Color

Light and color

Trichromatic color matching

- Grassman's laws
- Color coordinates
- Human color vision

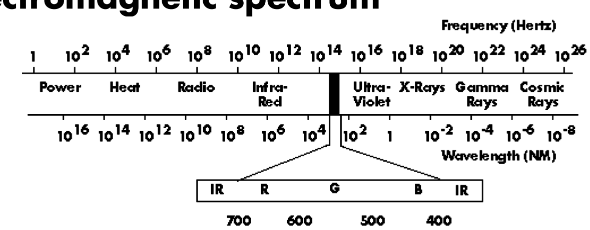
Intuitive color systems

Computer representations of color

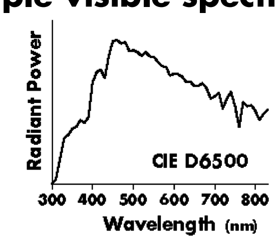
- RGB
- HSV, HSB, HSL
- CMYK

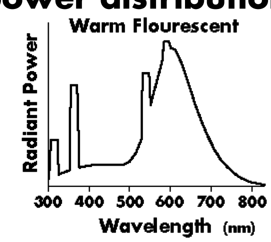
Spectrum

The electromagnetic spectrum



Example visible spectra power distribution





Measuring Light and Color

Physics: Radiometry

- The amount of *power* per wavelength interval

  Termed *radiance*, we will often use *intensity*

Psychophysics

Photometry

- The relative brightness of a light source (color or black/white) when compared to a standard candle

  Termed *luminance*

- Uniform perceptual scale

  Termed *lightness*

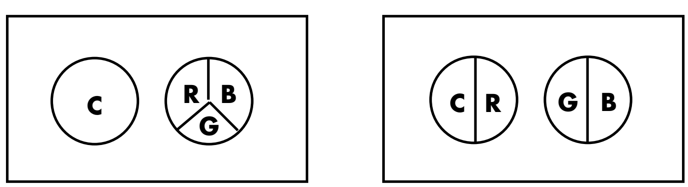
Colorimetry

Color Matching

Adjust brightness of 3 primaries to "match" color

C - color to be matched

RGB - laser sources (R=700 nm, G=546 nm, B=435 nm)



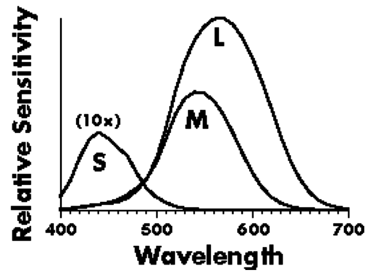
C = R + G + B   C + R = G + B

Therefore: *humans have trichromatic color vision*

Human Color Vision

- There are 3 light sensitive pigments in your cones (L,M,S), each with a different *spectral response curve*

$$L = \int L(\lambda)E(\lambda)d\lambda$$
$$M = \int M(\lambda)E(\lambda)d\lambda$$
$$S = \int S(\lambda)E(\lambda)d\lambda$$



- Metamerism
- Biological basis of color blindness - genetic disease

Color Matching is Linear!

Grassman's Laws

1. Scaling the color and the primaries by the same factor preserves the match

$$2C=2R+2G+2B$$

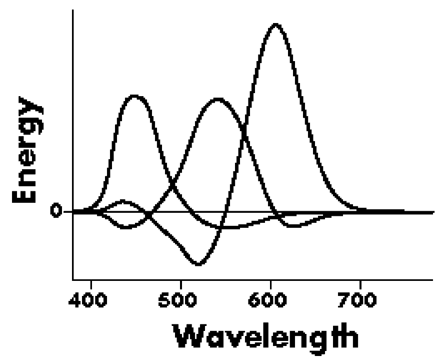
2. To match a color formed by adding two colors, add the primaries for each color

$$C_1+C_2=(R_1+R_2)+(G_1+G_2)+(B_1+B_2)$$

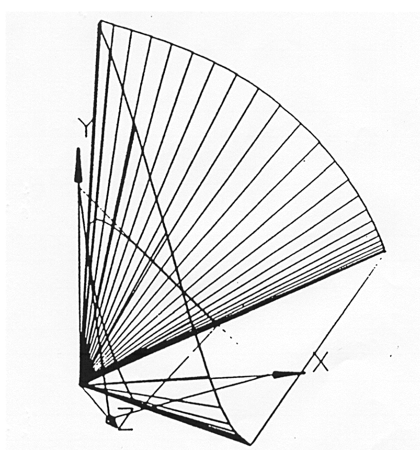
Spectral Matching Functions

Spectral matching curves

- **Match each pure color in the visible spectrum (rainbow), and record the color coordinates as a function of wavelength**

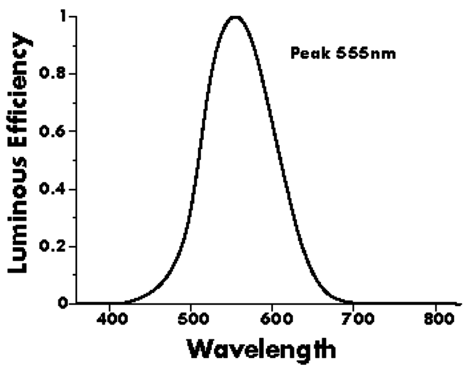


Spectral Locus



Human Perceptual Gamut

Luminance



Compare color source to a grey source

$$Y = \int V(\lambda) E(\lambda) d\lambda$$

- **Luminance**

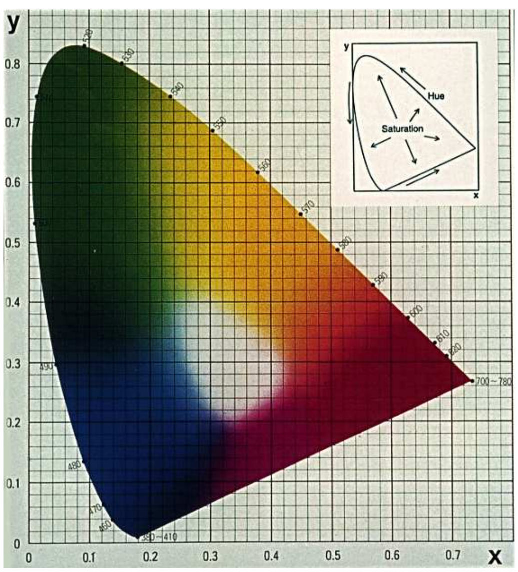
  Y = .30R + .59G + .11B

  Color signal on a BW TV (Except for gamma)

- **Lightness**

  $L^* = Y^{1/3}$

Chromaticity Diagram



CIE Color Coordinates

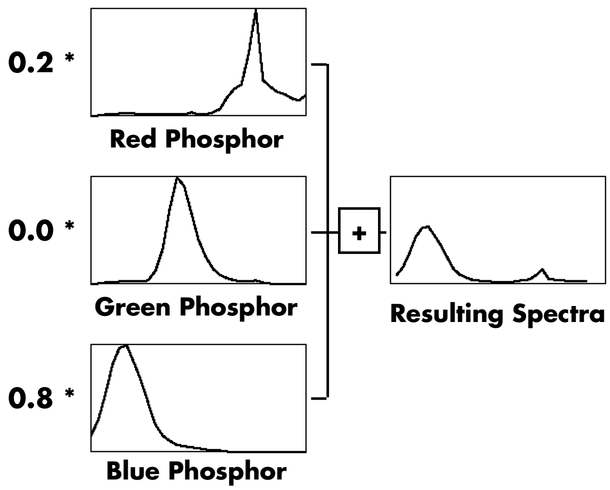
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.77 & 1.75 & 1.13 \\ 1.00 & 4.59 & 0.06 \\ 0.00 & 0.57 & 5.59 \end{bmatrix} \begin{bmatrix} R_\lambda \\ G_\lambda \\ B_\lambda \end{bmatrix}$$

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

1931 CIE Chromaticity Diagram From Minolta

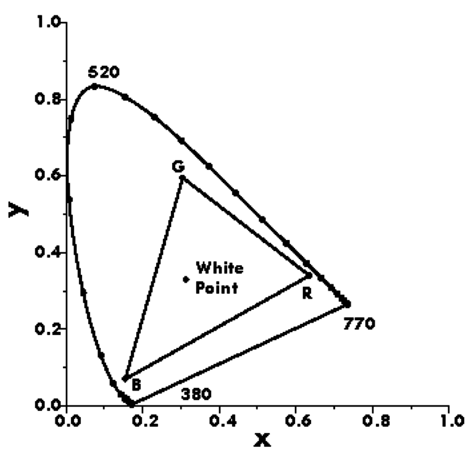
Monitor



Monitor Phosphors

x	y
.635	.340
.305	.595
.155	.070

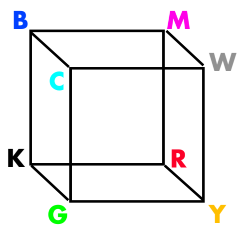
Gamut

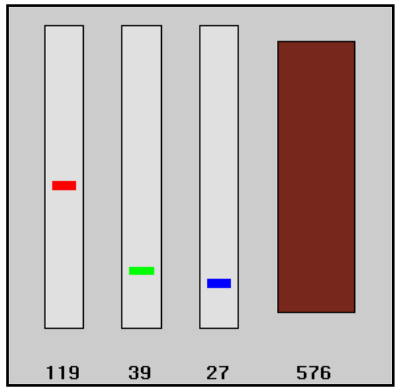


Monitor Phosphors

x	y
.635	.340
.305	.595
.155	.070
.313	.329

Color Cube





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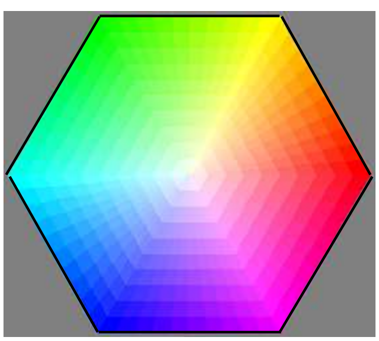
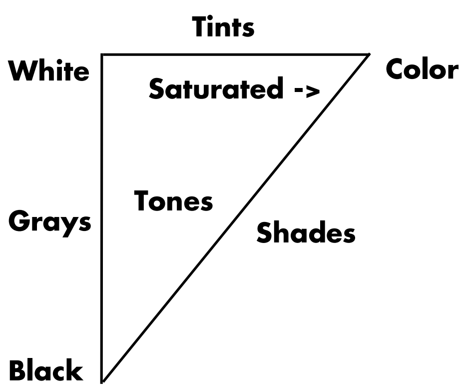
CS248 Fall 98 Lecture 4

Intuitive Color Spaces

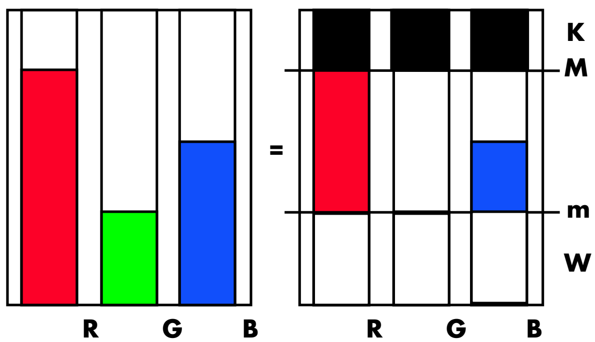




Hexagon is a diagonal Cross-Section of the Color Cube

CS248 Fall 98 Lecture 4

HSV and HSL

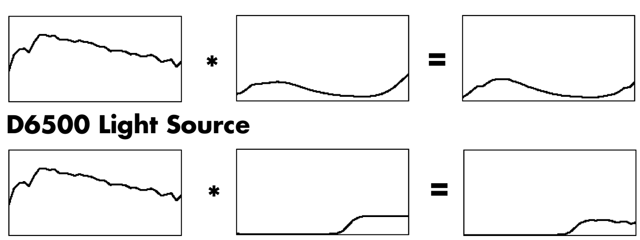


M=max(R,G,B),
m=min(R,G,B)
r=(M-R)/(M-m)
g=(M-G)/(M-m)
b=(M-B)/(M-m)
if(M==R) H=(6+b-g)/6
....

HSL	HSV
L=(M+m)/2	V=M
S=(M-m)/(M+m)	S=(M-m)/M

Filtering

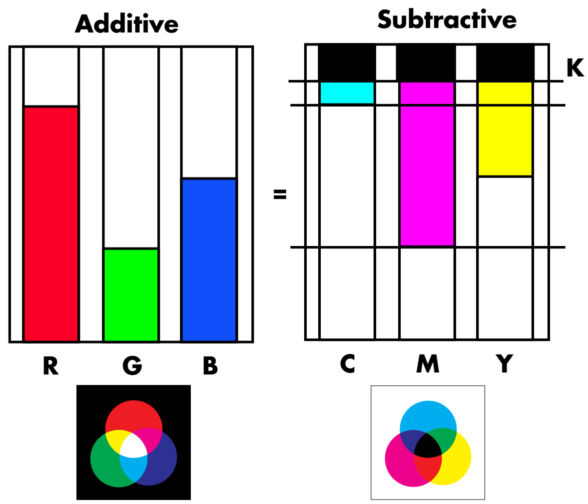
Reflection



Comments

- Transmission similar
- Things look different under different illuminations
- Multiplying color components is an approximation!

CMYK



$R = (1-C)\,(1-K)\,W$

$G = (1-M)\,(1-K)\,W$

$B = (1-Y)\,(1-K)\,W$

$K = G(1-\max(R,G,B))$

$C = 1 - R/(1-K)$

$M = 1 - G/(1-K)$

$Y = 1 - B/(1-K)$