

8 – human vision and color

Color & Graphics

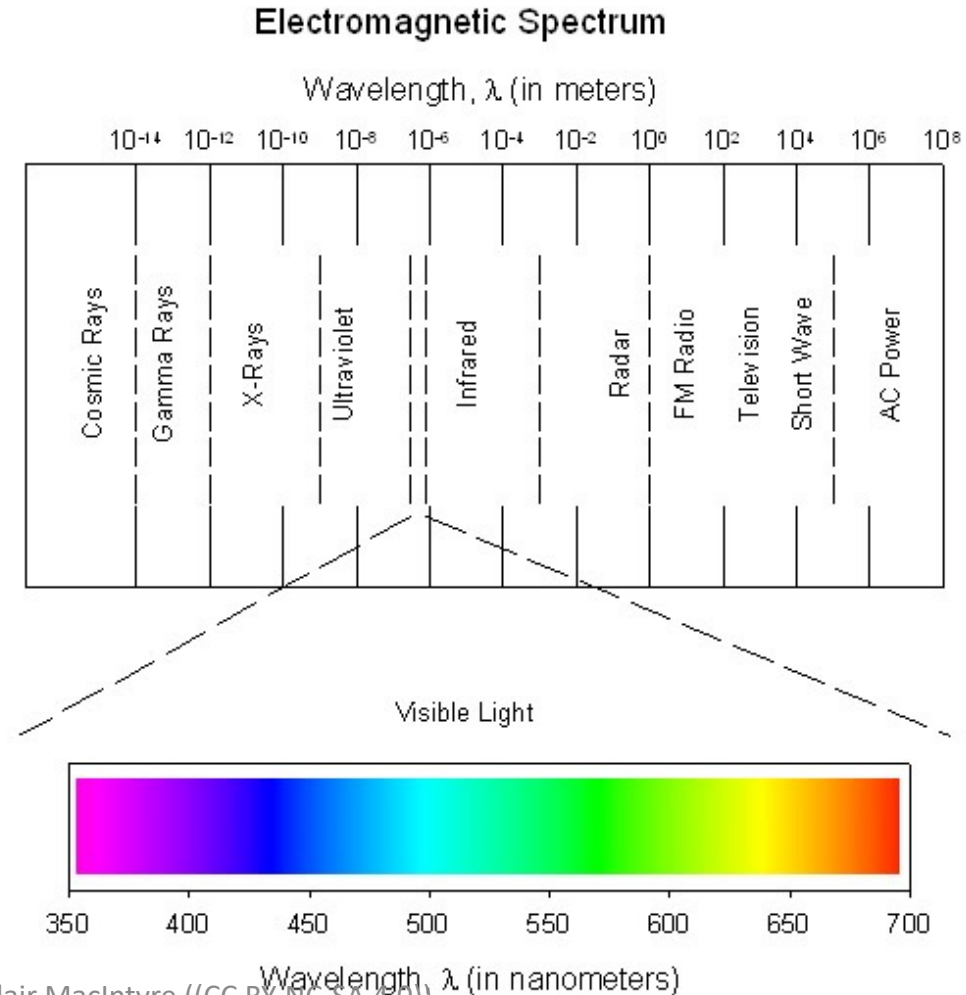
- The complete display system is:
 - Model
 - Frame Buffer
 - Screen
 - Eye
 - Brain

Color & Vision

- We'll talk about:
 - Light
 - Vision
 - Psychophysics, Colorimetry
 - Color
 - Perceptually based models
 - Hardware models

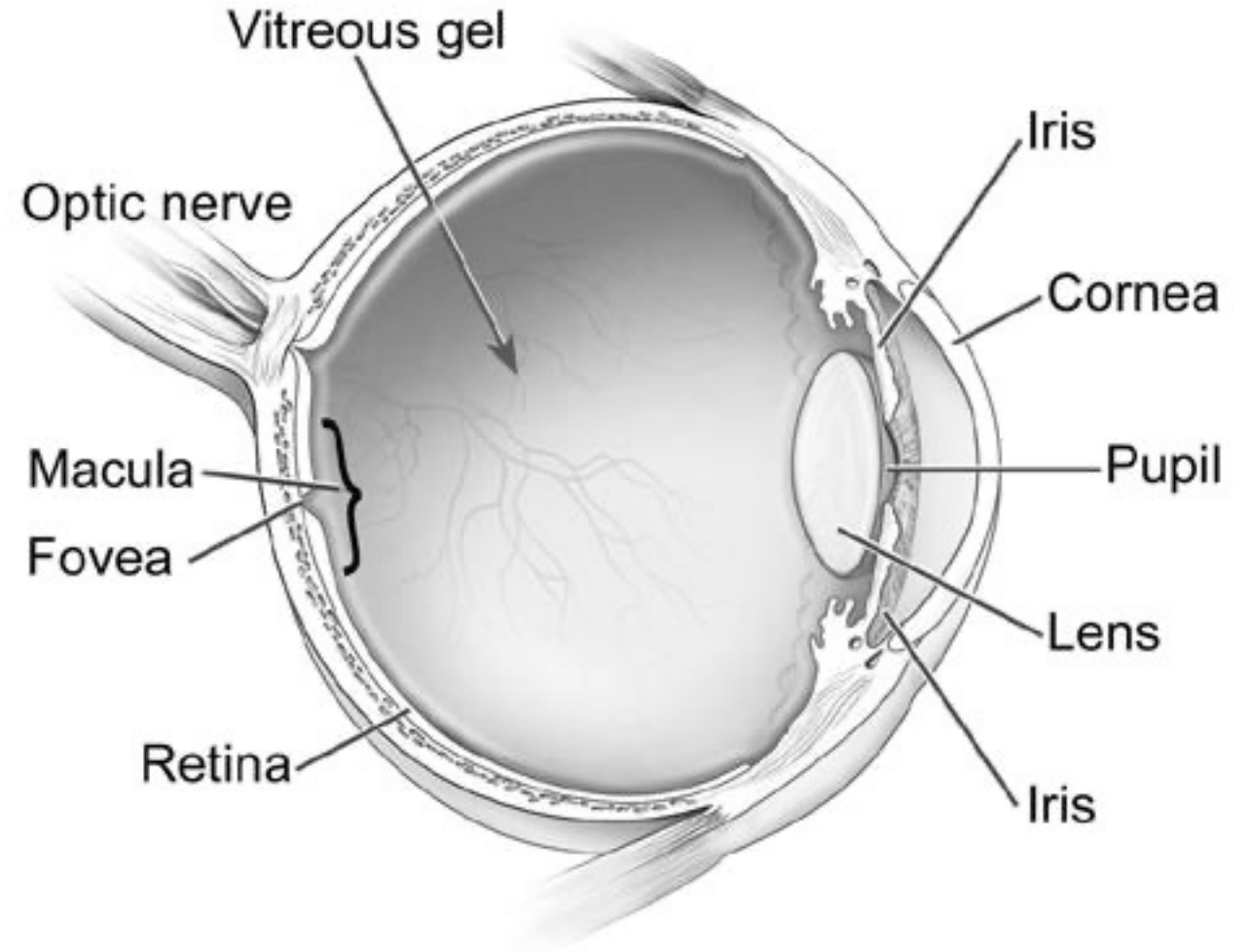
Light

- Vision = perception of electromagnetic energy
- Very small portion of EM spectrum is visible



Vision: The Eye

- A dynamic, biological camera!
 - a lens
 - a focal length
 - an equivalent of film

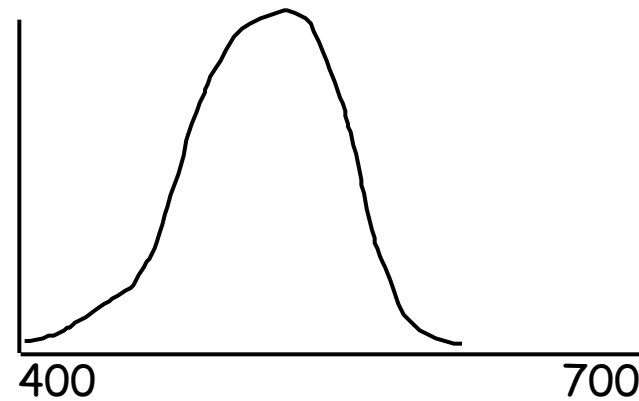


Vision: The Retina

- The eye's "film"
- Covered with cells sensitive to light
 - turn light into electrochemical impulses
- Two types of cells
 - rods
 - cones

Vision: Rods

- Sensitive to most wavelengths (brightness)
- About 120 million in eye
- Most outside of fovea (center of retina)
- Used for low light vision
- Absorption function:



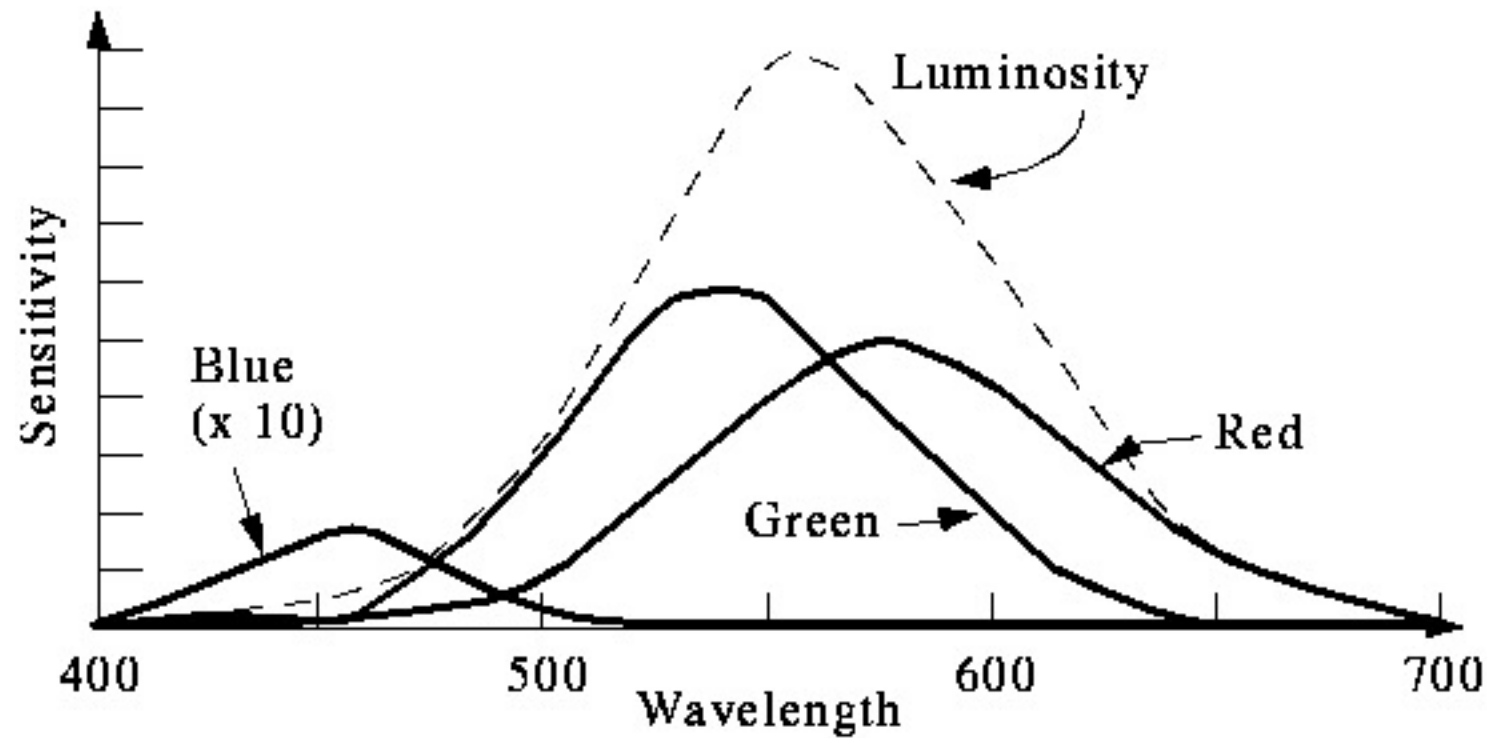
Vision: Cones

- Three kinds
 - R sensitive to long wavelengths (L in book)
 - G to middle (M in book)
 - B to short (S in book)
- About 8 million in eye
- Highly concentrated in fovea
 - B cones more evenly distributed than others
- Used for high detail color vision

- Nothing special about 3; other animals have different numbers
 - Mantis shrimp has 12 or more, but worse discrimination

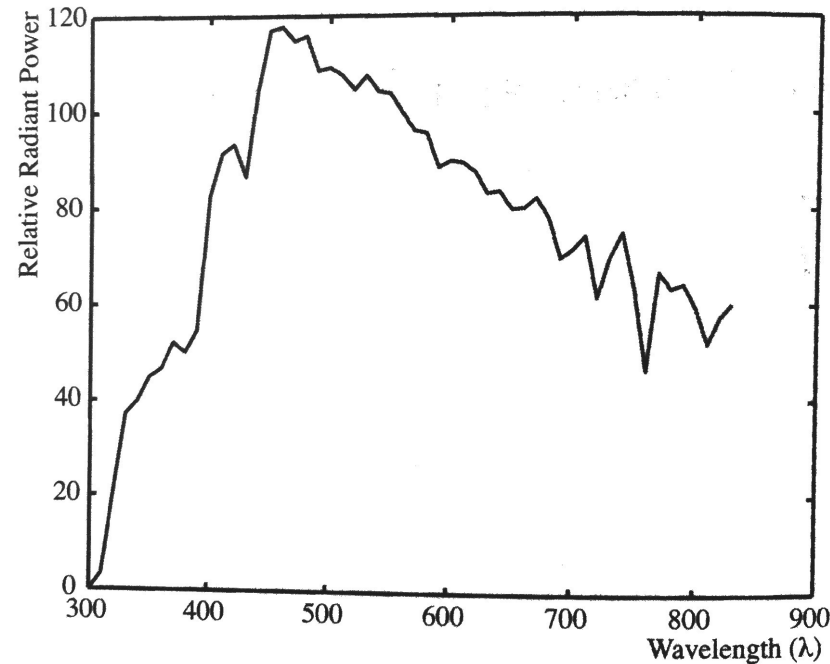
Vision: Cones

- The absorption functions of the cones are:



Psychophysics

- Spectral Energy Distribution
 - measure intensity of light at unit wavelength intervals of electromagnetic spectrum from ~400 nm to ~700 nm



Spectra From Common Sources of Visible Light

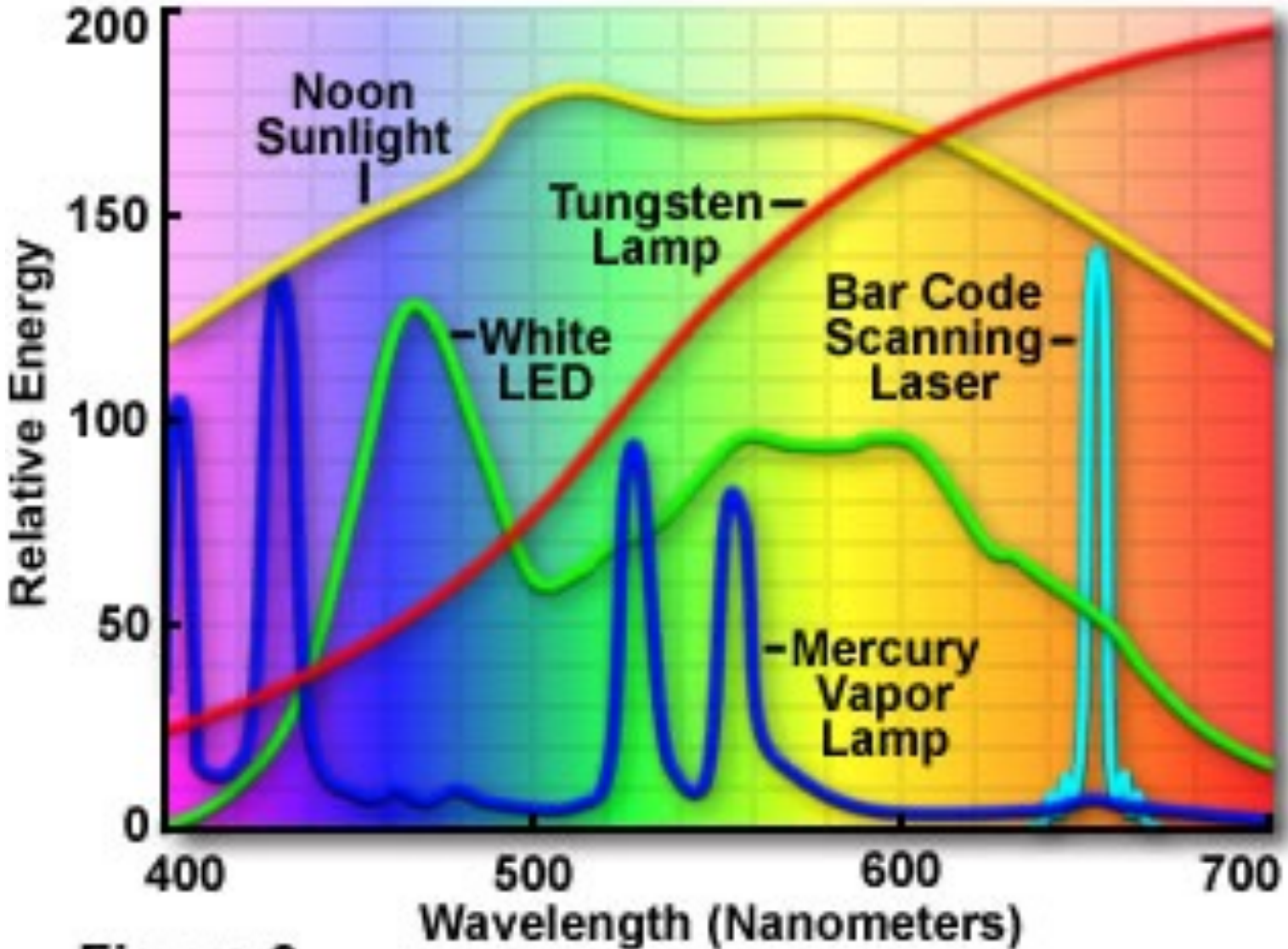


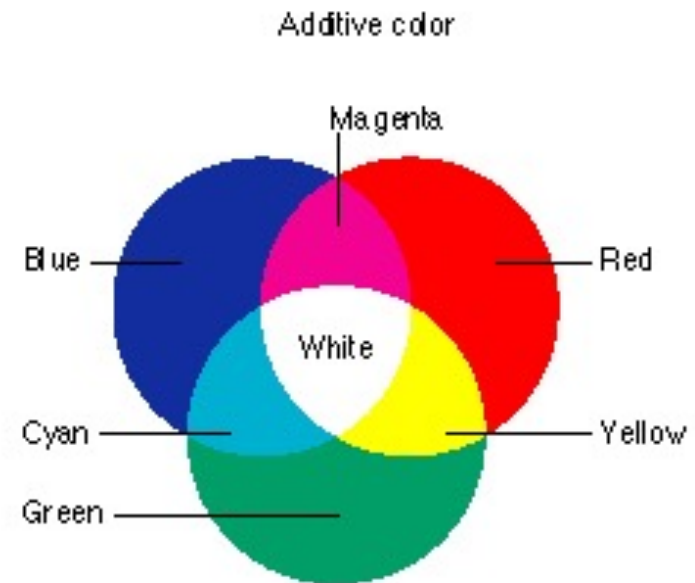
Figure 3

Psychophysics

- Dominant Wavelength \cong hue
- Excitation Purity \cong saturation
- Luminance \cong intensity
 - Lightness: luminance from a reflecting object
 - Brightness: luminance from a light source
- To mix colors
 - mix power distributions!

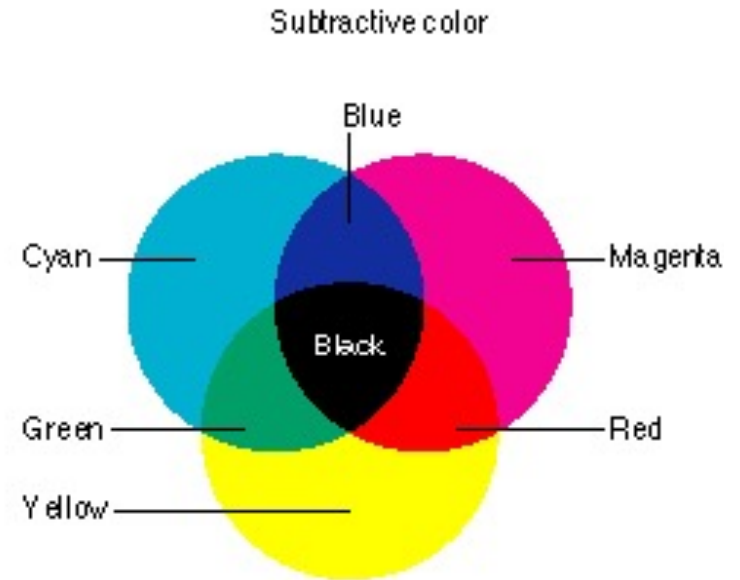
Color Mixing: Additive

- Luminous objects emit s.e.d.
- Linearly add s.e.d.'s
- Primaries: red green blue
- Complements:
cyan magenta yellow
- e.g. Monitors, lights



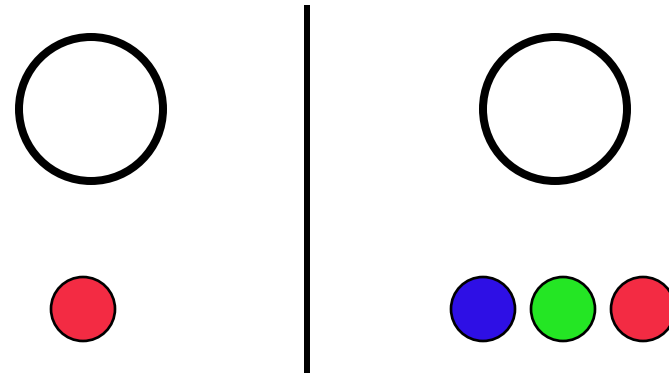
Color Mixing: Subtractive

- Reflective objects absorb (or filter) light
- Can't subtract s.e.d.'s
 - Filters: transmission functions
 - Pigment: suspension, scattering of light
- Primaries: cyan magenta yellow
- Complements: red green blue
- E.g., ink, film, paint, dye



Colorimetry

- Based on matching colors using additive color mixing

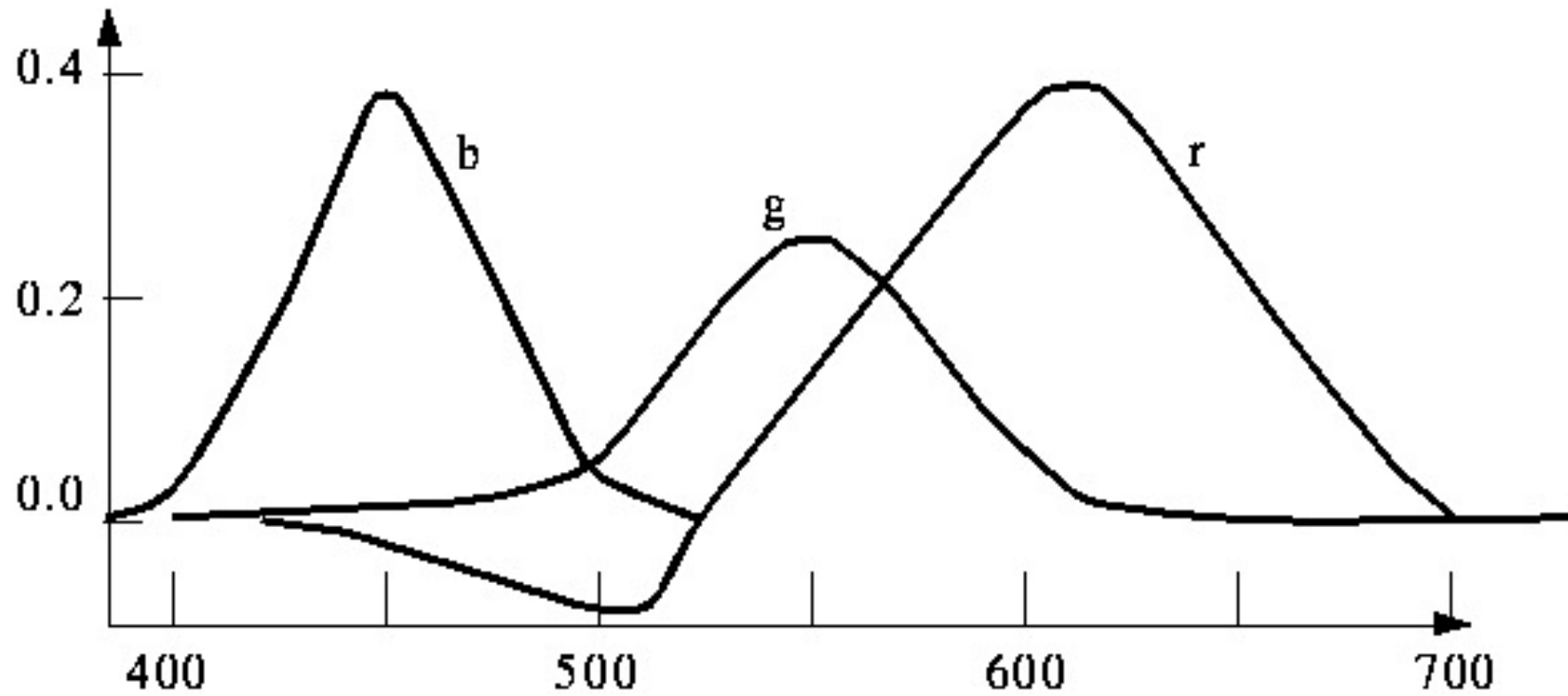


- Tristimulus Values
- Metamers
 - Different s.e.d.'s that appear the same
 - Same tristimulus values

Colorimetric Color Models

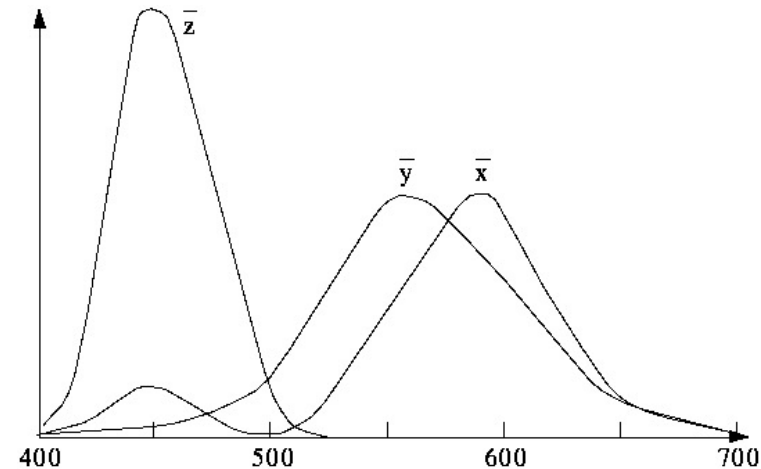
- Generated color match functions
 - match each wavelength, multiple people
 - some colors require negative red!
- CIE produced two device independent models:
 - 1931: Measured on 10 subjects (!) on samples subtending 2 (!) degrees of the field of view
 - 1964: Measured on larger number of subjects subtending 10 degrees of field of view

Color Match Functions



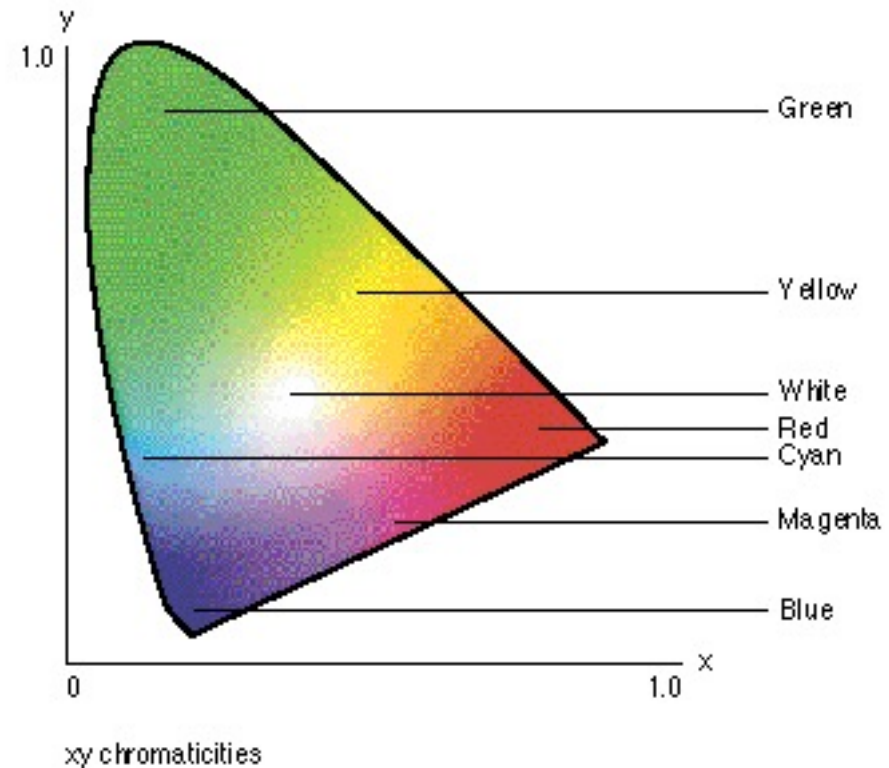
CIE 1931 Imaginary Primaries

- Defines three new primary “colors”
 - X, Y and Z
 - Mixtures positive valued
 - Y’s fcn corresponds to luminance-efficiency function
- To define a color
 - weights x, y, z for the X, Y, Z primaries (e.g. $\text{color} = xX + yY + zZ$)



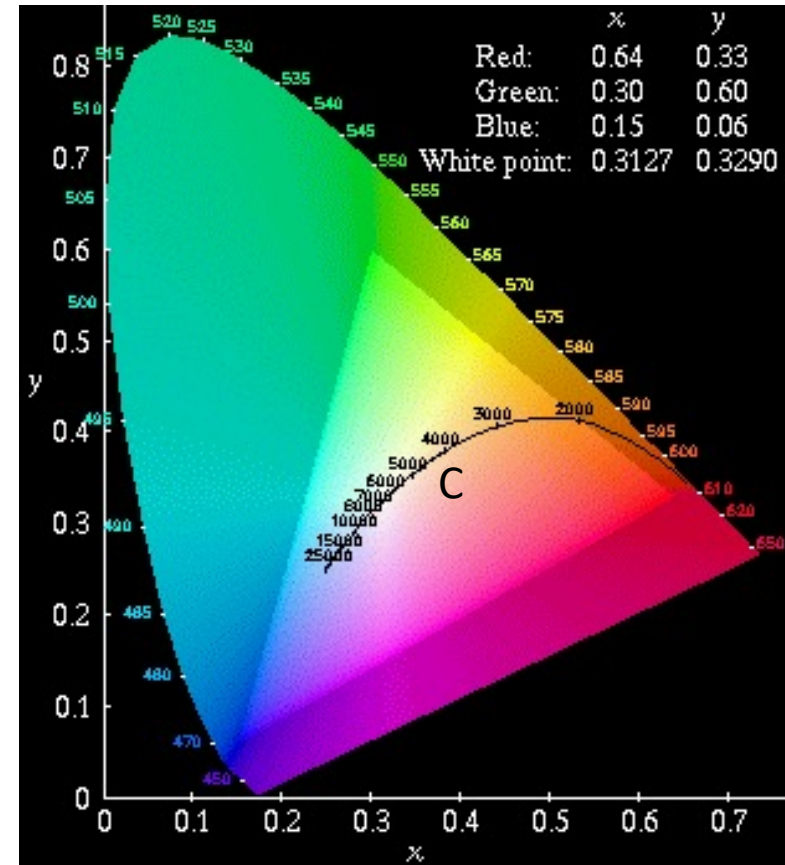
CIE 1931 Chromaticity

- X, Y and Z form a three dimensional color volume
 - Y is luminance, others aren't intuitive
- Factor luminance by normalizing $x+y+z = 1$
- *Chromaticity* values:
 - $x' = x/(x+y+z)$
 - $y' = y/(x+y+z)$
 - $z' = 1 - x' - y'$



CIE 1931 Chromaticity Diagram

- Chromaticity diagram
 - Plot of x' vs. y'
- Additive color mixing
 - linear interpolation
- Color gamuts
 - range of possible colors for a device
 - convex hull of primary colors



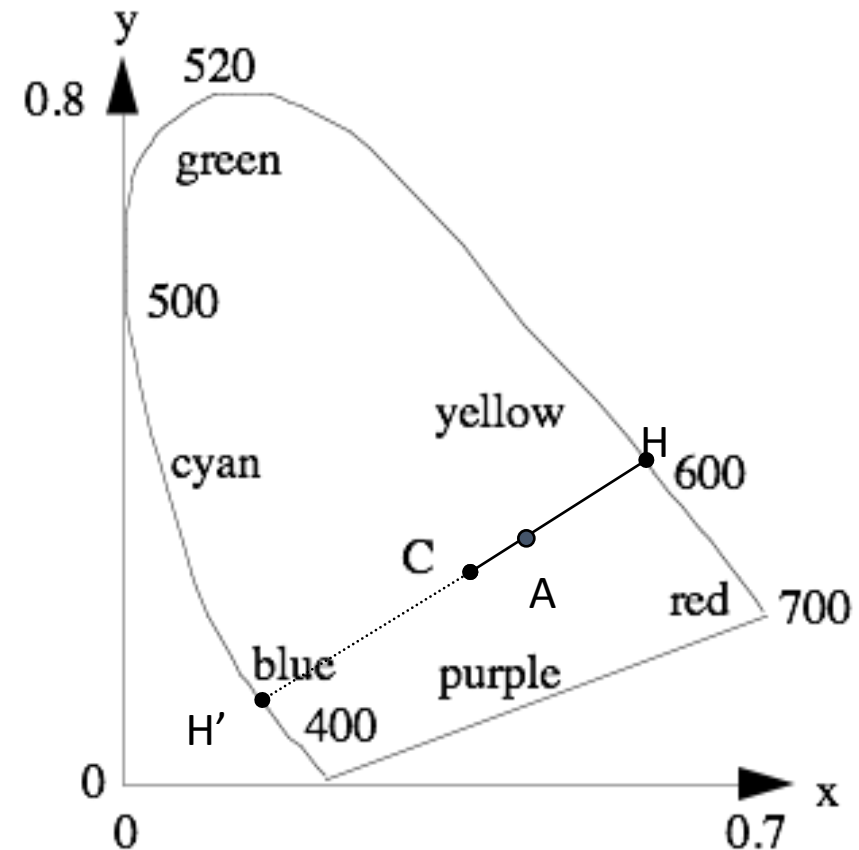
**C = standard illuminant,
approximates sunlight,
near 4K white**

HDTV (ITU-R BT.709) and sRGB

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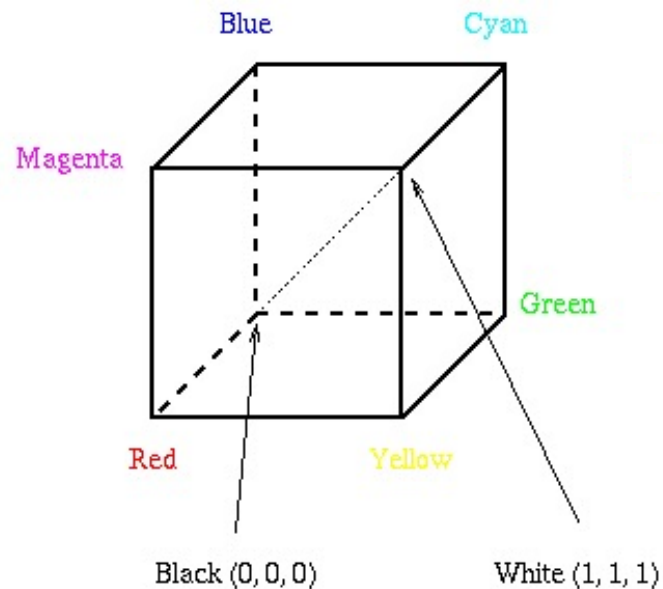
CIE 1931 Chromaticity Diagram

- Dominant Wavelength/Hue:
 - inscribe line from C through color (A) to edge of diagram (H)
- Saturation
 - $\frac{\text{distance C-A}}{\text{distance C-H}}$
- Complements
 - inscribe line through C to the edge of the diagram (H')
- What if edge is bottom?

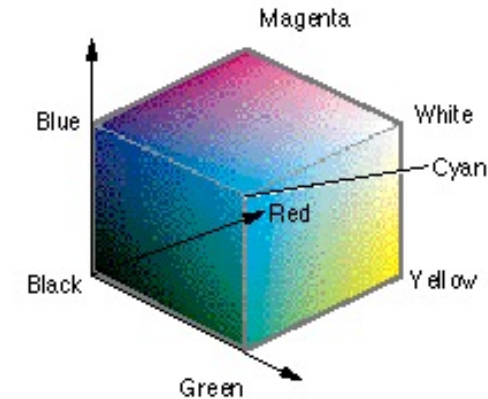


Hardware Models: RGB (Additive Color)

- (red, green, blue)
- Parameters vary between 0 and 1



The RGB Cube

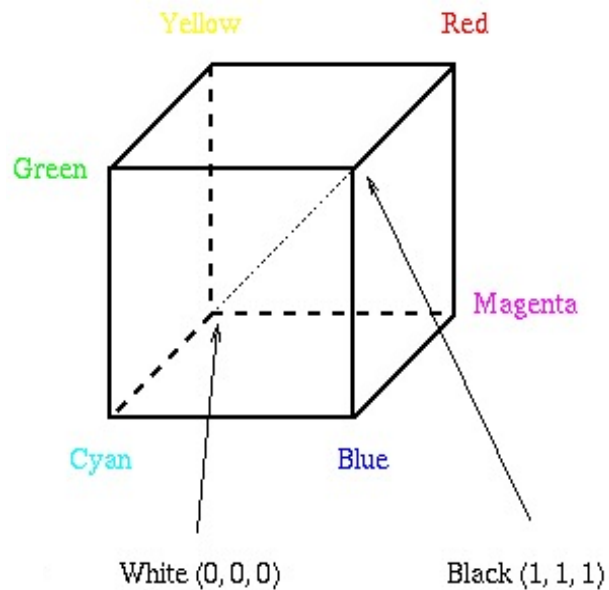


Hard to achieve intuitive effects:

- Hue is defined by the one or two largest parameters
- Saturation controlled by varying the collective minimum value of R, G and B
- Luminance controlled by varying magnitudes while keeping ratios constant

Hardware Models: CMY, CMYK (Subtractive Color)

- (cyan, magenta, yellow, +black)
- All parameters vary between 0 and 1

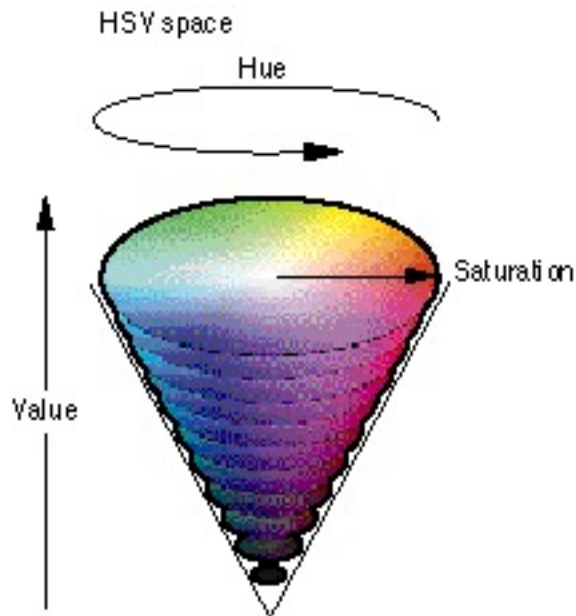


The CMY Cube

- $K = \min(C, M, Y)$
- subtract K from each

Intuitive Hardware Models: HSV

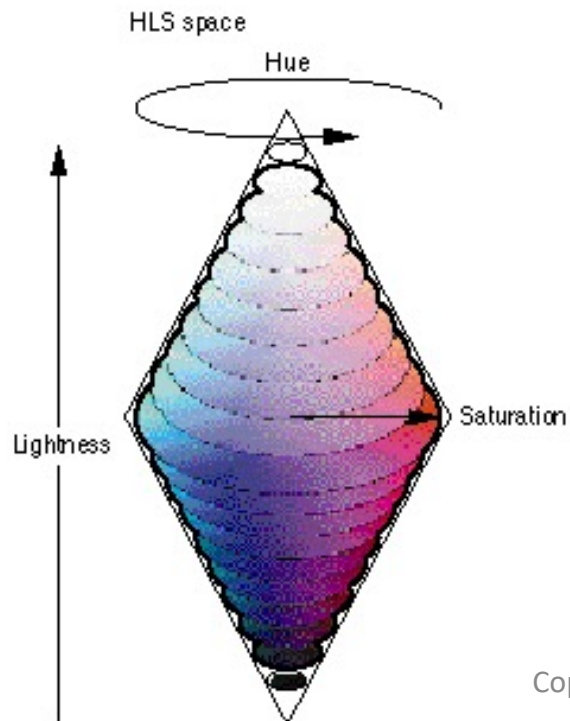
- (hue, saturation, value)
 - value roughly luminance
 - hue: (0...360), saturation/value: (0...1)



- Simple xform of RGB
- What do hexagonal and triangle cross sections look like?

Intuitive Hardware Models: HLS

- (hue, lightness, saturation)
 - lightness roughly luminance
 - hue: (0...360), saturation/value: (0...1)



- saturated colors at $l=0.5$
- *tints* above, *shades* below
- What do hexagonal and triangle cross sections look like?

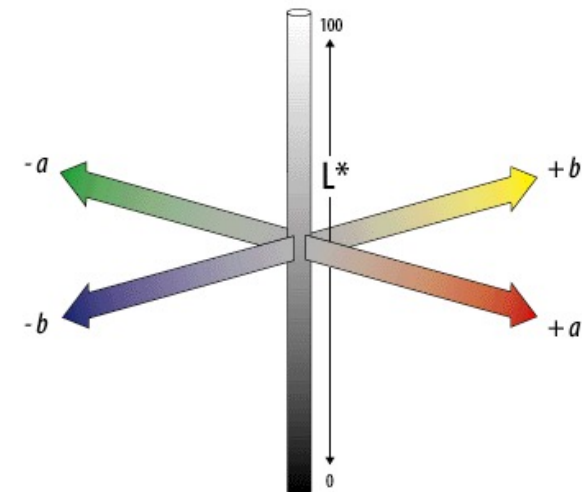
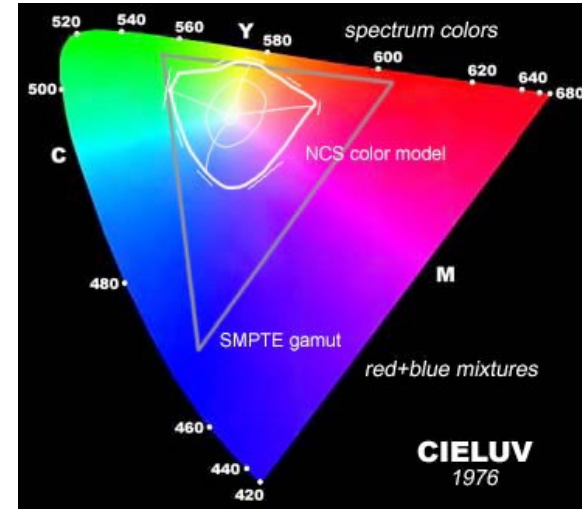
Problem: $V/L \neq$ Luminance

- Fully saturated colors (same v/l) have far different Y values in XYZ (Sun 17" monitor, 1991):

<u>Colour</u>	<u>RGB</u>	<u>XYZ</u>	<u>Chromaticity</u>
White	1 1 1	0.951 1.000 1.088	0.313 0.329
Red	1 0 0	0.589 0.290 0.000	0.670 0.330
Green	0 1 0	0.179 0.605 0.068	0.210 0.710
Blue	0 0 1	0.183 0.105 1.020	0.140 0.080
Cyan	0 1 1	0.362 0.710 1.088	0.168 0.329
Magenta	1 0 1	0.772 0.395 1.020	0.363 0.181
Yellow	1 1 0	0.768 0.895 0.068	0.444 0.517

Problem: None of these models are perceptually uniform

- Perceived distance between two colors not proportional to linear distance
- Uniform Color Spaces
 - Non-linear deformations
 - OSA Uniform Color Space (limited range)
 - CIELUV
 - CIELAB



Issue: Device-independent color

- Must use CIEXYZ
 - ie. Apple Colorsync
- RGB = (0.3,0.2,0.55) tells you what computer generates, not what the monitor will display!
 - Depends on phosphors, room lighting, monitor adjustment
- Moving between devices (and media)
 - Go through XYZ
 - Must know properties of devices