

Haar

January 14, 2020

```
In [5]: import os
import cv2
from time import time
import numpy as np
import matplotlib.pyplot as plt
from glob import glob
import random
from dask import delayed

In [6]: from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_split
from sklearn.metrics import roc_auc_score
from sklearn.linear_model import LogisticRegression

In [7]: from skimage.transform import integral_image
from skimage.feature import haar_like_feature
from skimage.feature import haar_like_feature_coord
from skimage.feature import draw_haar_like_feature

In [314]: from logistic import logistic_fit, logistic, logistic_prob

In [8]: import dill

In [290]: t_start = time()
dill.load_session('01_05_env.db')
time() - t_start

Out[290]: 466251.879352808

In [234]: np.savetxt("X_haar.csv", Xt, delimiter=",")
```

1 Helper Methods

```
In [115]: def proportion_b(facenames, n):
count = 0
for i in range(n):
    if int(facenames[i].split('_')[3]) == 0:
        count += 1
return count / n
```

```

In [14]: @delayed
def extract_feature_image(img, feature_type, feature_coord=None):
    """Extract the haar feature for the current image"""
    img = cv2.resize(img, (36,36))
    ii = integral_image(img)
    return haar_like_feature(ii, 0, 0, ii.shape[0], ii.shape[1],
                             feature_type=feature_type,
                             feature_coord=feature_coord)

In [116]: for f in [face_filenames0, face_filenames25, face_filenames50, face_filenames75, face_filenames100]:
    print(proportion_b(f, n))

1.0
0.7502487562189055
0.5
0.24975124378109453
0.0

In [307]: def getimgs(facefiles, nonfaces, n):
    faces = []
    for i in range(n):
        faces.append(cv2.imread(facefiles[i], cv2.IMREAD_GRAYSCALE))
    return faces + nonfaces[:n]

In [71]: def getx(facefiles, n):
    ims = getimgs(facefiles, n)
    X = delayed(extract_feature_image(img, feature_types) for img in ims)
    return np.array(X.compute(scheduler='threads'))

In [306]: def getx2(facefiles, n, nonfaces, feature_types, feature_coors):
    ims = getimgs(facefiles, nonfaces, n)
    X = delayed(extract_feature_image(img, feature_types, feature_coors) for img in ims)
    return np.array(X.compute(scheduler='threads'))

In [319]: n, len(nonfaces)

Out[319]: (4020, 300)

```

2 Feature selection

```

In [9]: test_face_names = sorted(glob(os.path.join('data/tests', '*.jpg')))
    n_test = len(test_face_names)

In [10]: b_inds = []
    w_inds = []
    for i in range(len(test_face_names)):
        if int(test_face_names[i].split('_')[2]) is 0: # race is white
            w_inds.append(i)
        else:
            b_inds.append(i)

```

```

In [11]: test_nonface_names = sorted(glob(os.path.join('data/testing_nonfaces', '*.jpg')))
        n_nonfaces_test = len(test_nonface_names)

In [12]: faces_t = []
        for i in range(n_test):
            faces_t.append(cv2.imread(test_face_names[i], cv2.IMREAD_GRAYSCALE))

In [13]: nonfaces_t = []
        for i in range(n_test):
            # Read a random nonface file
            j = random.randint(0, n_nonfaces_test - 1)
            nonface = cv2.imread(test_nonface_names[j], cv2.IMREAD_GRAYSCALE)

            wsize = random.randint(36, min(nonface.shape[0], nonface.shape[1]))
            row = random.randint(0, nonface.shape[0]-wsize)
            col = random.randint(0, nonface.shape[1]-wsize)
            crop = nonface[row:row+wsize, col:col+wsize]

            # Resize to be the right size
            crop = cv2.resize(crop, (200, 200))
            nonfaces_t.append(crop)

In [14]: images_t = faces_t + nonfaces_t
        len(images_t)

Out[14]: 600

In [11]: feature_types = ['type-2-x', 'type-2-y', 'type-3-x', 'type-3-y']

In [16]: t_start = time()
        Xf_t = delayed(extract_feature_image(img, feature_types) for img in images_t)
        Xf_t = np.array(Xf_t.compute(scheduler='threads'))
        time() - t_start

Out[16]: 11501.80655002594

In [295]: Xf_t = X

In [296]: yf_t = np.array([1]*len(faces_t) + [0]*len(nonfaces_t))

In [297]: # Train a random forest classifier and assess its performance
        clf = RandomForestClassifier(n_estimators=1000, max_depth=None,
                                    n_jobs=-1, random_state=0)

        t_start = time()
        clf.fit(Xf_t, yf_t)
        time() - t_start

Out[297]: 48.40756678581238

```

```

In [298]: feature_coord, feature_type = \
           haar_like_feature_coord(width=36, height=36,
                                   feature_type=feature_types)

In [299]: idx_sorted = np.argsort(clf.feature_importances_)[::-1]

In [300]: for i in range(1500):
           if len(feature_coord[idx_sorted[i]]) > 2:
               print(i)

In [301]: fig, axes = plt.subplots(4,4, figsize=(20,20))
           for idx, ax in enumerate(axes.ravel()):
               image = cv2.resize(images_t[0], (36,36))
               image = draw_haar_like_feature(image, 0, 0, 36, 36,
                                               [feature_coord[idx_sorted[idx]]])

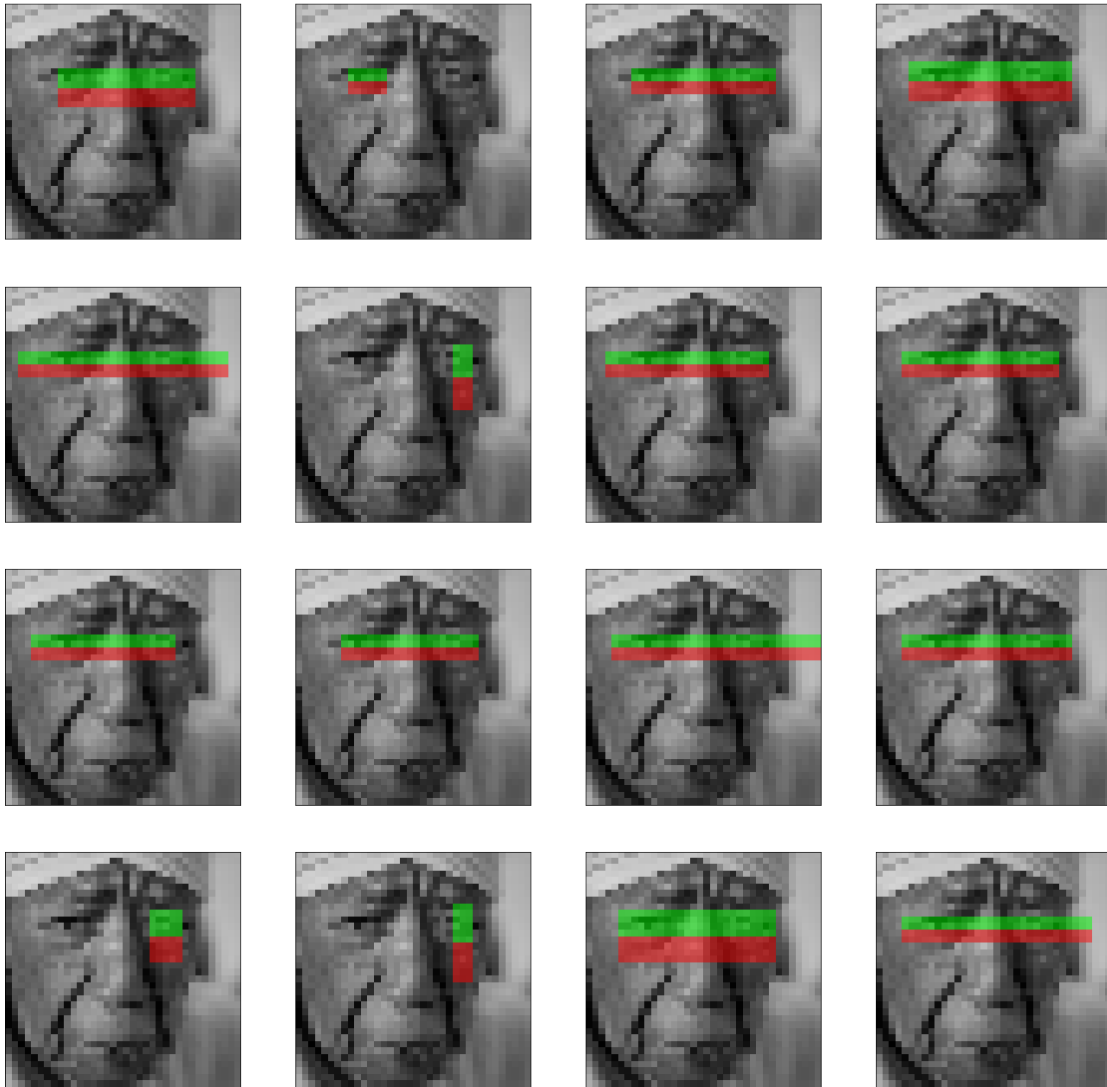
               ax.imshow(image)
               ax.set_xticks([])
               ax.set_yticks([])

           fig.suptitle('The most important features')

Out[301]: Text(0.5, 0.98, 'The most important features')

```

The most important features

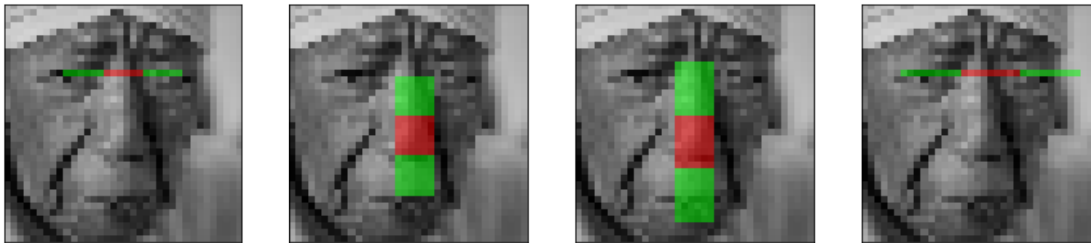


```
In [142]: fig, axes = plt.subplots(1,4, figsize=(12,4))
          idxs = [1250,1325,1341,1403,1448]
          for idx, ax in enumerate(axes.ravel()):
              image = cv2.resize(images_t[0], (36,36))
              image = draw_haar_like_feature(image, 0, 0, 36, 36,
                                             [feature_coord[idx_sorted[idxs[idx]]]])
              ax.imshow(image)
              ax.set_xticks([])
              ax.set_yticks([])
```

```
fig.suptitle('The most important features')
```

```
Out[142]: Text(0.5, 0.98, 'The most important features')
```

The most important features

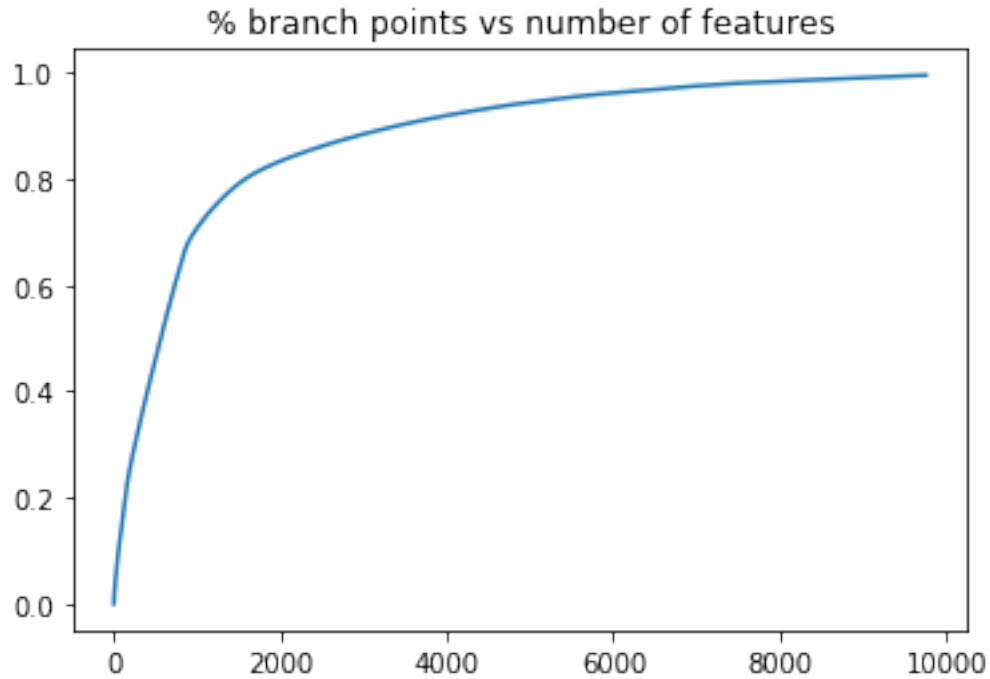


```
In [143]: cdf_feature_importances = np.cumsum(clf.feature_importances_[idx_sorted])
cdf_feature_importances /= np.max(cdf_feature_importances)
sig_feature_count = np.count_nonzero(cdf_feature_importances < 0.7)
sig_feature_percent = round(sig_feature_count /
                             len(cdf_feature_importances) * 100, 1)
print('{} features, or {}%, account for 70% of branch points in the '
      'random forest.'.format(sig_feature_count, sig_feature_percent))
```

967 features, or 0.1%, account for 70% of branch points in the random forest.

```
In [48]: ys = [i/200 for i in range(0,200)]
xs = []
for i in range(len(ys)):
    sig_feature_count = np.count_nonzero(cdf_feature_importances < ys[i])
    xs.append(sig_feature_count)
```

```
In [51]: plt.plot(xs, ys)
plt.title("% branch points vs number of features")
plt.show()
```



```
In [56]: np.count_nonzero(cdf_feature_importances < .82)
```

```
Out[56]: 1807
```

```
In [57]: n_features = 1800
```

```
In [58]: feature_coord_sel = feature_coord[idx_sorted[:n_features]]
         feature_type_sel = feature_type[idx_sorted[:n_features]]
```

```
In [303]: n_features2 = 900
```

```
In [304]: feature_coord_sel2 = feature_coord[idx_sorted[:n_features2]]
         feature_type_sel2 = feature_type[idx_sorted[:n_features2]]
```

```
In [308]: Xt_900 = getx2(test_face_names, 300, nonfaces_t, feature_type_sel2, feature_coord_sel2)
```

3 Getting data

```
In [15]: face_filenames0 = sorted(glob(os.path.join('data/train_0', '*.jpg')))
         num_face_filenames0 = len(face_filenames0)
         num_face_filenames0
```

```
Out[15]: 4020
```

```
In [16]: face_filenames25 = sorted(glob(os.path.join('data/train_25', '*.jpg')))
         num_face_filenames25 = len(face_filenames25)
         num_face_filenames25
```

Out[16]: 4020

```
In [17]: face_filenames50 = sorted(glob(os.path.join('data/train_50', '*.jpg')))
num_face_filenames50 = len(face_filenames50)
num_face_filenames50
```

Out[17]: 4020

```
In [18]: face_filenames75 = sorted(glob(os.path.join('data/train_75', '*.jpg')))
num_face_filenames75 = len(face_filenames75)
num_face_filenames75
```

Out[18]: 4020

```
In [19]: face_filenames100 = sorted(glob(os.path.join('data/train_100', '*.jpg')))
num_face_filenames100 = len(face_filenames100)
num_face_filenames100
```

Out[19]: 4020

```
In [33]: count = 0
for f in face_filenames0:
    if int(f.split('_')[3]) is 0: # race is white
        count += 1
count
```

Out[33]: 4020

```
In [20]: nonface_filenames = sorted(glob(os.path.join('data/training_nonfaces', '*.jpg')))
num_nonface_filenames = len(nonface_filenames)
num_nonface_filenames
```

Out[20]: 250

4 Classification

```
In [341]: def getacc(predicted, actual):
    preds = []
    for p in predicted:
        if p >= 0.5:
            preds.append(1)
        else:
            preds.append(0)
    return 1 - sum(abs(preds-actual))/len(preds)
```

```
In [340]: def getscore(X, y, params):
    predicted = logistic_prob(X, params)
    return getacc(predicted, y)
```

```
In [69]: n = 4020
```



```

In [320]: nonfaces = []
          for i in range(n):
              # Read a random nonface file
              j = random.randint(0, len(nonface_filenames) - 1)
              nonface = cv2.imread(nonface_filenames[j], cv2.IMREAD_GRAYSCALE)
              wsize = random.randint(36, min(nonface.shape[0], nonface.shape[1]))
              row = random.randint(0, nonface.shape[0]-wsize)
              col = random.randint(0, nonface.shape[1]-wsize)
              crop = nonface[row:row+wsize, col:col+wsize]

              # Resize to be the right size
              crop = cv2.resize(crop, (200, 200))
              nonfaces.append(crop)

In [323]: t_start = time()
          X0 = getx2(face_filenames0, n, nonfaces, feature_type_sel2, feature_coord_sel2)
          time() - t_start

Out[323]: 11.758322954177856

In [324]: X0.shape

Out[324]: (8040, 900)

In [325]: y = np.array([1]*n + [0]*n)

In [308]: X0 = getx2(face_filenames0, n, nonfaces, feature_type_sel2, feature_coord_sel2)
          X25 = getx2(face_filenames25, n, nonfaces, feature_type_sel2, feature_coord_sel2)
          X50 = getx2(face_filenames50, n, nonfaces, feature_type_sel2, feature_coord_sel2)
          X75 = getx2(face_filenames75, n, nonfaces, feature_type_sel2, feature_coord_sel2)
          X100 = getx2(face_filenames100, n, nonfaces, feature_type_sel2, feature_coord_sel2)
          Xt = getx2(face_filenames0, 300, nonfaces_t, feature_type_sel2, feature_coord_sel2)

In [311]: n = 4020

In [331]: n, y.shape

Out[331]: (4020, (8040,))

In [345]: def pipeline2(f, times):
          def getx3(facefiles, n, nonfaces, feature_types, feature_coords):
              ims = [f(i) for i in getimgs(facefiles, nonfaces, n)]
              X = delayed(extract_feature_image(img, feature_types, feature_coords) for img in ims)
              return np.array(X.compute(scheduler='threads'))

          t_start = time()

          os_rs = []
          bs_rs = []

```

```

ws_rs = []
for i in range(times):
    nonfaces, nonfaces_t = regenerate_nonfaces()

    X0 = getx3(face_filenames0, n, nonfaces, feature_type_sel2, feature_coord_sel2)
    print(X0.shape)
    X25 = getx3(face_filenames25, n, nonfaces, feature_type_sel2, feature_coord_sel2)
    print(X25.shape)
    X50 = getx3(face_filenames50, n, nonfaces, feature_type_sel2, feature_coord_sel2)
    print(X50.shape)
    X75 = getx3(face_filenames75, n, nonfaces, feature_type_sel2, feature_coord_sel2)
    print(X75.shape)
    X100 = getx3(face_filenames100, n, nonfaces, feature_type_sel2, feature_coord_sel2)
    print(X100.shape)
    Xt = getx3(test_face_names, 300, nonfaces_t, feature_type_sel2, feature_coord_sel2)
    print(Xt.shape)

    params0 = logistic_fit(X0, y, 0.005)
    predicted = logistic_prob(Xt, params0)
    print(getacc(predicted, y_t))
    params25 = logistic_fit(X25, y, 0.005)
    predicted = logistic_prob(Xt, params25)
    print(getacc(predicted, y_t))
    params50 = logistic_fit(X50, y, 0.005)
    predicted = logistic_prob(Xt, params50)
    print(getacc(predicted, y_t))
    params75 = logistic_fit(X75, y, 0.005)
    predicted = logistic_prob(Xt, params75)
    print(getacc(predicted, y_t))
    params100 = logistic_fit(X100, y, 0.005)
    predicted = logistic_prob(Xt, params100)
    print(getacc(predicted, y_t))

    os_r, bs_r, ws_r = logscores([params0, params25, params50, params75, params100])
    os_rs.append(os_r)
    bs_rs.append(bs_r)
    ws_rs.append(ws_r)

plt.plot([0, 25, 50, 75, 100], os_r, label="o")
plt.plot([0, 25, 50, 75, 100], bs_r, label="b")
plt.plot([0, 25, 50, 75, 100], ws_r, label="w")
plt.legend()
plt.show()

print(time()-t_start)
return os_rs, bs_rs, ws_rs

```

```
In [346]: os_l, bs_l, ws_l = pipeline2(lambda x: x, 10)
```

```
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.7766666666666666
0.7916666666666666
0.79
0.785
0.7783333333333333
0
overall: 0.7766666666666666
black: 0.9666666666666667
white: 1.0
25
overall: 0.7916666666666666
black: 0.9933333333333333
white: 1.0
50
overall: 0.79
black: 0.9933333333333333
white: 1.0
75
overall: 0.785
black: 1.0
white: 1.0
100
overall: 0.7783333333333333
black: 0.9933333333333333
white: 1.0
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.825
0.8166666666666667
0.8083333333333333
0.81
0.815
0
overall: 0.825
black: 0.98
white: 1.0
```

25
overall: 0.816666666666667
black: 0.9933333333333333
white: 1.0
50
overall: 0.8083333333333333
black: 0.9933333333333333
white: 1.0
75
overall: 0.81
black: 0.9933333333333333
white: 1.0
100
overall: 0.815
black: 0.9933333333333333
white: 1.0
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.816666666666667
0.81
0.8066666666666666
0.81
0.8083333333333333
0
overall: 0.816666666666667
black: 0.9933333333333333
white: 1.0
25
overall: 0.81
black: 1.0
white: 1.0
50
overall: 0.8066666666666666
black: 1.0
white: 1.0
75
overall: 0.81
black: 1.0
white: 0.9933333333333333
100
overall: 0.8083333333333333
black: 1.0
white: 1.0
(8040, 900)

```

(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.7983333333333333
0.8083333333333333
0.8316666666666667
0.8116666666666666
0.8083333333333333
0
overall: 0.7983333333333333
black: 0.96
white: 0.9933333333333333
25
overall: 0.8083333333333333
black: 0.9933333333333333
white: 0.9933333333333333
50
overall: 0.8316666666666667
black: 0.9866666666666667
white: 0.9933333333333333
75
overall: 0.8116666666666666
black: 0.9933333333333333
white: 0.9933333333333333
100
overall: 0.8083333333333333
black: 0.9933333333333333
white: 0.9866666666666667
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.7866666666666666
0.7883333333333333
0.7983333333333333
0.8033333333333333
0.7983333333333333
0
overall: 0.7866666666666666
black: 0.98
white: 0.9933333333333333
25
overall: 0.7883333333333333
black: 0.98

```

white: 1.0
50
overall: 0.7983333333333333
black: 1.0
white: 1.0
75
overall: 0.8033333333333333
black: 1.0
white: 1.0
100
overall: 0.7983333333333333
black: 1.0
white: 1.0
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.8
0.7883333333333333
0.795
0.7866666666666666
0.795
0
overall: 0.8
black: 0.9866666666666667
white: 1.0
25
overall: 0.7883333333333333
black: 0.9933333333333333
white: 1.0
50
overall: 0.795
black: 0.9933333333333333
white: 1.0
75
overall: 0.7866666666666666
black: 0.9933333333333333
white: 1.0
100
overall: 0.795
black: 0.9933333333333333
white: 1.0
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)

(8040, 900)
(600, 900)
0.8
0.7983333333333333
0.8166666666666667
0.795
0.7983333333333333
0
overall: 0.8
black: 0.98
white: 1.0
25
overall: 0.7983333333333333
black: 0.9866666666666667
white: 1.0
50
overall: 0.8166666666666667
black: 0.9933333333333333
white: 1.0
75
overall: 0.795
black: 0.9866666666666667
white: 1.0
100
overall: 0.7983333333333333
black: 0.9866666666666667
white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.775
0.7766666666666666
0.7833333333333333
0.7833333333333333
0.7933333333333333
0
overall: 0.775
black: 0.9666666666666667
white: 0.98
25
overall: 0.7766666666666666
black: 0.9666666666666667
white: 0.9933333333333333
50
overall: 0.7833333333333333

```

black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.7833333333333333
black: 0.98
white: 0.9933333333333333
100
overall: 0.7933333333333333
black: 0.98
white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.8083333333333333
0.8
0.8083333333333333
0.815
0.8083333333333333
0
overall: 0.8083333333333333
black: 1.0
white: 0.9933333333333333
25
overall: 0.8
black: 1.0
white: 0.9933333333333333
50
overall: 0.8083333333333333
black: 1.0
white: 1.0
75
overall: 0.815
black: 1.0
white: 0.9933333333333333
100
overall: 0.8083333333333333
black: 1.0
white: 0.9866666666666667
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.775

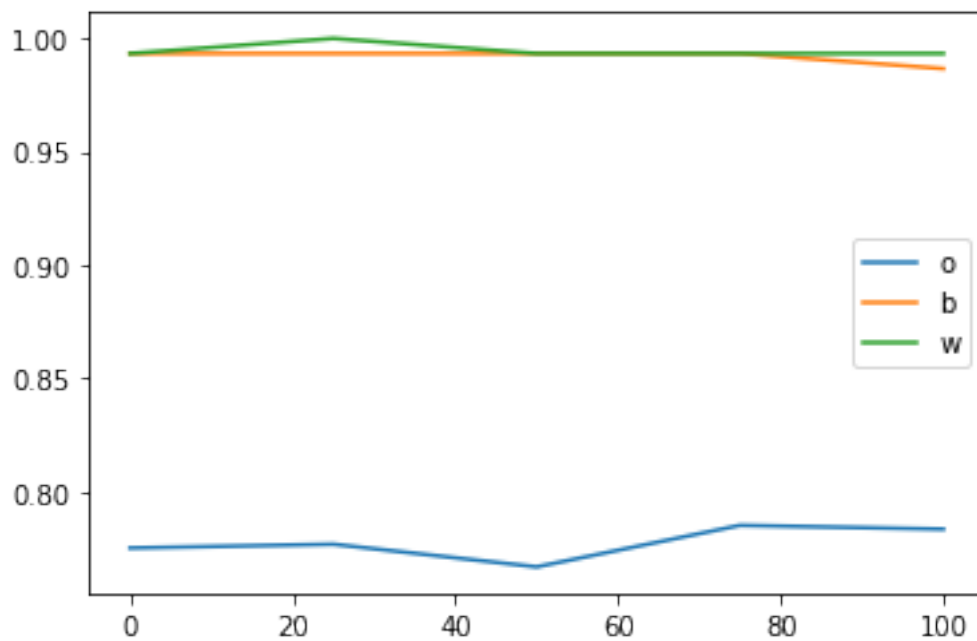
```



```

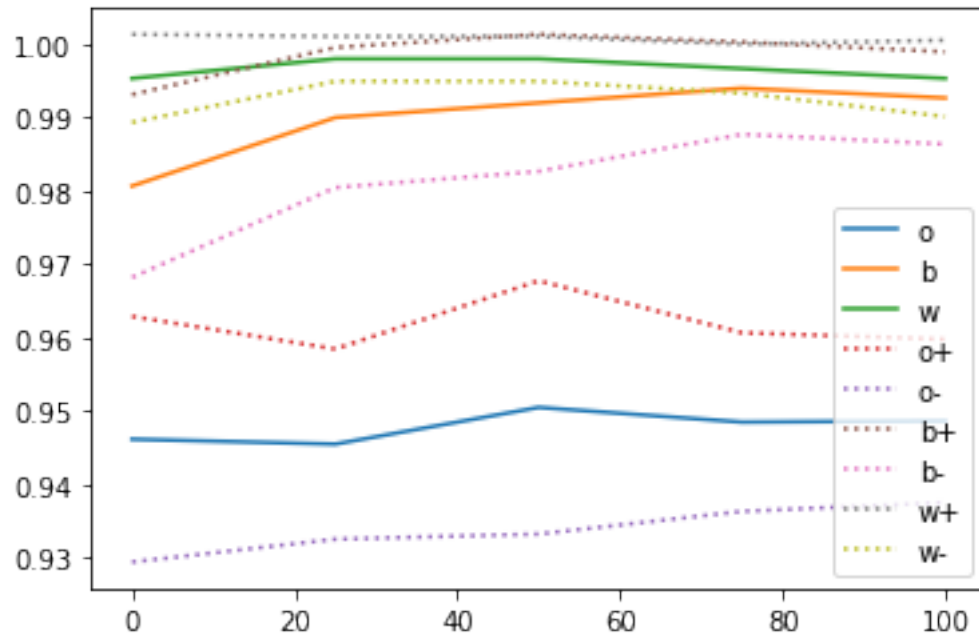
0.7766666666666666
0.7666666666666666
0.785
0.7833333333333333
0
overall: 0.775
black: 0.9933333333333333
white: 0.9933333333333333
25
overall: 0.7766666666666666
black: 0.9933333333333333
white: 1.0
50
overall: 0.7666666666666666
black: 0.9933333333333333
white: 0.9933333333333333
75
overall: 0.785
black: 0.9933333333333333
white: 0.9933333333333333
100
overall: 0.7833333333333333
black: 0.9866666666666667
white: 0.9933333333333333

```



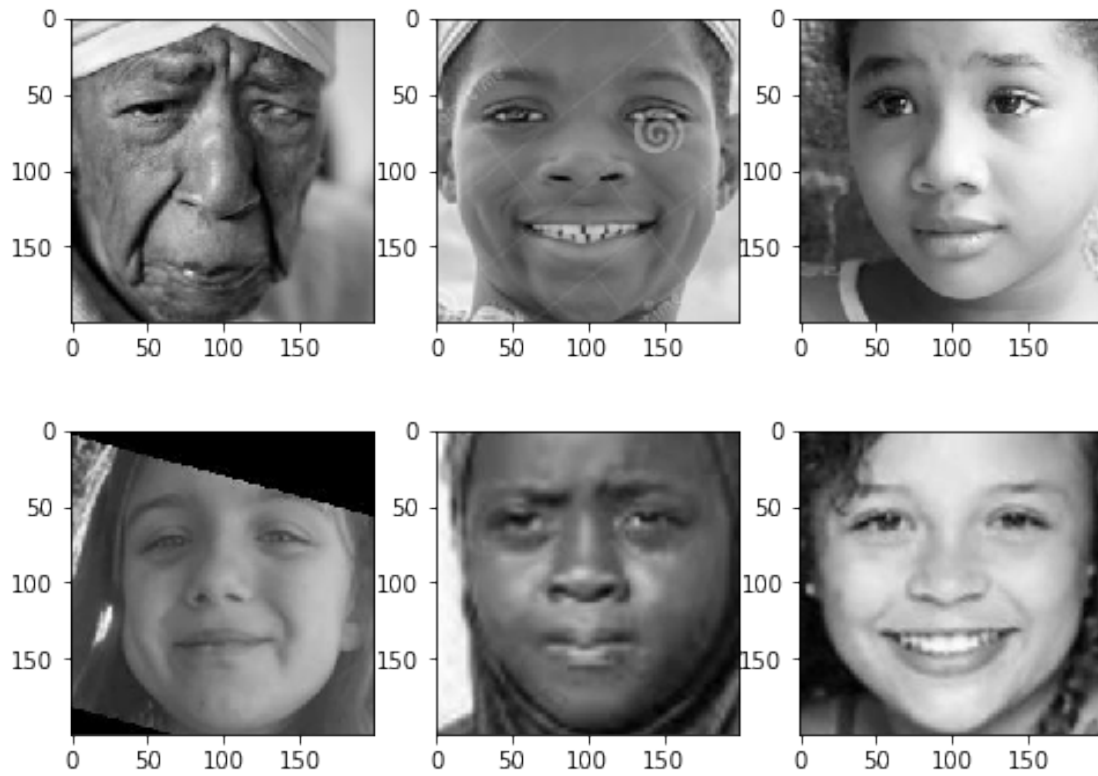
3658.2167851924896

```
In [365]: plots(np.array(os_1), bs_1, ws_1)
```

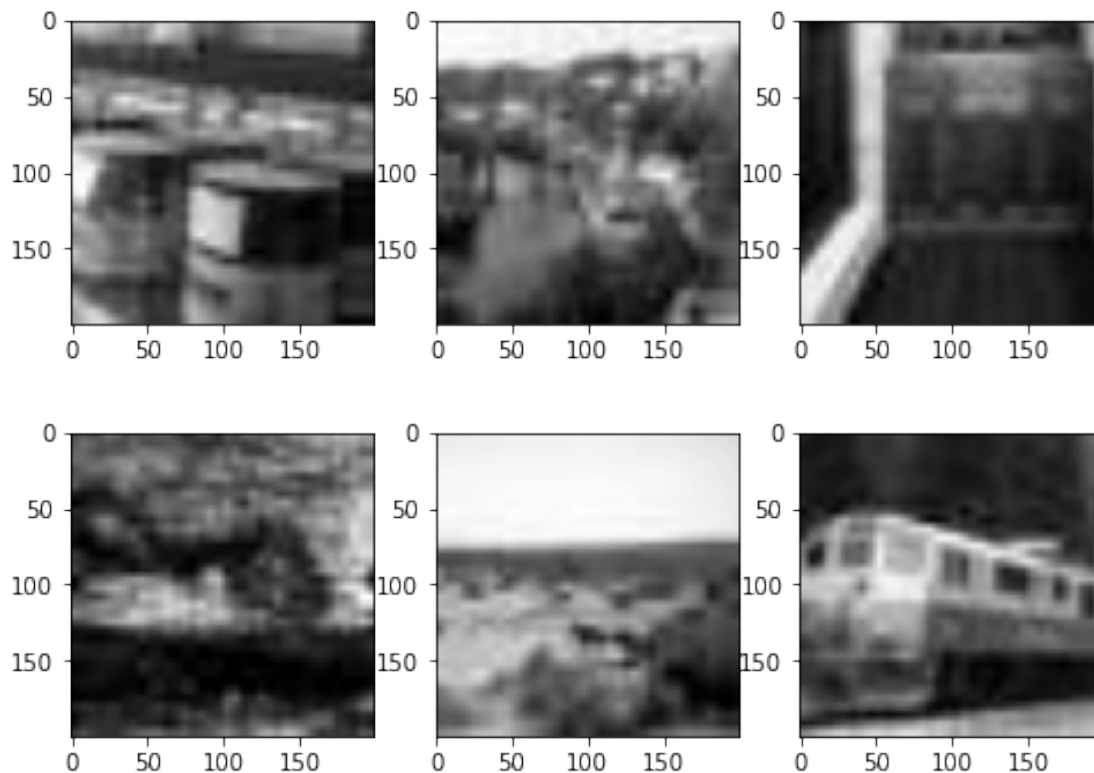


```
In [351]: yt = [1]*300 + [0]*300
```

```
In [355]: predictions = logistic_prob(Xt, params)
plt.subplots(2,3,figsize=(8,6))
count = 0
for i in range(300):
    if predictions[i] != yt[i]:
        count += 1
        if count < 7:
            plt.subplot(2,3,count)
            plt.imshow(cv2.imread(test_face_names[i], cv2.IMREAD_GRAYSCALE), cmap='g
```



```
In [362]: predictions = logistic_prob(Xt, params)
plt.subplots(2,3,figsize=(8,6))
count = 0
for i in range(300, 600):
    if predictions[i] != yt[i]:
        count += 1
    if count < 7:
        plt.subplot(2,3,count)
        plt.imshow(nonfaces_t[i-300], cmap='gray')
```



```
In [328]: Xt = getx2(test_face_names, 300, nonfaces_t, feature_type_sel2, feature_coord_sel2)
          print(Xt.shape)
```

```
(600, 900)
```

```
In [330]: Xt_900.shape
```

```
Out[330]: (600, 900)
```

4.0.1 0%

```
In [329]: t_start = time()
          params = logistic_fit(X0, y, 0.005)
          predicted = logistic_prob(Xt_900, params)
          print(time() - t_start)
          print(getacc(predicted, y_t))
```

```
64.03310108184814
0.8166666666666667
```

```
In [191]: t_start = time()
          rf0 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
          rf0.fit(X0, y)
          print(time() - t_start)
          print(rf0.score(Xt_900, y_t))
```

```
51.504207134246826
0.9733333333333334
```

```
In [330]: t_start = time()
          rf0_ = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
          rf0_.fit(X0, y)
          print(time() - t_start)
          print(rf0_.score(Xt_900, y_t))
```

```
28.579165935516357
0.9866666666666667
```

4.0.2 25%

```
In [419]: t_start = time()
          params25 = logistic_fit(X25, y, 0.005)
          predicted25 = logistic_prob(Xt_900, params25)
          print(time() - t_start)
          print(getacc(predicted25, y_t))
```

```
65.45319414138794
0.9883333333333333
```

```
In [193]: t_start = time()
          rf25 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
          rf25.fit(X25, y)
          print(time() - t_start)
          print(rf25.score(Xt_900, y_t))
```

```
54.29618191719055
0.9816666666666667
```

```
In [329]: t_start = time()
          rf25_ = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
          rf25_.fit(X25, y)
          print(time() - t_start)
          print(rf25_.score(Xt_900, y_t))
```

```
34.24504089355469
0.9966666666666667
```

4.0.3 50%

```
In [420]: t_start = time()
          params50 = logistic_fit(X50, y, 0.005)
          predicted50 = logistic_prob(Xt_900, params50)
          print(time() - t_start)
          print(getacc(predicted50, y_t))
```

66.63791012763977
0.9783333333333333

```
In [195]: t_start = time()
          rf50 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_s
          rf50.fit(X50, y)
          print(time() - t_start)
          print(rf50.score(Xt_900, y_t))
```

63.43332099914551
0.99

```
In [328]: t_start = time()
          rf50_ = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_s
          rf50_.fit(X50, y)
          print(time() - t_start)
          print(rf50_.score(Xt_900, y_t))
```

37.5260112285614
0.9966666666666667

4.0.4 75%

```
In [421]: t_start = time()
          params75 = logistic_fit(X75, y, 0.005)
          predicted75 = logistic_prob(Xt_900, params75)
          print(time() - t_start)
          print(getacc(predicted75, y_t))
```

60.54207682609558
0.985

```
In [197]: t_start = time()
          rf75 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_s
          rf75.fit(X75, y)
          print(time() - t_start)
          print(rf75.score(Xt_900, y_t))
```

```
63.48205590248108
0.9833333333333333
```

```
In [327]: t_start = time()
          rf75_ = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_
          rf75_.fit(X75, y)
          print(time() - t_start)
          print(rf75_.score(Xt_900, y_t))
```

```
35.21123290061951
0.9983333333333333
```

4.0.5 100%

```
In [422]: t_start = time()
          params100 = logistic_fit(X100, y, 0.005)
          predicted100 = logistic_prob(Xt_900, params100)
          print(time() - t_start)
          print(getacc(predicted100, y_t))
```

```
61.95895195007324
0.9833333333333333
```

```
In [199]: t_start = time()
          rf100 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_
          rf100.fit(X100, y)
          print(time() - t_start)
          print(rf100.score(Xt_900, y_t))
```

```
63.2666540145874
0.9816666666666667
```

```
In [326]: t_start = time()
          rf100_ = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_
          rf100_.fit(X100, y)
          print(time() - t_start)
          print(rf100_.score(Xt_900, y_t))
```

```
36.13964295387268
0.9966666666666667
```

4.0.6 Scores, separated by race

```
In [325]: # use b_inds and w_inds to select rows of X_t and y_t
          Xb_t = Xt_900[b_inds]
```

```

yb_t = y_t[b_inds]
Xw_t = Xt_900[w_inds]
yw_t = y_t[w_inds]
Xb_t.shape, Xb_t_1800.shape, yb_t.shape, Xw_t.shape, Xw_t_1800.shape, yw_t.shape

Out[325]: ((150, 900), (150, 1800), (150,)), (150, 900), (150, 1800), (150,))

In [240]: np.savetxt("b_inds.csv", np.array(b_inds), delimiter=",")

In [237]: np.savetxt("w_inds.csv", w_inds, delimiter=",")

In [209]: def rfcores(rfs, Xt, Xbt, Xwt):
    os = []
    bs = []
    ws = []
    for i in range(len(rfs)):
        print(i*25)
        o = rfs[i].score(Xt, y_t)
        b = rfs[i].score(Xbt, yb_t)
        w = rfs[i].score(Xwt, yw_t)
        print("overall:", o)
        print("black:", b)
        print("white:", w)
        os.append(o)
        bs.append(b)
        ws.append(w)
    return os, bs, ws

In [336]: def logscores(logs, Xt, Xbt, Xwt):
    os = []
    bs = []
    ws = []
    for i in range(len(logs)):
        print(i*25)
        o = getscore(Xt, y_t, logs[i])
        b = getscore(Xbt, yb_t, logs[i])
        w = getscore(Xwt, yw_t, logs[i])
        print("overall:", o)
        print("black:", b)
        print("white:", w)
        os.append(o)
        bs.append(b)
        ws.append(w)
    return os, bs, ws

In [423]: os_l, bs_l, ws_l = logscores([params, params25, params50, params75, params100], Xt_900,
0
overall: 0.9783333333333333

```



```

black: 0.94
white: 0.9733333333333334
25
overall: 0.9883333333333333
black: 0.96
white: 0.9933333333333333
50
overall: 0.9783333333333333
black: 0.96
white: 0.98
75
overall: 0.985
black: 0.9533333333333334
white: 0.9933333333333333
100
overall: 0.9833333333333333
black: 0.96
white: 0.98

```

```
In [213]: os_r, bs_r, ws_r = rfcores([rf0, rf25, rf50, rf75, rf100], Xt_900, Xb_t, Xw_t)
```

```

0
overall: 0.9733333333333334
black: 0.9
white: 0.9933333333333333
25
overall: 0.9816666666666667
black: 0.9466666666666667
white: 0.9866666666666667
50
overall: 0.99
black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.9833333333333333
black: 0.9733333333333334
white: 0.9933333333333333
100
overall: 0.9816666666666667
black: 0.9733333333333334
white: 0.9933333333333333

```

```
In [331]: os_r_, bs_r_, ws_r_ = rfcores([rf0_, rf25_, rf50_, rf75_, rf100_], Xt_900, Xb_t, Xw_t)
```

```

0
overall: 0.9866666666666667
black: 0.9466666666666667

```

```

white: 1.0
25
overall: 0.9966666666666667
black: 0.9866666666666667
white: 1.0
50
overall: 0.9966666666666667
black: 0.9866666666666667
white: 1.0
75
overall: 0.9983333333333333
black: 0.9933333333333333
white: 1.0
100
overall: 0.9966666666666667
black: 0.9933333333333333
white: 0.9933333333333333

```

```

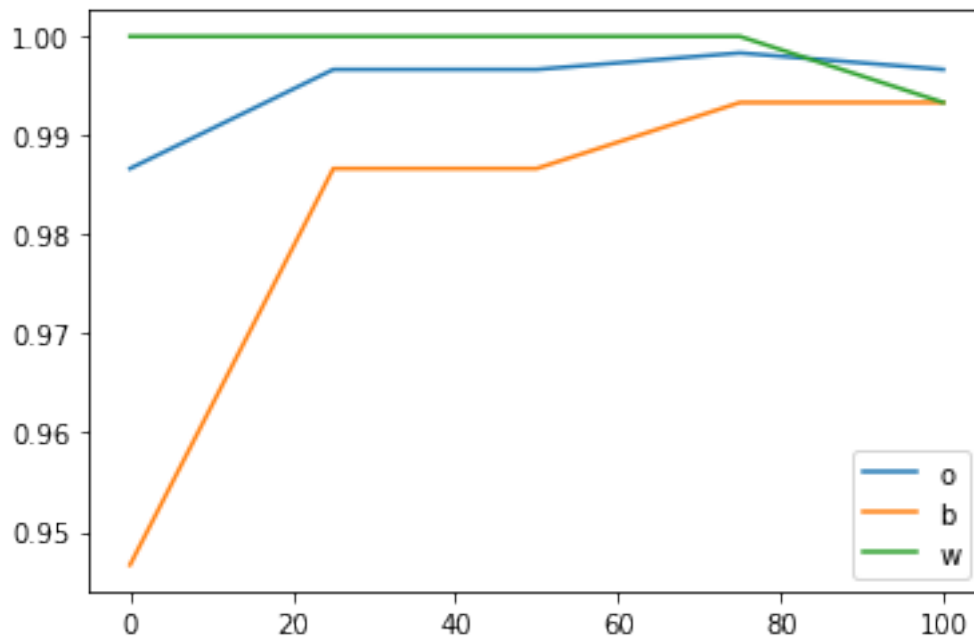
In [332]: plt.plot([0, 25, 50, 75, 100], os_r_, label="o")
          plt.plot([0, 25, 50, 75, 100], bs_r_, label="b")
          plt.plot([0, 25, 50, 75, 100], ws_r_, label="w")
          plt.legend()

```

```

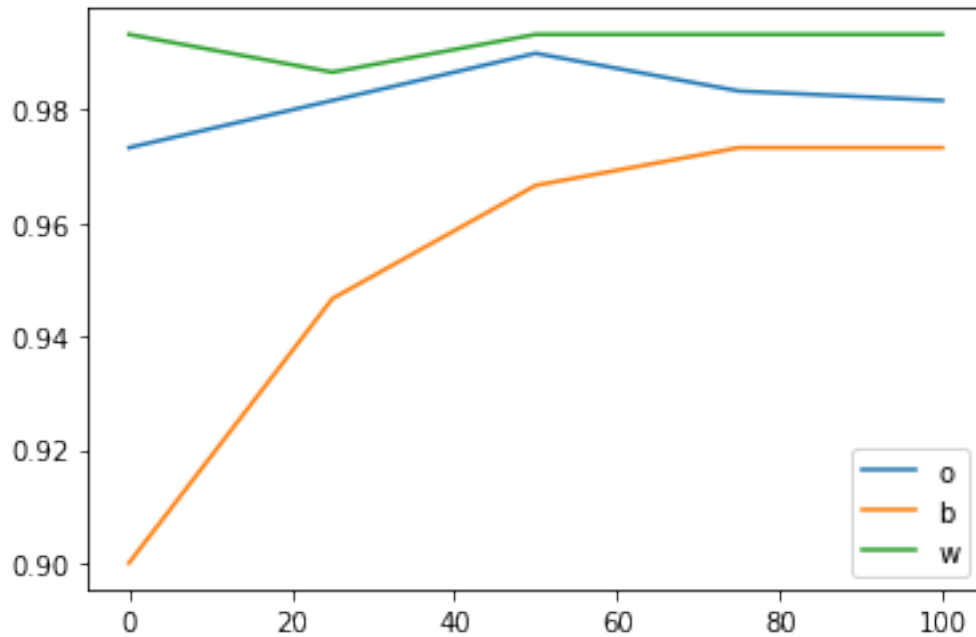
Out[332]: <matplotlib.legend.Legend at 0x1c5886fd90>

```



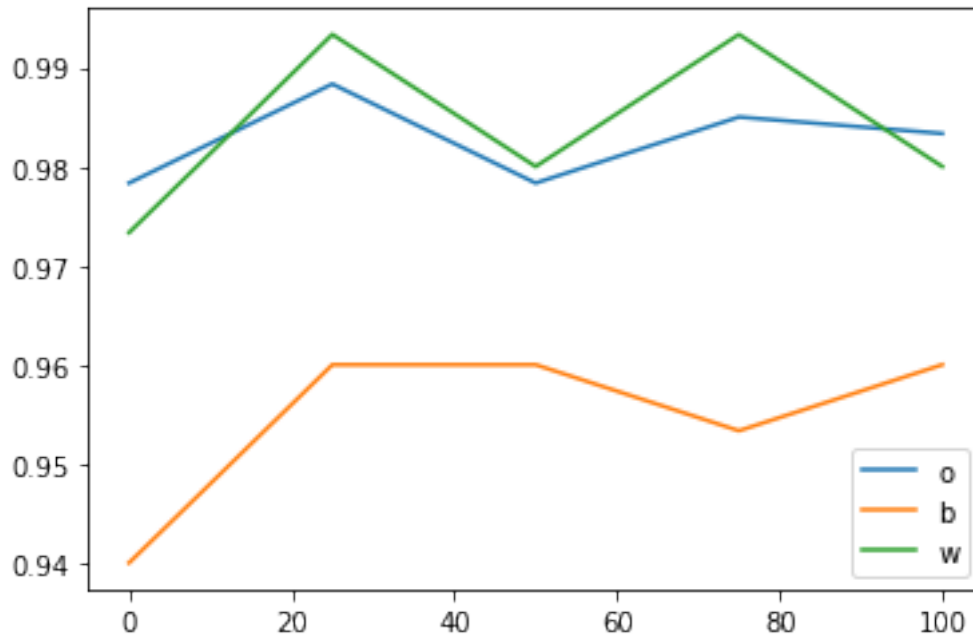
```
In [218]: plt.plot([0, 25, 50, 75, 100], os_r, label="o")
plt.plot([0, 25, 50, 75, 100], bs_r, label="b")
plt.plot([0, 25, 50, 75, 100], ws_r, label="w")
plt.legend()
```

Out[218]: <matplotlib.legend.Legend at 0x1c71f40650>



```
In [424]: plt.plot([0, 25, 50, 75, 100], os_l, label="o")
plt.plot([0, 25, 50, 75, 100], bs_l, label="b")
plt.plot([0, 25, 50, 75, 100], ws_l, label="w")
plt.legend()
```

Out[424]: <matplotlib.legend.Legend at 0x1c59345ad0>



In [294]: X.shape

Out[294]: (600, 430920)

4.1 Visualize Top Features

In [257]: *# Extract all possible features*

feature_coord, feature_type = feature_coord_sel2, feature_type_sel2

In [354]: **def** gettop(fnames, rf):

im = cv2.resize(cv2.imread(fnames[5], cv2.IMREAD_GRAYSCALE), (36,36))

fig, axes = plt.subplots(3,4, figsize=(16,8))

Sort features in order of importance and plot the six most significant

idx_sorted = np.argsort(rf.feature_importances_)[:-1]

for idx, ax **in** enumerate(axes.ravel()):

image = draw_haar_like_feature(im, 0, 0, 36, 36,

[feature_coord_sel[idx_sorted[idx]]])

ax.imshow(image)

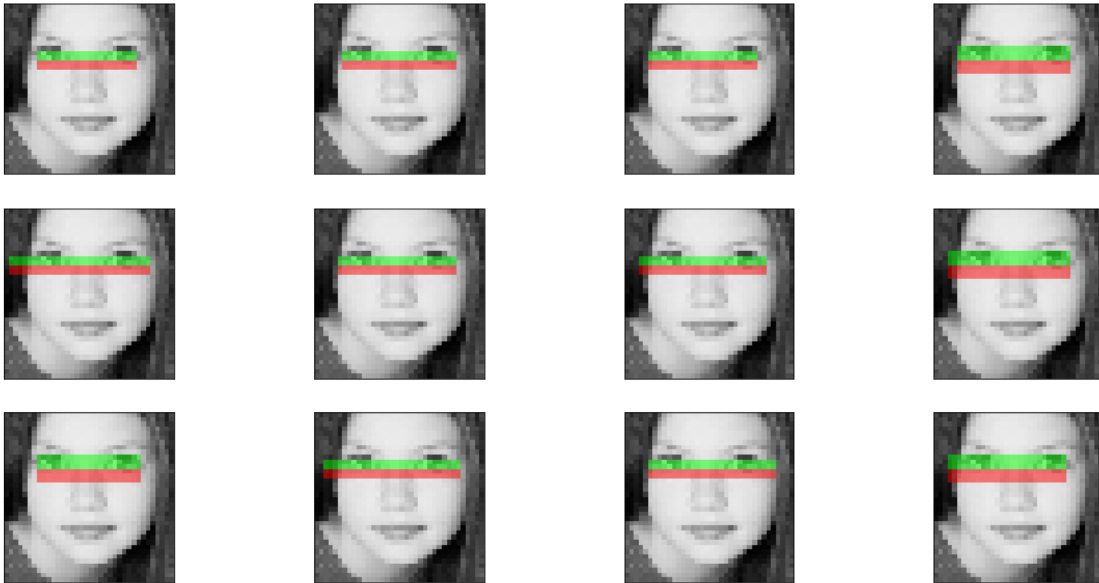
ax.set_xticks([])

ax.set_yticks([])

fig.suptitle('The most important features')

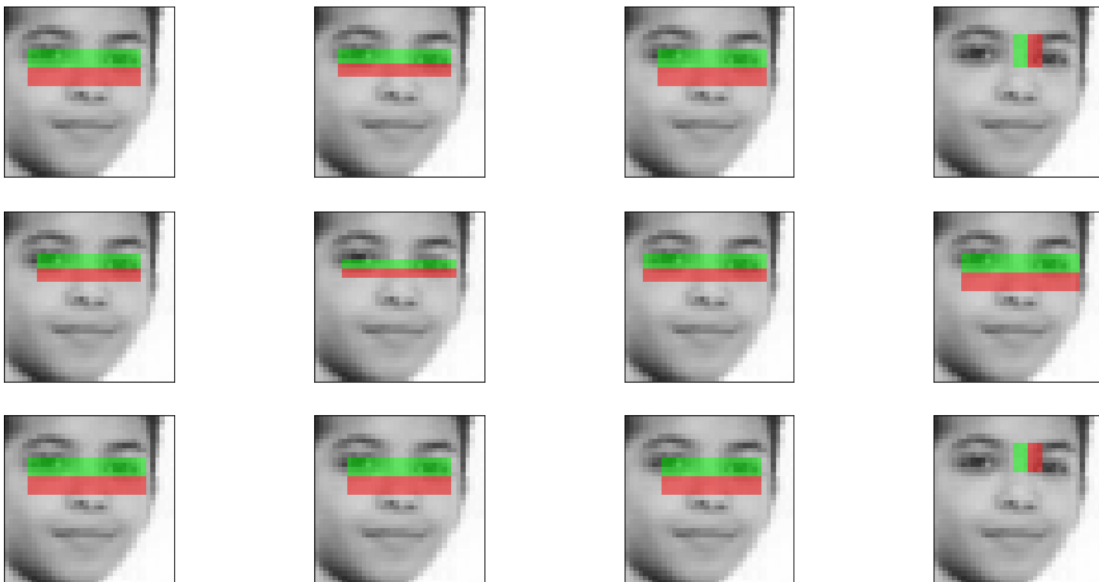
In [355]: gettop(face_filenames0, rf0_)

The most important features



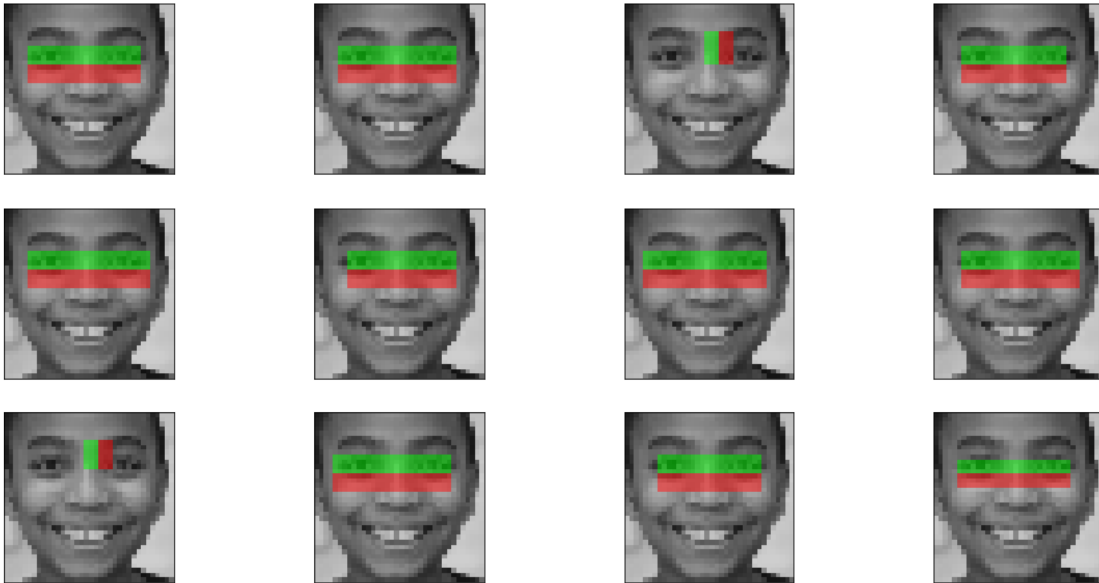
```
In [356]: gettop(face_filenames25, rf25_)
```

The most important features



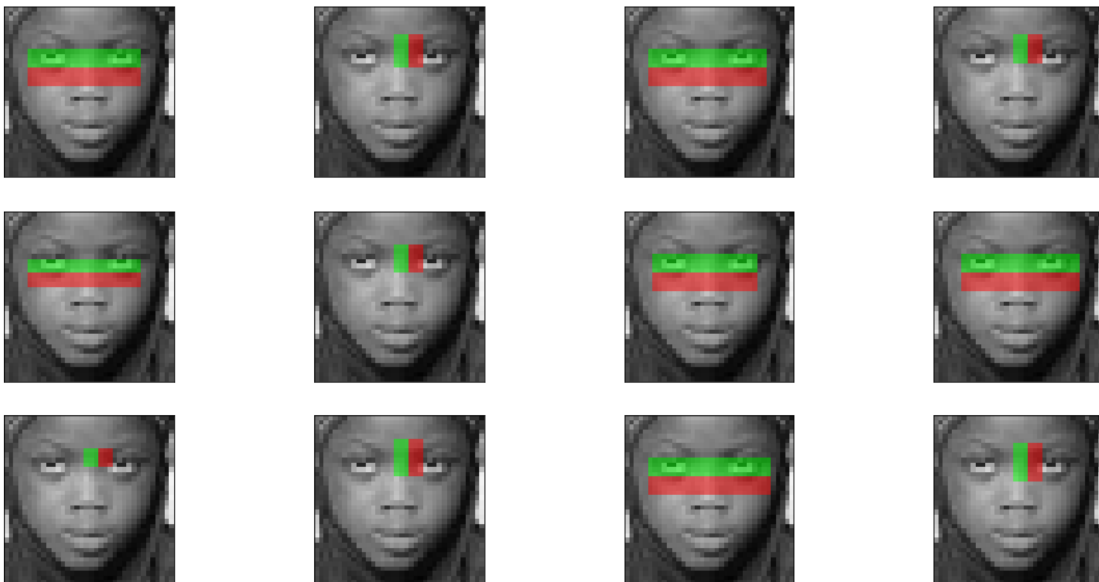
```
In [357]: gettop(face_filenames50, rf50_)
```

The most important features



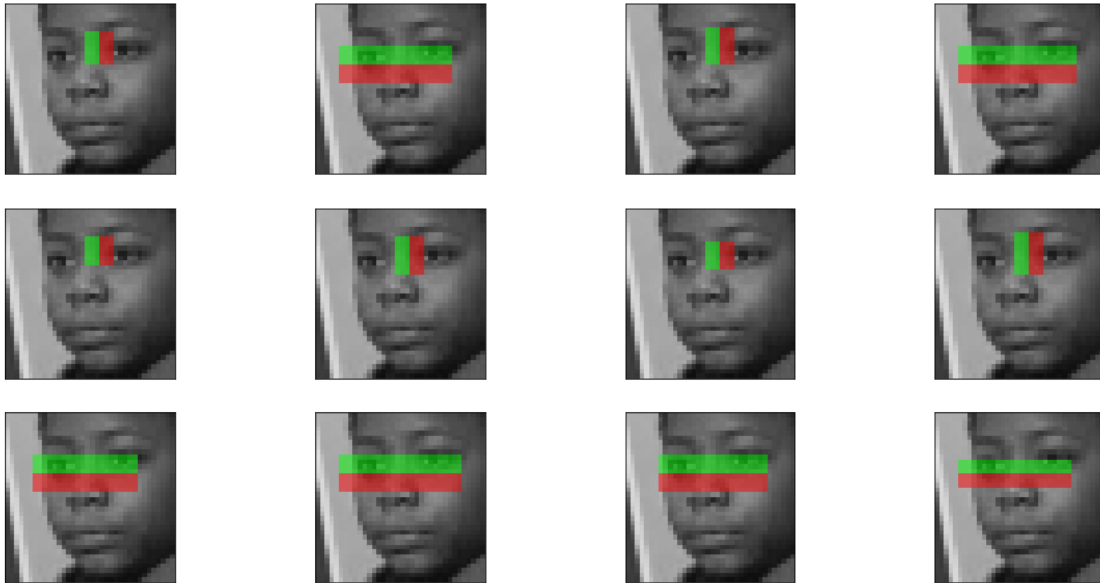
```
In [358]: gettop(face_filenames75, rf75_)
```

The most important features



```
In [347]: gettop(face_filenames100, rf100_)
```

The most important features



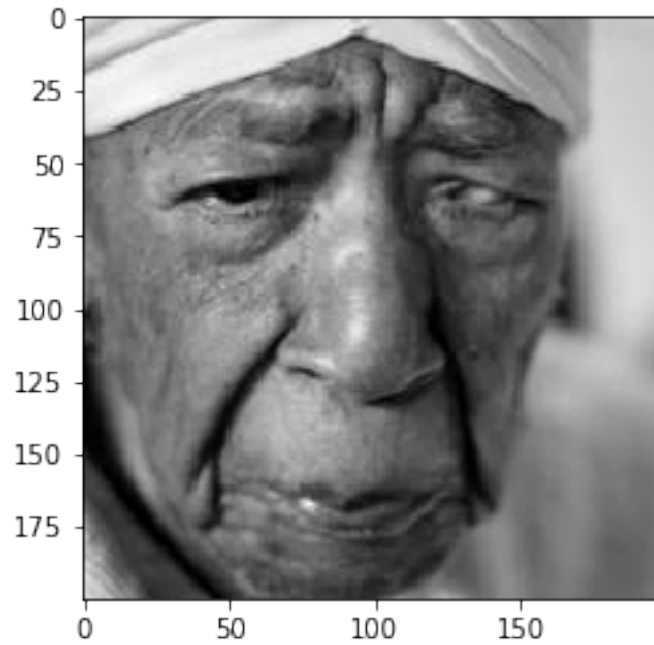
5 Comparing skin tone of images

```
In [367]: np.array(faces_t)[b_inds].shape
```

```
Out[367]: (150, 200, 200)
```

```
In [453]: plt.imshow(np.array(faces_t)[b_inds[0]], cmap='gray')
```

```
Out[453]: <matplotlib.image.AxesImage at 0x1c58b4cd10>
```



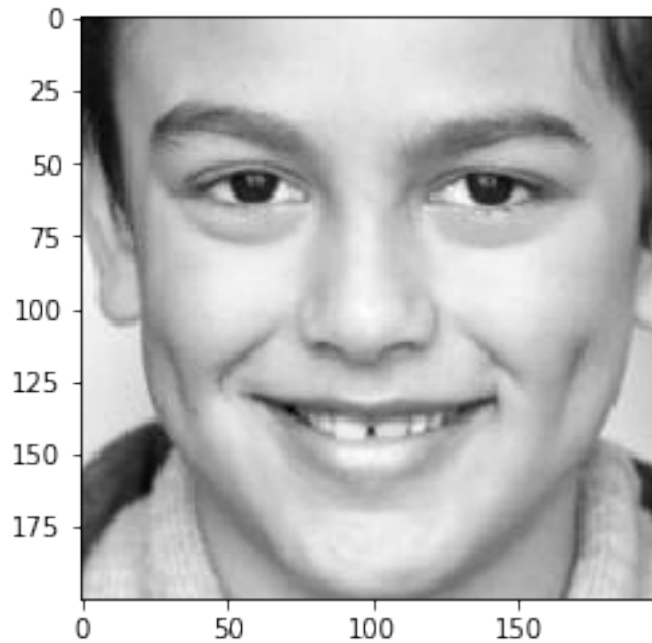
```
In [380]: img = np.array(faces_t)[b_inds[0]]
```

```
In [390]: hsv = cv2.cvtColor(cv2.cvtColor(img, cv2.COLOR_GRAY2BGR), cv2.COLOR_BGR2HSV)
          _, _, v = cv2.split(hsv)
          np.median(v)
```

```
Out[390]: 102.0
```

```
In [452]: plt.imshow(np.array(faces_t)[w_inds[0]], cmap='gray')
```

```
Out[452]: <matplotlib.image.AxesImage at 0x1c6dd52c10>
```

```
In [473]: img = np.array(faces_t)[w_inds[0]]
```

```
In [515]: hsv = cv2.cvtColor(cv2.cvtColor(img, cv2.COLOR_GRAY2BGR), cv2.COLOR_BGR2HSV)
_, _, v = cv2.split(hsv)
np.median(v)
```

```
Out[515]: 173.0
```

```
In [516]: hsv = hsv.astype(np.int32)
```

```
In [517]: hsv[:, :, 2]
```

```
Out[517]: array([[ 35,  35,  36, ...,  61,  56,  51],
 [ 34,  38,  41, ...,  60,  55,  50],
 [ 35,  41,  46, ...,  59,  55,  50],
 ...,
 [169, 182, 186, ..., 178, 179, 178],
 [172, 185, 190, ..., 185, 185, 185],
 [172, 184, 190, ..., 191, 191, 190]], dtype=int32)
```

```
In [508]: np.mean(hsv[:, :, 2]), np.std(hsv[:, :, 2])
```

```
Out[508]: (163.365525, 39.53961831472801)
```

```
In [518]: hsv[:, :, 2] = 125+47.5*(hsv[:, :, 2]-np.mean(hsv[:, :, 2]))/np.std(hsv[:, :, 2])
```

```
In [514]: 125+47.5*(35-163)/40
```

```
Out [514]: -27.0
```

```
In [519]: hsv[:, :, 2]
```

```
Out [519]: array([[ -29,  -29,  -28, ...,   2,   -3,   -9],
                  [ -30,  -25,  -22, ...,   0,   -5,  -11],
                  [ -29,  -22,  -15, ...,   0,   -5,  -11],
                  ...,
                  [131, 147, 152, ..., 142, 143, 142],
                  [135, 150, 156, ..., 150, 150, 150],
                  [135, 149, 156, ..., 158, 158, 156]], dtype=int32)
```

```
In [538]: hsv[hsv>254] = 254
```

```
In [523]: hsv[hsv<0] = 0
```

```
In [524]: hsv[:, :, 2]
```

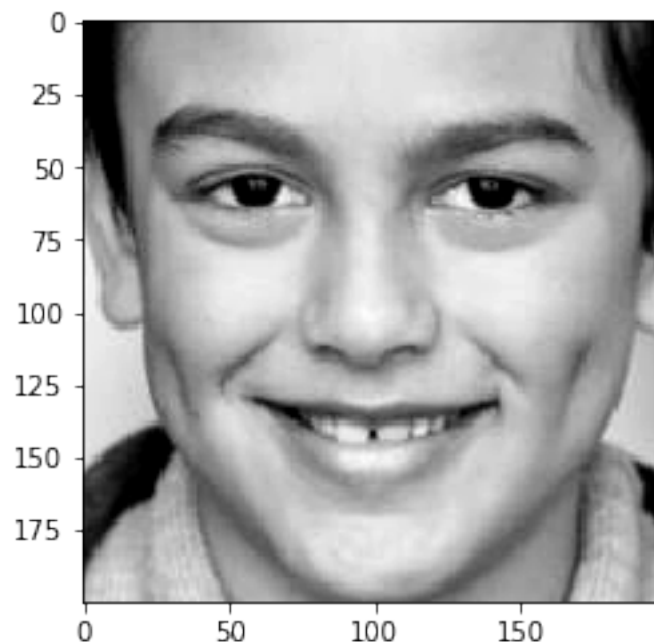
```
Out [524]: array([[ 0,  0,  0, ...,  2,  0,  0],
                  [ 0,  0,  0, ...,  0,  0,  0],
                  [ 0,  0,  0, ...,  0,  0,  0],
                  ...,
                  [131, 147, 152, ..., 142, 143, 142],
                  [135, 150, 156, ..., 150, 150, 150],
                  [135, 149, 156, ..., 158, 158, 156]], dtype=int32)
```

```
In [527]: np.mean(hsv[:, :, 2])
```

```
Out [527]: 124.953625
```

```
In [613]: plt.imshow(hsv[:, :, 2], cmap='gray')
```

```
Out [613]: <matplotlib.image.AxesImage at 0x1c6ac423d0>
```



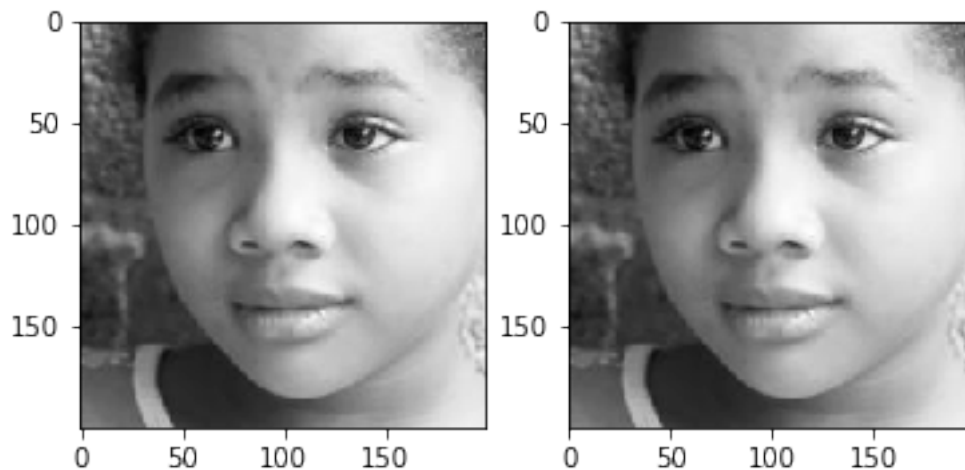
```
In [900]: def normalize(img):
            img = img.astype(np.int32)
            #     print(np.mean(img))
            m, s = np.mean(img), np.std(img)
            img = 125+47*(img-m)/max(1,s)
            img[img>255] = 255
            img[img<0] = 0
            #     print(np.mean(img))
            return img
```

```
In [652]: plt.subplot(1,2,1)
            plt.imshow(np.array(faces_t)[b_inds[2]], cmap='gray')
            plt.subplot(1,2,2)
            plt.imshow(normalize(np.array(faces_t)[b_inds[2]]), cmap='gray')
```

152.920125

125.0

Out [652]: <matplotlib.image.AxesImage at 0x1c5be86390>

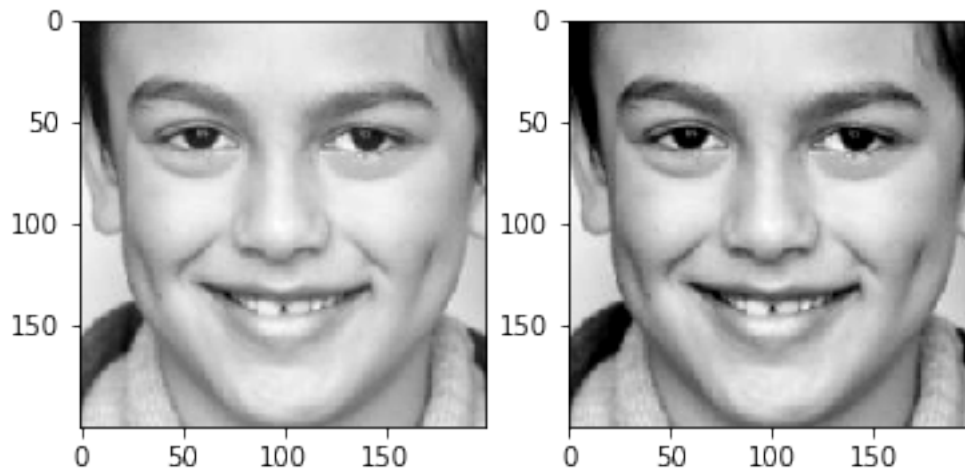


```
In [653]: plt.subplot(1,2,1)
            plt.imshow(np.array(faces_t)[w_inds[0]], cmap='gray')
            plt.subplot(1,2,2)
            plt.imshow(normalize(np.array(faces_t)[w_inds[0]]), cmap='gray')
```

163.365525

125.40513080163775

Out [653]: <matplotlib.image.AxesImage at 0x1c5bfcdad0>



In [449]: *# average black face image brightness/intensity:*

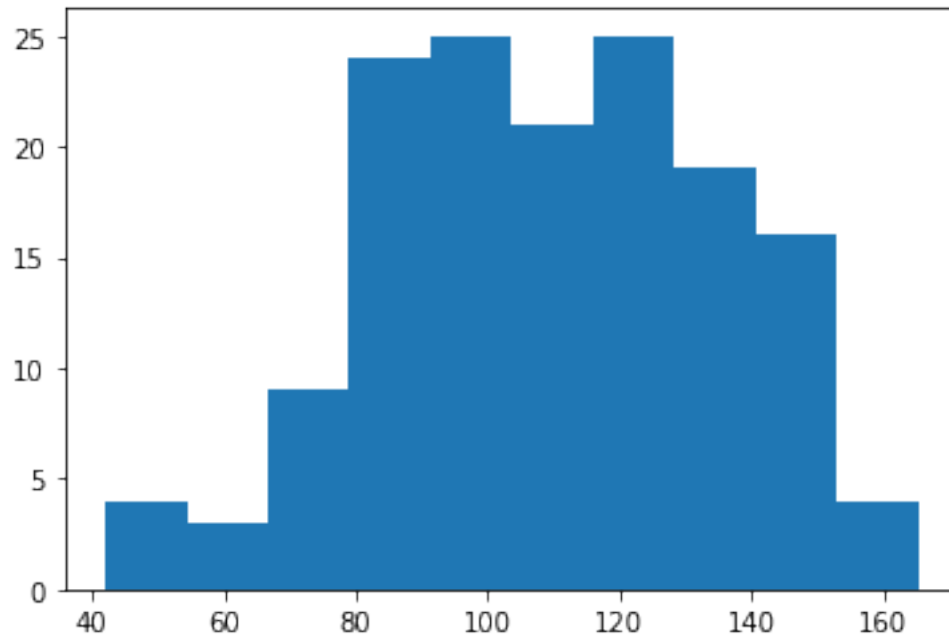
```
vs_b = []
vs_b2 = []
stds_b = []
for b in b_inds:
    img = np.array(faces_t)[b]
    hsv = cv2.cvtColor(cv2.cvtColor(img, cv2.COLOR_GRAY2BGR), cv2.COLOR_BGR2HSV)
    _, _, v = cv2.split(hsv)
    vs_b.append(np.mean(v))
    vs_b2.append(np.median(v))
    stds_b.append(np.std(v))
```

In [450]: np.mean(vs_b), np.median(vs_b2), np.mean(stds_b), np.median(stds_b)

Out [450]: (109.63445466666667, 105.5, 48.84662617726078, 47.37796866193072)

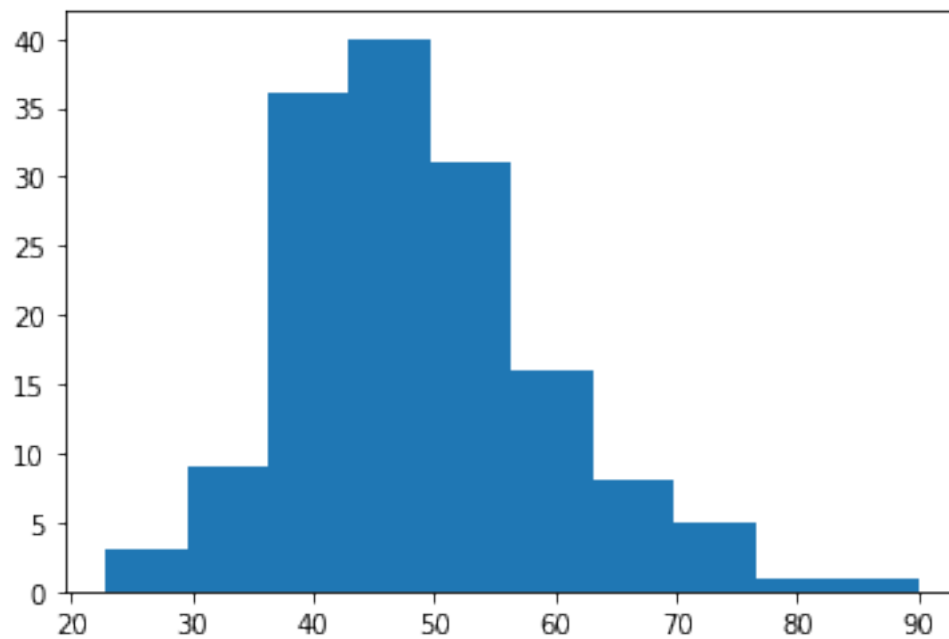
In [443]: plt.hist(vs_b)

Out [443]: (array([4., 3., 9., 24., 25., 21., 25., 19., 16., 4.]),
array([41.9701, 54.29725, 66.6244, 78.95155, 91.2787, 103.60585,
115.933, 128.26015, 140.5873, 152.91445, 165.2416]),
<a list of 10 Patch objects>)



```
In [451]: plt.hist(stds_b)
```

```
Out[451]: (array([ 3.,  9., 36., 40., 31., 16.,  8.,  5.,  1.,  1.]),
  array([22.81833815, 29.53079923, 36.24326031, 42.95572139, 49.66818247,
        56.38064354, 63.09310462, 69.8055657 , 76.51802678, 83.23048786,
        89.94294894]),
  <a list of 10 Patch objects>)
```



```

In [444]: # average white face image brightness/intensity:
vs_w = []
vs_w2 = []
stds_w = []
for w in w_inds:
    img = np.array(faces_t)[w]
    hsv = cv2.cvtColor(cv2.cvtColor(img, cv2.COLOR_GRAY2BGR), cv2.COLOR_BGR2HSV)
    _, _, v = cv2.split(hsv)
    vs_w.append(np.mean(v))
    vs_w2.append(np.median(v))
    stds_w.append(np.std(v))

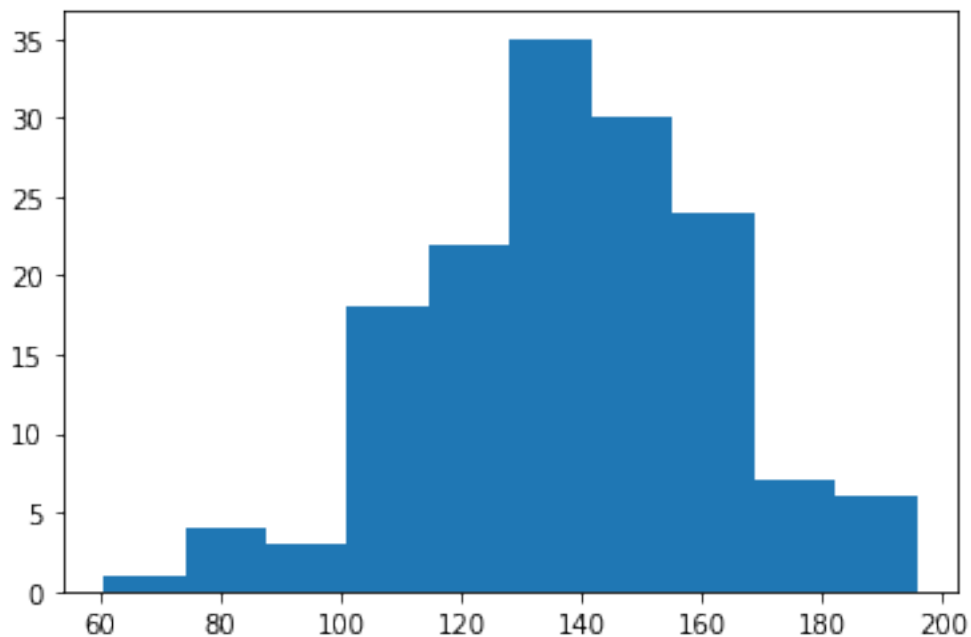
In [445]: np.mean(vs_w), np.median(vs_w2), np.mean(stds_w), np.median(stds_w)

Out[445]: (137.76237866666668, 147.0, 46.904933581518925, 47.001169565557745)

In [442]: plt.hist(vs_w)

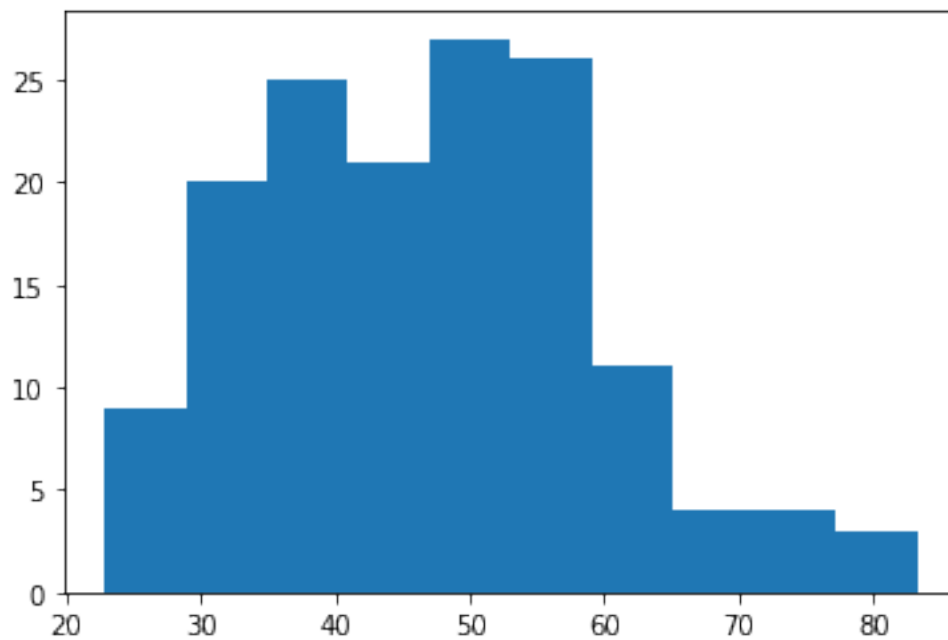
Out[442]: (array([ 1.,  4.,  3., 18., 22., 35., 30., 24.,  7.,  6.]),
  array([ 60.659425,  74.1564575,  87.65349, 101.1505225, 114.647555,
        128.1445875, 141.64162, 155.1386525, 168.635685, 182.1327175,
        195.62975 ]),
  <a list of 10 Patch objects>)

```



```
In [654]: plt.hist(stds_w)
```

```
Out[654]: (array([ 9., 20., 25., 21., 27., 26., 11.,  4.,  4.,  3.]),  
          array([22.80591848, 28.84964981, 34.89338114, 40.93711247, 46.9808438 ,  
                53.02457513, 59.06830646, 65.11203779, 71.15576911, 77.19950044,  
                83.24323177]),  
          <a list of 10 Patch objects>)
```



```
In [ ]:
```

6 Training on normalized images

```
In [281]: def regenerate_nonfaces():  
    nonfaces = []  
    for i in range(n):  
        # Read a random nonface file  
        j = random.randint(0, len(nonface_filenames) - 1)  
        nonface = cv2.imread(nonface_filenames[j], cv2.IMREAD_GRAYSCALE)  
        wsize = random.randint(36, min(nonface.shape[0], nonface.shape[1]))  
        row = random.randint(0, nonface.shape[0]-wsize)  
        col = random.randint(0, nonface.shape[1]-wsize)  
        crop = nonface[row:row+wsize, col:col+wsize]  
  
        # Resize to be the right size  
        crop = cv2.resize(crop, (200, 200))
```

```

        nonfaces.append(crop)
nonfaces_t = []
for i in range(n_test):
    # Read a random nonface file
    j = random.randint(0, n_nonfaces_test - 1)
    nonface = cv2.imread(test_nonface_names[j], cv2.IMREAD_GRAYSCALE)

    wsize = random.randint(36, min(nonface.shape[0], nonface.shape[1]))
    row = random.randint(0, nonface.shape[0]-wsize)
    col = random.randint(0, nonface.shape[1]-wsize)
    crop = nonface[row:row+wsize, col:col+wsize]

    # Resize to be the right size
    crop = cv2.resize(crop, (200, 200))
    nonfaces_t.append(crop)
return nonfaces, nonfaces_t

```

```

In [870]: def pipeline(f, times):
    def getx3(facefiles, n, nonfaces, feature_types, feature_coords):
        ims = [f(i) for i in getimgs(facefiles, nonfaces, n)]
        X = delayed(extract_feature_image(img, feature_types, feature_coords) for img in ims)
        return np.array(X.compute(scheduler='threads'))

    t_start = time()

    os_rs = []
    bs_rs = []
    ws_rs = []
    for i in range(times):
        nonfaces, nonfaces_t = regenerate_nonfaces()

        X0 = getx3(face_filenames0, n, nonfaces, feature_type_sel2, feature_coord_sel2)
        print(X0.shape)
        X25 = getx3(face_filenames25, n, nonfaces, feature_type_sel2, feature_coord_sel2)
        print(X25.shape)
        X50 = getx3(face_filenames50, n, nonfaces, feature_type_sel2, feature_coord_sel2)
        print(X50.shape)
        X75 = getx3(face_filenames75, n, nonfaces, feature_type_sel2, feature_coord_sel2)
        print(X75.shape)
        X100 = getx3(face_filenames100, n, nonfaces, feature_type_sel2, feature_coord_sel2)
        print(X100.shape)
        Xt = getx3(test_face_names, 300, nonfaces_t, feature_type_sel2, feature_coord_sel2)
        print(Xt.shape)

        rf0 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
        rf0.fit(X0, y)
        print(rf0.score(Xt_900, y_t))
        rf25 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=25)

```



```

rf25.fit(X25, y)
print(rf25.score(Xt_900, y_t))
rf50 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1,
rf50.fit(X50, y)
print(rf50.score(Xt_900, y_t))
rf75 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1,
rf75.fit(X75, y)
print(rf75.score(Xt_900, y_t))
rf100 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1,
rf100.fit(X100, y)
print(rf100.score(Xt_900, y_t))

os_r, bs_r, ws_r = rfscores([rf0, rf25, rf50, rf75, rf100], Xt_900, Xb_t, Xw_t)
os_rs.append(os_r)
bs_rs.append(bs_r)
ws_rs.append(ws_r)

plt.plot([0, 25, 50, 75, 100], os_r, label="o")
plt.plot([0, 25, 50, 75, 100], bs_r, label="b")
plt.plot([0, 25, 50, 75, 100], ws_r, label="w")
plt.legend()
plt.show()

print(time()-t_start)
return os_rs, bs_rs, ws_rs

```

```
In [890]: os_rs, bs_rs, ws_rs = pipeline(lambda x: x, 10)
```

```

(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.97
0.9816666666666667
0.9883333333333333
0.9866666666666667
0.9816666666666667
0
overall: 0.97
black: 0.9
white: 0.9866666666666667
25
overall: 0.9816666666666667
black: 0.94
white: 0.9933333333333333

```

50
overall: 0.9883333333333333
black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.9866666666666667
black: 0.9733333333333334
white: 0.9933333333333333
100
overall: 0.9816666666666667
black: 0.98
white: 0.9933333333333333
(8040, 900)
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(600, 900)
0.9733333333333334
0.9833333333333333
0.985
0.985
0.9766666666666667
0
overall: 0.9733333333333334
black: 0.9066666666666666
white: 0.9933333333333333
25
overall: 0.9833333333333333
black: 0.9533333333333334
white: 0.9866666666666667
50
overall: 0.985
black: 0.96
white: 0.9866666666666667
75
overall: 0.985
black: 0.9733333333333334
white: 0.98
100
overall: 0.9766666666666667
black: 0.9666666666666667
white: 0.9866666666666667
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(8040, 900)
(8040, 900)

```

(600, 900)
0.9716666666666667
0.9833333333333333
0.9866666666666667
0.9866666666666667
0.98
0
overall: 0.9716666666666667
black: 0.8933333333333333
white: 0.9933333333333333
25
overall: 0.9833333333333333
black: 0.9466666666666667
white: 0.9933333333333333
50
overall: 0.9866666666666667
black: 0.96
white: 0.9933333333333333
75
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9933333333333333
100
overall: 0.98
black: 0.9733333333333334
white: 0.9933333333333333
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(8040, 900)
(600, 900)
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0.9833333333333333
0.9883333333333333
0.985
0.98
0
overall: 0.9766666666666667
black: 0.9133333333333333
white: 0.9933333333333333
25
overall: 0.9833333333333333
black: 0.9533333333333334
white: 0.9866666666666667
50
overall: 0.9883333333333333
black: 0.96

```

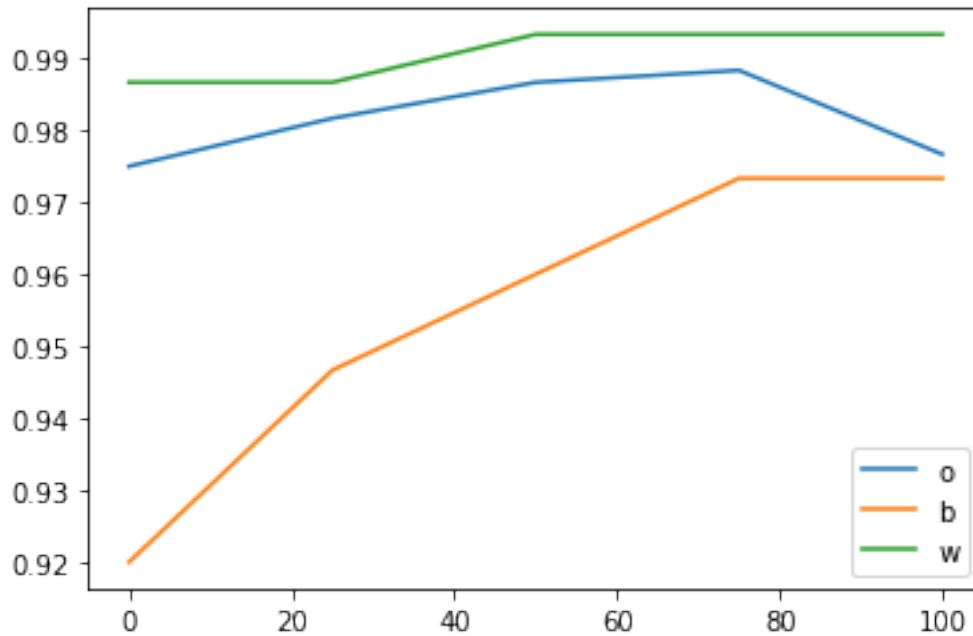
white: 0.9933333333333333
75
overall: 0.985
black: 0.9733333333333334
white: 0.9933333333333333
100
overall: 0.98
black: 0.9733333333333334
white: 0.9933333333333333
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(8040, 900)
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0.9866666666666667
0.985
0.9766666666666667
0
overall: 0.9716666666666667
black: 0.9
white: 0.9933333333333333
25
overall: 0.9816666666666667
black: 0.9466666666666667
white: 0.9866666666666667
50
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9866666666666667
75
overall: 0.985
black: 0.9733333333333334
white: 0.9866666666666667
100
overall: 0.9766666666666667
black: 0.9733333333333334
white: 0.9933333333333333
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0.9816666666666667

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 0.9783333333333334
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 overall: 0.9733333333333334
 black: 0.9133333333333333
 white: 0.9866666666666667
 25
 overall: 0.9816666666666667
 black: 0.9466666666666667
 white: 0.9866666666666667
 50
 overall: 0.9866666666666667
 black: 0.9666666666666667
 white: 0.9866666666666667
 75
 overall: 0.98
 black: 0.9733333333333334
 white: 0.9866666666666667
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 overall: 0.9783333333333334
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 white: 0.9866666666666667
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 white: 0.9866666666666667
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 overall: 0.98
 black: 0.94
 white: 0.9866666666666667
 50
 overall: 0.9816666666666667
 black: 0.9466666666666667
 white: 0.9866666666666667
 75
 overall: 0.99

black: 0.9733333333333334
white: 0.9933333333333333
100
overall: 0.9816666666666667
black: 0.9733333333333334
white: 0.9933333333333333
(8040, 900)
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0.9733333333333334
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0.9883333333333333
0.9866666666666667
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0
overall: 0.9733333333333334
black: 0.9066666666666666
white: 0.9933333333333333
25
overall: 0.98
black: 0.94
white: 0.9866666666666667
50
overall: 0.9883333333333333
black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.9866666666666667
black: 0.9733333333333334
white: 0.9866666666666667
100
overall: 0.98
black: 0.98
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(600, 900)
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0.9866666666666667
0.9883333333333333
0.9783333333333334

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overall: 0.97
black: 0.8933333333333333
white: 0.9933333333333333
25
overall: 0.9833333333333333
black: 0.9466666666666667
white: 0.9933333333333333
50
overall: 0.9866666666666667
black: 0.96
white: 0.9933333333333333
75
overall: 0.9883333333333333
black: 0.9733333333333334
white: 0.9933333333333333
100
overall: 0.9783333333333334
black: 0.9733333333333334
white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.975
0.9816666666666667
0.9866666666666667
0.9883333333333333
0.9766666666666667
0
overall: 0.975
black: 0.92
white: 0.9866666666666667
25
overall: 0.9816666666666667
black: 0.9466666666666667
white: 0.9866666666666667
50
overall: 0.9866666666666667
black: 0.96
white: 0.9933333333333333
75
overall: 0.9883333333333333
black: 0.9733333333333334
white: 0.9933333333333333
100

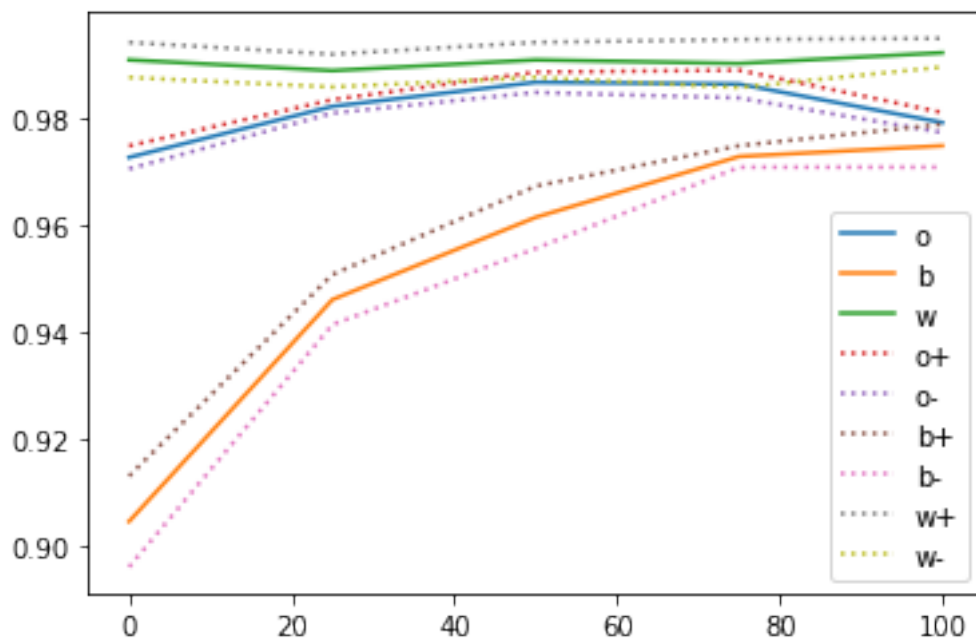
overall: 0.9766666666666667
black: 0.9733333333333334
white: 0.9933333333333333



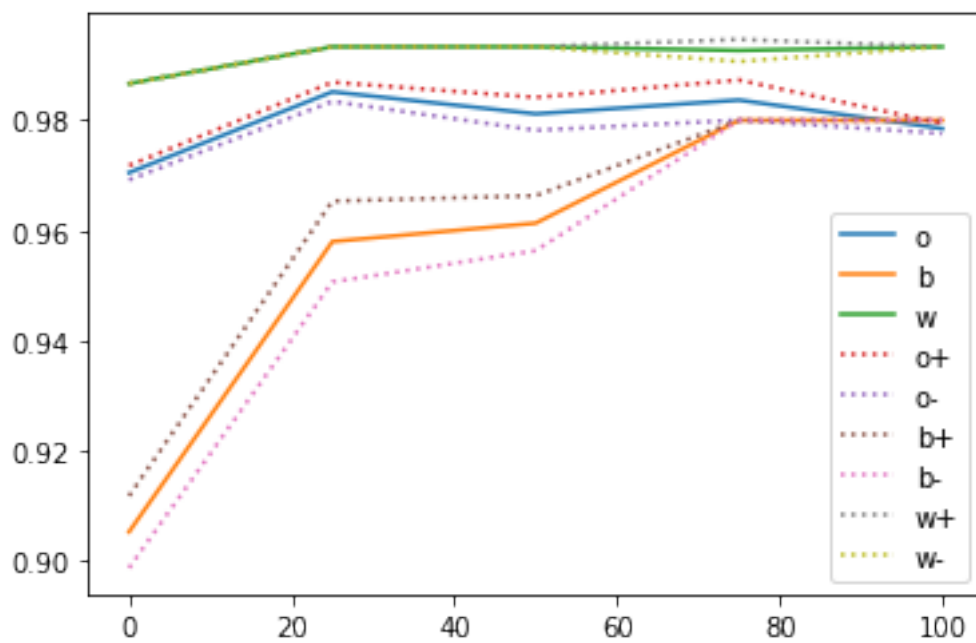
3550.007645368576

```
In [344]: def plots(os_rs, bs_rs, ws_rs):  
    plt.plot([0,25,50,75,100],np.mean(np.array(os_rs),axis=0),label='o')  
    plt.plot([0,25,50,75,100],np.mean(np.array(bs_rs),axis=0),label='b')  
    plt.plot([0,25,50,75,100],np.mean(np.array(ws_rs),axis=0),label='w')  
    plt.plot([0,25,50,75,100], np.array(np.mean(np.array(os_rs),axis=0)+np.std(np.ar  
    plt.plot([0,25,50,75,100], np.array(np.mean(np.array(os_rs),axis=0)-np.std(np.ar  
    plt.plot([0,25,50,75,100], np.array(np.mean(np.array(bs_rs),axis=0)+np.std(np.ar  
    plt.plot([0,25,50,75,100], np.array(np.mean(np.array(bs_rs),axis=0)-np.std(np.ar  
    plt.plot([0,25,50,75,100], np.array(np.mean(np.array(ws_rs),axis=0)+np.std(np.ar  
    plt.plot([0,25,50,75,100], np.array(np.mean(np.array(ws_rs),axis=0)-np.std(np.ar  
    plt.legend()  
    plt.show()
```

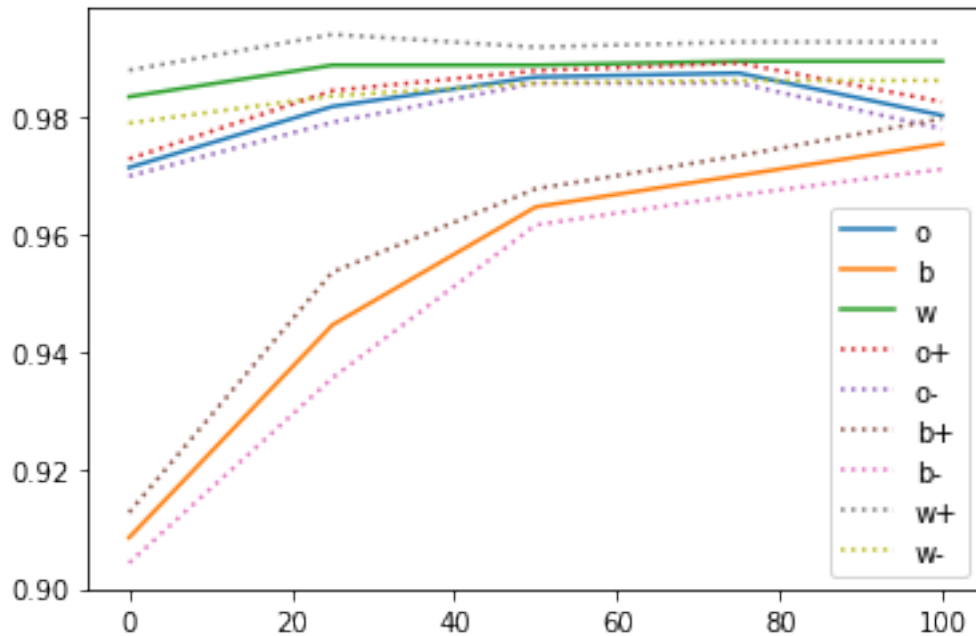
```
In [892]: plots(os_rs, bs_rs, ws_rs)
```

In [897]: `plots(os_rss, bs_rss, ws_rss)`



In [902]: `plots(os_rsn, bs_rsn, ws_rsn)`



```
In [901]: os_rsn, bs_rsn, ws_rsn = pipeline(normalize, 10)
```

```
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9716666666666667
0.9866666666666667
0.9866666666666667
0.9866666666666667
0.9816666666666667
0
overall: 0.9716666666666667
black: 0.9133333333333333
white: 0.98
25
overall: 0.9866666666666667
black: 0.96
white: 0.9933333333333333
50
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9866666666666667
75
```

overall: 0.986666666666667
black: 0.966666666666667
white: 0.986666666666667
100
overall: 0.981666666666667
black: 0.973333333333334
white: 0.993333333333333
(8040, 900)
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(8040, 900)
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(600, 900)
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0.981666666666667
0.985
0.988333333333333
0.981666666666667
0
overall: 0.97
black: 0.906666666666666
white: 0.98
25
overall: 0.981666666666667
black: 0.94
white: 0.993333333333333
50
overall: 0.985
black: 0.96
white: 0.993333333333333
75
overall: 0.988333333333333
black: 0.966666666666667
white: 0.993333333333333
100
overall: 0.981666666666667
black: 0.98
white: 0.993333333333333
(8040, 900)
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(8040, 900)
(600, 900)
0.973333333333334
0.976666666666667
0.985
0.988333333333333

0.9783333333333334
 0
 overall: 0.9733333333333334
 black: 0.9133333333333333
 white: 0.9866666666666667
 25
 overall: 0.9766666666666667
 black: 0.9333333333333333
 white: 0.98
 50
 overall: 0.985
 black: 0.96
 white: 0.9866666666666667
 75
 overall: 0.9883333333333333
 black: 0.9733333333333334
 white: 0.9933333333333333
 100
 overall: 0.9783333333333334
 black: 0.98
 white: 0.9866666666666667
 (8040, 900)
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 (600, 900)
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 0.9866666666666667
 0.9883333333333333
 0.9816666666666667
 0
 overall: 0.9716666666666667
 black: 0.9133333333333333
 white: 0.98
 25
 overall: 0.9816666666666667
 black: 0.9533333333333334
 white: 0.98
 50
 overall: 0.9866666666666667
 black: 0.9666666666666667
 white: 0.9866666666666667
 75
 overall: 0.9883333333333333
 black: 0.9733333333333334
 white: 0.9866666666666667

100
overall: 0.981666666666667
black: 0.973333333333334
white: 0.993333333333333
(8040, 900)
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(8040, 900)
(8040, 900)
(600, 900)
0.971666666666667
0.983333333333333
0.988333333333333
0.988333333333333
0.978333333333334
0
overall: 0.971666666666667
black: 0.906666666666666
white: 0.986666666666667
25
overall: 0.983333333333333
black: 0.946666666666667
white: 0.993333333333333
50
overall: 0.988333333333333
black: 0.966666666666667
white: 0.986666666666667
75
overall: 0.988333333333333
black: 0.966666666666667
white: 0.986666666666667
100
overall: 0.978333333333334
black: 0.973333333333334
white: 0.986666666666667
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.971666666666667
0.983333333333333
0.988333333333333
0.988333333333333
0.98
0
overall: 0.971666666666667

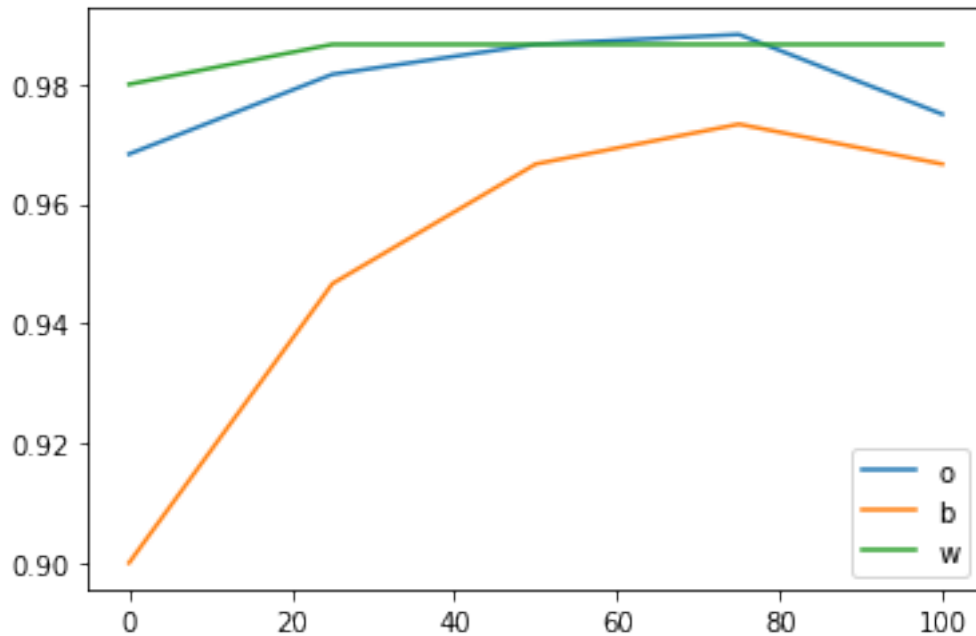
```

black: 0.9133333333333333
white: 0.98
25
overall: 0.9833333333333333
black: 0.9533333333333334
white: 0.9866666666666667
50
overall: 0.9883333333333333
black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.9883333333333333
black: 0.9666666666666667
white: 0.9933333333333333
100
overall: 0.98
black: 0.9733333333333334
white: 0.9866666666666667
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9716666666666667
0.9833333333333333
0.9866666666666667
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0.9833333333333333
0
overall: 0.9716666666666667
black: 0.9066666666666666
white: 0.9866666666666667
25
overall: 0.9833333333333333
black: 0.9466666666666667
white: 0.9933333333333333
50
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9866666666666667
75
overall: 0.9833333333333333
black: 0.9733333333333334
white: 0.9933333333333333
100
overall: 0.9833333333333333
black: 0.98

```

white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9733333333333334
0.98
0.9866666666666667
0.985
0.9816666666666667
0
overall: 0.9733333333333334
black: 0.9066666666666666
white: 0.9933333333333333
25
overall: 0.98
black: 0.9333333333333333
white: 0.9933333333333333
50
overall: 0.9866666666666667
black: 0.96
white: 0.9933333333333333
75
overall: 0.985
black: 0.9666666666666667
white: 0.9866666666666667
100
overall: 0.9816666666666667
black: 0.98
white: 0.9866666666666667
(8040, 900)
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(8040, 900)
(8040, 900)
(600, 900)
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0.98
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overall: 0.97
black: 0.9066666666666666
white: 0.98
25

overall: 0.9783333333333334
black: 0.9333333333333333
white: 0.9866666666666667
50
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9866666666666667
75
overall: 0.9883333333333333
black: 0.9733333333333334
white: 0.9866666666666667
100
overall: 0.98
black: 0.9733333333333334
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(8040, 900)
(8040, 900)
(8040, 900)
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(8040, 900)
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0.9816666666666667
0.9866666666666667
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0.975
0
overall: 0.9683333333333334
black: 0.9
white: 0.98
25
overall: 0.9816666666666667
black: 0.9466666666666667
white: 0.9866666666666667
50
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9866666666666667
75
overall: 0.9883333333333333
black: 0.9733333333333334
white: 0.9866666666666667
100
overall: 0.975
black: 0.9666666666666667
white: 0.9866666666666667



4317.321887731552

```
In [805]: np.array(np.mean(np.array(os_rs),axis=0)+np.std(np.array(os_rs),axis=0)+1)
```

```
Out[805]: array([1.975      , 1.98166667, 1.98666667, 1.985      , 1.98166667])
```

```
In [ ]: np.mean(np.array(os_rs),axis=0)+np.std(np.array(os_rs),axis=0)
```

```
In [664]: pipeline(normalize)
```

```
(8040, 900)
```

```
(8040, 900)
```

```
(8040, 900)
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(8040, 900)
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(8040, 900)
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(600, 900)
```

```
0.9733333333333334
```

```
0.9816666666666667
```

```
0.9883333333333333
```

```
0.9883333333333333
```

```
0.9816666666666667
```

```
0
```

```
overall: 0.9733333333333334
```

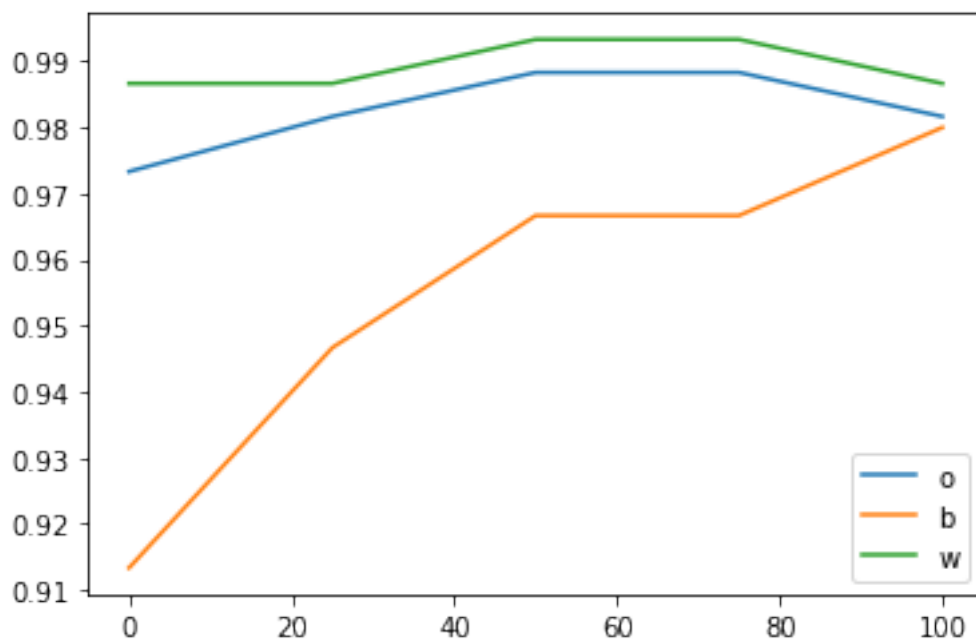
```
black: 0.9133333333333333
```

```
white: 0.9866666666666667
```

```

25
overall: 0.9816666666666667
black: 0.9466666666666667
white: 0.9866666666666667
50
overall: 0.9883333333333333
black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.9883333333333333
black: 0.9666666666666667
white: 0.9933333333333333
100
overall: 0.9816666666666667
black: 0.98
white: 0.9866666666666667

```



```
486.97529673576355
```

```

In [229]: sharpen_kernel = np.array([0, -1, 0, -1, 5, -1, 0, -1, 0])

In [ ]: im = np.array(faces_t)[b_inds[0]]

In [ ]: plt.imshow(gradient_strength(im), cmap='gray')

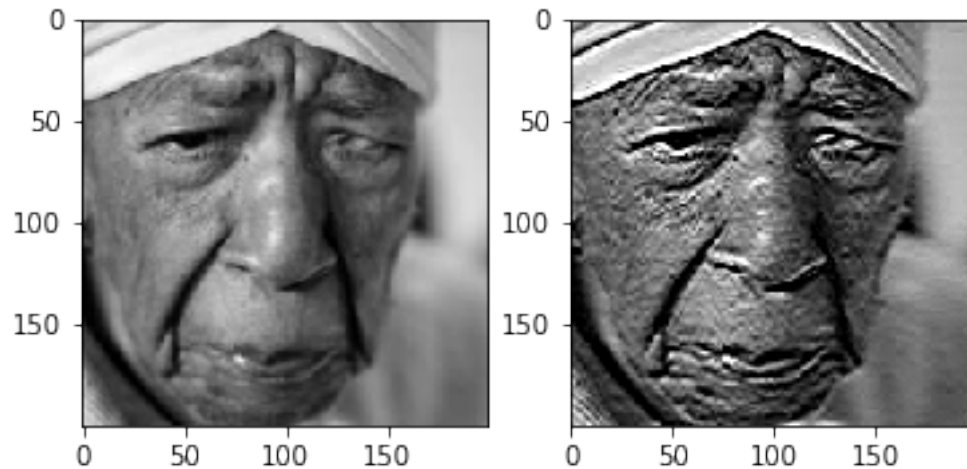
```

```
In [ ]: plt.imshow(gradient_orientation(im), cmap='gray')
```

```
In [674]: im_sharp = cv2.filter2D(src=im, ddepth=-1, kernel=sharpen_kernel)
```

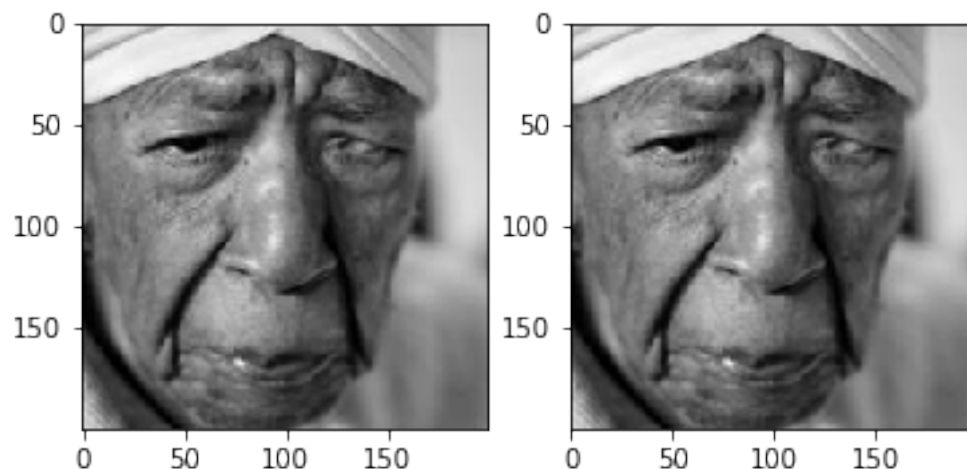
```
In [876]: plt.subplot(1,2,1)
plt.imshow(np.array(faces_t)[b_inds[0]], cmap='gray')
plt.subplot(1,2,2)
plt.imshow(sharpen(np.array(faces_t)[b_inds[0]]), cmap='gray')
```

```
Out [876]: <matplotlib.image.AxesImage at 0x1c53b30090>
```



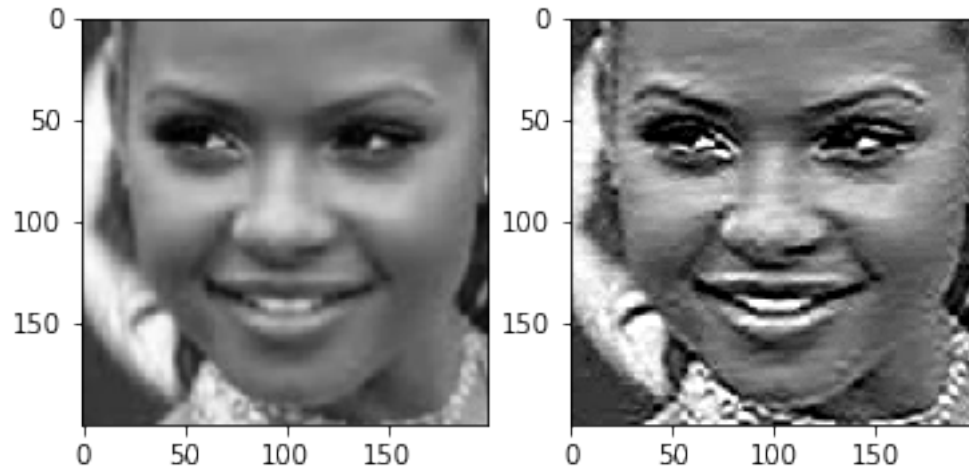
```
In [877]: plt.subplot(1,2,1)
plt.imshow(np.array(faces_t)[b_inds[0]], cmap='gray')
plt.subplot(1,2,2)
plt.imshow(normalize(np.array(faces_t)[b_inds[0]]), cmap='gray')
```

```
Out [877]: <matplotlib.image.AxesImage at 0x1c486613d0>
```



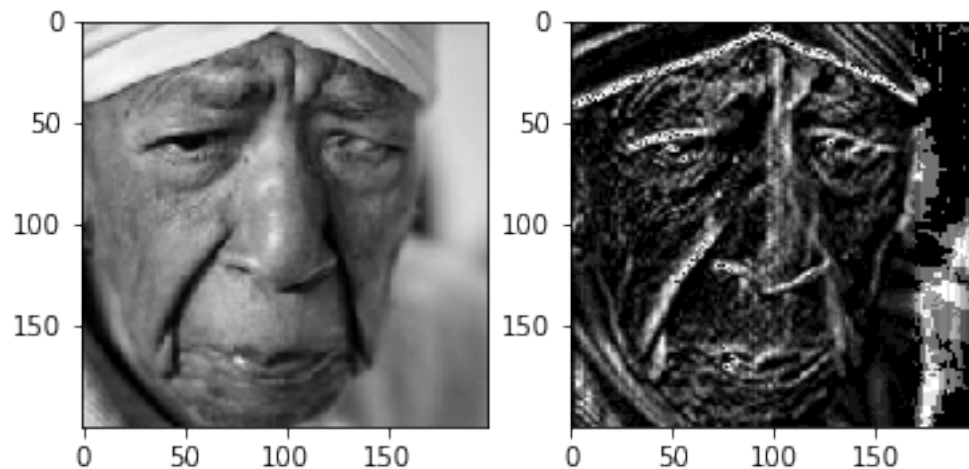
```
In [232]: plt.subplot(1,2,1)
plt.imshow(np.array(faces_t)[b_inds[]], cmap='gray')
plt.subplot(1,2,2)
plt.imshow(sharpen(np.array(faces_t)[b_inds[1]]), cmap='gray')
```

Out[232]: <matplotlib.image.AxesImage at 0x1c419b6f10>



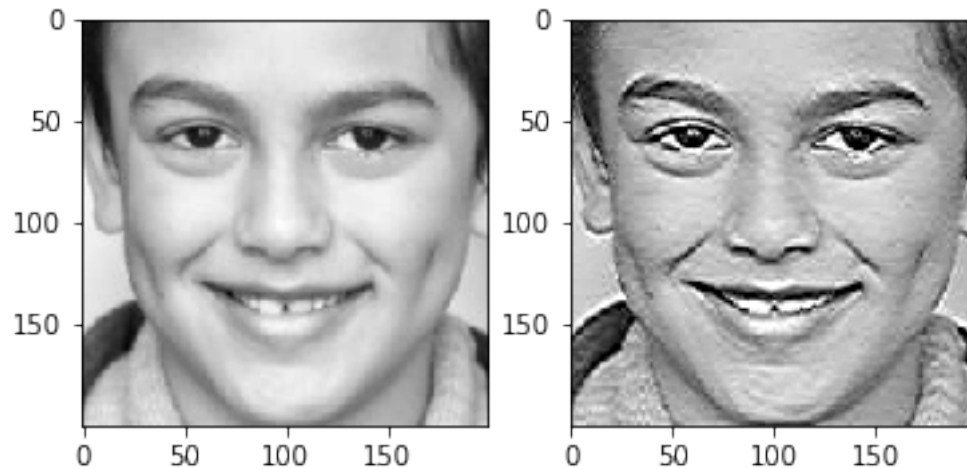
```
In [878]: plt.subplot(1,2,1)
plt.imshow(np.array(faces_t)[b_inds[0]], cmap='gray')
plt.subplot(1,2,2)
plt.imshow(gradient_strength(np.array(faces_t)[b_inds[0]]), cmap='gray')
```

Out[878]: <matplotlib.image.AxesImage at 0x1c71fec9d0>



```
In [874]: plt.subplot(1,2,1)
plt.imshow(np.array(faces_t)[w_inds[0]], cmap='gray')
plt.subplot(1,2,2)
plt.imshow(sharpen(np.array(faces_t)[w_inds[0]]), cmap='gray')
```

Out [874]: <matplotlib.image.AxesImage at 0x1c6afb7f50>



```
In [227]: def sharpen(im):
return cv2.filter2D(src=im, ddepth=-1, kernel=sharpen_kernel)
```

```
In [894]: pipeline(sharpen, 10)
```

```
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9683333333333334
0.9816666666666667
0.985
0.9883333333333333
0.9783333333333334
0
overall: 0.9683333333333334
black: 0.9
white: 0.9866666666666667
25
```

```

overall: 0.981666666666667
black: 0.946666666666667
white: 0.993333333333333
50
overall: 0.985
black: 0.96
white: 0.993333333333333
75
overall: 0.988333333333333
black: 0.98
white: 0.993333333333333
100
overall: 0.978333333333334
black: 0.98
white: 0.993333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.971666666666667
0.988333333333333
0.985
0.988333333333333
0.978333333333334
0
overall: 0.971666666666667
black: 0.906666666666666
white: 0.986666666666667
25
overall: 0.988333333333333
black: 0.966666666666667
white: 0.993333333333333
50
overall: 0.985
black: 0.96
white: 0.993333333333333
75
overall: 0.988333333333333
black: 0.98
white: 0.993333333333333
100
overall: 0.978333333333334
black: 0.98
white: 0.993333333333333
(8040, 900)
(8040, 900)

```

(8040, 900)
 (8040, 900)
 (8040, 900)
 (600, 900)
 0.9716666666666667
 0.985
 0.985
 0.9883333333333333
 0.9783333333333334
 0
 overall: 0.9716666666666667
 black: 0.9066666666666666
 white: 0.9866666666666667
 25
 overall: 0.985
 black: 0.96
 white: 0.9933333333333333
 50
 overall: 0.985
 black: 0.9666666666666667
 white: 0.9933333333333333
 75
 overall: 0.9883333333333333
 black: 0.98
 white: 0.9933333333333333
 100
 overall: 0.9783333333333334
 black: 0.98
 white: 0.9933333333333333
 (8040, 900)
 (8040, 900)
 (8040, 900)
 (8040, 900)
 (8040, 900)
 (600, 900)
 0.97
 0.985
 0.9816666666666667
 0.9866666666666667
 0.9783333333333334
 0
 overall: 0.97
 black: 0.9
 white: 0.9866666666666667
 25
 overall: 0.985
 black: 0.9533333333333334
 white: 0.9933333333333333

50
overall: 0.981666666666667
black: 0.953333333333334
white: 0.993333333333333
75
overall: 0.986666666666667
black: 0.98
white: 0.993333333333333
100
overall: 0.978333333333334
black: 0.98
white: 0.993333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.97
0.985
0.976666666666667
0.978333333333334
0.976666666666667
0
overall: 0.97
black: 0.906666666666666
white: 0.986666666666667
25
overall: 0.985
black: 0.953333333333334
white: 0.993333333333333
50
overall: 0.976666666666667
black: 0.96
white: 0.993333333333333
75
overall: 0.978333333333334
black: 0.98
white: 0.986666666666667
100
overall: 0.976666666666667
black: 0.98
white: 0.993333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)


```

(600, 900)
0.97
0.985
0.98
0.9816666666666667
0.98
0
overall: 0.97
black: 0.9
white: 0.9866666666666667
25
overall: 0.985
black: 0.96
white: 0.9933333333333333
50
overall: 0.98
black: 0.9666666666666667
white: 0.9933333333333333
75
overall: 0.9816666666666667
black: 0.98
white: 0.9933333333333333
100
overall: 0.98
black: 0.98
white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9716666666666667
0.9866666666666667
0.98
0.9816666666666667
0.9783333333333334
0
overall: 0.9716666666666667
black: 0.9133333333333333
white: 0.9866666666666667
25
overall: 0.9866666666666667
black: 0.9666666666666667
white: 0.9933333333333333
50
overall: 0.98
black: 0.9666666666666667

```

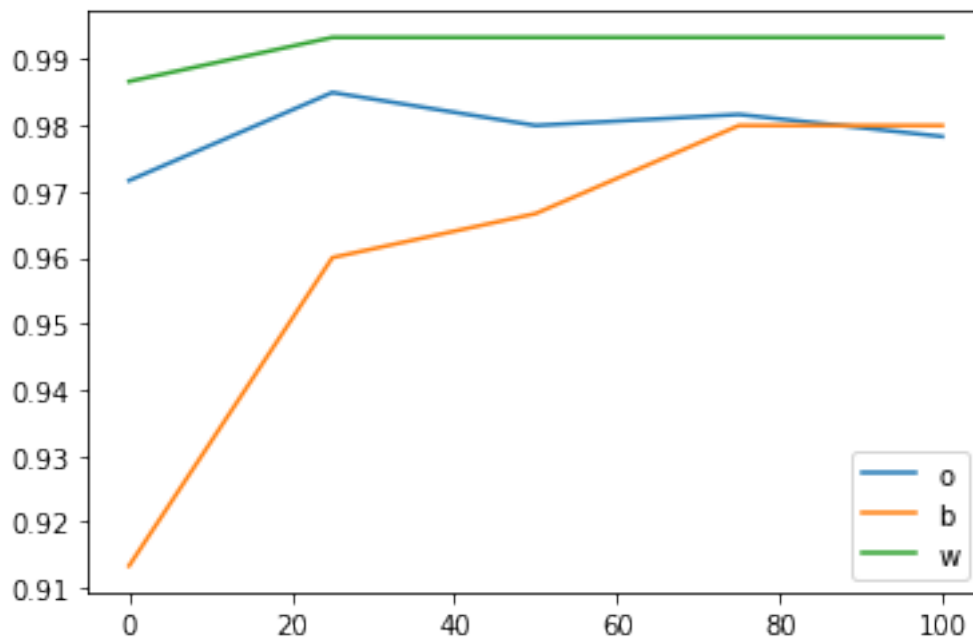
white: 0.9933333333333333
75
overall: 0.9816666666666667
black: 0.98
white: 0.9933333333333333
100
overall: 0.9783333333333334
black: 0.98
white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9683333333333334
0.9833333333333333
0.9816666666666667
0.9816666666666667
0.98
0
overall: 0.9683333333333334
black: 0.8933333333333333
white: 0.9866666666666667
25
overall: 0.9833333333333333
black: 0.9466666666666667
white: 0.9933333333333333
50
overall: 0.9816666666666667
black: 0.9533333333333334
white: 0.9933333333333333
75
overall: 0.9816666666666667
black: 0.98
white: 0.9933333333333333
100
overall: 0.98
black: 0.98
white: 0.9933333333333333
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.9716666666666667
0.9866666666666667

0.9766666666666667
 0.98
 0.9783333333333334
 0
 overall: 0.9716666666666667
 black: 0.9133333333333333
 white: 0.9866666666666667
 25
 overall: 0.9866666666666667
 black: 0.9666666666666667
 white: 0.9933333333333333
 50
 overall: 0.9766666666666667
 black: 0.96
 white: 0.9933333333333333
 75
 overall: 0.98
 black: 0.98
 white: 0.9933333333333333
 100
 overall: 0.9783333333333334
 black: 0.98
 white: 0.9933333333333333
 (8040, 900)
 (8040, 900)
 (8040, 900)
 (8040, 900)
 (8040, 900)
 (600, 900)
 0.9716666666666667
 0.985
 0.98
 0.9816666666666667
 0.9783333333333334
 0
 overall: 0.9716666666666667
 black: 0.9133333333333333
 white: 0.9866666666666667
 25
 overall: 0.985
 black: 0.96
 white: 0.9933333333333333
 50
 overall: 0.98
 black: 0.9666666666666667
 white: 0.9933333333333333
 75
 overall: 0.9816666666666667

```

black: 0.98
white: 0.9933333333333333
100
overall: 0.9783333333333334
black: 0.98
white: 0.9933333333333333

```



3937.3587787151337

```

Out [894]: ([[0.9683333333333334,
0.9816666666666667,
0.985,
0.9883333333333333,
0.9783333333333334],
[0.9716666666666667,
0.9883333333333333,
0.985,
0.9883333333333333,
0.9783333333333334],
[0.9716666666666667, 0.985, 0.985, 0.9883333333333333, 0.9783333333333334],
[0.97, 0.985, 0.9816666666666667, 0.9866666666666667, 0.9783333333333334],
[0.97, 0.985, 0.9766666666666667, 0.9783333333333334, 0.9766666666666667],
[0.97, 0.985, 0.98, 0.9816666666666667, 0.98],
[0.9716666666666667,

```

```
0.986666666666667,  
0.98,  
0.981666666666667,  
0.978333333333334],  
[0.968333333333334,  
0.983333333333333,  
0.981666666666667,  
0.981666666666667,  
0.98],  
[0.971666666666667,  
0.986666666666667,  
0.976666666666667,  
0.98,  
0.978333333333334],  
[0.971666666666667, 0.985, 0.98, 0.981666666666667, 0.978333333333334]],  
[[0.9, 0.946666666666667, 0.96, 0.98, 0.98],  
[0.906666666666666, 0.966666666666667, 0.96, 0.98, 0.98],  
[0.906666666666666, 0.96, 0.966666666666667, 0.98, 0.98],  
[0.9, 0.953333333333334, 0.953333333333334, 0.98, 0.98],  
[0.906666666666666, 0.953333333333334, 0.96, 0.98, 0.98],  
[0.9, 0.96, 0.966666666666667, 0.98, 0.98],  
[0.913333333333333, 0.966666666666667, 0.966666666666667, 0.98, 0.98],  
[0.893333333333333, 0.946666666666667, 0.953333333333334, 0.98, 0.98],  
[0.913333333333333, 0.966666666666667, 0.96, 0.98, 0.98],  
[0.913333333333333, 0.96, 0.966666666666667, 0.98, 0.98]],  
[[0.986666666666667,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333],  
[0.986666666666667,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333],  
[0.986666666666667,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333],  
[0.986666666666667,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333,  
0.993333333333333],  
[0.986666666666667,  
0.993333333333333,  
0.993333333333333,
```

```

0.9866666666666667,
0.9933333333333333],
[0.9866666666666667,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333],
[0.9866666666666667,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333],
[0.9866666666666667,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333],
[0.9866666666666667,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333],
[0.9866666666666667,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333,
0.9933333333333333]]))

```

In []:

In [678]: pipeline(sharpen)

```

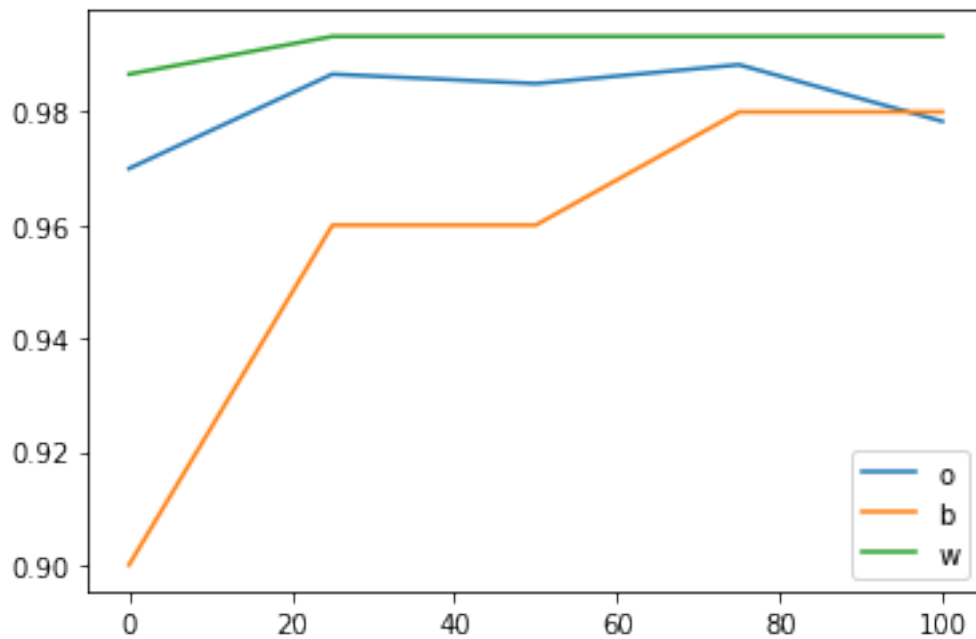
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.97
0.9866666666666667
0.985
0.9883333333333333
0.9783333333333334
0
overall: 0.97
black: 0.9
white: 0.9866666666666667
25

```

```

overall: 0.9866666666666667
black: 0.96
white: 0.9933333333333333
50
overall: 0.985
black: 0.96
white: 0.9933333333333333
75
overall: 0.9883333333333333
black: 0.98
white: 0.9933333333333333
100
overall: 0.9783333333333334
black: 0.98
white: 0.9933333333333333

```



441.55330204963684

```

In [679]: def filteredGradient(im, sigma):
            def gprime(x,s):
                return (-1/(np.sqrt(2*np.pi)*s**3))*x*np.exp(-x**2/(2*s**2))

            # Gaussian of x, stdev s
            def g(x,s):

```

```

    return (1/(np.sqrt(2*np.pi)*s))*np.exp(-x**2/(2*s**2))

# First derivative of Gaussian - kernel with halfwidth halfw, stdev s
def gprimekernel(halfw,s):
    k = [gprime(x,s) for x in np.linspace(-halfw, halfw, 2*halfw)]
    return k

# Gaussian - kernel with halfwidth halfw, stdev s
def gkernel(halfw, s):
    k = [g(x,s) for x in np.linspace(-halfw, halfw, 2*halfw)]
    return k/np.sum(k)

halfw = 3*sigma

# create filters
x = np.expand_dims(gprimekernel(halfw,sigma),0)
xg = np.expand_dims(gkernel(halfw,sigma),0)
y = np.expand_dims(gprimekernel(halfw,sigma),1)
yg = np.expand_dims(gkernel(halfw,sigma),1)

# convolve
Fx = cv2.filter2D(im, -1, x)
Fx = cv2.filter2D(Fx, -1, xg)
Fy = cv2.filter2D(im, -1, y)
Fy = cv2.filter2D(Fy, -1, yg)

return Fx, Fy

```

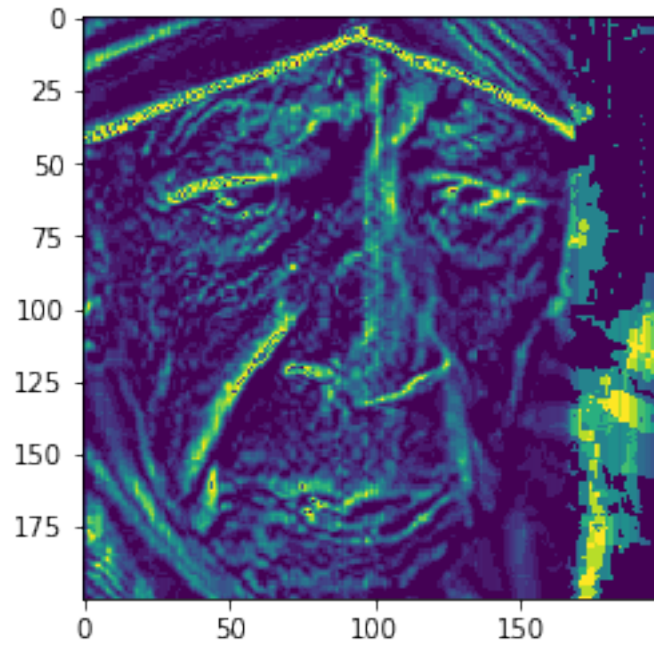
```
In [687]: from sklearn.preprocessing import MinMaxScaler
```

```
In [728]: def transform(im):
    return MinMaxScaler((0,255)).fit_transform(im).astype(np.uint8)
```

```
In [729]: def gradient_strength(im):
    Fx, Fy = filteredGradient(im, 1)
    return transform(np.array(np.sqrt(Fx**2 + Fy**2)))
```

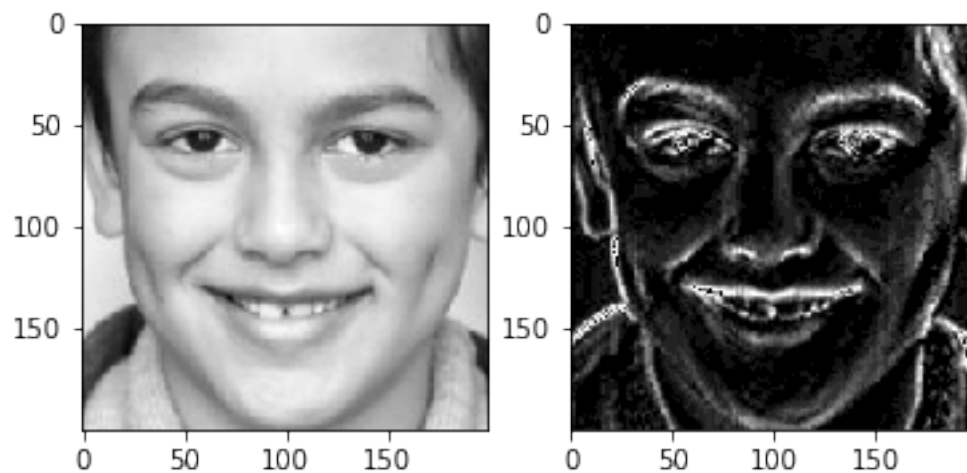
```
In [735]: plt.subplot(1,2,1)
    plt.imshow(np.array(faces_t)[w_inds[0]], cmap='gray')
    plt.subplot(1,2,2)
    plt.imshow(normalize(np.array(faces_t)[w_inds[0]]), cmap='gray')
    plt.imshow(gradient_strength(im))
```

```
Out[735]: <matplotlib.image.AxesImage at 0x1c5c317ad0>
```

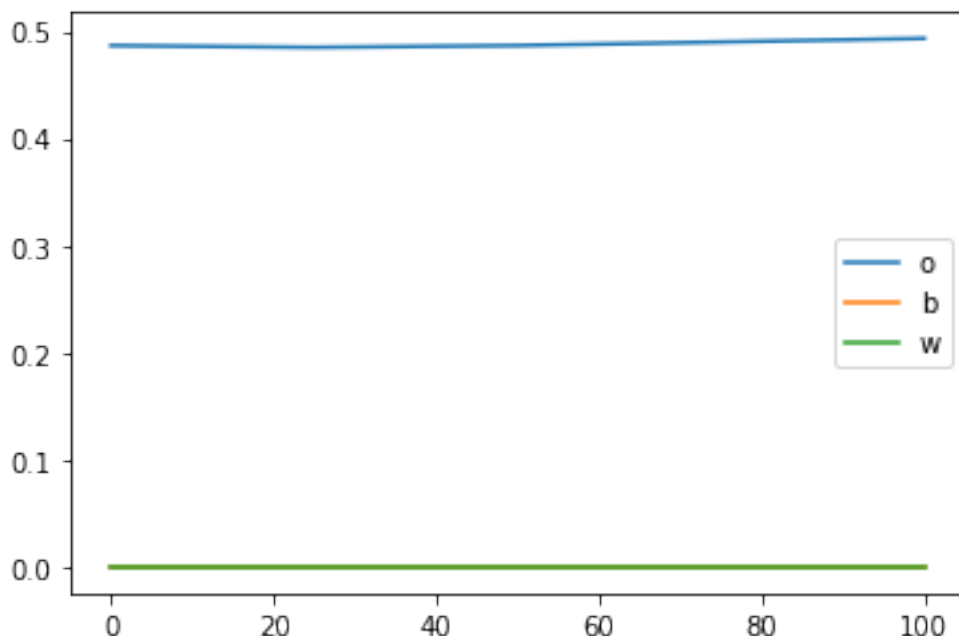
```
In [875]: plt.subplot(1,2,1)
plt.imshow(np.array(faces_t)[w_inds[0]], cmap='gray')
plt.subplot(1,2,2)
plt.imshow(gradient_strength(np.array(faces_t)[w_inds[0]]), cmap='gray')
```

Out [875]: <matplotlib.image.AxesImage at 0x1c6e1f9a10>



```
In [731]: pipeline(gradient_strength)
```

(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(8040, 900)
(600, 900)
0.4866666666666667
0.485
0.4866666666666667
0.49
0.4933333333333335
0
overall: 0.4866666666666667
black: 0.0
white: 0.0
25
overall: 0.485
black: 0.0
white: 0.0
50
overall: 0.4866666666666667
black: 0.0
white: 0.0
75
overall: 0.49
black: 0.0
white: 0.0
100
overall: 0.4933333333333335
black: 0.0
white: 0.0



547.8333580493927

7 Predicting skin tone from Haar features

In [448]: `X50[:4020].shape`

Out [448]: (4020, 900)

In [736]: `skintones = [int(face_filenames50[i].split('_')[3]) for i in range(n)]`

In [737]: `rfskin = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)`
`rfskin.fit(X50[:4020], skintones)`

Out [737]: `RandomForestClassifier(bootstrap=True, class_weight=None, criterion='gini', max_depth=None, max_features='auto', max_leaf_nodes=None, min_impurity_decrease=0.0, min_impurity_split=None, min_samples_leaf=1, min_samples_split=2, min_weight_fraction_leaf=0.0, n_estimators=1000, n_jobs=-1, oob_score=False, random_state=0, verbose=0, warm_start=False)`

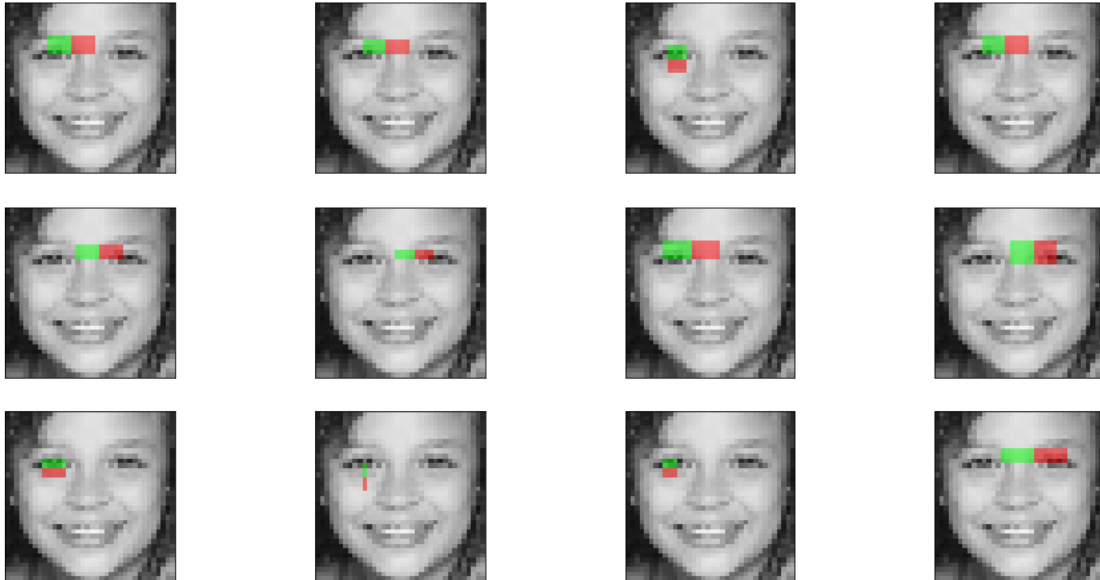
In [742]: `skintones_t = [int(test_face_names[i].split('_')[2]) for i in range(300)]`

In [744]: `rfskin.score(Xt_900[:300], skintones_t)`

Out [744]: 0.82

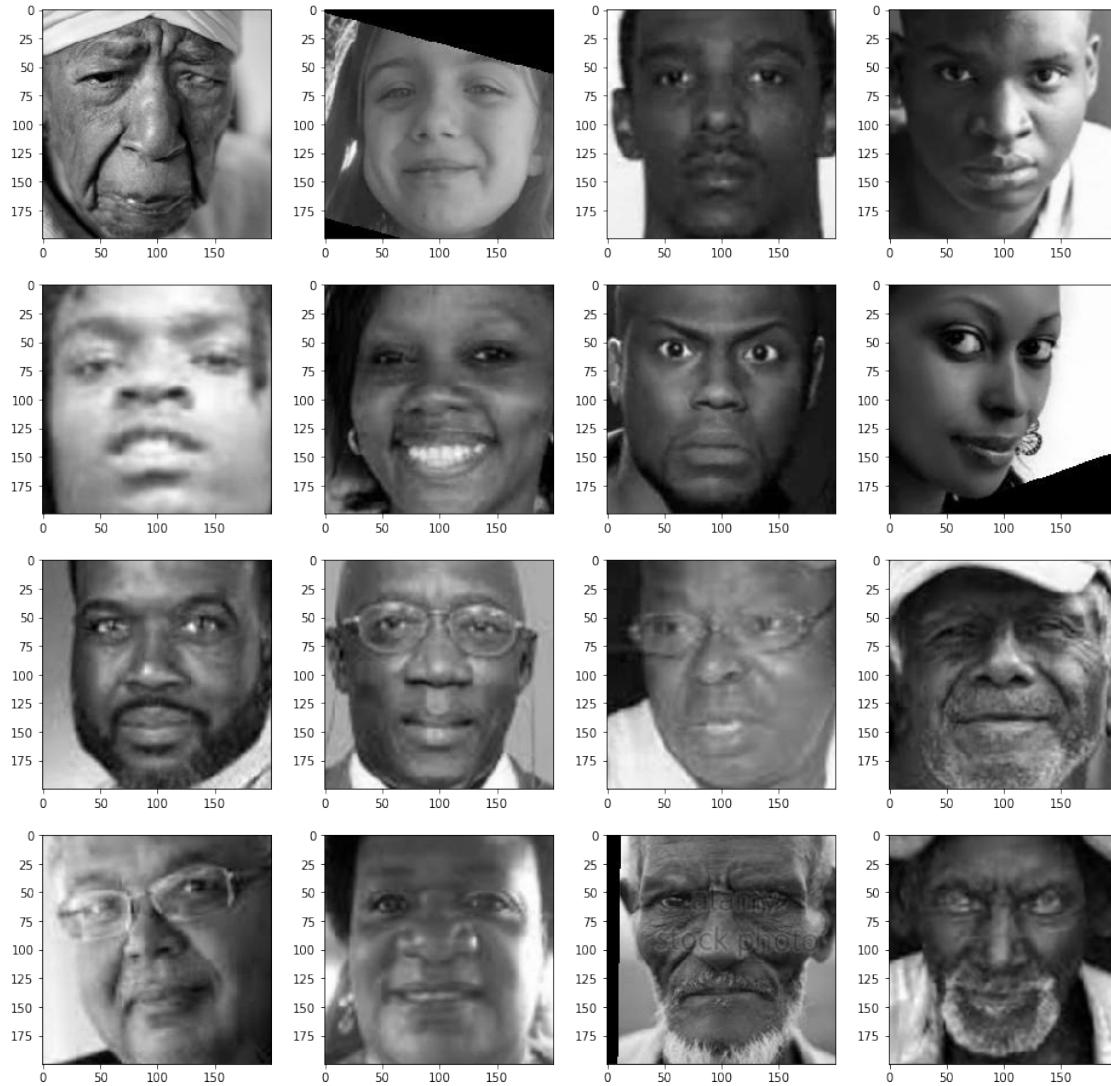
```
In [745]: gettop(test_face_names, rfskin)
```

The most important features



8 False Positives, False Negatives

```
In [755]: predictions0 = rf0.predict(Xt_900)
plt.subplots(4,4,figsize=(16,16))
count = 0
for i in range(300):
    if predictions0[i] != yt_900[i]:
        count += 1
        plt.subplot(4,4,count)
        plt.imshow(cv2.imread(test_face_names[i], cv2.IMREAD_GRAYSCALE), cmap='gray')
```

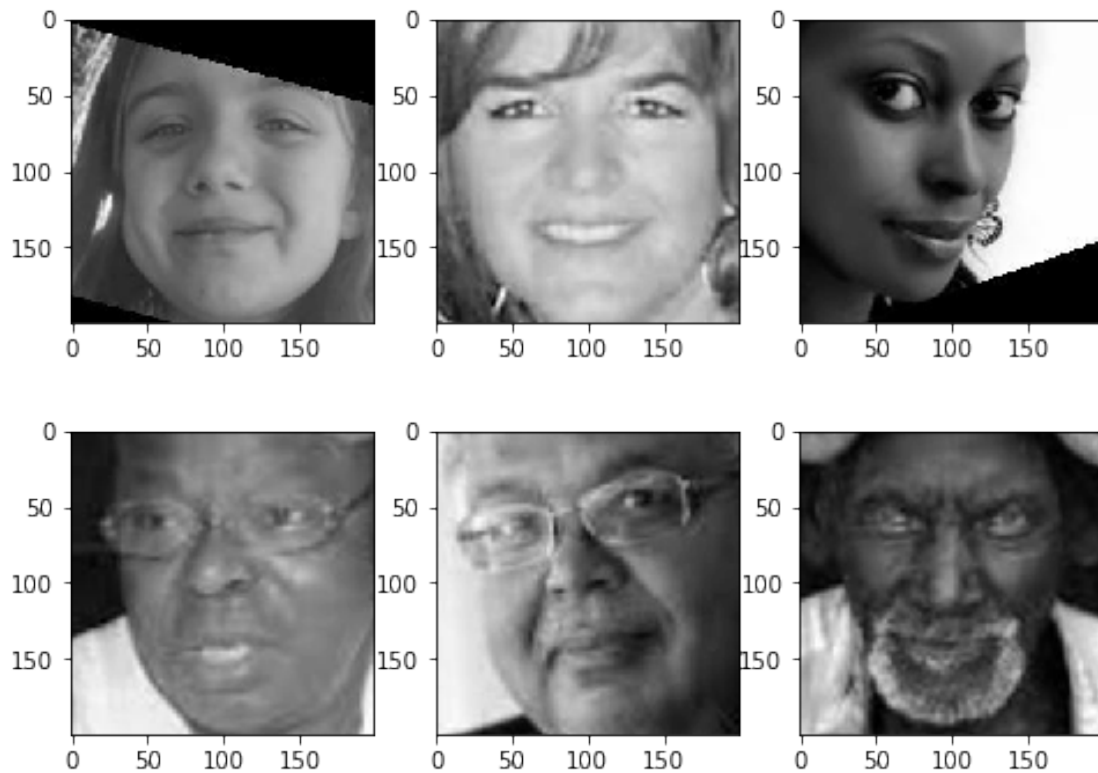


```
In [758]: count = 0
          for i in range(300,600):
              if predictions0[i] != yt_900[i]:
                  count += 1
          count
```

```
Out[758]: 0
```

```
In [767]: predictions50 = rf50.predict(Xt_900)
          plt.subplots(2,3,figsize=(8,6))
          count = 0
          for i in range(300):
              if predictions50[i] != yt_900[i]:
                  count += 1
```

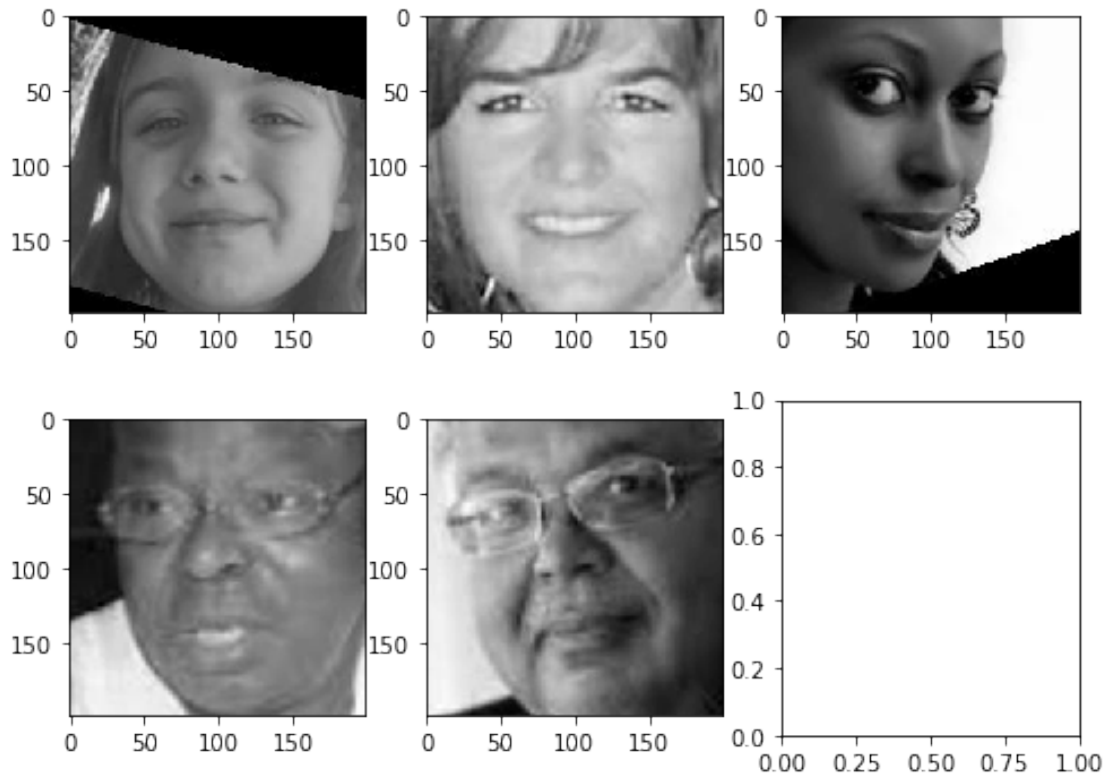
```
plt.subplot(2,3,count)
plt.imshow(cv2.imread(test_face_names[i], cv2.IMREAD_GRAYSCALE), cmap='gray')
```



```
In [768]: count = 0
          for i in range(300,600):
              if predictions50[i] != yt_900[i]:
                  count += 1
          count
```

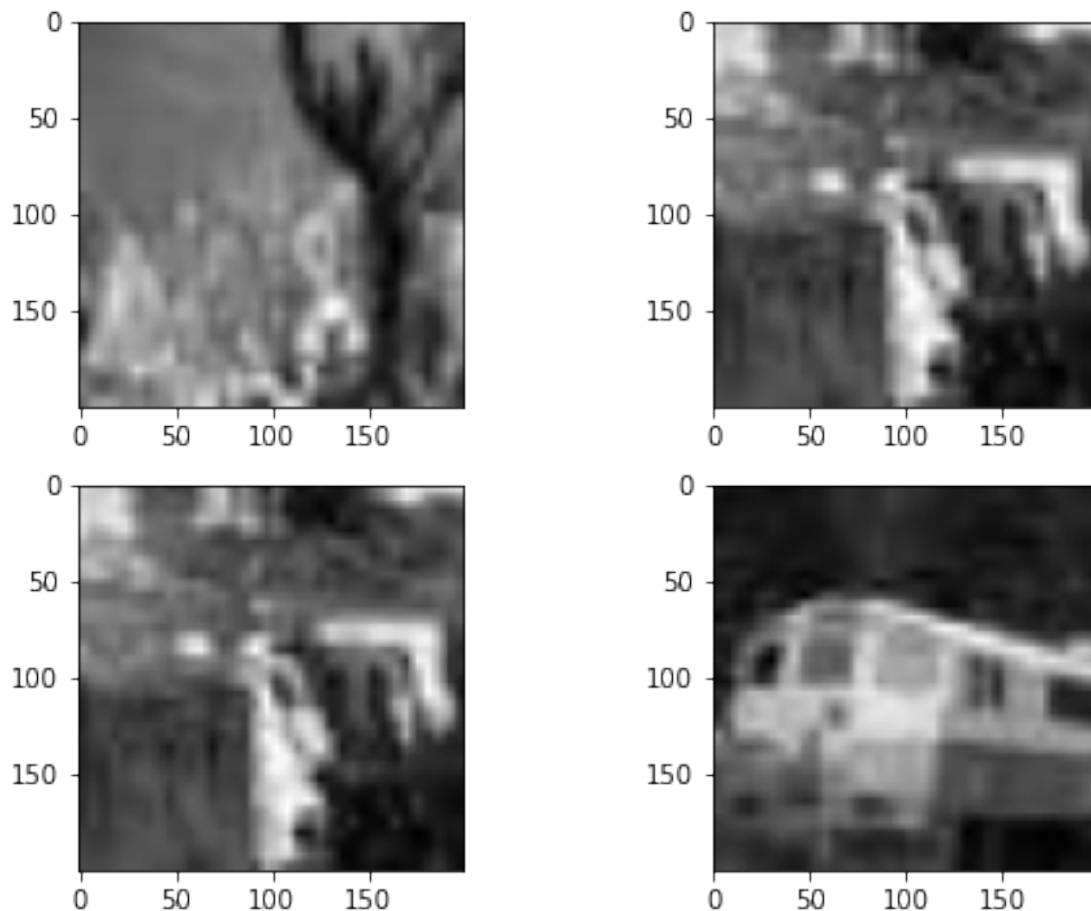
Out[768]: 0

```
In [769]: predictions100 = rf100.predict(Xt_900)
          plt.subplots(2,3,figsize=(8,6))
          count = 0
          for i in range(300):
              if predictions100[i] != yt_900[i]:
                  count += 1
                  plt.subplot(2,3,count)
                  plt.imshow(cv2.imread(test_face_names[i], cv2.IMREAD_GRAYSCALE), cmap='gray')
```



```
In [776]: count = 0
plt.subplots(2,2,figsize=(8,6))
for i in range(300,600):
    if predictions100[i] != yt_900[i]:
        count += 1
        plt.subplot(2,2,count)
        plt.imshow(nonfaces_t[i-300], cmap='gray')
count
```

Out[776]: 4



9 Combine HOG and Haar features

```
In [833]: # look at most important features as selected by randomforest
```

```
In [238]: from hog36 import hog36
```

```
In [787]: np.concatenate((np.array([[1,1],[2,2]]), np.array([[3],[3]])),axis=1)
```

```
Out[787]: array([[1, 1, 3],
                 [2, 2, 3]])
```

```
In [838]: hog0 = np.array([hog36(cv2.resize(im,(36,36)), 9, True) for im in getimgs(face_filenames)])
```

```
In [839]: hog0.shape
```

```
Out[839]: (8040, 900)
```

```
In [843]: X0h = np.concatenate((X0, hog0),axis=1)
```



```

In [844]: X0h.shape
Out[844]: (8040, 1800)

In [847]: hog25 = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(face_files)]
X25h = np.concatenate((X25, hog25),axis=1)

In [848]: hog50 = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(face_files)]
X50h = np.concatenate((X50, hog50),axis=1)

In [849]: hog75 = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(face_files)]
X75h = np.concatenate((X75, hog75),axis=1)

In [ ]: hog100 = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(face_files)]
X100h = np.concatenate((X100, hog100),axis=1)

In [240]: hog100 = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(face_files)]

In [241]: hogt = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(test_face_files)]

In [244]: y = np.array([1]*4020+[0]*4020)

In [245]: t_start = time()
h100 = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
h100.fit(hog100, y)
print(h100.score(hogt, y_t))
time() - t_start

0.99

Out[245]: 77.25064873695374

In [853]: hogt = np.array([hog36(cv2.resize(im,(36,36))), 9, True) for im in getimgs(test_face_files)]
Xt_900h = np.concatenate((Xt_900, hogt),axis=1)

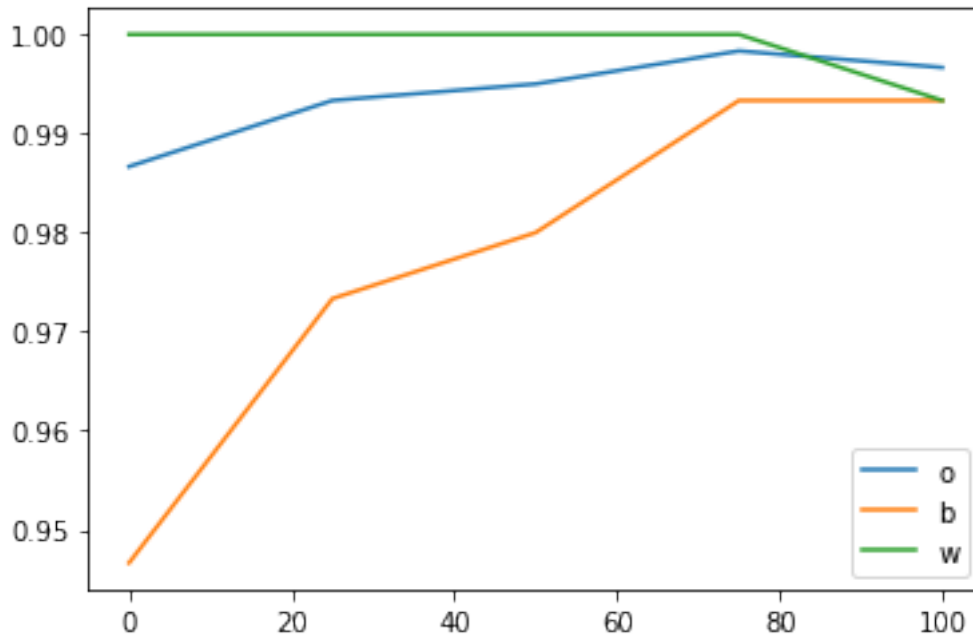
In [855]: rf0h = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
rf0h.fit(X0h, y)
print(rf0h.score(Xt_900h, y_t))
rf25h = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
rf25h.fit(X25h, y)
print(rf25h.score(Xt_900h, y_t))
rf50h = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
rf50h.fit(X50h, y)
print(rf50h.score(Xt_900h, y_t))
rf75h = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
rf75h.fit(X75h, y)
print(rf75h.score(Xt_900h, y_t))
rf100h = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random_state=0)
rf100h.fit(X100h, y)
print(rf100h.score(Xt_900h, y_t))

os_rh, bs_rh, ws_rh = rfcores([rf0h, rf25h, rf50h, rf75h, rf100h], Xt_900h, Xt_900h)

```

```
0.9866666666666667
0.9933333333333333
0.995
0.9983333333333333
0.9966666666666667
0
overall: 0.9866666666666667
black: 0.9466666666666667
white: 1.0
25
overall: 0.9933333333333333
black: 0.9733333333333334
white: 1.0
50
overall: 0.995
black: 0.98
white: 1.0
75
overall: 0.9983333333333333
black: 0.9933333333333333
white: 1.0
100
overall: 0.9966666666666667
black: 0.9933333333333333
white: 0.9933333333333333
```

```
In [856]: plt.plot([0, 25, 50, 75, 100], os_rh, label="o")
          plt.plot([0, 25, 50, 75, 100], bs_rh, label="b")
          plt.plot([0, 25, 50, 75, 100], ws_rh, label="w")
          plt.legend()
          plt.show()
```



```
In [857]: # top features
```

```
In [858]: idx_sortedh = np.argsort(rf75h.feature_importances_)[::-1]
```

```
In [883]: feats = list(zip(idx_sortedh, sorted(rf75h.feature_importances_, reverse=True)))
i = 0
for f in feats:
    if f[0] >= 900:
        print(i)
        break
i += 1
```

257

```
In [885]: rfskinh = RandomForestClassifier(n_estimators=1000, max_depth=None, n_jobs=-1, random
rfskinh.fit(hog50[:4020], skintones)
```

```
Out[885]: RandomForestClassifier(bootstrap=True, class_weight=None, criterion='gini',
max_depth=None, max_features='auto', max_leaf_nodes=None,
min_impurity_decrease=0.0, min_impurity_split=None,
min_samples_leaf=1, min_samples_split=2,
min_weight_fraction_leaf=0.0, n_estimators=1000,
n_jobs=-1, oob_score=False, random_state=0, verbose=0,
warm_start=False)
```

```
In [887]: hog50.shape, hogt.shape
```

```
Out[887]: ((8040, 900), (600, 900))
```

```
In [888]: rfskinh.score(hogt[:300], skintones_t)
```

```
Out[888]: 0.7866666666666666
```

10 Eigenfaces

```
In [2]: n = 4020
```

```
In [209]: images_t = np.array(images_t)
```

```
In [3]: def getims2(facefiles):  
    faces = []  
    for i in range(n):  
        faces.append(cv2.imread(facefiles[i], cv2.IMREAD_GRAYSCALE))  
    return np.array([cv2.resize(i,(36,36)).flatten() for i in faces])
```

```
In [21]: eigs50 = getims2(face_filenames50)
```

```
In [22]: eigs50.shape
```

```
Out[22]: (4020, 1296)
```

```
In [23]: eigs50
```

```
Out[23]: array([[251, 251, 251, ..., 213, 236, 235],  
                [ 23,  22,  20, ...,  12,  13,  16],  
                [ 55,  81, 113, ..., 236, 235, 234],  
                ...,  
                [174, 173, 171, ...,  89,  89,  87],  
                [ 67, 100, 162, ..., 136, 118, 122],  
                [ 49,  58,  60, ..., 107,  90,  89]], dtype=uint8)
```

```
In [24]: (np.sum(eigs50, axis=0)/len(eigs50)).shape
```

```
Out[24]: (1296,)
```

```
In [25]: mean50 = (np.sum(eigs50, axis=0)/len(eigs50))
```

```
In [249]: np.linalg.norm(m50-m0), np.linalg.norm(m50-m100)
```

```
Out[249]: (503.547752287338, 504.58659743690197)
```

```
In [27]: eigs50 = eigs50 - mean50
```

```
In [28]: eigs50
```

```
Out[28]: array([[164.76094527, 167.34925373, 168.03955224, ..., 113.87064677,
                135.52860697, 133.81616915],
               [-63.23905473, -61.65074627, -62.96044776, ..., -87.12935323,
                -87.47139303, -85.18383085],
               [-31.23905473, -2.65074627, 30.03955224, ..., 136.87064677,
                134.52860697, 132.81616915],
               ...,
               [ 87.76094527,  89.34925373,  88.03955224, ..., -10.12935323,
                -11.47139303, -14.18383085],
               [-19.23905473, 16.34925373, 79.03955224, ..., 36.87064677,
                17.52860697, 20.81616915],
               [-37.23905473, -25.65074627, -22.96044776, ..., 7.87064677,
                -10.47139303, -12.18383085]])
```

```
In [29]: eigs50.shape
```

```
Out[29]: (4020, 1296)
```

```
In [30]: t_start = time()
         cov = np.dot(np.transpose(eigs50), eigs50)
         time() - t_start
```

```
Out[30]: 0.13359594345092773
```

```
In [31]: cov.shape
```

```
Out[31]: (1296, 1296)
```

```
In [63]: w, v = np.linalg.eigh(cov)
```

```
In [64]: w
```

```
Out[64]: array([1.54126512e+04, 1.57645486e+04, 1.62259548e+04, ...,
                1.99973484e+09, 2.22327625e+09, 4.38198429e+09])
```

```
In [99]: np.linalg.norm(v[:,10])
```

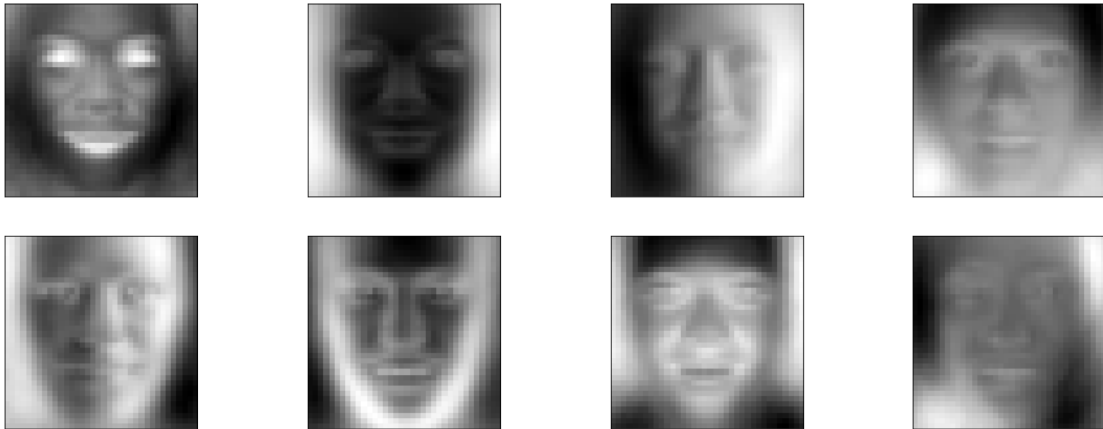
```
Out[99]: 1.0000000000000004
```

```
In [92]: fig, axes = plt.subplots(2,4, figsize=(16,6))
         for idx, ax in enumerate(axes.ravel()):
             image = v[:,1296-idx-1]
             ax.imshow(image.reshape(36,36), cmap='gray')
             ax.set_xticks([])
             ax.set_yticks([])
```

```
fig.suptitle('The most important features')
```

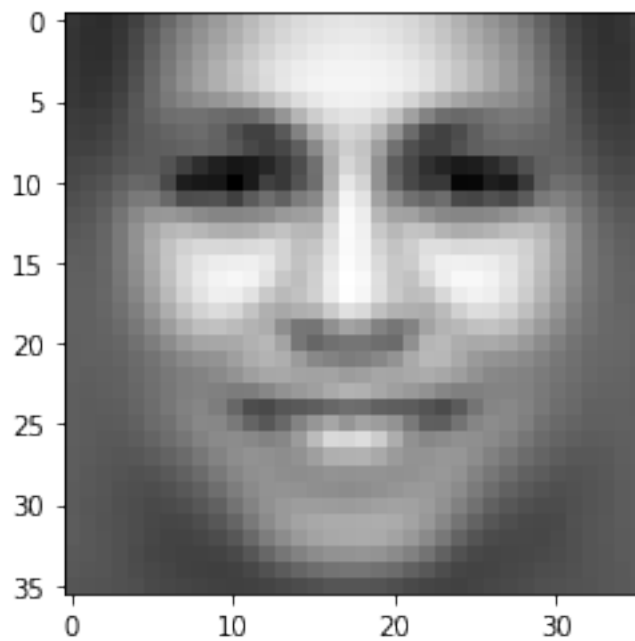
```
Out[92]: Text(0.5, 0.98, 'The most important features')
```

The most important features



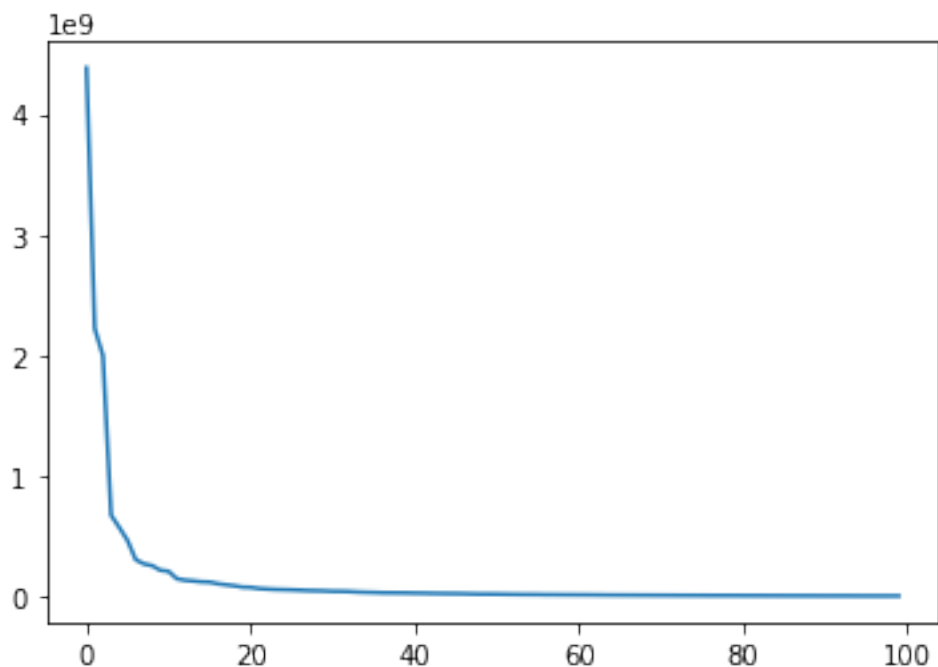
```
In [95]: plt.imshow(mean50.reshape(36,36), cmap='gray')
```

```
Out[95]: <matplotlib.image.AxesImage at 0x1c381aba10>
```



```
In [181]: plt.plot(sorted(w, reverse=True)[:100])
```

```
Out[181]: [<matplotlib.lines.Line2D at 0x1c38b3ae90>]
```



```
In [100]: for i in images_t:
           print(i)
```

```
[[192 194 196 ... 170 170 170]
 [194 192 189 ... 171 171 171]
 [191 188 183 ... 171 171 171]
 ...
 [192 185 174 ... 102 106 108]
 [185 185 180 ... 104 108 111]
 [177 183 186 ... 105 110 113]]
[[144 143 190 ... 238 228 225]
 [145 144 192 ... 232 227 228]
 [143 143 191 ... 230 228 228]
 ...
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 ...
 [134 135 135 ... 237 237 237]
 [135 136 137 ... 237 237 237]
 [133 135 137 ... 237 237 237]]
[[ 0 16 1 ... 0 0 0]
```

```

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[  0  1  6 ...  0  0  0]
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[  0  0  0 ... 122 131 136]
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 [133 117 103 ... 101 102 105]]
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 [ 35 41 46 ... 59 55 50]
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 [ 89 75 58 ... 61 58 54]
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 [ 65 71 80 ... 238 239 240]
 [ 62 68 77 ... 237 239 241]]

```



```

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 [ 82  79  74 ...  31  30  28]
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 [102  97  89 ...  85  98 116]

```

```

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[249 253 252 ... 254 254 254]

```

```

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...
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[ 41 42 43 ... 87 95 102]
[ 41 42 43 ... 85 93 100]
...

```

```

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```

```

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```

```

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 [ 77 77 77 ... 74 74 74]
...
 [135 135 135 ... 66 66 66]
 [135 135 135 ... 66 66 66]
 [135 135 135 ... 66 66 66]]
[[ 83 83 83 ... 108 108 108]
 [ 83 83 83 ... 108 108 108]
 [ 83 83 83 ... 108 108 108]
...
 [142 142 142 ... 59 59 59]

```

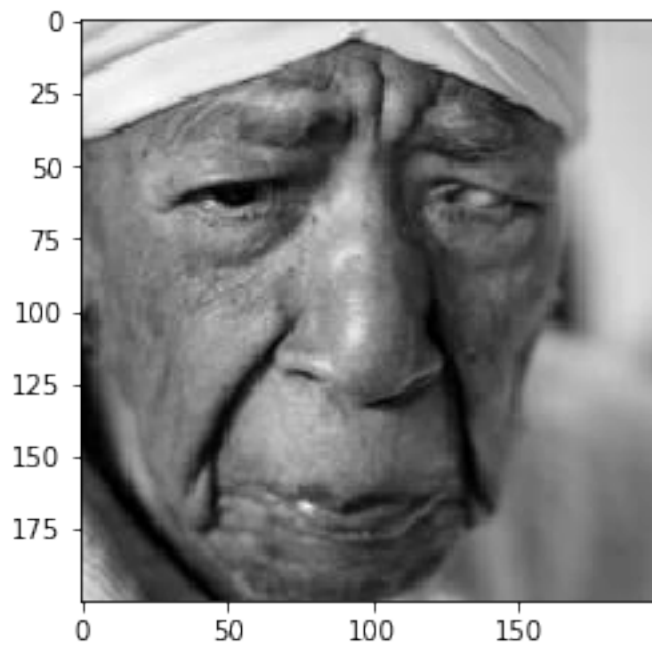
```
[142 142 142 ... 59 59 59]
[142 142 142 ... 59 59 59]]
```

```
In [102]: len(images_t)
```

```
Out[102]: 600
```

```
In [104]: plt.imshow(images_t[0], cmap='gray')
```

```
Out[104]: <matplotlib.image.AxesImage at 0x1c382b8310>
```



```
In [172]: phi = cv2.resize(images_t[0],(36,36)).flatten()-mean50
```

```
In [173]: topeigs50 = [v[:,1296-i-1] for i in range(30)]
```

```
In [174]: phi_hat = sum([np.dot(e, phi)*e for e in topeigs50])
```

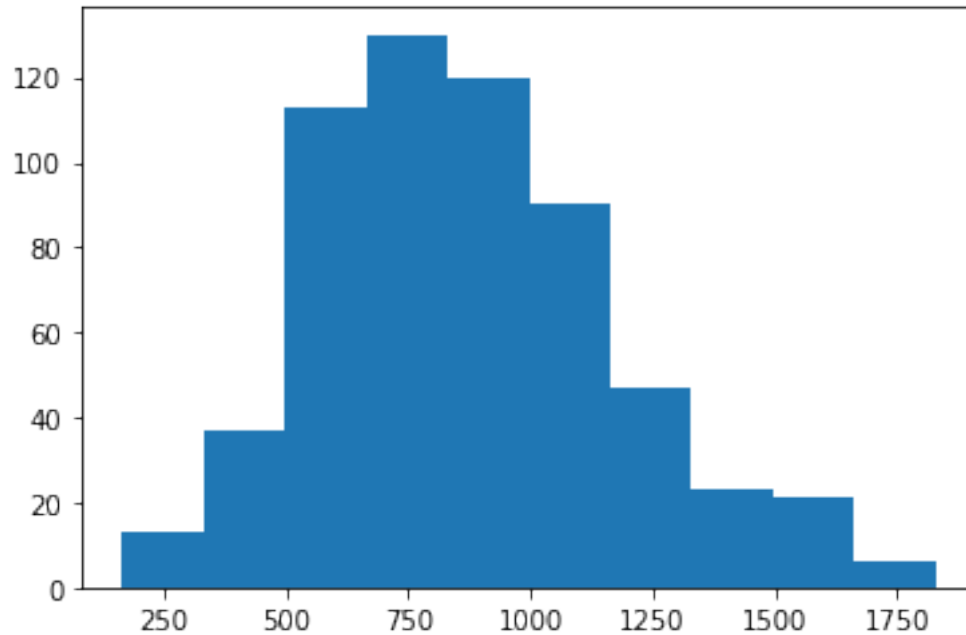
```
In [175]: np.linalg.norm(phi_hat - phi)
```

```
Out[175]: 943.7437068896014
```

```
In [163]: dists50 = []
          for i in range(len(images_t)):
              phi = cv2.resize(images_t[i],(36,36)).flatten()-mean50
              phi_hat = sum([np.dot(e, phi)*e for e in topeigs50])
              dist = np.linalg.norm(phi_hat - phi)
              dists50.append(dist)
```

```
In [164]: plt.hist(dists50)
```

```
Out[164]: (array([ 13.,  37., 113., 130., 120.,  90.,  47.,  23.,  21.,   6.]),
          array([ 163.83413921,  330.44617475,  497.0582103 ,  663.67024584,
                  830.28228139,  996.89431693, 1163.50635248, 1330.11838802,
                  1496.73042357, 1663.34245911, 1829.95449466]),
          <a list of 10 Patch objects>)
```



```
In [165]: y_t = np.array([1]*300 + [0]*300)
```

```
In [200]: def eigacc(t, m, topeigs, xt, yt):
           predictions = []
           for i in range(len(xt)):
               phi = cv2.resize(xt[i], (36,36)).flatten()-m
               phi_hat = sum([np.dot(e, phi)*e for e in topeigs])
               dist = np.linalg.norm(phi_hat - phi)
               if dist >= t:
                   predictions.append(0)
               else:
                   predictions.append(1)
           return getacc(predictions, yt)
```

```
In [202]: eigacc(1000, mean50, topeigs50, images_t, y_t)
```

```
Out[202]: 0.6699999999999999
```

```
In [170]: eigaccs = [eigacc(i) for i in range(600,1200,20)]
           np.max(eigaccs), np.argmax(eigaccs)*20+600
```


Out[170]: (0.6699999999999999, 1000)

```
In [193]: def eigfaces(face_filenames):
    eigs = getims2(face_filenames)
    m = (np.sum(eigs, axis=0)/len(eigs))
    eigs = eigs - m
    plt.imshow(m.reshape(36,36), cmap='gray')

    cov = np.dot(np.transpose(eigs), eigs)
    w, v = np.linalg.eigh(cov)

    topeigs = [v[:,1296-i-1] for i in range(30)]

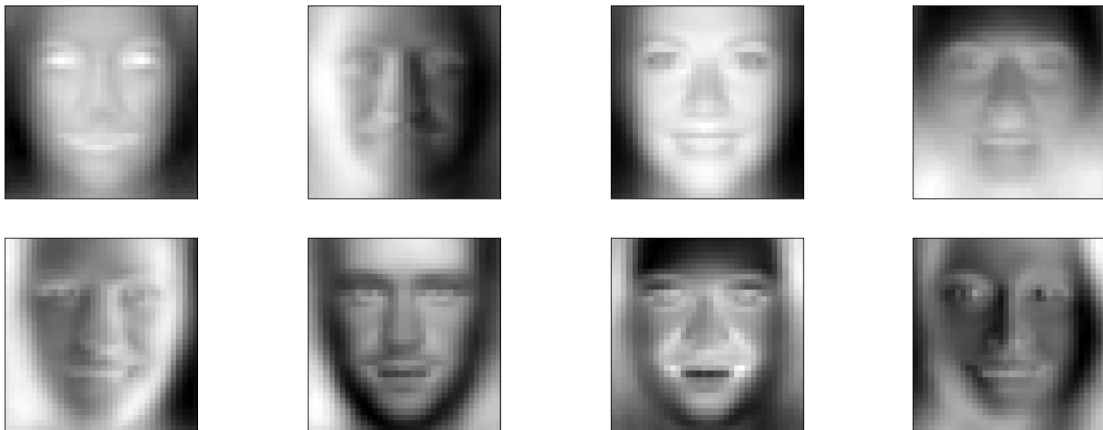
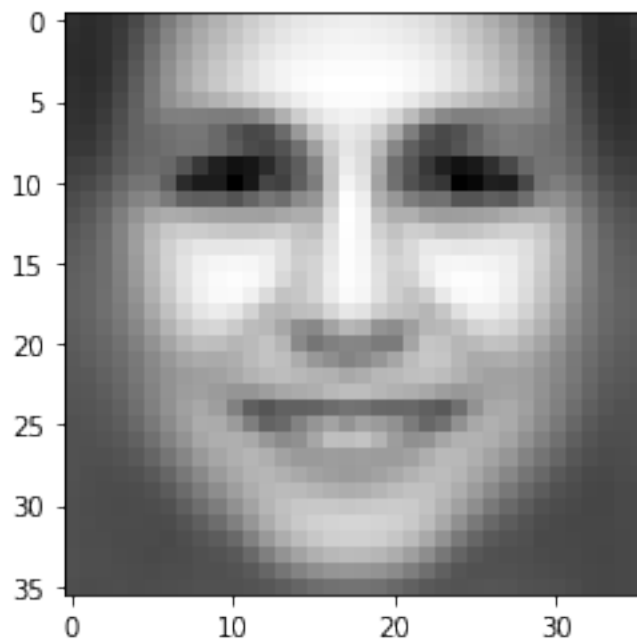
    fig, axes = plt.subplots(2,4, figsize=(16,6))
    for idx, ax in enumerate(axes.ravel()):
        image = v[:,1296-idx-1]
        ax.imshow(image.reshape(36,36), cmap='gray')
        ax.set_xticks([])
        ax.set_yticks([])

    dists = []
    for i in range(len(images_t)):
        phi = cv2.resize(images_t[i],(36,36)).flatten()-m
        phi_hat = sum([np.dot(e, phi)*e for e in topeigs])
        dist = np.linalg.norm(phi_hat - phi)
        dists.append(dist)

    return m, topeigs, w, v, dists

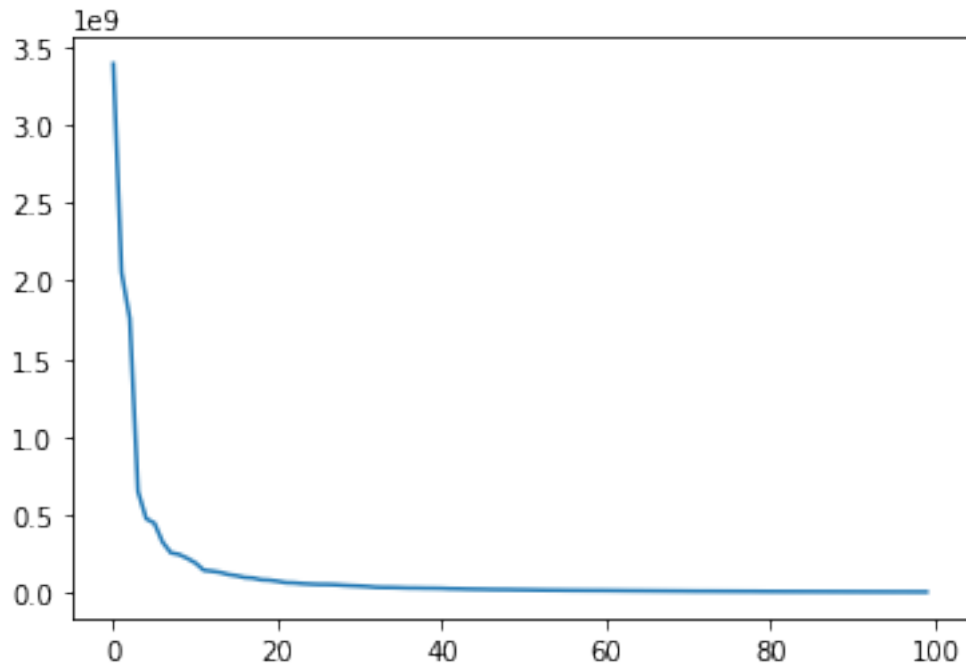
In [194]: t_start = time()
    m0, topeigs0, w0, v0, dists0 = eigfaces(face_filenames0)
    time() - t_start
```

Out[194]: 1.6849253177642822



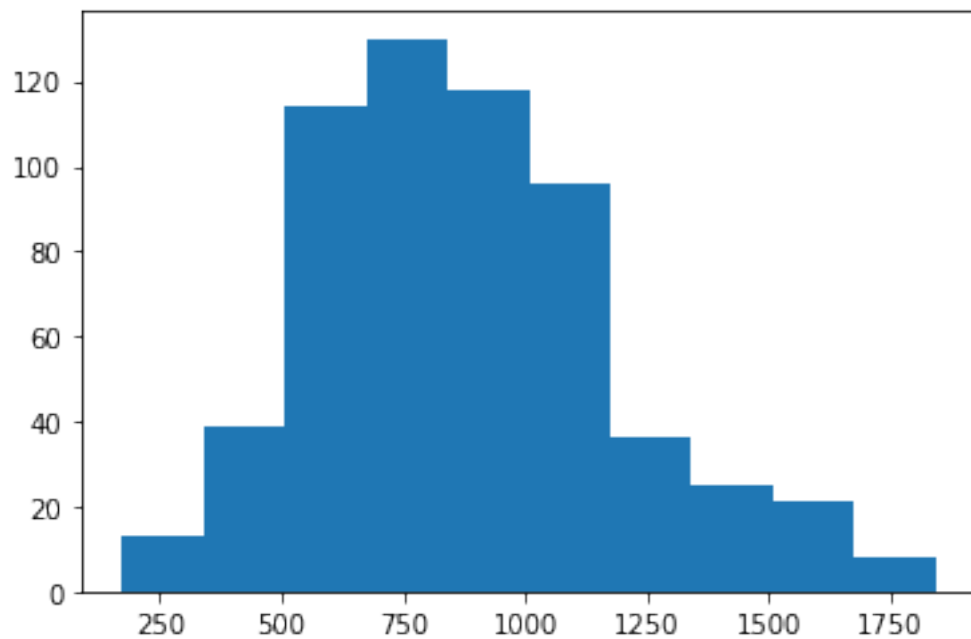
```
In [195]: plt.plot(sorted(w0, reverse=True)[:100])
```

```
Out[195]: [<matplotlib.lines.Line2D at 0x1c33ed5610>]
```



```
In [196]: plt.hist(dists0)
```

```
Out[196]: (array([ 13.,  39., 114., 130., 118.,  96.,  36.,  25.,  21.,   8.]),
          array([ 174.15630912,  340.93998797,  507.72366682,  674.50734567,
                  841.29102452, 1008.07470337, 1174.85838223, 1341.64206108,
                  1508.42573993, 1675.20941878, 1841.99309763])),
          <a list of 10 Patch objects>)
```



```
In [203]: eigaccs0 = [eigacc(i, m0, topeigs0, images_t, y_t) for i in range(600,1200,20)]  
          np.max(eigaccs0), np.argmax(eigaccs0)*20+600
```

```
Out[203]: (0.6666666666666667, 980)
```

```
In [214]: eigaccs0b = [eigacc(i, m0, topeigs0, images_t[b_inds], y_t[b_inds]) for i in range(600,1200,20)]  
          np.max(eigaccs0b), np.argmax(eigaccs0b)*20+600
```

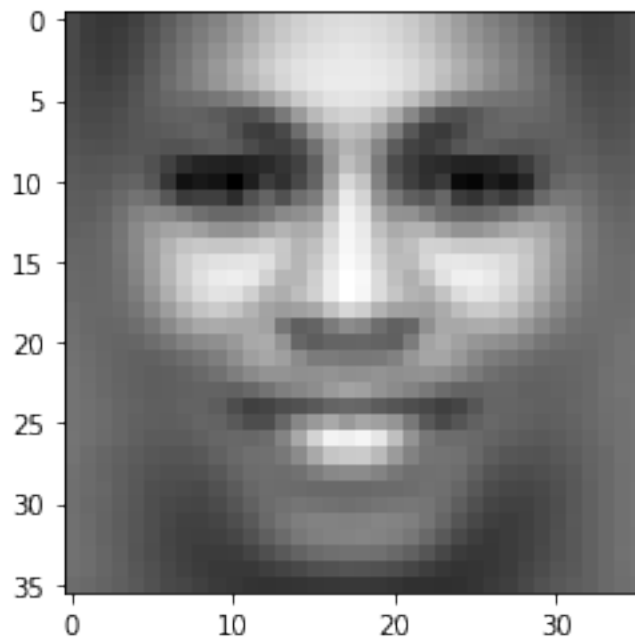
```
Out[214]: (0.94, 1180)
```

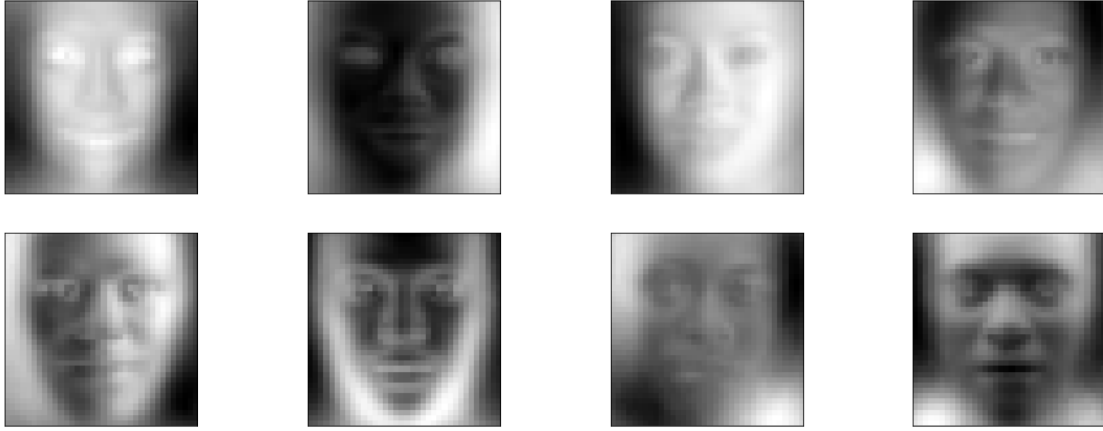
```
In [215]: eigaccs0w = [eigacc(i, m0, topeigs0, images_t[w_inds], y_t[w_inds]) for i in range(600,1200,20)]  
          np.max(eigaccs0w), np.argmax(eigaccs0w)*20+600
```

```
Out[215]: (0.9733333333333334, 1180)
```

```
In [198]: t_start = time()  
          m100, topeigs100, w100, v100, dists100 = eigfaces(face_filenames100)  
          time() - t_start
```

```
Out[198]: 3.6099929809570312
```





```
In [212]: eigaccs100 = [eigacc(i, m100, topeigs100, images_t, y_t) for i in range(600,1200,20)]
           np.max(eigaccs100), np.argmax(eigaccs100)*20+600
```

```
Out[212]: (0.6799999999999999, 1000)
```

```
In [216]: eigacc(1000, m100, topeigs100, images_t[b_inds], y_t[b_inds])
```

```
Out[216]: 0.8333333333333334
```

```
In [208]: images_t
```

```
Out[208]: [array([[192, 194, 196, ..., 170, 170, 170],
                  [194, 192, 189, ..., 171, 171, 171],
                  [191, 188, 183, ..., 171, 171, 171],
                  ...,
                  [192, 185, 174, ..., 102, 106, 108],
                  [185, 185, 180, ..., 104, 108, 111],
                  [177, 183, 186, ..., 105, 110, 113]], dtype=uint8),
          array([[144, 143, 190, ..., 238, 228, 225],
                  [145, 144, 192, ..., 232, 227, 228],
                  [143, 143, 191, ..., 230, 228, 228],
                  ...,
                  [160, 147, 144, ..., 212, 212, 212],
                  [151, 142, 147, ..., 210, 210, 210],
                  [158, 148, 153, ..., 209, 209, 209]], dtype=uint8),
          array([[188, 166, 142, ..., 123, 129, 120],
                  [199, 182, 158, ..., 94, 99, 126],
                  [192, 187, 171, ..., 101, 90, 125],
                  ...,
                  [134, 135, 135, ..., 237, 237, 237],
                  [135, 136, 137, ..., 237, 237, 237],
                  [133, 135, 137, ..., 237, 237, 237]], dtype=uint8),
```

```

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       ...,
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       [ 0,  0,  0, ..., 122, 132, 139]], dtype=uint8),
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       [65, 71, 80, ..., 238, 239, 240],

```

```

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       ...,
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```

```

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```



```

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```

```

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```

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```

```

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       [ 36,  36,  36, ..., 57, 57, 57],
       [ 36,  36,  36, ..., 57, 57, 57]], dtype=uint8),
array([[242, 242, 242, ..., 246, 246, 246],
       [242, 242, 242, ..., 246, 246, 246],
       [242, 242, 242, ..., 246, 246, 246],
       ...,
       [ 88,  88,  88, ..., 131, 131, 131],
       [ 88,  88,  88, ..., 131, 131, 131],
       [ 88,  88,  88, ..., 131, 131, 131]], dtype=uint8),
array([[ 67,  67,  67, ...,  65,  65,  65],
       [ 67,  67,  67, ...,  65,  65,  65],
       [ 67,  67,  67, ...,  65,  65,  65],
       ...,
       [ 19,  19,  19, ...,  31,  31,  31],
       [ 19,  19,  19, ...,  31,  31,  31],
       [ 19,  19,  19, ...,  31,  31,  31]], dtype=uint8),
array([[150, 150, 150, ..., 167, 167, 167],
       [150, 150, 150, ..., 167, 167, 167],
       [150, 150, 150, ..., 167, 167, 167],
       ...,
       [ 73,  73,  73, ...,  84,  84,  84],
       [ 73,  73,  73, ...,  84,  84,  84],
       [ 73,  73,  73, ...,  84,  84,  84]], dtype=uint8),
array([[ 77,  77,  77, ...,  74,  74,  74],
       [ 77,  77,  77, ...,  74,  74,  74],
       [ 77,  77,  77, ...,  74,  74,  74],
       ...,
       [135, 135, 135, ...,  66,  66,  66],
       [135, 135, 135, ...,  66,  66,  66],
       [135, 135, 135, ...,  66,  66,  66]], dtype=uint8),
array([[ 83,  83,  83, ..., 108, 108, 108],
       [ 83,  83,  83, ..., 108, 108, 108],
       [ 83,  83,  83, ..., 108, 108, 108],
       ...,

```

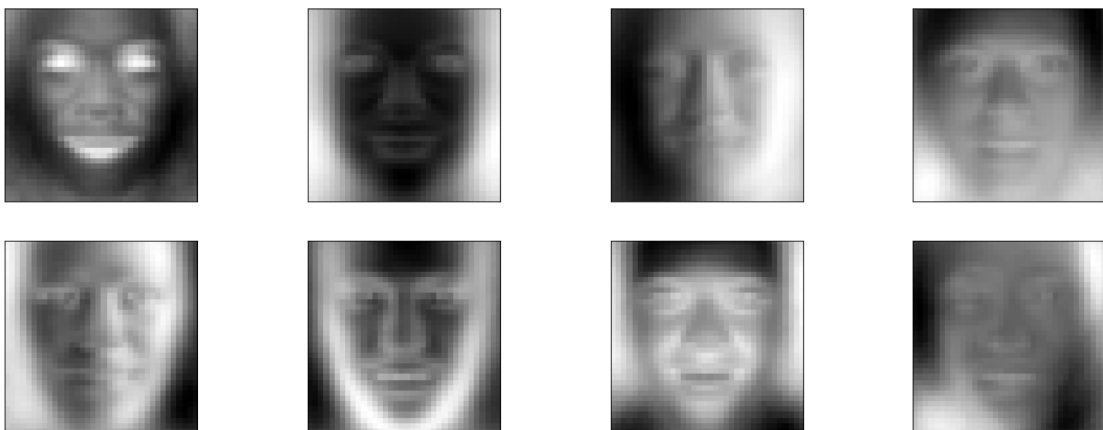
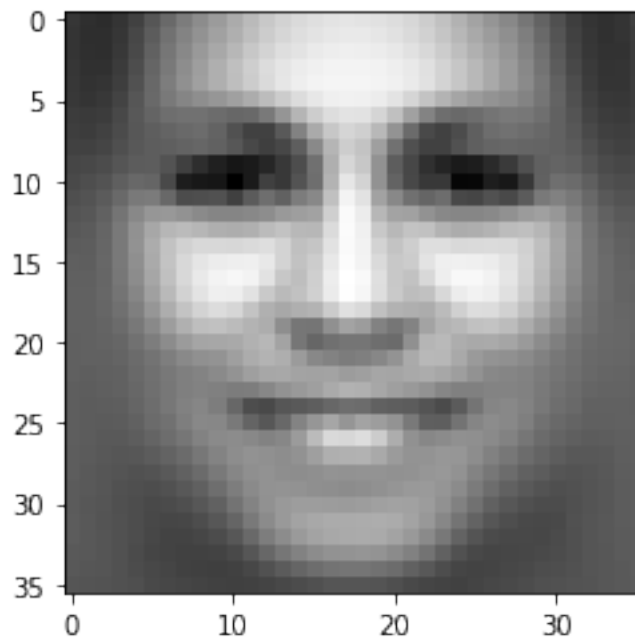
```
[142, 142, 142, ..., 59, 59, 59],
[142, 142, 142, ..., 59, 59, 59],
[142, 142, 142, ..., 59, 59, 59]], dtype=uint8)]
```

```
In [217]: eigacc(1000, m100, topeigs100, images_t[w_inds], y_t[w_inds])
```

```
Out[217]: 0.88
```

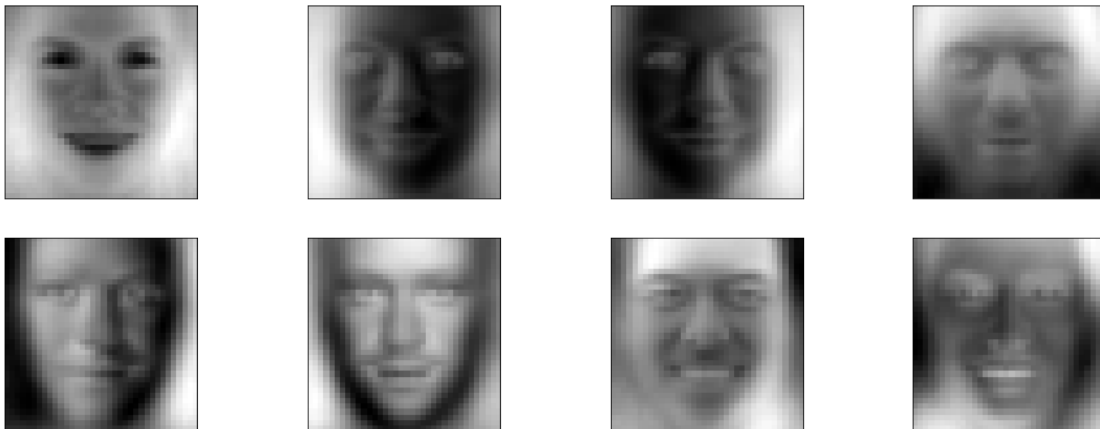
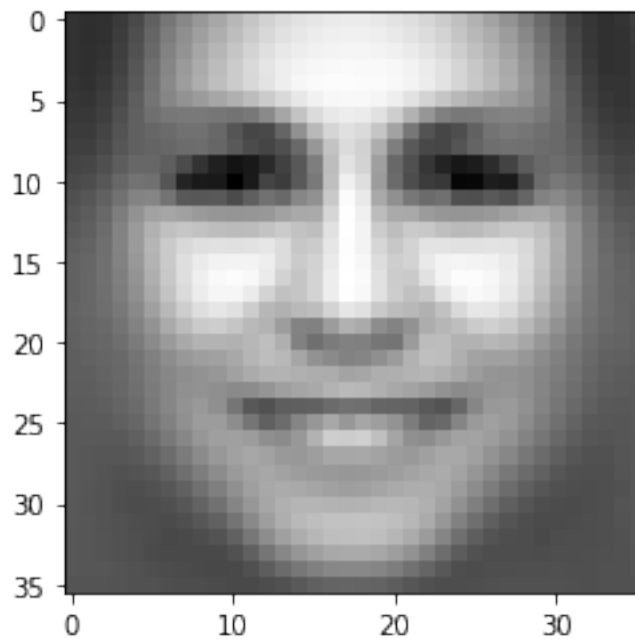
```
In [218]: m50, topeigs50, w50, v50, dists50 = eigfaces(face_filenames50)
          eigaccs50 = [eigacc(i, m50, topeigs50, images_t, y_t) for i in range(600,1200,20)]
          np.max(eigaccs50), np.argmax(eigaccs50)*20+600
```

```
Out[218]: (0.6699999999999999, 1000)
```



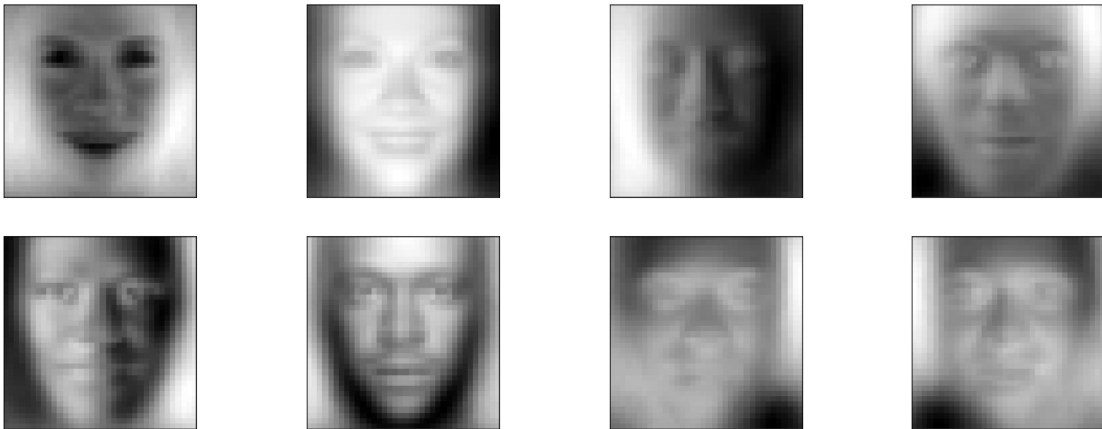
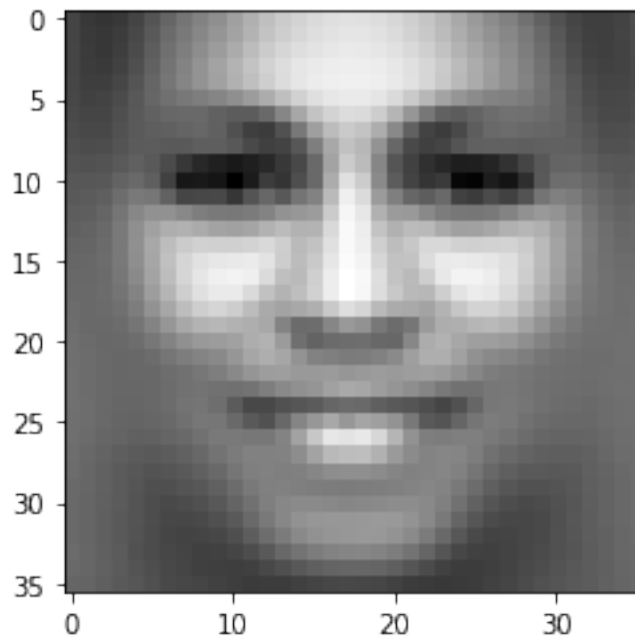
```
In [219]: m25, topeigs25, w25, v25, dists25 = eigfaces(face_filenames25)
          eigaccs25 = [eigacc(i, m25, topeigs25, images_t, y_t) for i in range(600,1200,20)]
          np.max(eigaccs25), np.argmax(eigaccs25)*20+600
```

```
Out[219]: (0.6716666666666666, 980)
```



```
In [220]: m75, topeigs75, w75, v75, dists75 = eigfaces(face_filenames75)
          eigaccs75 = [eigacc(i, m75, topeigs75, images_t, y_t) for i in range(600,1200,20)]
          np.max(eigaccs75), np.argmax(eigaccs75)*20+600
```

Out [220]: (0.675, 1000)



```
In [223]: os_e = []
          bs_e = []
          ws_e = []
          ms = [m0, m25, m50, m75, m100]
          topeigs = [topeigs0, topeigs25, topeigs50, topeigs75, topeigs100]
          thresholds = [980, 980, 1000, 1000, 1000]
          for i in range(5):
              accb = eigacc(thresholds[i], ms[i], topeigs[i], images_t[b_inds], y_t[b_inds])
```

```

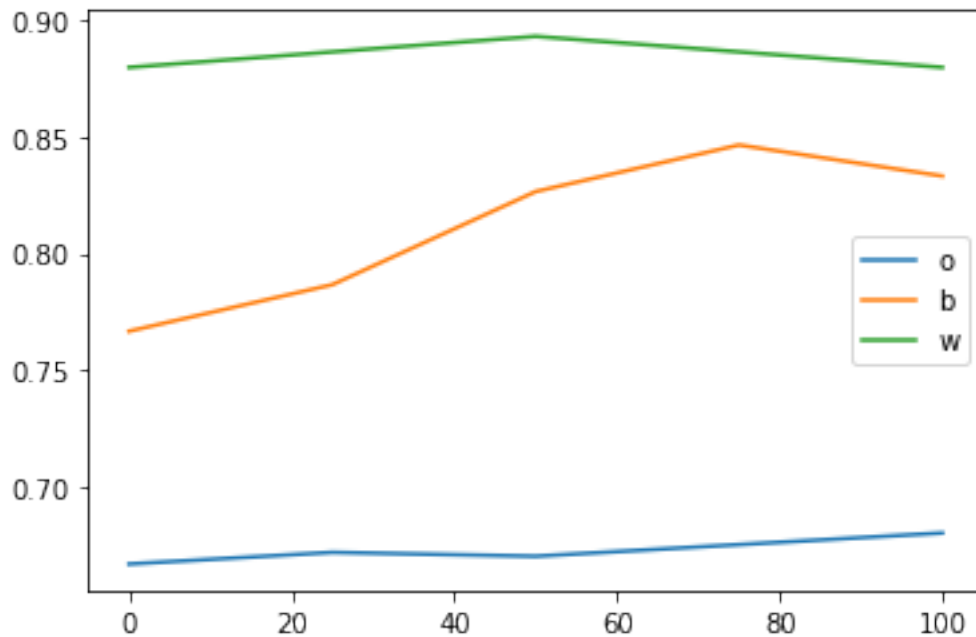
accw = eigacc(thresholds[i], ms[i], topeigs[i], images_t[w_inds], y_t[w_inds])
acco = eigacc(thresholds[i], ms[i], topeigs[i], images_t, y_t)
os_e.append(acco)
bs_e.append(accb)
ws_e.append(accw)

```

```

In [225]: plt.plot([0,25,50,75,100],os_e,label='o')
plt.plot([0,25,50,75,100],bs_e,label='b')
plt.plot([0,25,50,75,100],ws_e,label='w')
plt.legend()
plt.show()

```



```

In [ ]: # distributions of distances from the average face

```

```

In [251]: mean50.shape

```

```

Out[251]: (1296,)

```

```

In [ ]: def getims2(facefiles):
    faces = []
    for i in range(n):
        faces.append(cv2.imread(facefiles[i], cv2.IMREAD_GRAYSCALE))
    return np.array([cv2.resize(i,(36,36)).flatten() for i in faces])

```

```

In [252]: ims0 = getims2(face_filenames0)

```

```

In [253]: ims100 = getims2(face_filenames100)

```



```

In [254]: ims0.shape
Out[254]: (4020, 1296)

In [259]: distsw = []
          for i in ims0:
              distsw.append(np.linalg.norm(i-mean50))

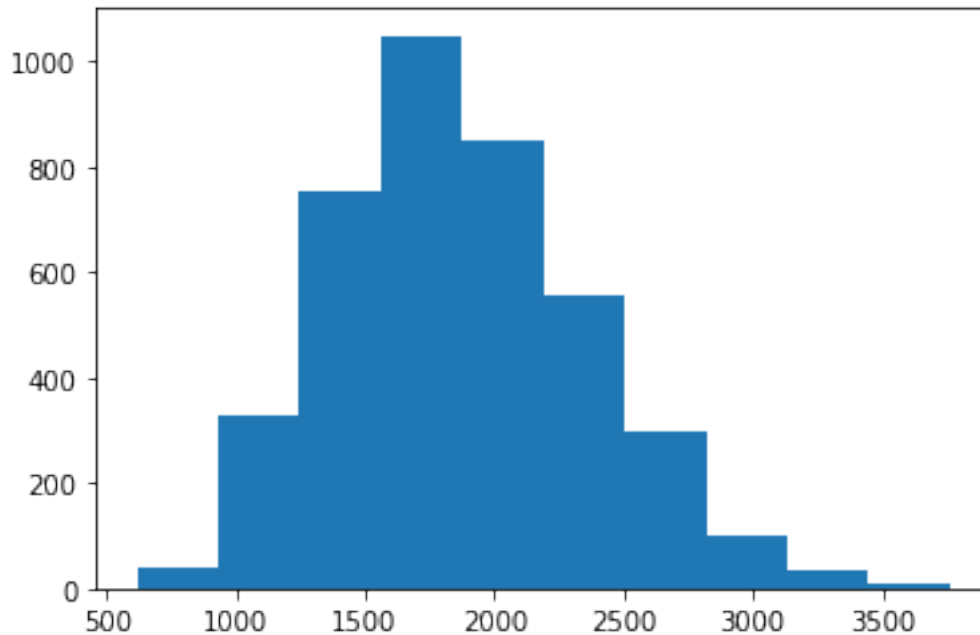
In [269]: distsw2 = []
          for i in ims0:
              distsw2.append(np.linalg.norm(i-m0))

In [260]: distsb = []
          for i in ims100:
              distsb.append(np.linalg.norm(i-mean50))

In [270]: distsb2 = []
          for i in ims100:
              distsb2.append(np.linalg.norm(i-m100))

In [261]: plt.hist(distsw)
Out[261]: (array([ 39., 328., 754., 1049., 852., 555., 299., 101., 34.,
                    9.]),
          array([ 617.71616792, 932.18219123, 1246.64821453, 1561.11423783,
                  1875.58026114, 2190.04628444, 2504.51230775, 2818.97833105,
                  3133.44435435, 3447.91037766, 3762.37640096]),
          <a list of 10 Patch objects>)

```

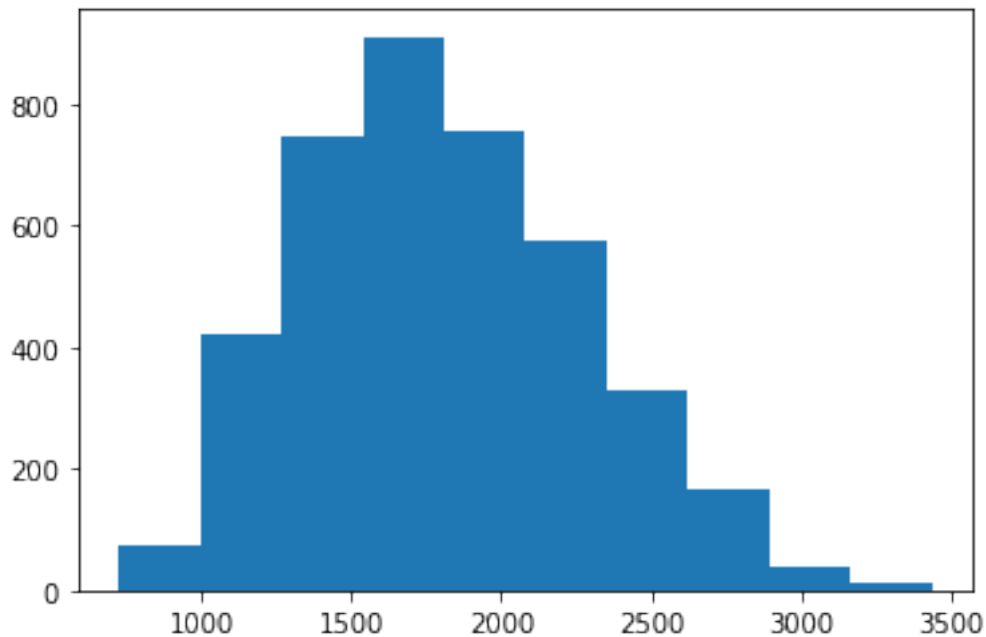


```
In [276]: np.mean(distsw), np.mean(distsb), np.mean(distsw2), np.mean(distsb2)
```

```
Out[276]: (1869.6707644840901, 1962.2139549077804, 1807.56507047241, 1891.9402963025414)
```

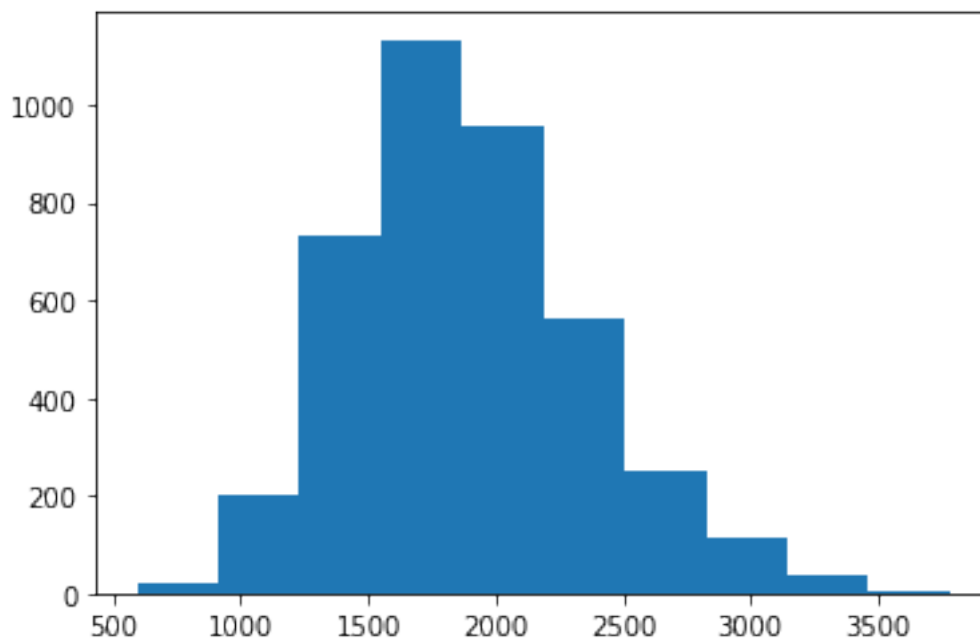
```
In [271]: plt.hist(distsw2)
```

```
Out[271]: (array([ 74., 419., 745., 910., 754., 575., 328., 164., 37., 14.]),  
          array([ 724.02784211, 995.254272 , 1266.48070189, 1537.70713178,  
                  1808.93356167, 2080.15999156, 2351.38642145, 2622.61285134,  
                  2893.83928123, 3165.06571112, 3436.29214101]),  
          <a list of 10 Patch objects>)
```



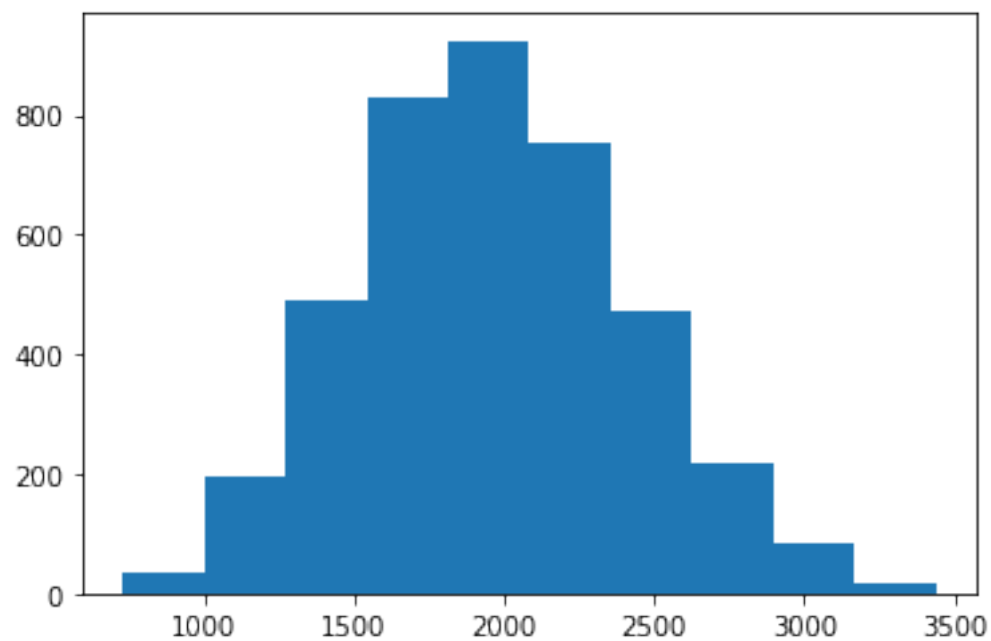
```
In [272]: plt.hist(distsb2)
```

```
Out[272]: (array([ 20., 203., 733., 1133., 959., 562., 251., 116., 36.,  
                  7.]),  
          array([ 591.56920186, 910.72751111, 1229.88582035, 1549.04412959,  
                  1868.20243883, 2187.36074808, 2506.51905732, 2825.67736656,  
                  3144.8356758 , 3463.99398505, 3783.15229429]),  
          <a list of 10 Patch objects>)
```



```
In [262]: plt.hist(distsb)
```

```
Out[262]: (array([ 33., 197., 491., 831., 924., 752., 471., 217., 85., 19.]),
  array([ 728.61126505, 999.5562729 , 1270.50128075, 1541.44628859,
    1812.39129644, 2083.33630429, 2354.28131214, 2625.22631999,
    2896.17132784, 3167.11633569, 3438.06134354]),
  <a list of 10 Patch objects>)
```



```
In [ ]:
```