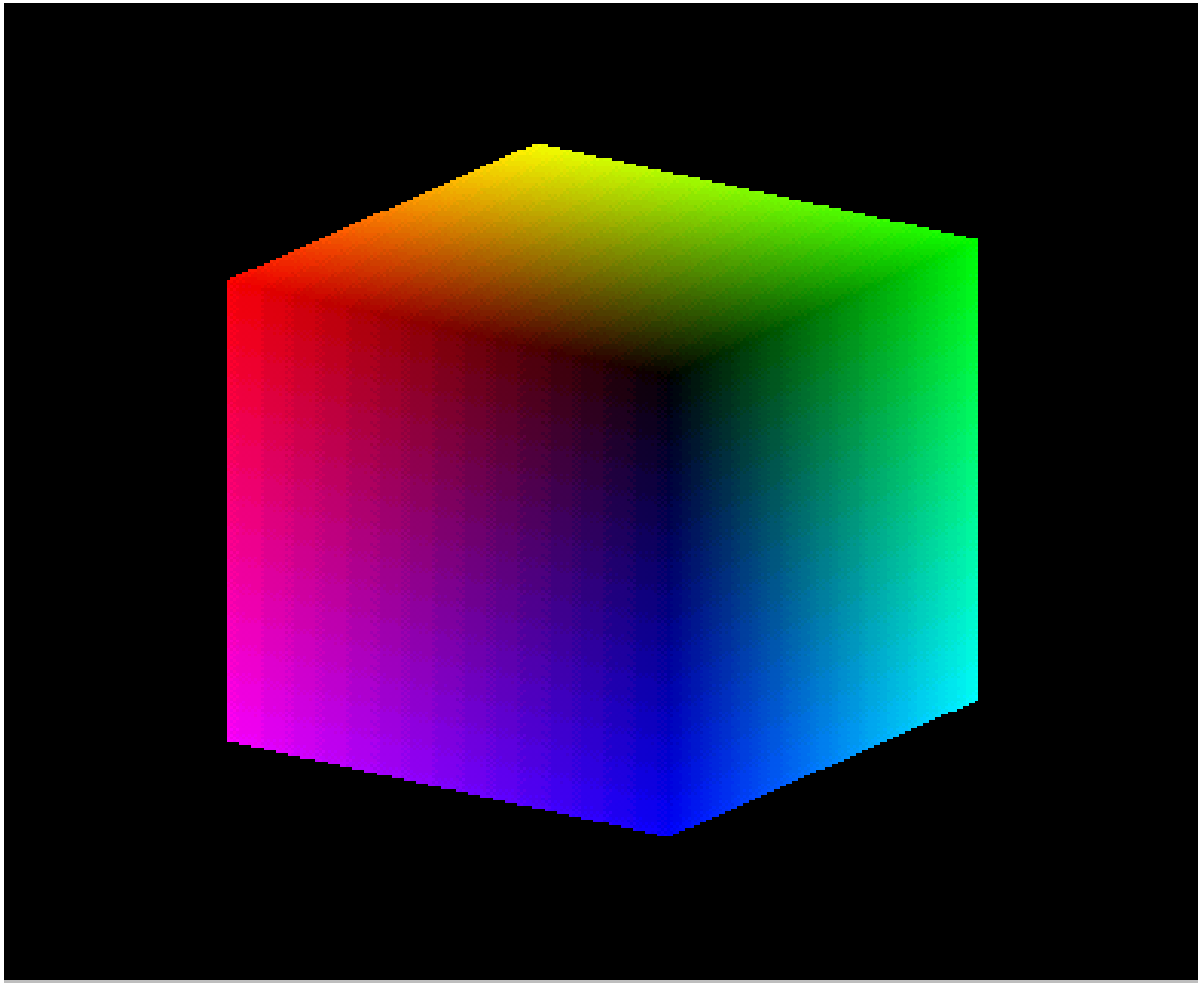
Color Representation

Foley & Van Dam, Chapter 13

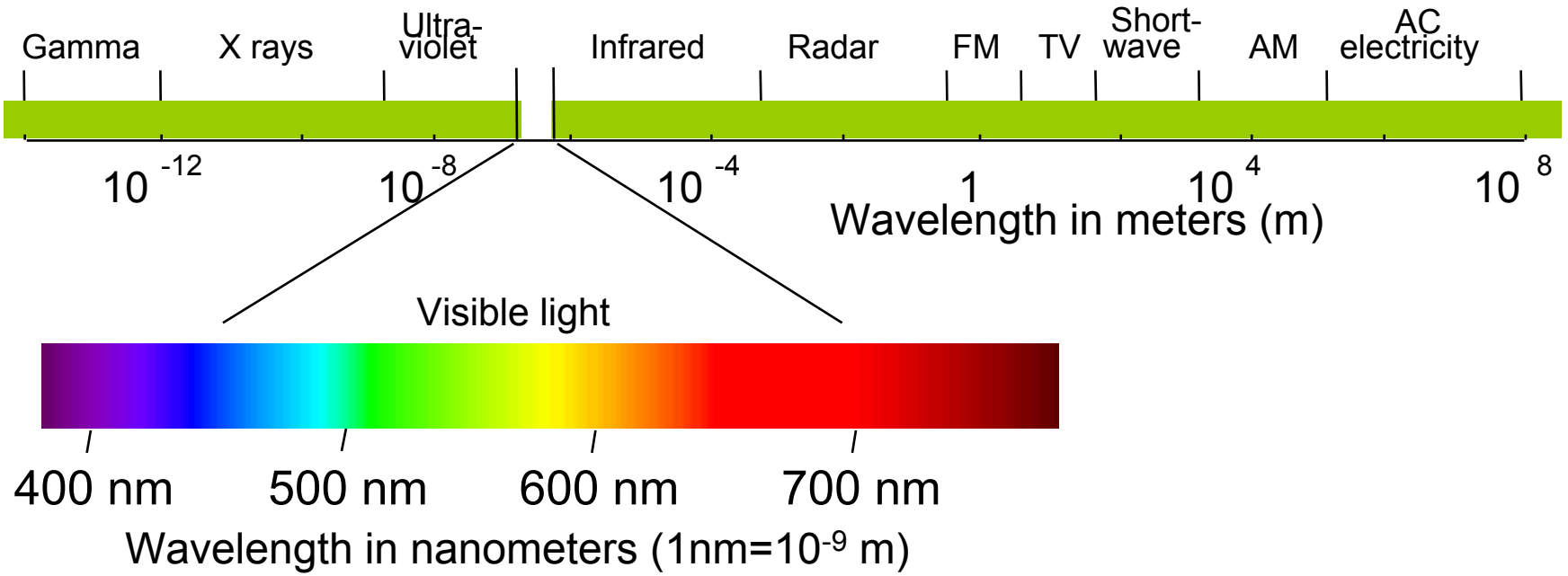


Color Representation

- Visible Light Spectrum
- Color Matching
- Trichromatic Color Theory
- Psychophysics
- CIE standard
- RGB and CMYK Color Spaces
- HLS Color Model
- YIQ Color Model

Visible Light Spectrum and Colors

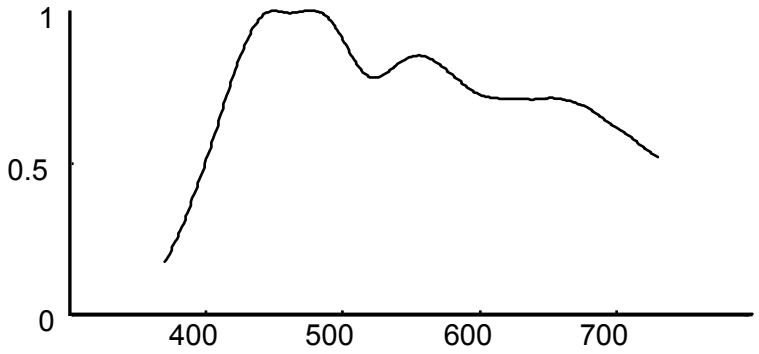
Light is an electro-magnetic radiation



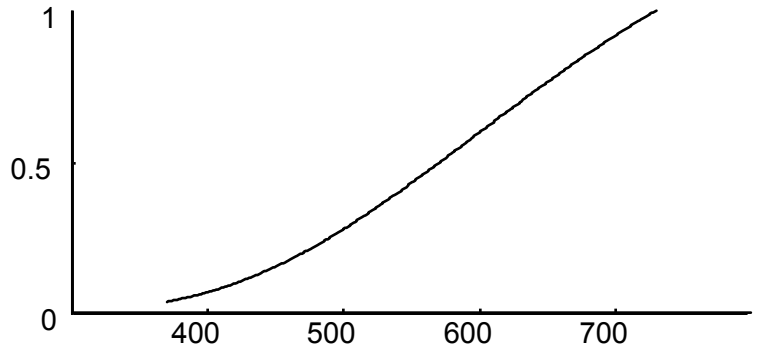
- **Hue**: distinguished among colors
- **Saturation**: how far is color from a gray of equal intensity
- **Lightness**: perceived intensity of a reflective surface
- **Brightness**: perceived intensity of emitting surface

Spectral Power Distribution

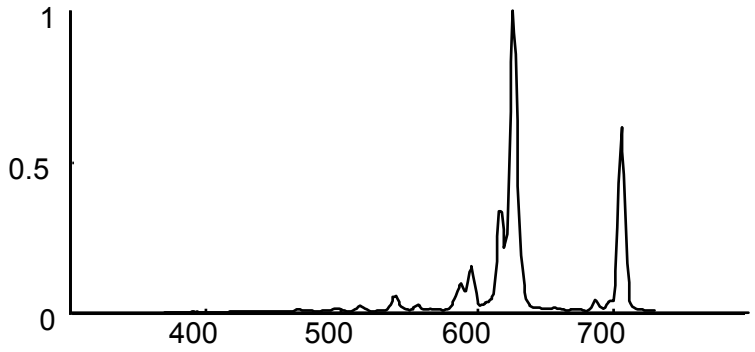
- The **Spectral Power Distribution** of a light is a function $f(\lambda)$ defining the energy at each wavelength



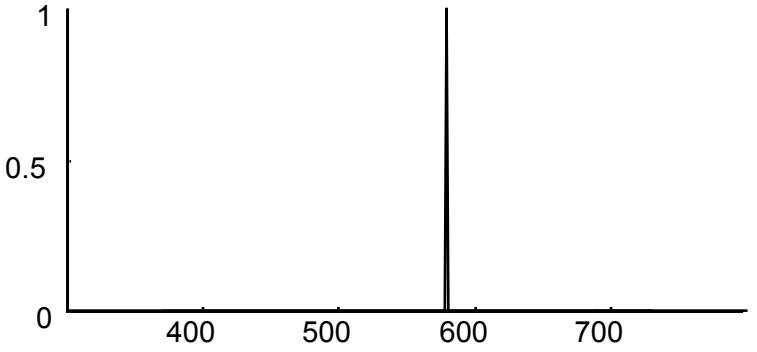
Blue Skylight



Tungsten bulb



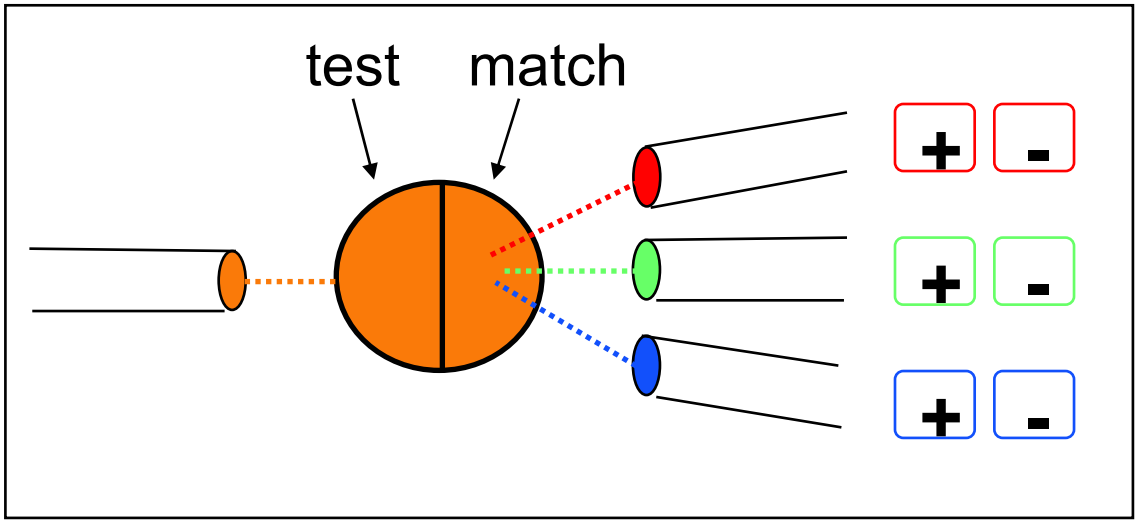
Red monitor phosphor

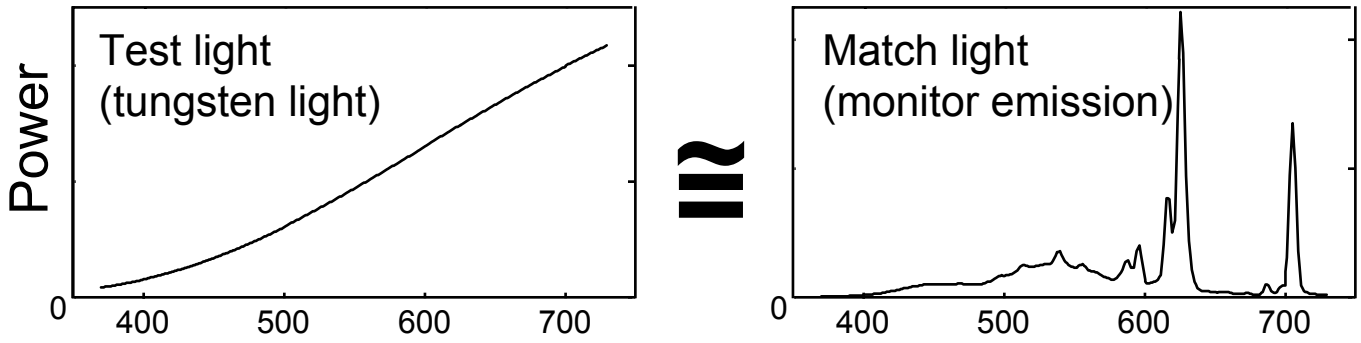


Monochromatic light

Color Matching Experiment

- Three primary lights are set to match a test light
- **Metamer**: two lights visually undistinguishable
  (they might have different spectral power distributions)



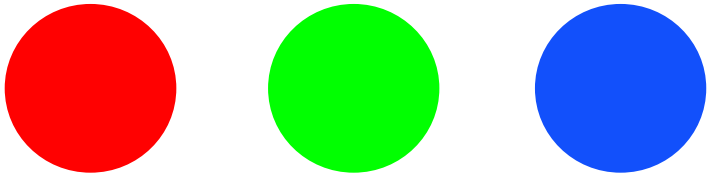


Trichromatic Color Theory

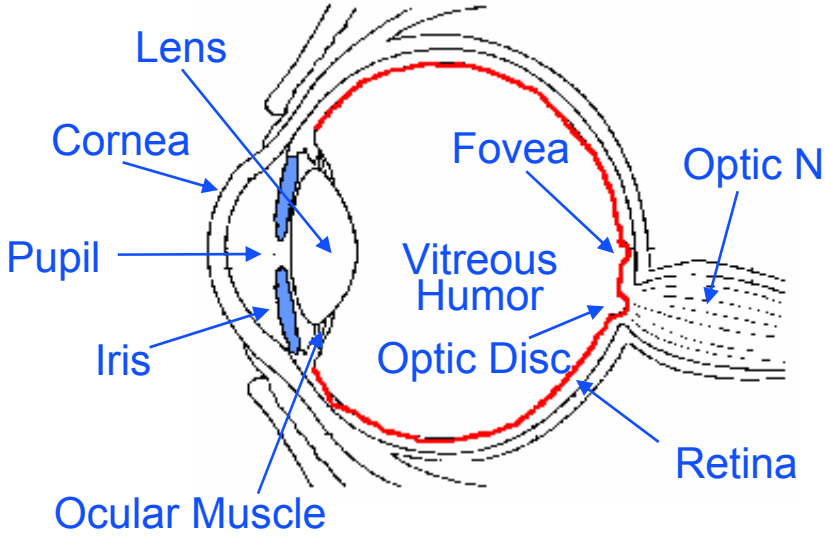
- **Trichromatic**: “tri”=three “chroma”=color also tristimulus color vision is based on three primaries (three dimensional)

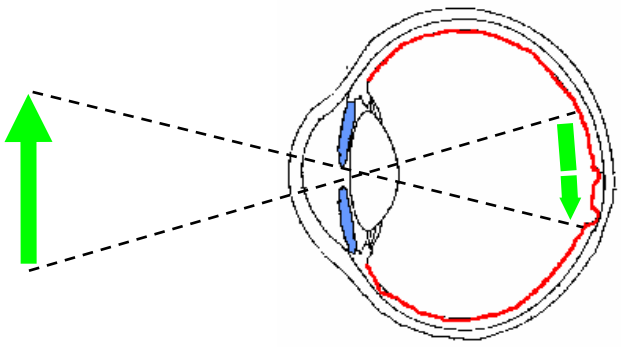
- Thomas Young
  - A few different retinal receptors operating with different wavelength sensitivities allow humans to perceive colors
  - Suggested 3 receptors

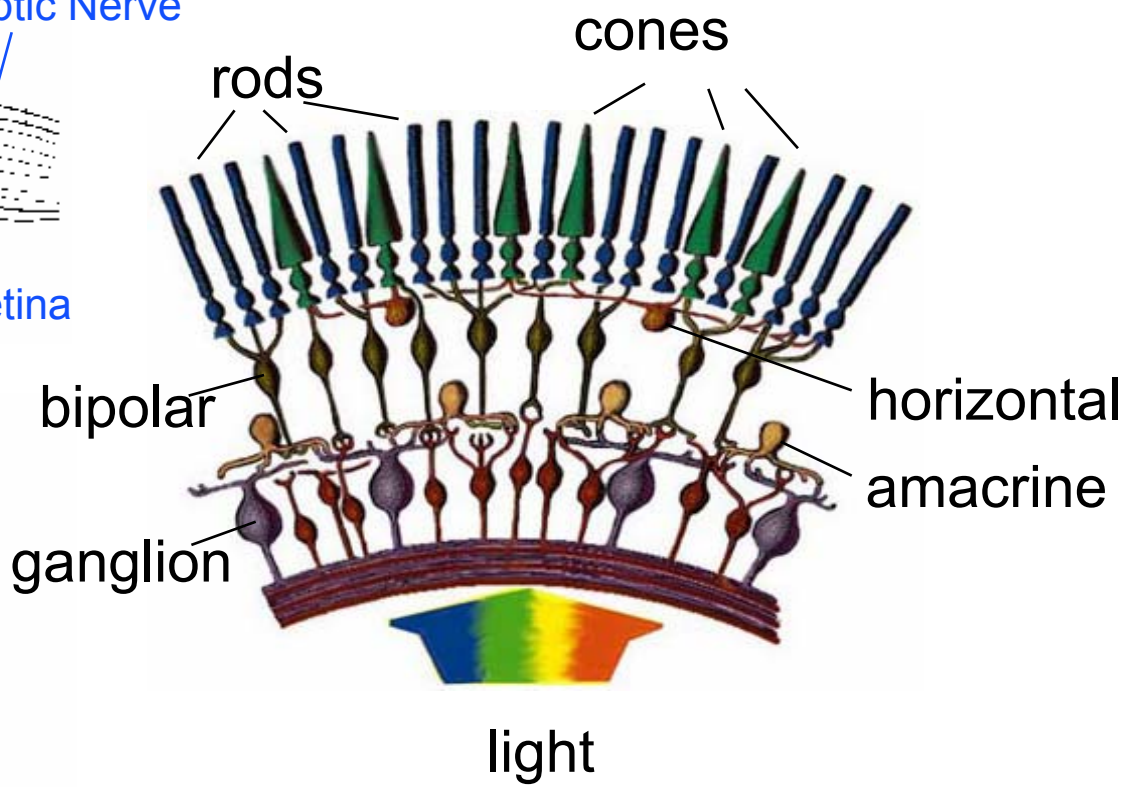
- Helmholtz & Maxwell
  - Color matching with 3 primaries



The Human Eye

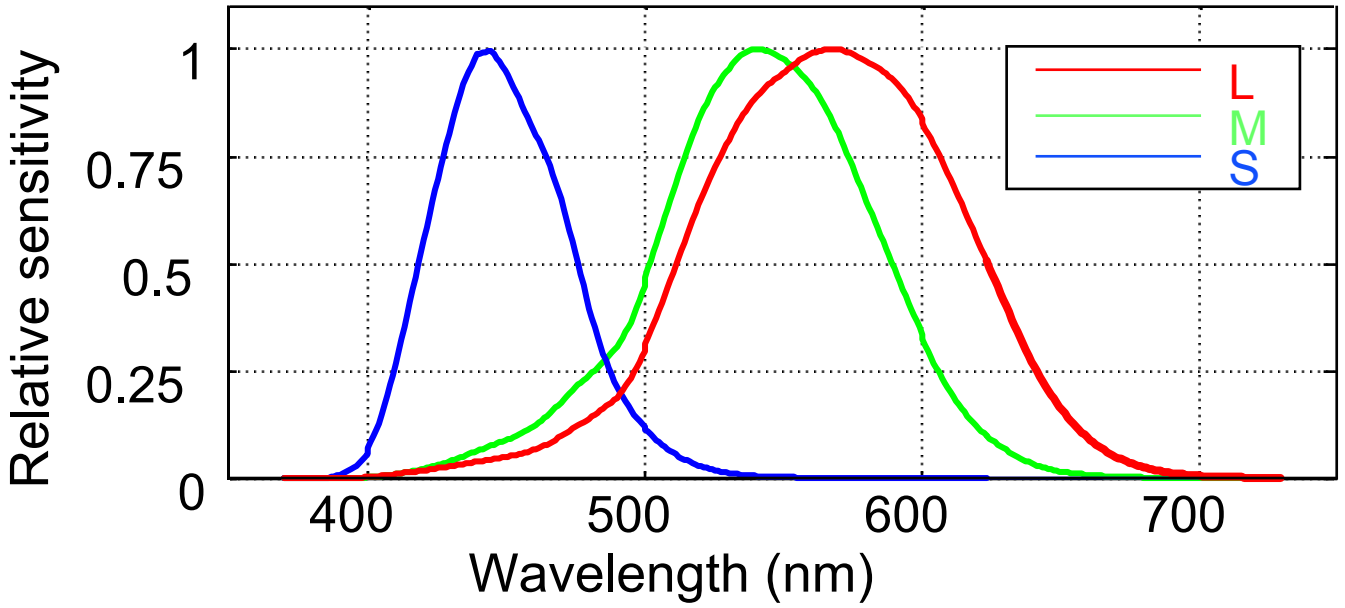




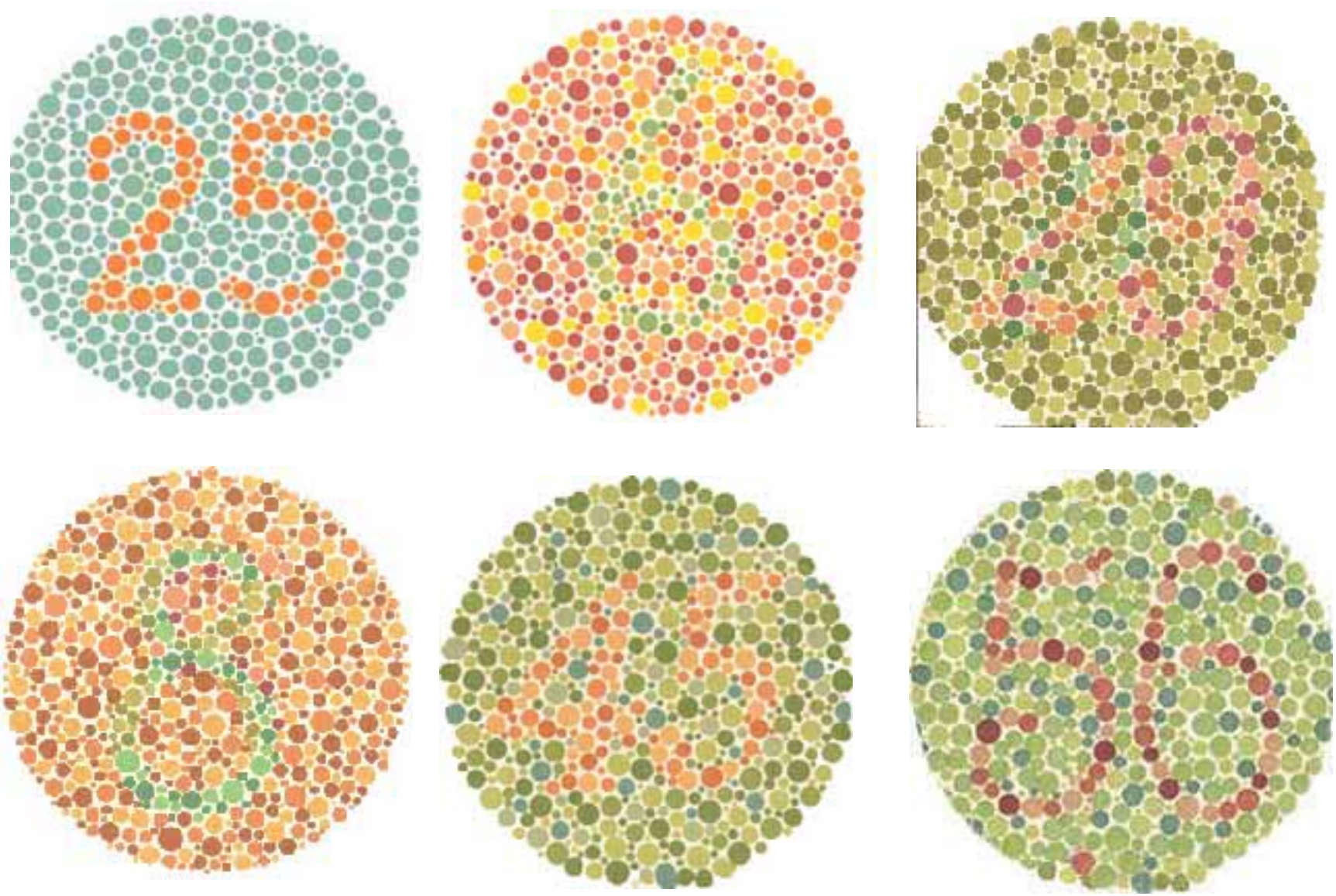


Retinal Photoreceptors

- **Cones:** Sensitive to high illumination levels (Photopic vision)
  Less sensitive than rods
  5 million cones in each eye
  Only cones in fovea (approx. 50,000)
  Density decreases with distance from fovea
  3 types differing in their spectral sensitivity: L , M, and S

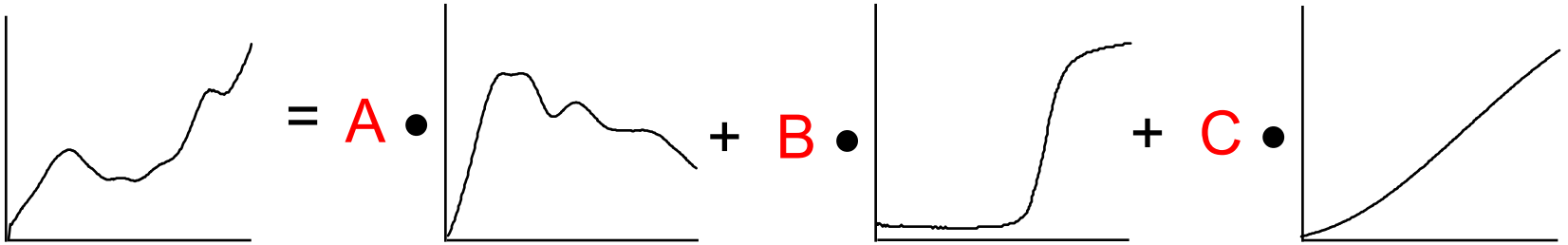


Retinal Photoreceptors

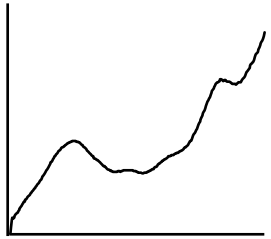


Linear Color Spaces

- Colors in 3D color space can be described as linear combinations of 3 basis colors called **primaries**



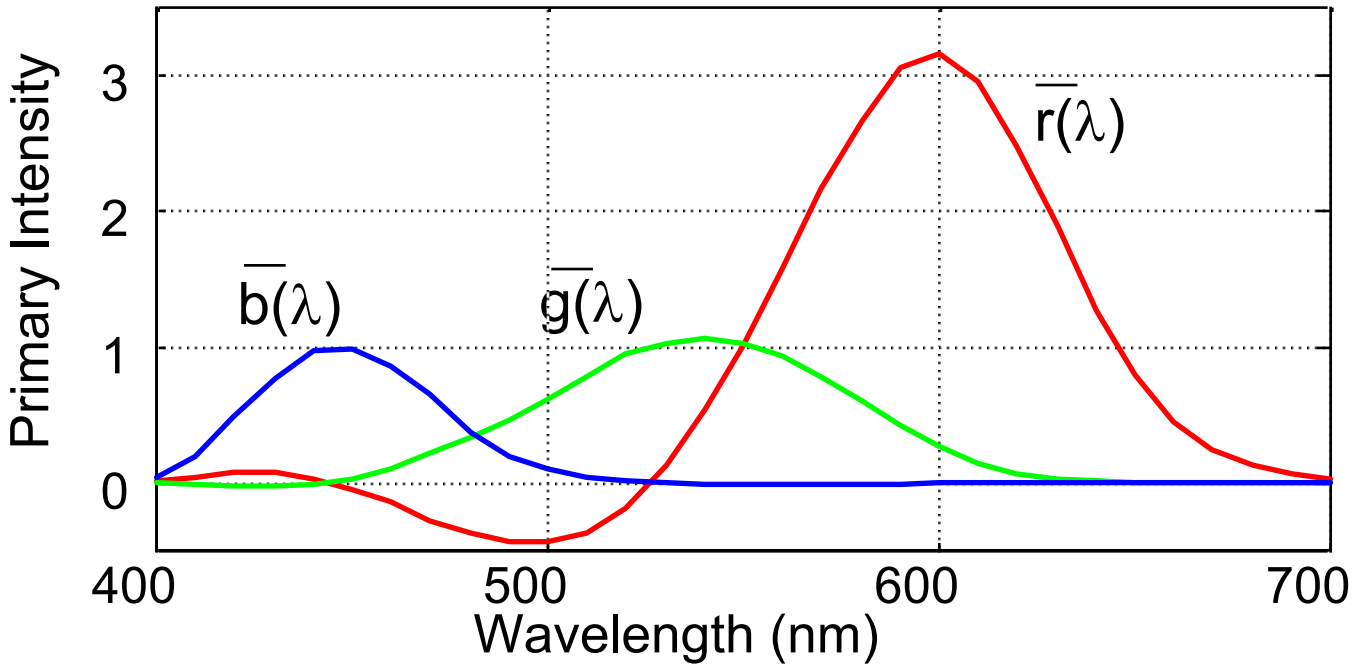
The representation of the color having spectrum:



Is given by **(A, B, C)**

Choosing The Primaries

- Stiles & Burch (1959) used 3 monochromatic primaries of wavelengths 444.4, 525.3 and 645.2

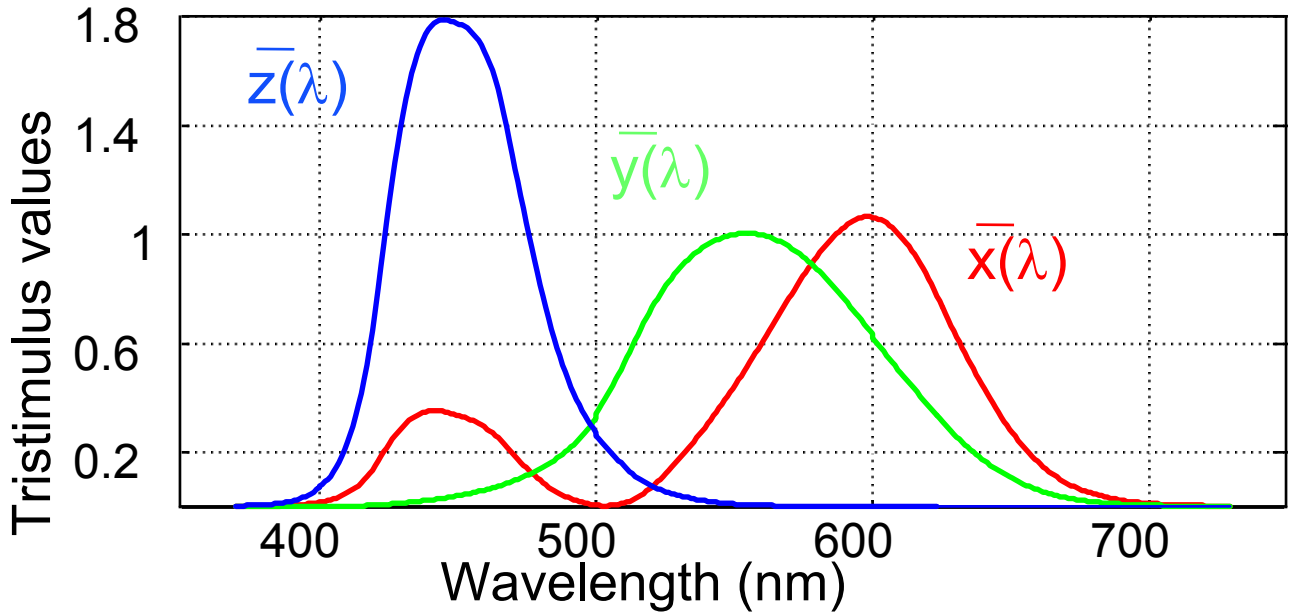


Color Matching Diagram

Problem: Subtractive components

CIE Color Standard

- **CIE:** Commision Internationale d'Eclairage (1931) defined a standard system (CIE- XYZ) for color representation



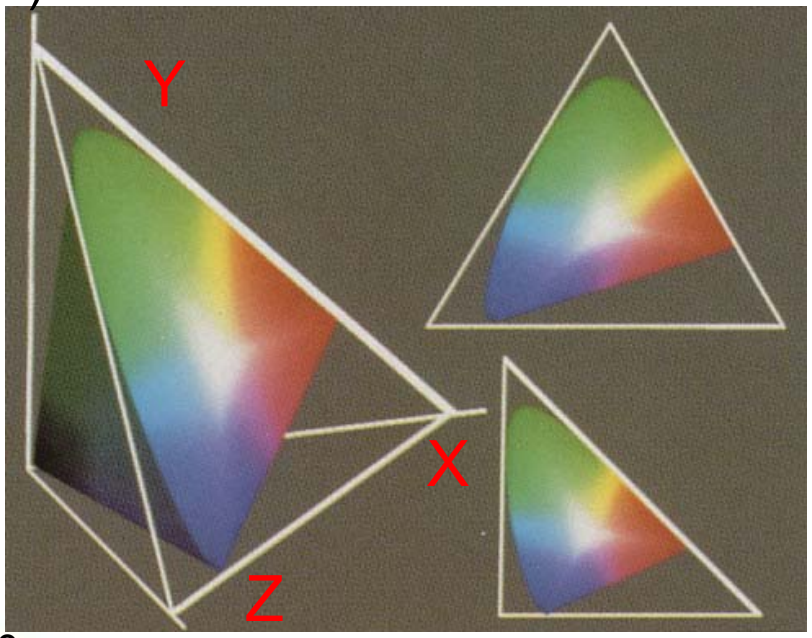
- Weights are non negative over the visible wavelengths
- The 3 primaries associated with x y z color matching functions cannot be easily realized in hardware
- y was chosen to equal *luminance* of monochromatic lights

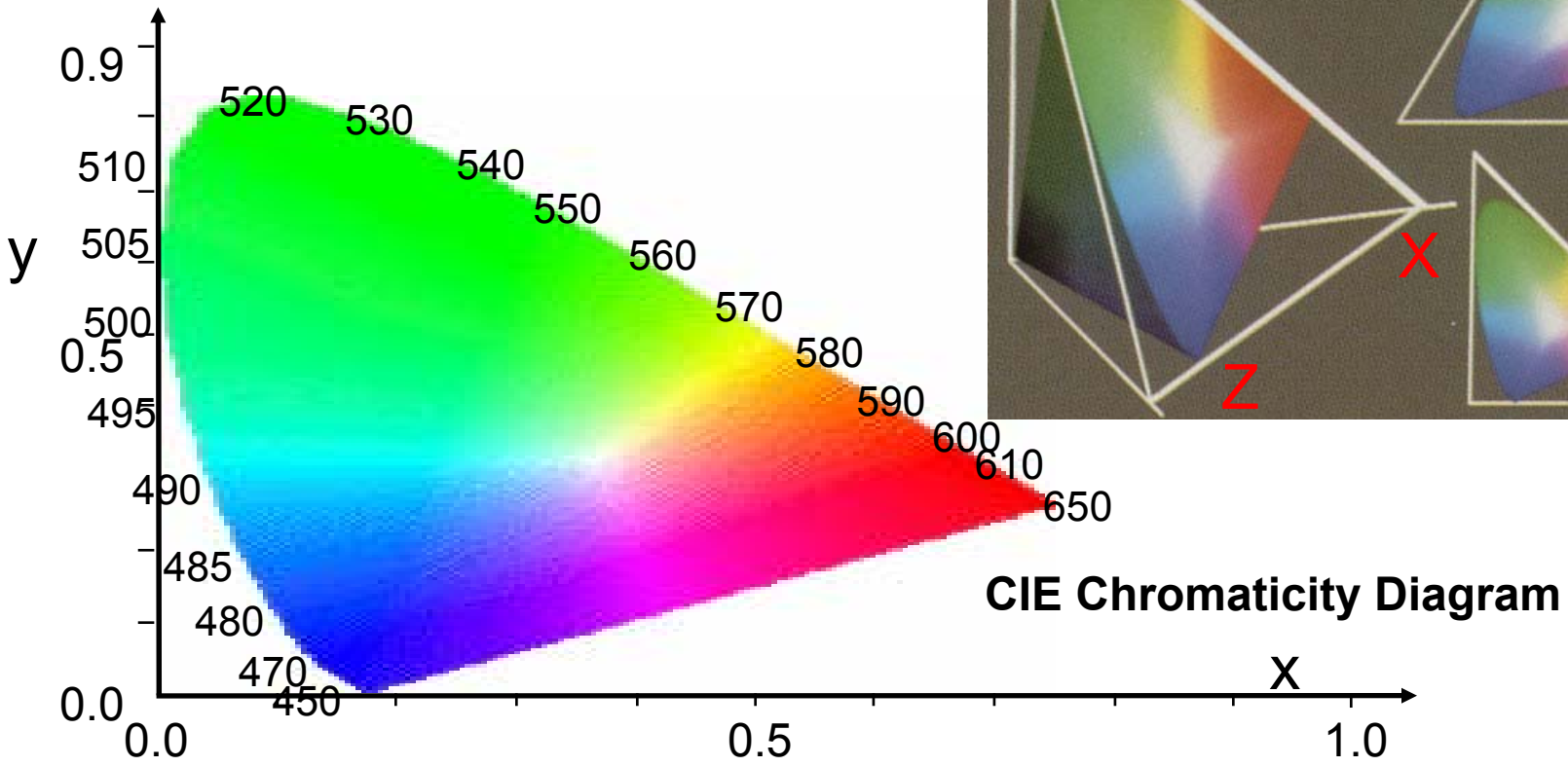
CIE Color Standard

If X, Y and Z are the weights used to define a color C, then the chromaticity values x, y, z (independent from the luminosity) are given by:

x= X/(X+Y+Z) y=Y/(X+Y+Z) z=Z/(X+Y+Z)

(x,y,z) is a point on the plane X+Y+Z=1

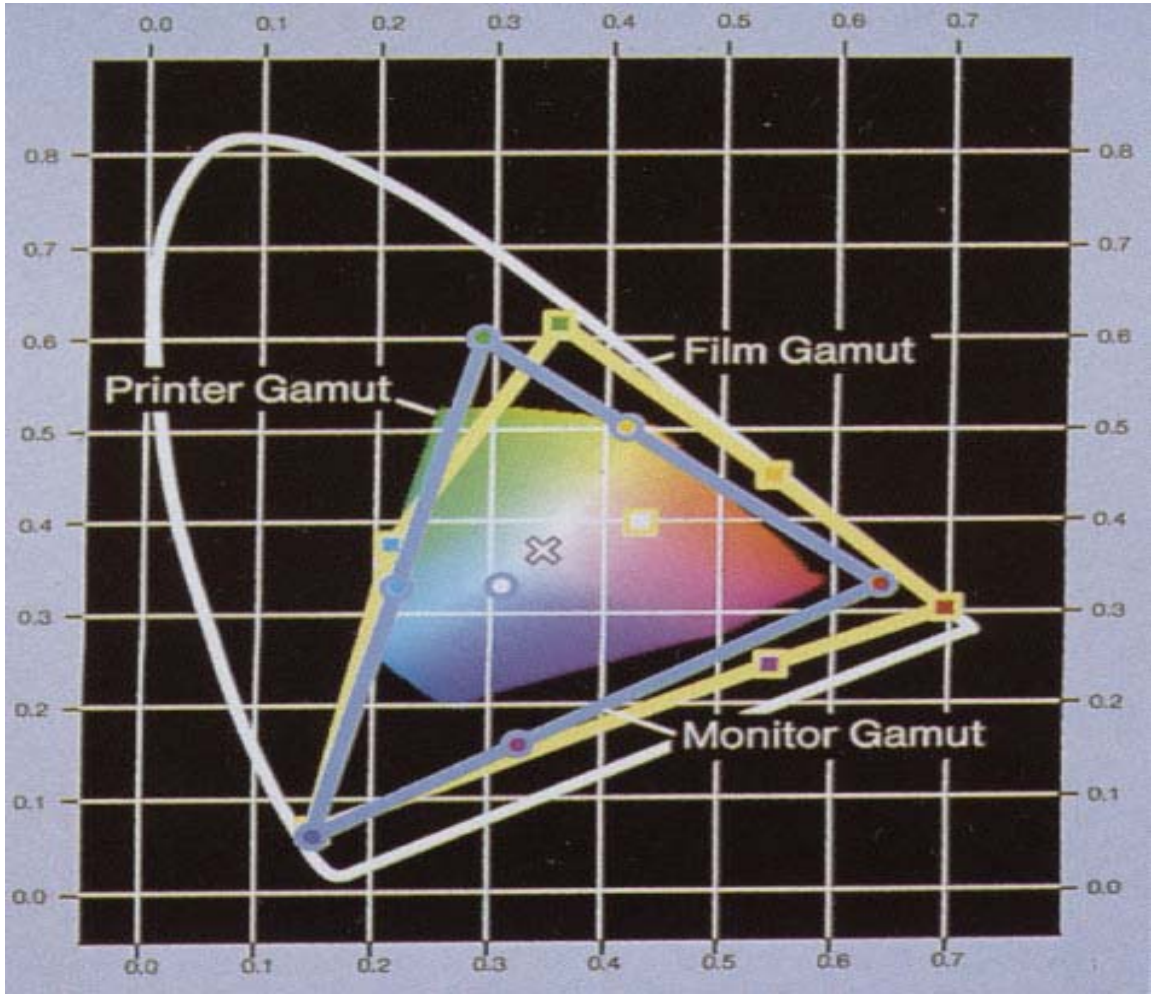




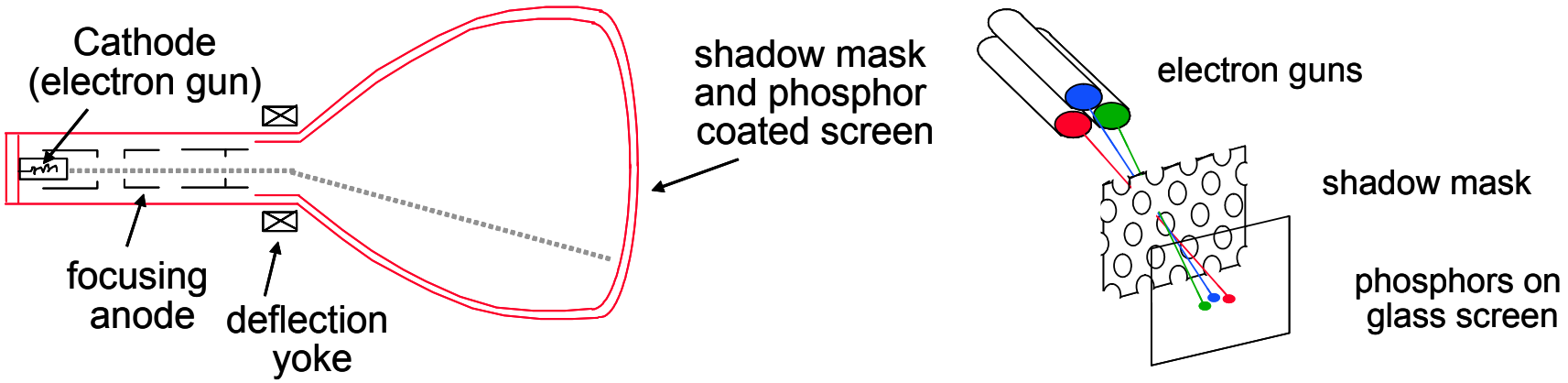
CIE Chromaticity Diagram

CIE Color Standard

- **Color Gamut**: A convex sum of several colors



RGB Color Representation



- In a CRT each color can be defined by the required power of each electron gun:

$$C = rR + gG + bB$$

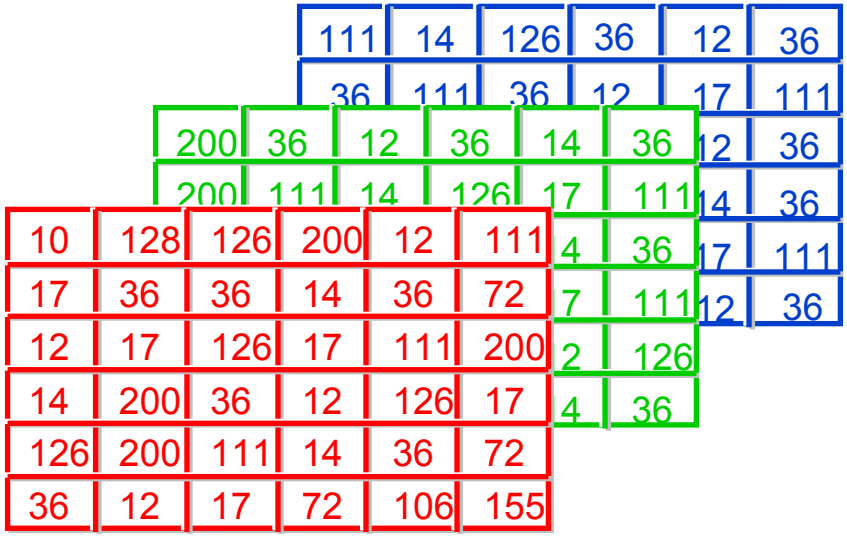
- The intensity is defined as:

$$I = r + g + b$$

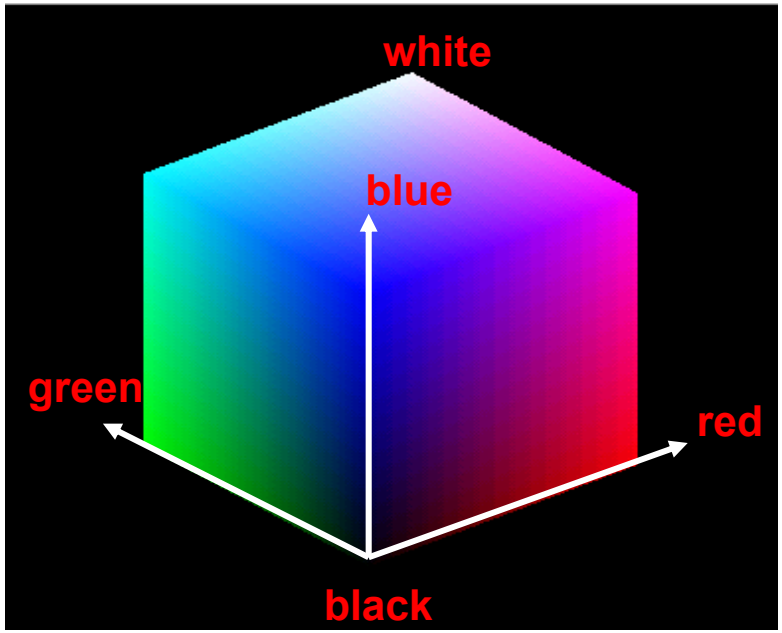
- The chroma(ticy) is defined as:

$$C = \frac{rR + gG + bB}{r + g + b}$$

RGB Color Images



10 200 111	128 36 14	126 12 126	200 36 36	12 14 12	111 36 36
17 200 36	36 111 111	36 14 36	14 126 12	36 17 17	72 111 111
12 36 17	17 36 111	126 111 200	17 36 36	111 14 12	200 36 36
14 17 14	200 126 36	36 72 12	12 126 36	126 17 14	17 111 36
126 200 17	200 36 111	111 12 14	14 36 126	36 12 17	72 126 111
36 72 12	12 12 126	17 17 200	72 111 36	106 14 12	155 36 36



RGB to CIE-XYZ Conversion

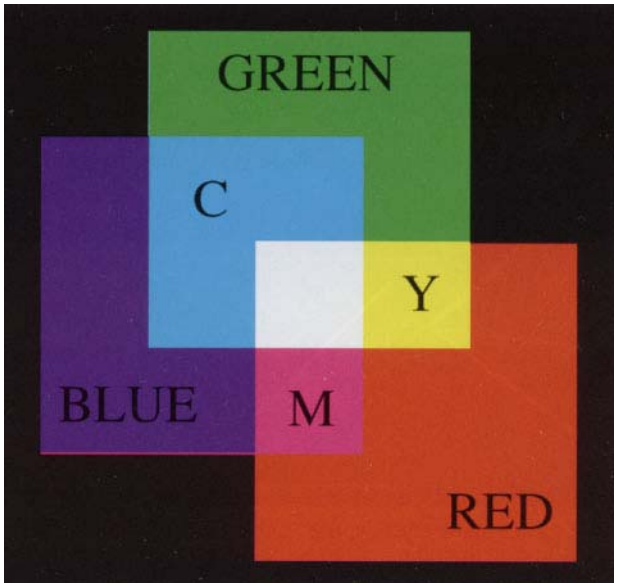
- RGB to CIE-XYZ is a linear transformation:

$$\begin{bmatrix} 2.365 & -0.515 & 0.005 \\ -0.897 & 1.426 & -0.014 \\ -0.468 & 0.089 & 1.009 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

- R = monochromatic primary 700nm
- G = monochromatic primary 546.1nm
- B = monochromatic primary 435.8nm

RGB vs. CMY(K) Color Scheme

- RGB and CMYK (Cyan, Magenta, Yellow and blacK) are **hardware-oriented** representations
- CMY is used in color photography and (with K) in most color printers



RGB is Additive

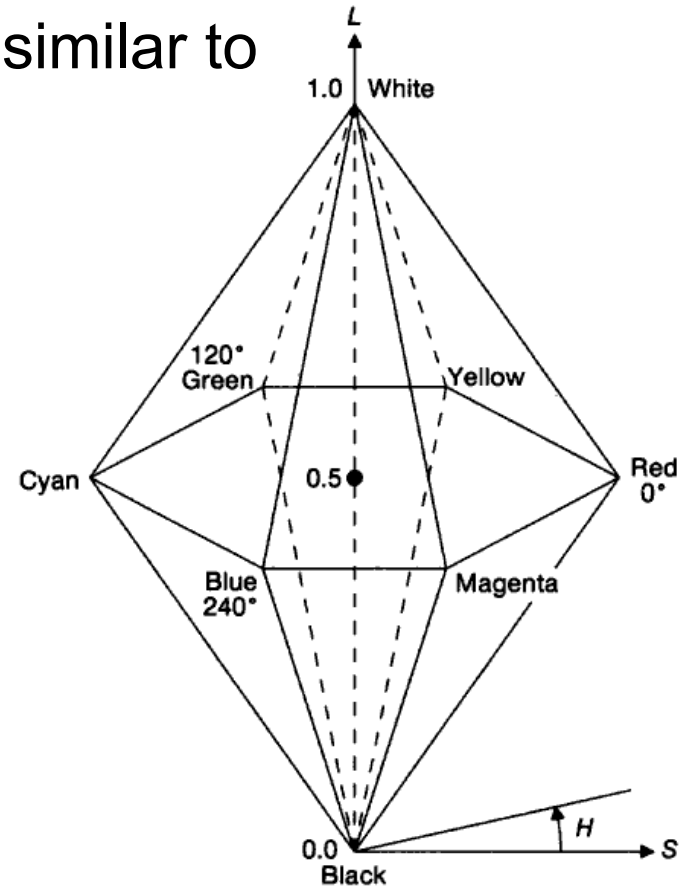
CMY is Subtractive

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

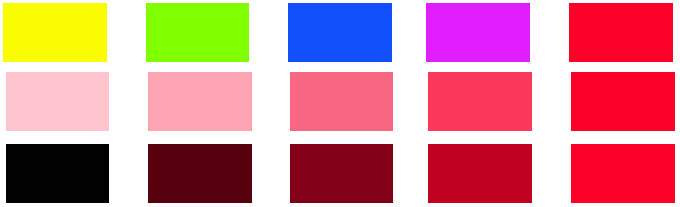
The HLS Color Model

- **HLS**: Hue Lightness, Saturation similar to **HSV**: Hue Saturation Value

Munsell Book of Colors



Hue (red, green, yellow, blue ...)
Saturation (pink, bright red, ...)
Lightness (black, grey, white ....)

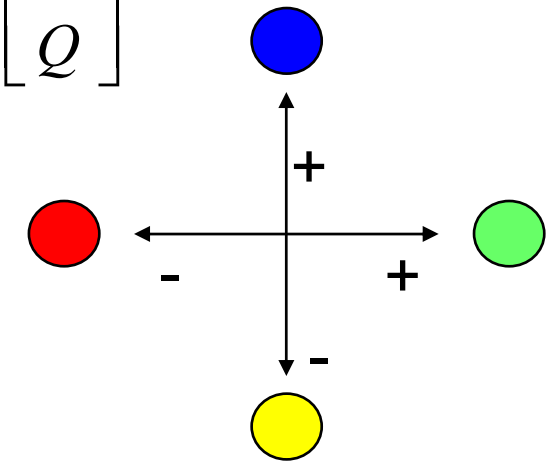


The YIQ Color Model

- Based on the concept of opponent colors
- Used in NTSC Television
  (National Television Systems Committee)
- Similar method (YC_bC_r) used in JPEG and MPEG

$$\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

- **Y** = Luminance
- **I** = Red-Green
- **Q** = Blue-Yellow

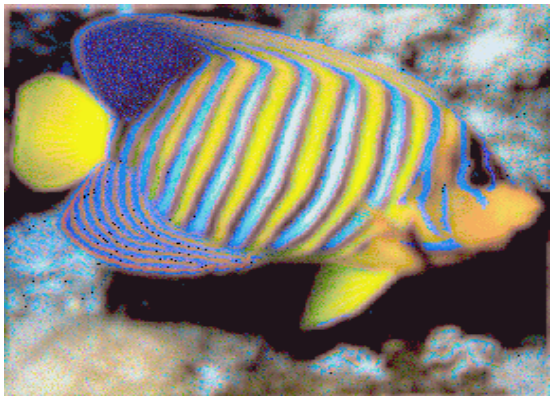


The YIQ Color Model

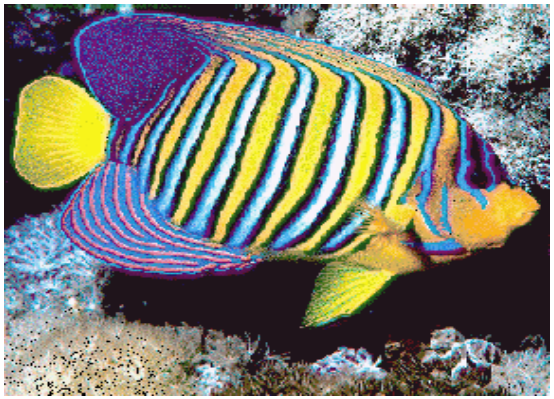
- The human eye is more sensitive to luminosity than to colors, so it is possible to save space by encoding colors more coarsely
- Preferred by the NTSC because of backward compatibility with B/W TV

Original

Y - Blur



I - Blur



Q - Blur

Summary

- **CIE-XYZ**
  - Tristimulus Coordinates
  - Device Independent
  - Universal standard
- **CIE-Lab**
  - Perceptual Space, used to assess image quality
- **RGB** and **CMY**
  - Hardware oriented
  - Additive spaces used for CRT, printers, photography
- **YIQ** and **YC_bC_r**
  - Opponent Space
  - Used for color television broadcast and image compression
- **HLS**
  - Perceptual Digitized Space
  - Used for Human Interactive Painting