

Color Theory

- ▶ What is color?
- ▶ How do we perceive it?
- ▶ How do we describe and match colors?
- ▶ Color spaces

What is color?

- ▶ Interaction of light and eye-brain system
- ▶ Light: electromagnetic phenomenon
 - Discerned by different wavelength

Color Spectra

Pure colors - single wavelength

Color Spectra

Sample lights:

How do we perceive them?

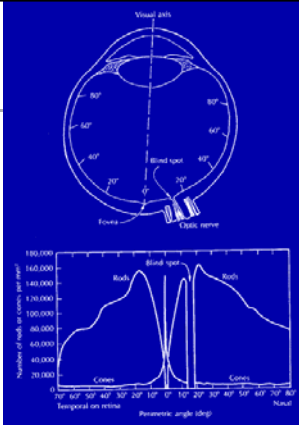
Human Visual System

Rods

- black & white receptors
- peripheral vision
- sensitive

Cones

- 3 type tuned to different frequencies
- 3 cones have different sensitivities
- central vision
- less sensitive



The diagram shows the visual path from the eye to the brain, with labels for the visual path, blind spot, optic nerve, and fovea. The graph below shows the number of rods and cones per square millimeter of the retina as a function of the retinal angle. Rods are most numerous in the peripheral vision (around 20 degrees), while cones are most numerous in the central vision (around 0 degrees).

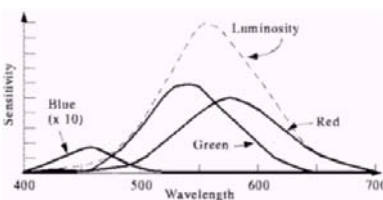
Tristimulus Theory of Color

Important principle:
Any color spectra is perceived by sensors with 3 different response frequencies!

Tristimulus theory of color:
Color is inherently a three-dimensional space

Metamers:
If two colors produce the same tristimulus values, then they are visually indistinguishable

Spectral Response of Human Visual System

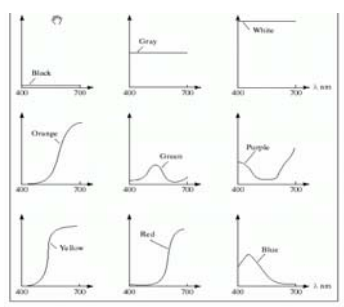


The graph plots Sensitivity (y-axis) against Wavelength in nanometers (x-axis, 400 to 700 nm). It shows three curves: Blue (x 10), Green, and Red. The Blue curve peaks at approximately 440 nm, the Green curve at 500 nm, and the Red curve at 610 nm. A dashed line represents the Luminosity curve, which is the sum of the three cone responses, peaking at approximately 555 nm.

Color Spectra

Sample lights:

How to describe them numerically?



The grid shows nine graphs, each representing a different color: Black, Gray, White, Orange, Green, Purple, Yellow, Red, and Blue. Each graph plots the spectral power distribution (SPD) of the light source across the visible spectrum (400-700 nm).

Color Spectra

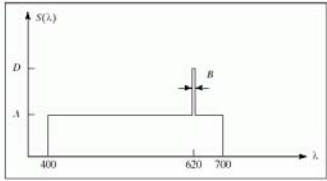
Important principle:

Any color spectra is perceived as:

- a single dominant wavelength - its hue
- mixed with a certain amount of white light (saturation)
- of a certain intensity or brightness

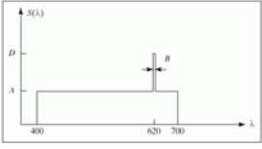
Dominant Wavelength

- ▶ Stating the numbers
 - Dominant wavelength (hue)
 - Luminance (total power)
 - Saturation (purity)



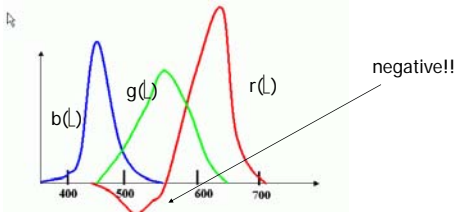
Luminance and Saturation

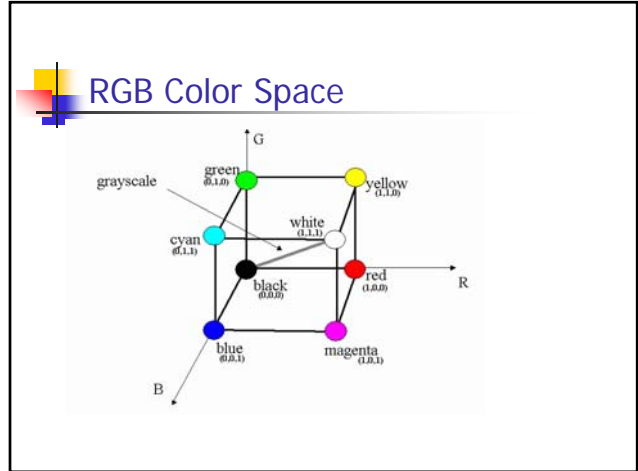
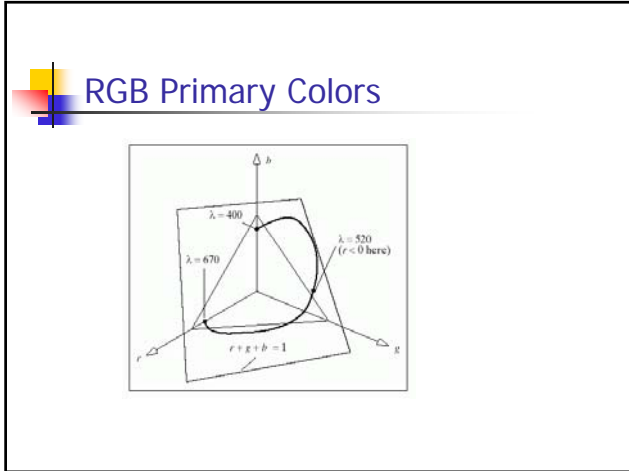
- ▶ Luminance (L) = (D-A)B + AW
- ▶ Saturation = (D-A)B/L * 100%
 - White light: D = A, i.e., Sat. = 0



RGB color description

- ▶ Use three primary color (r,g,b)
 - $C(L) = r(L)R + g(L)G + b(L)B$





- ### CMY Color Model
- ▶ C: Cyan; M: Magenta; Y: Yellow
 - ▶ Subtractive primaries - Cyan, Magenta, and Yellow are the complement of Red, Green Blue
 - ▶ Specified by what is being removed from white
 - ▶ Example: Cyan color = (1,0,0) means red is removed; CMY: (1,1,0) -> red and green is removed => what color?
 - ▶ Sometimes CMYK - K: Black

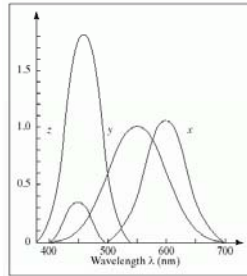
CMY <-> RGB

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

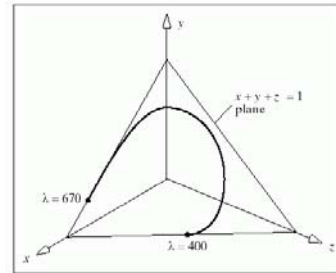
CIE Primary "Colors"

- ▶ (X,Y,Z) - Not real colors
- ▶ The combination coefficients are positive
- ▶ Perceptual space

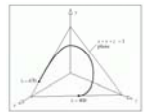
$$C(\lambda) = x(\lambda)X + y(\lambda)Y + z(\lambda)Z$$



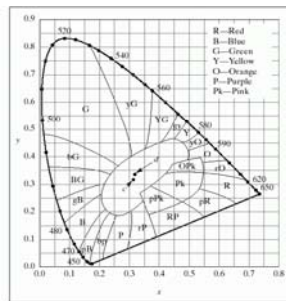
CIE Primary Colors



CIE Chromaticity Chart

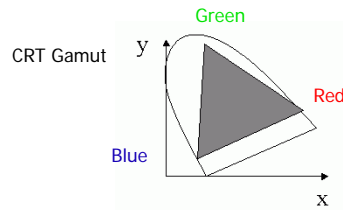


Project to xy plane



CIE Gamut

- The range of colors that can be produced on a device

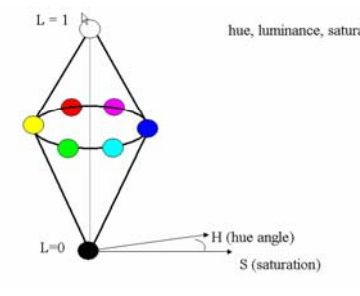


Color Spaces

- ▶ CIE model is a good color reference
- ▶ Not necessarily the most natural one
- ▶ Many other color spaces are used
 - RGB
 - HLS
 - CMY
 - HSV
 - YIQ
 - ...

HLS Color Space

hue, luminance, saturation



HLS Color Space (2)

