In [1]:

```
# Credits: https://github.com/SullyChen/Autopilot-TensorFlow
# Research paper: End to End Learning for Self-Driving Cars by Nvidia.
[https://arxiv.org/pdf/1604.07316.pdf]

# NVidia dataset: 72 hrs of video => 72*60*60*30 = 7,776,000 images
# Nvidia blog: https://devblogs.nvidia.com/deep-learning-self-driving-cars/


# Our Dataset: https://github.com/SullyChen/Autopilot-TensorFlow
[https://drive.google.com/file/d/0B-KJCaaF7elleG1RbzVPZWV4Tlk/view]
# Size: 25 minutes = 25*60*30 = 45,000 images ~ 2.3 GB


# If you want to try on a slightly large dataset: 70 minutes of data ~ 223GB
# Refer: https://medium.com/udacity/open-sourcing-223gb-of-mountain-view-driving-data-f6b5593fbfa5
# Format: Image, latitude, longitude, gear, brake, throttle, steering angles and speed



# Additional Installations:
# pip3 install h5py


# AWS: https://aws.amazon.com/blogs/machine-learning/get-started-with-deep-learning-using-the-aws-
deep-learning-ami/

# Youtube:https://www.youtube.com/watch?v=qhUvQiKec2U
# Further reading and extensions: https://medium.com/udacity/teaching-a-machine-to-steer-a-car-d73
217f2492c
# More data: https://medium.com/udacity/open-sourcing-223gb-of-mountain-view-driving-data-f6b5593f
bfa5
```

Loading the Dataset

In [41]:

```
import scipy.misc
import random

xs = []
ys = []

#points to the end of the last batch
train_batch_pointer = 0
val_batch_pointer = 0

#read data.txt
with open("D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-
master\driving_dataset\data.txt") as f:
    for line in f:
        xs.append("D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-master\driving_data
set/" + line.split()[0])
        #the paper by Nvidia uses the inverse of the turning radius,
        #but steering wheel angle is proportional to the inverse of turning radius
        #so the steering wheel angle in radians is used as the output
        ys.append(float(line.split()[1]) * scipy.pi / 180)

#get number of images
num_images = len(xs)


train_xs = xs[:int(len(xs) * 0.7)]
train_ys = ys[:int(len(xs) * 0.7)]

val_xs = xs[-int(len(xs) * 0.3):]
val_ys = ys[-int(len(xs) * 0.3):]

num_train_images = len(train_xs)
num_val_images = len(val_xs)
```

```
def LoadTrainBatch(batch_size):
    global train_batch_pointer
    x_out = []
    y_out = []
    for i in range(0, batch_size):
        x_out.append(scipy.misc.imresize(scipy.misc.imread(train_xs[(train_batch_pointer + i) % num
_train_images])[-150:], [66, 200]) / 255.0)
        y_out.append([train_ys[(train_batch_pointer + i) % num_train_images]])
    train_batch_pointer += batch_size
    return x_out, y_out

def LoadValBatch(batch_size):
    global val_batch_pointer
    x_out = []
    y_out = []
    for i in range(0, batch_size):
        x_out.append(scipy.misc.imresize(scipy.misc.imread(val_xs[(val_batch_pointer + i) % num_val
_images])[-150:], [66, 200]) / 255.0)
        y_out.append([val_ys[(val_batch_pointer + i) % num_val_images]])
    val_batch_pointer += batch_size
    return x_out, y_out
```

In [42]:

```
xs[40000]
```

Out[42]:

```
'D:\\self car\\Autopilot-TensorFlow-master\\Autopilot-TensorFlow-
master\\driving_dataset/40000.jpg'
```

In [43]:

```
# scipy.misc.imresize(scipy.misc.imread(train_xs[(train_batch_pointer + i) % num_train_images])[-1
50:], [66, 200]) / 255.0
# you can break the whole line into parts like this
# here (train_batch_pointer + i) % num_train_images => "% num_train_images" is used to make sure t
hat the
# (train_batch_pointer + i) values should not cross number of train images.

# lets explain whats happening with the first images
image_read = scipy.misc.imread(train_xs[0])
print("original image size",image_read.shape)

print("After taking the last 150 rows i.e lower part of the images where road is present, ",image_
read[-150:].shape)
image_read = image_read[-150:]
resized_image = scipy.misc.imresize(image_read, [66, 200])
print("After resizing the images into 66*200, ",resized_image.shape)
# 200/66 = 455/150 = 3.0303 => we are keeping aspect ratio when we are resizing it
```

```
original image size (256, 455, 3)
After taking the last 150 rows i.e lower part of the images where road is present,  (150, 455, 3)
After resizing the images into 66*200,  (66, 200, 3)
```

```
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:7: DeprecationWarning: `imread` i
s deprecated!
`imread` is deprecated in SciPy 1.0.0, and will be removed in 1.2.0.
Use ``imageio.imread`` instead.
  import sys
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:12: DeprecationWarning:
`imresize` is deprecated!
`imresize` is deprecated in SciPy 1.0.0, and will be removed in 1.2.0.
Use ``skimage.transform.resize`` instead.
  if sys.path[0] == '':
```

In [44]:

```
scipy.misc.imresize(scipy.misc.imread(train_xs[0])[-150:], [66, 200])
```

```
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:1: DeprecationWarning: `imread` i
s deprecated!
```

```
`imread` is deprecated in SciPy 1.0.0, and will be removed in 1.2.0.
Use ``imageio.imread`` instead.
  """Entry point for launching an IPython kernel.
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:1: DeprecationWarning: `imresize`
is deprecated!
`imresize` is deprecated in SciPy 1.0.0, and will be removed in 1.2.0.
Use ``skimage.transform.resize`` instead.
  """Entry point for launching an IPython kernel.
```

Out[44]:

```
array([[[180, 162, 166],
        [176, 172, 173],
        [176, 176, 171],
        ...,
        [ 90,  88, 113],
        [106,  93,  99],
        [101, 103,  81]],

       [[191, 188, 192],
        [186, 193, 204],
        [187, 196, 200],
        ...,
        [ 84,  82,  97],
        [ 86,  88,  79],
        [ 86, 101,  74]],

       [[208, 201, 223],
        [199, 212, 230],
        [201, 212, 226],
        ...,
        [128, 124, 115],
        [128, 126, 117],
        [132, 126, 119]],

       ...,

       [[ 54,  43,  55],
        [ 59,  43,  56],
        [ 55,  41,  53],
        ...,
        [ 23,  24,  25],
        [ 24,  25,  27],
        [ 25,  26,  29]],

       [[ 56,  36,  58],
        [ 53,  35,  63],
        [ 51,  39,  54],
        ...,
        [ 23,  25,  22],
        [ 23,  26,  23],
        [ 24,  27,  25]],

       [[ 68,  37,  44],
        [ 53,  41,  49],
        [ 49,  49,  37],
        ...,
        [ 28,  25,  26],
        [ 26,  23,  25],
        [ 24,  22,  24]]], dtype=uint8)
```

Exploratory Data Analysis

In [45]:

```
# read images and steering angles from driving_dataset folder

from __future__ import division

import os
import numpy as np
import random

from scipy import pi
```

```
from itertools import islice



DATA_FOLDER = "D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-
master\driving_dataset" # change this to your folder
TRAIN_FILE = os.path.join(DATA_FOLDER, 'data.txt')


split =0.7
X = []
y = []
LIMIT=1000
with open(TRAIN_FILE) as fp:
    for line in islice(fp, LIMIT):
        path, angle = line.strip().split()
        full_path = os.path.join(DATA_FOLDER, path)
        X.append(full_path)

        # converting angle from degrees to radians
        y.append(float(angle) * pi / 180 )


y = np.array(y)
print("Completed processing data.txt")

split_index = int(len(y)*0.7)

train_y = y[:split_index]
test_y = y[split_index:]
```

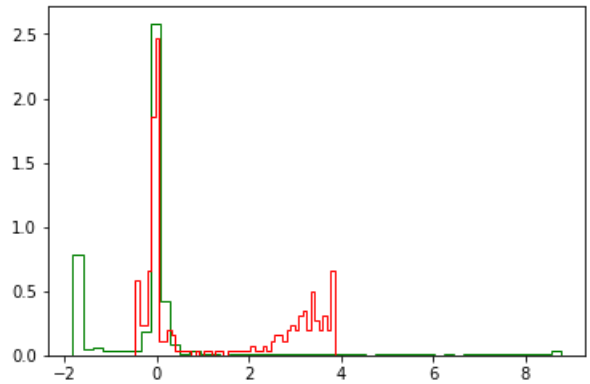
```
Completed processing data.txt
```

In [46]:

```
import numpy;

# PDF of train and test 'y' values.
import matplotlib.pyplot as plt
plt.hist(train_y, bins=50, normed=1, color='green', histtype ='step');
plt.hist(test_y, bins=50, normed=1, color='red', histtype ='step');
plt.show()
```

```
C:\ProgramData\Anaconda3\lib\site-packages\matplotlib\axes\_axes.py:6462: UserWarning: The
'normed' kwarg is deprecated, and has been replaced by the 'density' kwarg.
  warnings.warn("The 'normed' kwarg is deprecated, and has been "
```



In [47]:

```
#Model 0: Base line Model: y_test_pred = mean(y_train_i)
train_mean_y = np.mean(train_y)

print('Test_MSE(MEAN):%f' % np.mean(np.square(test_y-train_mean_y)) )

print('Test_MSE(ZERO):%f' % np.mean(np.square(test_y-0.0)) )
```

```
Test_MSE(MEAN):3.960951
Test_MSE(ZERO):4.153462
```

Defining the architecture of the Neural Network

In [2]:

```
import tensorflow as tf
import scipy

def weight_variable(shape):
  initial = tf.truncated_normal(shape, stddev=0.1)
  return tf.Variable(initial)

def bias_variable(shape):
  initial = tf.constant(0.1, shape=shape)
  return tf.Variable(initial)

def conv2d(x, W, stride):
  return tf.nn.conv2d(x, W, strides=[1, stride, stride, 1], padding='VALID')

x = tf.placeholder(tf.float32, shape=[None, 66, 200, 3])
y_ = tf.placeholder(tf.float32, shape=[None, 1])

x_image = x

#first convolutional layer
W_conv1 = weight_variable([5, 5, 3, 24])
b_conv1 = bias_variable([24])

h_conv1 = tf.nn.relu(conv2d(x_image, W_conv1, 2) + b_conv1)

#second convolutional layer
W_conv2 = weight_variable([5, 5, 24, 36])
b_conv2 = bias_variable([36])

h_conv2 = tf.nn.relu(conv2d(h_conv1, W_conv2, 2) + b_conv2)

#third convolutional layer
W_conv3 = weight_variable([5, 5, 36, 48])
b_conv3 = bias_variable([48])

h_conv3 = tf.nn.relu(conv2d(h_conv2, W_conv3, 2) + b_conv3)

#fourth convolutional layer
W_conv4 = weight_variable([3, 3, 48, 64])
b_conv4 = bias_variable([64])

h_conv4 = tf.nn.relu(conv2d(h_conv3, W_conv4, 1) + b_conv4)

#fifth convolutional layer
W_conv5 = weight_variable([3, 3, 64, 64])
b_conv5 = bias_variable([64])

h_conv5 = tf.nn.relu(conv2d(h_conv4, W_conv5, 1) + b_conv5)

#FCL 1
W_fc1 = weight_variable([1152, 1164])
b_fc1 = bias_variable([1164])

h_conv5_flat = tf.reshape(h_conv5, [-1, 1152])
h_fc1 = tf.nn.relu(tf.matmul(h_conv5_flat, W_fc1) + b_fc1)

keep_prob = tf.placeholder(tf.float32)
h_fc1_drop = tf.nn.dropout(h_fc1, keep_prob)

#FCL 2
W_fc2 = weight_variable([1164, 100])
b_fc2 = bias_variable([100])

h_fc2 = tf.nn.relu(tf.matmul(h_fc1_drop, W_fc2) + b_fc2)

h_fc2_drop = tf.nn.dropout(h_fc2, keep_prob)
```

```
#FCL 3
W_fc3 = weight_variable([100, 50])
b_fc3 = bias_variable([50])

h_fc3 = tf.nn.relu(tf.matmul(h_fc2_drop, W_fc3) + b_fc3)

h_fc3_drop = tf.nn.dropout(h_fc3, keep_prob)

#FCL 3
W_fc4 = weight_variable([50, 10])
b_fc4 = bias_variable([10])

h_fc4 = tf.nn.relu(tf.matmul(h_fc3_drop, W_fc4) + b_fc4)

h_fc4_drop = tf.nn.dropout(h_fc4, keep_prob)

#Output
W_fc5 = weight_variable([10, 1])
b_fc5 = bias_variable([1])

y = tf.multiply(tf.nn.relu(tf.matmul(h_fc4_drop, W_fc5) + b_fc5), 2) #scale the atan output
```

```
WARNING:tensorflow:From C:\ProgramData\Anaconda3\lib\site-
packages\tensorflow\python\framework\op_def_library.py:263: colocate_with (from
tensorflow.python.framework.ops) is deprecated and will be removed in a future version.
Instructions for updating:
Colocations handled automatically by placer.
WARNING:tensorflow:From <ipython-input-2-db1dd83d7446>:58: calling dropout (from
tensorflow.python.ops.nn_ops) with keep_prob is deprecated and will be removed in a future
version.
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 - keep_prob`.
```

In [5]:

```
import os
import tensorflow as tf
from tensorflow.core.protobuf import saver_pb2
```

Training the Neural Network

In [ ]:

```
LOGDIR = "D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-master\save"

sess = tf.InteractiveSession()

L2NormConst = 0.001

train_vars = tf.trainable_variables()

loss = tf.reduce_mean(tf.square(tf.subtract(y_, y))) + tf.add_n([tf.nn.l2_loss(v) for v in train_va
rs]) * L2NormConst
train_step = tf.train.AdamOptimizer(1e-3).minimize(loss)
sess.run(tf.initialize_all_variables())

# create a summary to monitor cost tensor
tf.summary.scalar("loss", loss)
# merge all summaries into a single op
merged_summary_op =  tf.summary.merge_all()

saver = tf.train.Saver(write_version = saver_pb2.SaverDef.V1)

# op to write logs to Tensorboard
logs_path = "D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-master\logs"
summary_writer = tf.summary.FileWriter(logs_path, graph=tf.get_default_graph())

epochs = 30
batch_size = 100

# train over the dataset about 30 times
for epoch in range(epochs):
    for i in range(int(num_images/batch_size)):
```

```
        xs, ys = LoadTrainBatch(batch_size)
        train_step.run(feed_dict={x: xs, y_: ys, keep_prob: 0.5})
        if i % 10 == 0:
            xs, ys = LoadValBatch(batch_size)
            loss_value = loss.eval(feed_dict={x:xs, y_: ys, keep_prob: 1.0})
            print("Epoch: %d, Step: %d, Loss: %g" % (epoch, epoch * batch_size + i, loss_value))

        # write logs at every iteration
        summary = merged_summary_op.eval(feed_dict={x:xs, y_: ys, keep_prob: 1.0})
        summary_writer.add_summary(summary, epoch * num_images/batch_size + i)

        if i % batch_size == 0:
            checkpoint_path = os.path.join(LOGDIR, "model.ckpt")
            filename = saver.save(sess, checkpoint_path)
    print("one_epoch_done")

print("Run the command line:\n" \
          "--> tensorboard --logdir=./logs " \
          "\nThen open http://0.0.0.0:6006/ into your web browser")
```

Visualizing the output

In [ ]:

```
#pip3 install opencv-python

import tensorflow as tf
import scipy.misc

import cv2
from subprocess import call
import math

sess = tf.InteractiveSession()
saver = tf.train.Saver()

saver.restore(sess, "D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-
master\save\model.ckpt")

img = cv2.imread("D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-
master\steering_wheel_image.jpg",0)
rows,cols = img.shape

smoothed_angle = 0


#read data.txt
xs = []
ys = []
with open("D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-
master\driving_dataset\data.txt") as f:
    for line in f:
        xs.append("D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-master\driving_data
set/" + line.split()[0])
        #the paper by Nvidia uses the inverse of the turning radius,
        #but steering wheel angle is proportional to the inverse of turning radius
        #so the steering wheel angle in radians is used as the output
        ys.append(float(line.split()[1]) * scipy.pi / 180)

#get number of images
num_images = len(xs)


i = math.ceil(num_images*0.7)
print("Starting frameofvideo:" +str(i))

while(cv2.waitKey(10) != ord('q')):
    full_image = scipy.misc.imread("D:\self car\Autopilot-TensorFlow-master\Autopilot-TensorFlow-
master\driving_dataset/" + str(i) + ".jpg", mode="RGB")
    image = scipy.misc.imresize(full_image[-150:], [66, 200]) / 255.0
    degrees = y.eval(feed_dict={x: [image], keep_prob: 1.0})[0][0] * 180.0 / scipy.pi
    #call("clear")
    #print("Predicted Steering angle: " + str(degrees))
    print("Steering angle: " + str(degrees) + " (pred)\t" + str(ys[i]*180/scipy.pi) + " (actual)")
    cv2.imshow("frame", cv2.cvtColor(full_image, cv2.COLOR_RGB2BGR))
```

```
    cv2.imshow("Frame", cv2.cvtColor(full_image, cv2.COLOR_RGB2BGR))
    #make smooth angle transitions by turning the steering wheel based on the difference of the cu
rrent angle
    #and the predicted angle
    smoothed_angle += 0.2 * pow(abs((degrees - smoothed_angle)), 2.0 / 3.0) * (degrees -
smoothed_angle) / abs(degrees - smoothed_angle)
    M = cv2.getRotationMatrix2D((cols/2,rows/2),-smoothed_angle,1)
    dst = cv2.warpAffine(img,M,(cols,rows))
    cv2.imshow("steering wheel", dst)
    i += 1

cv2.destroyAllWindows()
```