Self-Driving Car Engineer Nanodegree

Deep Learning

Project: Build a Traffic Sign Recognition Classifier

In this notebook, a template is provided for you to implement your functionality in stages, which is required to successfully complete this project. If additional code is required that cannot be included in the notebook, be sure that the Python code is successfully imported and included in your submission if necessary.

> **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 is a writeup to complete. The writeup should be completed in a separate file, which can be either a markdown file or a pdf document. There is a write up template (https://github.com/udacity/CarND-Traffic-Sign-Classifier-Project/blob/master/writeup_template.md) that can be used to guide the writing process. Completing the code template and writeup template will cover all of the rubric points (https://review.udacity.com/#!/rubrics/481/view) for this project.

The rubric (https://review.udacity.com/#!/rubrics/481/view) contains "Stand Out Suggestions" for enhancing the project beyond the minimum requirements. The stand out suggestions are optional. If you decide to pursue the "stand out suggestions", you can include the code in this Ipython notebook and also discuss the results in the writeup file.

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

Step 0: Load The Data

In [2]:
```
# Load pickled data
import pickle
import numpy as np

### Replace each question mark with the appropriate value.

training_file = './data/train.p'
testing_file = './data/test.p'

with open(training_file, mode='rb') as f:
    train = pickle.load(f)
with open(testing_file, mode='rb') as f:
    test = pickle.load(f)

X_train, y_train = train['features'], train['labels']
X_test, y_test = test['features'], test['labels']
```

Step 1: Dataset Summary & Exploration

The pickled data is a dictionary with 4 key/value pairs:

- `'features'` is a 4D array containing raw pixel data of the traffic sign images, (num examples, width, height, channels).
- `'labels'` is a 1D array containing the label/class id of the traffic sign. The file `signnames.csv` contains id -> name mappings for each id.
- `'sizes'` is a list containing tuples, (width, height) representing the original width and height the image.
- `'coords'` is a list containing tuples, (x1, y1, x2, y2) representing coordinates of a bounding box around the sign in the image. **THESE COORDINATES ASSUME THE ORIGINAL IMAGE. THE PICKLED DATA CONTAINS RESIZED VERSIONS (32 by 32) OF THESE IMAGES**

Complete the basic data summary below. Use python, numpy and/or pandas methods to calculate the data summary rather than hard coding the results. For example, the pandas shape method (http://pandas.pydata.org/pandas-docs/stable/generated/pandas.DataFrame.shape.html) might be useful for calculating some of the summary results.

Provide a Basic Summary of the Data Set Using Python, Numpy and/or Pandas

In [3]:
```
# TODO: Number of training examples
n_train = len(y_train)

# TODO: Number of testing examples.
n_test = len(y_test)

# TODO: What's the shape of an traffic sign image?
image_shape = X_train.shape[1:]

# TODO: How many unique classes/labels there are in the dataset.
n_classes = len(np.unique(y_train))

img_size = X_train.shape #Size of input images

print("Number of training examples =", n_train)
print("Number of testing examples =", n_test)
print("Image data shape =", image_shape)
print("Number of classes =", n_classes)

assert(len(X_train) == len(y_train))
assert(len(X_test) == len(y_test))
```

```
Number of training examples = 34799
Number of testing examples = 12630
Image data shape = (32, 32, 3)
Number of classes = 43
```

In [ ]:

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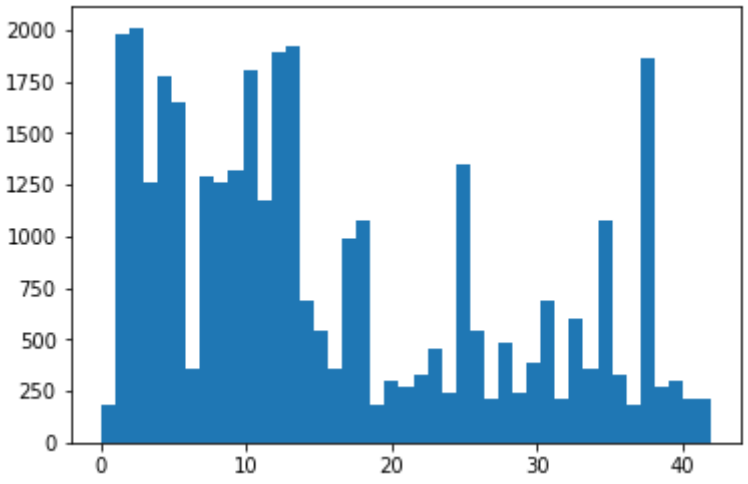
In [4]:
```
import random
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline

# Making a histogram for the distribution
plt.hist(y_train, bins = n_classes)
```

Out[4]:
```
(array([  180.,  1980.,  2010.,  1260.,  1770.,  1650.,   360.,  1290.,
         1260.,  1320.,  1800.,  1170.,  1890.,  1920.,   690.,   540.,
          360.,   990.,  1080.,   180.,   300.,   270.,   330.,   450.,
          240.,  1350.,   540.,   210.,   480.,   240.,   390.,   690.,
          210.,   599.,   360.,  1080.,   330.,   180.,  1860.,   270.,
          300.,   210.,   210.]),
 array([  0.        ,   0.97674419,   1.95348837,   2.93023256,
          3.90697674,   4.88372093,   5.86046512,   6.8372093 ,
          7.81395349,   8.79069767,   9.76744186,  10.74418605,
         11.72093023,  12.69767442,  13.6744186 ,  14.65116279,
         15.62790698,  16.60465116,  17.58139535,  18.55813953,
         19.53488372,  20.51162791,  21.48837209,  22.46511628,
         23.44186047,  24.41860465,  25.39534884,  26.37209302,
         27.34883721,  28.3255814 ,  29.30232558,  30.27906977,
         31.25581395,  32.23255814,  33.20930233,  34.18604651,
         35.1627907 ,  36.13953488,  37.11627907,  38.09302326,
         39.06976744,  40.04651163,  41.02325581,  42.        ]),
 <a list of 43 Patch objects>)
```



Step 2: Design and Test a Model Architecture

Design and implement a deep learning model that learns to recognize traffic signs. Train and test your model on the German Traffic Sign Dataset (http://benchmark.ini.rub.de/?section=gtsrb&subsection=dataset).

The LeNet-5 implementation shown in the classroom (https://classroom.udacity.com/nanodegrees/nd013/parts/fbf77062-5703-404e-b60c-95b78b2f3f9e/modules/6df7ae49-c61c-4bb2-a23e-6527e69209ec/lessons/601ae704-1035-4287-8b11-e2c2716217ad/concepts/d4aca031-508f-4e0b-b493-e7b706120f81) at the end of the CNN lesson is a solid starting point. You'll have to change the number of classes and possibly the preprocessing, but aside from that it's plug and play!

With the LeNet-5 solution from the lecture, you should expect a validation set accuracy of about 0.89. To meet specifications, the validation set accuracy will need to be at least 0.93. It is possible to get an even higher accuracy, but 0.93 is the minimum for a successful project submission.

There are various aspects to consider when thinking about this problem:

- Neural network architecture (is the network over or underfitting?)
- Play around preprocessing techniques (normalization, rgb to grayscale, etc)
- Number of examples per label (some have more than others).
- Generate fake data.

Here is an example of a published baseline model on this problem (http://yann.lecun.com/exdb/publis/pdf/sermanet-ijcnn-11.pdf). It's not required to be familiar with the approach used in the paper but, it's good practice to try to read papers like these.

Pre-process the Data Set (normalization, grayscale, etc.)

Minimally, the image data should be normalized so that the data has mean zero and equal variance. For image data, `(pixel - 128)/ 128` is a quick way to approximately normalize the data and can be used in this project.

Other pre-processing steps are optional. You can try different techniques to see if it improves performance.

Use the code cell (or multiple code cells, if necessary) to implement the first step of your project.

In [5]:
```
from sklearn.model_selection import train_test_split
from sklearn.utils import shuffle
import random

def normalize(data):
    return data / 255 * 0.8 + 0.1

# Normalizes the data between 0.1 and 0.9 instead of 0 to 255
def nornalizeArrray(data):
    images = []
    for image in data:
        image = normalize(image)
        images.append(image)

    return np.array(images)

print('Preprocessing data ...')

# Iterate and normalize
X_train = nornalizeArrray(X_train)
X_test  = nornalizeArrray(X_test)

print('Finished preprocessing data')

# Shuffle the data prior to splitting
X_train, y_train = shuffle(X_train, y_train)
X_train, X_valid, y_train, y_valid = train_test_split(X_train, y_train, stratify = y_train, test_size=0.

print('Dataset successfully split for training and validation.')

print ('Shape: ', X_train.shape[1:])
print('Number of images in the training dataset = ', len(X_train))
print('Number of images in the test dataset = ', len(X_test))
print('Number of images in the validation dataset = ', len(X_valid))
```

```
Preprocessing data ...
Finished preprocessing data
Dataset successfully split for training and validation.
Shape:  (32, 32, 3)
Number of images in the training dataset =  27839
Number of images in the test dataset =  12630
Number of images in the validation dataset =  6960
```

Model Architecture

In [6]:
```
from tensorflow.contrib.layers import flatten
import tensorflow as tf

def myNet(x):
    # Arguments used for tf.truncated_normal, randomly defines variables for the weights and biases for
    mu = 0
    sigma = 0.1

    # SOLUTION: Layer 1: Convolutional. Input = 32x32x3. Output = 28x28x6.
    conv1_W = tf.Variable(tf.truncated_normal(shape=(5, 5, 3, 6), mean = mu, stddev = sigma))
    conv1_b = tf.Variable(tf.zeros(6))
    conv1   = tf.nn.conv2d(x, conv1_W, strides=[1, 1, 1, 1], padding='VALID') + conv1_b

    # SOLUTION: Activation.
    conv1 = tf.nn.relu(conv1)
    conv1 = tf.nn.dropout(conv1, keep_prob)

    # SOLUTION: Pooling. Input = 28x28x6. Output = 14x14x6.
    conv1 = tf.nn.max_pool(conv1, ksize=[1, 2, 2, 1], strides=[1, 2, 2, 1], padding='VALID')

    # SOLUTION: Layer 2: Convolutional. Output = 10x10x16.
    conv2_W = tf.Variable(tf.truncated_normal(shape=(5, 5, 6, 16), mean = mu, stddev = sigma))
    conv2_b = tf.Variable(tf.zeros(16))
    conv2   = tf.nn.conv2d(conv1, conv2_W, strides=[1, 1, 1, 1], padding='VALID') + conv2_b

    # SOLUTION: Activation.
    conv2 = tf.nn.relu(conv2)
    conv2 = tf.nn.dropout(conv2, keep_prob)

    # SOLUTION: Pooling. Input = 10x10x16. Output = 5x5x16.
    conv2 = tf.nn.max_pool(conv2, ksize=[1, 2, 2, 1], strides=[1, 2, 2, 1], padding='VALID')

    # SOLUTION: Flatten. Input = 5x5x16. Output = 400.
    fc0   = flatten(conv2)

    # SOLUTION: Layer 3: Fully Connected. Input = 400. Output = 120.
    fc1_W = tf.Variable(tf.truncated_normal(shape=(400, 120), mean = mu, stddev = sigma))
    fc1_b = tf.Variable(tf.zeros(120))
    fc1   = tf.matmul(fc0, fc1_W) + fc1_b

    # SOLUTION: Activation.
    fc1    = tf.nn.relu(fc1)
```

```
    fc1 = tf.nn.dropout(fc1, keep_prob)

    # SOLUTION: Layer 4: Fully Connected. Input = 120. Output = 84.
    fc2_W  = tf.Variable(tf.truncated_normal(shape=(120, 84), mean = mu, stddev = sigma))
    fc2_b  = tf.Variable(tf.zeros(84))
    fc2    = tf.matmul(fc1, fc2_W) + fc2_b

    # SOLUTION: Activation.
    fc2    = tf.nn.relu(fc2)
    fc2 = tf.nn.dropout(fc2, keep_prob)

    # SOLUTION: Layer 5: Fully Connected. Input = 84. Output = 43.
    fc3_W  = tf.Variable(tf.truncated_normal(shape=(84, 43), mean = mu, stddev = sigma))
    fc3_b  = tf.Variable(tf.zeros(43))
    logits = tf.matmul(fc2, fc3_W) + fc3_b

    return logits
```

Train, Validate and Test the Model

A validation set can be used to assess how well the model is performing. A low accuracy on the training and validation sets imply underfitting. A high accuracy on the training set but low accuracy on the validation set implies overfitting.

In [7]:
```
rate = 0.001
EPOCHS = 20
BATCH_SIZE = 128

x = tf.placeholder(tf.float32, (None, 32, 32, 3))
y = tf.placeholder(tf.int32, (None))
one_hot_y = tf.one_hot(y, n_classes)
keep_prob = tf.placeholder(tf.float32) # probability to keep units
logits = myNet(x)

correct_prediction = tf.equal(tf.argmax(logits, 1), tf.argmax(one_hot_y, 1))
accuracy_operation = tf.reduce_mean(tf.cast(correct_prediction, tf.float32))
savedModel = './myModel.m'
saver = tf.train.Saver()

def evaluate(X_data, y_data):
    num_examples = len(X_data)
    total_accuracy = 0
    sess = tf.get_default_session()
    for offset in range(0, num_examples, BATCH_SIZE):
        batch_x, batch_y = X_data[offset:offset+BATCH_SIZE], y_data[offset:offset+BATCH_SIZE]
        accuracy = sess.run(accuracy_operation, feed_dict={x: batch_x, y: batch_y, keep_prob: 1.0})
        total_accuracy += (accuracy * len(batch_x))
    return total_accuracy / num_examples


cross_entropy = tf.nn.softmax_cross_entropy_with_logits(labels=one_hot_y, logits=logits)
loss_operation = tf.reduce_mean(cross_entropy)
optimizer = tf.train.AdamOptimizer(learning_rate = rate)
training_operation = optimizer.minimize(loss_operation)

with tf.Session() as sess:
    sess.run(tf.global_variables_initializer())
    num_examples = len(X_train)

    print("Training...")
    for i in range(EPOCHS):
        X_train, y_train = shuffle(X_train, y_train)
        for offset in range(0, num_examples, BATCH_SIZE):
            end = offset + BATCH_SIZE
            batch_x, batch_y = X_train[offset:end], y_train[offset:end]
            sess.run(training_operation, feed_dict={x: batch_x, y: batch_y, keep_prob: 0.5})
```

```
        validation_accuracy = evaluate(X_valid, y_valid)
        print("EPOCH {} ...".format(i+1))
        print("Validation Accuracy = {:.3f}".format(validation_accuracy))
        print()

    saver.save(sess, savedModel)
    print("Model saved")


# Launch the model on the test data
with tf.Session() as sess:
    saver.restore(sess, savedModel)

    test_accuracy = sess.run(accuracy_operation, feed_dict={x: X_test, y: y_test, keep_prob: 1.0})

print('Test Accuracy: {}'.format(test_accuracy))
```

```
Training...
EPOCH 1 ...
Validation Accuracy = 0.522

EPOCH 2 ...
Validation Accuracy = 0.666

EPOCH 3 ...
Validation Accuracy = 0.741

EPOCH 4 ...
Validation Accuracy = 0.779

EPOCH 5 ...
Validation Accuracy = 0.831

EPOCH 6 ...
Validation Accuracy = 0.842

EPOCH 7 ...
Validation Accuracy = 0.872

EPOCH 8 ...
Validation Accuracy = 0.890
```

```
EPOCH 9 ...
Validation Accuracy = 0.893

EPOCH 10 ...
Validation Accuracy = 0.891

EPOCH 11 ...
Validation Accuracy = 0.908

EPOCH 12 ...
Validation Accuracy = 0.919

EPOCH 13 ...
Validation Accuracy = 0.918

EPOCH 14 ...
Validation Accuracy = 0.920

EPOCH 15 ...
Validation Accuracy = 0.936

EPOCH 16 ...
Validation Accuracy = 0.942

EPOCH 17 ...
Validation Accuracy = 0.930

EPOCH 18 ...
Validation Accuracy = 0.943

EPOCH 19 ...
Validation Accuracy = 0.933

EPOCH 20 ...
Validation Accuracy = 0.941

Model saved
Test Accuracy: 0.8886777758598328
```

Step 3: Test a Model on New Images

To give yourself more insight into how your model is working, download at least five pictures of German traffic signs from the web and use your model to predict the traffic sign type.

You may find `signnames.csv` useful as it contains mappings from the class id (integer) to the actual sign name.

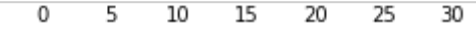
Load and Output the Images

In [11]:
```
import os
import matplotlib.image as mpimg
testPics = os.listdir("./test")
testPics = testPics[0:5]

# Show the images, add to a list to process for classifying
testPicsData = []
for i in testPics:
    i = 'test/' + i
    image = mpimg.imread(i)
    testPicsData.append(image)
    plt.imshow(image)
    plt.show()

# Make into numpy array for processing
testPicsData = np.array(testPicsData)

print('Preprocessing additional pictures...')
# Iterate
picsData = nornalizeArrray(testPicsData)
print('Finished preprocessing additional pictures.')
```



Predict the Sign Type for Each Image

In [16]:
```
def test(picsData, sess):
    prob = sess.run(tf.nn.softmax(logits), feed_dict={x: picsData, keep_prob: 1.0})
    top_5 = tf.nn.top_k(prob, k=5, sorted=True)
    return sess.run(top_5)


with tf.Session() as sess:
    saver.restore(sess, savedModel)
    signs_top_5 = test(picsData, sess)
```

Analyze Performance

In [17]:
```
 print (signs_top_5)
```

```
TopKV2(values=array([[  7.53496230e-01,   2.44850814e-01,   1.28227135e-03,
          1.31779772e-04,   7.23789635e-05],
       [  2.32064888e-01,   1.46351159e-01,   1.36603251e-01,
          1.30658001e-01,   1.18910760e-01],
       [  7.76498497e-01,   1.71019733e-01,   2.48671062e-02,
          9.30203497e-03,   4.53942874e-03],
       [  9.16136742e-01,   2.31424551e-02,   1.85112618e-02,
          1.63072962e-02,   6.41634129e-03],
       [  9.99998569e-01,   5.80454355e-07,   3.76286920e-07,
          1.61356624e-07,   9.77846071e-08]], dtype=float32), indices=array([[17, 14, 15, 13, 22],
       [23, 11, 19, 30, 12],
       [13, 10, 12,  9,  5],
       [25, 31,  5,  3, 13],
       [12, 41, 17, 10, 32]], dtype=int32))
```

Output Top 5 Softmax Probabilities For Each Image Found on the Web

For each of the new images, print out the model's softmax probabilities to show the **certainty** of the model's predictions (limit the output to the top 5 probabilities for each image). `tf.nn.top_k` (https://www.tensorflow.org/versions/r0.12/api_docs/python/nn.html#top_k) could prove helpful here.

The example below demonstrates how tf.nn.top_k can be used to find the top k predictions for each image.

`tf.nn.top_k` will return the values and indices (class ids) of the top k predictions. So if k=3, for each sign, it'll return the 3 largest probabilities (out of a possible 43) and the correspoding class ids.

Take this numpy array as an example. The values in the array represent predictions. The array contains softmax probabilities for five candidate images with six possible classes. `tk.nn.top_k` is used to choose the three classes with the highest probability:

```
# (5, 6) array
a = np.array([[ 0.24879643,  0.07032244,  0.12641572,  0.34763842,  0.07893497,
         0.12789202],
       [ 0.28086119,  0.27569815,  0.08594638,  0.0178669 ,  0.18063401,
         0.15899337],
       [ 0.26076848,  0.23664738,  0.08020603,  0.07001922,  0.1134371 ,
         0.23892179],
       [ 0.11943333,  0.29198961,  0.02605103,  0.26234032,  0.1351348 ,
         0.16505091],
       [ 0.09561176,  0.34396535,  0.0643941 ,  0.16240774,  0.24206137,
         0.09155967]])
```

Running it through `sess.run(tf.nn.top_k(tf.constant(a), k=3))` produces:

```
TopKV2(values=array([[ 0.34763842,  0.24879643,  0.12789202],
       [ 0.28086119,  0.27569815,  0.18063401],
       [ 0.26076848,  0.23892179,  0.23664738],
       [ 0.29198961,  0.26234032,  0.16505091],
       [ 0.34396535,  0.24206137,  0.16240774]]), indices=array([[3, 0, 5],
       [0, 1, 4],
       [0, 5, 1],
       [1, 3, 5],
       [1, 4, 3]], dtype=int32))
```

Looking just at the first row we get `[ 0.34763842,  0.24879643,  0.12789202]`, you can confirm these are the 3 largest probabilities in `a`. You'll also notice `[3, 0, 5]` are the corresponding indices.

In [58]:
```
### Print out the top five softmax probabilities for the predictions on the German traffic sign images f
### Feel free to use as many code cells as needed.
```

Project Writeup

Once you have completed the code implementation, document your results in a project writeup using this template (https://github.com/udacity/CarND-Traffic-Sign-Classifier-Project/blob/master/writeup_template.md) as a guide. The writeup can be in a markdown or pdf file.

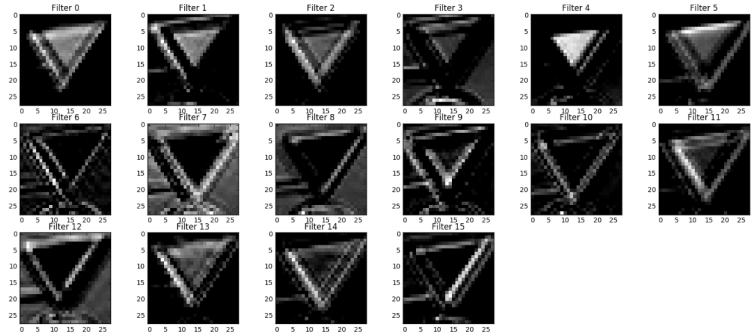
> **Note**: Once you have completed all of the code implementations and successfully answered each question above, you may finalize your work by exporting the iPython Notebook as an HTML document. You can do this by using the menu above and navigating to \n", "**File -> Download as -> HTML (.html)**. Include the finished document along with this notebook as your submission.

Step 4 (Optional): Visualize the Neural Network's State with Test Images

This Section is not required to complete but acts as an additional excersise for understaning the output of a neural network's weights. While neural networks can be a great learning device they are often referred to as a black box. We can understand what the weights of a neural network look like better by plotting their feature maps. After successfully training your neural network you can see what it's feature maps look like by plotting the output of the network's weight layers in response to a test stimuli image. From these plotted feature maps, it's possible to see what characteristics of an image the network finds interesting. For a sign, maybe the inner network feature maps react with high activation to the sign's boundary outline or to the contrast in the sign's painted symbol.

Provided for you below is the function code that allows you to get the visualization output of any tensorflow weight layer you want. The inputs to the function should be a stimuli image, one used during training or a new one you provided, and then the tensorflow variable name that represents the layer's state during the training process, for instance if you wanted to see what the LeNet lab's (https://classroom.udacity.com/nanodegrees/nd013/parts/fbf77062-5703-404e-b60c-95b78b2f3f9e/modules/6df7ae49-c61c-4bb2-a23e-6527e69209ec/lessons/601ae704-1035-4287-8b11-e2c2716217ad/concepts/d4aca031-508f-4e0b-b493-e7b706120f81) feature maps looked like for it's second convolutional layer you could enter conv2 as the tf_activation variable.

For an example of what feature map outputs look like, check out NVIDIA's results in their paper End-to-End Deep Learning for Self-Driving Cars (https://devblogs.nvidia.com/parallelforall/deep-learning-self-driving-cars/) in the section Visualization of internal CNN State. NVIDIA was able to show that their network's inner weights had high activations to road boundary lines by comparing feature maps from an image with a clear path to one without. Try experimenting with a similar test to show that your trained network's weights are looking for interesting features, whether it's looking at differences in feature maps from images with or without a sign, or even what feature maps look like in a trained network vs a completely untrained one on the same sign image.



Your output should look something like this (above)

In [59]:
```
### Visualize your network's feature maps here.
### Feel free to use as many code cells as needed.

# image_input: the test image being fed into the network to produce the feature maps
# tf_activation: should be a tf variable name used during your training procedure that represents the ca
# activation_min/max: can be used to view the activation contrast in more detail, by default matplot set
# plt_num: used to plot out multiple different weight feature map sets on the same block, just extend th

def outputFeatureMap(image_input, tf_activation, activation_min=-1, activation_max=-1 ,plt_num=1):
    # Here make sure to preprocess your image_input in a way your network expects
    # with size, normalization, ect if needed
    # image_input =
    # Note: x should be the same name as your network's tensorflow data placeholder variable
    # If you get an error tf_activation is not defined it may be having trouble accessing the variable f
    activation = tf_activation.eval(session=sess,feed_dict={x : image_input})
    featuremaps = activation.shape[3]
    plt.figure(plt_num, figsize=(15,15))
    for featuremap in range(featuremaps):
        plt.subplot(6,8, featuremap+1) # sets the number of feature maps to show on each row and column
        plt.title('FeatureMap ' + str(featuremap)) # displays the feature map number
        if activation_min != -1 & activation_max != -1:
            plt.imshow(activation[0,:,:, featuremap], interpolation="nearest", vmin =activation_min, vma
        elif activation_max != -1:
            plt.imshow(activation[0,:,:, featuremap], interpolation="nearest", vmax=activation_max, cmap
        elif activation_min !=-1:
            plt.imshow(activation[0,:,:, featuremap], interpolation="nearest", vmin=activation_min, cmap
        else:
            plt.imshow(activation[0,:,:, featuremap], interpolation="nearest", cmap="gray")
```

In [ ]: