_960530_fa.jpg       F/Matched:00744_941201_fa.jpg   55433907.515526965
Input:00876_960530_fb.jpg       F/Matched:00744_941201_fa.jpg   44354768.593997344
Input:00879_960530_fa.jpg       F/Matched:00797_941205_fa.jpg   44897093.13547314
Input:00879_960530_fb.jpg       F/Matched:00797_941205_fa.jpg   42228054.2415042
Input:00894_960530_fa.jpg       F/Matched:00781_941205_fa.jpg   40255117.3914715
Input:00894_960530_fb.jpg       F/Matched:00781_941205_fa.jpg   37625178.90044493
Input:00900_960530_fa.jpg       F/Matched:00745_941201_fa.jpg   55566607.455226995
Input:00900_960530_fb.jpg       F/Matched:00745_941201_fa.jpg   50361147.60444705
Input:00903_960530_fa.jpg       F/Matched:00745_941201_fa.jpg   91323857.85102595
Input:00903_960530_fb.jpg       F/Matched:00745_941201_fa.jpg   54705102.14316333
Correct predictions: 21/40 = 0.525               FMR: 0.475      FNMR: 0.0
```

Visualisation result of prediction

with high error threshold: t0 = 2e8

```
def rg(r):
    if r: return 'g'
    else: return 'r'
cl = [rg(r) for r in result]

x=[x[0] for x in wts]
y=[y[1] for y in wts]
plt.scatter(x,y, color=cl, label = 'Distance measure (true ang false pred.)')

x2=[x[0] for x in wts]
y2=[2.7e7 for y in wts]

plt.plot(x2,y2, label = 'Empirical error threshold')
plt.legend()
plt.grid()

plt.show()
```



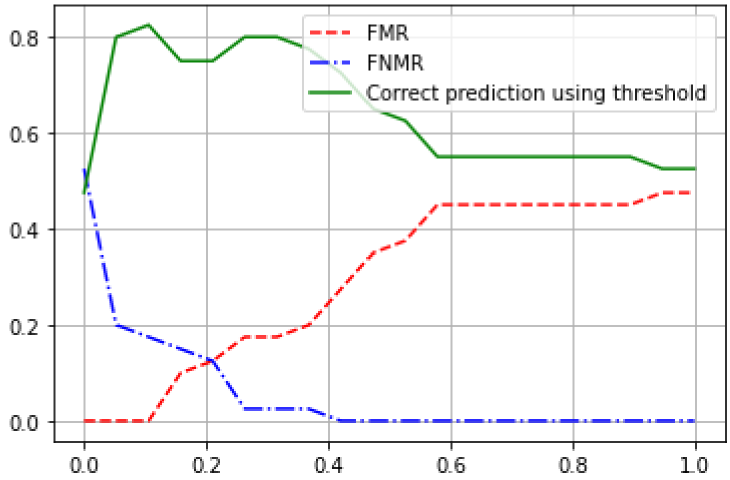

```
CPR_list, t0_list, FMR_list, FNMR_list = [], [] , [] , []
for t0 in np.linspace(start=0, stop=1e8, num=20):
    print('{:e}'.format(t0), end=' ')
    wts, result, correct_pred, num_images, FMR, FNMR = recogniser(test_image_names, train_

    CPR_list.append(correct_pred/num_images)
    t0_list.append(t0)
    FMR_list.append(FMR)
    FNMR_list.append(FNMR)
```

```
 0.000000e+00 Correct predictions: 19/40 = 0.475                FMR: 0.0         FNMI
 5.263158e+06 Correct predictions: 32/40 = 0.8          FMR: 0.0         FNMR: 0.2
 1.052632e+07 Correct predictions: 33/40 = 0.825                FMR: 0.0         FNMI
 1.578947e+07 Correct predictions: 30/40 = 0.75         FMR: 0.1         FNMR: 0.15
 2.105263e+07 Correct predictions: 30/40 = 0.75         FMR: 0.125       FNMR: 0.125
 2.631579e+07 Correct predictions: 32/40 = 0.8          FMR: 0.175       FNMR: 0.025
 3.157895e+07 Correct predictions: 32/40 = 0.8          FMR: 0.175       FNMR: 0.025
 3.684211e+07 Correct predictions: 31/40 = 0.775                FMR: 0.2         FNMI
 4.210526e+07 Correct predictions: 29/40 = 0.725                FMR: 0.275       FNMI
 4.736842e+07 Correct predictions: 26/40 = 0.65         FMR: 0.35        FNMR: 0.0
 5.263158e+07 Correct predictions: 25/40 = 0.625                FMR: 0.375       FNMI
 5.789474e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 6.315789e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 6.842105e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 7.368421e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 7.894737e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 8.421053e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 8.947368e+07 Correct predictions: 22/40 = 0.55         FMR: 0.45        FNMR: 0.0
 9.473684e+07 Correct predictions: 21/40 = 0.525                FMR: 0.475       FNMI
 1.000000e+08 Correct predictions: 21/40 = 0.525                FMR: 0.475       FNMI
```

```
x1=t0_list
y1=FMR_list

x2=t0_list
y2=FNMR_list

x3=t0_list
y3=CPR_list
```

```
plt.plot(x1,y1, ls='--', color='r', label='FMR',)
plt.plot(x2,y2, ls='-.', color='b', label='FNMR')
plt.plot(x3,y3, color='g', label='Correct prediction using threshold')

plt.grid()
plt.legend()
```

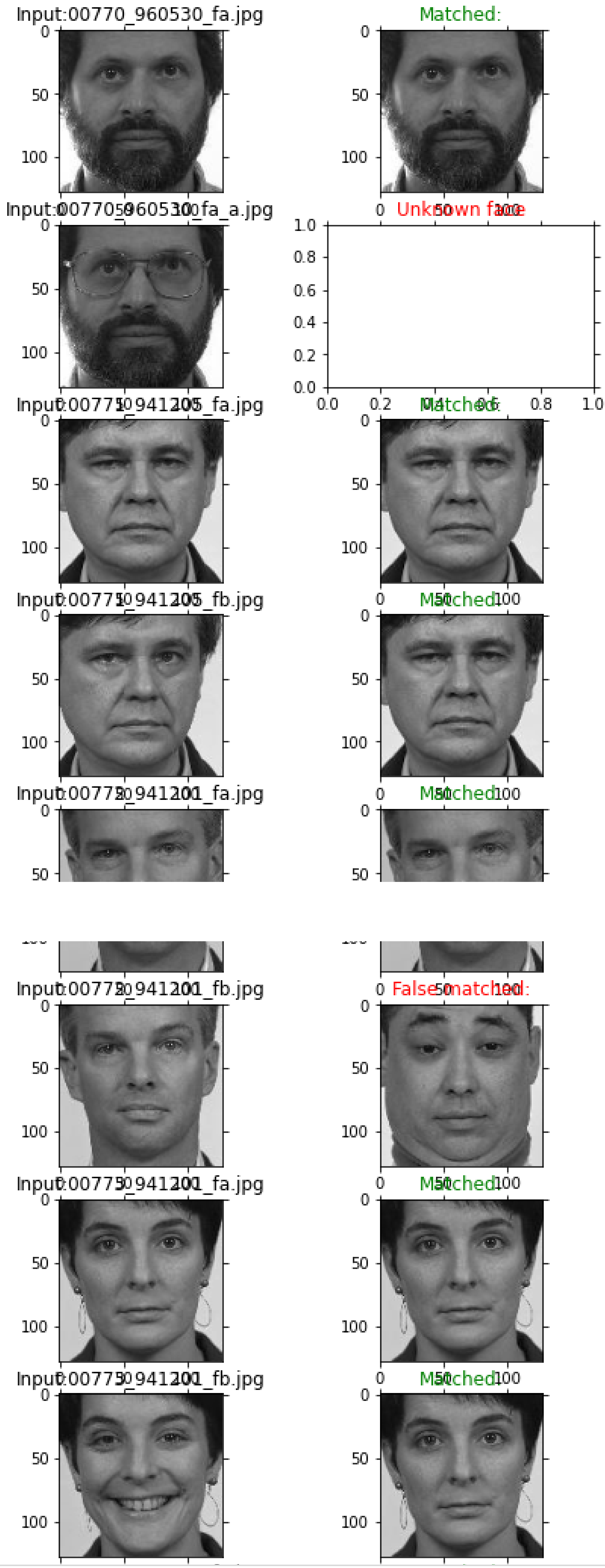
```
<matplotlib.legend.Legend at 0x7f2ba40e5c10>
```



Visualization of prediction result on all test images

```
count       = 0
num_images  = 0
correct_pred = 0
def Visualization(img, train_image_names,proj_data,w, t0):
    global count,highest_min,num_images,correct_pred
    unknown_face        = plt.imread(os.path.join(TEST_IMG_FOLDER, img))
    num_images          += 1
    unknown_face_vector = np.array(unknown_face, dtype='float64').flatten()
    normalised_uface_vector = np.subtract(unknown_face_vector,mean_face)

    plt.subplot(40,2,1+count)
    plt.imshow(unknown_face, cmap='gray')
    plt.title('Input:'+'.'.join(img.split('.')[:2]))
    plt.tick_params(labelleft='off', labelbottom='off', bottom='off',top='off',right='off'
    count+=1

    w_unknown = np.dot(proj_data, normalised_uface_vector)
    diff  = w - w_unknown
    norms = np.linalg.norm(diff, axis=1)
    index = np.argmin(norms)



    plt.subplot(40,2,1+count)
    if norms[index] < t0: # It's a face
```

```
        match = img.split('_')[0] == train_image_names[index].split('_')[0]
        #if img.split('.')[0] == train_image_names[index].split('.')[0]:
        if match:
            #plt.title('Matched:'+'.'.join(train_image_names[index].split('.')[:2]), color
            plt.title('Matched:', color='g')
            plt.imshow(imread(os.path.join(TRAIN_IMG_FOLDER, train_image_names[index])), c
             #img = plt.imread(os.path.join(TRAIN_IMG_FOLDER, train_image_names[i]))
            correct_pred += 1
        else:
            #plt.title('Matched:'+'.'.join(train_image_names[index].split('.')[:2]), color
            plt.title('False matched:', color='r')
            plt.imshow(imread(os.path.join(TRAIN_IMG_FOLDER, train_image_names[index])), c
    else:
        #if img.split('.')[0] not in [i.split('.')[0] for i in train_image_names] and img.
        if img.split('_')[0] not in [i.split('_')[0] for i in train_image_names]:
            plt.title('Unknown face', color='g')
            correct_pred += 1
        else:
            plt.title('Unknown face', color='r')

    plt.tick_params(labelleft='off', labelbottom='off', bottom='off',top='off',right='off'
    plt.subplots_adjust(right=1.2, top=2.5)

    count+=1


fig = plt.figure(figsize=(5, 30))

test_image_names2 = sorted(test_image_names)
for i in range(len(test_image_names2)):
    Visualization(test_image_names2[i], train_image_names,proj_data,w, t0=2.7e7)

plt.show()
```


Input:00770_960530_fa.jpg
Matched:
Input:00770_960530_fa_a.jpg
Unknown face
Input:00771_941205_fa.jpg
Matched:
Input:00771_941205_fb.jpg
Matched:
Input:00772_941201_fa.jpg
Matched:
Input:00772_941201_fb.jpg
False matched:
Input:00773_941201_fa.jpg
Matched:
Input:00773_941201_fb.jpg
Matched: