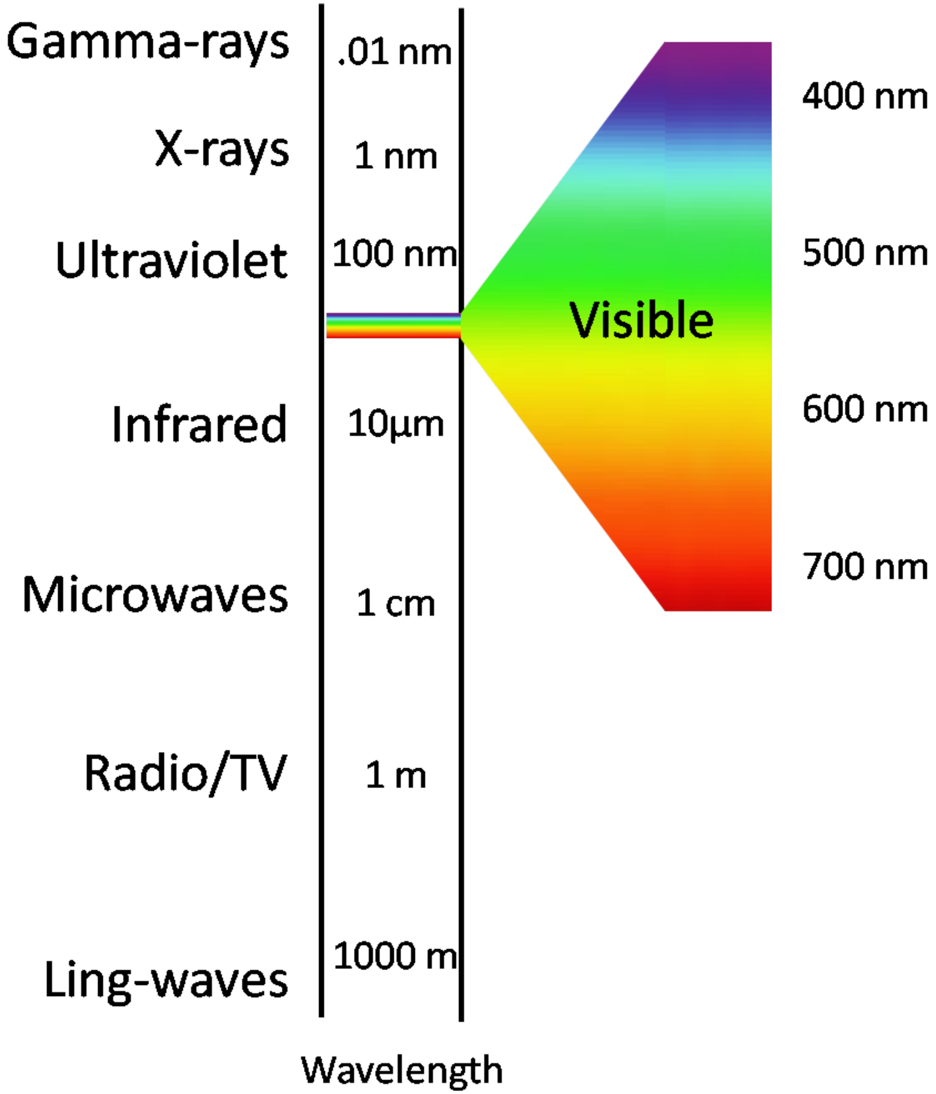
Module #5a: Visualization and Color Theory

Objectives

- Describe the basis of color perception
- Explain the theory behind the primary colors
- Describe different color spaces such as RGB, HLS, CIE, YUV, and Lab
- Explain best practices of color in visualization

Visible Light

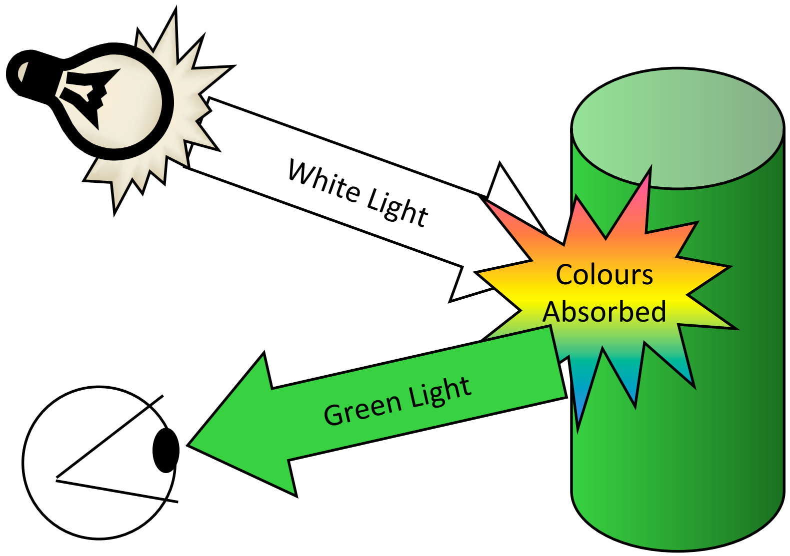
- Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm



Color Fundamentals

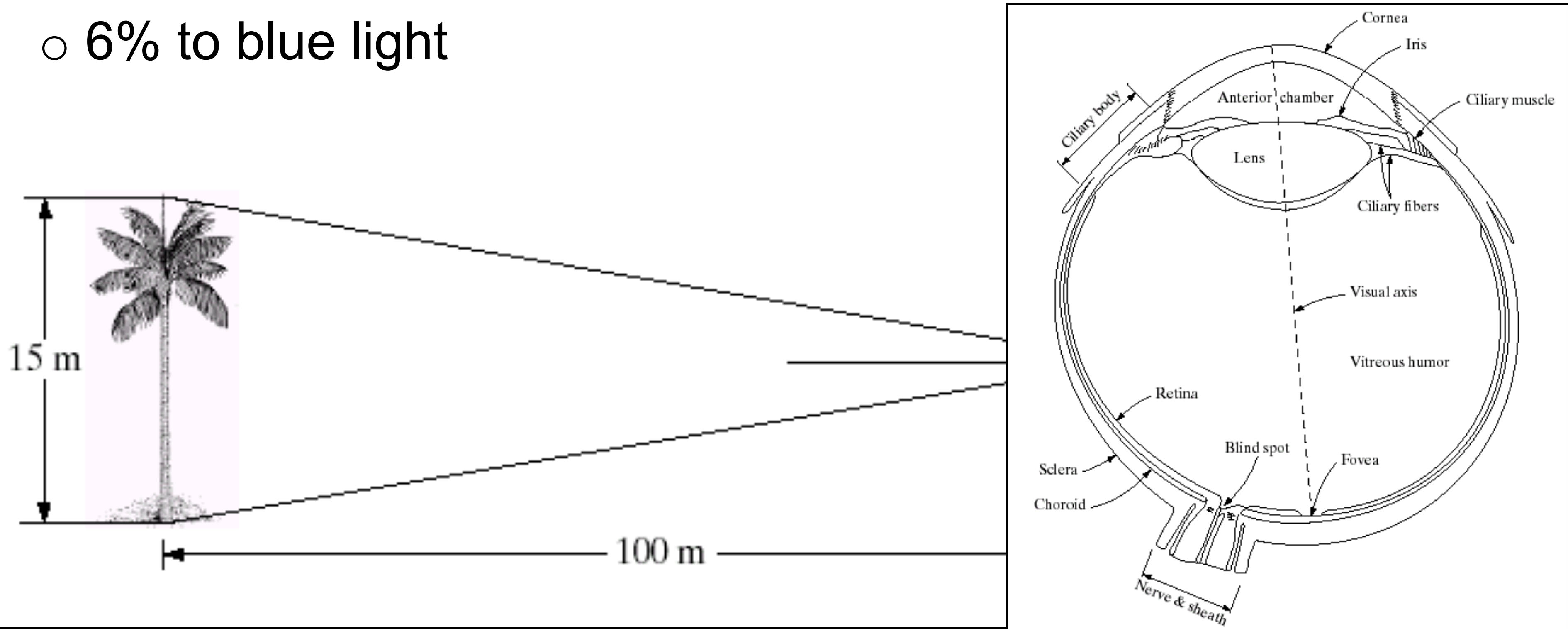
- The colors that humans and most animals perceive in an object are determined by the nature of the light reflected from the object

- A green object reflects light with wave lengths in the range of 500 – 570 nm while absorbing most of the energy at other wavelengths

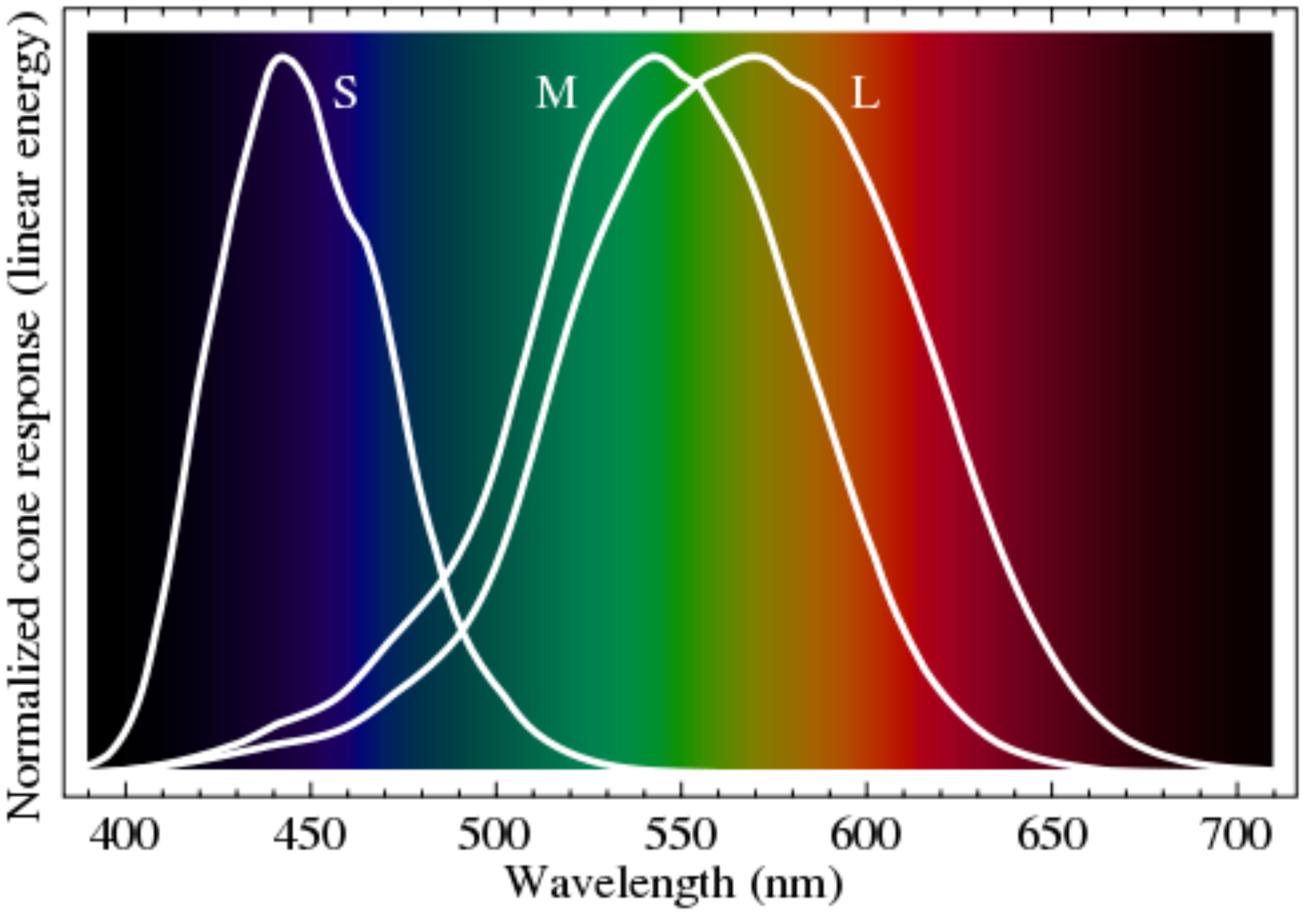


Color Fundamentals

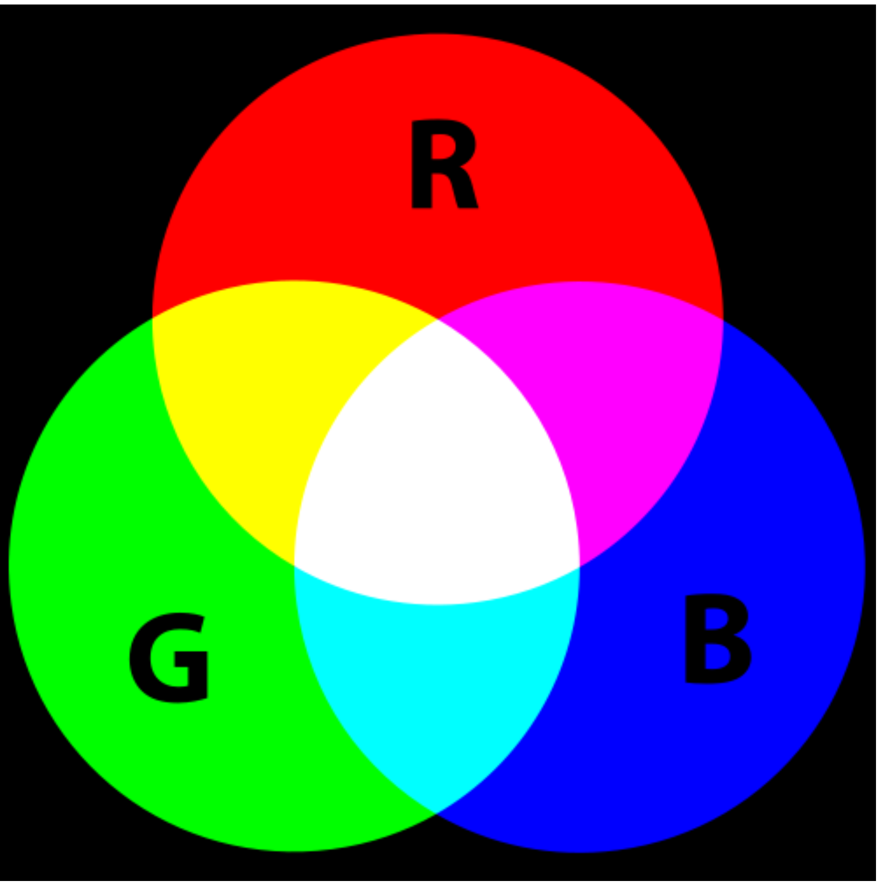
- The human color vision is achieved through 6 to 7 million cones in each eye
  - 66% of these cones are sensitive to red light
  - 33% to green light
  - 6% to blue light



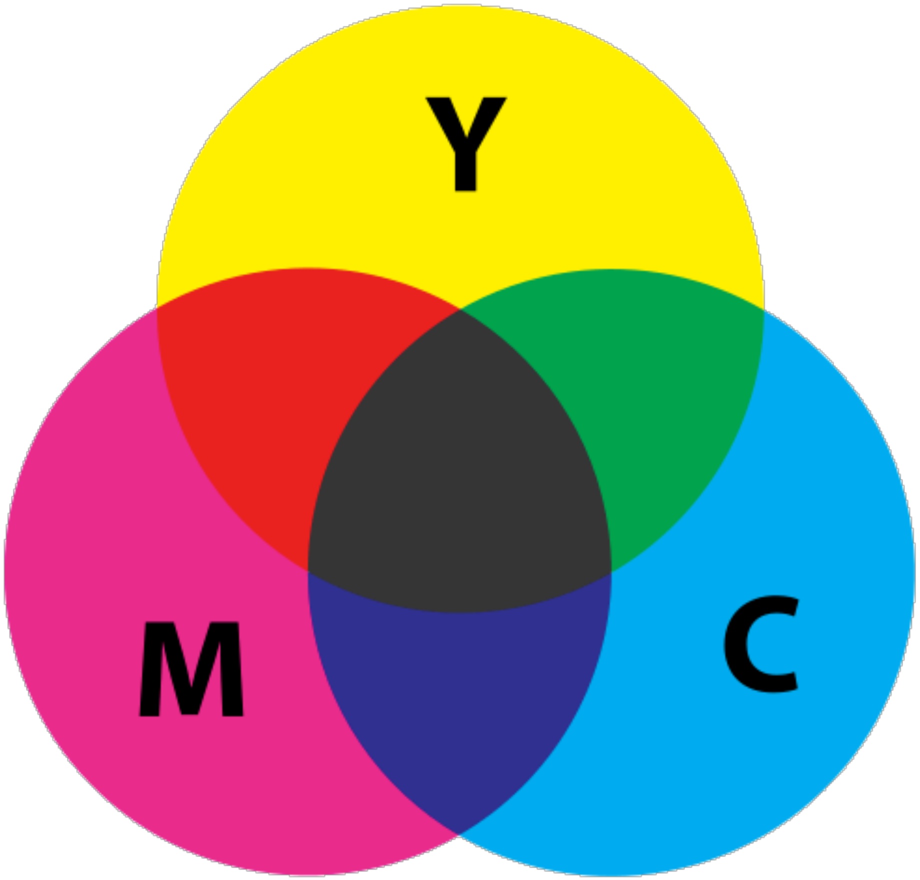
Color Fundamentals (cont…)



Primary Colors



Adaptive Color Mixing



Subtractive Color Mixing

CIE standard

- CIE - Commision Internationale d'Eclairage
- In 1931, CIE defined a standard system for color representation.
- XYZ coordinate system
- Strangely these do not match the CIE standards for
  - red (700nm)
  - green (546.1nm)
  - blue (435.8nm)

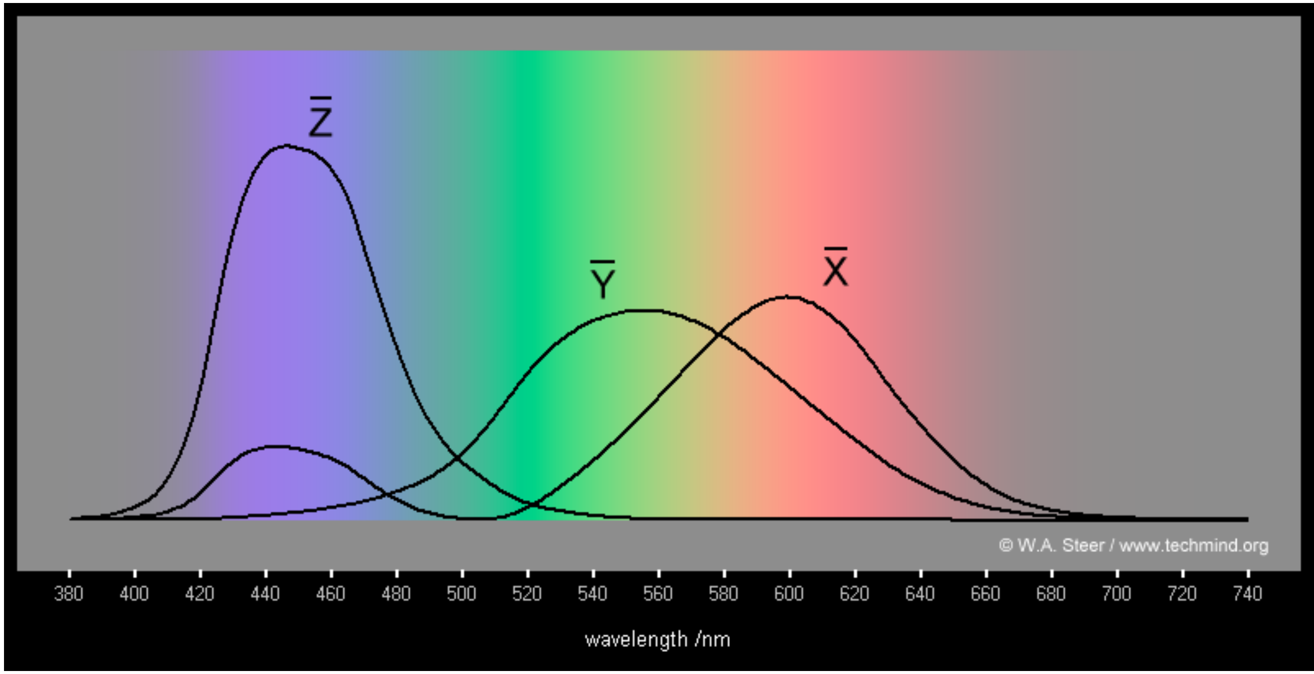
CIE standard

Color matching functions

$$X = \int_{380}^{780} L_{e,\Omega,\lambda}(\lambda)\,\overline{x}(\lambda)\,d\lambda,$$

$$Y = \int_{380}^{780} L_{e,\Omega,\lambda}(\lambda)\,\overline{y}(\lambda)\,d\lambda,$$

$$Z = \int_{380}^{780} L_{e,\Omega,\lambda}(\lambda)\,\overline{z}(\lambda)\,d\lambda.$$



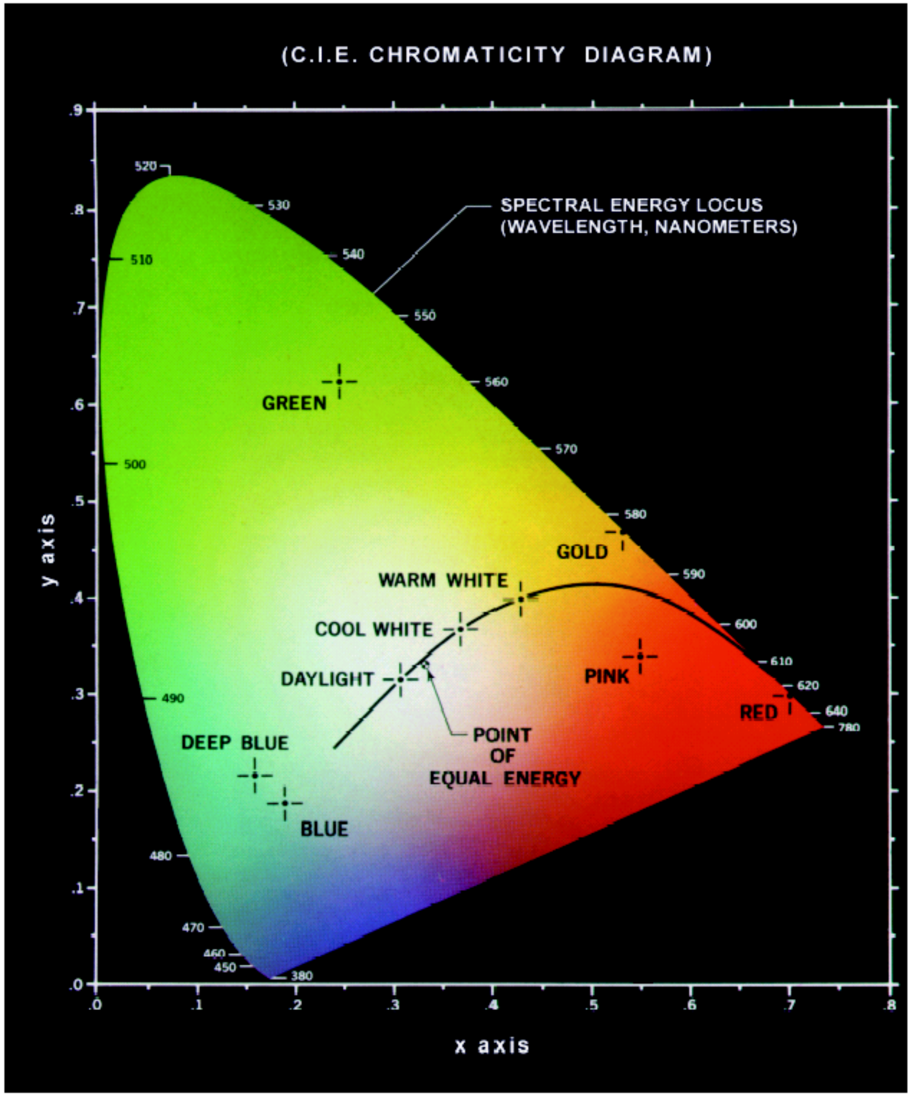
CIE Chromaticity Diagram

- Specifying colors systematically can be achieved using the CIE **chromacity diagram**

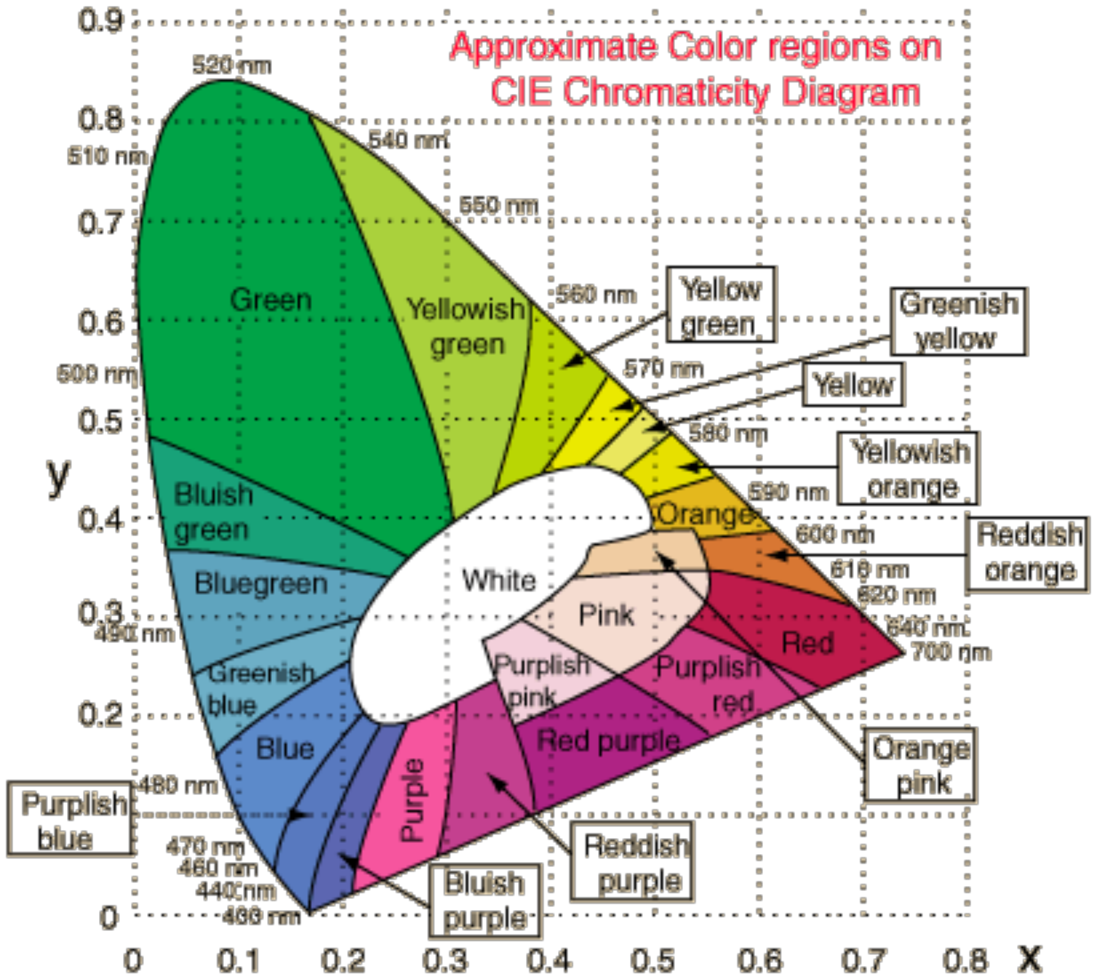
- The point "green"
  - 25% red
  - 62% green
  - 13% blue

- The positions of the various spectrum colors (from violet to red) are indicated around the boundary

- The CIE system characterizes colors by a luminance parameter *Y* and two color coordinates *x* and *y* which specify the point on the chromaticity diagram.



CIE Chromaticity Diagram



CIE Chromaticity Diagram

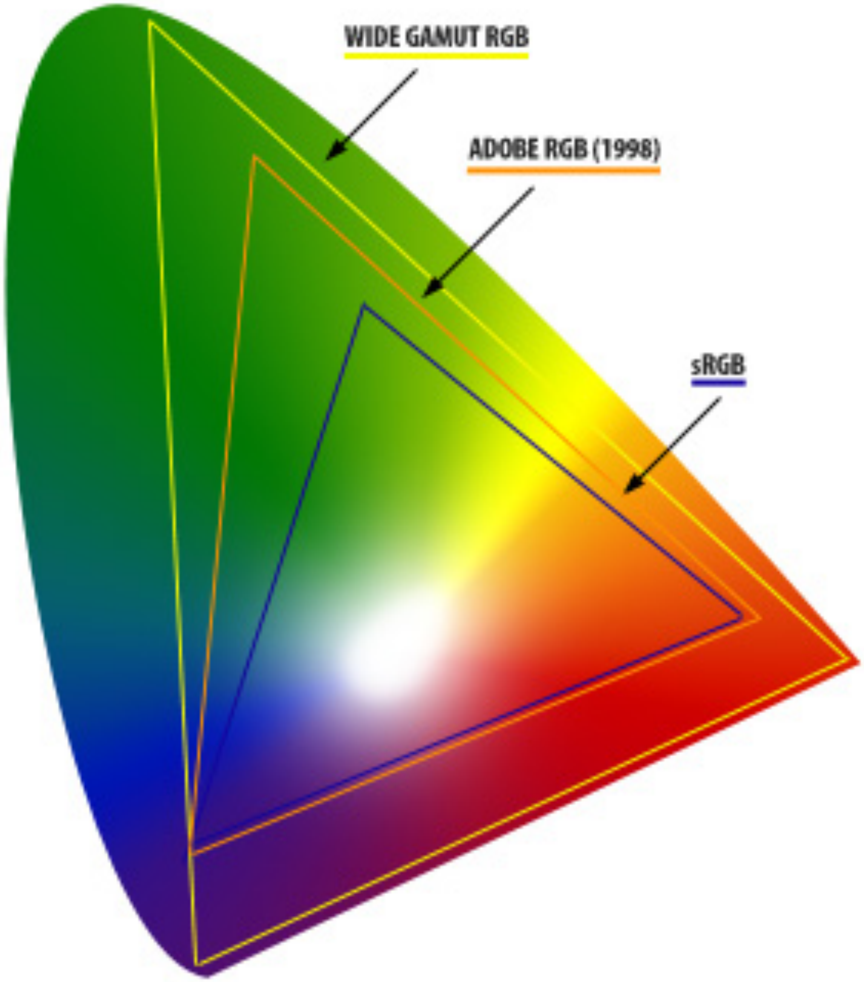
•Any color located on the boundary of the chromacity chart is fully saturated

•The *point of equal energy* has equal amounts of each color and is the CIE standard for pure white

•Any straight line joining two points in the diagram defines all of the different colors that can be obtained by combining these two colors additively

•This can be easily extended to three points

Color gamut

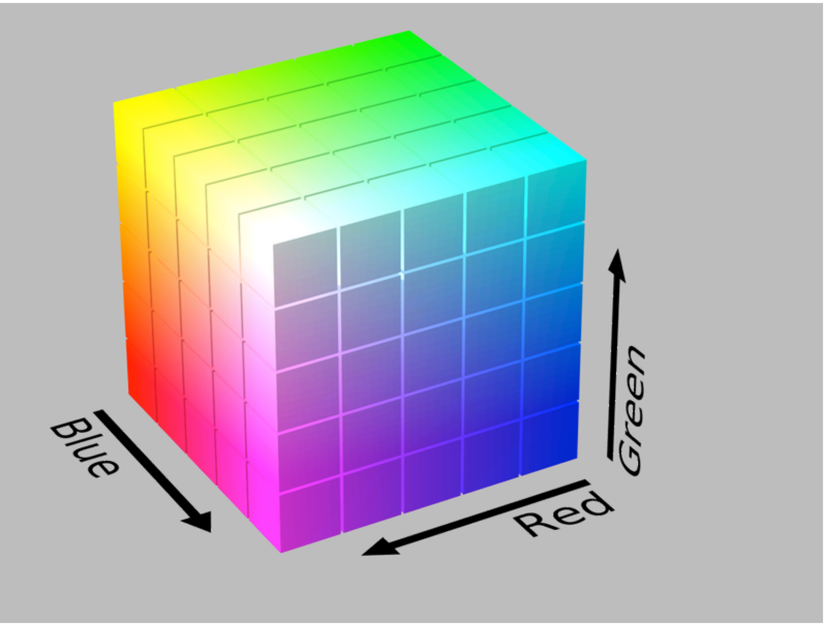


Color Models

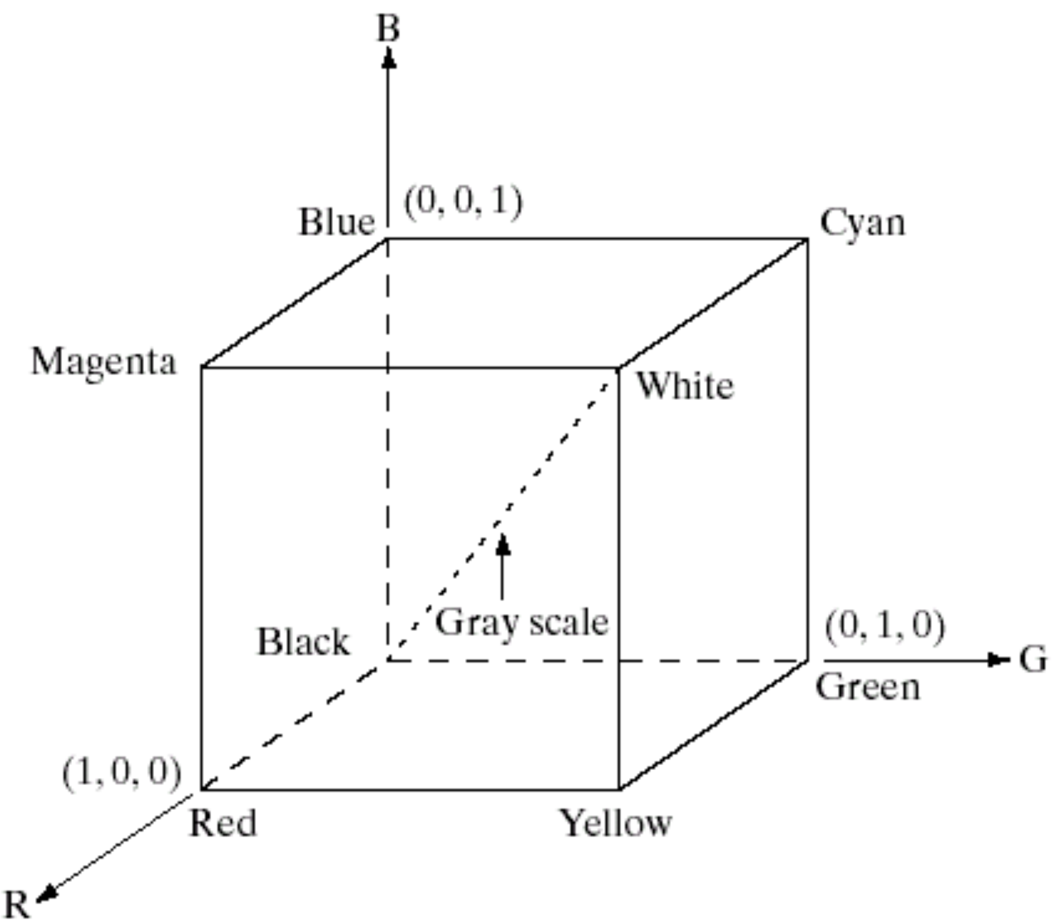
- There are different ways to model color

- Color Spaces:
    - Linear (RGB, CMYK)
    - Artistic View (Munsell, HSV, HLS, HSI)
    - Standard (CIE-XYZ)
    - Perceptual (Luv, Lab, L*a*b*)
    - Opponent (YIQ, YUV)

- We will consider two very popular models used in color image processing:
    - RGB (**R**ed **G**reen **B**lue)
    - HSI (**H**ue **S**aturation **I**ntensity)


Blue
Red
Green

RGB


B
Blue
(0, 0, 1)
Cyan
Magenta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

RGB

- Images represented in the RGB color model consist of three component images – one for each primary color

- When fed into a monitor these images are combined to create a composite color image

- The number of bits used to represent each pixel is referred to as the color depth

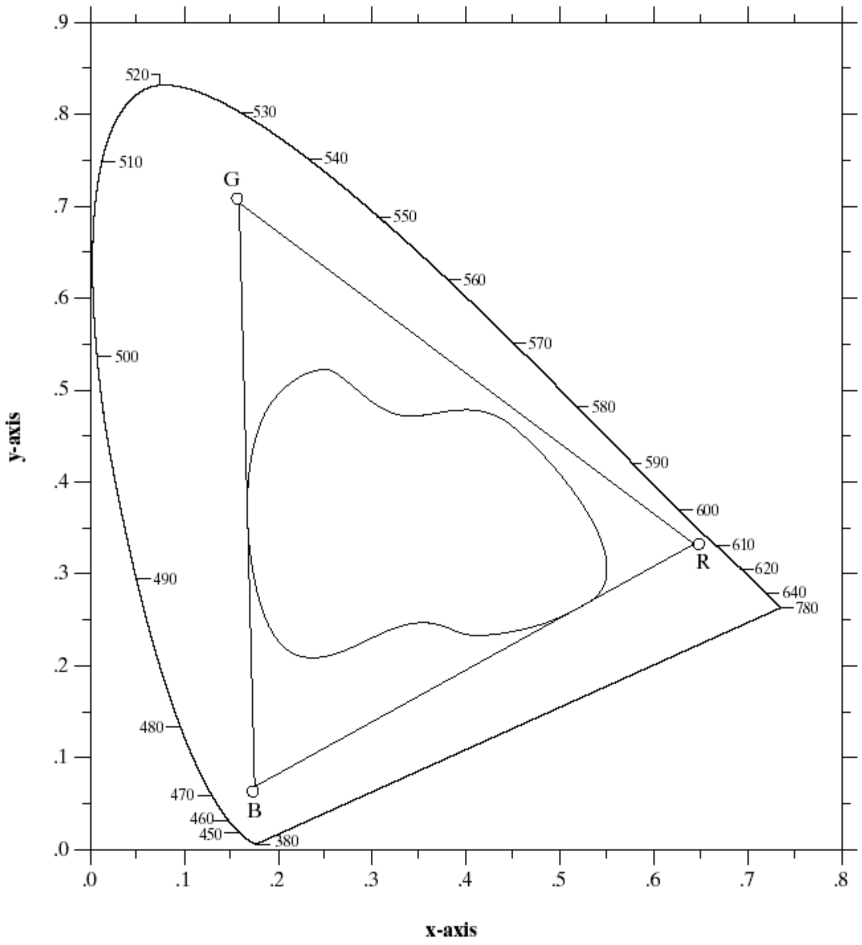
- A 24-bit image is often referred to as a full-color image as it allows $\left(2^8\right)^3 = 16,777,216$ colors

RGB to XYZ

- RGB to XYZ is a linear transformation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

CIE Chromacity Diagram & RGB



- The entire color range cannot be displayed based on any three colors
- The triangle shows the typical color gamut produced by RGB monitors
- The strange shape is the gamut achieved by high quality color printers

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