Color Vision

Intro to Data Visualization

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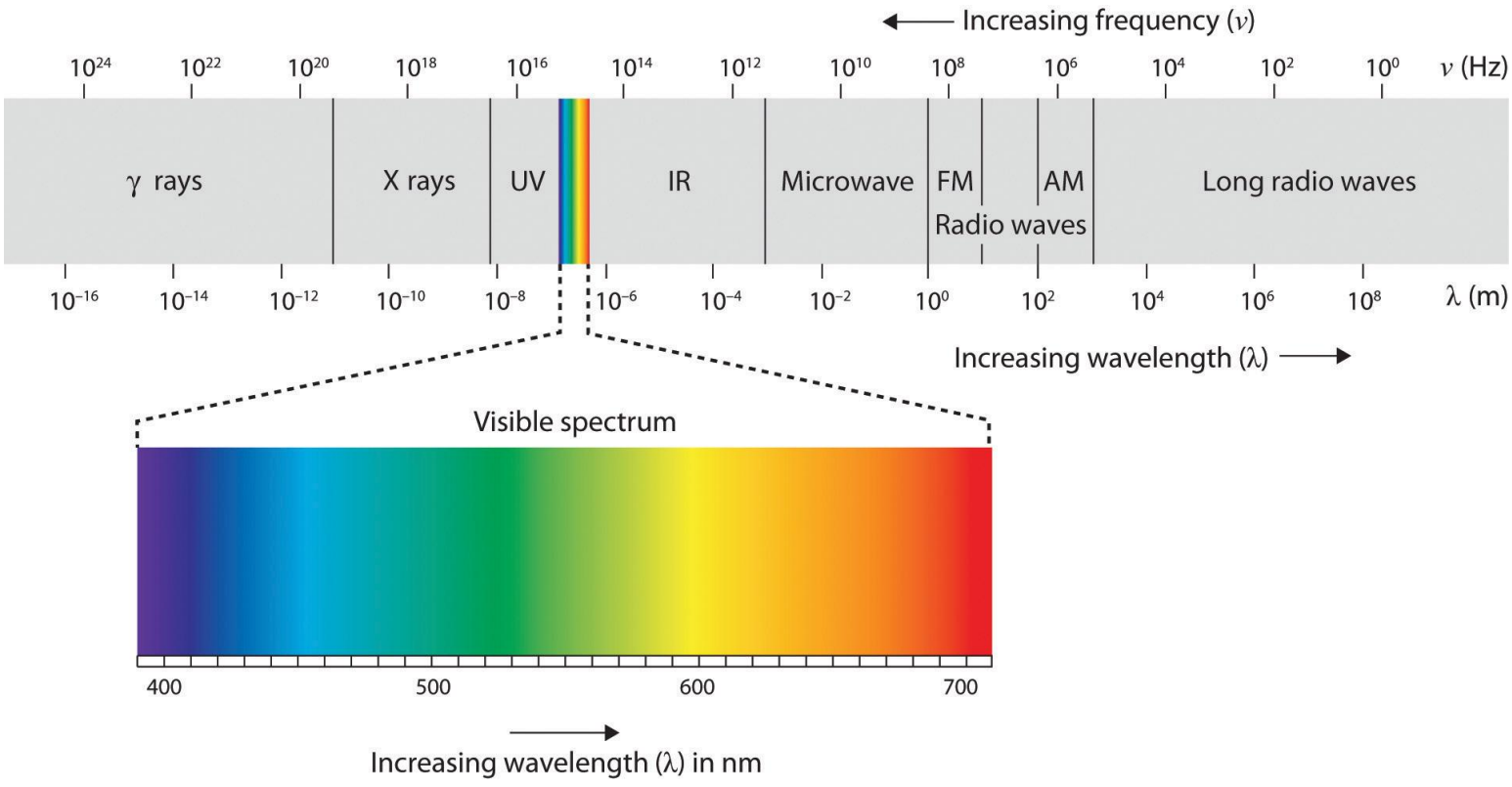
Light and Color

Light Recap

- Light is a form of electromagnetic radiation.
- Electromagnetic radiations are characterized by their wavelength.
- Visible light has wavelengths in a narrow band centered on 600 nanometers.

Electromagnetic Spectrum



http://open.lib.umn.edu/intropsyc/chapter/4-2-seeing/

Visible Light

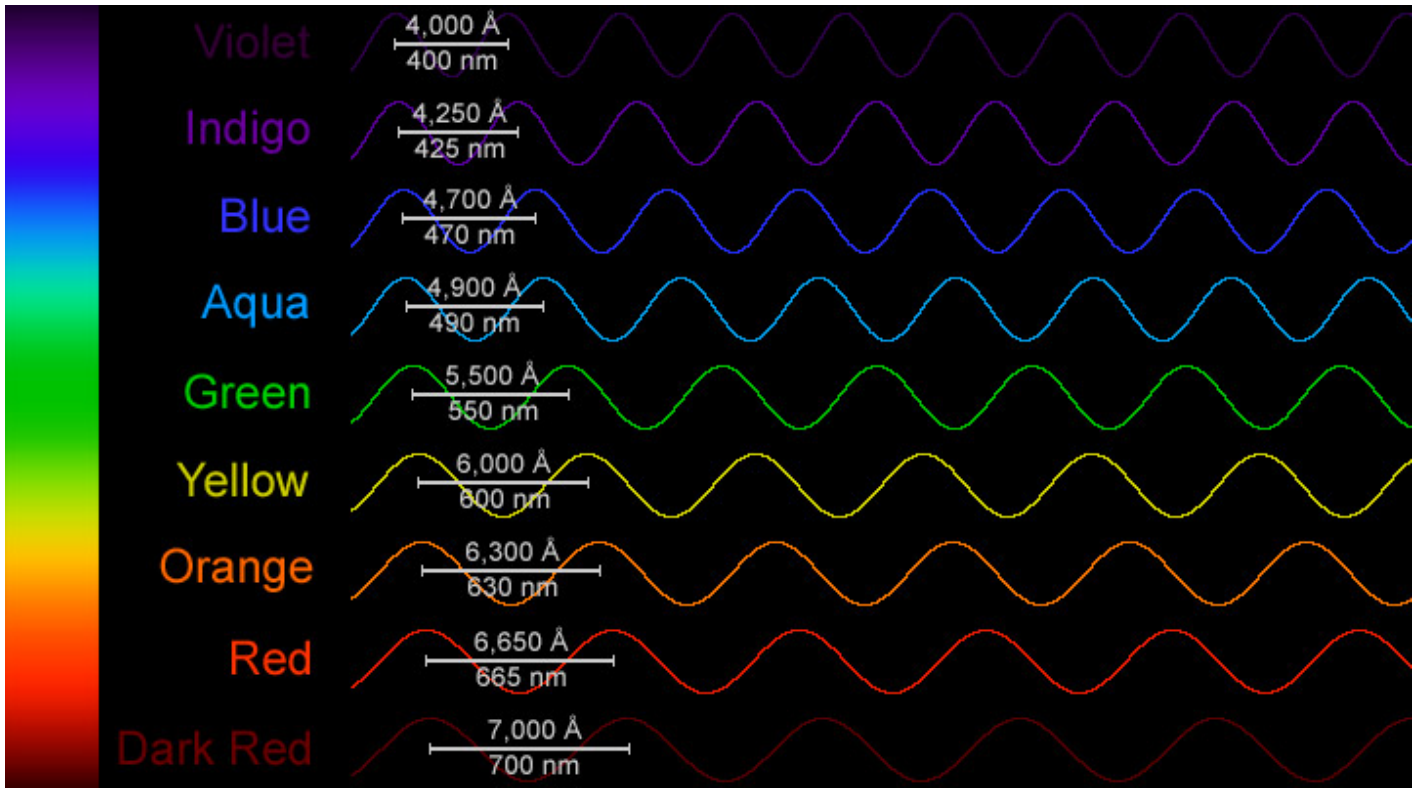
Visible Spectrum

If the electromagnetic spectrum spanned the distance from Los Angeles to New York City, the part visible to the human eye would span the width of a dime.

Visible Light

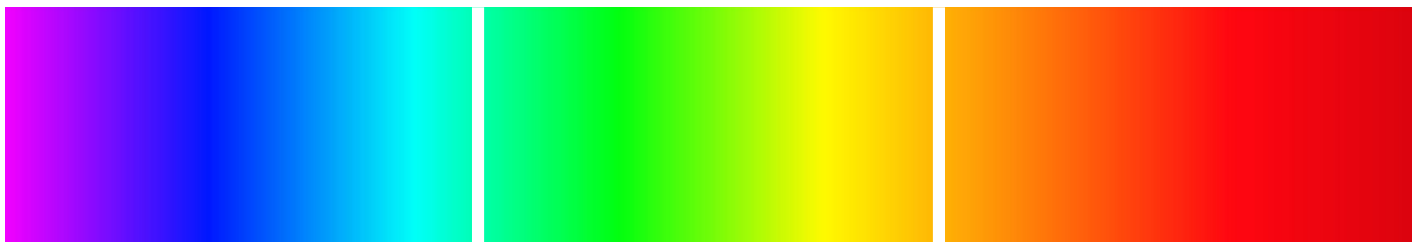
- Our eyes detect wavelengths in a tiny portion of the *EM* spectrum.
- We call this the *visible light spectrum*.
- We perceive short wavelengths as blue.
- We perceive longer wavelengths as red.
- We cannot perceive wavelength beyond the limits of the visible spectrum.
- Shorter wavelengths of ultraviolet light.
- Longer wavelengths of infrarred radiation.

Electromagnetic Spectrum



www.astronomersgroup.org/EMspectrum.html

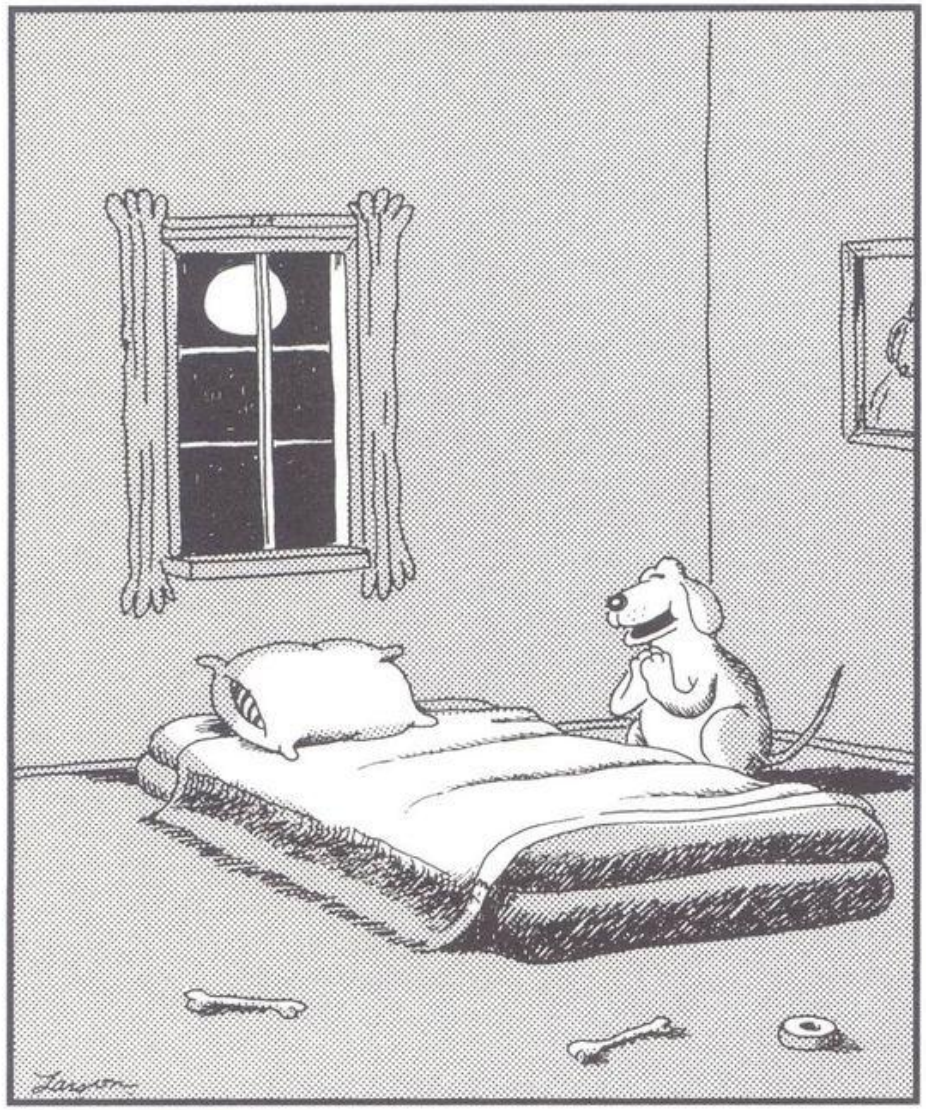
Visible Spectrum



If the visible spectrum is divided into thirds, the predominant colors are blue, green, and red.

Some considerations

- Color is part of how we sense the world around us.
- Light enters the eyes.
- It is processed by light receptors (cones and rods).
- And sent via the optic nerves to the brain for further processing and interpretation.
- Light varies in wavelengths, which our eyes and brain interpret as varying colors.



"…And please let Mom, Dad, Rex, Ginger, Tucker, me, and all the rest of the family see color."

Color Vision Theories

Color Vision Theories

There are two complementary color vision theories that explain how we perceive colors, and how our brain "sees" colors

- **Trichromatic** theory.
- **Opponent** theory.

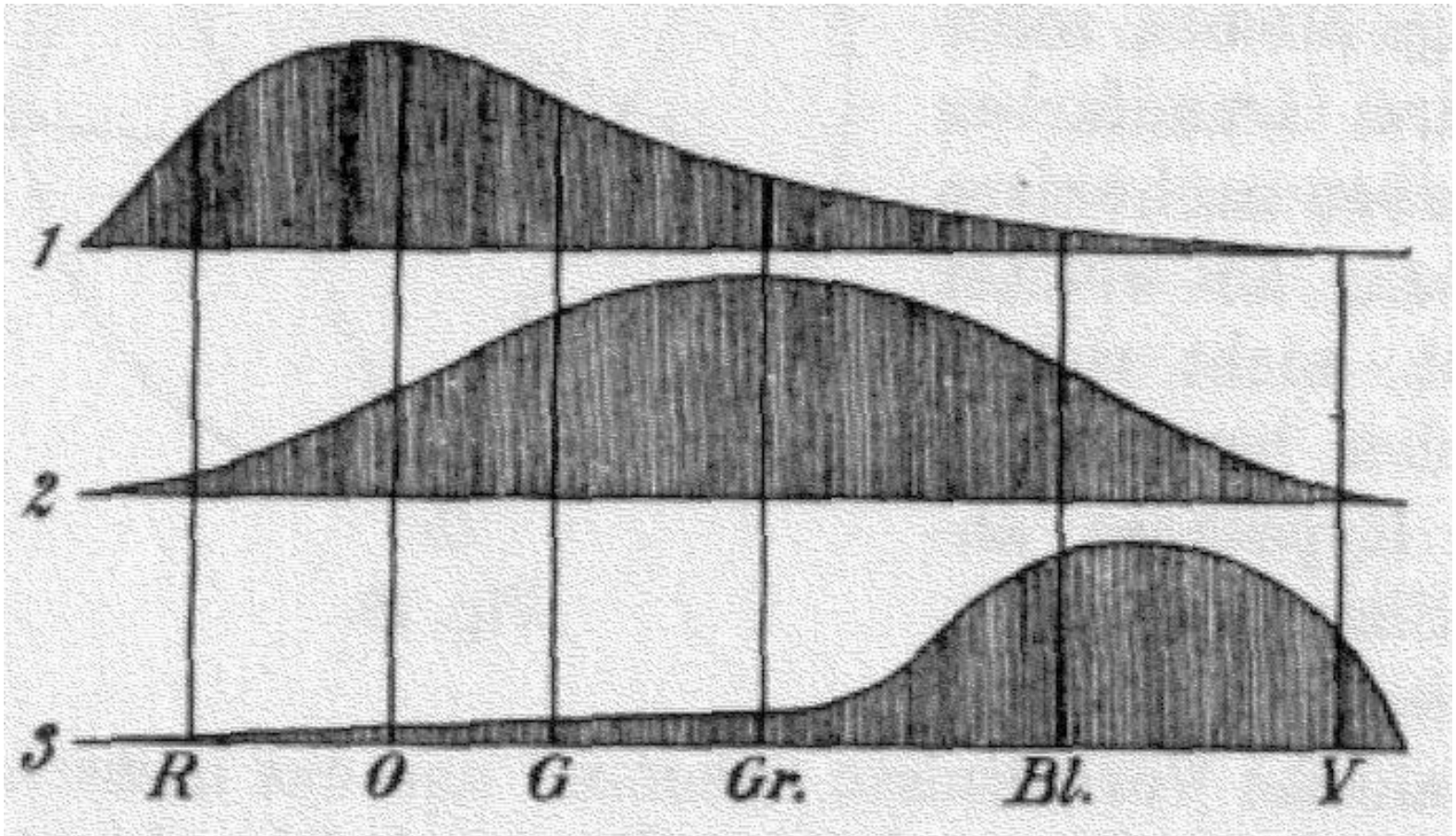
Trichromatic Theory

Trichromatic Theory

Young-Helmholtz Theory

- Originally proposed by Thomas Young in 1802.
- Further expanded by Hermann von Helmholtz.
- Human color vision could be explained by the existence of 3 receptors: Red, Green, and Blue.
- https://en.wikipedia.org/wiki/Young%E2%80%93Helmholtz_theory

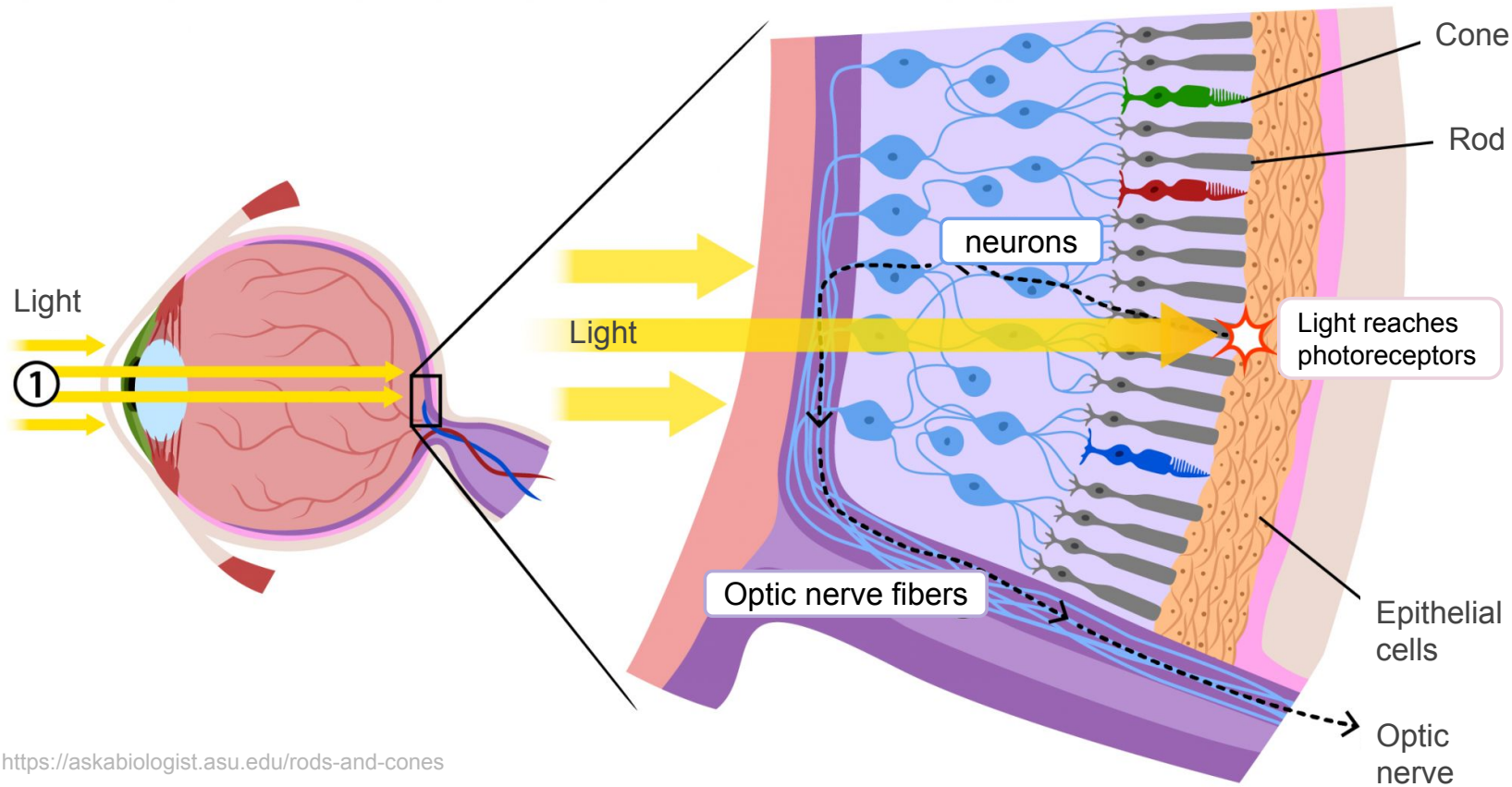
3 kinds of light receptors



Trichromatic Theory

- Young suggested that the eye contained different photoreceptor cells.
- Each cell was sensitive to different wavelengths of light in the visible spectrum.
- Young's original theory was based on Red, Green, and Blue receptors.
- We now know that there are really three kinds of color receptors in the eye.
- As a result the 3 kinds of cones in the eye are called **R**, **G**, and **B**.

Retina Cell Receptors



https://askabiologist.asu.edu/rods-and-cones

Trichromatic Theory

Young-Helmholtz Theory

Helmholtz used color-matching experiments where participants would alter the amounts of three different wavelengths of light to match a test color.

Participants could not match the colors if they used only two wavelengths, but could match any color in the spectrum if they used three (Red, Green, Blue).

Opponent Theory

Opponent Theory

Opponent-Process Theory

- Predates Young-Helmholtz theory. Dates as far back as Leonardo Da Vinci.
- The color pairs red-green and yellow-blue are in opposition.
- No color can simultaneously exhibit both redness and grenness, or blueness and yellowness.

Opponent Theory

Opponent-Process Theory

- Formally developed by Ewald Hering.
- Hering noted color combinations that we never see
  reddish-green or yellowish-blue
- This theory suggests that color perception is controlled by the activity of three opponent systems:
  white and black, blue and yellow, and red and green.
- https://en.wikipedia.org/wiki/Opponent-process_theory

Opponent Theory

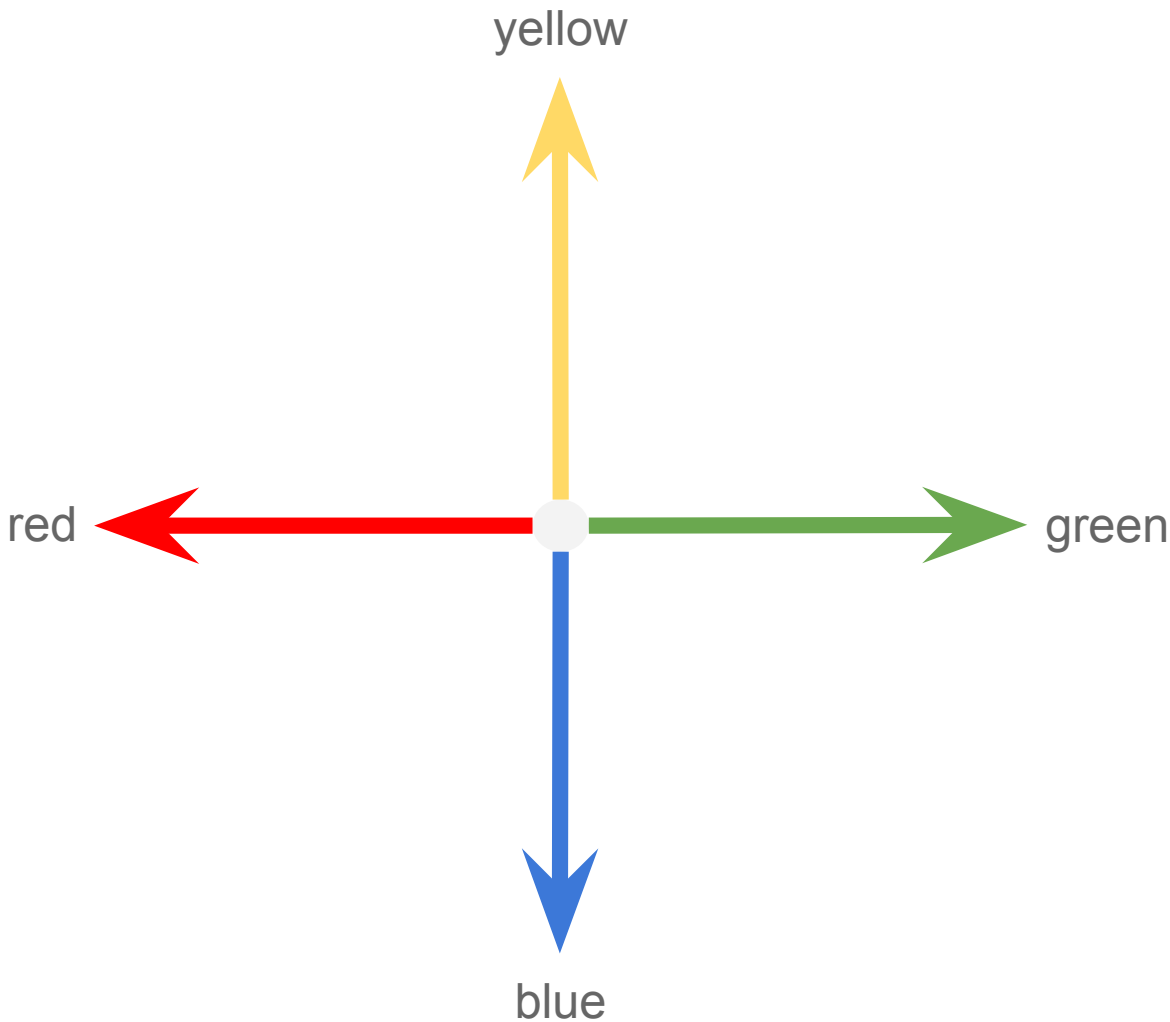
Opponent-Process Theory

Colors are created by the eye and brain as combinations of red-green, and yellow-blue color signals.

R-G and B-Y pairs

Our eyes and brain create four basic colors: yellow, blue, red, and green, arranged in two pairs.

Color Pairs of Opponent Theory



Opponent Theory

A color can be described by three parameters

- Where it lies on a light/dark scale
- Where it lies on a red/green scale
- Where it lies on a blue/yellow scale

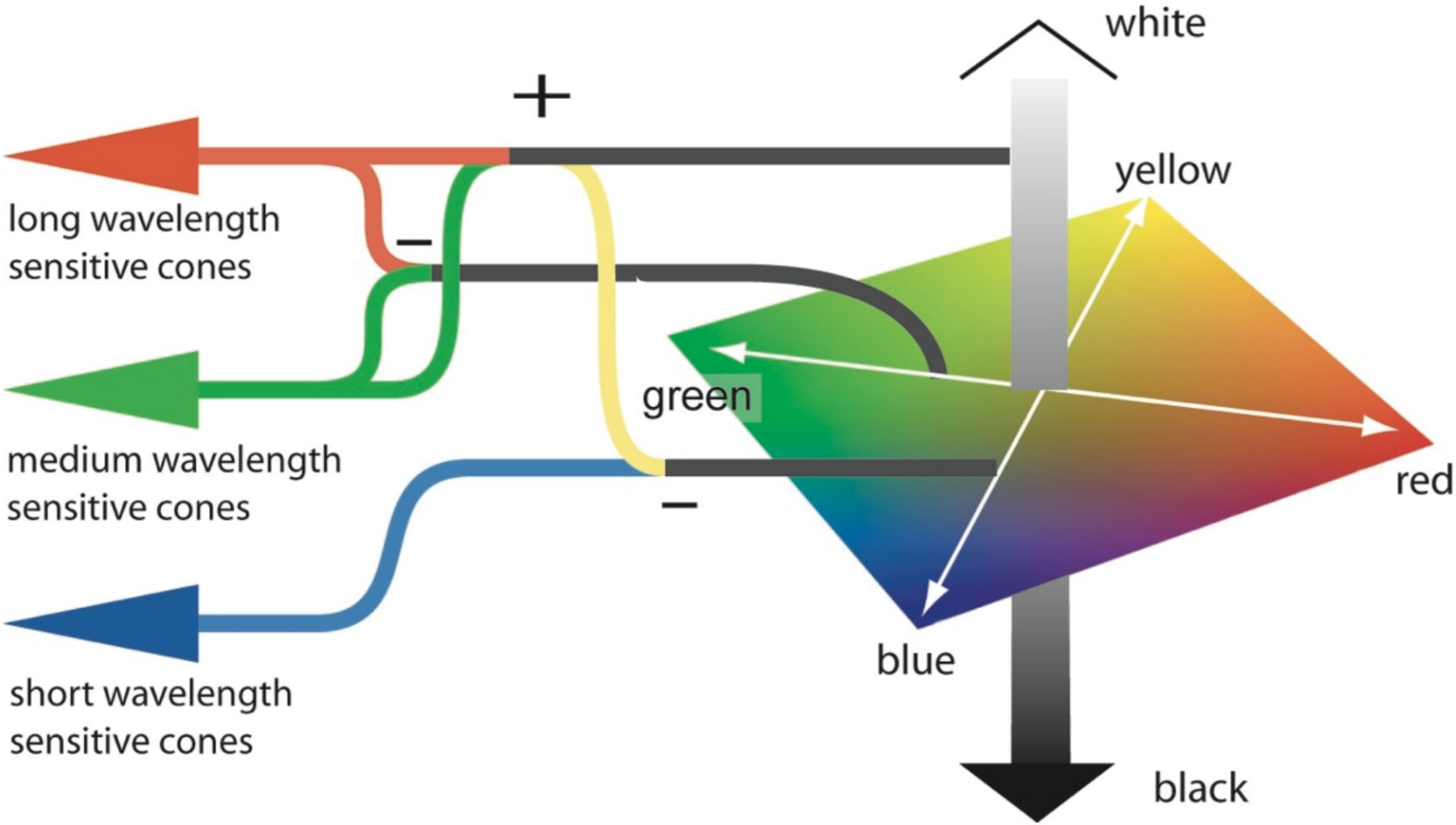
These three dimensions, “green or red,”, “blue or yellow,” and brightness, form the foundation for the way our brain perceives color.

Opponent Theory

Our sensation of color comes from nerve cells that send messages to the brain about:

- The brightness of color.
- Greenness vs. redness.
- Blueness vs. yellowness.
- Color nerves sense green or red, but never both.
- Likewise color nerves sense blue or yellow, but never both.
- We never see bluish-yellows or reddish-greens.

Color Opponency



C. Ware, "Visual Thinking for Design"

Opponent Colors and Television

- Initially, television was only available in black and white.
- Later on, technology became available to make color television.
- Engineers faced the problem of how to transmit the color information but still remain compatible with all the existing black and white sets.
- They chose to add the color information by adding two additional color signals.
- The two signals were the color positions on the opponent red/green and yellow/blue scales.

Evolution of Color Vision

Evolution of Color Vision

- The human color vision system appears to have evolved in steps.
- Initially our (very remote) ancestors had a single class of light sensitive cells.
- At a point predating the evolution of the mammals this single class of cells differentiated into separate yellow and blue classes.
- Much later, in primates, the class of yellow sensitive cells differentiated into separate red and green sensitive classes.

Primitive Color

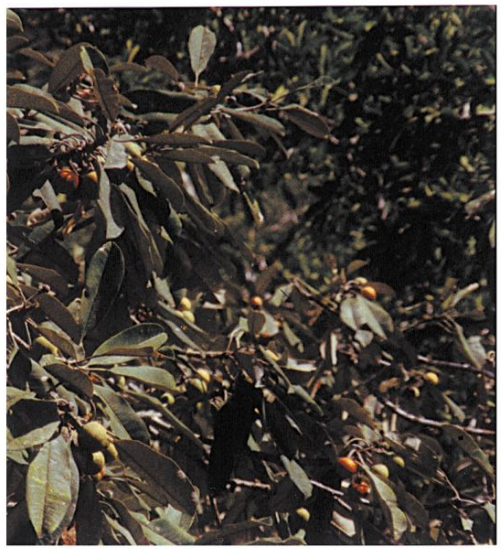
image as it would appear to an animal with just a yellow/blue based vision system

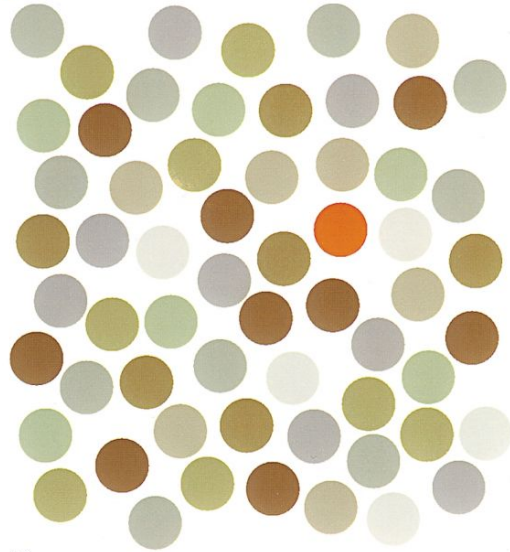
Primate Color

image as it would appear to a primate with a red/green/blue based vision system

Primate Color Vision: Searching for Fruits

Trichromatic vision





Orange circle

Dichromatic (protanope)

Dichromatic (deuteranope)

Fruits and Primate Color Vision

- Natural task facing monkeys foraging for fruit (a).
- Typical stimulus array from laboratory: searching for orange circle (b).
- Photograph as it would appear to a protanope (c).
- Photograph as it would appear to a deuteranope (d).

Regan et al. (2001) Fruits, foliage and the evolution of primate colour vision. The Philos Trans R Soc Lond B Biol Sci. 356, 229-283.

Trichromatic and Opponent Theories

Trichromatic and Opponent Theories

- Both theories are complementary
- The Thrichromatic theory applies in the eyes (physical-sensory)
- The Opponent theory applies in the brain (cognition)

Trichromatic and Opponent Theories

Color vision in three major processes

- **Trichromatic input**: information is recorded by the responses of the L, M and S cone cells in the retina.
- **Opponent output**: responses from the L, M and S cones are converted into signals for yellowness vs blueness and redness vs greenness, plus total brightness.
- **Processing for color constancy**: color information from the visual field is analyzed, interpreting object properties (i.e. hue, value and chroma) and lighting properties (i.e. hue, brightness and saturation of the illumination).

References

- http://www.handprint.com/HP/WCL/color7.html
  by Bruce MacEvoy
- **The Dimensions of Colour** by David Briggs
- **Causes of Color** by WebExhibits

  http://www.webexhibits.org/causesofcolor/1.html
- **How do we perceive color** by ColoRotate

  http://learn.colorotate.org/how-do-we-perceive-color