CS148: Introduction to Computer Graphics and Imaging

Light and Color

Painting by Cheryl Yaney

Topics

Physics of light

- Electromagnetic spectrum
- Fundamental operations: add, filter, measure

Perception of color

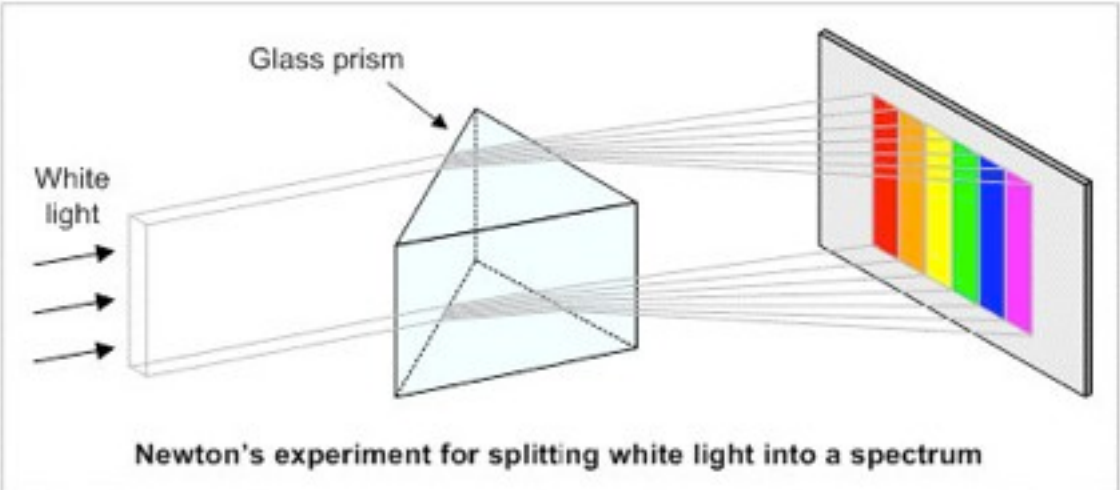
- Trichromatic theory
- Luminance

Art

- Color terms
- Color wheels and intuitive color spaces

Physics of Light

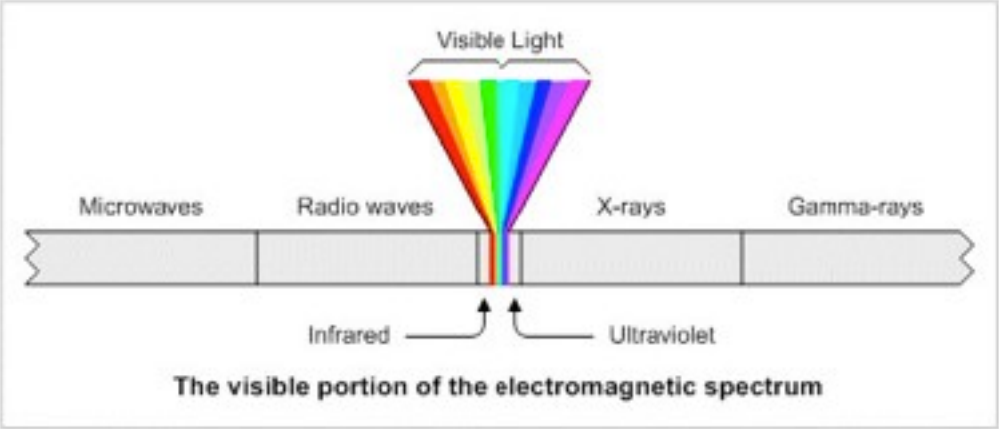
Light



Newton's experiment for splitting white light into a spectrum

Image from Clive Maxfield

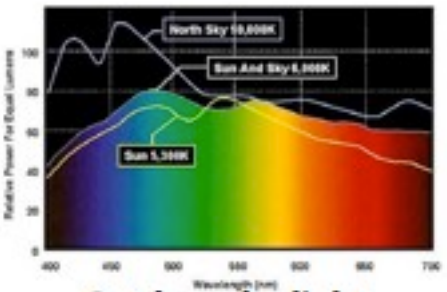
Electromagnetic Spectrum



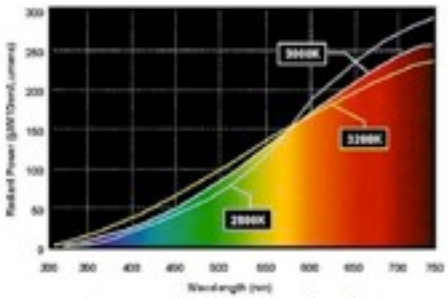
The visible portion of the electromagnetic spectrum

Image from Clive Maxfield

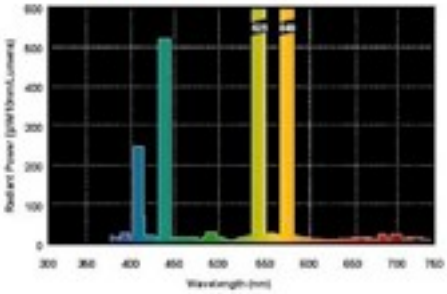
Spectral Power Distribution of Lights



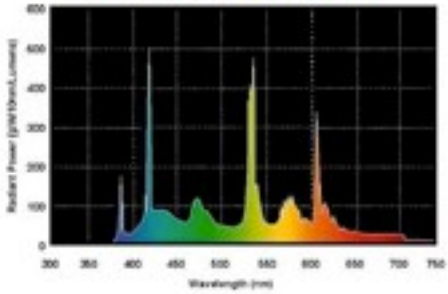
Outdoor daylight



Incandescent bulb

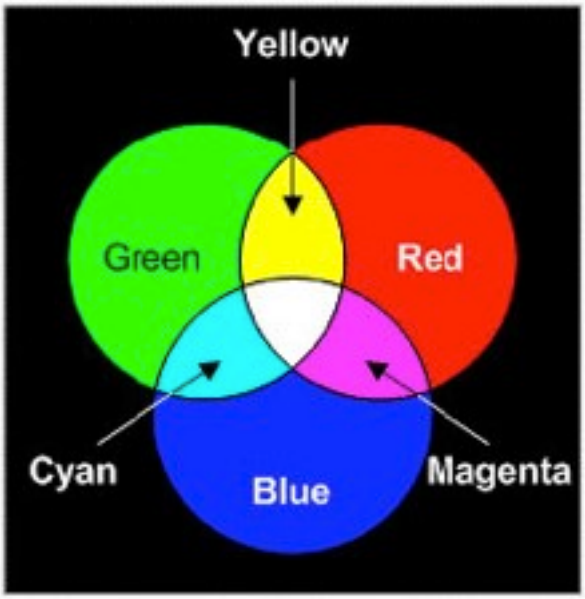


Mercury lamp

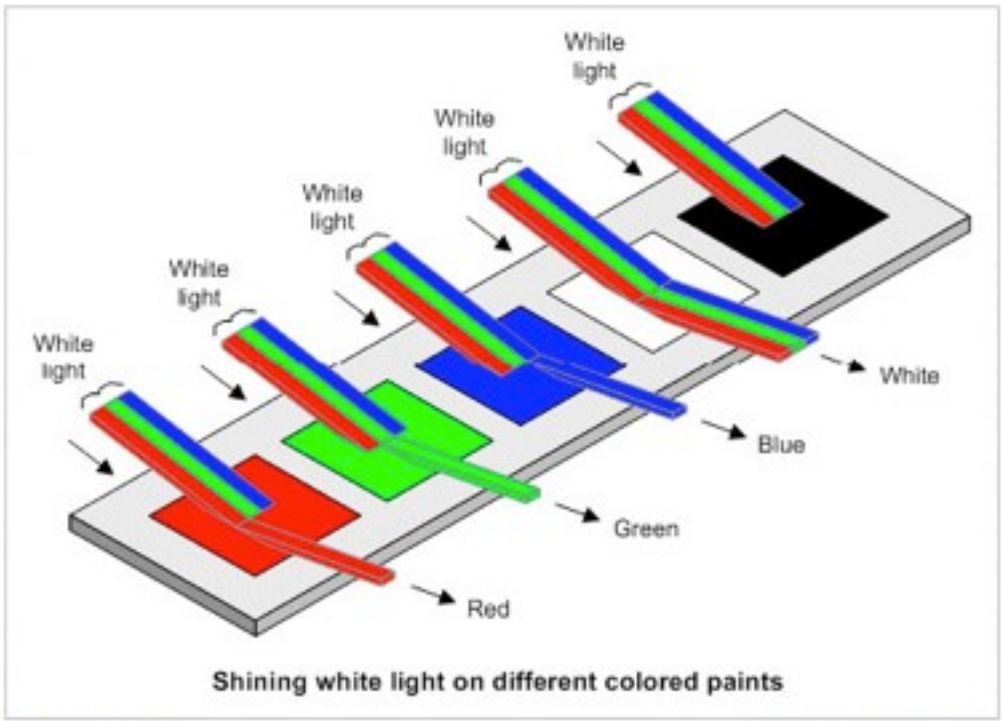


SP65 triphosphor fluorescent

Adding Light Energy



Reflecting Light



Shining white light on different colored paints

Light Operations

Add spectra $E(\lambda) = S_1(\lambda) + s_2(\lambda)$

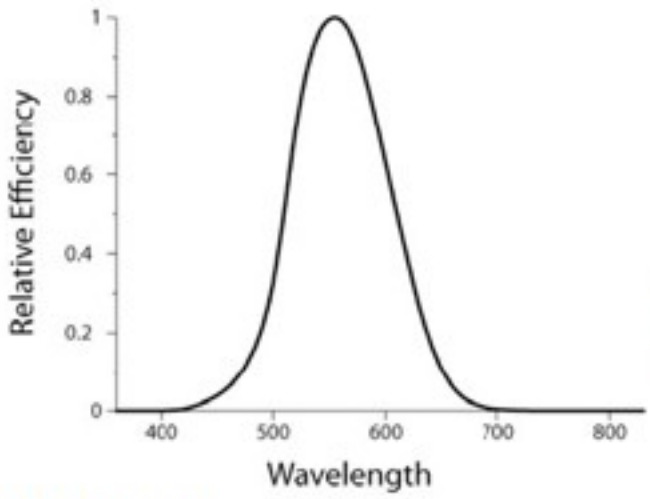
$$R = R_1 + R_2$$
$$G = G_1 + G_2$$
$$B = B_1 + B_2$$

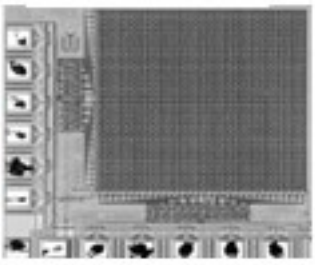
Multiply spectra $E(\lambda) = T(\lambda)S(\lambda)$

$$R = R_1 R_2$$
$$G = G_1 G_2$$
$$B = B_1 B_2$$

Measuring Light

Photon detector $R = \int R(\lambda)E(\lambda)\,d\lambda$





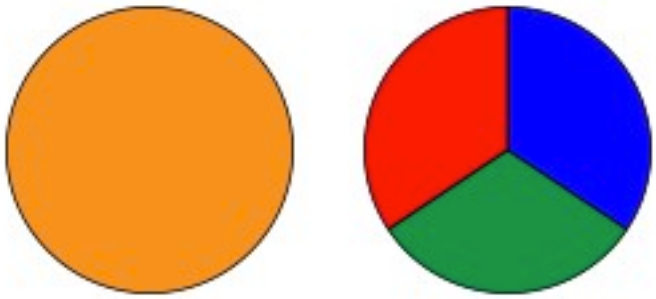
Trichromatic Theory

Color Matching Experiment

Adjust brightness of three primaries

Lasers: R = 700 nm, G = 546 nm, B = 435 nm

until it "matches" another color C



C = R + G + B

Result: all colors can be matched with three colors

Therefore: humans have trichromatic color vision

Human Retina: Three Types of Cones

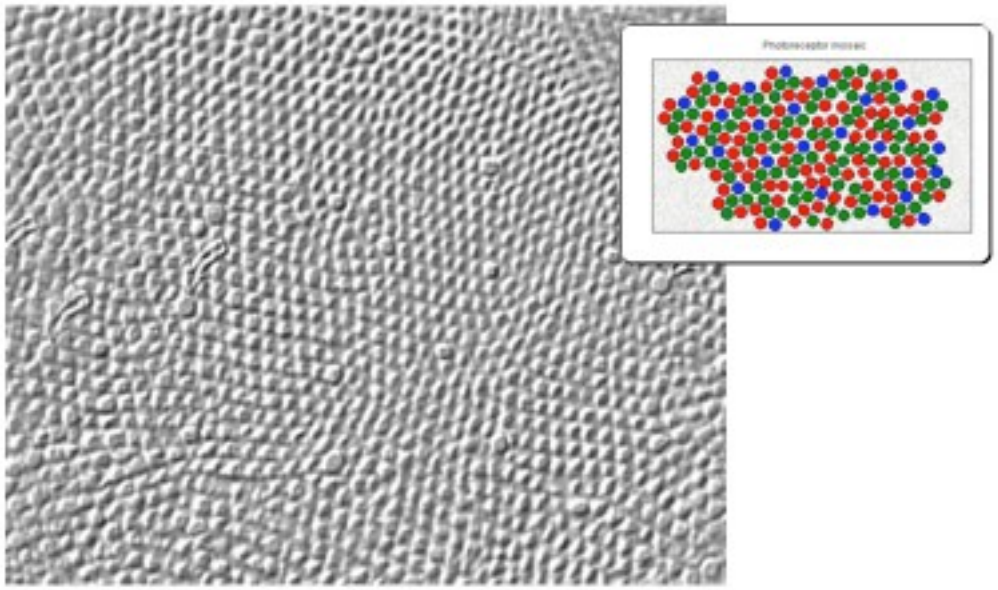
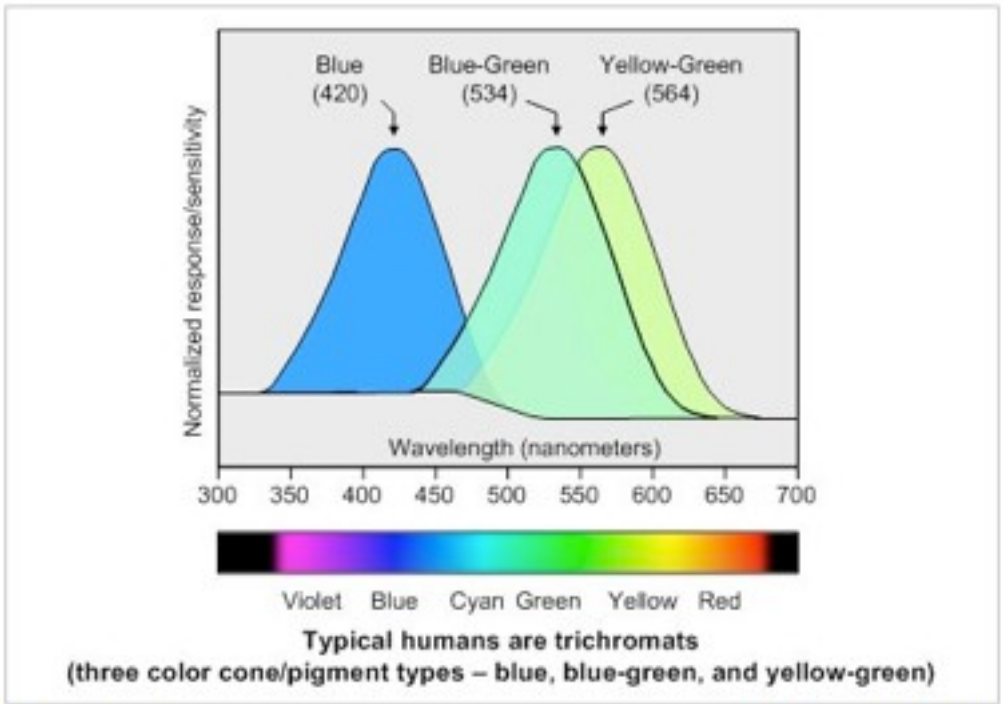


Fig. 13. Tangential section through the human fovea.
Larger cones (arrows) are blue cones.

From http://webvision.med.utah.edu/imageswv/fovmoswv.jpeg

Response of Three Cones



Typical humans are trichromats
(three color cone/pigment types – blue, blue-green, and yellow-green)

Cone Response

Three cones

L (long) $$L = \int L(\lambda)E(\lambda)\,d\lambda$$

M (medium) $$M = \int M(\lambda)E(\lambda)\,d\lambda$$

S (short) $$S = \int S(\lambda)E(\lambda)\,d\lambda$$

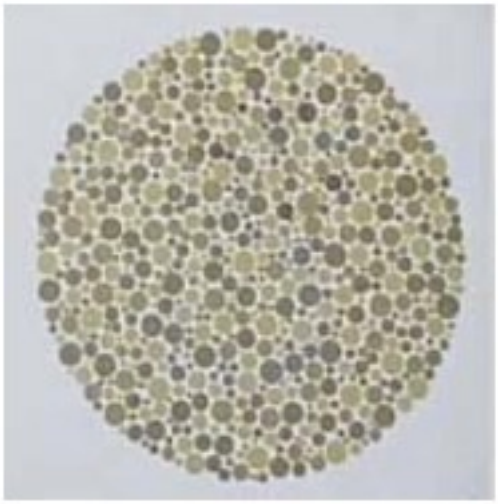
Metamerism: Different spectra, same color

Color Blindness: Ishihara Test

Normal

http://www.toledo-bend.com/colorblind/Ishihara.html

Color Blindness: Ishihara Test



Normal Deuteranopia

http://www.toledo-bend.com/colorblind/Ishihara.html

Types of Color Blindness

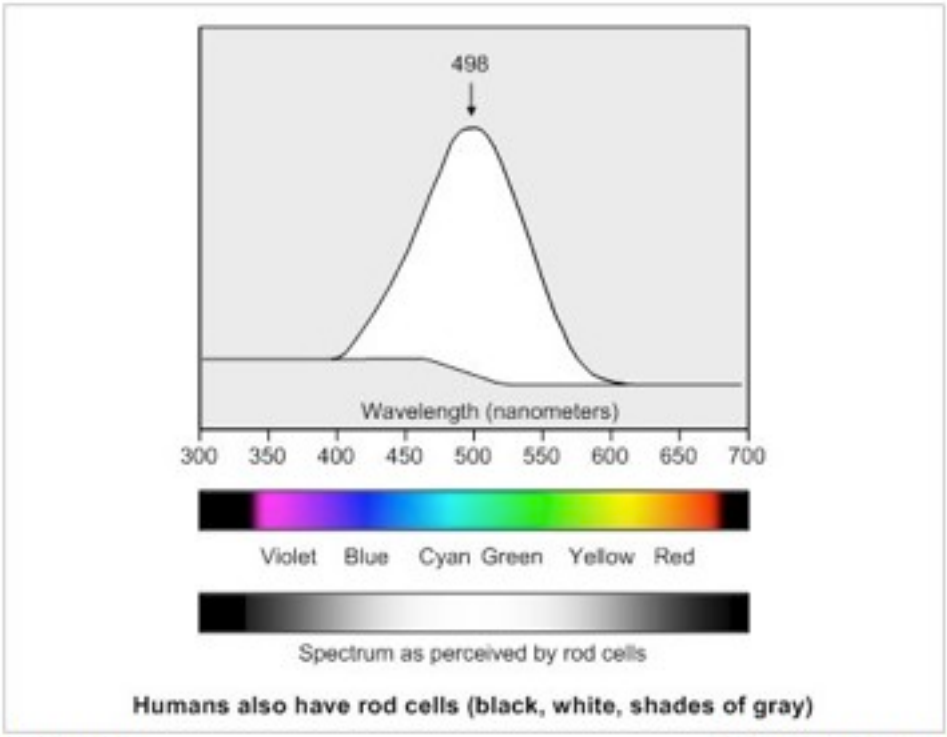
Dichromacy: missing pigment (10% M, 1% F)

- Protanopia – missing L
- Deuteranopia – missing M (red-green)
- Tritanopia – missing S

Normal Deuteranopia Tritanopia

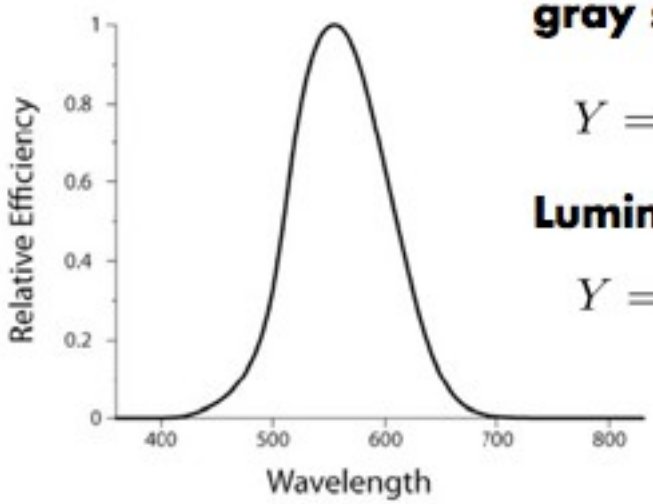
www.vischeck.com

Rod



Humans also have rod cells (black, white, shades of gray)

Luminance



Compare color to a gray source

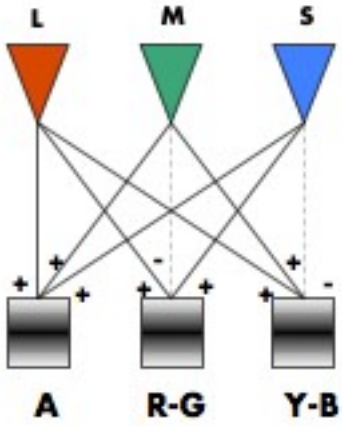
$$Y = \int V(\lambda)E(\lambda)\,d\lambda$$

Luminance (B&W TV)

$$Y = 0.30R + .59G + .11B$$

Perceptual Models of Color

Early Visual Processing

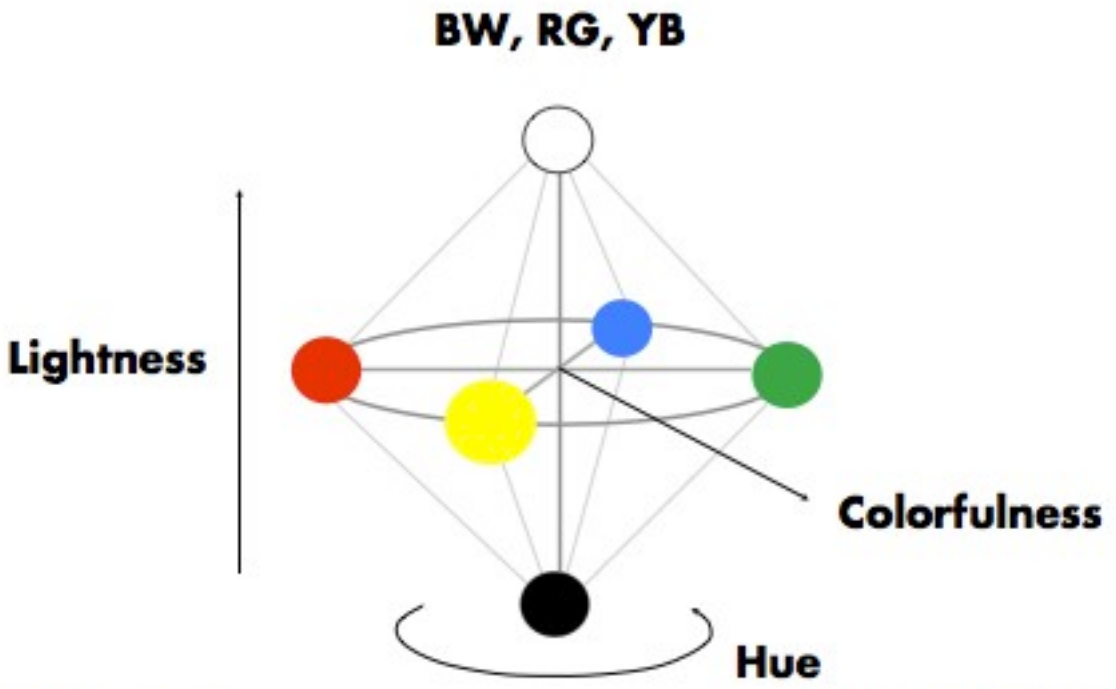


$$A = R + G + B$$

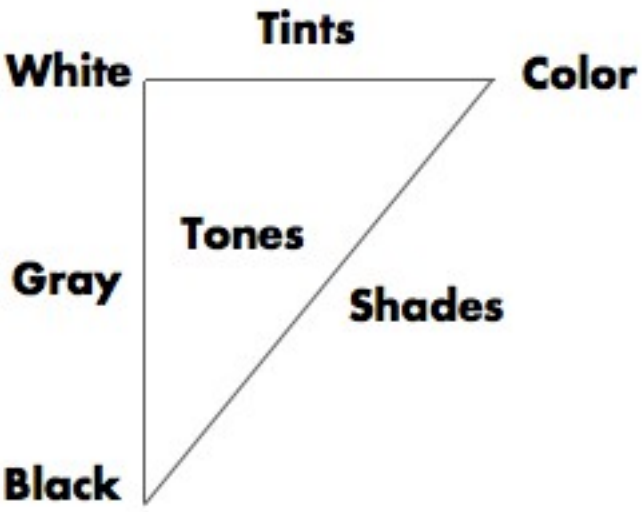
$$(Y - B) = R + G - B$$

$$(R - G) = R - G$$

Perceptual Organization

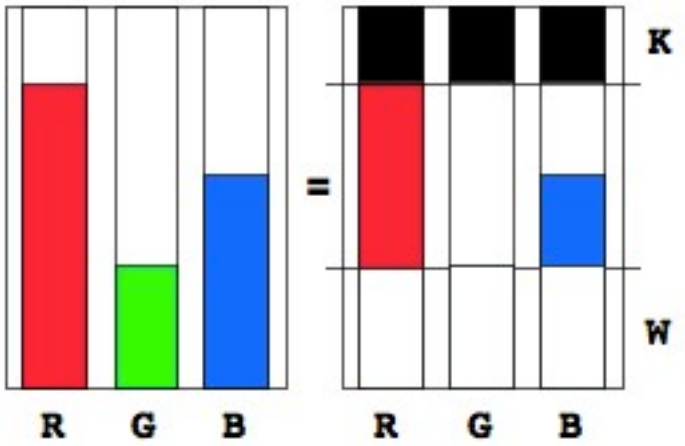


Intuitive Color Space



MetaDesign Color Picker

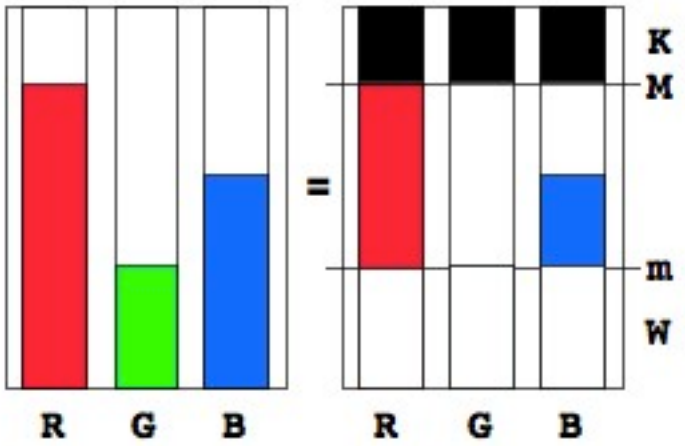
RGB to HSV



W = White

K = Black

RGB to HSV



W = m

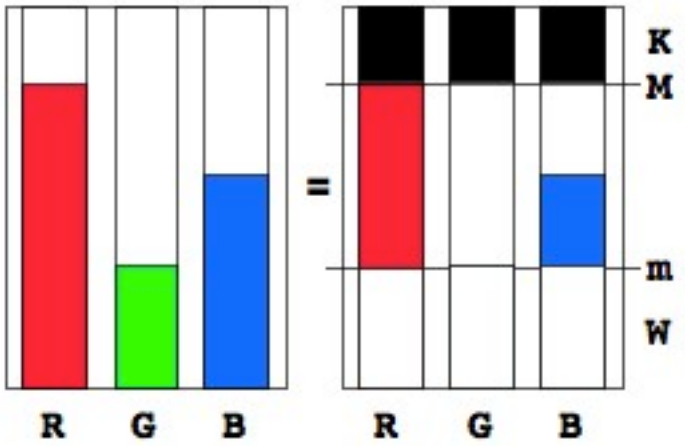
K = (1-M)

where

M = max(R,G,B)

m = min(R,G,B)

RGB to HSV



Value

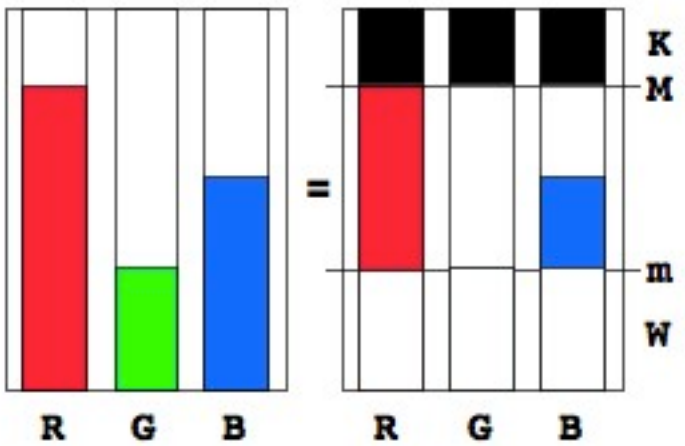
$V = M$

Saturation

$m = V*(1-S)$

$S = (M-m)/M$

RGB to HSV

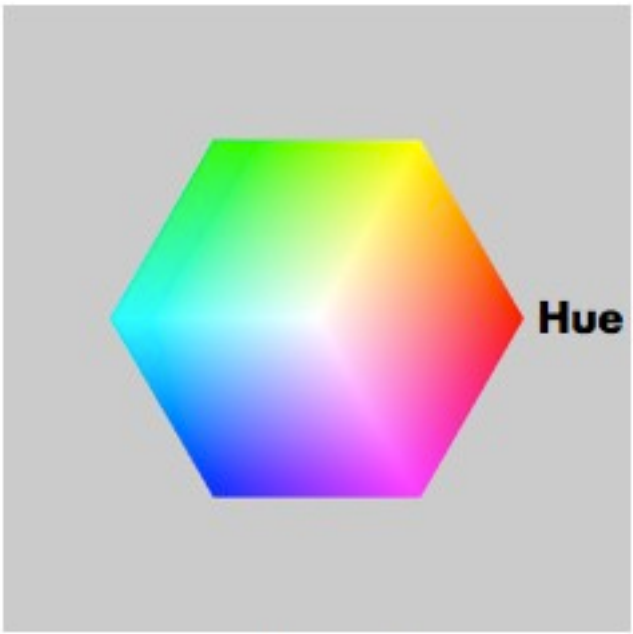


$r=(M-R)/(M-m)$

$g=(M-G)/(M-m)$

$b=(M-B)/(M-m)$

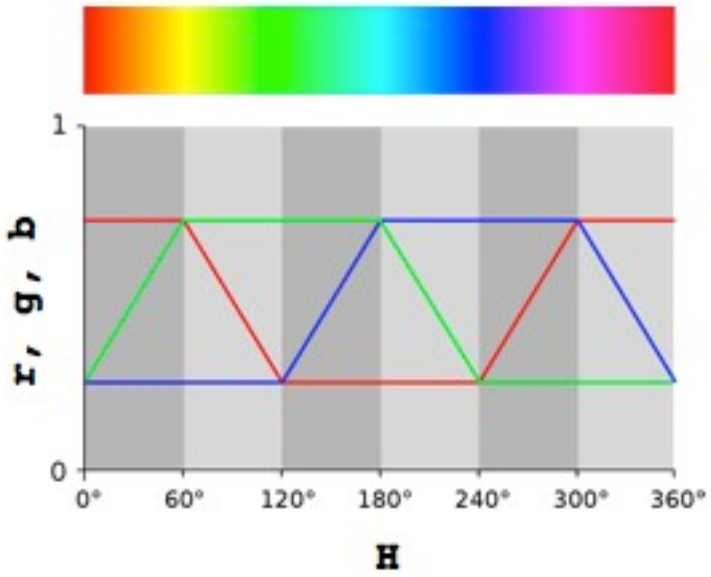
RGB to HSV



Hue is the angle

Color Cube

RGB to HSV




```
if    (b==0)
  H = (1+g-r)*60
elif (r==0)
  H = (3+b-g)*60
elif (g==0)
  H = (5+r-b)*60
```

Things to Remember

Physics of color

- Adding light spectra
- Transmission and reflection
- Measurement

Perception of color

- Three colors will match another color
- Trichromatic because we have 3 cones
- Explains metamerism, color blindness
- Perceptual organization: BW, YB, RG
- Hue-Saturation-Value