In [1]:

```
import pandas as pd
import itertools
from sklearn.metrics import confusion_matrix
from tqdm import tqdm
tqdm.pandas()
```

Summary

The Deepface framework we used in our study also uses the OpenCv library during the face detection phase. In the process of recognition and vector expression of the face, it uses deep learning-based facial recognition models (Serengil &Özpinar, 2020). Face recognition models are regular convolutional neural networks models. They represent face photos as vectors. We find the distance between these two vectors to compare two faces. Finally, we classify two faces as same person whose distance is less than a threshold value(Serengil, 2020b).

Using the Google Facenet facial recognition model and the euclidean_l2 metric, we will calculate the threshold values in the Black Woman Data set.

For the original notebook, see: [https://github.com/serengil/deepface/blob/master/tests/Fine-Tuning-Threshold.ipynb (https://github.com/serengil/deepface/blob/master/tests/Fine-Tuning-Threshold.ipynb)](https://github.com/serengil/deepface/blob/master/tests/Fine-Tuning-Threshold.ipynb)

Data set

In [2]:

```
idendities = {
    "Laura Harrier": ["img1.jpg", "img2.jpg", "img3.jpg", "img4.jpg"],
    "Zendaya": ["img5.jpg", "img6.jpg", "img7.jpg", "img8.jpg"],
    "Oprah Winfrey": ["img9.jpg", "img10.jpg", "img11.jpg", "img12.jpg"],
    "Zoe Saldana": ["img13.jpg", "img14.jpg", "img15.jpg", "img16.jpg"],
    "Halle Berry":["img17.jpg", "img18.jpg", "img19.jpg", "img20.jpg"],
    "Viola Davis": ["img21.jpg", "img22.jpg", "img23.jpg", "img24.jpg"],
    "Octavia Spencer": ["img25.jpg", "img26.jpg", "img27.jpg", "img28.jpg"],
    "Rihanna": ["img29.jpg", "img30.jpg", "img31.jpg", "img32.jpg"],
    "Javicia Leslie": ["img33.jpg", "img34.jpg", "img35.jpg", "img36.jpg"],
    "Lashana lynch": ["img37.jpg", "img38.jpg", "img39.jpg", "img40.jpg"],
    "Tessa Thompson": ["img41.jpg", "img42.jpg", "img43.jpg", "img44.jpg"],
    "Damaris Lewis": ["img45.jpg", "img46.jpg", "img47.jpg", "img48.jpg"]
}
```

Positive samples

Find different photos of same people

In [3]:

```
positives = []

for key, values in idendities.items():

    #print(key)
    for i in range(0, len(values)-1):
        for j in range(i+1, len(values)):
            #print(values[i], " and ", values[j])
            positive = []
            positive.append(values[i])
            positive.append(values[j])
            positives.append(positive)
```

In [4]:

```
positives = pd.DataFrame(positives, columns = ["file_x", "file_y"])
positives["decision"] = "Yes"
```

Negative samples

Compare photos of different people

In [5]:

```
samples_list = list(idendities.values())
```

In [6]:

```
negatives = []

for i in range(0, len(idendities) - 1):
    for j in range(i+1, len(idendities)):
        #print(samples_list[i], " vs ",samples_list[j])
        cross_product = itertools.product(samples_list[i], samples_list[j])
        cross_product = list(cross_product)
        #print(cross_product)

        for cross_sample in cross_product:
            #print(cross_sample[0], " vs ", cross_sample[1])
            negative = []
            negative.append(cross_sample[0])
            negative.append(cross_sample[1])
            negatives.append(negative)
```

In [7]:

```
negatives = pd.DataFrame(negatives, columns = ["file_x", "file_y"])
negatives["decision"] = "No"
```

Merge Positives and Negative Samples

In [8]:

```
df = pd.concat([positives, negatives]).reset_index(drop = True)
```

In [9]:

```
df.shape
```

Out[9]:

```
(1128, 3)
```

In [10]:

```
df.decision.value_counts()
```

Out[10]:

```
No     1056
Yes      72
Name: decision, dtype: int64
```

In [11]:

```
df.file_x = "black_woman_dataset/"+df.file_x
df.file_y = "black_woman_dataset/"+df.file_y
```

DeepFace

In [12]:

```
from deepface import DeepFace
```

In [13]:

```
instances = df[["file_x", "file_y"]].values.tolist()
```

In [14]:

```
model_name = "Facenet"
distance_metric = "euclidean_l2"
```

In [15]:

```
resp_obj = DeepFace.verify(instances, model_name = model_name, distance_metric = distance_m
```

```
Verification: 100%|████████████████████████████████████████████████████████
███████| 1128/1128 [16:18<00:00,  1.15it/s]
```

In [16]:

```
distances = []
for i in range(0, len(instances)):
    distance = round(resp_obj["pair_%s" % (i+1)]["distance"], 4)
    distances.append(distance)
```

In [17]:

```
df["distance"] = distances
```

Analyzing Distances

In [18]:

```
tp_mean = round(df[df.decision == "Yes"].mean().values[0], 4)
tp_std = round(df[df.decision == "Yes"].std().values[0], 4)
fp_mean = round(df[df.decision == "No"].mean().values[0], 4)
fp_std = round(df[df.decision == "No"].std().values[0], 4)
```

In [19]:

```
print("Mean of true positives: ", tp_mean)
print("Std of true positives: ", tp_std)
print("Mean of false positives: ", fp_mean)
print("Std of false positives: ", fp_std)
```

```
Mean of true positives:  0.6087
Std of true positives:  0.1262
Mean of false positives:  1.221
Std of false positives:  0.1335
```

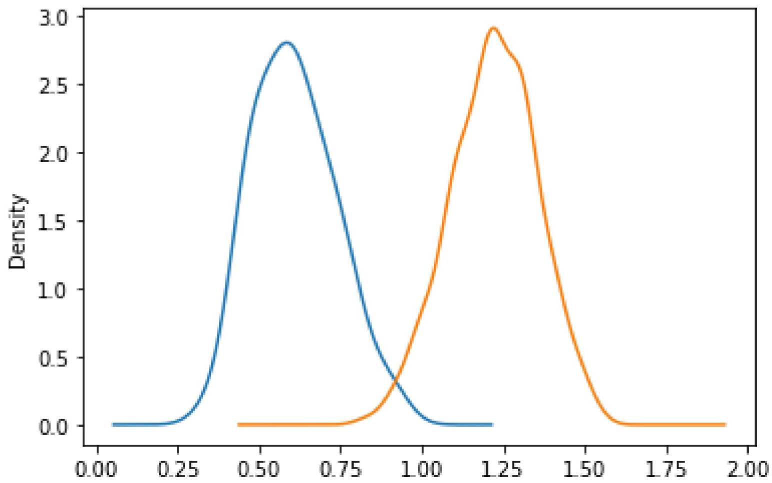
Distribution

In [20]:

```
df[df.decision == "Yes"].distance.plot.kde()
df[df.decision == "No"].distance.plot.kde()
```

Out[20]:

```
<AxesSubplot:ylabel='Density'>
```



Sigma

In [167]:

```
sigma = 1
#2 sigma corresponds 95.45% confidence, and 3 sigma corresponds 99.73% confidence

#threshold = round(tp_mean + sigma * tp_std, 4)
threshold = 0.955 #comes from c4.5 algorithm
print("threshold: ", threshold)
```

```
threshold:  0.955
```

In [168]:

```
df[df.decision == 'Yes'].distance.max()
```

Out[168]:

```
0.924
```

In [169]:

```
df[df.decision == 'No'].distance.min()
```

Out[169]:

```
0.8116
```

Evaluation

In [170]:

```
df["prediction"] = "No"
```

In [171]:

```
idx = df[df.distance <= threshold].index
df.loc[idx, 'prediction'] = 'Yes'
```

In [172]:

```
df.head(5)
```

Out[172]:

	file_x	file_y	decision	distance	prediction
0	black_woman_dataset/img1.jpg	black_woman_dataset/img2.jpg	Yes	0.5013	Yes
1	black_woman_dataset/img1.jpg	black_woman_dataset/img3.jpg	Yes	0.4271	Yes
2	black_woman_dataset/img1.jpg	black_woman_dataset/img4.jpg	Yes	0.4808	Yes
3	black_woman_dataset/img2.jpg	black_woman_dataset/img3.jpg	Yes	0.5103	Yes
4	black_woman_dataset/img2.jpg	black_woman_dataset/img4.jpg	Yes	0.4825	Yes

In [173]:

```python
cm = confusion_matrix(df.decision.values, df.prediction.values)
```

In [174]:

```python
cm
```

Out[174]:

```
array([[1029,   27],
       [   0,   72]], dtype=int64)
```

In [175]:

```python
tn, fp, fn, tp = cm.ravel()
```

In [176]:

```python
tn, fp, fn, tp
```

Out[176]:

```
(1029, 27, 0, 72)
```

In [177]:

```python
recall = tp / (tp + fn)
precision = tp / (tp + fp)
accuracy = (tp + tn)/(tn + fp +  fn + tp)
f1 = 2 * (precision * recall) / (precision + recall)
```

In [178]:

```python
print("Precision: ", 100*precision,"%")
print("Recall: ", 100*recall,"%")
print("F1 score ",100*f1, "%")
print("Accuracy: ", 100*accuracy,"%")
```

```
Precision:  72.72727272727273 %
Recall:  100.0 %
F1 score  84.21052631578948 %
Accuracy:  97.6063829787234 %
```

In [80]:

```python
df.to_csv("threshold_pivot_bw_Facenet.csv", index = False)
```

Test results

Threshold = 0.68

Precision: 100.0 %
Recall: 72.22 %
F1 score 83.87 %
Accuracy: 98.22 %

Threshold = 0.7349 (1 sigma)

```
Precision:  100.0 %
Recall:  83.33 %
F1 score  90.90 %
Accuracy:  98.93 %
```

Threshold = 0.8611 (2 sigma)

```
Precision:  94.52 %
Recall:  95.83 %
F1 score  95.17 %
Accuracy:  99.37 %
```

Threshold = 0.955

```
Precision:  72.72727272727273 %
Recall:  100.0 %
F1 score  84.21052631578948 %
Accuracy:  97.6063829787234 %
```

Threshold = 0.9873 (3 sigma)

```
Precision:  58.53%
Recall:  100.0 %
F1 score  73.84 %
Accuracy:  95.47 %
```

Threshold = 1.16

```
Precision:  17.69 %
Recall:  100.0 %
F1 score  30.06 %
Accuracy:  70.30 %
```

In [ ]:

```

```