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9.01 Introduction to Neuroscience
Fall 2007

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9.01 Problem Set 2: Visual neuroscience

Fall 2007

Due Friday, Oct. 26 at 12 noon.

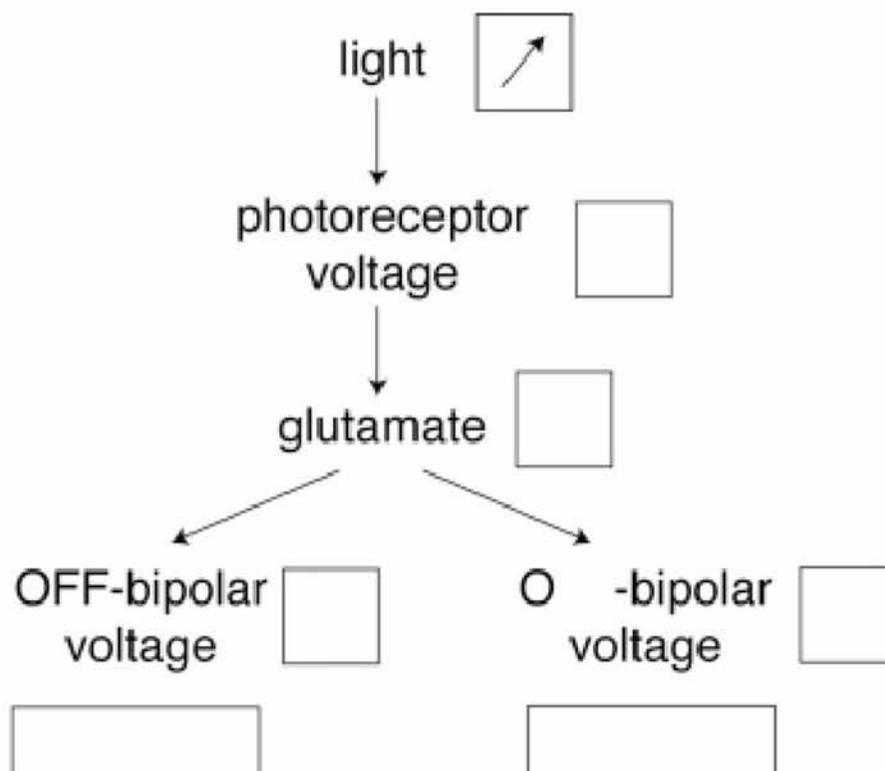
No late submissions will be accepted.

This problem set will develop your understanding of the visual system. While collaboration is allowed, you are required to write up your solutions independently, as well as document the names of your collaborators. In your answers, please try to address all major points yet also be concise.

1. **The “sign” of bipolar cell responses.** Below is a diagram of the chain of events in the “outer layers” of the retina.

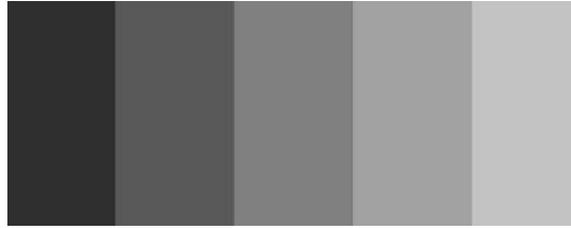
a) Suppose that light level increases (upward pointing arrow). What happens to all the other quantities? Indicate your answer by drawing an upward or downward pointing arrow in each square box.

b) Bipolar cells have two types of glutamate receptors, ionotropic and metabotropic. Suppose that the ionotropic receptors have a reversal potential of 0 mV, while the metabotropic receptors have a reversal potential of -70 mV. Which type of receptor is in the OFF-bipolar cell, and which type is in the ON-bipolar cell? Indicate your answer in the rectangular boxes below, and explain why in no more than a few sentences.



ionotropic or metabotropic receptors?

2. **The center-surround interpretation of Chevreul's illusion.** Chevreul's illusion consists of vertical stripes of varying luminance. Although the luminance is actually constant within each stripe, the borders of each stripe are perceived to be different in lightness than its interior.



This image can be represented by a set of numbers, where each number is the amount of light coming from the corresponding location in the image.

↖	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	↗	
...	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	...
...	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	...
...	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	...
...	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	...
↙	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	↘

The 0's corresponds to the black stripe, the 1's to the slightly lighter stripe next to it, and so on. The ellipses indicate that the same numbers continue at the borders.

In class we modeled a center-surround receptive field as a set of numbers like this.

-1/8	-1/8	-1/8
-1/8	1	-1/8
-1/8	-1/8	-1/8

According to this model, a center-surround cell computes a weighted sum of nine image pixels, where the weights are given in the 3×3 box. For these particular numerical values, the center-surround cell computes the difference between the central image pixel and the average of the eight surrounding pixels. This is an ON-center cell, since the central number is positive.

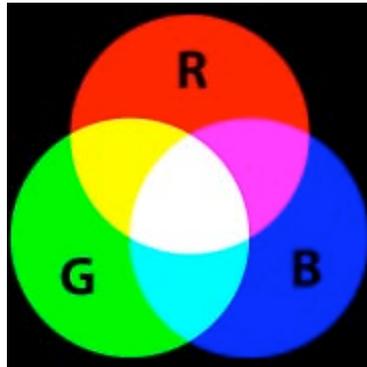
a) Now imagine an array of these center-surround cells, one at each location in the above image. What would the output of these cells be? Fill in the blanks below.

↖	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	↗
...																		...
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b) The filled-in table is a model of the retinal response to Chevreul's illusion (or at least the response of the ON-center cells). How is this model different from your own subjective perception of lightness in Chevreul's illusion?

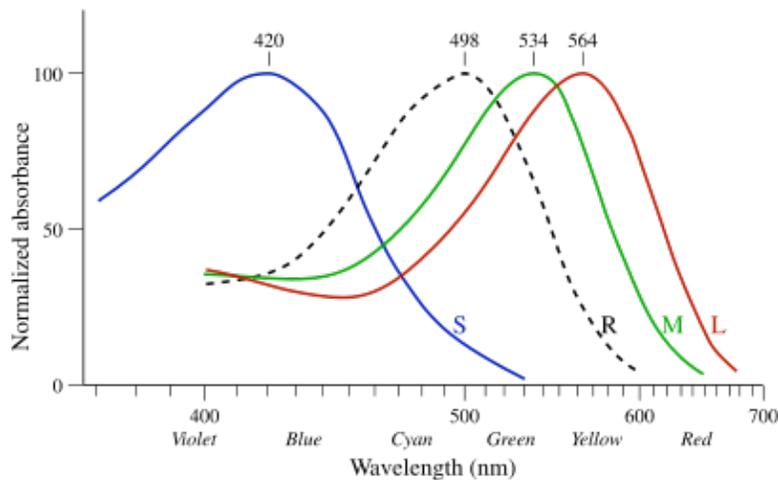
c) How would you change the numbers in the receptive field model to improve the match between the model response and your perceived lightness? Explain your answer.

3. **Neural coding of color.** From the physics perspective, color space is infinite-dimensional, as a complete description of the frequency content of light requires one number for every frequency. But from the psychological perspective, color space is three-dimensional, because our color perceptions are based on the signals from three types of cones. That's why essentially all colors can be generated by mixing just three primary colors.



red + blue = magenta
 red + green = yellow
 green + blue = cyan
 red+green+blue =white

For example, the above diagram shows how secondary colors can be generated by mixing pairs of primary colors. Let's try to understand this mixing phenomenon in terms of the responses of cone photoreceptors. The normalized responses of the cones to monochromatic light are shown in this graph (ignore the dotted line, which is for rods).



By reading values from the graph, fill in the following table with numbers. Don't worry about being exact; just give approximate numbers.

	S	M	L
violet			
blue			
cyan			
green			
yellow			
red			

Each row contains the cone responses when the retina is stimulated with monochromatic light of a particular frequency/wavelength. The three numbers in each row could be regarded as the "neural code" for that color. The graph can also be used to predict the

cone responses when the retina is stimulated with a 50-50 mixture of two monochromatic lights. The response to the mixture is just the average of the responses to the monochromatic stimuli.

a) Compute the average of the blue and green rows. Your answer should be a set of three numbers (a 3d vector) representing the cone responses when exposed to a mixture of blue light and green light. These numbers should be similar to those in the cyan row. This is why a mixture of blue and green light looks the same to our brains as a monochromatic cyan light, even though these two stimuli are physically different.

b) Compute the average of the green and red rows. While this average is somewhat similar to the numbers in the yellow row, the match is not as good as it was in part (a). Think about why the brain still perceives yellow when stimulated with a mixture of green and red (but don't write your thoughts in the homework).

c) Compute the average of the blue and red rows. This is the neural code for the color magenta. Note that the table only includes colors from the rainbow, those that can be produced by monochromatic light. To what rainbow color is magenta most similar (where similarity is measured based on their neural codes)? How is magenta different from this color?