Computer Vision
Homework 02: Light and Color
CS 670, Fall 2019

Name: Kunjal Panchal
Student ID: 32126469
Email: kpanchal@umass.edu

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1 Problem 1: Metamers

1.1 General Definitions and Concepts

Let's look at some general definitions first:

- SPECTRAL POWER DISTRIBUTION the concentration, as a function of wavelength, of any radiometric or photometric quantity. As shown in Figure 1

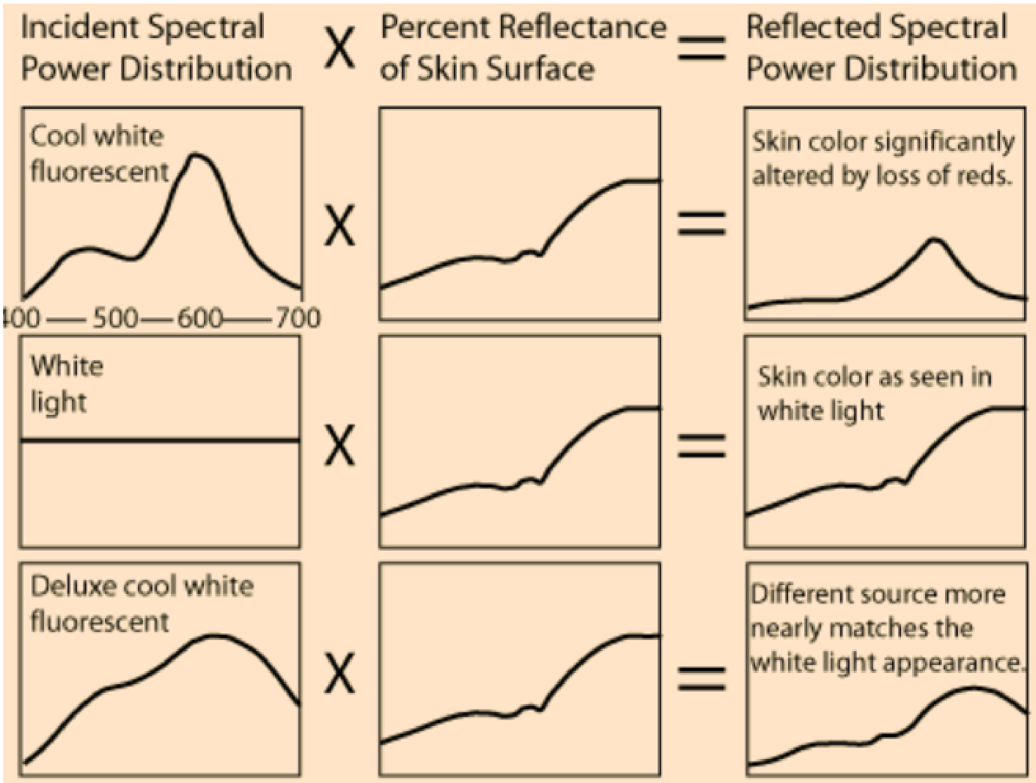

Figure 1: Light may be precisely characterized by giving the power of the light at each wavelength in the visible spectrum. [2]

- METAMERS metamerism is a "perceived" matching of colors with dissimilar spectral power distributions.

- COLOR is a psychological property of our visual experiences when we look at objects and lights, not a physical property of those objects or lights. [3]

- ROD responsible for vision at low light levels.
- CONE active at higher light levels. There are 3 types of cones: L, M and S that respond best to light of long (especially 560 nm), medium (530 nm), and short (420 nm) wavelengths respectively. See Figure 2

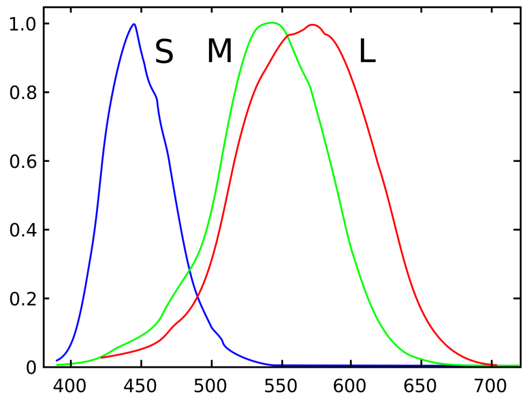

Figure 2: Normalised responsivity spectra of human cone cells. [4]

With the above three statements in mind, let's discuss the problem at hand.

1.2 Why Metamers Exist

The L, M and S cones act like filter for the reflected light.

To get a final value of the color, we need to multiply the spectral power distribution with the reflectance and integrate over the whole wavelength. [1]

This means, we are representing a color with only 3 values. Naturally, a lot of information is lost that way.

As a consequence of this, two different colors might result into same combination of 3 values, as despite having different reflectance, look like they are of same color.

Keep in mind, they look same colored, **only under certain light conditions, not all**. As its reflectance is different and only a particular light makes the resultant integration result into same 3 color values.

These colors are called METAMERS.

1.3 Conclusion and Bottom Line

The visualized color of an object depends on mainly three things:

1. Reflected light wavelengths by the object

2. Wavelength of light sources

3. Perception capability of a human eye with the workings of Rods and Cones [how they respond to certain intensities]

If these 3 factors make up the same resultant wavelength, we will perceive it as the one and the same color, that's how metamerism exist.

And discretization of the three primary colors which are supposed to make the color in question is also limited by numerical constraints, hence, much information about the true color is lost in translation.

So, that's what colors that looks the same to us, but actually have different light spectrums are.

2 Problem 2: Reading Under Low Light

Again, we will redefine some term for ease of understanding:

2.1 General Definitions

- ROD responsible for vision at low light levels. Helps with intensity. [1]
- CONE active at higher light levels. Helps with color perception. [1]
- FOVEA small region (1 or 2°) at the center of the visual field containing the highest density of cones - and no rods. [1] See Figure 3

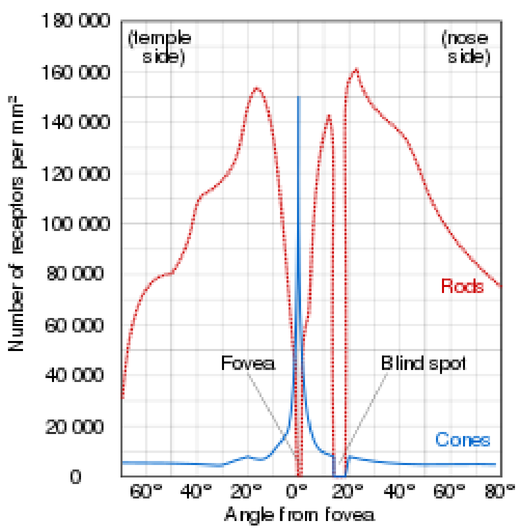

Figure 3: Human Photoreceptor Distribution. [4]

2.2 Why is it Difficult to Read Under Low Light

- UNDER LOW LIGHT rods adapt to darkness, and cones cannot function at this low intensity.
- BUT TO READ we need to move our eye word-by-word, to catch the reflection from the paper on lens.
- FOVEA is where the reflection of words or letters fall, as we are centrally focused on that region.

- BUT THERE ARE ONLY CONES at the fovea. And as stated earlier, we need rods to adapt to low intensities, cones are just for color perception, which has no use here.
- THUS it is difficult to read in dark, as rods are more helpful there, but fovea doesn't have much rods, and we always focus text on fovea.
- THAT'S WHY IT IS DIFFICULT TO READ IN DIM-LIT ENVIROMENTS

3 Problem 3: Representation of Colors

3.1 General Definitions

- TRICHROMACY is the possessing of three independent channels for conveying color information, derived from the three different types of cone cells in the eye. [4]

- PRIMARY COLORS are those which cannot be created by mixing other colors in a given color space.

- CONES three types of color receptors (L at 560nm, responsible for red-yellow color wavelengths; M at 530nm, responsible for yellow-green color wavelengths; S at 440nm, responsible for blue color wavelengths) with different absorption spectra

3.2 Three Numbers are Sufficient to Represent Any Color

In the color matching experiments described in lecture slides [1] and in the applet [5], which is derived from Maxwell's Experiment [6] of the same kind; the results derived point to one thing:

The three primary colors Red, Green and Blue are enough to tweak the each individual wavelength intensity in a way that we can produce any color which is visually matching to the test color.

The primary colors are independent and their individual "weights" or "intensities", while summed together, are sufficient to create any color in spectral range.

3.3 Conclusion

Suppose, primaries are monochromatic lights as shown in Figure 4,

Any color or in more technical terms, a spectral signal can be thought of as a combination of this primary monochromatic lights, at different weights/ intensities. Sometimes, we will have to take negative wavelength into account to get an exact shade; which just means that we will have to change the intensity of the test color.

If a color is represented as a monochromatic light λ_i, it can be reproduced as a combination of different weights of the 3 primary color wavelengths $c_1(\lambda_i)$**,** $c_2(\lambda_i)$ **and** $c_3(\lambda_i)$.

If there are N colors, there will be a weighed primary wavelength matrix like this: [1]

$$C = \begin{bmatrix} c_1(\lambda_1) & c_1(\lambda_2) & \dots & c_1(\lambda_N) \\ c_2(\lambda_1) & c_2(\lambda_2) & \dots & c_2(\lambda_N) \\ c_3(\lambda_1) & c_3(\lambda_2) & \dots & c_3(\lambda_N) \end{bmatrix}$$

and just find the weights to create color wavelength t_λ will be

$$\vec{e} = C\vec{t}$$

Hence, we will get THREE components e_1, e_2 and e_3 to describe any color.

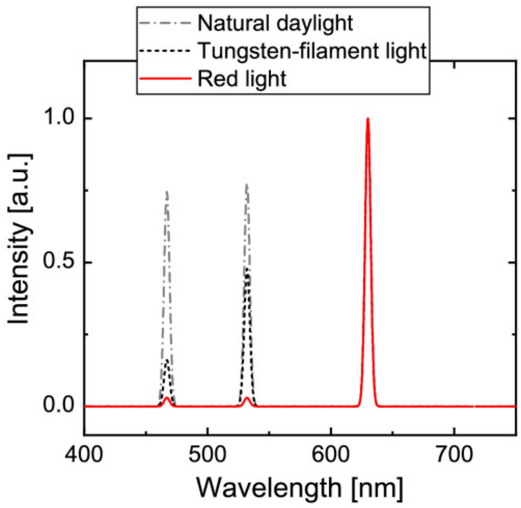

Figure 4: A monochromatic red/ laser light wavelength [7]

References

[1] Subhransu Maji, *Light and Color* https://www.dropbox.com/s/7ji2vdxqbzpq5vc/lec03\%2B04_light_and_color.pdf?dl=0

[2] *Spectral Power Distribution* http://hyperphysics.phy-astr.gsu.edu/hbase/vision/spd.html

[3] Stephen Palmer, *Vision Science: Photons to Phenomenology*

[4] *Trichromacy* https://en.wikipedia.org/wiki/Trichromacy

[5] *Color Matching Applet* http://graphics.stanford.edu/courses/cs178/applets/colormatching.html

[6] *do "primary" colors exist?* http://www.handprint.com/HP/WCL/color6.html

[7] *Effect of spectroradiometer characteristics on chromaticity for tricolor laser light sources* https://www.osapublishing.org/josaa/viewmedia.cfm?uri=josaa-36-8-1379