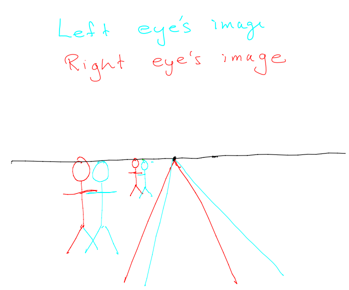
Questions

1. Consider the following statement. "Let $I_1(\lambda)$ and $I_2(\lambda)$ be any two color spectra. If a color blind person who is missing the L cones can distinguish these two spectra, then a normal color vision person can distinguish these spectra." Is the statement true or not? Justify your answer.

2. Suppose we have two different monitors with RGB emission spectra $\mathbf{P}_1$ and $\mathbf{P}_2$ respectively. These two monitors could be made by different companies, for example. Suppose that we want corresponding pixels on the two monitors to be a color match, so that when you place the two monitors side-by-side, the images appear identical.

   What mapping we can perform on the RGB values of the image displayed on the second monitor so that we get a color match to the first monitor? Hint: it is a 3×3 matrix.

3. In the lecture slides, I showed the sketch below and said that the anaglyph glasses should have a red filter on the left eye and a cyan filter on the right eye. However, the sketch below seems to indicate the opposite: it shows the words "left eye's image" in cyan and "right eye's image" in red. Explain: if the left eye's image is the one shown in cyan color, then why should we put the red filter on the left eye?



4. In the 1850's, James Clerk Maxwell proposed a method for helping color blind people to discrimate red from green, using colored glasses that have one glass tinted red and the other tinted green. Maxwell claimed that although the color blind person would not have normal experience of the colors red and green using such glasses, they would at least be able to decide which objects are red and which are green. Explain how this ability would be possible.

5. Suppose you are shopping for clothes and you pick out a shirt and pants that you think go well together. But then when you bring the clothes home and try them on, you find that the colors no longer go well together and indeed appear different. How can this happen? To make the question simpler, suppose you pick a shirt and pants that appear to have the same color when viewed in the store.

6. **I may add more later. Check back.**

Answers

1. The statement is true. If a person is missing say the L cones, then the color sensitivity matrix $\mathbf{C}$ has only two rows instead of three. In this case, two spectra $I_1(\lambda)$ and $I_2(\lambda)$ are indistinguishable (metameric) for this person if and only if

$$\begin{bmatrix} C_M \\ C_S \end{bmatrix}_{2\times N} I_1(\lambda) \;=\; \begin{bmatrix} C_M \\ C_S \end{bmatrix}_{2\times N} I_2(\lambda)$$

   If a person missing the L cones can discriminate the two, then the pairs are not the same. In this case, a person with normal color vision can also discriminate the two spectra since

$$\begin{bmatrix} C_L \\ C_M \\ C_S \end{bmatrix}_{3\times N} I_1(\lambda) \;\neq\; \begin{bmatrix} C_L \\ C_M \\ C_S \end{bmatrix}_{3\times N} I_2(\lambda)$$

   and so a person with all three types of cones can discriminate the two spectra also.

   Notice that the converse does not hold. There may be spectrum pairs that a person with all three types of cones can discriminate, but a person with only two cone systems cannot discriminate. (And that is what we mean by color blindness.)

2. Let $\mathbf{s}_1$ be the RGB values of the original image at some pixel. Let $\mathbf{s}_2$ be the RGB values that we need to use at a pixel on the second monitor so that we get a color match to the corresponding pixel on the first monitor. We want

$$\mathbf{C}\;\mathbf{P}_1\;\mathbf{s}_1 \;=\; \mathbf{C}\;\mathbf{P}_2\;\mathbf{s_2}$$

   Since $\mathbf{CP}_1$ and $\mathbf{CP}_2$ are 3×3 matrices, we require

$$(\mathbf{C}\;\mathbf{P_2})^{-1}\;(\mathbf{C}\;\mathbf{P_1})\;\mathbf{s}_1 \;=\; \mathbf{s_2}$$

   Notice that this equation does not guarantee that for any $\mathbf{s}_1$, the three corresponding $\mathbf{s_2}$ will be positive numbers. Indeed, if the $\mathbf{s_2}$ are not all positive numbers for some $\mathbf{s}$, then we cannot produce a match for that pixel.

3. Assume for simplicity of argument that the red filter passes the display's R channel but completely blocks (absorbs) the G and B channels. This should make sense: the reason the red filter looks red is that it lets long wavelength light through and blocks the medium and short wavelengths. Similarly, assume the cyan filter passes the G and B channels but blocks the R channel.

   The red stickmen in the figure appear red in the sketch because they are coded with RGB values of $(255, 0, 0)$. The background is white, which means the background is coded with value $(255, 255, 255)$. If the red filter is in front of the left eye, then the red stick man will *not* be visible in the left eye, because both it and the background will pass the same value through the red filter namely (255,0,0).

   The cyan stickman, however, has RGB values $(0, 255, 255)$. When it passes through the red filter, it appears the same as $(0, 0, 0)$ i.e. black since the red filter doesn't let B and G channels through. Thus, the left eye with the red filter sees the cyan stickman, which appears as a black stickman on a red background.

The same argument applies to the right eye looking through the cyan filter. The stickmen appear as black lines on a cyan background.

4. The idea here is that the light reflected from a red colored object (an object which has greater reflectance for longer wavelengths of light) will by definition tend to reflect more light over longer wavelengths, and hence pass more light through the red lens than through the green lens, whereas a green colored object would tend to pass more reflected light through a green lens. Thus, if some particular red and green objects look about the same to the colorblind observer without the lens, then the red object would look brighter through the red lens than through the green lens (and vice-versa for green objects). Maxwell's idea was that a colorblind person could discriminate red vs. green objects on this basis, i.e. objects that appeared brighter in the left/right eye could be interpreted as reddish/greenish, respectively.

5. The spectrum reflected from an object is the product of two spectra: the illumination spectrum and the reflectance spectrum. If two two reflected spectra are metameric under the lighting used in the store, there is no guarentee they will be metameric under the lighting that you have at home since the illuminance spectra could be quite different.