Artificial Intelligence Nanodegree

Convolutional Neural Networks

Project: Write an Algorithm for a Dog Identification App

In this notebook, some template code has already been provided for you, and you will need to implement additional functionality to successfully complete this project. You will not need to modify the included code beyond what is requested. Sections that begin with **'(IMPLEMENTATION)'** in the header indicate that the following block of code will require additional functionality which you must provide. Instructions will be provided for each section, and the specifics of the implementation are marked in the code block with a 'TODO' statement. Please be sure to read the instructions carefully!

> **Note**: Once you have completed all of the code implementations, you need to finalize your work by exporting the iPython Notebook as an HTML document. Before exporting the notebook to html, all of the code cells need to have been run so that reviewers can see the final implementation and output. You can then export the notebook by using the menu above and navigating to \n", "**File -> Download as -> HTML (.html)**. Include the finished document along with this notebook as your submission.

In addition to implementing code, there will be questions that you must answer which relate to the project and your implementation. Each section where you will answer a question is preceded by a **'Question X'** header. Carefully read each question and provide thorough answers in the following text boxes that begin with **'Answer:'**. Your project submission will be evaluated based on your answers to each of the questions and the implementation you provide.

> **Note:** Code and Markdown cells can be executed using the **Shift + Enter** keyboard shortcut. Markdown cells can be edited by double-clicking the cell to enter edit mode.

The rubric contains *optional* "Stand Out Suggestions" for enhancing the project beyond the minimum requirements. If you decide to pursue the "Stand Out Suggestions", you should include the code in this IPython notebook.

Why We're Here

In this notebook, you will make the first steps towards developing an algorithm that could be used as part of a mobile or web app. At the end of this project, your code will accept any user-supplied image as input. If a dog is detected in the image, it will provide an estimate of the dog's breed. If a human is detected, it will provide an estimate of the dog breed that is most resembling. The image below displays potential sample output of your finished project (... but we expect that each student's algorithm will behave differently!).

Sample Dog Output

In this real-world setting, you will need to piece together a series of models to perform different tasks; for instance, the algorithm that detects humans in an image will be different from the CNN that infers dog breed. There are many points of possible failure, and no perfect algorithm exists. Your imperfect solution will nonetheless create a fun user experience!

The Road Ahead

We break the notebook into separate steps. Feel free to use the links below to navigate the notebook.

- Step 0: Import Datasets
- Step 1: Detect Humans
- Step 2: Detect Dogs
- Step 3: Create a CNN to Classify Dog Breeds (from Scratch)
- Step 4: Use a CNN to Classify Dog Breeds (using Transfer Learning)
- Step 5: Create a CNN to Classify Dog Breeds (using Transfer Learning)
- Step 6: Write your Algorithm
- Step 7: Test Your Algorithm

Step 0: Import Datasets

Import Dog Dataset

In the code cell below, we import a dataset of dog images. We populate a few variables through the use of the `load_files` function from the scikit-learn library:

- `train_files`, `valid_files`, `test_files` - numpy arrays containing file paths to images
- `train_targets`, `valid_targets`, `test_targets` - numpy arrays containing onehot-encoded classification labels
- `dog_names` - list of string-valued dog breed names for translating labels

In [18]:
```
from sklearn.datasets import load_files
from keras.utils import np_utils
import numpy as np
from glob import glob

# define function to load train, test, and validation datasets
def load_dataset(path):
    data = load_files(path)
    dog_files = np.array(data['filenames'])
    dog_targets = np_utils.to_categorical(np.array(data['target']), 133)
    return dog_files, dog_targets

# load train, test, and validation datasets
train_files, train_targets = load_dataset('dogImages/train')
valid_files, valid_targets = load_dataset('dogImages/valid')
test_files, test_targets = load_dataset('dogImages/test')

# load list of dog names
dog_names = [item[20:-1] for item in sorted(glob("dogImages/train/*/"))]

# print statistics about the dataset
print('There are %d total dog categories.' % len(dog_names))
print('There are %s total dog images.\n' % len(np.hstack([train_files, v
alid_files, test_files])))
print('There are %d training dog images.' % len(train_files))
print('There are %d validation dog images.' % len(valid_files))
print('There are %d test dog images.'% len(test_files))
```

```
There are 133 total dog categories.
There are 8351 total dog images.

There are 6680 training dog images.
There are 835 validation dog images.
There are 836 test dog images.
```

Import Human Dataset

In the code cell below, we import a dataset of human images, where the file paths are stored in the numpy array `human_files`.

In [86]:
```
import random
random.seed(8675309)

# load filenames in shuffled human dataset
human_files = np.array(glob("lfw/*/*"))
random.shuffle(human_files)

# print statistics about the dataset
print('There are %d total human images.' % len(human_files))
```

```
There are 13233 total human images.
```

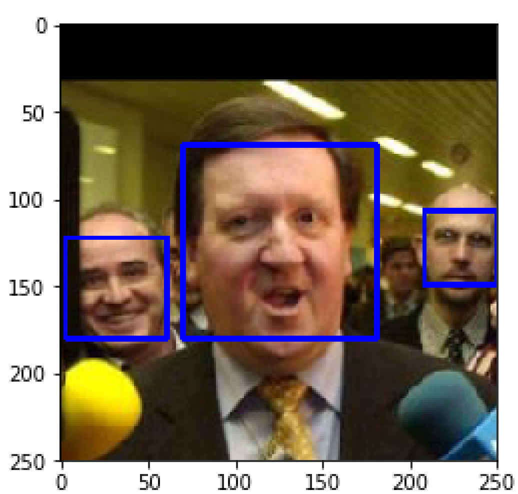
Step 1: Detect Humans

We use OpenCV's implementation of Haar feature-based cascade classifiers (http://docs.opencv.org/trunk/d7/d8b/tutorial_py_face_detection.html) to detect human faces in images. OpenCV provides many pre-trained face detectors, stored as XML files on github (https://github.com/opencv/opencv/tree/master/data/haarcascades). We have downloaded one of these detectors and stored it in the `haarcascades` directory.

In the next code cell, we demonstrate how to use this detector to find human faces in a sample image.

In [3]:
```
import cv2
import matplotlib.pyplot as plt
%matplotlib inline

# extract pre-trained face detector
face_cascade = cv2.CascadeClassifier('haarcascades/haarcascade_frontalfa
ce_alt.xml')

# load color (BGR) image
img = cv2.imread(human_files[3])
# convert BGR image to grayscale
gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

# find faces in image
faces = face_cascade.detectMultiScale(gray)

# print number of faces detected in the image
print('Number of faces detected:', len(faces))

# get bounding box for each detected face
for (x,y,w,h) in faces:
    # add bounding box to color image
    cv2.rectangle(img,(x,y),(x+w,y+h),(255,0,0),2)

# convert BGR image to RGB for plotting
cv_rgb = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)

# display the image, along with bounding box
plt.imshow(cv_rgb)
plt.show()
```

```
Number of faces detected: 3
```



Before using any of the face detectors, it is standard procedure to convert the images to grayscale. The `detectMultiScale` function executes the classifier stored in `face_cascade` and takes the grayscale image as a parameter.

In the above code, `faces` is a numpy array of detected faces, where each row corresponds to a detected face. Each detected face is a 1D array with four entries that specifies the bounding box of the detected face. The first two entries in the array (extracted in the above code as `x` and `y`) specify the horizontal and vertical positions of the top left corner of the bounding box. The last two entries in the array (extracted here as `w` and `h`) specify the width and height of the box.

Write a Human Face Detector

We can use this procedure to write a function that returns `True` if a human face is detected in an image and `False` otherwise. This function, aptly named `face_detector`, takes a string-valued file path to an image as input and appears in the code block below.

In [4]:
```
# returns "True" if face is detected in image stored at img_path
def face_detector(img_path):
    img = cv2.imread(img_path)
    gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
    faces = face_cascade.detectMultiScale(gray)
    return len(faces) > 0
```

(IMPLEMENTATION) Assess the Human Face Detector

Question 1: Use the code cell below to test the performance of the `face_detector` function.

- What percentage of the first 100 images in `human_files` have a detected human face?
- What percentage of the first 100 images in `dog_files` have a detected human face?

Ideally, we would like 100% of human images with a detected face and 0% of dog images with a detected face. You will see that our algorithm falls short of this goal, but still gives acceptable performance. We extract the file paths for the first 100 images from each of the datasets and store them in the numpy arrays `human_files_short` and `dog_files_short`.

Answer:

99% of the first 100 human files have a detected human face. 11% of the first 100 dog files have a detected human face.

In [87]:
```
human_files_short = human_files[:100]
dog_files_short = train_files[:100]
# Do NOT modify the code above this line.
```

In [6]:
```
## Test the performance of the face_detector algorithm
## on the images in human_files_short and dog_files_short.
v_face_detector = np.vectorize(face_detector)
humans_detected_in_human = np.sum(v_face_detector(human_files_short))
print('There are %d humans detected in the first 100 human files.' % hum
ans_detected_in_human)
humans_detected_in_dog = np.sum(v_face_detector(dog_files_short))
print('There are %d humans detected in the first 100 dog files.' % human
s_detected_in_dog)
```

```
There are 99 humans detected in the first 100 human files.
There are 11 humans detected in the first 100 dog files.
```

Question 2: This algorithmic choice necessitates that we communicate to the user that we accept human images only when they provide a clear view of a face (otherwise, we risk having unneccessarily frustrated users!). In your opinion, is this a reasonable expectation to pose on the user? If not, can you think of a way to detect humans in images that does not necessitate an image with a clearly presented face?

Answer:

We suggest the face detector from OpenCV as a potential way to detect human images in your algorithm, but you are free to explore other approaches, especially approaches that make use of deep learning :). Please use the code cell below to design and test your own face detection algorithm. If you decide to pursue this *optional* task, report performance on each of the datasets.

In [105]:
```
## (Optional) Report the performance of another
## face detection algorithm on the LFW dataset
### Feel free to use as many code cells as needed.

# Split the human images into training (64%), validation (16%) and test
 sets (20%)
human_file_count = len(human_files)
break1 = int(human_file_count * 0.64)
break2 = int(human_file_count * 0.8)
(human_train, human_valid, human_test) = np.array_split(human_files, [br
eak1, break2])
print('Human files split: {0} training, {1} validation, {2}
test'.format(len(human_train), len(human_valid), len(human_test)))
```

```
Human files split: 8469 training, 2117 validation, 2647 test
```

In [143]:
```
# Prepare images for dog vs human training

# Create the necessary directory tree for use with Keras' ImageDataGener
ator
import os
import shutil
dirname = 'dogvshuman'
shutil.rmtree(dirname, ignore_errors=True)
os.makedirs(dirname + '/train/dogs')
os.makedirs(dirname + '/train/humans')
os.makedirs(dirname + '/validation/dogs')
os.makedirs(dirname + '/validation/humans')

# Copy training images into training folder
for dogImage in train_files:
    shutil.copy(dogImage, dirname + '/train/dogs')
for humanImage in human_train:
    shutil.copy(humanImage, dirname + '/train/humans')

# Copy validation images into validation folder
for dogImage in valid_files:
    shutil.copy(dogImage, dirname + '/validation/dogs')
for humanImage in human_valid:
    shutil.copy(humanImage, dirname + '/validation/humans')
```

In [1]:
```
# Start with the convolutional layers of VGG16
from keras.applications.vgg16 import VGG16

base_model = VGG16(weights='imagenet', include_top=False)

# Freeze all the layers
for layer in base_model.layers:
    layer.trainable = False
```

```
Using TensorFlow backend.
```

In [2]:

```python
from keras.layers import Dense, GlobalAveragePooling2D, Dropout, Flatten
from keras.models import Model

# Build a new model to follow the convolutional layers of Resnet50
x = base_model.output
x = GlobalAveragePooling2D()(x)
predictions = Dense(1, activation="sigmoid")(x)
doghuman_model = Model(inputs = base_model.input, outputs = predictions)
doghuman_model.compile(loss='binary_crossentropy',
                       optimizer='rmsprop',
                       metrics=['accuracy'])
doghuman_model.summary()
print(base_model.output.shape)
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_1 (InputLayer)         (None, None, None, 3)     0
_________________________________________________________________
block1_conv1 (Conv2D)        (None, None, None, 64)    1792
_________________________________________________________________
block1_conv2 (Conv2D)        (None, None, None, 64)    36928
_________________________________________________________________
block1_pool (MaxPooling2D)   (None, None, None, 64)    0
_________________________________________________________________
block2_conv1 (Conv2D)        (None, None, None, 128)   73856
_________________________________________________________________
block2_conv2 (Conv2D)        (None, None, None, 128)   147584
_________________________________________________________________
block2_pool (MaxPooling2D)   (None, None, None, 128)   0
_________________________________________________________________
block3_conv1 (Conv2D)        (None, None, None, 256)   295168
_________________________________________________________________
block3_conv2 (Conv2D)        (None, None, None, 256)   590080
_________________________________________________________________
block3_conv3 (Conv2D)        (None, None, None, 256)   590080
_________________________________________________________________
block3_pool (MaxPooling2D)   (None, None, None, 256)   0
_________________________________________________________________
block4_conv1 (Conv2D)        (None, None, None, 512)   1180160
_________________________________________________________________
block4_conv2 (Conv2D)        (None, None, None, 512)   2359808
_________________________________________________________________
block4_conv3 (Conv2D)        (None, None, None, 512)   2359808
_________________________________________________________________
block4_pool (MaxPooling2D)   (None, None, None, 512)   0
_________________________________________________________________
block5_conv1 (Conv2D)        (None, None, None, 512)   2359808
_________________________________________________________________
block5_conv2 (Conv2D)        (None, None, None, 512)   2359808
_________________________________________________________________
block5_conv3 (Conv2D)        (None, None, None, 512)   2359808
_________________________________________________________________
block5_pool (MaxPooling2D)   (None, None, None, 512)   0
_________________________________________________________________
global_average_pooling2d_1 ( (None, 512)               0
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 513
=================================================================
Total params: 14,715,201
Trainable params: 513
Non-trainable params: 14,714,688
_________________________________________________________________
(?, ?, ?, 512)
```

In [164]:

```
from keras.preprocessing.image import ImageDataGenerator
from keras.callbacks import ModelCheckpoint, EarlyStopping

# Allow truncated images to be loaded
from PIL import ImageFile
ImageFile.LOAD_TRUNCATED_IMAGES = True

# Use ImageDataGenerators to generate the training and validation data
batch_size = 16
train_datagen = ImageDataGenerator(rescale=1./255,
                                   shear_range=0.2,
                                   zoom_range=0.2,
                                   horizontal_flip=True)
validation_datagen = ImageDataGenerator(rescale=1./255)
train_generator = train_datagen.flow_from_directory(
        dirname + '/train',
        target_size=(224, 224),
        batch_size=batch_size,
        class_mode='binary')
validation_generator = validation_datagen.flow_from_directory(
        dirname + '/validation',
        target_size=(224, 224),
        batch_size=batch_size,
        class_mode='binary')

# Train the model
checkpointer = ModelCheckpoint(filepath='saved_models/dogvshuman.vgg16.w
eights.best.hdf5', verbose=1, save_best_only=True)
stopper = EarlyStopping(monitor='val_loss', min_delta=1e-4, patience=10,
 verbose=1, mode='auto')

doghuman_model.fit_generator(train_generator,
                             epochs=20,
                             steps_per_epoch=100,
                             validation_data=validation_generator,
                             validation_steps=10,
                             callbacks=[checkpointer, stopper],
                             verbose=1)
```

```
Found 15149 images belonging to 2 classes.
Found 2952 images belonging to 2 classes.
Epoch 1/20
 99/100 [============================>.] - ETA: 0s - loss: 0.1349 - ac
c: 0.9735Epoch 00000: val_loss improved from inf to 0.10716, saving mod
el to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.1345 - acc: 0.
9738 - val_loss: 0.1072 - val_acc: 0.9812
Epoch 2/20
 99/100 [============================>.] - ETA: 0s - loss: 0.1069 - ac
c: 0.9817Epoch 00001: val_loss improved from 0.10716 to 0.09304, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.1068 - acc: 0.
9813 - val_loss: 0.0930 - val_acc: 0.9875
Epoch 3/20
 99/100 [============================>.] - ETA: 0s - loss: 0.1037 - ac
c: 0.9823Epoch 00002: val_loss improved from 0.09304 to 0.07070, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.1032 - acc: 0.
9825 - val_loss: 0.0707 - val_acc: 0.9938
Epoch 4/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0934 - ac
c: 0.9830Epoch 00003: val_loss improved from 0.07070 to 0.06416, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0932 - acc: 0.
9831 - val_loss: 0.0642 - val_acc: 1.0000
Epoch 5/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0833 - ac
c: 0.9855Epoch 00004: val_loss improved from 0.06416 to 0.06064, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0836 - acc: 0.
9856 - val_loss: 0.0606 - val_acc: 0.9938
Epoch 6/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0867 - ac
c: 0.9792Epoch 00005: val_loss improved from 0.06064 to 0.04377, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0864 - acc: 0.
9794 - val_loss: 0.0438 - val_acc: 1.0000
Epoch 7/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0752 - ac
c: 0.9861Epoch 00006: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0754 - acc: 0.
9856 - val_loss: 0.0450 - val_acc: 0.9812
Epoch 8/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0768 - ac
c: 0.9823Epoch 00007: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0764 - acc: 0.
9825 - val_loss: 0.0466 - val_acc: 0.9938
Epoch 9/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0697 - ac
c: 0.9830Epoch 00008: val_loss improved from 0.04377 to 0.03425, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0700 - acc: 0.
9831 - val_loss: 0.0343 - val_acc: 0.9938
Epoch 10/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0606 - ac
c: 0.9905Epoch 00009: val_loss did not improve
```

```
100/100 [==============================] - 65s - loss: 0.0603 - acc: 0.
9906 - val_loss: 0.0483 - val_acc: 0.9868
Epoch 11/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0557 - ac
c: 0.9880Epoch 00010: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0553 - acc: 0.
9881 - val_loss: 0.0366 - val_acc: 0.9875
Epoch 12/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0549 - ac
c: 0.9912Epoch 00011: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0550 - acc: 0.
9912 - val_loss: 0.0356 - val_acc: 1.0000
Epoch 13/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0502 - ac
c: 0.9886Epoch 00012: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0501 - acc: 0.
9887 - val_loss: 0.0348 - val_acc: 0.9938
Epoch 14/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0552 - ac
c: 0.9867Epoch 00013: val_loss improved from 0.03425 to 0.03129, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0548 - acc: 0.
9869 - val_loss: 0.0313 - val_acc: 1.0000
Epoch 15/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0507 - ac
c: 0.9855Epoch 00014: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0515 - acc: 0.
9850 - val_loss: 0.0371 - val_acc: 0.9875
Epoch 16/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0494 - ac
c: 0.9899Epoch 00015: val_loss improved from 0.03129 to 0.02340, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0491 - acc: 0.
9900 - val_loss: 0.0234 - val_acc: 1.0000
Epoch 17/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0481 - ac
c: 0.9880Epoch 00016: val_loss improved from 0.02340 to 0.02322, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0480 - acc: 0.
9881 - val_loss: 0.0232 - val_acc: 1.0000
Epoch 18/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0449 - ac
c: 0.9899Epoch 00017: val_loss did not improve
100/100 [==============================] - 65s - loss: 0.0450 - acc: 0.
9900 - val_loss: 0.0570 - val_acc: 0.9812
Epoch 19/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0453 - ac
c: 0.9874Epoch 00018: val_loss improved from 0.02322 to 0.01828, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 65s - loss: 0.0450 - acc: 0.
9875 - val_loss: 0.0183 - val_acc: 1.0000
Epoch 20/20
 99/100 [============================>.] - ETA: 0s - loss: 0.0437 - ac
c: 0.9924Epoch 00019: val_loss improved from 0.01828 to 0.01747, saving
model to saved_models/dogvshuman.vgg16.weights.best.hdf5
100/100 [==============================] - 66s - loss: 0.0435 - acc: 0.
9925 - val_loss: 0.0175 - val_acc: 1.0000
```

Out[164]: <keras.callbacks.History at 0x7ff25af378d0>

In [3]:
```
doghuman_model.load_weights('saved_models/dogvshuman.vgg16.weights.best.
hdf5')
print(doghuman_model.metrics_names)
```

```
['loss', 'acc']
```

In [6]:
```
# Predict whether human or dog
from glob import glob
dogvshuman_names = [item[17:-2] for item in sorted(glob("dogvshuman/trai
n/*/"))]
print(dogvshuman_names)
def dogvshuman_predict(img_path):
    # obtain predicted vector
    predicted_vector = doghuman_model.predict(path_to_tensor(img_path))
    # print(dogvshuman_names)
    # return dog breed that is predicted by the model
    return dogvshuman_names[int(np.round(predicted_vector[0][0]))]
```

```
['dog', 'human']
```

In [167]:
```
predictions_for_dogs = [dogvshuman_predict(img) for img in dog_files_sho
rt]
predictions_for_humans = [dogvshuman_predict(img) for img in human_files
_short]
print(predictions_for_dogs)
print(predictions_for_humans)
```

```
['dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog',
 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog',
 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog',
 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog',
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 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog',
 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog',
 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog', 'dog']
['human', 'human', 'human', 'human', 'human', 'human', 'human', 'huma
n', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'hum
an', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'hu
man', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'h
uman', 'human', 'human', 'human', 'human', 'human', 'human', 'human',
 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'huma
n', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'hum
an', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'hu
man', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'h
uman', 'human', 'human', 'human', 'human', 'human', 'human', 'human',
 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'huma
n', 'human', 'human', 'human', 'human', 'human', 'human', 'human', 'hum
an', 'human', 'human', 'human', 'human', 'human', 'human', 'human']
```

In this approach, I have used the dog images and the human images together as input to train a CNN to distinguish humans from dogs. My CNN is based on the convolutional layers of VGG16, followed by a Dense layers to distinguish between humans and dogs. To minimize training time, I only used narrow layers, limited epochs, limited steps per epoch and limited validation steps. On an AWS g2.2xlarge instance, this network took about 2 minutes per epoch for a total time of almost an hour to train.

On the subset of human images, this CNN identified 100% of humans. On the subset of dog images, this CNN identified 100% of them dogs.

This CNN is much improved on the Haar-feature based classifier (which identified 11% of the dogs as humans).

Step 2: Detect Dogs

In this section, we use a pre-trained ResNet-50 (http://ethereon.github.io/netscope/#/gist/db945b393d40bfa26006) model to detect dogs in images. Our first line of code downloads the ResNet-50 model, along with weights that have been trained on ImageNet (http://www.image-net.org/), a very large, very popular dataset used for image classification and other vision tasks. ImageNet contains over 10 million URLs, each linking to an image containing an object from one of 1000 categories (https://gist.github.com/yrevar/942d3a0ac09ec9e5eb3a). Given an image, this pre-trained ResNet-50 model returns a prediction (derived from the available categories in ImageNet) for the object that is contained in the image.

In [54]:
```
from keras.applications.resnet50 import ResNet50

# define ResNet50 model
ResNet50_model = ResNet50(weights='imagenet')
```

Pre-process the Data

When using TensorFlow as backend, Keras CNNs require a 4D array (which we'll also refer to as a 4D tensor) as input, with shape

$$(\text{nb\_samples}, \text{rows}, \text{columns}, \text{channels}),$$

where `nb_samples` corresponds to the total number of images (or samples), and `rows`, `columns`, and `channels` correspond to the number of rows, columns, and channels for each image, respectively.

The `path_to_tensor` function below takes a string-valued file path to a color image as input and returns a 4D tensor suitable for supplying to a Keras CNN. The function first loads the image and resizes it to a square image that is 224×224 pixels. Next, the image is converted to an array, which is then resized to a 4D tensor. In this case, since we are working with color images, each image has three channels. Likewise, since we are processing a single image (or sample), the returned tensor will always have shape

$$(1, 224, 224, 3).$$

The `paths_to_tensor` function takes a numpy array of string-valued image paths as input and returns a 4D tensor with shape

$$(\text{nb\_samples}, 224, 224, 3).$$

Here, `nb_samples` is the number of samples, or number of images, in the supplied array of image paths. It is best to think of `nb_samples` as the number of 3D tensors (where each 3D tensor corresponds to a different image) in your dataset!

In [16]:

```
from keras.preprocessing import image
from tqdm import tqdm

def path_to_tensor(img_path):
    # loads RGB image as PIL.Image.Image type
    img = image.load_img(img_path, target_size=(224, 224))
    # convert PIL.Image.Image type to 3D tensor with shape (224, 224, 3)
    x = image.img_to_array(img)
    # convert 3D tensor to 4D tensor with shape (1, 224, 224, 3) and ret
urn 4D tensor
    return np.expand_dims(x, axis=0)

def paths_to_tensor(img_paths):
    list_of_tensors = [path_to_tensor(img_path) for img_path in tqdm(img
_paths)]
    return np.vstack(list_of_tensors)
```

Making Predictions with ResNet-50

Getting the 4D tensor ready for ResNet-50, and for any other pre-trained model in Keras, requires some additional processing. First, the RGB image is converted to BGR by reordering the channels. All pre-trained models have the additional normalization step that the mean pixel (expressed in RGB as $[103.939, 116.779, 123.68]$ and calculated from all pixels in all images in ImageNet) must be subtracted from every pixel in each image. This is implemented in the imported function `preprocess_input`. If you're curious, you can check the code for `preprocess_input` here (https://github.com/fchollet/keras/blob/master/keras/applications/imagenet_utils.py).

Now that we have a way to format our image for supplying to ResNet-50, we are now ready to use the model to extract the predictions. This is accomplished with the `predict` method, which returns an array whose i-th entry is the model's predicted probability that the image belongs to the i-th ImageNet category. This is implemented in the `ResNet50_predict_labels` function below.

By taking the argmax of the predicted probability vector, we obtain an integer corresponding to the model's predicted object class, which we can identify with an object category through the use of this dictionary (https://gist.github.com/yrevar/942d3a0ac09ec9e5eb3a).

In [56]:
```
from keras.applications.resnet50 import preprocess_input, decode_predict
ions

def ResNet50_predict_labels(img_path):
    # returns prediction vector for image located at img_path
    img = preprocess_input(path_to_tensor(img_path))
    return np.argmax(ResNet50_model.predict(img))
```

Write a Dog Detector

While looking at the dictionary (https://gist.github.com/yrevar/942d3a0ac09ec9e5eb3a), you will notice that the categories corresponding to dogs appear in an uninterrupted sequence and correspond to dictionary keys 151-268, inclusive, to include all categories from `'Chihuahua'` to `'Mexican hairless'`. Thus, in order to check to see if an image is predicted to contain a dog by the pre-trained ResNet-50 model, we need only check if the `ResNet50_predict_labels` function above returns a value between 151 and 268 (inclusive).

We use these ideas to complete the `dog_detector` function below, which returns `True` if a dog is detected in an image (and `False` if not).

In [57]:
```
### returns "True" if a dog is detected in the image stored at img_path
def dog_detector(img_path):
    prediction = ResNet50_predict_labels(img_path)
    return ((prediction <= 268) & (prediction >= 151))
```

(IMPLEMENTATION) Assess the Dog Detector

Question 3: Use the code cell below to test the performance of your `dog_detector` function.

- What percentage of the images in `human_files_short` have a detected dog?
- What percentage of the images in `dog_files_short` have a detected dog?

Answer:

In [31]:
```
### Test the performance of the dog_detector function
### on the images in human_files_short and dog_files_short.
dogs_in_human_files = [dog_detector(img_path) for img_path in human_file
s_short]
print(np.sum(dogs_in_human_files))

dogs_in_dog_files = [dog_detector(img_path) for img_path in dog_files_sh
ort]
print(np.sum(dogs_in_dog_files))
```

```
0
100
```

There are no dogs in the human files. There are no humans in the dog files.

Step 3: Create a CNN to Classify Dog Breeds (from Scratch)

Now that we have functions for detecting humans and dogs in images, we need a way to predict breed from images. In this step, you will create a CNN that classifies dog breeds. You must create your CNN *from scratch* (so, you can't use transfer learning *yet*!), and you must attain a test accuracy of at least 1%. In Step 5 of this notebook, you will have the opportunity to use transfer learning to create a CNN that attains greatly improved accuracy.

Be careful with adding too many trainable layers! More parameters means longer training, which means you are more likely to need a GPU to accelerate the training process. Thankfully, Keras provides a handy estimate of the time that each epoch is likely to take; you can extrapolate this estimate to figure out how long it will take for your algorithm to train.

We mention that the task of assigning breed to dogs from images is considered exceptionally challenging. To see why, consider that *even a human* would have great difficulty in distinguishing between a Brittany and a Welsh Springer Spaniel.

Brittany	Welsh Springer Spaniel

It is not difficult to find other dog breed pairs with minimal inter-class variation (for instance, Curly-Coated Retrievers and American Water Spaniels).

Curly-Coated Retriever	American Water Spaniel

Likewise, recall that labradors come in yellow, chocolate, and black. Your vision-based algorithm will have to conquer this high intra-class variation to determine how to classify all of these different shades as the same breed.

Yellow Labrador	Chocolate Labrador	Black Labrador

We also mention that random chance presents an exceptionally low bar: setting aside the fact that the classes are slightly imabalanced, a random guess will provide a correct answer roughly 1 in 133 times, which corresponds to an accuracy of less than 1%.

Remember that the practice is far ahead of the theory in deep learning. Experiment with many different architectures, and trust your intuition. And, of course, have fun!

Pre-process the Data

We rescale the images by dividing every pixel in every image by 255.

In [19]:

```
from PIL import ImageFile
ImageFile.LOAD_TRUNCATED_IMAGES = True

# pre-process the data for Keras
train_tensors = paths_to_tensor(train_files).astype('float32')/255
valid_tensors = paths_to_tensor(valid_files).astype('float32')/255
test_tensors = paths_to_tensor(test_files).astype('float32')/255
```

```
100%|██████████| 6680/6680 [00:55<00:00, 119.63it/s]
100%|██████████| 835/835 [00:06<00:00, 153.52it/s]
100%|██████████| 836/836 [00:06<00:00, 134.74it/s]
```

(IMPLEMENTATION) Model Architecture

Create a CNN to classify dog breed. At the end of your code cell block, summarize the layers of your model by executing the line:

```
model.summary()
```

We have imported some Python modules to get you started, but feel free to import as many modules as you need. If you end up getting stuck, here's a hint that specifies a model that trains relatively fast on CPU and attains >1% test accuracy in 5 epochs:

Sample CNN

Question 4: Outline the steps you took to get to your final CNN architecture and your reasoning at each step. If you chose to use the hinted architecture above, describe why you think that CNN architecture should work well for the image classification task.

Answer: I tried to use a multi-layer CNN with increasing number of filters to progressively detect more complex shapes. I also used dropout to prevent overfitting and maxpooling to reduce the inputs as we progress through the layers.

In [32]:

```
print(train_tensors.shape)
```

```
(6680, 224, 224, 3)
```

In [36]:
```
from keras.layers import Conv2D, MaxPooling2D, GlobalAveragePooling2D
from keras.layers import Dropout, Flatten, Dense
from keras.models import Sequential

model = Sequential()

### Define your architecture.
model.add(Conv2D(filters=32, kernel_size=3, padding='same',
activation='relu',
                 input_shape=(224, 224, 3)))
model.add(Conv2D(filters=32, kernel_size=3, padding='same',
activation='relu'))
model.add(MaxPooling2D(pool_size=2))
model.add(Dropout(0.1))
model.add(Conv2D(filters=64, kernel_size=3, padding='same',
activation='relu'))
model.add(Conv2D(filters=64, kernel_size=3, padding='same',
activation='relu'))
model.add(MaxPooling2D(pool_size=2))
model.add(Dropout(0.2))
model.add(Conv2D(filters=128, kernel_size=3, padding='same',
activation='relu'))
model.add(Conv2D(filters=128, kernel_size=3, padding='same',
activation='relu'))
model.add(MaxPooling2D(pool_size=2))
model.add(Dropout(0.3))
model.add(Conv2D(filters=256, kernel_size=3, padding='same',
activation='relu'))
model.add(Conv2D(filters=256, kernel_size=3, padding='same',
activation='relu'))
model.add(GlobalAveragePooling2D())
model.add(Dropout(0.4))
model.add(Dense(532, activation='relu'))
model.add(Dropout(0.5))
model.add(Dense(266, activation='relu'))
model.add(Dropout(0.5))
model.add(Dense(133, activation='softmax'))

model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_25 (Conv2D)           (None, 224, 224, 32)      896       
_________________________________________________________________
conv2d_26 (Conv2D)           (None, 224, 224, 32)      9248      
_________________________________________________________________
max_pooling2d_12 (MaxPooling (None, 112, 112, 32)      0         
_________________________________________________________________
dropout_21 (Dropout)         (None, 112, 112, 32)      0         
_________________________________________________________________
conv2d_27 (Conv2D)           (None, 112, 112, 64)      18496     
_________________________________________________________________
conv2d_28 (Conv2D)           (None, 112, 112, 64)      36928     
_________________________________________________________________
max_pooling2d_13 (MaxPooling (None, 56, 56, 64)        0         
_________________________________________________________________
dropout_22 (Dropout)         (None, 56, 56, 64)        0         
_________________________________________________________________
conv2d_29 (Conv2D)           (None, 56, 56, 128)       73856     
_________________________________________________________________
conv2d_30 (Conv2D)           (None, 56, 56, 128)       147584    
_________________________________________________________________
max_pooling2d_14 (MaxPooling (None, 28, 28, 128)       0         
_________________________________________________________________
dropout_23 (Dropout)         (None, 28, 28, 128)       0         
_________________________________________________________________
conv2d_31 (Conv2D)           (None, 28, 28, 256)       295168    
_________________________________________________________________
conv2d_32 (Conv2D)           (None, 28, 28, 256)       590080    
_________________________________________________________________
global_average_pooling2d_5 ( (None, 256)               0         
_________________________________________________________________
dropout_24 (Dropout)         (None, 256)               0         
_________________________________________________________________
dense_13 (Dense)             (None, 532)               136724    
_________________________________________________________________
dropout_25 (Dropout)         (None, 532)               0         
_________________________________________________________________
dense_14 (Dense)             (None, 266)               141778    
_________________________________________________________________
dropout_26 (Dropout)         (None, 266)               0         
_________________________________________________________________
dense_15 (Dense)             (None, 133)               35511     
=================================================================
Total params: 1,486,269
Trainable params: 1,486,269
Non-trainable params: 0
_________________________________________________________________
```

Compile the Model

In [39]:
```
model.compile(optimizer='rmsprop', loss='categorical_crossentropy', metr
ics=['accuracy'])
```

(IMPLEMENTATION) Train the Model

Train your model in the code cell below. Use model checkpointing to save the model that attains the best validation loss.

You are welcome to augment the training data (https://blog.keras.io/building-powerful-image-classification-models-using-very-little-data.html), but this is not a requirement.

In [40]:
```
from keras.callbacks import ModelCheckpoint

### Specify the number of epochs that you would like to use to train the
 model.

epochs = 10

### Do NOT modify the code below this line.

checkpointer = ModelCheckpoint(filepath='saved_models/weights.best.from_
scratch.hdf5',
                               verbose=1, save_best_only=True)

model.fit(train_tensors, train_targets,
          validation_data=(valid_tensors, valid_targets),
          epochs=epochs, batch_size=20, callbacks=[checkpointer], verbos
e=1)
```

```
Train on 6680 samples, validate on 835 samples
Epoch 1/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8746 - a
cc: 0.0101Epoch 00000: val_loss improved from inf to 4.86928, saving mo
del to saved_models/weights.best.from_scratch.hdf5
6680/6680 [==============================] - 242s - loss: 4.8746 - acc:
0.0100 - val_loss: 4.8693 - val_acc: 0.0108
Epoch 2/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8722 - a
cc: 0.0104Epoch 00001: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8723 - acc:
0.0103 - val_loss: 4.8700 - val_acc: 0.0108
Epoch 3/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8703 - a
cc: 0.0081Epoch 00002: val_loss improved from 4.86928 to 4.86910, savin
g model to saved_models/weights.best.from_scratch.hdf5
6680/6680 [==============================] - 241s - loss: 4.8704 - acc:
0.0081 - val_loss: 4.8691 - val_acc: 0.0108
Epoch 4/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8692 - a
cc: 0.0108Epoch 00003: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8693 - acc:
0.0108 - val_loss: 4.8695 - val_acc: 0.0108
Epoch 5/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8682 - a
cc: 0.0093Epoch 00004: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8683 - acc:
0.0093 - val_loss: 4.8704 - val_acc: 0.0108
Epoch 6/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8685 - a
cc: 0.0093Epoch 00005: val_loss improved from 4.86910 to 4.86865, savin
g model to saved_models/weights.best.from_scratch.hdf5
6680/6680 [==============================] - 241s - loss: 4.8684 - acc:
0.0093 - val_loss: 4.8686 - val_acc: 0.0108
Epoch 7/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8670 - a
cc: 0.0104Epoch 00006: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8669 - acc:
0.0103 - val_loss: 4.8689 - val_acc: 0.0108
Epoch 8/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8680 - a
cc: 0.0116Epoch 00007: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8679 - acc:
0.0115 - val_loss: 4.8689 - val_acc: 0.0108
Epoch 9/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8666 - a
cc: 0.0108Epoch 00008: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8668 - acc:
0.0108 - val_loss: 4.8688 - val_acc: 0.0108
Epoch 10/10
6660/6680 [============================>.] - ETA: 0s - loss: 4.8660 - a
cc: 0.0111Epoch 00009: val_loss did not improve
6680/6680 [==============================] - 241s - loss: 4.8660 - acc:
0.0111 - val_loss: 4.8690 - val_acc: 0.0108
```

```
Out[40]: <keras.callbacks.History at 0x7f8160db4e10>
```

Load the Model with the Best Validation Loss

In [41]:
```
model.load_weights('saved_models/weights.best.from_scratch.hdf5')
```

Test the Model

Try out your model on the test dataset of dog images. Ensure that your test accuracy is greater than 1%.

In [42]:
```
# get index of predicted dog breed for each image in test set
dog_breed_predictions = [np.argmax(model.predict(np.expand_dims(tensor, axis=0))) for tensor in test_tensors]

# report test accuracy
test_accuracy = 100*np.sum(np.array(dog_breed_predictions)==np.argmax(test_targets, axis=1))/len(dog_breed_predictions)
print('Test accuracy: %.4f%%' % test_accuracy)
```

```
Test accuracy: 1.1962%
```

Step 4: Use a CNN to Classify Dog Breeds

To reduce training time without sacrificing accuracy, we show you how to train a CNN using transfer learning. In the following step, you will get a chance to use transfer learning to train your own CNN.

Obtain Bottleneck Features

In [43]:
```
bottleneck_features = np.load('bottleneck_features/DogVGG16Data.npz')
train_VGG16 = bottleneck_features['train']
valid_VGG16 = bottleneck_features['valid']
test_VGG16 = bottleneck_features['test']
```

Model Architecture

The model uses the the pre-trained VGG-16 model as a fixed feature extractor, where the last convolutional output of VGG-16 is fed as input to our model. We only add a global average pooling layer and a fully connected layer, where the latter contains one node for each dog category and is equipped with a softmax.

In [44]:
```
VGG16_model = Sequential()
VGG16_model.add(GlobalAveragePooling2D(input_shape=train_VGG16.shape[1:])

VGG16_model.add(Dense(133, activation='softmax'))

VGG16_model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
global_average_pooling2d_6 ( (None, 512)               0
_________________________________________________________________
dense_16 (Dense)             (None, 133)               68229
=================================================================
Total params: 68,229
Trainable params: 68,229
Non-trainable params: 0
_________________________________________________________________
```

Compile the Model

In [45]:
```
VGG16_model.compile(loss='categorical_crossentropy',
optimizer='rmsprop', metrics=['accuracy'])
```

Train the Model

In [46]:
```
checkpointer = ModelCheckpoint(filepath='saved_models/weights.best.VGG1
6.hdf5',
                               verbose=1, save_best_only=True)

VGG16_model.fit(train_VGG16, train_targets,
          validation_data=(valid_VGG16, valid_targets),
          epochs=20, batch_size=20, callbacks=[checkpointer], verbose=1)
```

```
Train on 6680 samples, validate on 835 samples
Epoch 1/20
6620/6680 [============================>.] - ETA: 0s - loss: 12.5194 -
 acc: 0.1198Epoch 00000: val_loss improved from inf to 11.09797, saving
model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 2s - loss: 12.4985 - acc:
 0.1213 - val_loss: 11.0980 - val_acc: 0.2168
Epoch 2/20
6580/6680 [============================>.] - ETA: 0s - loss: 10.3350 -
 acc: 0.2775Epoch 00001: val_loss improved from 11.09797 to 10.10341, s
aving model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 10.3207 - acc:
 0.2778 - val_loss: 10.1034 - val_acc: 0.2982
Epoch 3/20
6640/6680 [============================>.] - ETA: 0s - loss: 9.6881 - a
cc: 0.3423Epoch 00002: val_loss improved from 10.10341 to 9.83501, savi
ng model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 9.6817 - acc:
 0.3428 - val_loss: 9.8350 - val_acc: 0.3198
Epoch 4/20
6580/6680 [============================>.] - ETA: 0s - loss: 9.3959 - a
cc: 0.3775Epoch 00003: val_loss improved from 9.83501 to 9.71915, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 9.3899 - acc:
 0.3772 - val_loss: 9.7192 - val_acc: 0.3329
Epoch 5/20
6620/6680 [============================>.] - ETA: 0s - loss: 9.1392 - a
cc: 0.4029Epoch 00004: val_loss improved from 9.71915 to 9.54046, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 9.1401 - acc:
 0.4027 - val_loss: 9.5405 - val_acc: 0.3485
Epoch 6/20
6440/6680 [===========================>..] - ETA: 0s - loss: 9.0471 - a
cc: 0.4183Epoch 00005: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 9.0656 - acc:
 0.4169 - val_loss: 9.5498 - val_acc: 0.3509
Epoch 7/20
6660/6680 [============================>.] - ETA: 0s - loss: 9.0109 - a
cc: 0.4267Epoch 00006: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 9.0225 - acc:
 0.4260 - val_loss: 9.5469 - val_acc: 0.3617
Epoch 8/20
6560/6680 [============================>.] - ETA: 0s - loss: 8.9888 - a
cc: 0.4328Epoch 00007: val_loss improved from 9.54046 to 9.52993, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.9990 - acc:
 0.4322 - val_loss: 9.5299 - val_acc: 0.3605
Epoch 9/20
6540/6680 [============================>.] - ETA: 0s - loss: 8.8467 - a
cc: 0.4365Epoch 00008: val_loss improved from 9.52993 to 9.38032, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.8580 - acc:
 0.4355 - val_loss: 9.3803 - val_acc: 0.3605
Epoch 10/20
6580/6680 [============================>.] - ETA: 0s - loss: 8.7260 - a
cc: 0.4480Epoch 00009: val_loss improved from 9.38032 to 9.28256, savin
g model to saved_models/weights.best.VGG16.hdf5
```

```
6680/6680 [==============================] - 1s - loss: 8.7330 - acc:
 0.4478 - val_loss: 9.2826 - val_acc: 0.3749
Epoch 11/20
6580/6680 [============================>.] - ETA: 0s - loss: 8.6862 - a
cc: 0.4512Epoch 00010: val_loss improved from 9.28256 to 9.20765, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.6756 - acc:
 0.4516 - val_loss: 9.2076 - val_acc: 0.3832
Epoch 12/20
6540/6680 [============================>.] - ETA: 0s - loss: 8.6173 - a
cc: 0.4535Epoch 00011: val_loss improved from 9.20765 to 9.14352, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.6049 - acc:
 0.4542 - val_loss: 9.1435 - val_acc: 0.3820
Epoch 13/20
6660/6680 [============================>.] - ETA: 0s - loss: 8.5049 - a
cc: 0.4614Epoch 00012: val_loss improved from 9.14352 to 9.05249, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.5062 - acc:
 0.4612 - val_loss: 9.0525 - val_acc: 0.3832
Epoch 14/20
6620/6680 [============================>.] - ETA: 0s - loss: 8.4411 - a
cc: 0.4696Epoch 00013: val_loss improved from 9.05249 to 8.98777, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.4501 - acc:
 0.4690 - val_loss: 8.9878 - val_acc: 0.3940
Epoch 15/20
6560/6680 [============================>.] - ETA: 0s - loss: 8.4158 - a
cc: 0.4698Epoch 00014: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 8.4129 - acc:
 0.4701 - val_loss: 9.0462 - val_acc: 0.3844
Epoch 16/20
6660/6680 [============================>.] - ETA: 0s - loss: 8.3548 - a
cc: 0.4743Epoch 00015: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 8.3592 - acc:
 0.4740 - val_loss: 9.0348 - val_acc: 0.3832
Epoch 17/20
6580/6680 [============================>.] - ETA: 0s - loss: 8.3396 - a
cc: 0.4778Epoch 00016: val_loss improved from 8.98777 to 8.93620, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.3285 - acc:
 0.4784 - val_loss: 8.9362 - val_acc: 0.3976
Epoch 18/20
6440/6680 [===========================>..] - ETA: 0s - loss: 8.2171 - a
cc: 0.4812Epoch 00017: val_loss improved from 8.93620 to 8.80418, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.1876 - acc:
 0.4826 - val_loss: 8.8042 - val_acc: 0.3964
Epoch 19/20
6620/6680 [============================>.] - ETA: 0s - loss: 8.0774 - a
cc: 0.4902Epoch 00018: val_loss improved from 8.80418 to 8.76392, savin
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 8.0865 - acc:
 0.4897 - val_loss: 8.7639 - val_acc: 0.4084
Epoch 20/20
6640/6680 [============================>.] - ETA: 0s - loss: 7.8661 - a
cc: 0.4952Epoch 00019: val_loss improved from 8.76392 to 8.55809, savin
```

```
g model to saved_models/weights.best.VGG16.hdf5
6680/6680 [==============================] - 1s - loss: 7.8619 - acc:
 0.4954 - val_loss: 8.5581 - val_acc: 0.4072
```

Out[46]:
```
<keras.callbacks.History at 0x7f8160b28c18>
```

Load the Model with the Best Validation Loss

In [47]:
```
VGG16_model.load_weights('saved_models/weights.best.VGG16.hdf5')
```

Test the Model

Now, we can use the CNN to test how well it identifies breed within our test dataset of dog images. We print the test accuracy below.

In [48]:
```
# get index of predicted dog breed for each image in test set
VGG16_predictions = [np.argmax(VGG16_model.predict(np.expand_dims(featur
e, axis=0))) for feature in test_VGG16]

# report test accuracy
test_accuracy = 100*np.sum(np.array(VGG16_predictions)==np.argmax(test_t
argets, axis=1))/len(VGG16_predictions)
print('Test accuracy: %.4f%%' % test_accuracy)
```

```
Test accuracy: 41.8660%
```

Predict Dog Breed with the Model

In [49]:
```
from extract_bottleneck_features import *

def VGG16_predict_breed(img_path):
    # extract bottleneck features
    bottleneck_feature = extract_VGG16(path_to_tensor(img_path))
    # obtain predicted vector
    predicted_vector = VGG16_model.predict(bottleneck_feature)
    # return dog breed that is predicted by the model
    return dog_names[np.argmax(predicted_vector)]
```

Step 5: Create a CNN to Classify Dog Breeds (using Transfer Learning)

You will now use transfer learning to create a CNN that can identify dog breed from images. Your CNN must attain at least 60% accuracy on the test set.

In Step 4, we used transfer learning to create a CNN using VGG-16 bottleneck features. In this section, you must use the bottleneck features from a different pre-trained model. To make things easier for you, we have pre-computed the features for all of the networks that are currently available in Keras:

- VGG-19 (https://s3-us-west-1.amazonaws.com/udacity-aind/dog-project/DogVGG19Data.npz) bottleneck features
- ResNet-50 (https://s3-us-west-1.amazonaws.com/udacity-aind/dog-project/DogResnet50Data.npz) bottleneck features
- Inception (https://s3-us-west-1.amazonaws.com/udacity-aind/dog-project/DogInceptionV3Data.npz) bottleneck features
- Xception (https://s3-us-west-1.amazonaws.com/udacity-aind/dog-project/DogXceptionData.npz) bottleneck features

The files are encoded as such:

```
Dog{network}Data.npz
```

where `{network}`, in the above filename, can be one of `VGG19`, `Resnet50`, `InceptionV3`, or `Xception`. Pick one of the above architectures, download the corresponding bottleneck features, and store the downloaded file in the `bottleneck_features/` folder in the repository.

(IMPLEMENTATION) Obtain Bottleneck Features

In the code block below, extract the bottleneck features corresponding to the train, test, and validation sets by running the following:

```
bottleneck_features = np.load('bottleneck_features/Dog{network}Data.npz')
train_{network} = bottleneck_features['train']
valid_{network} = bottleneck_features['valid']
test_{network} = bottleneck_features['test']
```

In [8]:

```
### Obtain bottleneck features from another pre-trained CNN.
import numpy as np
bottleneck_model = 'Resnet50'
bottleneck_features = np.load('bottleneck_features/Dog' + bottleneck_mod
el + 'Data.npz')
train_bottleneck = bottleneck_features['train']
valid_bottleneck = bottleneck_features['valid']
test_bottleneck = bottleneck_features['test']
```

(IMPLEMENTATION) Model Architecture

Create a CNN to classify dog breed. At the end of your code cell block, summarize the layers of your model by executing the line:

```
<your model's name>.summary()
```

Question 5: Outline the steps you took to get to your final CNN architecture and your reasoning at each step. Describe why you think the architecture is suitable for the current problem.

Answer:

I started out with VGG19, Resnet50, InceptionV3 and Xception bottleneck features and followed them with a GAP layer and Dense layer which I then trained. I used early stopping in my training. With these tests I found that Resnet50 gave me the best performance. This isn't really suprising since the Resnet50 architecture is trained on ImageNet and is much deeper than both VGG16 and VGG19. The data for our dog breed detector is very similar and just changing the top layer of Resnet50 was sufficient to get a big boost in performance. This architecture got me to 79-80% accuracy. (VGG19 got me to 60%.) Then, I starting playing with more convolutional layers, more dense layers, variety of optimizers, more epochs, etc. This got me to 81% accuracy.

In [9]:

```
### Define your architecture.
from keras.models import Sequential
from keras.layers import Dense, GlobalAveragePooling2D, MaxPooling2D, Co
nv2D, Dropout
my_model = Sequential()
my_model.add(GlobalAveragePooling2D(input_shape=train_bottleneck.shape[1:

my_model.add(Dense(133, activation='softmax'))

my_model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
global_average_pooling2d_2 ( (None, 2048)              0
_________________________________________________________________
dense_2 (Dense)              (None, 133)               272517
=================================================================
Total params: 272,517
Trainable params: 272,517
Non-trainable params: 0
_________________________________________________________________
```

(IMPLEMENTATION) Compile the Model

In [11]:

```
### Compile the model.
from keras.optimizers import SGD
my_model.compile(loss='categorical_crossentropy', optimizer='rmsprop', m
etrics=['accuracy'])
```

(IMPLEMENTATION) Train the Model

Train your model in the code cell below. Use model checkpointing to save the model that attains the best validation loss.

You are welcome to augment the training data (https://blog.keras.io/building-powerful-image-classification-models-using-very-little-data.html), but this is not a requirement.

In [10]:
```
weights_file = 'saved_models/weights.best.' + bottleneck_model + '.hdf5'
```

In [53]:
```
### Train the model.
from keras.callbacks import ModelCheckpoint, EarlyStopping
checkpointer = ModelCheckpoint(filepath=weights_file, verbose=1, save_be
st_only=True)
stopper = EarlyStopping(monitor='val_loss', min_delta=1e-4, patience=10,
 verbose=1, mode='auto')

my_model.fit(train_bottleneck,
             train_targets,
             validation_data=(valid_bottleneck, valid_targets),
             epochs=125,
             batch_size=20,
             callbacks=[checkpointer, stopper],
             verbose=1)
```

```
Train on 6680 samples, validate on 835 samples
Epoch 1/125
6640/6680 [============================>.] - ETA: 0s - loss: 1.6467 - a
cc: 0.5959Epoch 00000: val_loss improved from inf to 0.83921, saving mo
del to saved_models/weights.best.Resnet50.hdf5
6680/6680 [==============================] - 2s - loss: 1.6415 - acc:
 0.5970 - val_loss: 0.8392 - val_acc: 0.7473
Epoch 2/125
6640/6680 [============================>.] - ETA: 0s - loss: 0.4349 - a
cc: 0.8651Epoch 00001: val_loss improved from 0.83921 to 0.69506, savin
g model to saved_models/weights.best.Resnet50.hdf5
6680/6680 [==============================] - 1s - loss: 0.4357 - acc:
 0.8650 - val_loss: 0.6951 - val_acc: 0.7868
Epoch 3/125
6620/6680 [============================>.] - ETA: 0s - loss: 0.2625 - a
cc: 0.9168Epoch 00002: val_loss improved from 0.69506 to 0.64853, savin
g model to saved_models/weights.best.Resnet50.hdf5
6680/6680 [==============================] - 1s - loss: 0.2619 - acc:
 0.9171 - val_loss: 0.6485 - val_acc: 0.8012
Epoch 4/125
6560/6680 [============================>.] - ETA: 0s - loss: 0.1775 - a
cc: 0.9431Epoch 00003: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.1767 - acc:
 0.9433 - val_loss: 0.6858 - val_acc: 0.8108
Epoch 5/125
6420/6680 [===========================>..] - ETA: 0s - loss: 0.1213 - a
cc: 0.9629Epoch 00004: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.1218 - acc:
 0.9629 - val_loss: 0.6709 - val_acc: 0.8048
Epoch 6/125
6580/6680 [============================>.] - ETA: 0s - loss: 0.0886 - a
cc: 0.9734Epoch 00005: val_loss improved from 0.64853 to 0.64568, savin
g model to saved_models/weights.best.Resnet50.hdf5
6680/6680 [==============================] - 1s - loss: 0.0882 - acc:
 0.9737 - val_loss: 0.6457 - val_acc: 0.8216
Epoch 7/125
6440/6680 [===========================>..] - ETA: 0s - loss: 0.0641 - a
cc: 0.9809Epoch 00006: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0639 - acc:
 0.9810 - val_loss: 0.6986 - val_acc: 0.8228
Epoch 8/125
6540/6680 [============================>.] - ETA: 0s - loss: 0.0488 - a
cc: 0.9864Epoch 00007: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0489 - acc:
 0.9862 - val_loss: 0.6910 - val_acc: 0.8228
Epoch 9/125
6620/6680 [============================>.] - ETA: 0s - loss: 0.0359 - a
cc: 0.9912Epoch 00008: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0358 - acc:
 0.9912 - val_loss: 0.6917 - val_acc: 0.8311
Epoch 10/125
6520/6680 [============================>.] - ETA: 0s - loss: 0.0274 - a
cc: 0.9931Epoch 00009: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0283 - acc:
 0.9928 - val_loss: 0.8159 - val_acc: 0.8036
Epoch 11/125
6600/6680 [============================>.] - ETA: 0s - loss: 0.0226 - a
```

```
cc: 0.9945Epoch 00010: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0226 - acc:
 0.9946 - val_loss: 0.7938 - val_acc: 0.8263
Epoch 12/125
6460/6680 [===========================>.] - ETA: 0s - loss: 0.0157 - a
cc: 0.9960Epoch 00011: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0155 - acc:
 0.9961 - val_loss: 0.8100 - val_acc: 0.8120
Epoch 13/125
6660/6680 [===========================>.] - ETA: 0s - loss: 0.0146 - a
cc: 0.9956Epoch 00012: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0146 - acc:
 0.9957 - val_loss: 0.8078 - val_acc: 0.8251
Epoch 14/125
6520/6680 [===========================>.] - ETA: 0s - loss: 0.0111 - a
cc: 0.9971Epoch 00013: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0110 - acc:
 0.9972 - val_loss: 0.8096 - val_acc: 0.8228
Epoch 15/125
6500/6680 [===========================>.] - ETA: 0s - loss: 0.0090 - a
cc: 0.9974Epoch 00014: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0089 - acc:
 0.9975 - val_loss: 0.8670 - val_acc: 0.8168
Epoch 16/125
6660/6680 [===========================>.] - ETA: 0s - loss: 0.0085 - a
cc: 0.9974Epoch 00015: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0085 - acc:
 0.9975 - val_loss: 0.8195 - val_acc: 0.8192
Epoch 17/125
6560/6680 [===========================>.] - ETA: 0s - loss: 0.0065 - a
cc: 0.9980Epoch 00016: val_loss did not improve
6680/6680 [==============================] - 1s - loss: 0.0068 - acc:
 0.9979 - val_loss: 0.9089 - val_acc: 0.8299
Epoch 00016: early stopping
```

Out[53]: `<keras.callbacks.History at 0x7f8160911048>`

(IMPLEMENTATION) Load the Model with the Best Validation Loss

In [12]:
```
### Load the model weights with the best validation loss.
my_model.load_weights(weights_file)
```

(IMPLEMENTATION) Test the Model

Try out your model on the test dataset of dog images. Ensure that your test accuracy is greater than 60%.

In [8]:
```
### Calculate classification accuracy on the test dataset.
# get index of predicted dog breed for each image in test set
my_model_predictions = [np.argmax(my_model.predict(np.expand_dims(featur
e, axis=0))) for feature in test_bottleneck]

# report test accuracy
test_accuracy = 100*np.sum(np.array(my_model_predictions)==np.argmax(tes
t_targets, axis=1))/len(my_model_predictions)
print('Test accuracy: %.4f%%' % test_accuracy)
```

```
Test accuracy: 81.1005%
```

(IMPLEMENTATION) Predict Dog Breed with the Model

Write a function that takes an image path as input and returns the dog breed (`Affenpinscher`, `Afghan_hound`, etc) that is predicted by your model.

Similar to the analogous function in Step 5, your function should have three steps:

1. Extract the bottleneck features corresponding to the chosen CNN model.
2. Supply the bottleneck features as input to the model to return the predicted vector. Note that the argmax of this prediction vector gives the index of the predicted dog breed.
3. Use the `dog_names` array defined in Step 0 of this notebook to return the corresponding breed.

The functions to extract the bottleneck features can be found in `extract_bottleneck_features.py`, and they have been imported in an earlier code cell. To obtain the bottleneck features corresponding to your chosen CNN architecture, you need to use the function

```
extract_{network}
```

where `{network}`, in the above filename, should be one of `VGG19`, `Resnet50`, `InceptionV3`, or `Xception`.

In [13]:
```
### Write a function that takes a path to an image as input
### and returns the dog breed that is predicted by the model.
from extract_bottleneck_features import *

def my_model_predict_breed(img_path):
    # extract bottleneck features
    if bottleneck_model == 'VGG16':
        bottleneck_feature = extract_VGG16(path_to_tensor(img_path))
    elif bottleneck_model == 'VGG19':
        bottleneck_feature = extract_VGG19(path_to_tensor(img_path))
    elif bottleneck_model == 'Resnet50':
        bottleneck_feature = extract_Resnet50(path_to_tensor(img_path))
    elif bottleneck_model == 'InceptionV3':
        bottleneck_feature =
extract_InceptionV3(path_to_tensor(img_path))
    elif bottleneck_model == 'Xception':
        bottleneck_feature = extract_Xception(path_to_tensor(img_path))
    # obtain predicted vector
    predicted_vector = my_model.predict(bottleneck_feature)
    # return dog breed that is predicted by the model
    return dog_names[np.argmax(predicted_vector)]
```

Step 6: Write your Algorithm

Write an algorithm that accepts a file path to an image and first determines whether the image contains a human, dog, or neither. Then,

- if a **dog** is detected in the image, return the predicted breed.
- if a **human** is detected in the image, return the resembling dog breed.
- if **neither** is detected in the image, provide output that indicates an error.

You are welcome to write your own functions for detecting humans and dogs in images, but feel free to use the `face_detector` and `dog_detector` functions developed above. You are **required** to use your CNN from Step 5 to predict dog breed.

Some sample output for our algorithm is provided below, but feel free to design your own user experience!

Sample Human Output

(IMPLEMENTATION) Write your Algorithm

In [1]:
```
### Write your algorithm.
### Feel free to use as many code cells as needed.

# Predict whether human or dog using my CNN built in step 1
# See dogvshuman_predict above for code
```

Step 7: Test Your Algorithm

In this section, you will take your new algorithm for a spin! What kind of dog does the algorithm think that **you** look like? If you have a dog, does it predict your dog's breed accurately? If you have a cat, does it mistakenly think that your cat is a dog?

(IMPLEMENTATION) Test Your Algorithm on Sample Images!

Test your algorithm at least six images on your computer. Feel free to use any images you like. Use at least two human and two dog images.

Question 6: Is the output better than you expected :) ? Or worse :(? Provide at least three possible points of improvement for your algorithm.

Answer:

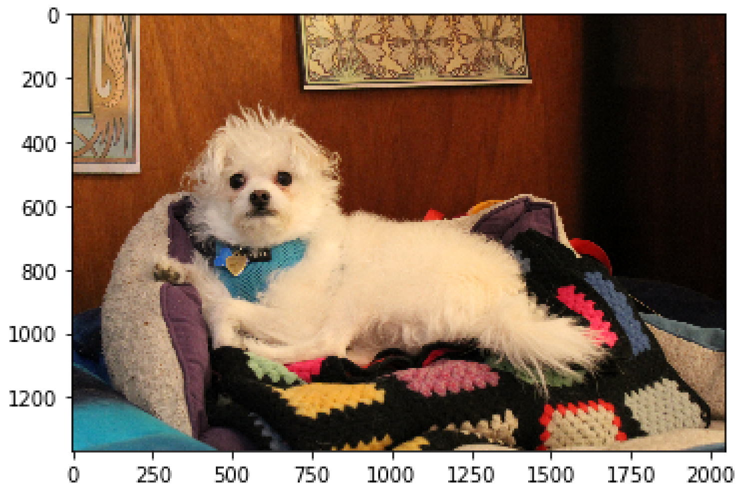
My dog vs human detector is pretty good but the breed detector has lots of room to improve. I could use more epochs, better optimizers (like SGD) and some image augmentation to increase its accuracy.

In [14]:
```
## Execute your algorithm from Step 6 on
## at least 6 images on your computer.
## Feel free to use as many code cells as needed.

import os, cv2
import matplotlib.pyplot as plt
%matplotlib inline

def show_test_image(img_path):
    # load color (BGR) image
    img = cv2.imread(img_path)
    if img == None or img.size == 0:
        print('Image loaded is empty')
    else:
        # convert to RGB
        b,g,r = cv2.split(img)
        img2 = cv2.merge([r,g,b])
        # display the image
        plt.imshow(img2)
        plt.show()
```

In [27]:

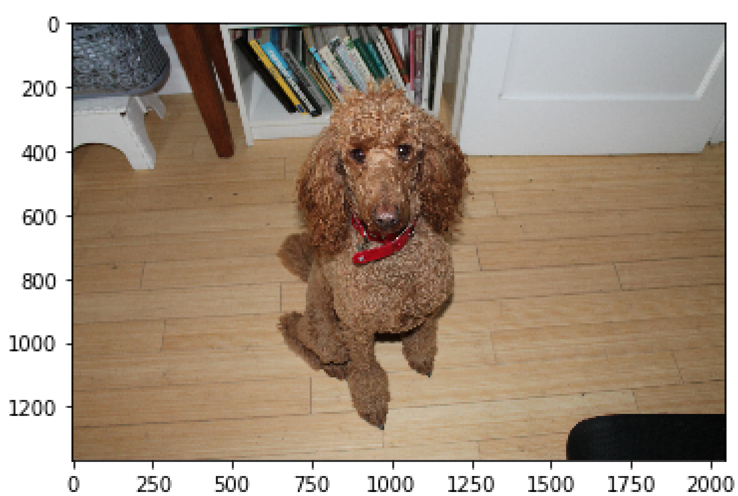
```
algo_test_image_dir = 'algoImages/'
algo_test_images = ['dog1.jpg', 'dog2.jpg', 'dog3.jpg', 'human1.jpg', 'h
uman2.jpg', 'human3.jpg']

for algo_test_image in algo_test_images:
    algo_test_image = algo_test_image_dir + algo_test_image
    if os.path.isfile(algo_test_image):
        show_test_image(algo_test_image)
        species = dogvshuman_predict(algo_test_image)
        breed = my_model_predict_breed(algo_test_image)
        print("Hello, ", species, ". You look like a ", breed)
    else:
        print("Image not found")
```

```
/home/aind2/anaconda3/envs/aind2/lib/python3.6/site-packages/ipykernel_
launcher.py:12: FutureWarning: comparison to `None` will result in an e
lementwise object comparison in the future.
  if sys.path[0] == '':
```

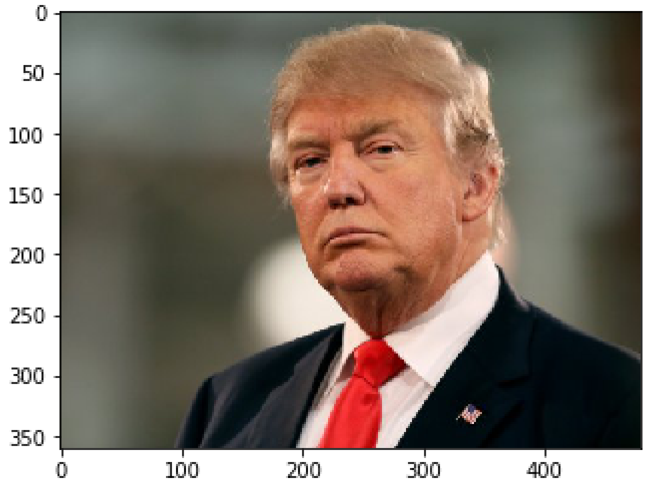



```
Hello,  dog . You look like a  Poodle
```

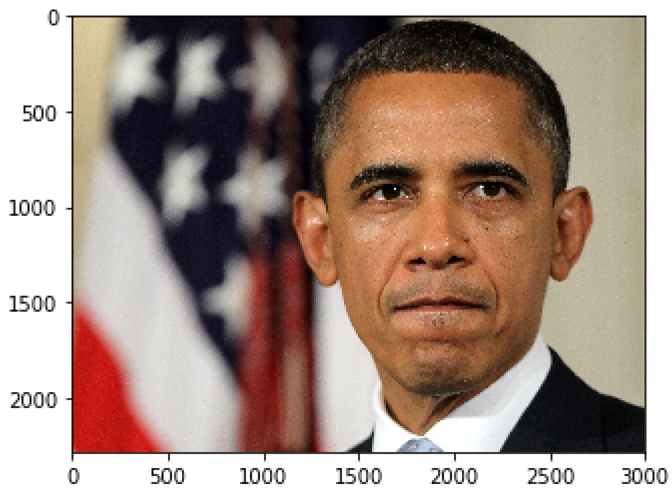

```
Hello,  dog . You look like a  Poodle
```



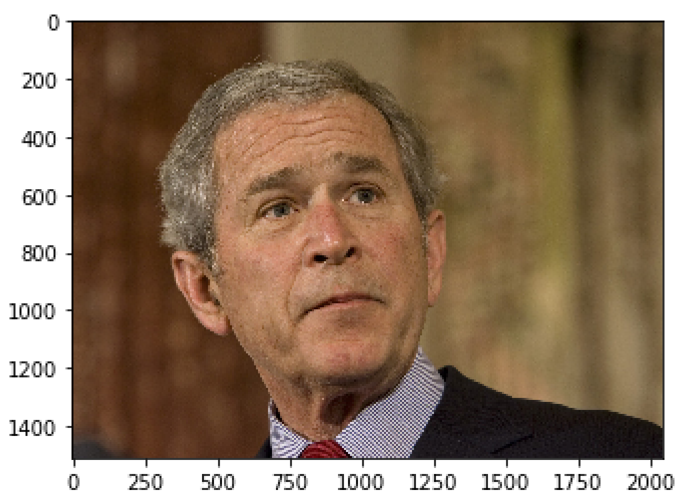

```
Hello,  dog . You look like a  Poodle
```



```
Hello,  human . You look like a  Nova_scotia_duck_tolling_retriever
```



```
Hello,  human . You look like a  Beagle
```



```
Hello,  human . You look like a  Xoloitzcuintli
```

In [ ]: