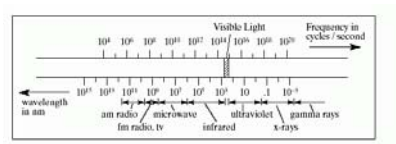
Color Theory

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

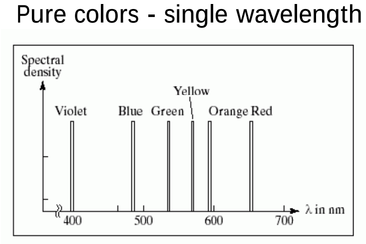
What is color?

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



Color Spectra

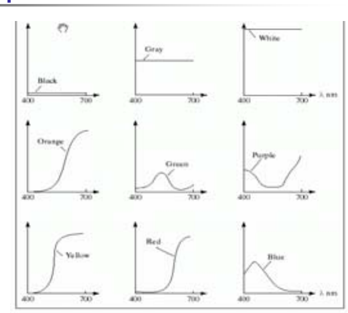
Pure colors - single wavelength



Color Spectra

Sample lights:

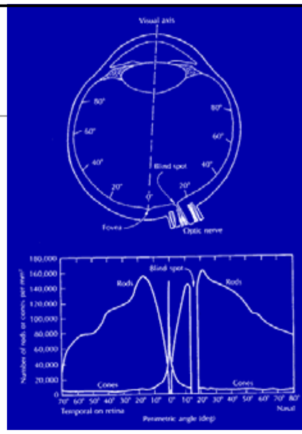
How do we perceive them?



Human Visual System

<u>Rods</u>
- black & white receptors
- peripheral vision
- sensitive

<u>Cones</u>
- 3 type tuned to different frequencies
- 3 cones have different sensitivities
- central vision
- less sensitive



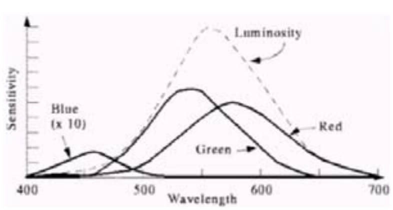
Tristimulus Theory of Color

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

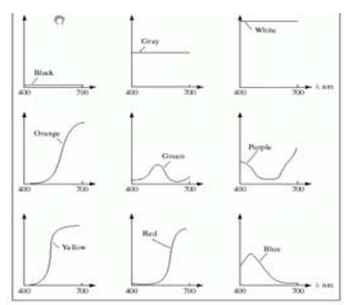
Spectral Response of Human Visual System



Color Spectra

Sample lights:

How to describe them numerically?



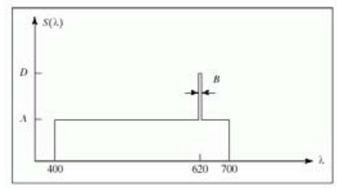
Color Spectra

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

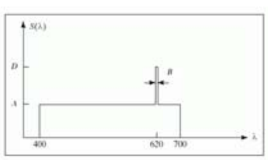
Dominant Wavelength

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



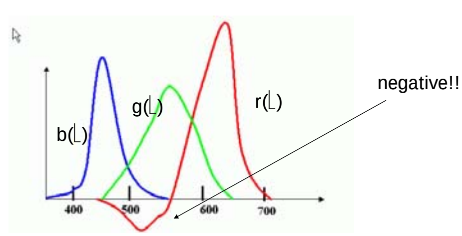
Luminance and Saturation

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

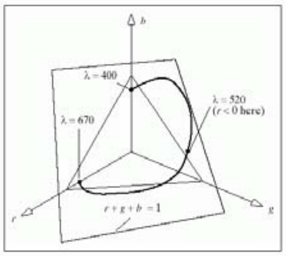


RGB color description

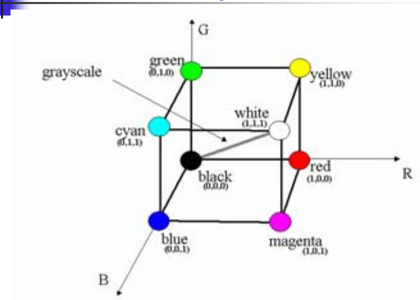
- Use three primary color (r,g,b)
  - C(L) = r(L)R + g(L)G + b(L)B



RGB Primary Colors



RGB Color Space



CMY Color Model

- C: Cyan; M: Magenta; Y: Yellow
- Subtractive primaries - Cyan, Magenta, and Yellow are the compliment 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

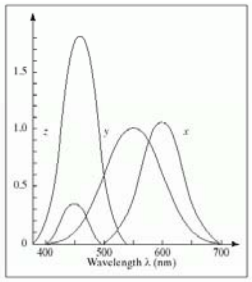
CMY <-> RGB

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

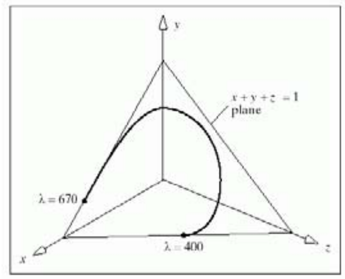
CIE Primary "Colors"

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

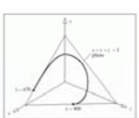
$C(\lambda) = x(\lambda)X + y(\lambda)Y + z(\lambda)Z$



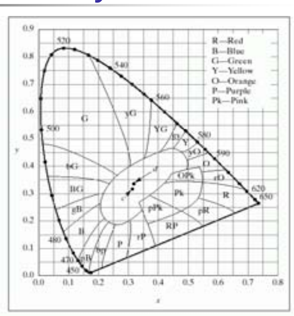
CIE Primary Colors



CIE Chromaticity Chart



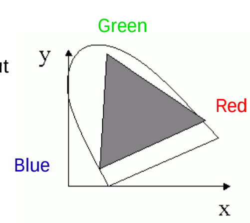
Project to xy plane



CIE Gamut

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

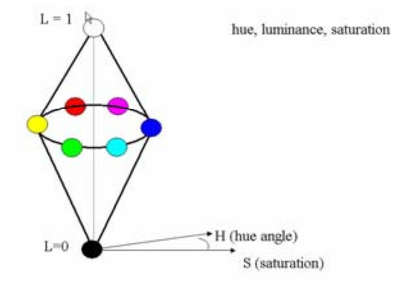
CRT Gamut



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



HLS Color Space (2)