

P1

October 21, 2020

1 Self-Driving Car Engineer Nanodegree

1.1 Project: Finding Lane Lines on the Road

In this project, you will use the tools you learned about in the lesson to identify lane lines on the road. You can develop your pipeline on a series of individual images, and later apply the result to a video stream (really just a series of images). Check out the video clip "raw-lines-example.mp4" (also contained in this repository) to see what the output should look like after using the helper functions below.

Once you have a result that looks roughly like "raw-lines-example.mp4", you'll need to get creative and try to average and/or extrapolate the line segments you've detected to map out the full extent of the lane lines. You can see an example of the result you're going for in the video "P1_example.mp4". Ultimately, you would like to draw just one line for the left side of the lane, and one for the right.

In addition to implementing code, there is a brief 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](#) that can be used to guide the writing process. Completing both the code in the Ipython notebook and the writeup template will cover all of the [rubric points](#) for this project.

The tools you have are color selection, region of interest selection, grayscaling, Gaussian smoothing, Canny Edge Detection and Hough Transform line detection. You are also free to explore and try other techniques that were not presented in the lesson. Your goal is piece together a pipeline to detect the line segments in the image, then average/extrapolate them and draw them onto the image for display (as below). Once you have a working pipeline, try it out on the video stream below.

Your output should look something like this (above) after detecting line segments using the helper functions below

Your goal is to connect/average/extrapolate line segments to get output like this

Run the cell below to import some packages. If you get an `import` error for a package you've already installed, try changing your kernel (select the Kernel menu above --> Change Kernel). Still have problems? Try relaunching Jupyter Notebook from the terminal prompt. Also, consult the forums for more troubleshooting tips.

1.2 Import Packages

```
In [1]: #importing some useful packages
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
import numpy as np
import cv2
%matplotlib inline
```

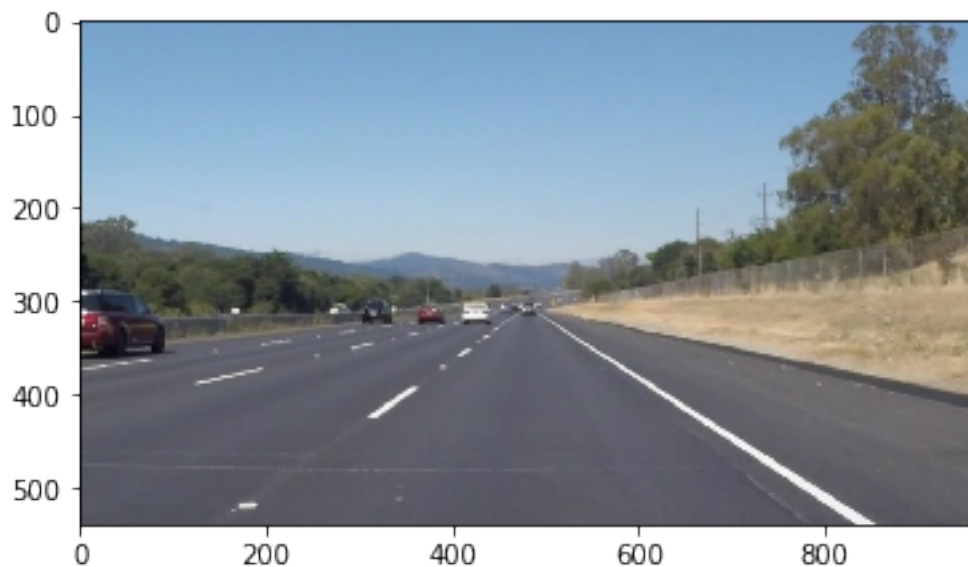
1.3 Read in an Image

```
In [2]: #reading in an image
image = mpimg.imread('test_images/solidWhiteRight.jpg')

#printing out some stats and plotting
print('This image is:', type(image), 'with dimensions:', image.shape)
plt.imshow(image) # if you wanted to show a single color channel image called 'gray', f
```

This image is: <class 'numpy.ndarray'> with dimensions: (540, 960, 3)

Out[2]: <matplotlib.image.AxesImage at 0x7f42f6719400>



1.4 Ideas for Lane Detection Pipeline

Some OpenCV functions (beyond those introduced in the lesson) that might be useful for this project are:

- cv2.inRange() for color selection
- cv2.fillPoly() for regions selection

cv2.line() to draw lines on an image given endpoints
cv2.addWeighted() to coadd / overlay two images cv2.cvtColor() to grayscale or change color
cv2.imwrite() to output images to file
cv2.bitwise_and() to apply a mask to an image

Check out the OpenCV documentation to learn about these and discover even more awesome functionality!

1.5 Helper Functions

Below are some helper functions to help get you started. They should look familiar from the lesson!

```
In [3]: import math
```

```
# NOTE : everything is copied below in "One Shot preparation" to avoid having to execute  
# everytime I open and want to run code.
```

1.6 Test Images

Build your pipeline to work on the images in the directory "test_images"

You should make sure your pipeline works well on these images before you try the videos.

```
In [4]: import os  
        os.listdir("test_images/")
```

```
Out[4]: ['solidWhiteCurve.jpg',  
        'whiteCarLaneSwitch.jpg',  
        'solidWhiteRight.jpg',  
        'solidYellowCurve.jpg',  
        'solidYellowCurve2.jpg',  
        'solidYellowLeft.jpg']
```

1.7 Build a Lane Finding Pipeline

Build the pipeline and run your solution on all test_images. Make copies into the test_images_output directory, and you can use the images in your writeup report.

Try tuning the various parameters, especially the low and high Canny thresholds as well as the Hough lines parameters.

```
In [5]: # One Shot preparation with Helper Functions.  
        # NOTE :  
        # - hough_lines() slightly modified for lanes extension overlay.  
        # - draw_lines() heavily modified for lanes extension overlay  
  
        # importing some useful packages  
        #####  
        import matplotlib.pyplot as plt  
        import matplotlib.image as mpimg  
        import numpy as np
```

```

import cv2
%matplotlib inline

# Helper functions
#####

import math

def grayscale(img):
    """Applies the Grayscale transform
    This will return an image with only one color channel
    but NOTE: to see the returned image as grayscale
    (assuming your grayscaled image is called 'gray')
    you should call plt.imshow(gray, cmap='gray')"""
    return cv2.cvtColor(img, cv2.COLOR_RGB2GRAY)
    # Or use BGR2GRAY if you read an image with cv2.imread()
    # return cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

def canny(img, low_threshold, high_threshold):
    """Applies the Canny transform"""
    return cv2.Canny(img, low_threshold, high_threshold)

def gaussian_blur(img, kernel_size):
    """Applies a Gaussian Noise kernel"""
    return cv2.GaussianBlur(img, (kernel_size, kernel_size), 0)

def region_of_interest(img, vertices):
    """
    Applies an image mask.

    Only keeps the region of the image defined by the polygon
    formed from `vertices`. The rest of the image is set to black.
    `vertices` should be a numpy array of integer points.
    """
    #defining a blank mask to start with
    mask = np.zeros_like(img)

    #defining a 3 channel or 1 channel color to fill the mask with depending on the input
    if len(img.shape) > 2:
        channel_count = img.shape[2] # i.e. 3 or 4 depending on your image
        ignore_mask_color = (255,) * channel_count
    else:
        ignore_mask_color = 255

    #filling pixels inside the polygon defined by "vertices" with the fill color
    cv2.fillPoly(mask, vertices, ignore_mask_color)

    #returning the image only where mask pixels are nonzero

```

```

masked_image = cv2.bitwise_and(img, mask)
return masked_image

def draw_lines(img, lines, topOfLines, laneExtrapolation, color=[255, 0, 0], thickness=2)
    """
    NOTE: this is the function you might want to use as a starting point once you want to
    average/extrapolate the line segments you detect to map out the full
    extent of the lane (going from the result shown in raw-lines-example.mp4
    to that shown in P1_example.mp4).

    Think about things like separating line segments by their
    slope ((y2-y1)/(x2-x1)) to decide which segments are part of the left
    line vs. the right line. Then, you can average the position of each of
    the lines and extrapolate to the top and bottom of the lane.

    This function draws `lines` with `color` and `thickness`.
    Lines are drawn on the image inplace (mutates the image).
    If you want to make the lines semi-transparent, think about combining
    this function with the weighted_img() function below
    """

    # NOTE : added one more input argument "topOfLine" to draw_lines() to fix top length
    # of Lane extension overlay + 1 more to toggle Lane extrapolation for write-up image

    if laneExtrapolation :
        # map out the full extent of the lane : needed to calculate lines extremities
        ySize = img.shape[0]
        xSize = img.shape[1]

        # map out the full extent of the lane : list x/y to extrapolate left/right Lanes
        yLeftList = []
        xLeftList = []
        yRightList = []
        xRightList = []

    for line in lines:
        for x1,y1,x2,y2 in line:
            cv2.line(img, (x1, y1), (x2, y2), color, thickness)

            if laneExtrapolation :

                # map out the full extent of the lane :
                if (x2 != x1) :
                    # slope calculation for each line
                    slope = ((y2-y1)/(x2-x1)) # left slope is <0, right slope is >0

                    # NOTE : below I am filtering any slope between [-0.5;+0.5]

```

```

# to filter anomalies of Hough lines coming vertical or almost vertical
# and therefore not being part of targetted lanes we try to highlight
# also due to challenge video having lines with slope = 0 and therefore
# creating error in dividing calculation with slope = 0 as a divider

# Split x/y for left/right lane, store them in separate lists
# if left line, ie slope < 0
if slope < -0.5 : # Left lane
    # collect the points in an array for LeftLane
    xLeftList.append(x1)
    xLeftList.append(x2)
    yLeftList.append(y1)
    yLeftList.append(y2)
if slope > 0.5 : # Right Lane
    # collect the points in an array for LeftLane
    xRightList.append(x1)
    xRightList.append(x2)
    yRightList.append(y1)
    yRightList.append(y2)

# end if
# end if
#end if
# end for
# end for

if laneExtrapolation :

    # Convert x/y lists to numpy arrays to use with np.polyfit() function
    yLeft = np.array(yLeftList)
    xLeft = np.array(xLeftList)
    yRight = np.array(yRightList)
    xRight = np.array(xRightList)

    # Next step : interpolate line passing through all those list of (x,y) for left
    # Using np.polyfit(x,y) --> giving back m and b for  $y = m.x + b$ 
    # Then we can calculate extended lane extremities knowing coordinate Y of each e
    # Then we can draw the 2 left and right lanes with those coordinates info.

    # testing if x/y lists are not empty otherwise impossible to draw Lane lines
    if xLeft.size > 0 and yLeft.size > 0:
        mLeft, bLeft = np.polyfit(xLeft, yLeft, 1)
        xBottomLeft = int((ySize - bLeft) / mLeft)
        xTopLeft = int((topOfLines - bLeft) / mLeft)
        # Draw Left Lane extension overlay
        cv2.line(img, (xBottomLeft, ySize), (xTopLeft, topOfLines), color, thickness)

    # testing if x/y lists are not empty otherwise impossible to draw Lane lines

```

```

        if xRight.size > 0 and yRight.size > 0:
            mRight, bRight = np.polyfit(xRight,yRight,1)
            xBottomRight = int((ySize -bRight) / mRight)
            xTopRight = int((topOfLines -bRight) / mRight)
            # Draw Right Lane extension overlay
            cv2.line(img, (xBottomRight, ySize), (xTopRight, topOfLines), color, thickness)

def hough_lines(img, rho, theta, threshold, min_line_len, max_line_gap, topOfLines, laneExtrapolation):
    """
    `img` should be the output of a Canny transform.

    Returns an image with hough lines drawn.
    """

    # NOTE : added one more input argument "topOfLine" to draw_lines() to fix top length
    # of Lane extension overlay + 1 more to toggle Lane extrapolation for write-up images

    lines = cv2.HoughLinesP(img, rho, theta, threshold, np.array([]), minLineLength=min_line_len,
                             maxLineGap=max_line_gap)
    line_img = np.zeros((img.shape[0], img.shape[1], 3), dtype=np.uint8)
    # NOTE : added one more input argument "topOfLine" to hough_lines() and draw_lines()
    # of Lane extension overlay
    draw_lines(line_img, lines, topOfLines, laneExtrapolation)
    return line_img

# Python 3 has support for cool math symbols.

def weighted_img(img, initial_img, =0.8, =1., =0.):
    """
    `img` is the output of the hough_lines(), An image with lines drawn on it.
    Should be a blank image (all black) with lines drawn on it.

    `initial_img` should be the image before any processing.

    The result image is computed as follows:

    initial_img * + img * +
    NOTE: initial_img and img must be the same shape!
    """
    return cv2.addWeighted(initial_img, , img, , )

import os

In [6]: # DONE : Build your pipeline that will draw lane lines on the test_images
        # then save them to the test_images_output directory.

        # Collect all image filenames to process

```

```

image_folder = "test_images"
output_folder = "test_images_output"
gray_folder = output_folder + '/' + '01_Gray'
cannyEdgeDetection_folder = output_folder + '/' + '02_CannyEdgeDetection'
maskedEdge_folder = output_folder + '/' + '03_MaskedEdge'
HoughTransform_folder = output_folder + '/' + '04_HoughTransform'
HoughTransformExtrapolate_folder = output_folder + '/' + '05_HoughTransformExtrapolate'
LineEdgeImage_folder = output_folder + '/' + '06_LineEdgeImage'

filenames = os.listdir(image_folder)

# Factorized all the pipeline in one pipeline function
def pipeline(filename) :

    # Read in image and grayscale the image
    image = mpimg.imread(image_folder + '/' + filename)

    gray = grayscale(image)
    # save them to the test_images_output directory. -- for Writeup illustrations
    mpimg.imsave(gray_folder + '/' + filename, gray, cmap='gray')

    # Define a kernel size and apply Gaussian smoothing
    blur_gray = gaussian_blur(gray, kernel_size=5)

    # Define our parameters for Canny and apply
    edges = canny(blur_gray, low_threshold=160, high_threshold=180)
    # save them to the test_images_output directory.-- for Writeup illustrations
    mpimg.imsave(cannyEdgeDetection_folder + '/' + filename, edges, cmap='gray')

    # Next we'll create a masked edges image using cv2.fillPoly()
    # This time we are defining a four sided polygon to mask
    ySize = image.shape[0]
    xSize = image.shape[1]
    topOfLines = int(ySize*39/64)
    vertices = np.array([(0,ySize), (xSize*7/16, topOfLines), (xSize*9/16, topOfLines),
    masked_edges = region_of_interest(edges, vertices)
    # save them to the test_images_output directory.-- for Writeup illustrations
    mpimg.imsave(maskedEdge_folder + '/' + filename, masked_edges, cmap='gray')

    # Define the Hough transform parameters
    # Make a blank the same size as our image to draw on
    rho = 2 #
    theta = np.pi/180 # angular resolution in radians of the Hough grid
    threshold = 15 #15 # minimum number of votes (intersections in Hough grid cell)
    min_line_length = 5 #40 #minimum number of pixels making up a line
    max_line_gap = 4 #20 maximum gap in pixels between connectable line segments

```



```

# Run Hough on edge detected image
# Output "lines" is an array containing endpoints of detected line segments
# + draw lines over the image.
line_img = hough_lines(masked_edges, rho, theta, threshold, min_line_length, max_line_length)
# save them to the test_images_output directory.-- for Writeup illustrations
mpimg.imsave(HoughTransformExtrapolate_folder + '/' + filename, line_img)

# Draw the lines on the edge image
lines_edges = weighted_img(image, line_img)

# Used for showing images at specific steps for debugging.
#plt.imshow(image)
#plt.imshow(edges, cmap='gray')
#plt.imshow(masked_edges, cmap='gray')
#plt.imshow(line_img)
#plt.imshow(color_edges)
plt.imshow(lines_edges)

# then save them to the test_images_output directory.
# Note : if using cv2.imwrite() function, not getting red channel because image read as grayscale
#mpimg.imsave(output_folder + '/' + filename, masked_edges)
#mpimg.imsave(output_folder + '/' + filename, line_img)
mpimg.imsave(output_folder + '/' + filename, lines_edges)

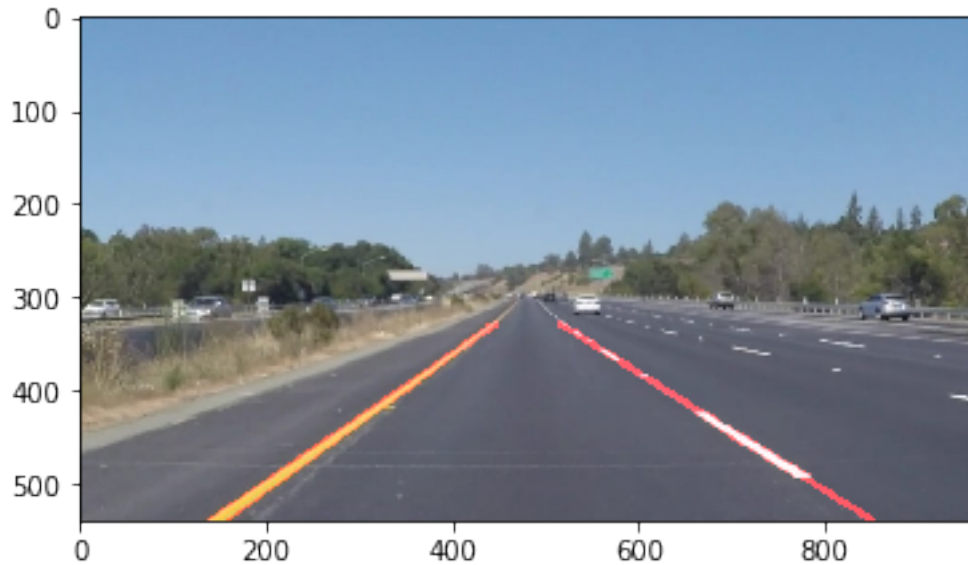
# NOTE : BELOW IS JUST FOR SAVING IMAGES FOR WRITE_UP ILLUSTRATION --- WITHOUT LANE DETECTION

line_img = hough_lines(masked_edges, rho, theta, threshold, min_line_length, max_line_length)
mpimg.imsave(HoughTransform_folder + '/' + filename, line_img)
lines_edges = weighted_img(image, line_img)
mpimg.imsave(LineEdgeImage_folder + '/' + filename, lines_edges)

#end def

# Loop to process all input files through the pipeline
for name in filenames :
    pipeline(name)

```



1.8 Test on Videos

You know what's cooler than drawing lanes over images? Drawing lanes over video!

We can test our solution on two provided videos:

`solidWhiteRight.mp4`

`solidYellowLeft.mp4`

Note: if you get an import error when you run the next cell, try changing your kernel (select the Kernel menu above --> Change Kernel). Still have problems? Try relaunching Jupyter Notebook from the terminal prompt. Also, consult the forums for more troubleshooting tips.

If you get an error that looks like this:

```
NeedDownloadError: Need ffmpeg exe.
```

You can download it by calling:

```
imageio.plugins.ffmpeg.download()
```

Follow the instructions in the error message and check out [this forum post](#) for more troubleshooting tips across operating systems.

```
In [7]: # Import everything needed to edit/save/watch video clips
        from moviepy.editor import VideoFileClip
        from IPython.display import HTML
```

```
In [8]: def process_image(image):
        # NOTE: The output you return should be a color image (3 channel) for processing via
        # DONE: put your pipeline here,
        # you should return the final output (image where lines are drawn on lanes)

        gray = grayscale(image)
```

```

# Define a kernel size and apply Gaussian smoothing
blur_gray = gaussian_blur(gray, kernel_size=5)

# Define our parameters for Canny and apply
edges = canny(blur_gray, low_threshold=160, high_threshold=180)

# Next we'll create a masked edges image using cv2.fillPoly()
# This time we are defining a four sided polygon to mask
ysize = image.shape[0]
xsize = image.shape[1]
topOfLines = int(ysize*39/64)
vertices = np.array([(0, ysize), (xsize*7/16, topOfLines), (xsize*9/16, topOfLines),
masked_edges = region_of_interest(edges, vertices)

# Define the Hough transform parameters
# Make a blank the same size as our image to draw on
rho = 2 #
theta = np.pi/180 # angular resolution in radians of the Hough grid
threshold = 15 #15 # minimum number of votes (intersections in Hough grid cell)
min_line_length = 5 #40 # minimum number of pixels making up a line
max_line_gap = 4 #20 maximum gap in pixels between connectable line segments

# Run Hough on edge detected image
# Output "lines" is an array containing endpoints of detected line segments
# + draw lines over the image.
line_img = hough_lines(masked_edges, rho, theta, threshold, min_line_length, max_line

# Draw the lines on the edge image
result = weighted_img(image, line_img)

return result

```

Let's try the one with the solid white lane on the right first ...

```

In [9]: white_output = 'test_videos_output/solidWhiteRight.mp4'
## To speed up the testing process you may want to try your pipeline on a shorter subclip
## To do so add .subclip(start_second, end_second) to the end of the line below
## Where start_second and end_second are integer values representing the start and end of
## You may also uncomment the following line for a subclip of the first 5 seconds
## clip1 = VideoFileClip("test_videos/solidWhiteRight.mp4").subclip(0,5)
clip1 = VideoFileClip("test_videos/solidWhiteRight.mp4")
white_clip = clip1.fl_image(process_image) #NOTE: this function expects color images!!
%time white_clip.write_videofile(white_output, audio=False)

```

```

[MoviePy] >>> Building video test_videos_output/solidWhiteRight.mp4
[MoviePy] Writing video test_videos_output/solidWhiteRight.mp4

```

```
100%|| 221/222 [00:13<00:00, 15.34it/s]
```

```
[MoviePy] Done.
```

```
[MoviePy] >>> Video ready: test_videos_output/solidWhiteRight.mp4
```

```
CPU times: user 2.53 s, sys: 258 ms, total: 2.79 s
```

```
Wall time: 14.7 s
```

Play the video inline, or if you prefer find the video in your filesystem (should be in the same directory) and play it in your video player of choice.

```
In [10]: HTML("""
        <video width="960" height="540" controls>
          <source src="{0}">
        </video>
        """.format(white_output))
```

```
Out[10]: <IPython.core.display.HTML object>
```

1.9 Improve the draw_lines() function

At this point, if you were successful with making the pipeline and tuning parameters, you probably have the Hough line segments drawn onto the road, but what about identifying the full extent of the lane and marking it clearly as in the example video (P1_example.mp4)? Think about defining a line to run the full length of the visible lane based on the line segments you identified with the Hough Transform. As mentioned previously, try to average and/or extrapolate the line segments you've detected to map out the full extent of the lane lines. You can see an example of the result you're going for in the video "P1_example.mp4".

Go back and modify your draw_lines function accordingly and try re-running your pipeline. The new output should draw a single, solid line over the left lane line and a single, solid line over the right lane line. The lines should start from the bottom of the image and extend out to the top of the region of interest.

Now for the one with the solid yellow lane on the left. This one's more tricky!

```
In [11]: yellow_output = 'test_videos_output/solidYellowLeft.mp4'
        ## To speed up the testing process you may want to try your pipeline on a shorter subcl
        ## To do so add .subclip(start_second,end_second) to the end of the line below
        ## Where start_second and end_second are integer values representing the start and end
        ## You may also uncomment the following line for a subclip of the first 5 seconds
        ##clip2 = VideoFileClip('test_videos/solidYellowLeft.mp4').subclip(0,5)
        clip2 = VideoFileClip('test_videos/solidYellowLeft.mp4')
        yellow_clip = clip2.fl_image(process_image)
        %time yellow_clip.write_videofile(yellow_output, audio=False)
```

```
[MoviePy] >>> Building video test_videos_output/solidYellowLeft.mp4
```

```
[MoviePy] Writing video test_videos_output/solidYellowLeft.mp4
```

```
100%|| 681/682 [00:43<00:00, 15.62it/s]
```

```
[MoviePy] Done.
```

```
[MoviePy] >>> Video ready: test_videos_output/solidYellowLeft.mp4
```

```
CPU times: user 7.84 s, sys: 830 ms, total: 8.67 s
```

```
Wall time: 45.3 s
```

```
In [12]: HTML("""
        <video width="960" height="540" controls>
          <source src="{0}">
        </video>
        """.format(yellow_output))
```

```
Out[12]: <IPython.core.display.HTML object>
```

1.10 Writeup and Submission

If you're satisfied with your video outputs, it's time to make the report writeup in a pdf or mark-down file. Once you have this Ipython notebook ready along with the writeup, it's time to submit for review! Here is a [link](#) to the writeup template file.

1.11 Optional Challenge

Try your lane finding pipeline on the video below. Does it still work? Can you figure out a way to make it more robust? If you're up for the challenge, modify your pipeline so it works with this video and submit it along with the rest of your project!

```
In [13]: challenge_output = 'test_videos_output/challenge.mp4'
        ## To speed up the testing process you may want to try your pipeline on a shorter subcl
        ## To do so add .subclip(start_second,end_second) to the end of the line below
        ## Where start_second and end_second are integer values representing the start and end
        ## You may also uncomment the following line for a subclip of the first 5 seconds
        ##clip3 = VideoFileClip('test_videos/challenge.mp4').subclip(0,5)
        clip3 = VideoFileClip('test_videos_output/challenge.mp4')
        challenge_clip = clip3.fl_image(process_image)
        %time challenge_clip.write_videofile(challenge_output, audio=False)
```

```
[MoviePy] >>> Building video test_videos_output/challenge.mp4
```

```
[MoviePy] Writing video test_videos_output/challenge.mp4
```

```
100%|| 251/251 [00:32<00:00, 7.51it/s]
```

```
[MoviePy] Done.
```

```
[MoviePy] >>> Video ready: test_videos_output/challenge.mp4
```

CPU times: user 4.84 s, sys: 543 ms, total: 5.39 s
Wall time: 35.8 s

```
In [14]: HTML("""
        <video width="960" height="540" controls>
          <source src="{0}">
        </video>
        """.format(challenge_output))
```

```
Out[14]: <IPython.core.display.HTML object>
```

```
In [ ]:
```