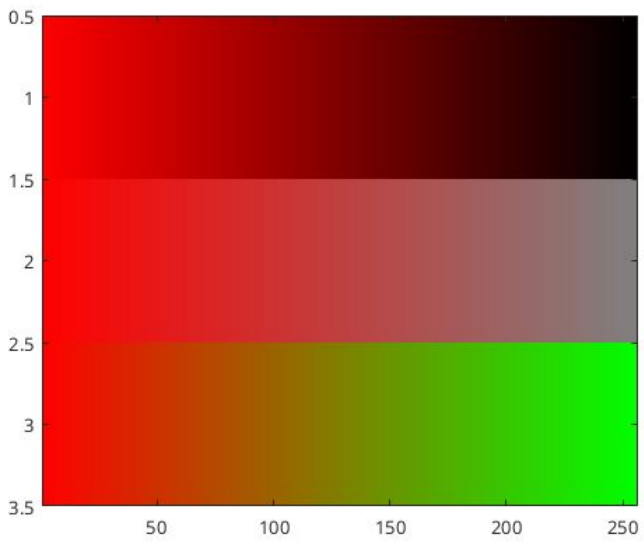
Assignment 1 **LE, Nhat Hung**
COMP 546 - Computational Perception McGill ID: 260793376
Prof. Michael Langer Date: February 4, 2019
Winter 2019 Due date: February 5, 2019

Question 1: RGB images in Matlab (30 points)
In this question, you will familiarize yourselves with the basics of making color images in Matlab. You will make and display an RGB image in Matlab using a 3D matrix. Note that in Matlab, matrices are indexed by (row, column) which is what you learned in your linear algebra course. Note this is the opposite to what is used in other places in mathematics e.g. $I(x,y)$ generally means that (x,y) refers to horizontal and vertical, i.e. (column, row). Sometimes in Matlab the latter is used too; so be aware of this issue.
a) Create an RGB images that consists of three horizontal stripes (top, middle, bottom) which have the following properties:

- the top stripe goes from bright red at the left image border to black at the right image border
- the middle stripe goes from bright red at the left image border to middle grey at the right image border.
- the lower stripe goes from bright red at the left image border to bright green at the right border.

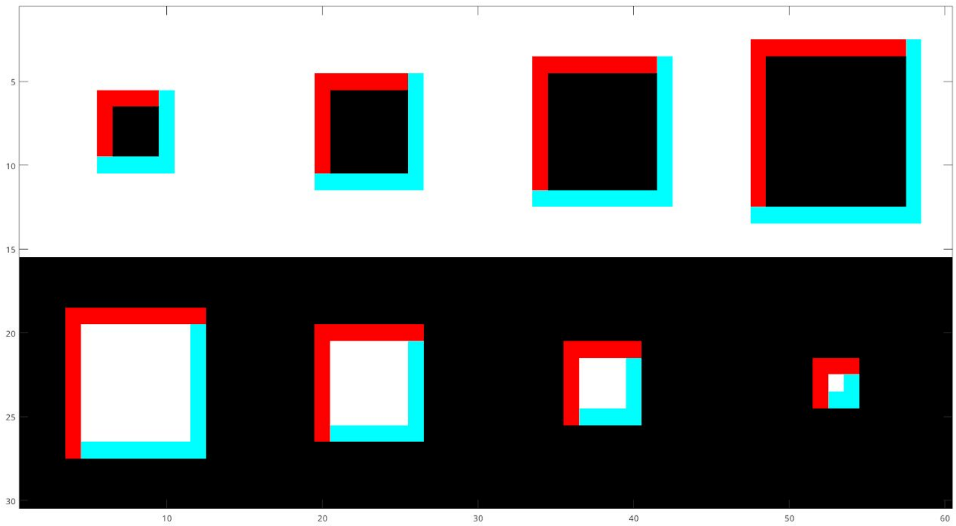
Within each stripe, the intensities in each R, G, B channel must depend only on *x* position, in particular, the intensities in each stripe must be of the form $I(x,y) = ax + b$, where *a* and *b* are



constant (possibly 0).
b) Create your own anaglyph image which consists of two halves. The upper half has a white background and should have several small squares whose disparities correspond to depths that are closer than the background. When viewed through anaglyph glasses, the squares should appear to lie closer than the background, the depth of each square should be constant, and the depths should decrease (getting closer to observer) from left to right. You will need to choose appropriate colors for the squares.

The lower half consists of a black background. It should have several small squares with disparities corresponding to depths that are further than the background, and the depth of the squares should increase from left to right. You will need to choose the color of your squares in the upper and lower half, so that they are visible, given their background.

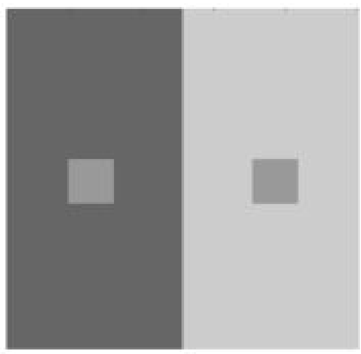
Anaglyph glasses are available for loan from the instructor.



Question 2: Local Contrast (20 points)
Given any original RGB image, let's define a few other images:

- an **intensity** image is obtained by taking the average of the RGB values at each pixel, that is, (R+G+B)/3. From here on in this question, we will deal with grey levels (intensities) only.
- the *local mean intensity* image is obtained by blurring the *intensity* image with a Gaussian. You may use the Matlab `imgaussfilt.m` function. You will need to choose a sigma of this Gaussian.
- the *local contrast* image is obtained by taking the *intensity* image, subtracting the *local mean intensity* from each pixel (which can result in either a positive or negative value), and then dividing by the *local mean intensity*. The division can be considered a normalization.

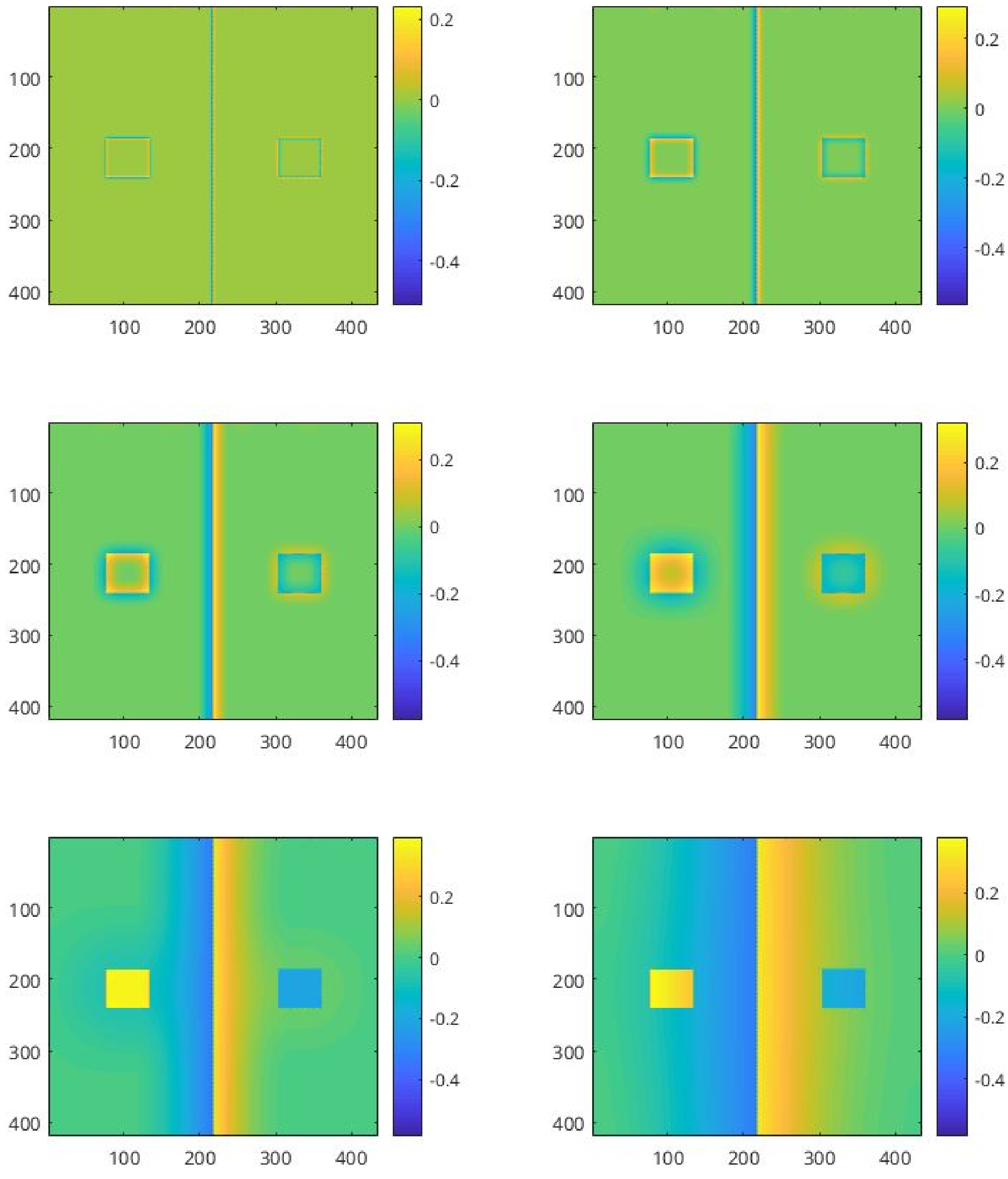
Consider the image shown below. The two halves are dark grey and light grey, and the two small squares within the two halves have identical grey values. However, the left grey square appears to be slightly brighter than the right one, even though the two grey squares have the same RGB values. (Note that for this original image, the RGB channels at each pixel are all of the same value, and so we only need to deal with intensity from the start.)



Some have argued that this illusion that the two grey squares have different values is due to local contrast. That is, we do not perceive absolute intensity at each point, but rather we perceive relative intensities, namely relative to what is nearby in the image.

Is *local contrast* (as defined above) consistent with the perceptual effect that the squares don't appear equally bright? Justify your answer by making an image such was shown above, and computing the local contrast and comparing values across the image. Note that the values of local contrast can be positive or negative, so be sure to use the `colorbar` command to indicate what the values are.

In your answer, compare the effects of choosing different sigma values for the Gaussian.



Local contrast images with sigma = 2, 5, 10, 20, 50 and 100

The local contrast is consistent with the perceptual effect that the squares don't appear equally bright.

We observe, more clearly as sigma increases, that the intensity of left square is higher than the right's. The left square therefore appears to us brighter than the right one.

The results also reproduce the Mach bands illusion, which exaggerates the contrast between edges of the slightly differing shades of gray as soon as they contact one another by triggering edge-detection in the human visual system.

Question 3: DOG filtering of spatial patterns (50 points)

a) Define a 2D difference of Gaussian (DOG) function using two 2D Gaussians whose sigmas are very similar. The cell should be on-center off-surround. There are several ways you can do this, and feel free to use Matlab's built in libraries.

Consider again the image which you made for Q2. Choose the DOG such that the on-center is roughly the same size as the grey squares. Convolve this image with your 2D DOG function and show the result. Briefly discuss whether your result is consistent with the illusion by comparing the computed values at the pixels corresponding to the left versus right squares.

In your answer, be sure to indicate the size of the Gaussians you used to create the DOG and the size of the grey square and image overall.

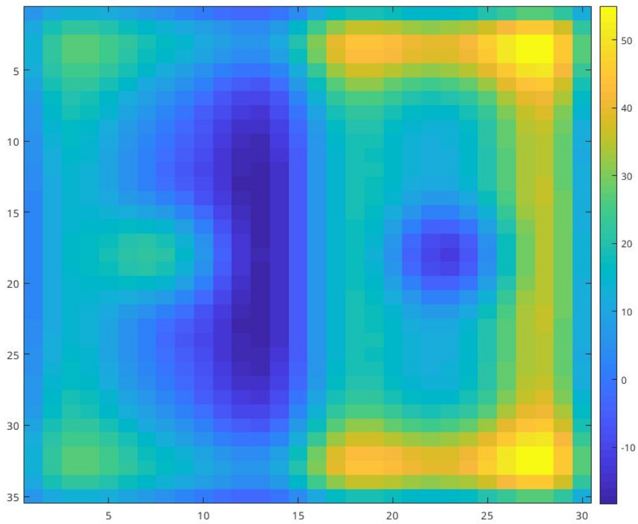
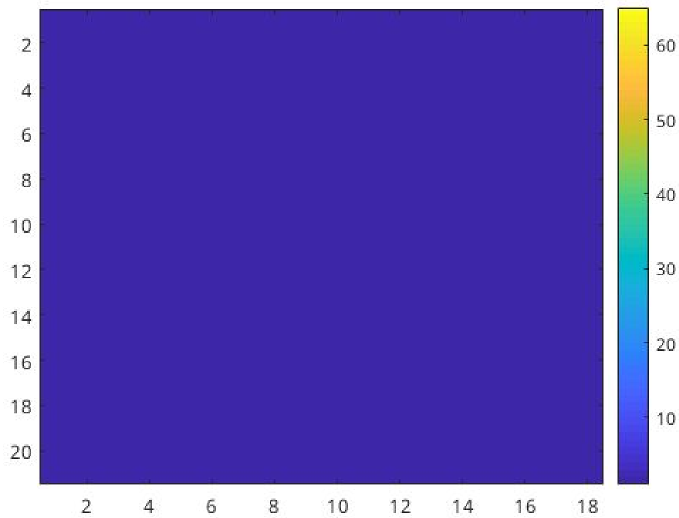


Image: 35x30
Square: 5x5
On-center gaussian sigma: 2
Off-surround gaussian sigma: 4

We observe once again the left and right squares hold different values from the DOG function. This further reinforces the argument that the optical illusion is due to the local contrast of each square.

b) A red-green double-opponent cell can be modelled by using a DOG in the R channel and a DOG in the G channel, such that the sizes of the two DOGs are the same but the signs are opposite. For this question, let’s say the DOG in the R channel is on-center off-surround and the DOG in the G channel is off-center on-surround. Use the same DOG sizes as in (a).

Verify that such a double opponent cell produces zero output when it is convolved with the image you made for Q2.



Zero intensity obtained from output of a red-green double-opponent cell convolved with the optical illusion

> Convolving the double-opponent cell with the optical illusion produces zero output. This is because the illusion only contains shades of grey - each pixel then has an equal intensity of R, G and B. Because the sign of the DOG in the G channel is opposite of that of the DOG in the R channel, their outputs then cancel themselves out.

Now create a new image which is similar to the lower stripe of the image you made in Q1. This image should go from bright red at the left image border to bright green at the right border. Add in grey squares to this image, one on the left side and one on the right side. The square sizes should be roughly the same size as the center of the DOG. Show this image, and show the output of the double opponent cell when convolved with this image. Note that each of the RGB channels of the image and DOG will need to be convolved separately and the results should be summed together.

Briefly describe any perceptual effects you observe when look at your image. (Do the grey squares appear grey?) Relate those perceptual effects to what your double opponent cell computes.

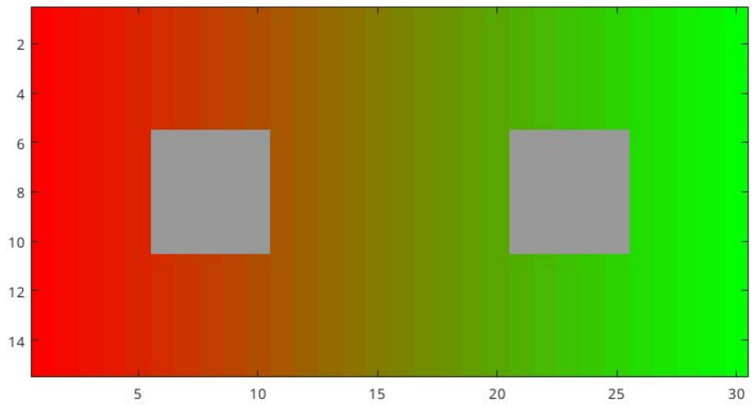
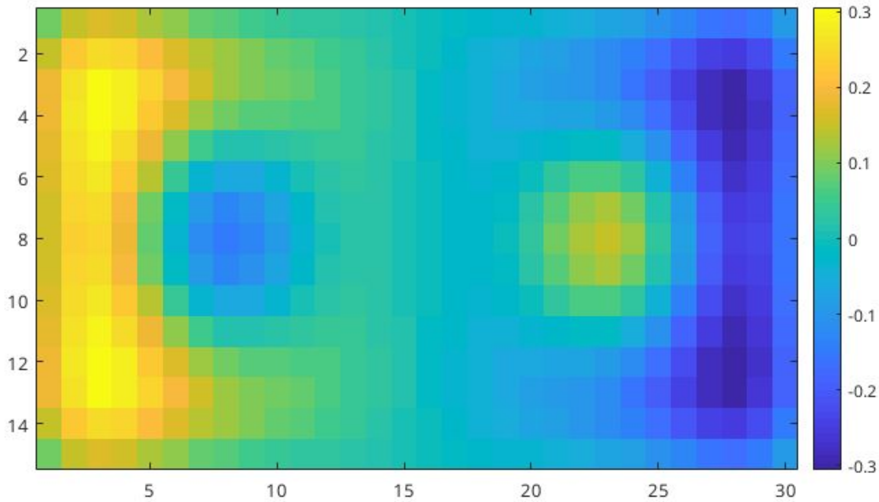


Image to be convolved with the RG double-opponent cell



Output of convolution

First, putting the squares aside, we observe the intensity at its maximum at the left of the image, gradually decreasing to its minimum when moving towards the right.

The left has the most red, which activates the R channel DOG's on-center the most. Towards the middle, there is equal amount of red and green, making the 2 DOGs cancel out.

Finally to the right with the most green, the off-center of the G channel DOG is most activated, producing the lowest negative intensity.

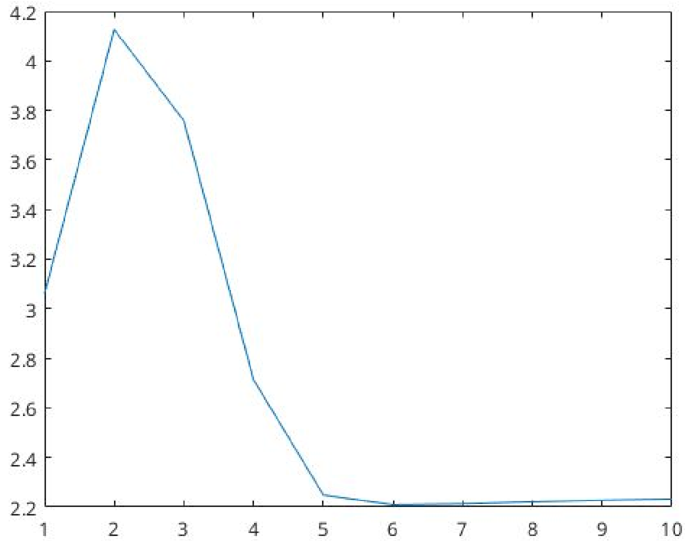
Now to the squares. The left square has negative intensity for two reasons. First, the grey value which has equal red and green intensities make the 2 DOGs' center outputs cancel out. When it comes to the surround however, only the red DOG's surround is activated because the left side of the image has little to no green. Because the red DOG's surround is negative, it bring down the perceived intensity to a negative value.

The opposite applies to the right square.

c) Here we go back to grey level only. Take the DOG that you used in (a) and convolve it with a grey level image that is a raised 2D sinusoid.

$$I(x,y) = \frac{1}{2}\left(1 + \sin\left(\frac{2\pi}{N}kx\right)\right)$$

Repeat this for many different spatial frequencies k, and for each k compute the root mean square (RMS) values of the filtered image. Plot these RMS values as a function of spatial frequency k. Which spatial frequency gives the largest RMS filter outputs? How does the wavelength of this 'optimal' spatial frequency compare to the size of the center and surround regions of DOG ?



RMS values with spatial frequencies k = 1, …, 10

The above was computed with image size 15x30 (height x width), number of samples N = 30. `rms(I)` gives the column rms values in a 1x30 vector, the *y* value is the sum of the elements in this vector.

Spatial frequency 2 gives the largest RMS outputs. The wavelength is therefore 30/2 = 15 pixels wide.

Since this is a sinusoidal wave, in the first half i.e the first 7.5 pixels of the wavelength, the intensity goes from 0 to 1 then back to 0; in the second half, from 0 to -1 then 0 again.

7.5 pixels is just above the 5 pixels on-center of our DOG cell. Therefore one whole DOG cell (center and surround) can be contained in a half-wavelength.

When this happens, the whole DOG cell is activated by either all positive intensities, or all negative intensities. In the former case, the on-center would be fully activated by the maximum positive value, thereby returning maximum absolute output. The off-surround however, is activated by lower, still positive intensities, and thus its effect on the DOG cell's whole output is minimum. The latter case is similar, producing again maximum absolute output but from negative intensities.

This is the reason why spatial frequency $k = 2$ is the sweet spot.