Course Reminders

Perceptually aware visualization

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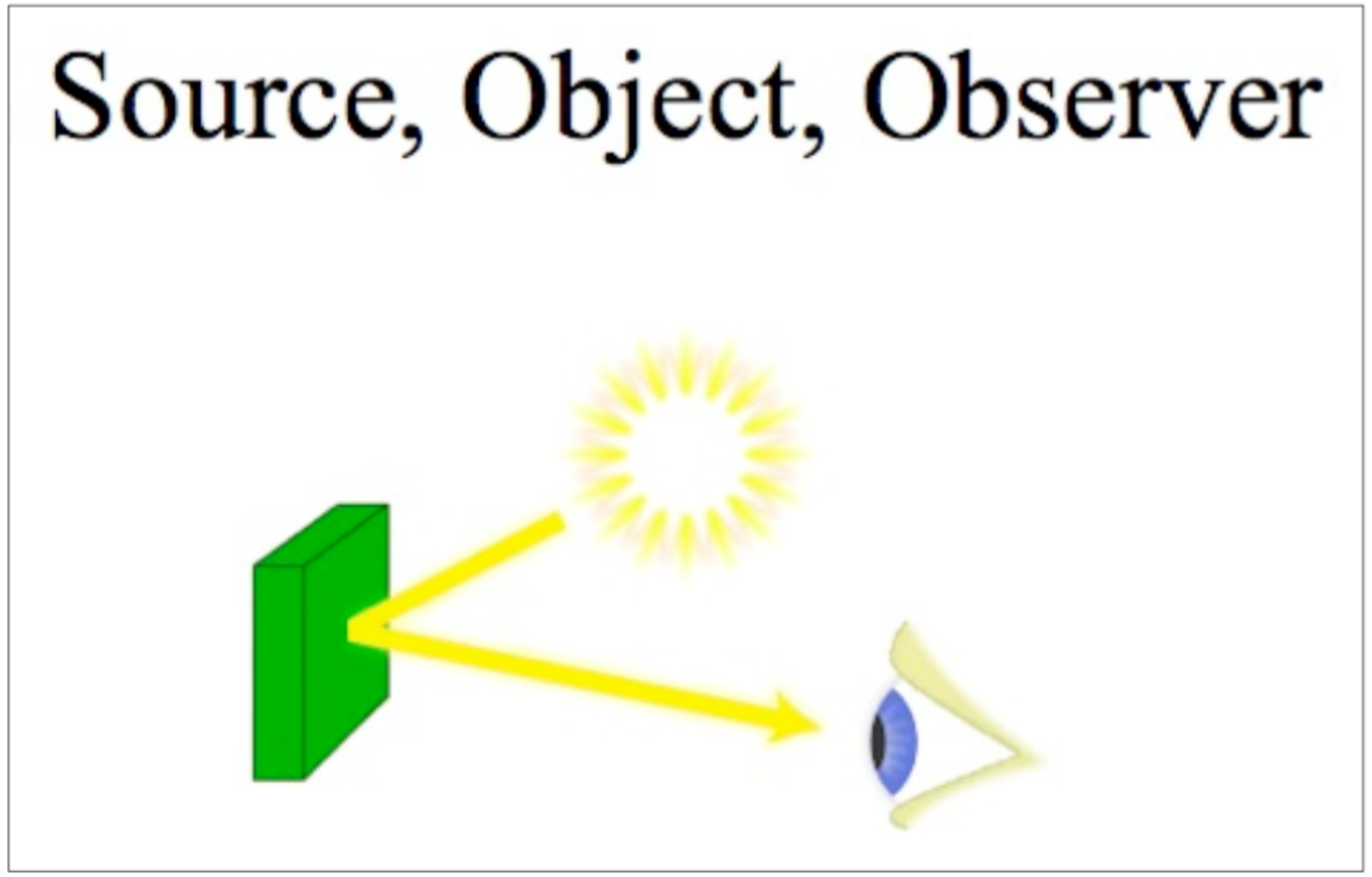
Lectures : https://github.com/COGS108/Lectures-Wi23

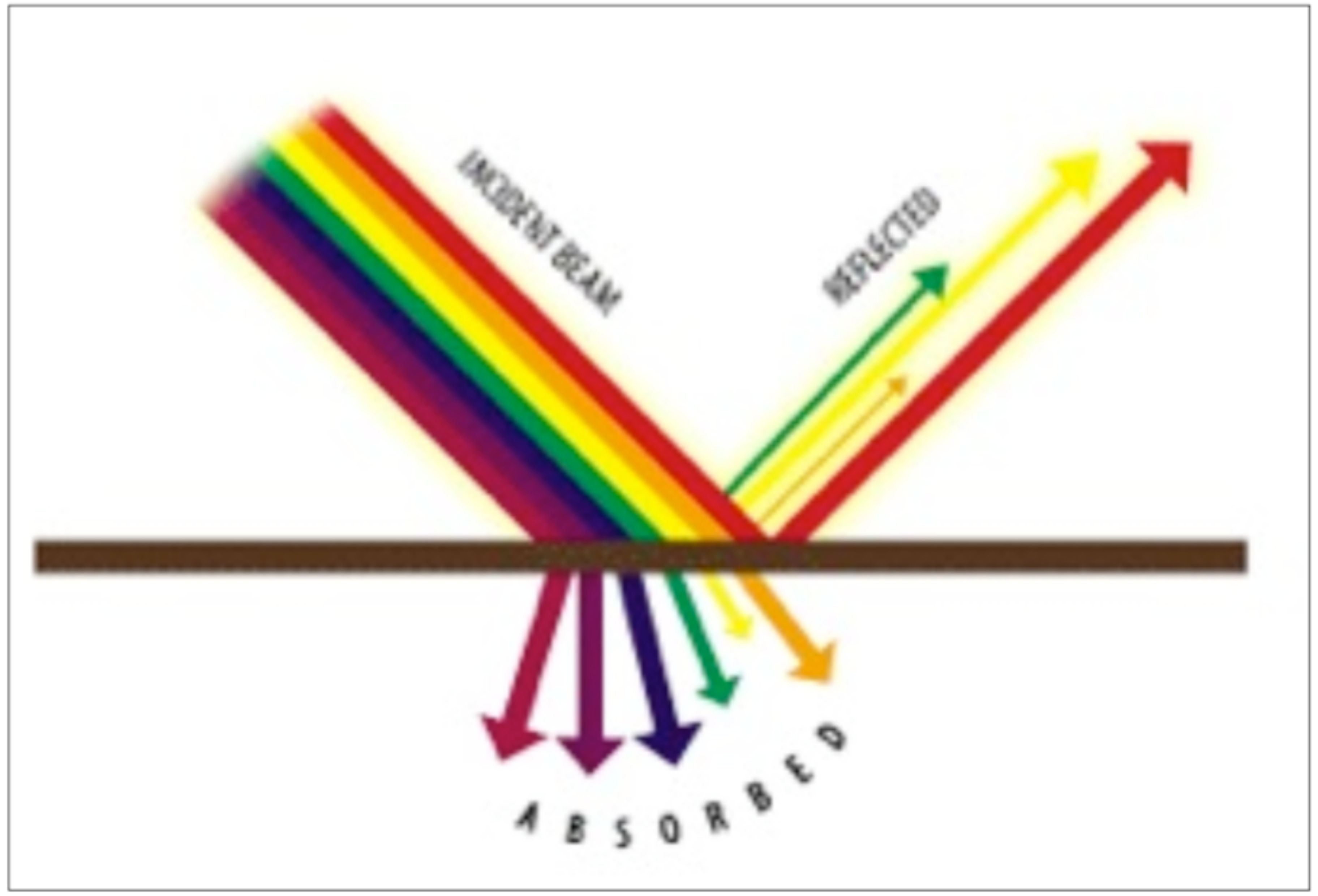
Visualization

- Human brain has trouble making sense of large amounts of data produced by computational modeling and experimentation
- As more computational methods are applied, more and more information is being created
- Scientific visualization is one way of making important information explicit and simple to process
- http://svs.gsfc.nasa.gov/

What is color?

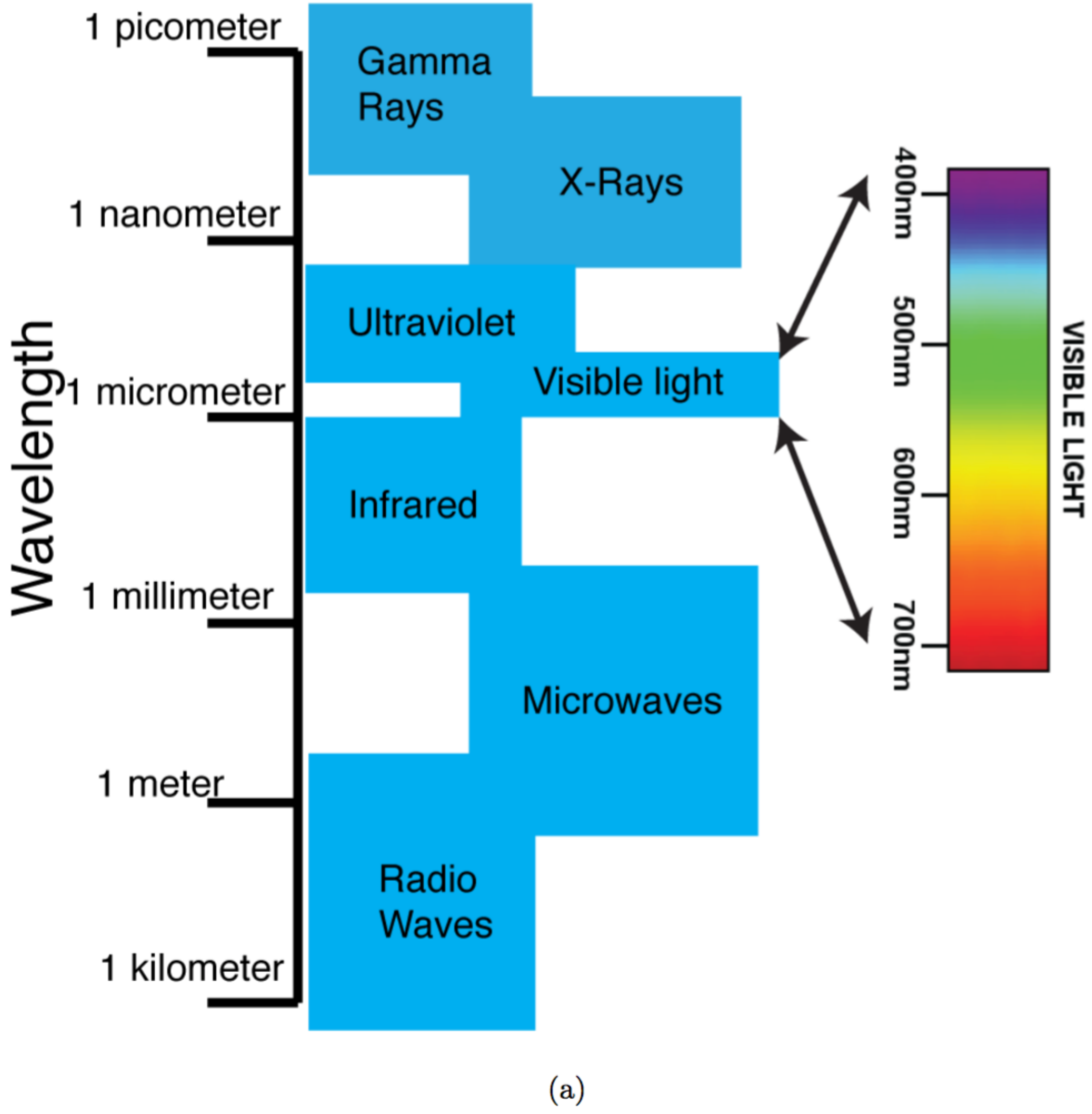
- Reflected light = color of object
- Color is the set of wavelengths of light reflected from an object
- A light source can be a light bulb, the sun, etc or another object





Electromagnetic Spectrum

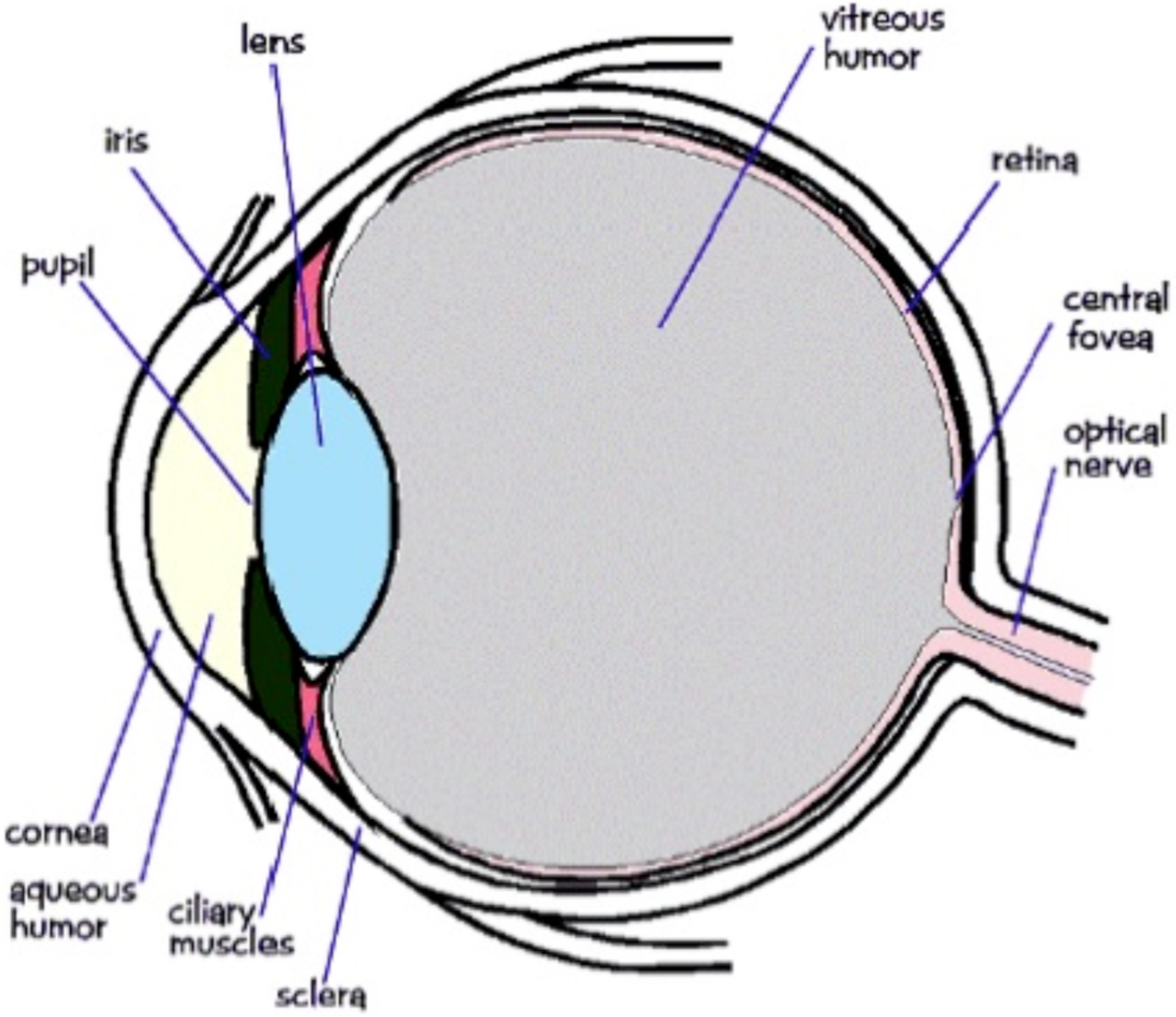
- Visual light is a tiny part
- How can we visualize these quantities in a perceptually useful way?



(a)

Figure 5.2: Visible light (i.e. the portion of the electromagnetic spectrum that human beings can perceive using their eyes) is a very small subset of the entire electromagnetic spectrum, as the reader can see here.

The Eye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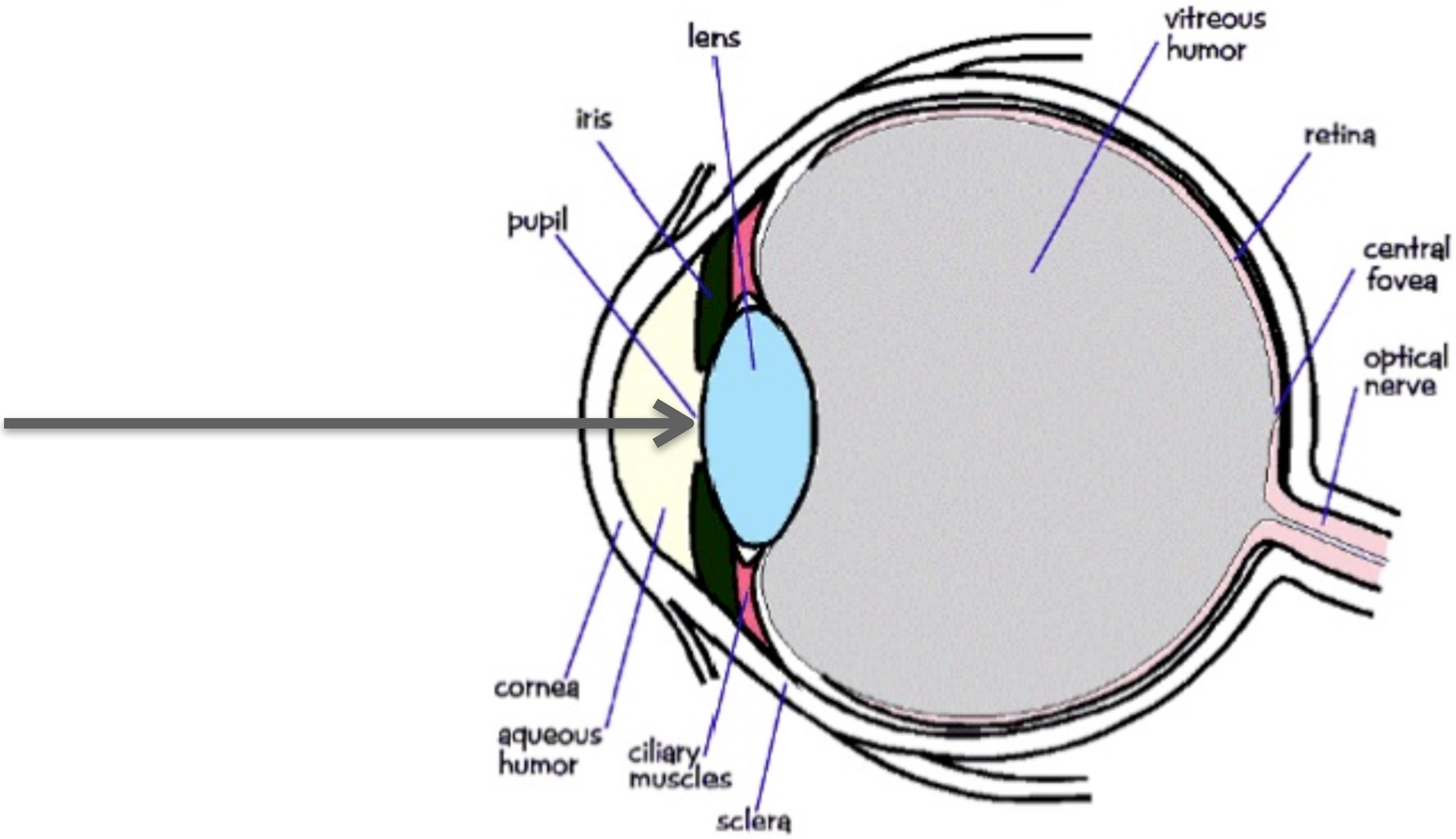
iris
retina
pupil
central fovea
optical nerve
cornea
aqueous humor
ciliary muscles
sclera

The Eye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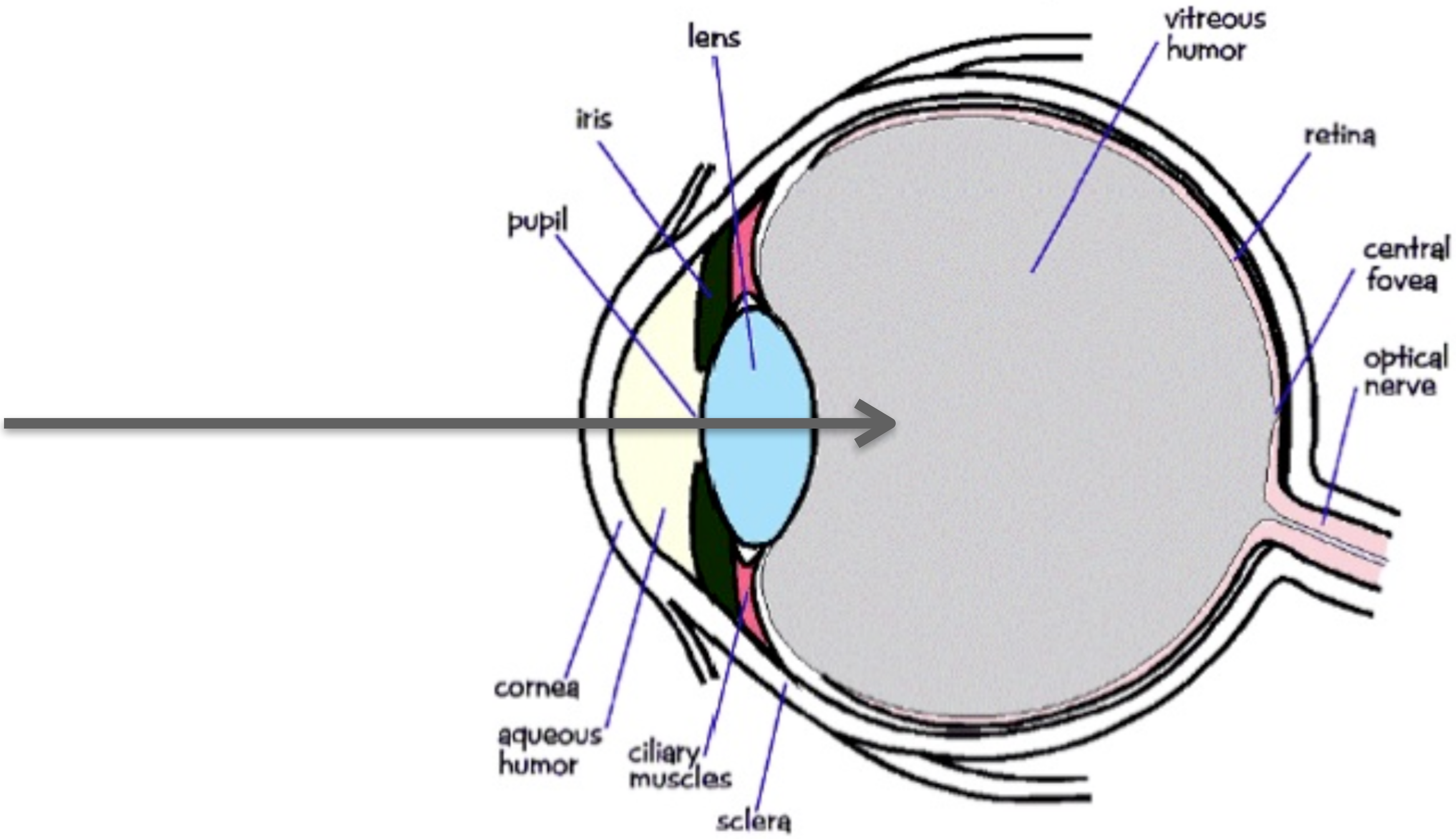
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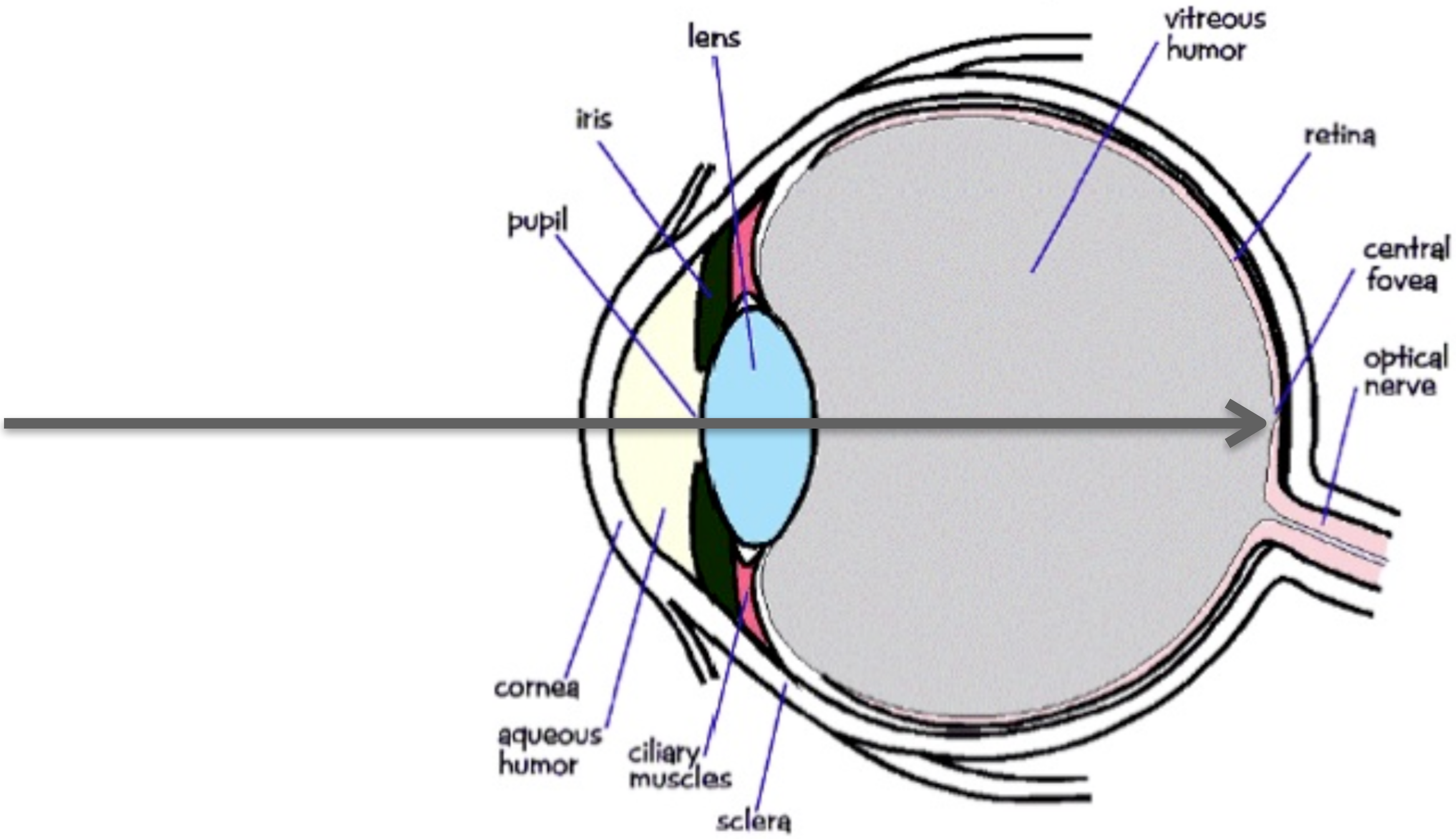
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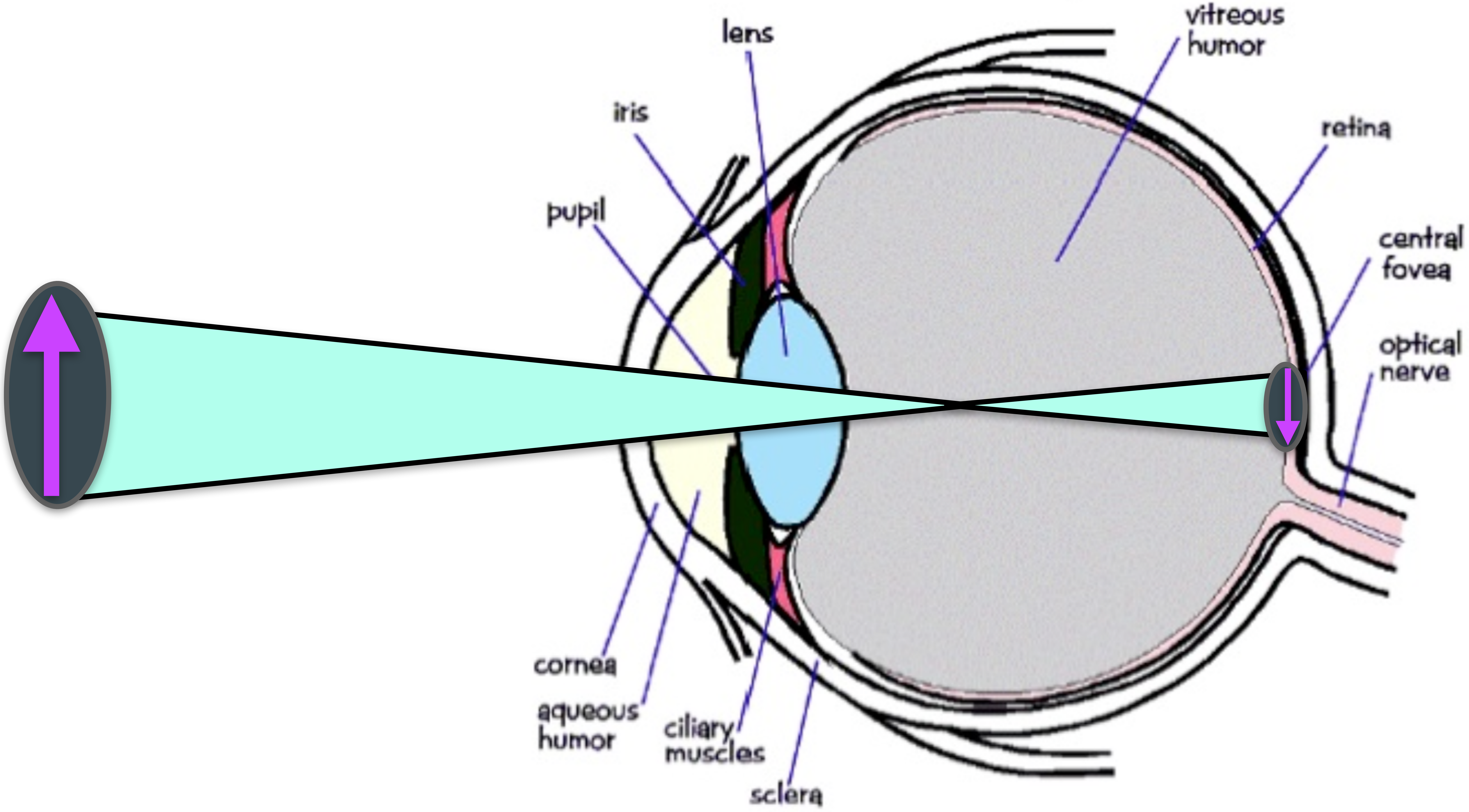
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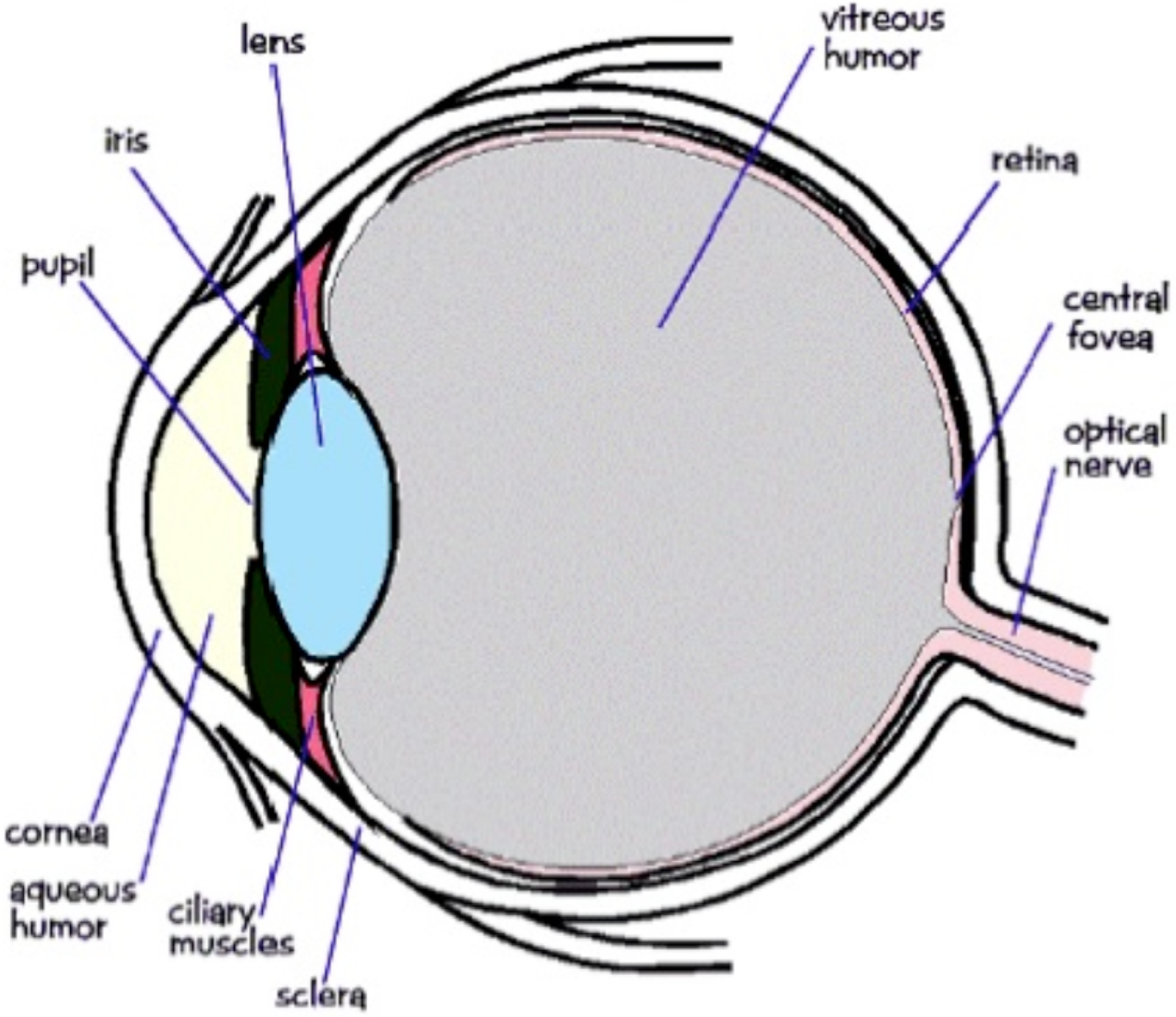
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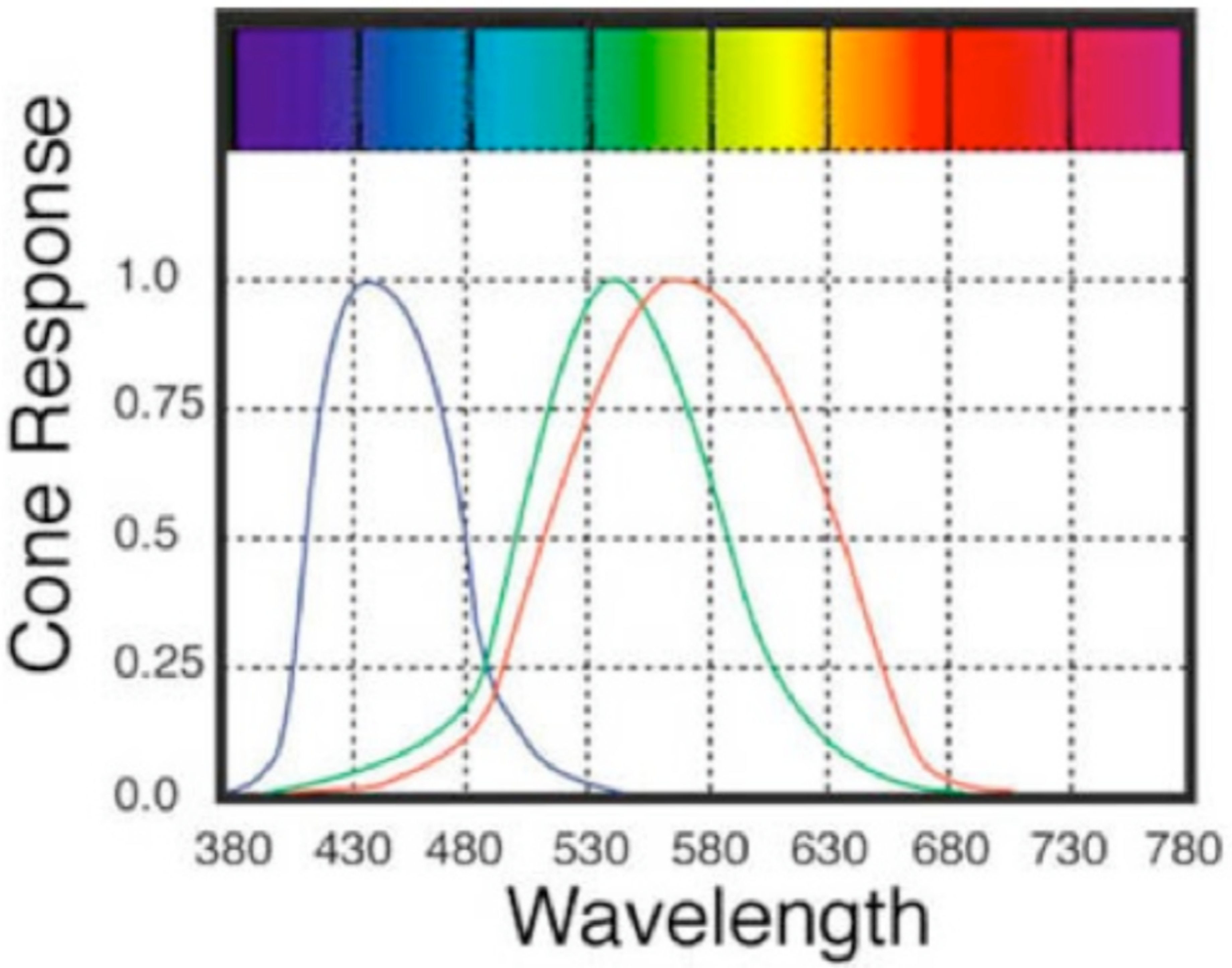
Human perception of color

- **Color constancy** - our visual perception is constantly adjusting to compensate for changing surroundings
- Human color perception is ***context dependent***
  - Ever try to perceive the difference between two colors of clothing in low light?
  - Movie example - Abyss Yellow/green light source, “Cut the blue wire with the white stripe, NOT the black wire with the yellow strip”
  - Side note- how to fix this as the designer of the device?
    - Use one wire with dashes instead of a stripe - “Cut the wire with the dashes.” Person cutting: “Easy. It’s done!”

Rods and Cones - Color vs. Intensity

Rods - sensitive to intensity (black and white sensitivity in low light conditions)

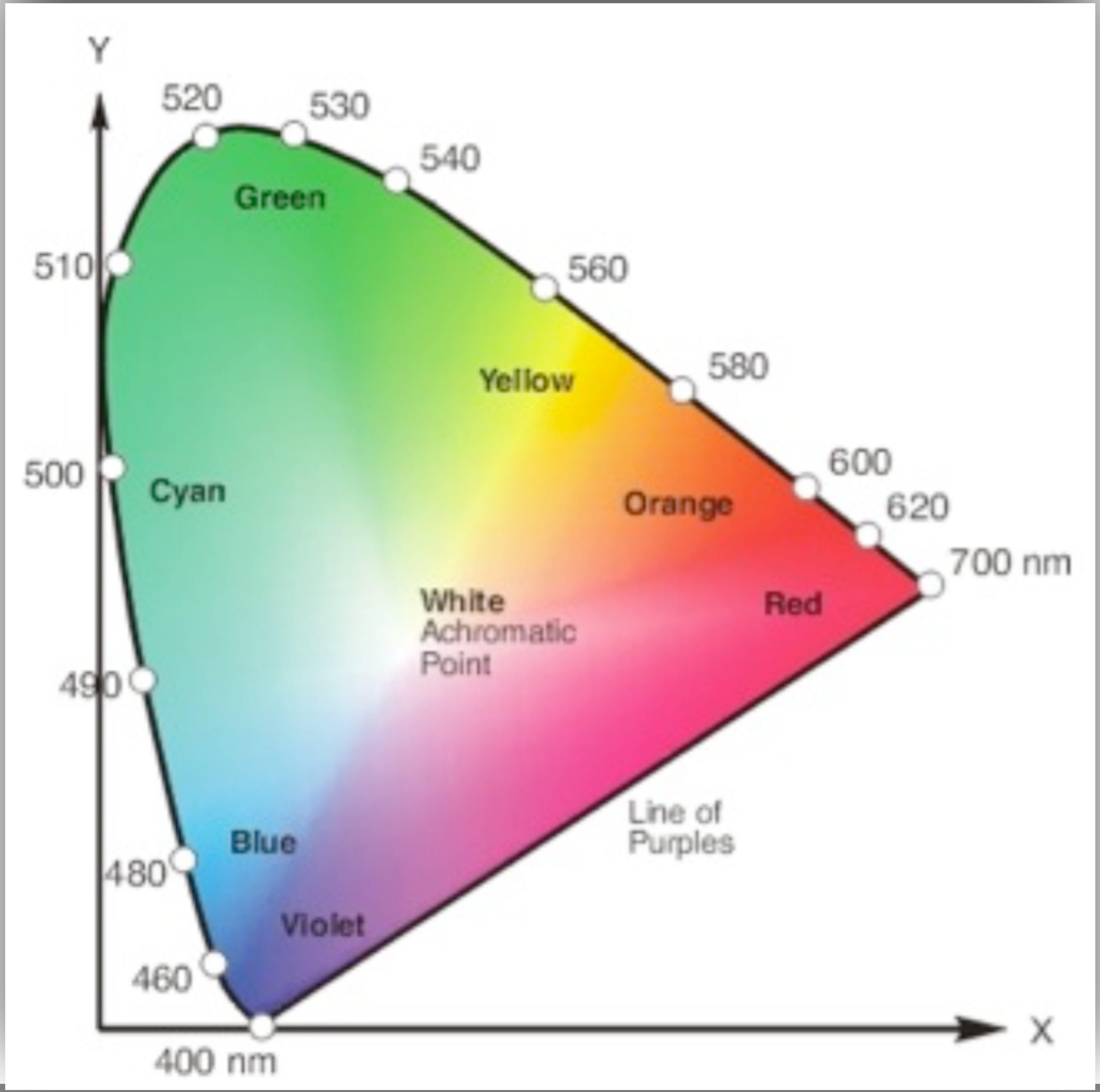
Cones - three types, S, M and L corresponding to short, medium and long wavelength light sensitivities



Perceptual example - afterimages

Perceptual example - afterimages

CIE Color Chromaticity Chart



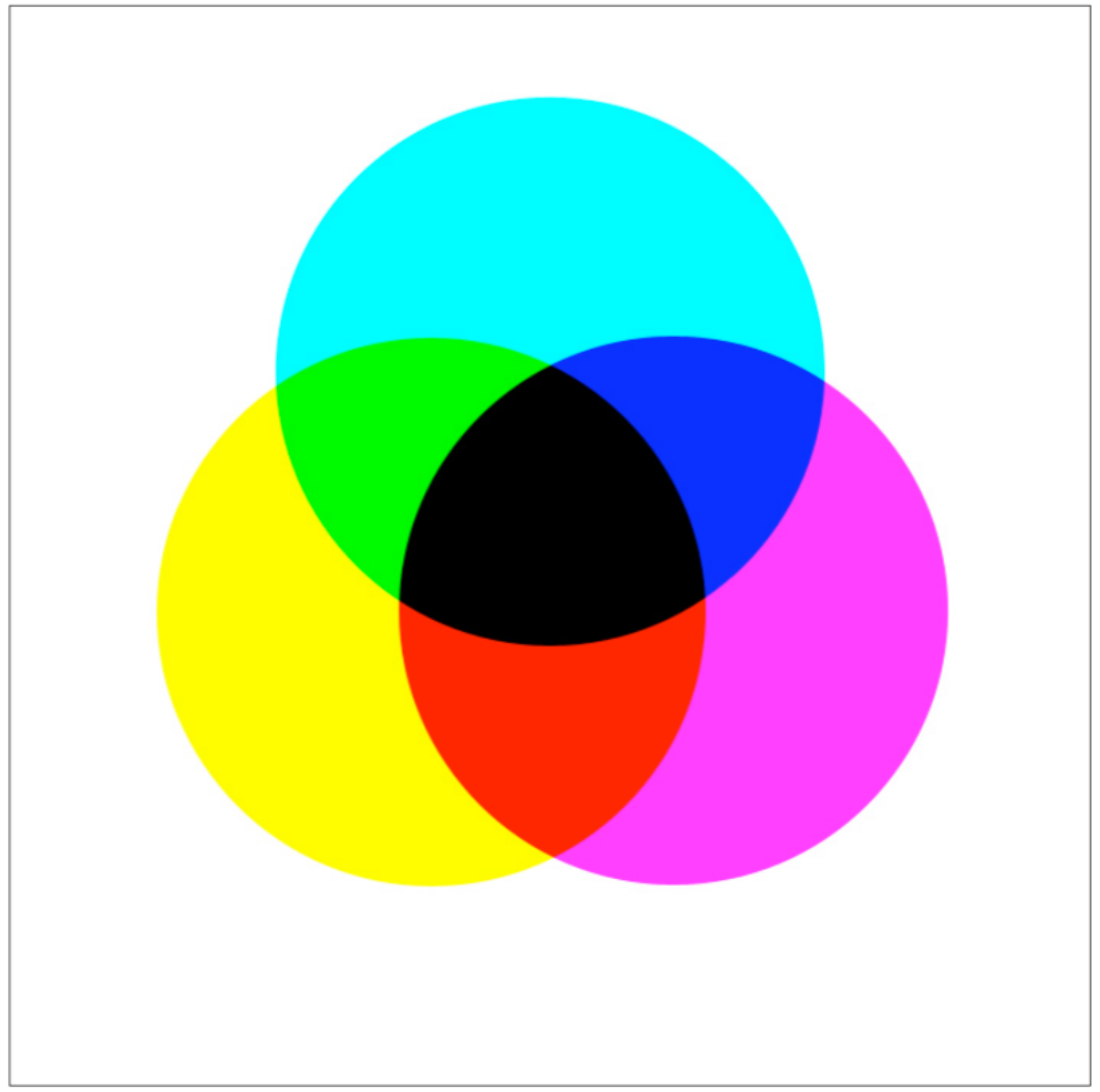
Color Spaces

- Now that we have a sense of how we perceive light and color, we can define several MODELS of color
- Each color is assigned a coordinate which has three components relative to some color space model (i.e. RGB)
- Some of these color spaces are additive, some are subtractive

Additive vs. Subtractive Color

Additive (RGB)

Subtractive (CMY)



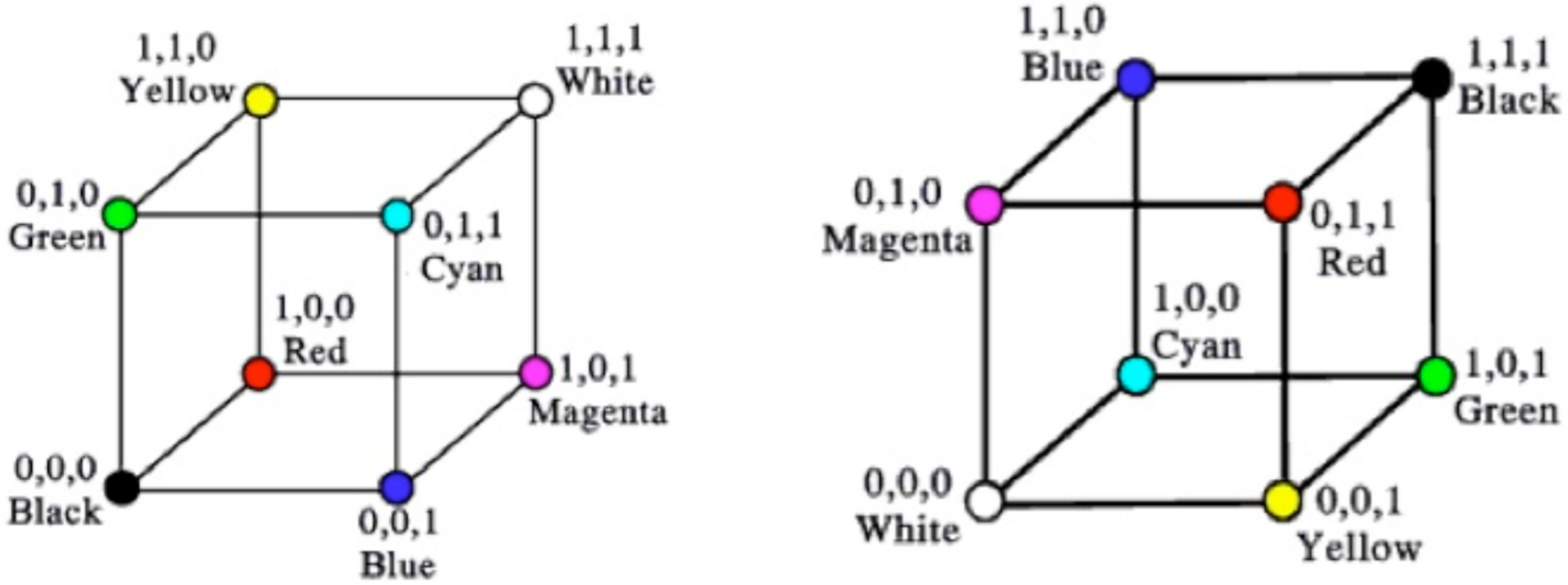
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1-R \\ 1-G \\ 1-B \end{bmatrix}$$

Additive vs. Subtractive Color

- RGB
  - **red-green-blue**
  - **Additive scheme**
- CMY
  - **Cyan-magenta-yellow**
  - **Subtractive scheme**
  - **Black (CMYK) is typically added to inkjet printers**
    - Difficult to make exact black by mixing CMY, requires precision
    - Typically one uses black the most so it makes sense to have a separate ink cartridge for black
- HSV
  - **Hue-saturation-value**
  - **Many feel this is a more natural way to describe color for humans**

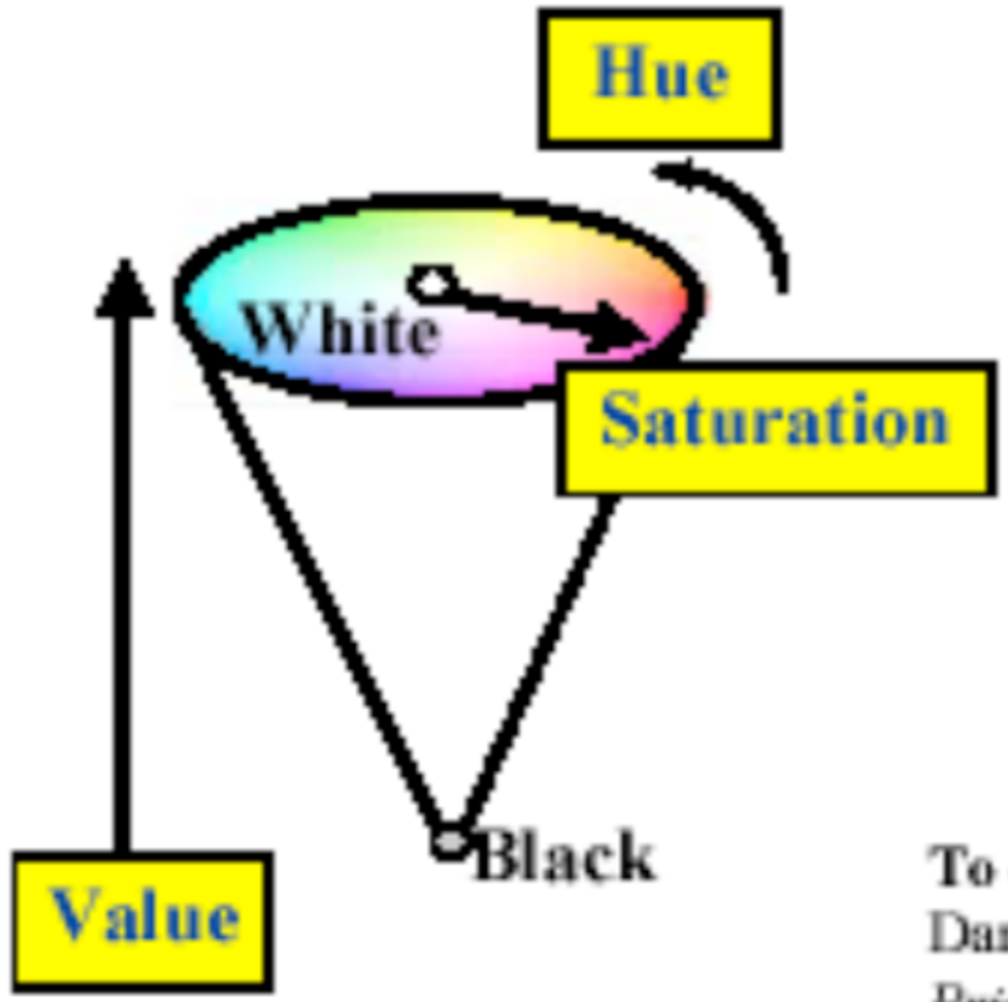
RGB and CMY color cubes

- Map (r,g,b)->(x,y,z) or (c,m,y)->(x,y,z)
- Combinations of primary color components (R, G, B) use to produce any desired color
- The two spaces are complements of each other



HSV color cone

- Hue
  - the various colors we perceive
  - Each has its own unique wavelength
- Saturation
  - Also called chroma
  - Comparison of color to neutral gray
  - Richness of color
  - 100% - pure color, 0% gray
- Value
  - Lightness or darkness of a hue, or achromatic color
  - Lower when darker, higher when lighter



To convert from HSV to RGB, see: Foley, Van Dam, Feiner, and Hughes, *Computer Graphics: Principles and Practices*, Addison-Wesley, 1990.

Example: Bad color matching

- Eeeghh!
- The red and blue are on opposite ends of the visual color spectrum, so we have trouble focusing on both colors simultaneously
- I could have made this worse by adding all equations, but last time too many people passed out!
- AVOID REDS ON BLUES OR BLUES ON REDS

Example: Good color matching

- Ahhh…
- This is much more comfortable for the eyes.
- Choose colors which are based on luminance differences
- generally avoid two fully saturated colors as foreground and background
- Increase contrast by reducing the perceived intensity of either the foreground or background

Bad Contrast

Bad Contrast
Bad Contrast

- The most important thing you need to know to get the most out of your education is that you should value the learning and try to make it your own
- The most important thing in this paper is that we did not really find anything important

Good Contrast

- Use the luminance equation (or an intuitive understanding of it) to suggest good contrast combinations, also can use the precomputed luminance and contrast tables

Luminance Equation

$$Y = 0.30 * Red + 0.59 * Green + 0.11 * Blue$$

- Perceived intensity due to a color
  - Different contributions of red/green/blue components
  - Empirically determined

We perceive the world through contrast

- No contrast, no boundary
- No boundary, we cannot discern shapes and objects
- Understanding color contrast will help Data Scientists create color groupings that are easy to perceive

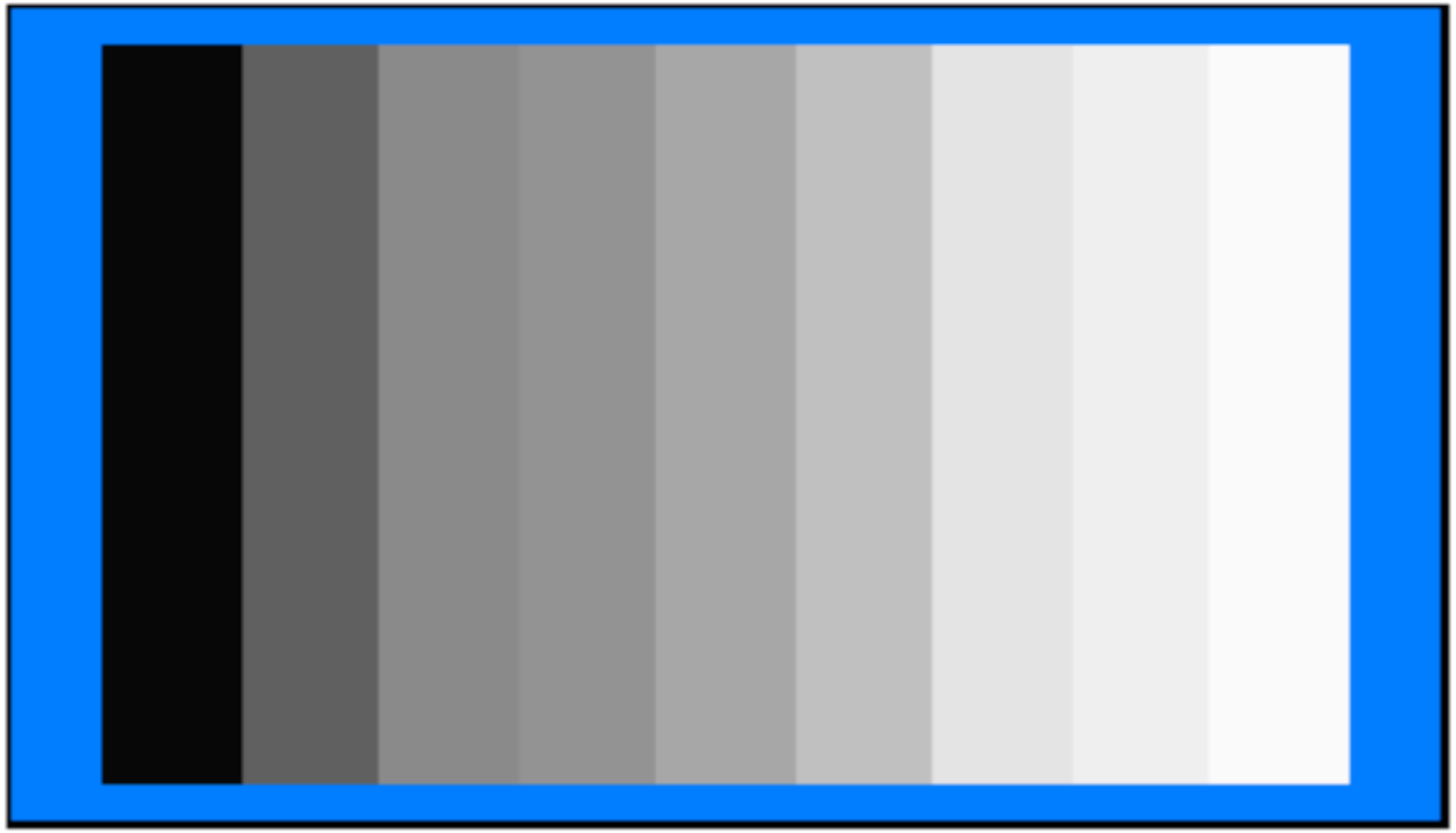
Contrast tables

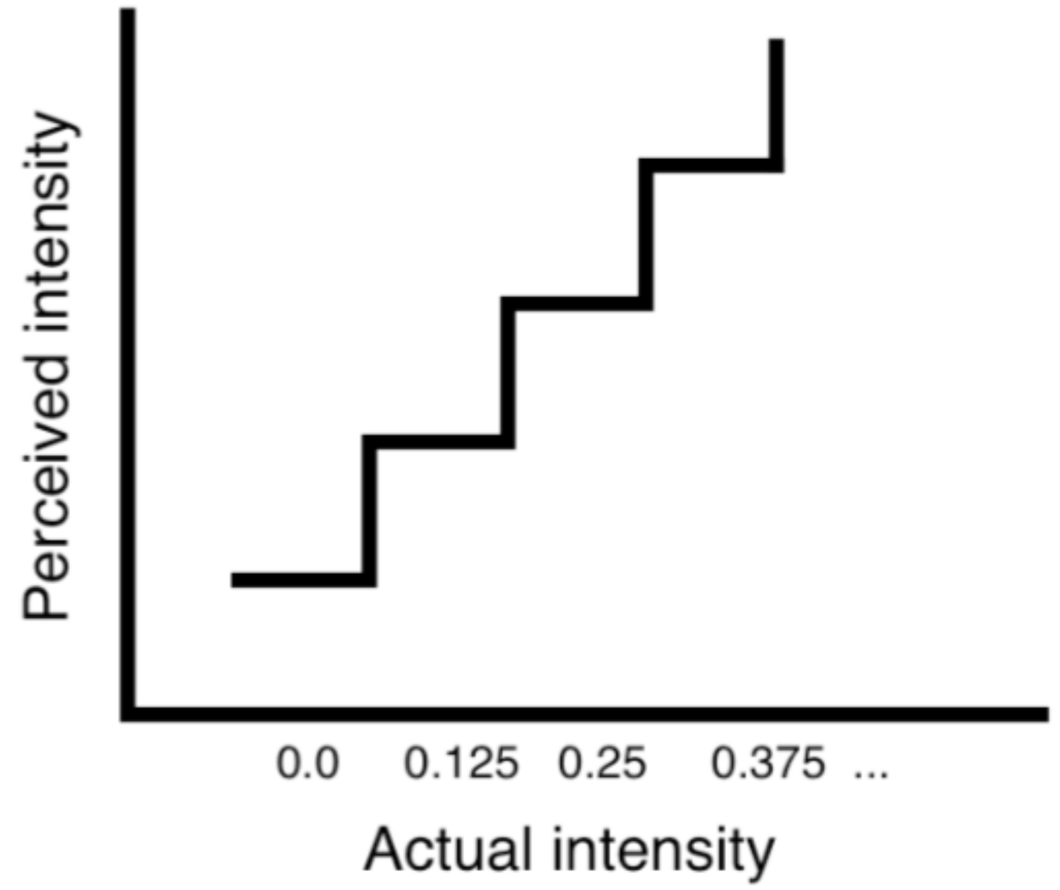
	Black	White	Red	Green	Blue	Cyan	Magenta	Orange	Yellow
Black	0.00	1.00	0.30	0.59	0.11	0.70	0.41	0.60	0.89
White	1.00	0.00	0.70	0.41	0.89	0.30	0.59	0.41	0.11
Red	0.3	0.7	0.00	0.29	0.19	0.40	0.11	0.30	0.59
Green	0.59	0.41	0.29	0.00	0.48	0.11	0.18	0.01	0.30
Blue	0.11	0.89	0.19	0.48	0.00	0.59	0.30	0.49	0.78
Cyan	0.70	0.30	0.40	0.11	0.59	0.00	0.29	0.11	0.19
Magenta	0.41	0.59	0.11	0.18	0.30	0.29	0.00	0.19	0.48
Orange	0.60	0.41	0.30	0.01	0.49	0.11	0.19	0.00	0.30
Yellow	0.89	0.11	0.59	0.30	0.78	0.19	0.48	0.30	0.00

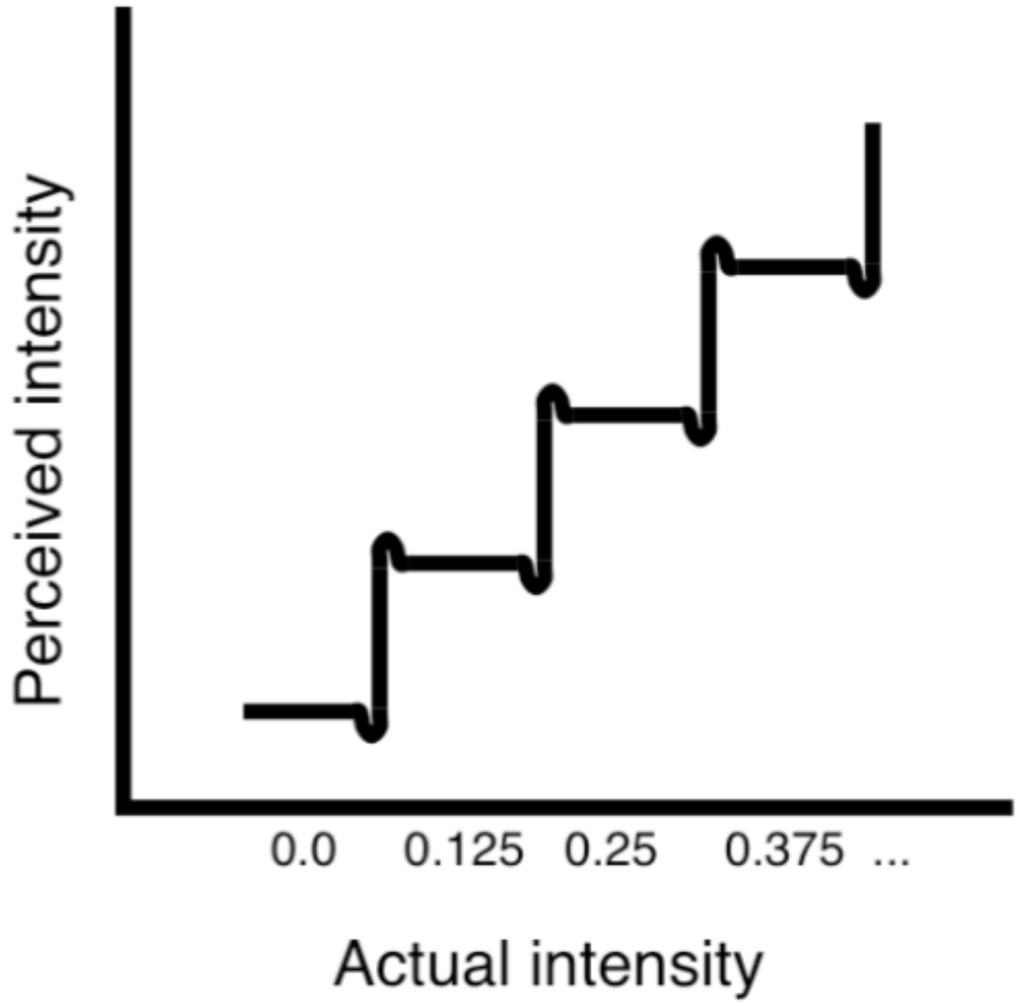
Table 5.1: A color contrast table can be formed by subtracting the luminance equation values for two different colors, then taking the absolute value.

From C.A. Simpkins, *Design*, Manuscript

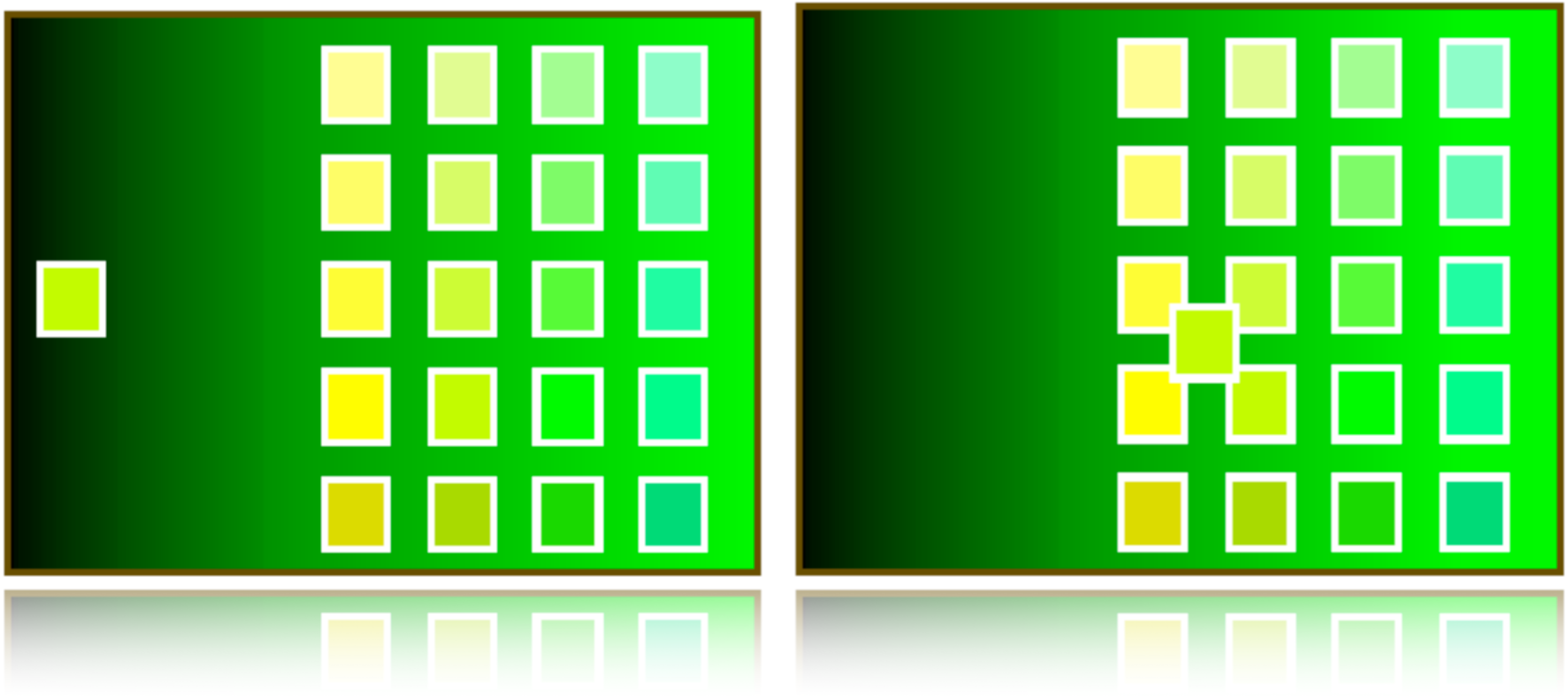
Beware of Mach Banding





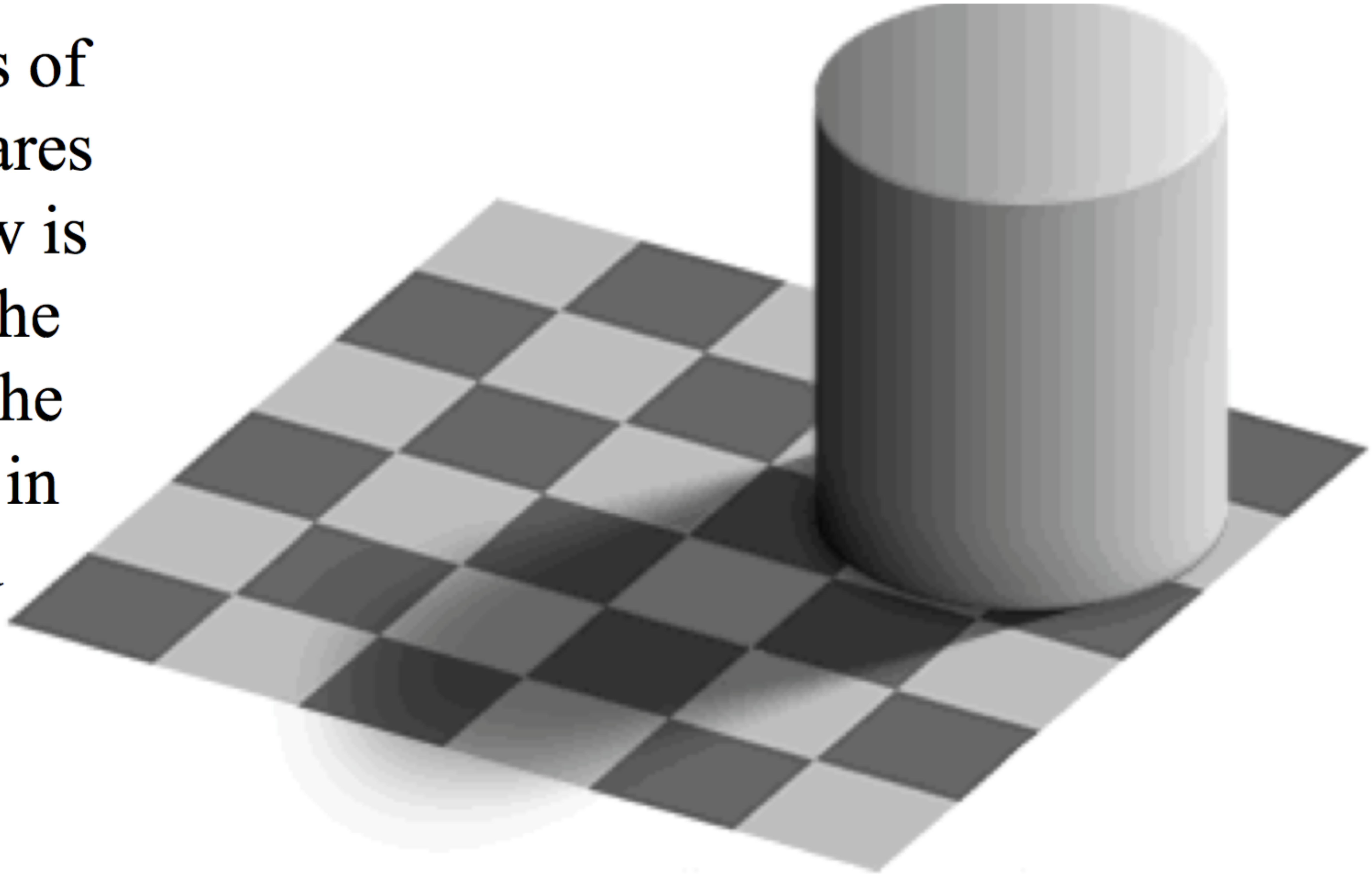


Recall that perceived color intensity is also context dependent



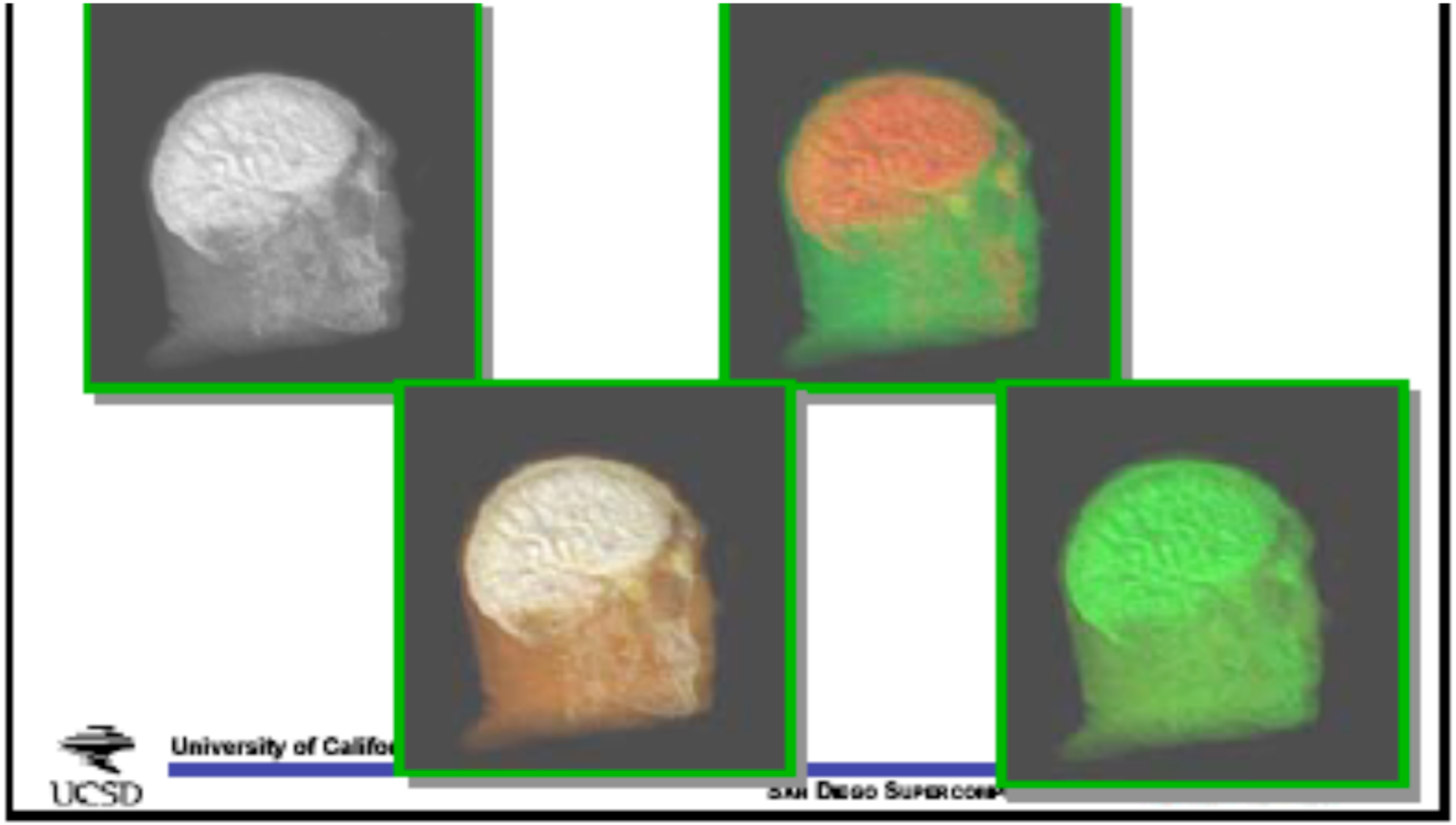
Perceived lightness is context dependent as well

- The lightness of the light squares in the shadow is the same as the lightness of the dark squares in the unshaded region



False color representation and color maps

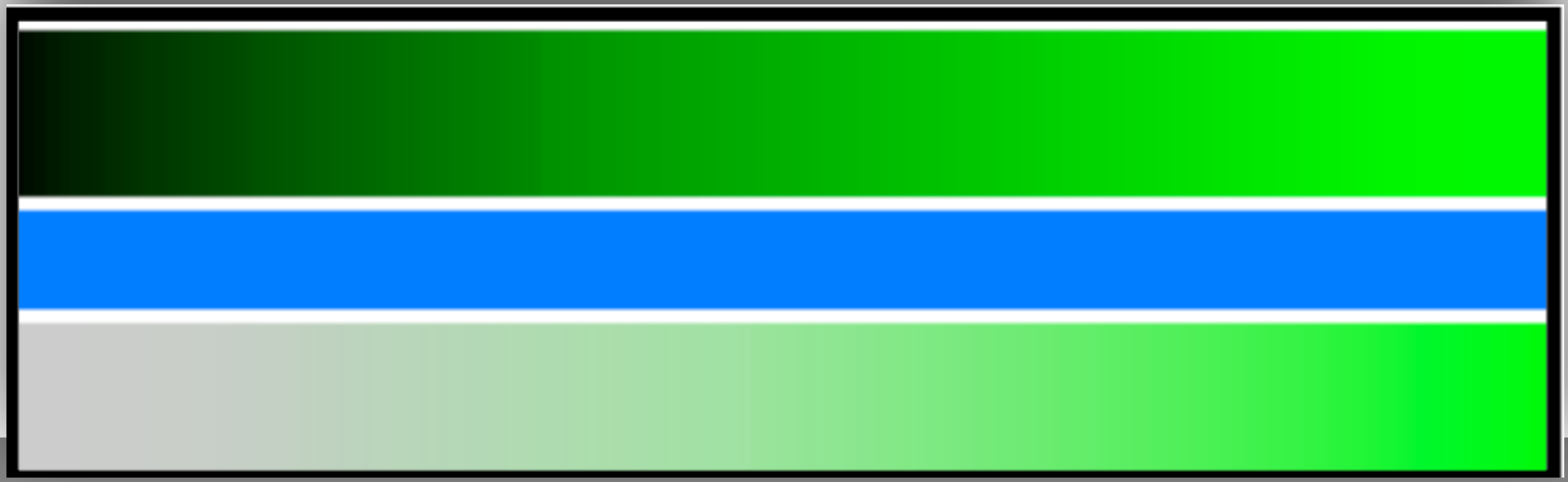
- Map values from any range to a map of colors
  - i.e. a matrix of 0-1 range-> white-black



False color representation and color maps

- Gray Scale - get gray by setting all three color values the same

- Intensity and saturation color scales - we often feel black means nothing



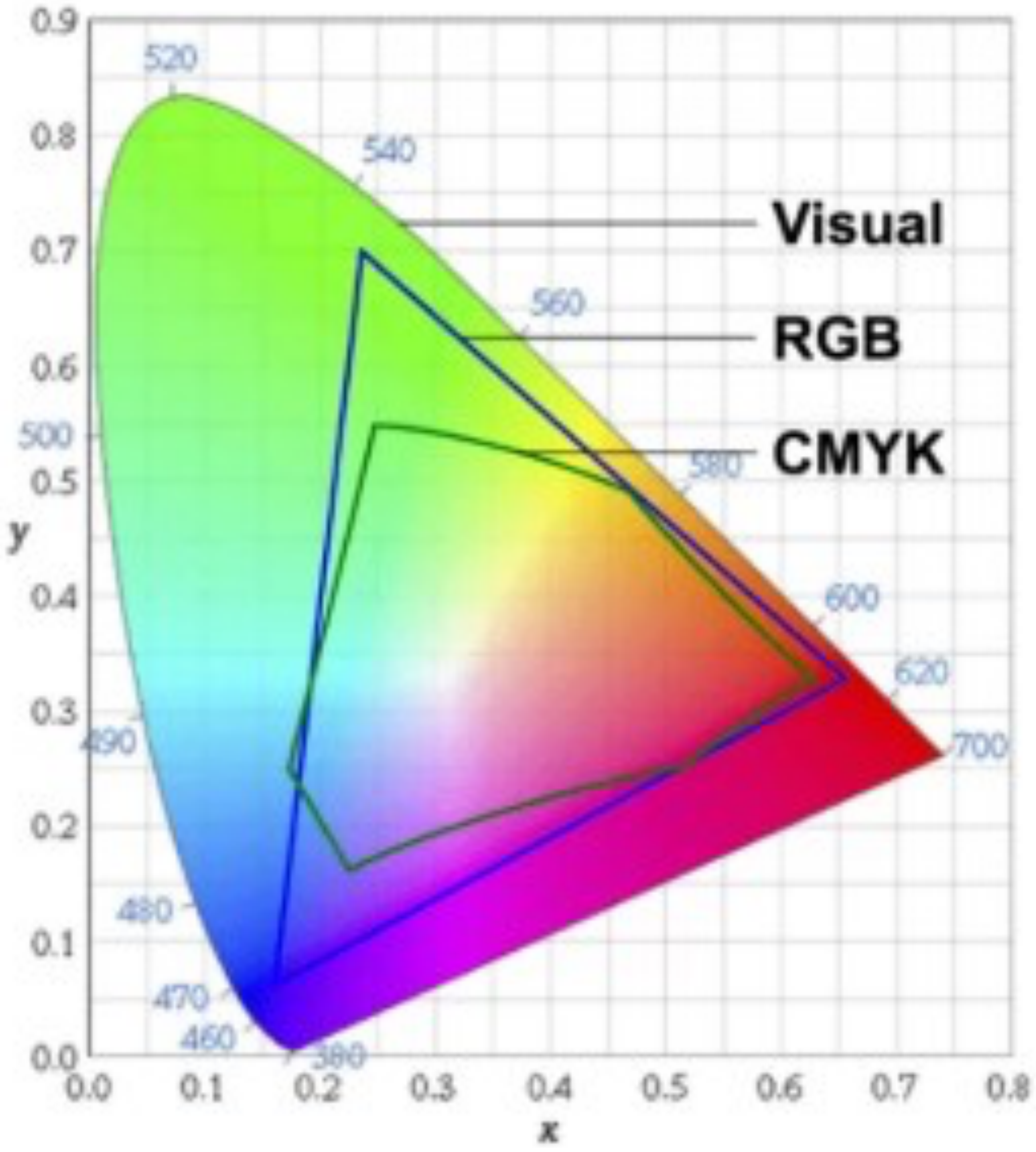
More color maps

- Rainbow color scale - magenta is not directly in the EM spectrum

- Heated object color scale - intensity increases left->right

Color **Gamut comparison**

- The range of colors a device can display
- This can be a triangle or more complex shapes
- Typically a subset of human perception
  - Stay away from what cannot be printed when creating for papers



Different display technologies have different limitations

- LCD
  - Slow response (faster than it used to be)
  - Narrower color gamut than older CRTs, but improving
  - Tough
  - Not good for extreme temperatures
  - Multiple resolutions are interpolated
- Film
  - Wider color gamut
  - Fairly good resolution typically

Different display technologies have different limitations

- Color Printers
  - Narrow color gamut
  - Subtractive color
  - Requires special paper to realize maximum potential
- NTSC TV
  - Narrow color gamut
  - Slow refresh
  - Interlacing

Output

- If you are creating visualizations for multiple contexts (video, computer monitors, printed papers, etc) be aware of device limitations
- Use **redundant encoding of information** if you don't know what the output is or who will be looking at it
  - **Different fonts**
  - **Symbols**
  - **Fill pattern**
  - **Outline pattern**
  - **Outline thickness**

A final word about colors…

- Just because you *have* 2^{24} different colors
- Doesn't mean you have to use them all…