dog_app

January 27, 2019

1 Convolutional Neural Networks

1.1 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 Jupyter 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 **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 Jupyter notebook.

Step 0: Import Datasets

Make sure that you've downloaded the required human and dog datasets: * Download the dog dataset. Unzip the folder and place it in this project's home directory, at the location `/dog_images`.

- Download the human dataset. Unzip the folder and place it in the home directory, at location `/lfw`.

Note: If you are using a Windows machine, you are encouraged to use 7zip to extract the folder.

In the code cell below, we save the file paths for both the human (LFW) dataset and dog dataset in the numpy arrays `human_files` and `dog_files`.

```
In [1]: import numpy as np
        from glob import glob


        # load filenames for human and dog images
        human_files = np.array(glob("/data/lfw/*/*"))
        dog_files = np.array(glob("/data/dog_images/*/*/*"))

        # print number of images in each dataset
        print('There are %d total human images.' % len(human_files))
        print('There are %d total dog images.' % len(dog_files))
```

```
There are 13233 total human images.
There are 8351 total dog images.
```

Step 1: Detect Humans

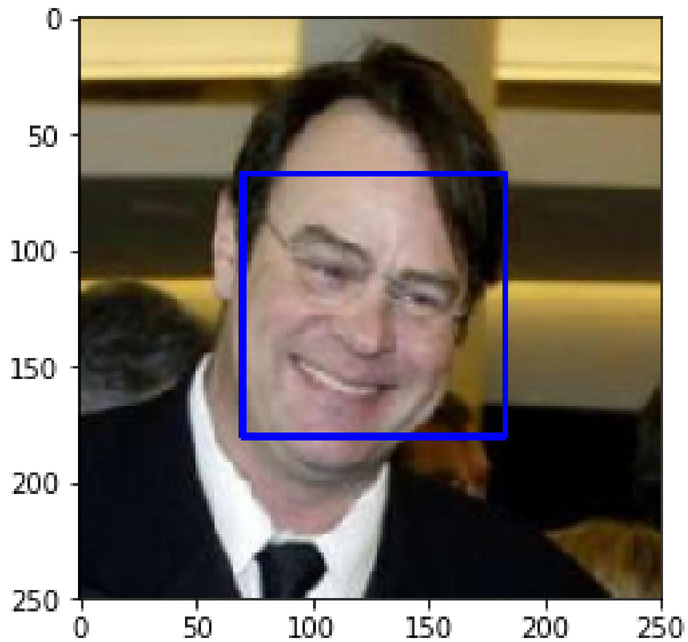
In this section, we use OpenCV's implementation of Haar feature-based cascade classifiers to detect human faces in images.

OpenCV provides many pre-trained face detectors, stored as XML files on github. 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 [2]: import cv2
        import matplotlib.pyplot as plt
        %matplotlib inline

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

        # load color (BGR) image
        img = cv2.imread(human_files[0])
        # 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: 1
```



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.

1.1.1 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 [3]: # 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
```

1.1.2 (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: (You can print out your results and/or write your percentages in this cell)

```
In [4]: from tqdm import tqdm_notebook as tqdm
        human_files_short = human_files[:100]
        dog_files_short = dog_files[:100]

        #-#-# Do NOT modify the code above this line. #-#-#

        ## TODO: Test the performance of the face_detector algorithm
        ## on the images in human_files_short and dog_files_short.
        faces_detected = 0
        for i, human_image in enumerate(tqdm(human_files_short, desc="Human faces")):
            img = cv2.imread(human_image)
            gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
            faces = face_cascade.detectMultiScale(gray)
            if(len(faces)>0):
                faces_detected+=1

        dogs_imaged_with_detected_face_count = 0
        for i, dog_image in enumerate(tqdm(dog_files_short, desc="Dog faces")):
            img = cv2.imread(dog_image)
            gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
            faces = face_cascade.detectMultiScale(gray)
            if(len(faces)>0):
                dogs_imaged_with_detected_face_count += 1

        print("% of faces detected ",(faces_detected/ len(human_files_short))*100 )
        print("% of dog detected with human face ",(dogs_imaged_with_detected_face_count/ len(do
```

```
HBox(children=(IntProgress(value=0, description='Human faces: '), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0, description='Dog faces: '), HTML(value='')))
```

```
% of faces detected  98.0
% of dog detected with human face  17.0
```

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 `human_files_short` and `dog_files_short`.

```
In [5]: ### (Optional)
        ### TODO: Test performance of anotherface detection algorithm.
        ### Feel free to use as many code cells as needed.
```

Step 2: Detect Dogs
In this section, we use a pre-trained model to detect dogs in images.

1.1.3 Obtain Pre-trained VGG-16 Model

The code cell below downloads the VGG-16 model, along with weights that have been trained on ImageNet, 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.

```
In [6]: import torch
        import torchvision.models as models

        # define VGG16 model
        VGG16 = models.vgg16(pretrained=True)

        # check if CUDA is available
        use_cuda = torch.cuda.is_available()

        # move model to GPU if CUDA is available
        if use_cuda:
            VGG16 = VGG16.cuda()
```

Given an image, this pre-trained VGG-16 model returns a prediction (derived from the 1000 possible categories in ImageNet) for the object that is contained in the image.

1.1.4 (IMPLEMENTATION) Making Predictions with a Pre-trained Model

In the next code cell, you will write a function that accepts a path to an image (such as `'dogImages/train/001.Affenpinscher/Affenpinscher_00001.jpg'`) as input and returns the index corresponding to the ImageNet class that is predicted by the pre-trained VGG-16 model. The output should always be an integer between 0 and 999, inclusive.

Before writing the function, make sure that you take the time to learn how to appropriately pre-process tensors for pre-trained models in the PyTorch documentation.

```
In [7]: from PIL import Image
        from PIL import ImageFile
        ImageFile.LOAD_TRUNCATED_IMAGES = True

        import torchvision.transforms as transforms
        from torch.autograd import Variable

        min_img_size = 220  # The min size, as noted in the PyTorch pretrained models doc, is 22
        transform_pipeline = transforms.Compose([
                                                  transforms.CenterCrop(224),
                                                  transforms.ToTensor(),
                                                  transforms.Normalize(mean=[0.485, 0.456, 0.406]
                                                                       std=[0.229, 0.224, 0.225])



        def VGG16_predict(img_path):
            '''
            Use pre-trained VGG-16 model to obtain index corresponding to
            predicted ImageNet class for image at specified path

            Args:
                img_path: path to an image

            Returns:
                Index corresponding to VGG-16 model's prediction
            '''

            ## TODO: Complete the function.
            ## Load and pre-process an image from the given img_path
            ## Return the *index* of the predicted class for that image

            image = Image.open(img_path)
            image = transform_pipeline(image)
            image = image.unsqueeze(0)
            image = Variable(image)

            if use_cuda:
                image = image.cuda()
```

```
    prediction = VGG16(image)

    if use_cuda:
        prediction = prediction.cpu()
        index = np.argmax(prediction.detach().numpy())
    else:
        index = prediction.data.numpy().argmax()
    return index # predicted class index
```

1.1.5 (IMPLEMENTATION) Write a Dog Detector

While looking at the dictionary, 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 VGG-16 model, we need only check if the pre-trained model predicts an index between 151 and 268 (inclusive).

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 [8]: ### returns "True" if a dog is detected in the image stored at img_path
        def dog_detector(img_path):
            ## TODO: Complete the function.
            index = VGG16_predict(img_path)
            if index >= 151 and index <= 268:
                return True
            else:
                return False      # true/false
```

1.1.6 (IMPLEMENTATION) Assess the Dog Detector

Question 2: 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 [9]: ### TODO: Test the performance of the dog_detector function
        ### on the images in human_files_short and dog_files_short.


        faces_detected = 0
        for i, human_image in enumerate(tqdm(human_files_short, desc="Human faces")):
            prediction = dog_detector(human_image)
            if prediction:
                faces_detected += 1

        dogs_imaged_with_detected_face_count = 0
        for dog_image in tqdm(dog_files_short, desc="Dog faces"):
            prediction = dog_detector(dog_image)
```

```
            if prediction:
                dogs_imaged_with_detected_face_count += 1

        print("% of faces detected ",(faces_detected/ len(human_files_short))*100, "%" )
        print("% of dog detected with human face ",(dogs_imaged_with_detected_face_count/ len(do
```

```
HBox(children=(IntProgress(value=0, description='Human faces: '), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0, description='Dog faces: '), HTML(value='')))
```

```
% of faces detected  1.0 %
% of dog detected with human face  90.0 %
```

We suggest VGG-16 as a potential network to detect dog images in your algorithm, but you are free to explore other pre-trained networks (such as Inception-v3, ResNet-50, etc). Please use the code cell below to test other pre-trained PyTorch models. If you decide to pursue this *optional* task, report performance on `human_files_short` and `dog_files_short`.

In [10]:
```
### (Optional)
### TODO: Report the performance of another pre-trained network.
### Feel free to use as many code cells as needed.


resnet50 = models.vgg16(pretrained=True)

# check if CUDA is available
use_cuda = torch.cuda.is_available()

# move model to GPU if CUDA is available
if use_cuda:
    resnet50 = resnet50.cuda()


min_img_size = 220  # The min size, as noted in the PyTorch pretrained models doc, is 2
transform_pipeline = transforms.Compose([
                                         transforms.CenterCrop(224),
                                         transforms.ToTensor(),
                                         transforms.Normalize(mean=[0.485, 0.456, 0.406
                                                              std=[0.229, 0.224, 0.225]
```

```python
def RESNET50_predict(img_path):
    '''
    Use pre-trained VGG-16 model to obtain index corresponding to
    predicted ImageNet class for image at specified path

    Args:
        img_path: path to an image

    Returns:
        Index corresponding to VGG-16 model's prediction
    '''

    ## TODO: Complete the function.
    ## Load and pre-process an image from the given img_path
    ## Return the *index* of the predicted class for that image

    image = Image.open(img_path)
    image = transform_pipeline(image)
    image = image.unsqueeze(0)
    image = Variable(image)

    if use_cuda:
        image = image.cuda()

    prediction = resnet50(image)
    if use_cuda:
        prediction = prediction.cpu()
        index = np.argmax(prediction.detach().numpy())
    else:
        index = prediction.data.numpy().argmax()

    return index # predicted class index


def dog_detector(img_path):
    ## TODO: Complete the function.
    index = RESNET50_predict(img_path)
    #print(index)
    if index >= 151 and index <= 268:
        return True
    else:
        return False # true/false


faces_detected = 0
for i, human_image in enumerate(tqdm(human_files_short, desc="Human faces")):
    prediction = dog_detector(human_image)
    if prediction:
```

```
                faces_detected += 1

        dogs_imaged_with_detected_face_count = 0
        for dog_image in tqdm(dog_files_short, desc="Dog faces"):
            prediction = dog_detector(dog_image)
            if prediction:
                dogs_imaged_with_detected_face_count += 1

        print("% of faces detected ",(faces_detected/ len(human_files_short))*100, "%" )
        print("% of dog detected with human face ",(dogs_imaged_with_detected_face_count/ len(d
```

```
HBox(children=(IntProgress(value=0, description='Human faces: '), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0, description='Dog faces: '), HTML(value='')))
```

```
% of faces detected  0.0 %
% of dog detected with human face  92.0 %
```

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 10%. In Step 4 of this notebook, you will have the opportunity to use transfer learning to create a CNN that attains greatly improved accuracy.

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 trouble 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

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!

1.1.7 (IMPLEMENTATION) Specify Data Loaders for the Dog Dataset

Use the code cell below to write three separate data loaders for the training, validation, and test datasets of dog images (located at `dog_images/train`, `dog_images/valid`, and `dog_images/test`, respectively). You may find this documentation on custom datasets to be a useful resource. If you are interested in augmenting your training and/or validation data, check out the wide variety of transforms!

In [11]:
```python
import os
from torchvision import datasets


### TODO: Write data loaders for training, validation, and test sets
## Specify appropriate transforms, and batch_sizes

num_workers = 1
batch_size = 32

data_dir = "/data/dog_images"

transform = transforms.Compose([transforms.Resize(size=(240,240)),
                                transforms.ToTensor(),
                                transforms.Normalize(mean=[0.485, 0.456, 0.406], std=[0


train_data = datasets.ImageFolder(data_dir + "/train", transform=transform)

validation_data = datasets.ImageFolder(data_dir + "/valid", transform=transform)

test_data = datasets.ImageFolder(data_dir + "/test", transform=transform)


train_loader = torch.utils.data.DataLoader(train_data, batch_size=batch_size,
                                           num_workers=num_workers,shuffle=True)
valid_loader = torch.utils.data.DataLoader(validation_data, batch_size=batch_size,
                                           num_workers=num_workers)
```

```
test_loader = torch.utils.data.DataLoader(test_data, batch_size=4,
                                           num_workers=num_workers)


loaders_scratch = {}
loaders_scratch['train'] = train_loader
loaders_scratch['valid'] = valid_loader
loaders_scratch['test'] = test_loader
```

Question 3: Describe your chosen procedure for preprocessing the data. - How does your code resize the images (by cropping, stretching, etc)? What size did you pick for the input tensor, and why? - Did you decide to augment the dataset? If so, how (through translations, flips, rotations, etc)? If not, why not?

Answer:

1.1.8 (IMPLEMENTATION) Model Architecture

Create a CNN to classify dog breed. Use the template in the code cell below.

```
In [12]: import torch.nn as nn
         import torch.nn.functional as F

         # define the CNN architecture
         class Net(nn.Module):
             ### TODO: choose an architecture, and complete the class
             def __init__(self):
                 super(Net, self).__init__()
                 ## Define layers of a CNN

                 self.conv1 = nn.Conv2d(3, 32, 3, padding=1)
                 self.bn1 = nn.BatchNorm2d(32)

                 self.conv2 = nn.Conv2d(32, 64, 3, padding=0)
                 self.bn2 = nn.BatchNorm2d(64)

                 self.conv3 = nn.Conv2d(64, 128, 3, padding=0)
                 self.bn3 = nn.BatchNorm2d(128)

                 self.pool = nn.MaxPool2d(2, 2)

                 self.fc1 = nn.Linear(28 * 28 * 128, 133)

                 self.dropout_dense = nn.Dropout(0.25)


             def forward(self, x):
                 ## Define forward behavior
```

```
        x = self.conv1(x)
        x = F.relu(x)
        x = self.pool(x)
        x = self.bn1(x)

        x = self.conv2(x)
        x = F.relu(x)
        x = self.pool(x)
        x = self.bn2(x)

        x = self.conv3(x)
        x = F.relu(x)
        x = self.pool(x)
        x = self.bn3(x)

        x = x.view(-1, 28 * 28 * 128)
        x = self.dropout_dense(x)
        x = self.fc1(x)

        return x

#-#-# You so NOT have to modify the code below this line. #-#-#

# instantiate the CNN
model_scratch = Net()

print(model_scratch)

# move tensors to GPU if CUDA is available
if use_cuda:
    model_scratch.cuda()
    model_scratch = nn.DataParallel(model_scratch)
```

```
Net(
  (conv1): Conv2d(3, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (bn1): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
  (conv2): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
  (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
  (conv3): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1))
  (bn3): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
  (pool): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (fc1): Linear(in_features=100352, out_features=133, bias=True)
  (dropout_dense): Dropout(p=0.25)
)
```

Question 4: Outline the steps you took to get to your final CNN architecture and your reasoning at each step.

Answer:

1.1.9 (IMPLEMENTATION) Specify Loss Function and Optimizer

Use the next code cell to specify a loss function and optimizer. Save the chosen loss function as `criterion_scratch`, and the optimizer as `optimizer_scratch` below.

```
In [13]: import torch.optim as optim

         ### TODO: select loss function
         criterion_scratch = nn.CrossEntropyLoss()

         ### TODO: select optimizer
         #optimizer_scratch = optim.Adam(model_scratch.parameters(), lr = 0.0001)

         optimizer_scratch = optim.Adam([
             {'params': model_scratch.parameters(), 'weight_decay': 0.1, 'amsgrad': True}
         ], lr=0.00001)

         #optimizer_scratch = optim.Adam([
         #    {'params': model_scratch.parameters(), 'amsgrad': True}
         #])

         #print(optimizer_scratch)
```

1.1.10 (IMPLEMENTATION) Train and Validate the Model

Train and validate your model in the code cell below. Save the final model parameters at filepath `'model_scratch.pt'`.

```
In [14]: import numpy as np
         from PIL import Image
         from PIL import ImageFile
         ImageFile.LOAD_TRUNCATED_IMAGES = True
         def train(n_epochs, loaders, model, optimizer, criterion, use_cuda, save_path):
             """returns trained model"""
             # initialize tracker for minimum validation loss
             valid_loss_min = np.Inf

             for epoch in range(1, n_epochs+1):
                 # initialize variables to monitor training and validation loss
                 train_loss = 0.0
                 valid_loss = 0.0

                 ###################
                 # train the model #
                 ###################
                 model.train()
                 for batch_idx, (data, target) in enumerate(loaders['train']):
                     # move to GPU
                     if use_cuda:
```

```
                data, target = data.cuda(), target.cuda()
            #print(data)
            ## find the loss and update the model parameters accordingly
            ## record the average training loss, using something like
            ## train_loss = train_loss + ((1 / (batch_idx + 1)) * (loss.data - train_lo

            optimizer.zero_grad()
            output = model(data)
            loss = criterion(output, target)
            loss.backward()
            optimizer.step()

            train_loss = train_loss + ((1 / (batch_idx + 1)) * (loss.data - train_loss)
            #if(batch_idx % 20 == 0):
            #    print("batch_idx {} , train_loss {}".format(batch_idx, train_loss))

        ######################
        # validate the model #
        ######################
        model.eval()
        for batch_idx, (data, target) in enumerate(loaders['valid']):
            # move to GPU
            if use_cuda:
                data, target = data.cuda(), target.cuda()
            ## update the average validation loss
            output = model(data)
            loss = criterion(output, target)
            valid_loss += loss.item()*data.size(0)
            #valid_loss = valid_loss + ((1 / (batch_idx + 1)) * (loss.data - valid_loss

        #train_loss = train_loss/len(train_loader.dataset)
        valid_loss = valid_loss/len(loaders['valid'])
        # print training/validation statistics
        print('Epoch: {} \tTraining Loss: {:.6f} \tValidation Loss: {:.6f}'.format(
            epoch,
            train_loss,
            valid_loss
            ))

        ## TODO: save the model if validation loss has decreased
        if valid_loss <= valid_loss_min:
            print('Validation loss decreased ({:.6f} --> {:.6f}).  Saving model ...'.fo
            valid_loss_min,
            valid_loss))
            torch.save(model.state_dict(), save_path)
            valid_loss_min = valid_loss
    # return trained model
    return model
```

In [15]:
```
# train the model
model_scratch = train(20, loaders_scratch, model_scratch, optimizer_scratch,criterion_s

# load the model that got the best validation accuracy
model_scratch.load_state_dict(torch.load('model_scratch.pt'))
```

```
Epoch: 1 	Training Loss: 4.597413 	Validation Loss: 134.843486
Validation loss decreased (inf --> 134.843486).  Saving model ...
Epoch: 2 	Training Loss: 3.670432 	Validation Loss: 130.149244
Validation loss decreased (134.843486 --> 130.149244).  Saving model ...
Epoch: 3 	Training Loss: 3.035337 	Validation Loss: 127.790802
Validation loss decreased (130.149244 --> 127.790802).  Saving model ...
Epoch: 4 	Training Loss: 2.518497 	Validation Loss: 126.373228
Validation loss decreased (127.790802 --> 126.373228).  Saving model ...
Epoch: 5 	Training Loss: 2.078970 	Validation Loss: 125.459603
Validation loss decreased (126.373228 --> 125.459603).  Saving model ...
Epoch: 6 	Training Loss: 1.709330 	Validation Loss: 124.974160
Validation loss decreased (125.459603 --> 124.974160).  Saving model ...
Epoch: 7 	Training Loss: 1.402512 	Validation Loss: 124.737253
Validation loss decreased (124.974160 --> 124.737253).  Saving model ...
Epoch: 8 	Training Loss: 1.156993 	Validation Loss: 124.632610
Validation loss decreased (124.737253 --> 124.632610).  Saving model ...
Epoch: 9 	Training Loss: 0.963685 	Validation Loss: 124.465560
Validation loss decreased (124.632610 --> 124.465560).  Saving model ...
Epoch: 10 	Training Loss: 0.808099 	Validation Loss: 124.398366
Validation loss decreased (124.465560 --> 124.398366).  Saving model ...
Epoch: 11 	Training Loss: 0.686424 	Validation Loss: 124.439450
Epoch: 12 	Training Loss: 0.592849 	Validation Loss: 124.427560
Epoch: 13 	Training Loss: 0.522729 	Validation Loss: 124.292440
Validation loss decreased (124.398366 --> 124.292440).  Saving model ...
Epoch: 14 	Training Loss: 0.465331 	Validation Loss: 124.339839
Epoch: 15 	Training Loss: 0.424518 	Validation Loss: 124.136849
Validation loss decreased (124.292440 --> 124.136849).  Saving model ...
Epoch: 16 	Training Loss: 0.389970 	Validation Loss: 124.036956
Validation loss decreased (124.136849 --> 124.036956).  Saving model ...
Epoch: 17 	Training Loss: 0.361617 	Validation Loss: 124.263043
Epoch: 18 	Training Loss: 0.343206 	Validation Loss: 124.093574
Epoch: 19 	Training Loss: 0.326344 	Validation Loss: 123.950537
Validation loss decreased (124.036956 --> 123.950537).  Saving model ...
Epoch: 20 	Training Loss: 0.310466 	Validation Loss: 123.911051
Validation loss decreased (123.950537 --> 123.911051).  Saving model ...
```

1.1.11 (IMPLEMENTATION) Test the Model

Try out your model on the test dataset of dog images. Use the code cell below to calculate and print the test loss and accuracy. Ensure that your test accuracy is greater than 10%.

```
In [16]: def test(loaders, model, criterion, use_cuda):

             # monitor test loss and accuracy
             test_loss = 0.
             correct = 0.
             total = 0.

             model.eval()
             for batch_idx, (data, target) in enumerate(loaders['test']):
                 # move to GPU
                 if use_cuda:
                     data, target = data.cuda(), target.cuda()
                 # forward pass: compute predicted outputs by passing inputs to the model
                 output = model(data)
                 # calculate the loss
                 loss = criterion(output, target)
                 # update average test loss
                 test_loss = test_loss + ((1 / (batch_idx + 1)) * (loss.data - test_loss))
                 # convert output probabilities to predicted class
                 pred = output.data.max(1, keepdim=True)[1]
                 # compare predictions to true label
                 correct += np.sum(np.squeeze(pred.eq(target.data.view_as(pred))).cpu().numpy())
                 total += data.size(0)

             print('Test Loss: {:.6f}\n'.format(test_loss))

             print('\nTest Accuracy: %2d%% (%2d/%2d)' % (
                 100. * correct / total, correct, total))
```

```
In [17]: # call test function
         test(loaders_scratch, model_scratch, criterion_scratch, use_cuda)
```

```
Test Loss: 3.961295


Test Accuracy: 10% (91/836)
```

Step 4: 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.

1.1.12 (IMPLEMENTATION) Specify Data Loaders for the Dog Dataset

Use the code cell below to write three separate data loaders for the training, validation, and test datasets of dog images (located at `dogImages/train`, `dogImages/valid`, and `dogImages/test`, respectively).

If you like, **you are welcome to use the same data loaders from the previous step**, when you created a CNN from scratch.

```
In [18]: ## TODO: Specify data loaders

         import os
         from torchvision import datasets
         from torchvision.transforms import transforms

         import torch

         num_workers = 1
         batch_size = 32

         data_dir = "/data/dog_images"

         train_transform = transforms.Compose([transforms.RandomResizedCrop(size=256, scale=(0.8
                                               transforms.RandomRotation(degrees=15),
                                               transforms.ColorJitter(),
                                               transforms.RandomHorizontalFlip(),
                                               transforms.CenterCrop(size=224),
                                               transforms.ToTensor(),
                                               transforms.Normalize(mean=[0.485, 0.456, 0.406], std=[0

         valid_tranform = transforms.Compose([transforms.Resize(256),
                                                     transforms.CenterCrop(224),
                                                     transforms.ToTensor(),
                                                     transforms.Normalize([0.485, 0.456, 0.406], [0.229


         transform = transforms.Compose([transforms.Resize(size=(240,240)),
                                               transforms.ToTensor(),
                                               transforms.Normalize(mean=[0.485, 0.456, 0.406], std=[0


         train_data = datasets.ImageFolder(data_dir + "/train", transform=transform)

         validation_data = datasets.ImageFolder(data_dir + "/valid", transform=transform)

         test_data = datasets.ImageFolder(data_dir + "/test", transform=transform)


         train_loader = torch.utils.data.DataLoader(train_data, batch_size=batch_size,
                                                                num_workers=num_workers,shuffle=True)

         valid_loader = torch.utils.data.DataLoader(validation_data, batch_size=batch_size,
                                                                num_workers=num_workers,shuffle=True)
```

```
test_loader = torch.utils.data.DataLoader(test_data, batch_size=4,
                                          num_workers=num_workers)


loaders_transfer = {}
loaders_transfer['train'] = train_loader
loaders_transfer['valid'] = valid_loader
loaders_transfer['test'] = test_loader
```

1.1.13 (IMPLEMENTATION) Model Architecture

Use transfer learning to create a CNN to classify dog breed. Use the code cell below, and save your initialized model as the variable `model_transfer`.

In [19]:
```
import torch
import torchvision.models as models
import torch.nn as nn

## TODO: Specify model architecture
model_transfer = models.vgg16(pretrained=True)
for param in model_transfer.parameters():
    param.requires_grad = False


num_features = model_transfer.classifier[6].in_features

features = list(model_transfer.classifier.children())[:-1] # Remove last layer
features.extend([nn.Linear(num_features, 133)]) # Add our layer with 4 outputs
model_transfer.classifier = nn.Sequential(*features) # Replace the model classifier
print(model_transfer)



use_cuda = torch.cuda.is_available()

print(use_cuda)

if use_cuda:
    model_transfer = model_transfer.cuda()
```

```
VGG(
  (features): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): ReLU(inplace)
    (2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (3): ReLU(inplace)
    (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (5): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
```

```
    (6): ReLU(inplace)
    (7): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (8): ReLU(inplace)
    (9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (10): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): ReLU(inplace)
    (12): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (13): ReLU(inplace)
    (14): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (15): ReLU(inplace)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (17): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (18): ReLU(inplace)
    (19): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (20): ReLU(inplace)
    (21): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (22): ReLU(inplace)
    (23): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (24): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (25): ReLU(inplace)
    (26): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (27): ReLU(inplace)
    (28): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (29): ReLU(inplace)
    (30): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=25088, out_features=4096, bias=True)
    (1): ReLU(inplace)
    (2): Dropout(p=0.5)
    (3): Linear(in_features=4096, out_features=4096, bias=True)
    (4): ReLU(inplace)
    (5): Dropout(p=0.5)
    (6): Linear(in_features=4096, out_features=133, bias=True)
  )
)
True
```

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:

1.1.14 (IMPLEMENTATION) Specify Loss Function and Optimizer

Use the next code cell to specify a loss function and optimizer. Save the chosen loss function as `criterion_transfer`, and the optimizer as `optimizer_transfer` below.

```
In [20]: import torch.optim as optim

         parameters = filter(lambda p: p.requires_grad, model_transfer.parameters())

         criterion_transfer = nn.CrossEntropyLoss()
         optimizer_transfer = optim.Adam(parameters, lr=0.001)
```

1.1.15 (IMPLEMENTATION) Train and Validate the Model

Train and validate your model in the code cell below. Save the final model parameters at filepath `'model_transfer.pt'`.

```
In [21]: # train the model
         n_epochs = 5
         #model_transfer =  train(n_epochs, loaders_transfer, model_transfer, optimizer_transfer

         # load the model that got the best validation accuracy (uncomment the line below)
         model_transfer.load_state_dict(torch.load('model_transfer.pt'))
```

1.1.16 (IMPLEMENTATION) Test the Model

Try out your model on the test dataset of dog images. Use the code cell below to calculate and print the test loss and accuracy. Ensure that your test accuracy is greater than 60%.

```
In [22]: test(loaders_transfer, model_transfer, criterion_transfer, use_cuda)

Test Loss: 0.487059


Test Accuracy: 86% (721/836)
```

1.1.17 (IMPLEMENTATION) Predict Dog Breed with the Model

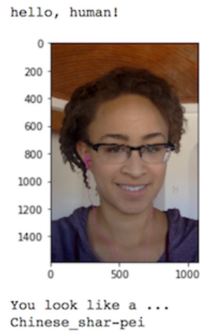
Write a function that takes an image path as input and returns the dog breed (`Affenpinscher`, `Afghan hound`, etc) that is predicted by your model.

```
In [23]: import os

         classes = list()
         for dir_ in os.listdir("/data/dog_images/train"):
             classes.append(dir_)

         loaders_transfer['train'].classes = classes

         class_dict = {}
         for item in loaders_transfer['train'].classes:
             index = item[:3]
             breed_name = item[4:].replace("_", " ")
```

```
            class_dict[int(index)] = breed_name

        class_names = [item[4:].replace("_", " ") for item in loaders_transfer['train'].classes
```

In [33]:
```
### TODO: Write a function that takes a path to an image as input
### and returns the dog breed that is predicted by the model.

# list of class names by index, i.e. a name can be accessed like class_names[0]
class_names = [item[4:].replace("_", " ") for item in loaders_transfer['train'].classes
#print(class_names)

import numpy as np
from PIL import *
from torch.autograd import Variable
from torchvision.transforms import ToTensor

def predict_breed_transfer(img_path):
    # load the image and return the predicted breed

    data_transforms = transforms.Compose([
        transforms.Resize(256),
        transforms.CenterCrop(224),
        transforms.ToTensor()
    ])


    image = Image.open(img_path)
    image = data_transforms(image).float()
    image = Variable(image, requires_grad=False)
    image = image.unsqueeze(0)
    if use_cuda:
        image = image.cuda()

    model_transfer.eval()
    val = model_transfer(image)
    val_ = val.cpu()
    #print(val_)
    val2 = np.argmax(val_.detach().numpy())
    #print(val2)
    return class_dict[val2+1]

#indx = predict_breed_transfer('/data/dog_images/train/001.Affenpinscher/Affenpinscher_
#print(indx)
#indx = predict_breed_transfer('/data/dog_images/train/004.Akita/Akita_00280.jpg')
#print(indx)
#indx = predict_breed_transfer('/data/dog_images/train/010.Anatolian_shepherd_dog/Anato
#print(indx)
```

```
Affenpinscher
```



Sample Human Output

```
Akita
Anatolian shepherd dog
```

Step 5: 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 `human_detector` functions developed above. You are **required** to use your CNN from Step 4 to predict dog breed.

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

1.1.18 (IMPLEMENTATION) Write your Algorithm

In [36]:
```
### TODO: Write your algorithm.
### Feel free to use as many code cells as needed.

import numpy as np

def run_app(img_path):
    ## handle cases for a human face, dog, and neither
    if(dog_detector(img_path)):
        #print("is a dog")
        return predict_breed_transfer(img_path)
    elif(face_detector(img_path)):
        #print("is a human")
        return predict_breed_transfer(img_path)
    else:
        raise Exception("Not a valid input")
```

Step 6: 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?

1.1.19 (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: (Three possible points for improvement)

```
In [39]: ## TODO: Execute your algorithm from Step 6 on
         ## at least 6 images on your computer.
         ## Feel free to use as many code cells as needed.

         ## suggested code, below
         for file in np.hstack((human_files[:3], dog_files[:3])):
             print("input ",file, "output ", run_app(file))
```

```
input  /data/lfw/Dan_Ackroyd/Dan_Ackroyd_0001.jpg output  English toy spaniel
input  /data/lfw/Alex_Corretja/Alex_Corretja_0001.jpg output  Dogue de bordeaux
input  /data/lfw/Daniele_Bergamin/Daniele_Bergamin_0001.jpg output  Poodle
input  /data/dog_images/train/103.Mastiff/Mastiff_06833.jpg output  Anatolian shepherd dog
input  /data/dog_images/train/103.Mastiff/Mastiff_06826.jpg output  Anatolian shepherd dog
input  /data/dog_images/train/103.Mastiff/Mastiff_06871.jpg output  Dogue de bordeaux
```

```
In [ ]:
```