BioE 1586

Homework: Computational Vision

Physiologists have found that the response properties of neurons in the visual system obey some simple rules. Neurons in the retina detect spots of light against dark backgrounds. Neurons in the primary visual cortex detect oriented bars of a particular spatial frequency. These response properties can be explained just with simple anatomical considerations, and they are already sufficiently powerful to explain some aspects of visual perception. The three questions here reveal the power that simple models of neurons in the visual system have to explain perceptual phenomena.

1) In this problem you will understand how an optical illusion, the Mach Band illusion, might arise in the visual system. You will recreate it using a simple model of retinal ganglion cells. The Mach Band illusion is a perceived enhanced contrast near the edges of a luminance ramp.

a) Create the visual input for the Mach Band Illusion.
- Create a 64 X 128 matrix.
- Have the brightness of this matrix begin dark (luminance of 10 for the first 32 columns) and increase at rate of one per column to a max brightness (value of 75). The rest of the columns should be at this maximal brightness.
- Plot the input image (imagesc will do this). To see the illusion well, you may need to use ‘colormap gray’. At the transition from the ramp to the white area, you should see a brighter vertical bar. At the transition from the ramp to the black area, you should see a darker vertical bar. As you know, since you made the image, these “Mach bands” are illusions - they aren’t really present in the local luminance of the image.

b) Plot brightness as a function of horizontal position. That is, take a horizontal slice through the middle of the matrix (adjust the vertical axis so the slice edges are visible on the graph.)

c) Create the receptive field of a retinal ganglion cell. This can be constructed as the difference of two 2D Gaussians.
- In Matlab create two 5 X 5 matrices (X and Y) where Y is the transpose of X. Have the columns of X range from -2 to 2 in steps of one. Hint: [X,Y]=meshgrid(x)
- Switch the 5 X 5 matrix into polar coordinates where R is now a N by N grid of lattice distances from the center pixel.
- Create a Gaussian for the excitatory center (Egaus). Make this one narrow (e.g. variance = 2.)
- Create a Gaussian for the inhibitory surround (Igaus). Make this one broad (e.g. variance = 6.)
- Use the equation S*(Egaus – IE*Igaus) to create your receptive field - Here S=500 and is the overall strength of the field’s connectivity and IE=6 is the ratio of inhibition to excitation. This is a model retinal ganglion cell receptive field. Plot it (use imagesc again).

d) Convolve your receptive field and input image to observe how the first stages of your visual system perceives the image. Convolving the image with one filter (corresponding to one neuron’s receptive field) is the equivalent of viewing the world through a bank of identical filters, each at a different location (corresponding to the whole retina, operating in parallel.)

- When computing the convolution use the function conv2. This is a two-dimensional convolution. This function will output a matrix whose size in each dimension is equal to the sum of the corresponding dimensions of the input matrices, minus one. Define the option within the conv2 function to be 'valid'.

- Plot the output of your convolution (use imagesc again).

- Now plot a horizontal slice through your output matrix. Put it on the same axis as the slice in part b. Make sure you include a legend on the figure that labels the slices.

- Briefly describe how the plots explain the Mach Band Illusion. At what level of the visual system does the Mach Band illusion arise? Does this illusion reveal any desirable property of the visual system, or do you think it is just a coincidence?

2) Simple cells in V1 respond to bars of light at specific orientations and scales. One way to model these cells is with a Gabor function. A Gabor function is a two-dimensional Gaussian modulated by a sinusoid. We are going to create this function, and use it to illustrate how an image appears at the level of V1 simple cells.

a) Define two values OR=0 (orientation in radians) and SF=.01 (spatial frequency)

b) Create two matrices (x and y) where y is the transpose of x. Have the columns of x range from -20 to 20 in steps of one. Hint: [x,y]=meshgrid(x)

c) A Gabor function is a sine wave "windowed" by a Gaussian. The first component is a two-dimensional sine wave. That is, it has a frequency, phase, and because it is 2D, an orientation. The second component is a two-dimensional Gaussian. (Here use std_x=7 and std_y=17). Start with a 2D Gaussian defined as:

$$f(x, y) = Ae^{-((x^2/2\sigma_x^2)+(y^2/2\sigma_y^2))}$$

Modulate the Gaussian using:

$$A = sin(2\pi * SF * x)/(2\pi * \sigma_x * \sigma_y)$$

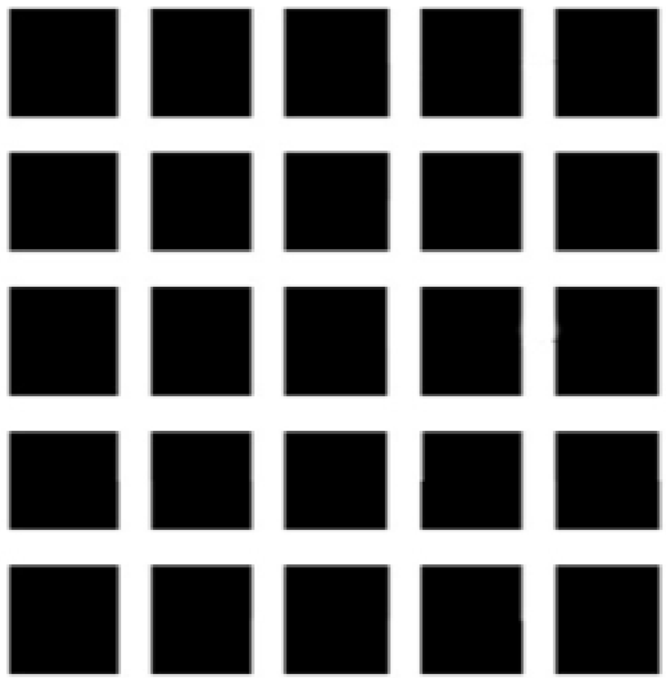
Skew and rotate the Gaussian using:
X=x*cos(OR) + y*sin(OR) and Y=-x*sin(OR) + y*cos(OR)

d) Plot the Gabor function you have created.

e) Load 'rose.jpg' and convolve this image with your Gabor function. Create plots showing the original image, and the result of the convolution.

f) Play with OR (try pi/2 or pi/4) and SF (try .05 or .1) and observe the change in your output. Describe briefly what changing OR and SF is doing to the representation of the image as seen by the network of simple cells. In your explanation describe what you think this means about how V1 simple cells encode an image.

3) Look at the image below. See all those fleeting grey spots that vanish when you look directly at them? Neat illusion, huh? Can we use models of visual system cell types to explain this effect? In particular, two things need to be explained. First, of course, why the spots appear. Second, why do they vanish when you look directly at them.



This question will walk you through the steps required to generate a simulated visual field that shows the gray spots, and another one where they are not present. Turn in those plots, and describe what arguments you sent the “retina” function to generate them. Then, explain in terms of this model and what you know of the visual system why these spots appear in the periphery, and why they don’t appear at the fovea. (Hint: uncomment the “keyboard” command in the code pack to examine the retina simulation function and see what it is doing.)

1) Load into Matlab the image above. You can find it in the zip file as hgrid.mat. You can view it with imshow(hgrid).

2) Construct a receptive field, and convolve it with the image. To do this, load the function retina.m. Supply it with three arguments: (1) the size of the neural receptive fields, as a fraction of the image. (2) the standard deviation of the kernel. Set this to 0.15. (3) the image you want the simulated retina to look at - in this case, the hgrid you just loaded.

Play with the arguments till you can make the illusory gray dots come and go. What are you changing, and physiologically speaking, why does that matter?