Deep face recognition

Environment setup

In [1]:
```
import bz2
import os

from urllib.request import urlopen

def download_landmarks(dst_file):
    url = 'http://dlib.net/files/shape_predictor_68_face_landmarks.dat.bz2'
    decompressor = bz2.BZ2Decompressor()

    with urlopen(url) as src, open(dst_file, 'wb') as dst:
        data = src.read(1024)
        while len(data) > 0:
            dst.write(decompressor.decompress(data))
            data = src.read(1024)

dst_dir = 'models'
dst_file = os.path.join(dst_dir, 'landmarks.dat')

if not os.path.exists(dst_file):
    os.makedirs(dst_dir)
    download_landmarks(dst_file)
```

CNN architecture and training

In [2]:
```
import tensorflow as tf
import numpy as np
import os

from numpy import genfromtxt
from keras.layers import Conv2D, ZeroPadding2D, Activation
from tensorflow.keras.layers import (
    BatchNormalization, SeparableConv2D, MaxPooling2D,AveragePooling2D, Activation, Flatten, Dropout, Dense
)

_FLOATX = 'float32'
```

```
def variable(value, dtype=_FLOATX, name=None):
  v = tf.Variable(np.asarray(value, dtype=dtype), name=name)
  _get_session().run(v.initializer)
  return v

def shape(x):
  return x.get_shape()

def square(x):
  return tf.square(x)

def zeros(shape, dtype=_FLOATX, name=None):
  return variable(np.zeros(shape), dtype, name)

def concatenate(tensors, axis=-1):
  if axis < 0:
      axis = axis % len(tensors[0].get_shape())
  return tf.concat(axis, tensors)

def LRN2D(x):
  return tf.nn.lrn(x, alpha=1e-4, beta=0.75)

def conv2d_bn(
  x,
  layer=None,
  cv1_out=None,
  cv1_filter=(1, 1),
  cv1_strides=(1, 1),
  cv2_out=None,
  cv2_filter=(3, 3),
  cv2_strides=(1, 1),
  padding=None,
):
  num = '' if cv2_out == None else '1'
  tensor = Conv2D(cv1_out, cv1_filter, strides=cv1_strides, name=layer+'_conv'+num)(x)
  tensor = BatchNormalization(axis=3, epsilon=0.00001, name=layer+'_bn'+num)(tensor)
  tensor = Activation('relu')(tensor)
  if padding == None:
    return tensor
  tensor = ZeroPadding2D(padding=padding)(tensor)
  if cv2_out == None:
    return tensor
  tensor = Conv2D(cv2_out, cv2_filter, strides=cv2_strides, name=layer+'_conv'+'2')(tensor)
  tensor = BatchNormalization(axis=3, epsilon=0.00001, name=layer+'_bn'+'2')(tensor)
```

```
  tensor = Activation('relu')(tensor)
  return tensor

weights = [
  'conv1', 'bn1', 'conv2', 'bn2', 'conv3', 'bn3',
  'inception_3a_1x1_conv', 'inception_3a_1x1_bn',
  'inception_3a_pool_conv', 'inception_3a_pool_bn',
  'inception_3a_5x5_conv1', 'inception_3a_5x5_conv2', 'inception_3a_5x5_bn1', 'inception_3a_5x5_bn2',
  'inception_3a_3x3_conv1', 'inception_3a_3x3_conv2', 'inception_3a_3x3_bn1', 'inception_3a_3x3_bn2',
  'inception_3b_3x3_conv1', 'inception_3b_3x3_conv2', 'inception_3b_3x3_bn1', 'inception_3b_3x3_bn2',
  'inception_3b_5x5_conv1', 'inception_3b_5x5_conv2', 'inception_3b_5x5_bn1', 'inception_3b_5x5_bn2',
  'inception_3b_pool_conv', 'inception_3b_pool_bn',
  'inception_3b_1x1_conv', 'inception_3b_1x1_bn',
  'inception_3c_3x3_conv1', 'inception_3c_3x3_conv2', 'inception_3c_3x3_bn1', 'inception_3c_3x3_bn2',
  'inception_3c_5x5_conv1', 'inception_3c_5x5_conv2', 'inception_3c_5x5_bn1', 'inception_3c_5x5_bn2',
  'inception_4a_3x3_conv1', 'inception_4a_3x3_conv2', 'inception_4a_3x3_bn1', 'inception_4a_3x3_bn2',
  'inception_4a_5x5_conv1', 'inception_4a_5x5_conv2', 'inception_4a_5x5_bn1', 'inception_4a_5x5_bn2',
  'inception_4a_pool_conv', 'inception_4a_pool_bn',
  'inception_4a_1x1_conv', 'inception_4a_1x1_bn',
  'inception_4e_3x3_conv1', 'inception_4e_3x3_conv2', 'inception_4e_3x3_bn1', 'inception_4e_3x3_bn2',
  'inception_4e_5x5_conv1', 'inception_4e_5x5_conv2', 'inception_4e_5x5_bn1', 'inception_4e_5x5_bn2',
  'inception_5a_3x3_conv1', 'inception_5a_3x3_conv2', 'inception_5a_3x3_bn1', 'inception_5a_3x3_bn2',
  'inception_5a_pool_conv', 'inception_5a_pool_bn',
  'inception_5a_1x1_conv', 'inception_5a_1x1_bn',
  'inception_5b_3x3_conv1', 'inception_5b_3x3_conv2', 'inception_5b_3x3_bn1', 'inception_5b_3x3_bn2',
  'inception_5b_pool_conv', 'inception_5b_pool_bn',
  'inception_5b_1x1_conv', 'inception_5b_1x1_bn',
  'dense_layer'
]

conv_shape = {
  'conv1': [64, 3, 7, 7],
  'conv2': [64, 64, 1, 1],
  'conv3': [192, 64, 3, 3],
  'inception_3a_1x1_conv': [64, 192, 1, 1],
  'inception_3a_pool_conv': [32, 192, 1, 1],
  'inception_3a_5x5_conv1': [16, 192, 1, 1],
  'inception_3a_5x5_conv2': [32, 16, 5, 5],
  'inception_3a_3x3_conv1': [96, 192, 1, 1],
  'inception_3a_3x3_conv2': [128, 96, 3, 3],
  'inception_3b_3x3_conv1': [96, 256, 1, 1],
  'inception_3b_3x3_conv2': [128, 96, 3, 3],
  'inception_3b_5x5_conv1': [32, 256, 1, 1],
  'inception_3b_5x5_conv2': [64, 32, 5, 5],
  'inception_3b_pool_conv': [64, 256, 1, 1],
```

```
  'inception_3b_1x1_conv': [64, 256, 1, 1],
  'inception_3c_3x3_conv1': [128, 320, 1, 1],
  'inception_3c_3x3_conv2': [256, 128, 3, 3],
  'inception_3c_5x5_conv1': [32, 320, 1, 1],
  'inception_3c_5x5_conv2': [64, 32, 5, 5],
  'inception_4a_3x3_conv1': [96, 640, 1, 1],
  'inception_4a_3x3_conv2': [192, 96, 3, 3],
  'inception_4a_5x5_conv1': [32, 640, 1, 1,],
  'inception_4a_5x5_conv2': [64, 32, 5, 5],
  'inception_4a_pool_conv': [128, 640, 1, 1],
  'inception_4a_1x1_conv': [256, 640, 1, 1],
  'inception_4e_3x3_conv1': [160, 640, 1, 1],
  'inception_4e_3x3_conv2': [256, 160, 3, 3],
  'inception_4e_5x5_conv1': [64, 640, 1, 1],
  'inception_4e_5x5_conv2': [128, 64, 5, 5],
  'inception_5a_3x3_conv1': [96, 1024, 1, 1],
  'inception_5a_3x3_conv2': [384, 96, 3, 3],
  'inception_5a_pool_conv': [96, 1024, 1, 1],
  'inception_5a_1x1_conv': [256, 1024, 1, 1],
  'inception_5b_3x3_conv1': [96, 736, 1, 1],
  'inception_5b_3x3_conv2': [384, 96, 3, 3],
  'inception_5b_pool_conv': [96, 736, 1, 1],
  'inception_5b_1x1_conv': [256, 736, 1, 1],
}

def load_weights():
  weightsDir = './weights'
  fileNames = filter(lambda f: not f.startswith('.'), os.listdir(weightsDir))
  paths = {}
  weights_dict = {}

  for n in fileNames:
    paths[n.replace('.csv', '')] = weightsDir + '/' + n

  for name in weights:
    if 'conv' in name:
      conv_w = genfromtxt(paths[name + '_w'], delimiter=',', dtype=None)
      conv_w = np.reshape(conv_w, conv_shape[name])
      conv_w = np.transpose(conv_w, (2, 3, 1, 0))
      conv_b = genfromtxt(paths[name + '_b'], delimiter=',', dtype=None)
      weights_dict[name] = [conv_w, conv_b]
    elif 'bn' in name:
      bn_w = genfromtxt(paths[name + '_w'], delimiter=',', dtype=None)
      bn_b = genfromtxt(paths[name + '_b'], delimiter=',', dtype=None)
      bn_m = genfromtxt(paths[name + '_m'], delimiter=',', dtype=None)
```

```
      bn_v = genfromtxt(paths[name + '_v'], delimiter=',', dtype=None)
      weights_dict[name] = [bn_w, bn_b, bn_m, bn_v]
    elif 'dense' in name:
      dense_w = genfromtxt(weightsDir+'/dense_w.csv', delimiter=',', dtype=None)
      dense_w = np.reshape(dense_w, (128, 736))
      dense_w = np.transpose(dense_w, (1, 0))
      dense_b = genfromtxt(weightsDir+'/dense_b.csv', delimiter=',', dtype=None)
      weights_dict[name] = [dense_w, dense_b]

  return weights_dict
```

```
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:541: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_qint8 = np.dtype([("qint8", np.int8, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:542: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_quint8 = np.dtype([("quint8", np.uint8, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:543: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_qint16 = np.dtype([("qint16", np.int16, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:544: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_quint16 = np.dtype([("quint16", np.uint16, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:545: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_qint32 = np.dtype([("qint32", np.int32, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:550: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  np_resource = np.dtype([("resource", np.ubyte, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:541: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_qint8 = np.dtype([("qint8", np.int8, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:542: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_quint8 = np.dtype([("quint8", np.uint8, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:543: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_qint16 = np.dtype([("qint16", np.int16, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:544: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_quint16 = np.dtype([("quint16", np.uint16, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:545: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  _np_qint32 = np.dtype([("qint32", np.int32, 1)])
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\tensorboard\compat\tensorflow_stub\dtypes.py:550: FutureWarning:
```

```
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future version of numpy, it will be understood as
(type, (1,)) / '(1,)type'.
  np_resource = np.dtype([("resource", np.ubyte, 1)])
```

In [3]:

```python
from keras.layers import Conv2D, ZeroPadding2D, Activation, Input, concatenate
from keras.layers.core import Lambda, Flatten, Dense


from tensorflow.keras.layers import (
    BatchNormalization, SeparableConv2D, MaxPooling2D,AveragePooling2D, Activation, Flatten, Dropout, Dense
)
from keras.models import Model
from keras import backend as K


#from utils import LRN2D

def create_model():
    myInput = Input(shape=(96, 96, 3))

    x = ZeroPadding2D(padding=(3, 3), input_shape=(96, 96, 3))(myInput)
    x = Conv2D(64, (7, 7), strides=(2, 2), name='conv1')(x)
    x = BatchNormalization(axis=3, epsilon=0.00001, name='bn1')(x)
    x = Activation('relu')(x)
    x = ZeroPadding2D(padding=(1, 1))(x)
    x = MaxPooling2D(pool_size=3, strides=2)(x)
    x = Lambda(LRN2D, name='lrn_1')(x)
    x = Conv2D(64, (1, 1), name='conv2')(x)
    x = BatchNormalization(axis=3, epsilon=0.00001, name='bn2')(x)
    x = Activation('relu')(x)
    x = ZeroPadding2D(padding=(1, 1))(x)
    x = Conv2D(192, (3, 3), name='conv3')(x)
    x = BatchNormalization(axis=3, epsilon=0.00001, name='bn3')(x)
    x = Activation('relu')(x)
    x = Lambda(LRN2D, name='lrn_2')(x)
    x = ZeroPadding2D(padding=(1, 1))(x)
    x = MaxPooling2D(pool_size=3, strides=2)(x)

    # Inception3a
    inception_3a_3x3 = Conv2D(96, (1, 1), name='inception_3a_3x3_conv1')(x)
    inception_3a_3x3 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3a_3x3_bn1')(inception_3a_3x3)
    inception_3a_3x3 = Activation('relu')(inception_3a_3x3)
    inception_3a_3x3 = ZeroPadding2D(padding=(1, 1))(inception_3a_3x3)
    inception_3a_3x3 = Conv2D(128, (3, 3), name='inception_3a_3x3_conv2')(inception_3a_3x3)
    inception_3a_3x3 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3a_3x3_bn2')(inception_3a_3x3)
```

```
inception_3a_3x3 = Activation('relu')(inception_3a_3x3)

inception_3a_5x5 = Conv2D(16, (1, 1), name='inception_3a_5x5_conv1')(x)
inception_3a_5x5 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3a_5x5_bn1')(inception_3a_5x5)
inception_3a_5x5 = Activation('relu')(inception_3a_5x5)
inception_3a_5x5 = ZeroPadding2D(padding=(2, 2))(inception_3a_5x5)
inception_3a_5x5 = Conv2D(32, (5, 5), name='inception_3a_5x5_conv2')(inception_3a_5x5)
inception_3a_5x5 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3a_5x5_bn2')(inception_3a_5x5)
inception_3a_5x5 = Activation('relu')(inception_3a_5x5)

inception_3a_pool = MaxPooling2D(pool_size=3, strides=2)(x)
inception_3a_pool = Conv2D(32, (1, 1), name='inception_3a_pool_conv')(inception_3a_pool)
inception_3a_pool = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3a_pool_bn')(inception_3a_pool)
inception_3a_pool = Activation('relu')(inception_3a_pool)
inception_3a_pool = ZeroPadding2D(padding=((3, 4), (3, 4)))(inception_3a_pool)

inception_3a_1x1 = Conv2D(64, (1, 1), name='inception_3a_1x1_conv')(x)
inception_3a_1x1 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3a_1x1_bn')(inception_3a_1x1)
inception_3a_1x1 = Activation('relu')(inception_3a_1x1)

inception_3a = concatenate([inception_3a_3x3, inception_3a_5x5, inception_3a_pool, inception_3a_1x1], axis=3)

# Inception3b
inception_3b_3x3 = Conv2D(96, (1, 1), name='inception_3b_3x3_conv1')(inception_3a)
inception_3b_3x3 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3b_3x3_bn1')(inception_3b_3x3)
inception_3b_3x3 = Activation('relu')(inception_3b_3x3)
inception_3b_3x3 = ZeroPadding2D(padding=(1, 1))(inception_3b_3x3)
inception_3b_3x3 = Conv2D(128, (3, 3), name='inception_3b_3x3_conv2')(inception_3b_3x3)
inception_3b_3x3 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3b_3x3_bn2')(inception_3b_3x3)
inception_3b_3x3 = Activation('relu')(inception_3b_3x3)

inception_3b_5x5 = Conv2D(32, (1, 1), name='inception_3b_5x5_conv1')(inception_3a)
inception_3b_5x5 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3b_5x5_bn1')(inception_3b_5x5)
inception_3b_5x5 = Activation('relu')(inception_3b_5x5)
inception_3b_5x5 = ZeroPadding2D(padding=(2, 2))(inception_3b_5x5)
inception_3b_5x5 = Conv2D(64, (5, 5), name='inception_3b_5x5_conv2')(inception_3b_5x5)
inception_3b_5x5 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3b_5x5_bn2')(inception_3b_5x5)
inception_3b_5x5 = Activation('relu')(inception_3b_5x5)

inception_3b_pool = AveragePooling2D(pool_size=(3, 3), strides=(3, 3))(inception_3a)
inception_3b_pool = Conv2D(64, (1, 1), name='inception_3b_pool_conv')(inception_3b_pool)
inception_3b_pool = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3b_pool_bn')(inception_3b_pool)
inception_3b_pool = Activation('relu')(inception_3b_pool)
inception_3b_pool = ZeroPadding2D(padding=(4, 4))(inception_3b_pool)
```

```
    inception_3b_1x1 = Conv2D(64, (1, 1), name='inception_3b_1x1_conv')(inception_3a)
    inception_3b_1x1 = BatchNormalization(axis=3, epsilon=0.00001, name='inception_3b_1x1_bn')(inception_3b_1x1)
    inception_3b_1x1 = Activation('relu')(inception_3b_1x1)

    inception_3b = concatenate([inception_3b_3x3, inception_3b_5x5, inception_3b_pool, inception_3b_1x1], axis=3)

    # Inception3c
    inception_3c_3x3 = conv2d_bn(inception_3b,
                                 layer='inception_3c_3x3',
                                 cv1_out=128,
                                 cv1_filter=(1, 1),
                                 cv2_out=256,
                                 cv2_filter=(3, 3),
                                 cv2_strides=(2, 2),
                                 padding=(1, 1))

    inception_3c_5x5 = conv2d_bn(inception_3b,
                                 layer='inception_3c_5x5',
                                 cv1_out=32,
                                 cv1_filter=(1, 1),
                                 cv2_out=64,
                                 cv2_filter=(5, 5),
                                 cv2_strides=(2, 2),
                                 padding=(2, 2))

    inception_3c_pool = MaxPooling2D(pool_size=3, strides=2)(inception_3b)
    inception_3c_pool = ZeroPadding2D(padding=((0, 1), (0, 1)))(inception_3c_pool)

    inception_3c = concatenate([inception_3c_3x3, inception_3c_5x5, inception_3c_pool], axis=3)

    #inception 4a
    inception_4a_3x3 = conv2d_bn(inception_3c,
                                 layer='inception_4a_3x3',
                                 cv1_out=96,
                                 cv1_filter=(1, 1),
                                 cv2_out=192,
                                 cv2_filter=(3, 3),
                                 cv2_strides=(1, 1),
                                 padding=(1, 1))
    inception_4a_5x5 =conv2d_bn(inception_3c,
                                 layer='inception_4a_5x5',
                                 cv1_out=32,
                                 cv1_filter=(1, 1),
                                 cv2_out=64,
                                 cv2_filter=(5, 5),
```

```
                                    cv2_strides=(1, 1),
                                    padding=(2, 2))

    inception_4a_pool = AveragePooling2D(pool_size=(3, 3), strides=(3, 3))(inception_3c)
    inception_4a_pool = conv2d_bn(inception_4a_pool,
                                     layer='inception_4a_pool',
                                     cv1_out=128,
                                     cv1_filter=(1, 1),
                                     padding=(2, 2))
    inception_4a_1x1 =conv2d_bn(inception_3c,
                                    layer='inception_4a_1x1',
                                    cv1_out=256,
                                    cv1_filter=(1, 1))
    inception_4a = concatenate([inception_4a_3x3, inception_4a_5x5, inception_4a_pool, inception_4a_1x1], axis=3)

    #inception4e
    inception_4e_3x3 = conv2d_bn(inception_4a,
                                    layer='inception_4e_3x3',
                                    cv1_out=160,
                                    cv1_filter=(1, 1),
                                    cv2_out=256,
                                    cv2_filter=(3, 3),
                                    cv2_strides=(2, 2),
                                    padding=(1, 1))
    inception_4e_5x5 = conv2d_bn(inception_4a,
                                    layer='inception_4e_5x5',
                                    cv1_out=64,
                                    cv1_filter=(1, 1),
                                    cv2_out=128,
                                    cv2_filter=(5, 5),
                                    cv2_strides=(2, 2),
                                    padding=(2, 2))
    inception_4e_pool = MaxPooling2D(pool_size=3, strides=2)(inception_4a)
    inception_4e_pool = ZeroPadding2D(padding=((0, 1), (0, 1)))(inception_4e_pool)

    inception_4e = concatenate([inception_4e_3x3, inception_4e_5x5, inception_4e_pool], axis=3)

    #inception5a
    inception_5a_3x3 = conv2d_bn(inception_4e,
                                    layer='inception_5a_3x3',
                                    cv1_out=96,
                                    cv1_filter=(1, 1),
                                    cv2_out=384,
                                    cv2_filter=(3, 3),
                                    cv2_strides=(1, 1),
```

```
                                    padding=(1, 1))

    inception_5a_pool = AveragePooling2D(pool_size=(3, 3), strides=(3, 3))(inception_4e)
    inception_5a_pool = conv2d_bn(inception_5a_pool,
                                     layer='inception_5a_pool',
                                     cv1_out=96,
                                     cv1_filter=(1, 1),
                                     padding=(1, 1))
    inception_5a_1x1 = conv2d_bn(inception_4e,
                                    layer='inception_5a_1x1',
                                    cv1_out=256,
                                    cv1_filter=(1, 1))

    inception_5a = concatenate([inception_5a_3x3, inception_5a_pool, inception_5a_1x1], axis=3)

    #inception_5b
    inception_5b_3x3 = conv2d_bn(inception_5a,
                                    layer='inception_5b_3x3',
                                    cv1_out=96,
                                    cv1_filter=(1, 1),
                                    cv2_out=384,
                                    cv2_filter=(3, 3),
                                    cv2_strides=(1, 1),
                                    padding=(1, 1))
    inception_5b_pool = MaxPooling2D(pool_size=3, strides=2)(inception_5a)
    inception_5b_pool = conv2d_bn(inception_5b_pool,
                                     layer='inception_5b_pool',
                                     cv1_out=96,
                                     cv1_filter=(1, 1))
    inception_5b_pool = ZeroPadding2D(padding=(1, 1))(inception_5b_pool)

    inception_5b_1x1 =conv2d_bn(inception_5a,
                                    layer='inception_5b_1x1',
                                    cv1_out=256,
                                    cv1_filter=(1, 1))
    inception_5b = concatenate([inception_5b_3x3, inception_5b_pool, inception_5b_1x1], axis=3)

    av_pool = AveragePooling2D(pool_size=(3, 3), strides=(1, 1))(inception_5b)
    reshape_layer = Flatten()(av_pool)
    dense_layer = Dense(128, name='dense_layer')(reshape_layer)
    norm_layer = Lambda(lambda  x: K.l2_normalize(x, axis=1), name='norm_layer')(dense_layer)

    return Model(inputs=[myInput], outputs=norm_layer)
```

In [4]:
```
nn4_small2 = create_model()
```

In [5]:
```
from keras import backend as K
from keras.models import Model
from keras.layers import Input, Layer

# Input for anchor, positive and negative images
in_a = Input(shape=(96, 96, 3))
in_p = Input(shape=(96, 96, 3))
in_n = Input(shape=(96, 96, 3))

# Output for anchor, positive and negative embedding vectors
# The nn4_small model instance is shared (Siamese network)
emb_a = nn4_small2(in_a)
emb_p = nn4_small2(in_p)
emb_n = nn4_small2(in_n)

class TripletLossLayer(Layer):
    def __init__(self, alpha, **kwargs):
        self.alpha = alpha
        super(TripletLossLayer, self).__init__(**kwargs)

    def triplet_loss(self, inputs):
        a, p, n = inputs
        p_dist = K.sum(K.square(a-p), axis=-1)
        n_dist = K.sum(K.square(a-n), axis=-1)
        return K.sum(K.maximum(p_dist - n_dist + self.alpha, 0), axis=0)

    def call(self, inputs):
        loss = self.triplet_loss(inputs)
        self.add_loss(loss)
        return loss

# Layer that computes the triplet loss from anchor, positive and negative embedding vectors
triplet_loss_layer = TripletLossLayer(alpha=0.2, name='triplet_loss_layer')([emb_a, emb_p, emb_n])

# Model that can be trained with anchor, positive negative images
nn4_small2_train = Model([in_a, in_p, in_n], triplet_loss_layer)
```

In [6]:
```
import numpy as np

def triplet_generator():


    while True:
```

```
        a_batch = np.random.rand(4, 96, 96, 3)
        p_batch = np.random.rand(4, 96, 96, 3)
        n_batch = np.random.rand(4, 96, 96, 3)
        yield [a_batch , p_batch, n_batch], None
```

In [7]:
```
generator = triplet_generator()

nn4_small2_train.compile(loss=None, optimizer='adam')
nn4_small2_train.fit_generator(generator, epochs=10, steps_per_epoch=100)
```

```
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\ipykernel_launcher.py:10: UserWarning: `Model.fit_generator` is deprecated and will be removed in a future version. Please use `Model.fit`, which supports generators.
  # Remove the CWD from sys.path while we load stuff.
C:\Users\ayasa\anaconda3\envs\face1\lib\site-packages\ipykernel_launcher.py:10: UserWarning: `Model.fit_generator` is deprecated and will be removed in a future version. Please use `Model.fit`, which supports generators.
  # Remove the CWD from sys.path while we load stuff.
```

```
Epoch 1/10
Epoch 1/10
100/100 [==============================] - 74s 579ms/step - loss: 0.7989
Epoch 2/10
100/100 [==============================] - 74s 579ms/step - loss: 0.7989
Epoch 2/10
100/100 [==============================] - 52s 519ms/step - loss: 0.8012
100/100 [==============================] - 52s 519ms/step - loss: 0.8012
Epoch 3/10
Epoch 3/10
100/100 [==============================] - 49s 487ms/step - loss: 0.8011
100/100 [==============================] - 49s 487ms/step - loss: 0.8011
Epoch 4/10
Epoch 4/10
100/100 [==============================] - 45s 449ms/step - loss: 0.8003
100/100 [==============================] - 45s 449ms/step - loss: 0.8003
Epoch 5/10
Epoch 5/10
100/100 [==============================] - 45s 448ms/step - loss: 0.7999
100/100 [==============================] - 45s 448ms/step - loss: 0.7999
Epoch 6/10
Epoch 6/10
100/100 [==============================] - 45s 454ms/step - loss: 0.8004
100/100 [==============================] - 45s 454ms/step - loss: 0.8004
Epoch 7/10
Epoch 7/10
100/100 [==============================] - 45s 453ms/step - loss: 0.8000
100/100 [==============================] - 45s 453ms/step - loss: 0.8000
Epoch 8/10
Epoch 8/10
100/100 [==============================] - 45s 454ms/step - loss: 0.8003
100/100 [==============================] - 45s 454ms/step - loss: 0.8003
Epoch 9/10
Epoch 9/10
100/100 [==============================] - 45s 449ms/step - loss: 0.8001
100/100 [==============================] - 45s 449ms/step - loss: 0.8001
Epoch 10/10
Epoch 10/10
100/100 [==============================] - 45s 450ms/step - loss: 0.8001
100/100 [==============================] - 45s 450ms/step - loss: 0.8001
```

Out[7]:
```
<keras.callbacks.History at 0x17314e2b548>
```

Out[7]:
```
<keras.callbacks.History at 0x17314e2b548>
```

In [8]:
```
nn4_small2_pretrained = create_model()
nn4_small2_pretrained.load_weights('weights/nn4.small2.v1.h5')
```

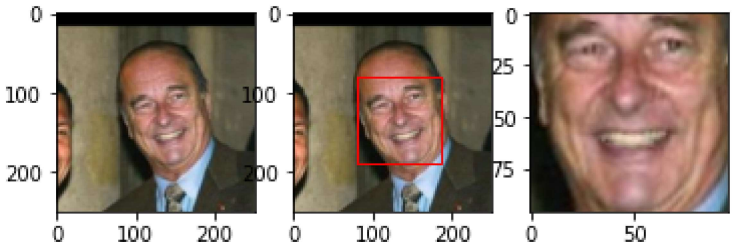
Custom dataset

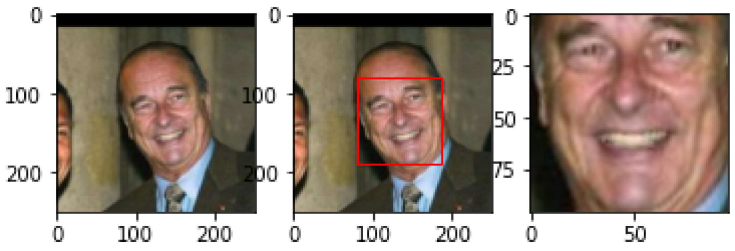
In [9]:
```
import numpy as np
import os.path

class IdentityMetadata():
    def __init__(self, base, name, file):
        # dataset base directory
        self.base = base
        # identity name
        self.name = name
        # image file name
        self.file = file

    def __repr__(self):
        return self.image_path()

    def image_path(self):
        return os.path.join(self.base, self.name, self.file)

def load_metadata(path):
    metadata = []
    for i in sorted(os.listdir(path)):
        for f in sorted(os.listdir(os.path.join(path, i))):
            # Check file extension. Allow only jpg/jpeg' files.
            ext = os.path.splitext(f)[1]
            if ext == '.jpg' or ext == '.jpeg':
                metadata.append(IdentityMetadata(path, i, f))
    return np.array(metadata)

metadata = load_metadata('images')
```

Face alignment

In [13]:
```
import cv2
import matplotlib.pyplot as plt
import matplotlib.patches as patches

from align import AlignDlib
```

```
%matplotlib inline

def load_image(path):
    img = cv2.imread(path, 1)

    return img[...,::-1]


alignment = AlignDlib('models/landmarks.dat')


jc_orig = load_image(metadata[77].image_path())


bb = alignment.getLargestFaceBoundingBox(jc_orig)


jc_aligned = alignment.align(96, jc_orig, bb, landmarkIndices=AlignDlib.OUTER_EYES_AND_NOSE)


plt.subplot(131)
plt.imshow(jc_orig)

# Show original image with bounding box
plt.subplot(132)
plt.imshow(jc_orig)
plt.gca().add_patch(patches.Rectangle((bb.left(), bb.top()), bb.width(), bb.height(), fill=False, color='red'))

# Show aligned image
plt.subplot(133)
plt.imshow(jc_aligned);
```



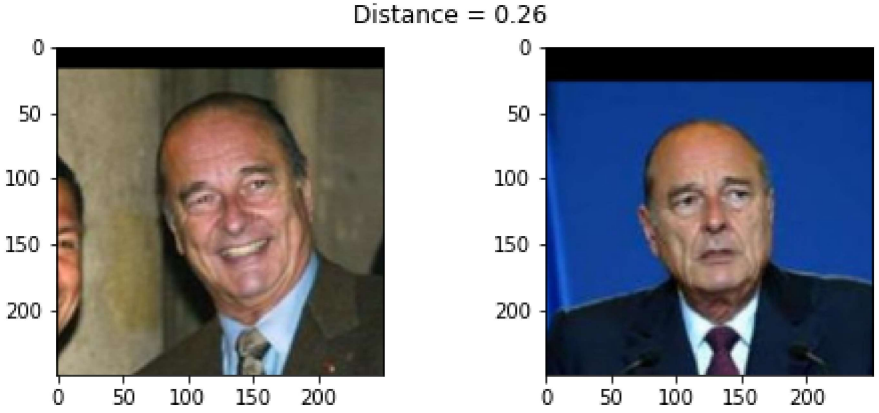


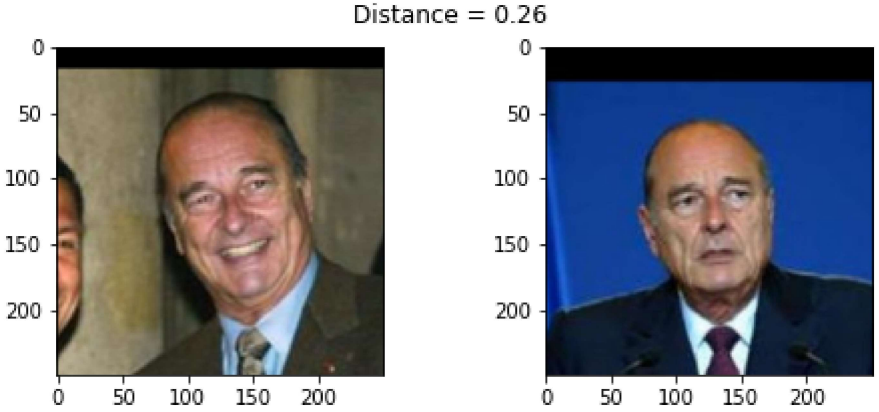
In [14]:
```
def align_image(img):
    return alignment.align(96, img, alignment.getLargestFaceBoundingBox(img),
                           landmarkIndices=AlignDlib.OUTER_EYES_AND_NOSE)
```

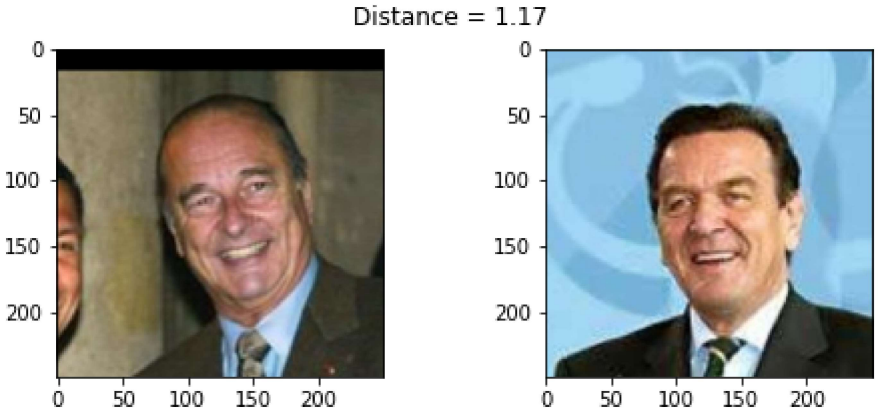
Embedding vectors

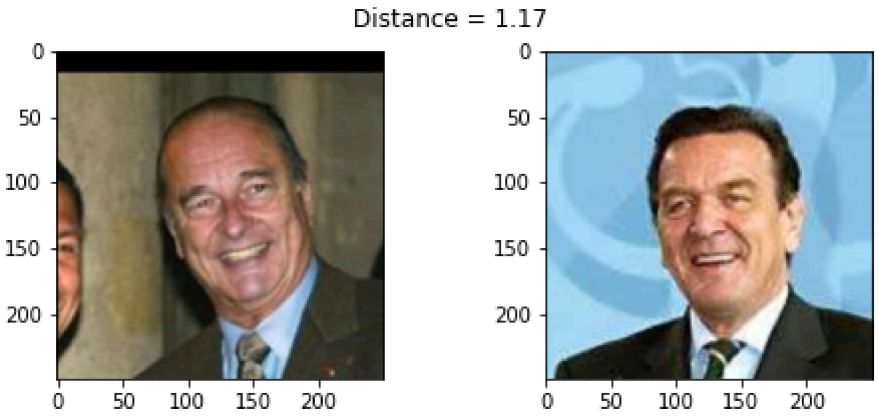
In [15]:
```
embedded = np.zeros((metadata.shape[0], 128))

for i, m in enumerate(metadata):
    img = load_image(m.image_path())
    img = align_image(img)
    # scale RGB values to interval [0,1]
    img = (img / 255.).astype(np.float32)
    # obtain embedding vector for image
    embedded[i] = nn4_small2_pretrained.predict(np.expand_dims(img, axis=0))[0]
```

In [16]:
```
def distance(emb1, emb2):
    return np.sum(np.square(emb1 - emb2))

def show_pair(idx1, idx2):
    plt.figure(figsize=(8,3))
    plt.suptitle(f'Distance = {distance(embedded[idx1], embedded[idx2]):.2f}')
    plt.subplot(121)
    plt.imshow(load_image(metadata[idx1].image_path()))
    plt.subplot(122)
    plt.imshow(load_image(metadata[idx2].image_path()));

show_pair(77, 78)
show_pair(77, 50)
```


Distance = 0.26
0
50
100
150
200


Distance = 0.26
0
50
100
150
200


Distance = 1.17
0
50
100
150
200

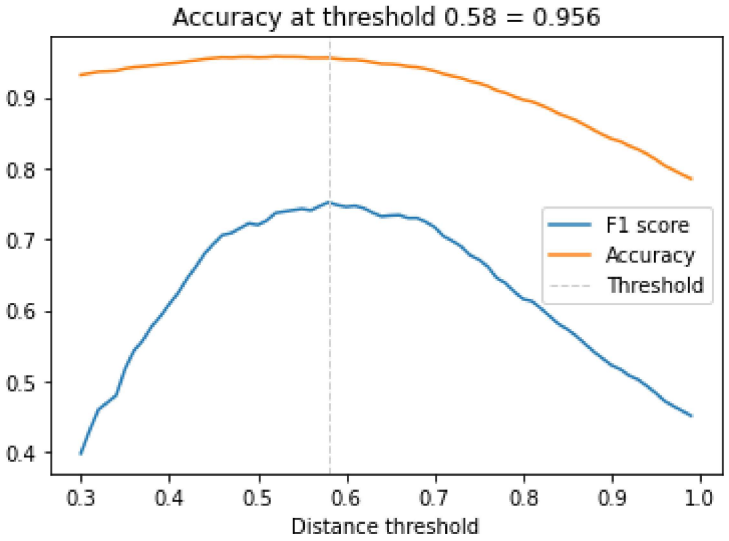


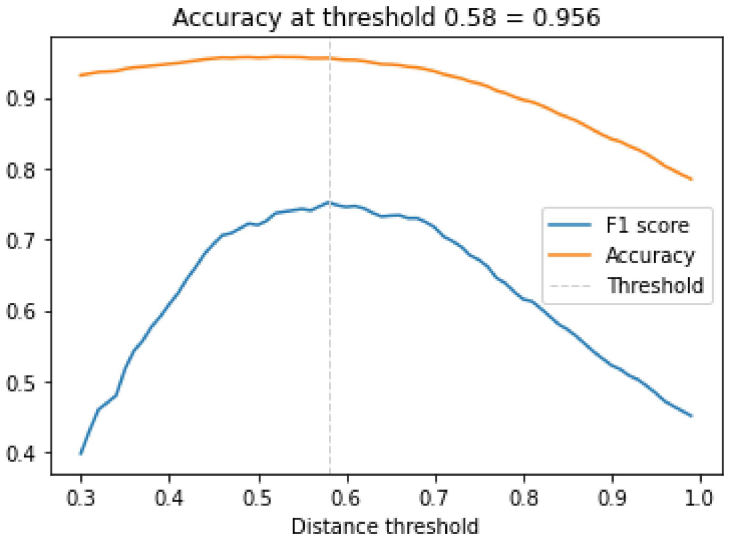
Distance threshold

In [18]:

```
from sklearn.metrics import f1_score, accuracy_score

distances = [] # squared L2 distance between pairs
identical = [] # 1 if same identity, 0 otherwise

num = len(metadata)

for i in range(num - 1):
    for j in range(i + 1, num):
        distances.append(distance(embedded[i], embedded[j]))
        identical.append(1 if metadata[i].name == metadata[j].name else 0)

distances = np.array(distances)
identical = np.array(identical)

thresholds = np.arange(0.3, 1.0, 0.01)

f1_scores = [f1_score(identical, distances < t) for t in thresholds]
acc_scores = [accuracy_score(identical, distances < t) for t in thresholds]

opt_idx = np.argmax(f1_scores)
# Threshold at maximal F1 score
opt_tau = thresholds[opt_idx]
# Accuracy at maximal F1 score
opt_acc = accuracy_score(identical, distances < opt_tau)

# Plot F1 score and accuracy as function of distance threshold
```

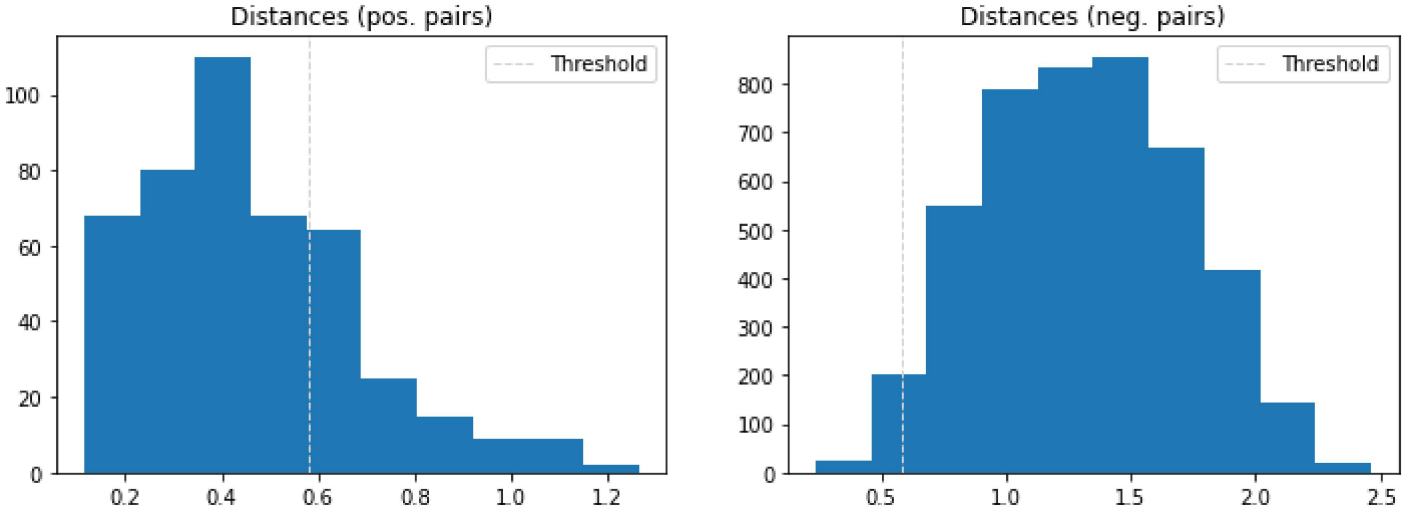
```
plt.plot(thresholds, f1_scores, label='F1 score');
plt.plot(thresholds, acc_scores, label='Accuracy');
plt.axvline(x=opt_tau, linestyle='--', lw=1, c='lightgrey', label='Threshold')
plt.title(f'Accuracy at threshold {opt_tau:.2f} = {opt_acc:.3f}');
plt.xlabel('Distance threshold')
plt.legend();
```

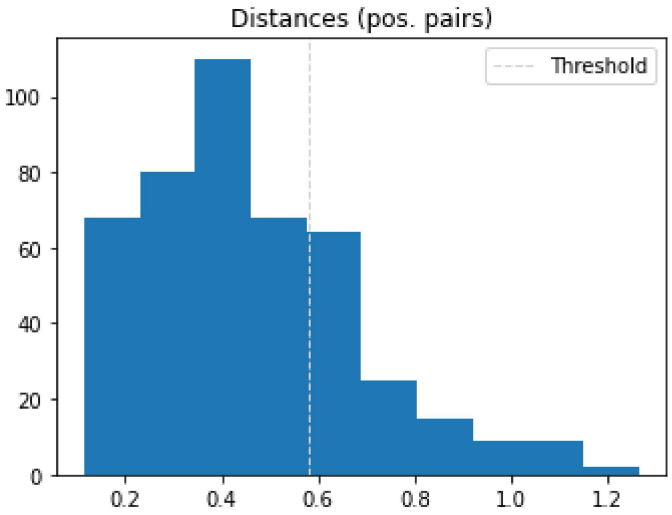


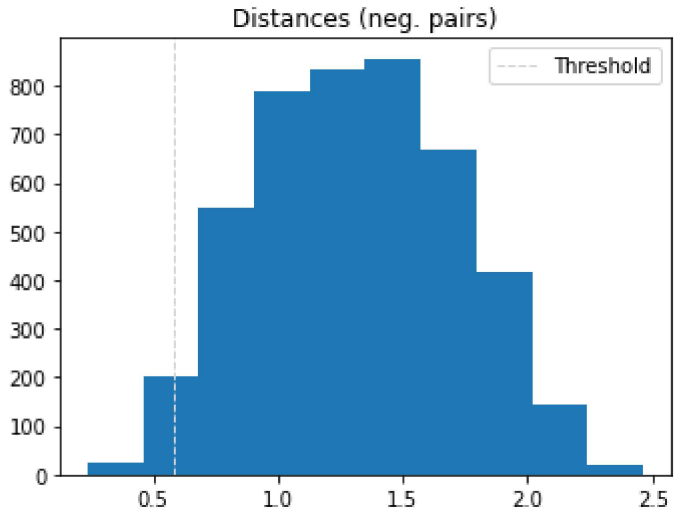


In [19]:
```
dist_pos = distances[identical == 1]
dist_neg = distances[identical == 0]
```

```
plt.figure(figsize=(12,4))

plt.subplot(121)
plt.hist(dist_pos)
plt.axvline(x=opt_tau, linestyle='--', lw=1, c='lightgrey', label='Threshold')
plt.title('Distances (pos. pairs)')
plt.legend();

plt.subplot(122)
plt.hist(dist_neg)
plt.axvline(x=opt_tau, linestyle='--', lw=1, c='lightgrey', label='Threshold')
plt.title('Distances (neg. pairs)')
plt.legend();
```







Face recognition

In [20]:

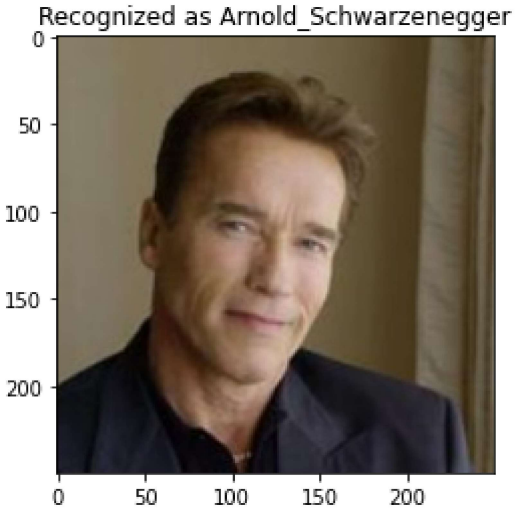
```
from sklearn.preprocessing import LabelEncoder
from sklearn.neighbors import KNeighborsClassifier
from sklearn.svm import LinearSVC

targets = np.array([m.name for m in metadata])

encoder = LabelEncoder()
encoder.fit(targets)

# Numerical encoding of identities
y = encoder.transform(targets)

train_idx = np.arange(metadata.shape[0]) % 2 != 0
test_idx = np.arange(metadata.shape[0]) % 2 == 0

# 50 train examples of 10 identities (5 examples each)
X_train = embedded[train_idx]
# 50 test examples of 10 identities (5 examples each)
X_test = embedded[test_idx]

y_train = y[train_idx]
y_test = y[test_idx]

knn = KNeighborsClassifier(n_neighbors=1, metric='euclidean')
```

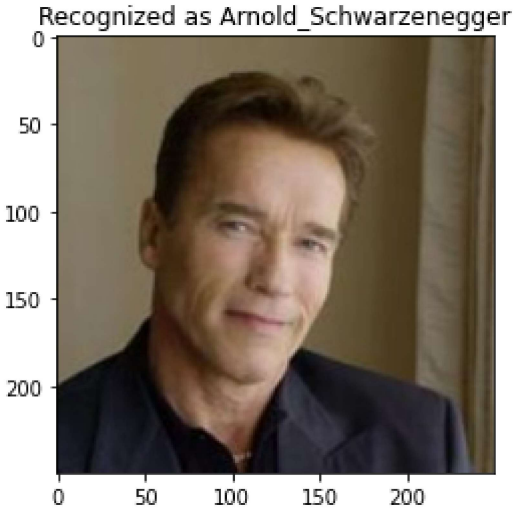
```
svc = LinearSVC()

knn.fit(X_train, y_train)
svc.fit(X_train, y_train)

acc_knn = accuracy_score(y_test, knn.predict(X_test))
acc_svc = accuracy_score(y_test, svc.predict(X_test))

print(f'KNN accuracy = {acc_knn}, SVM accuracy = {acc_svc}')
```

```
KNN accuracy = 0.96, SVM accuracy = 0.98
KNN accuracy = 0.96, SVM accuracy = 0.98
```

In [21]:

```
import warnings
# Suppress LabelEncoder warning
warnings.filterwarnings('ignore')

example_idx = 6

example_image = load_image(metadata[test_idx][example_idx].image_path())
example_prediction = svc.predict([embedded[test_idx][example_idx]])
example_identity = encoder.inverse_transform(example_prediction)[0]

plt.imshow(example_image)
plt.title(f'Recognized as {example_identity}');
```

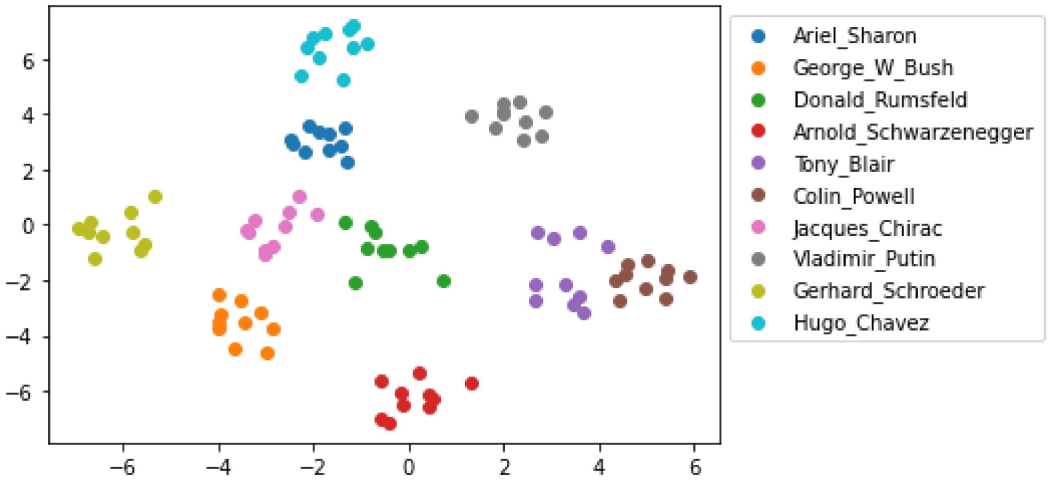


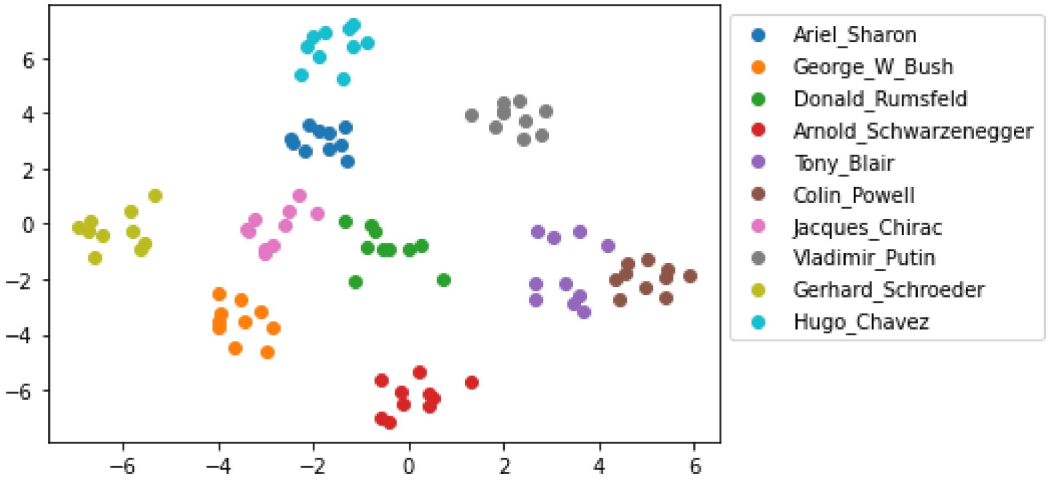


Dataset visualization

In [22]:

```
from sklearn.manifold import TSNE

X_embedded = TSNE(n_components=2).fit_transform(embedded)

for i, t in enumerate(set(targets)):
    idx = targets == t
    plt.scatter(X_embedded[idx, 0], X_embedded[idx, 1], label=t)

plt.legend(bbox_to_anchor=(1, 1));
```


Ariel_Sharon
George_W_Bush
Donald_Rumsfeld
Arnold_Schwarzenegger
Tony_Blair
Colin_Powell
Jacques_Chirac
Vladimir_Putin
Gerhard_Schroeder
Hugo_Chavez


Ariel_Sharon
George_W_Bush
Donald_Rumsfeld
Arnold_Schwarzenegger
Tony_Blair
Colin_Powell
Jacques_Chirac
Vladimir_Putin
Gerhard_Schroeder
Hugo_Chavez