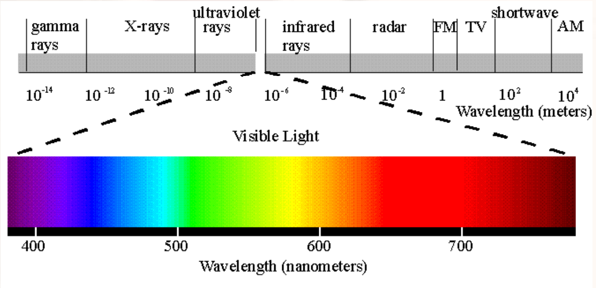
Color Seminar

Mark Shaw
Hewlett Packard Company
mark.q.shaw@hp.com

SENSITOMETRY AND THE HUMAN VISUAL SYSTEM

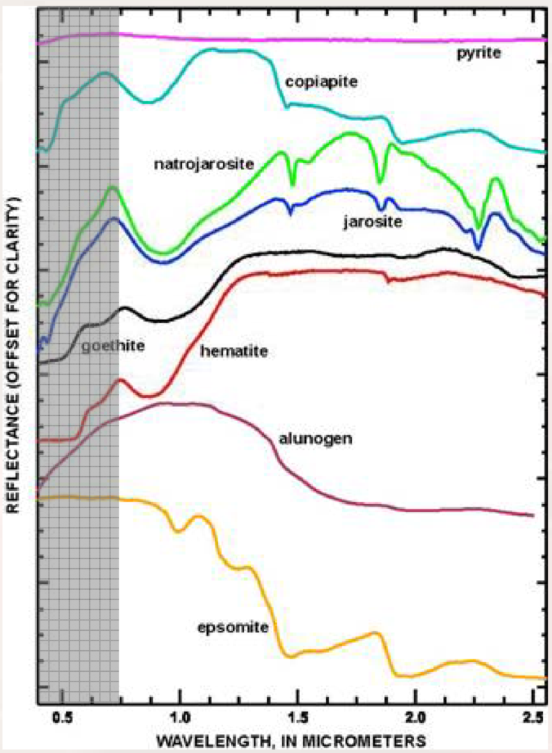
- ***Basics***
  - Spectral Properties
    - Visible spectrum
    - Wavelength range ~ 400-700nm

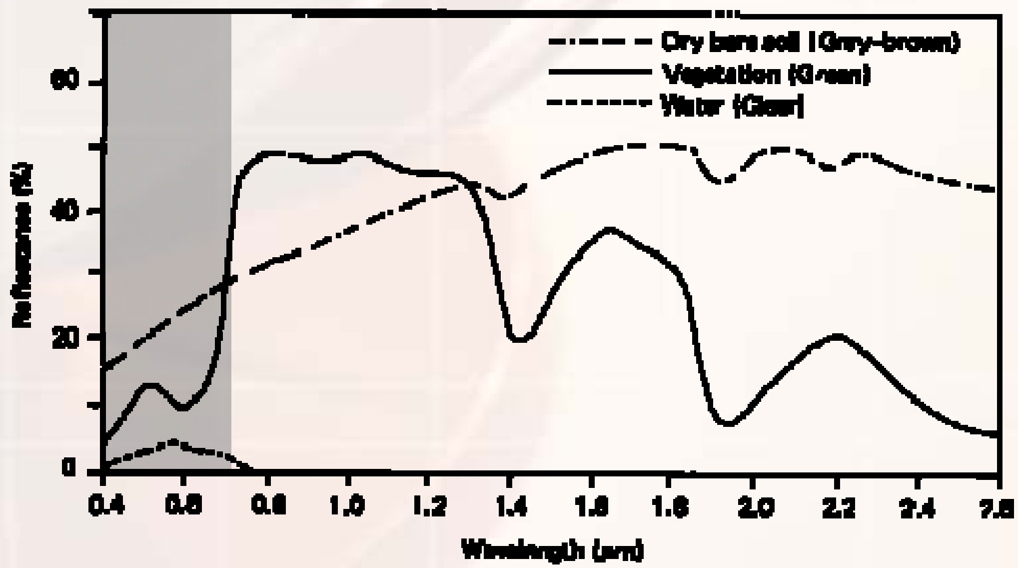


  - Reflectance
    - Light hits an object, then the eye
    - Perception is relative to a white reference

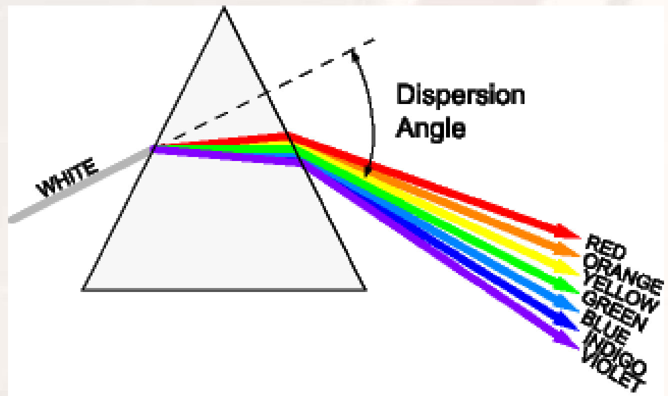
  - Radiance
    - Emissive device
    - Not illuminant dependant

- What does reflectance factor look like?

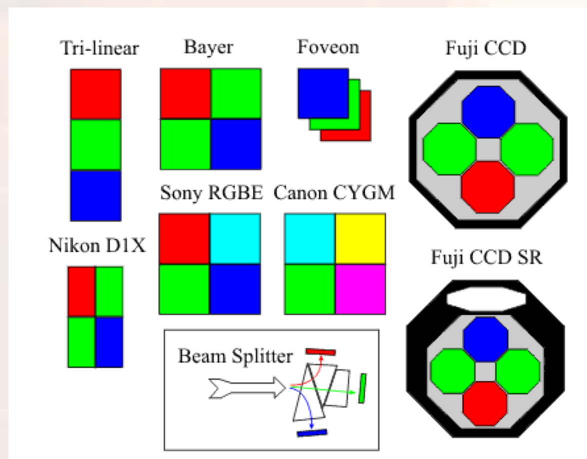




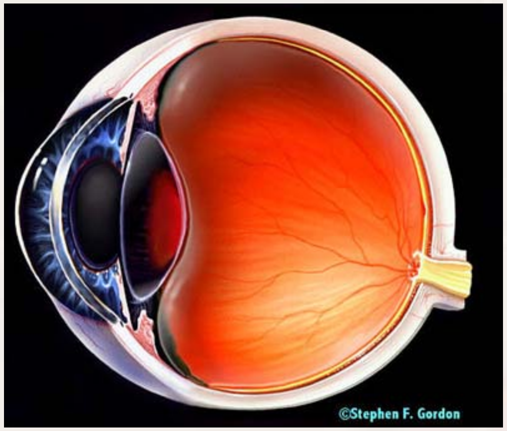
- How do we measure color?
  - Spectral Analysis



  - Tri-Chromatic



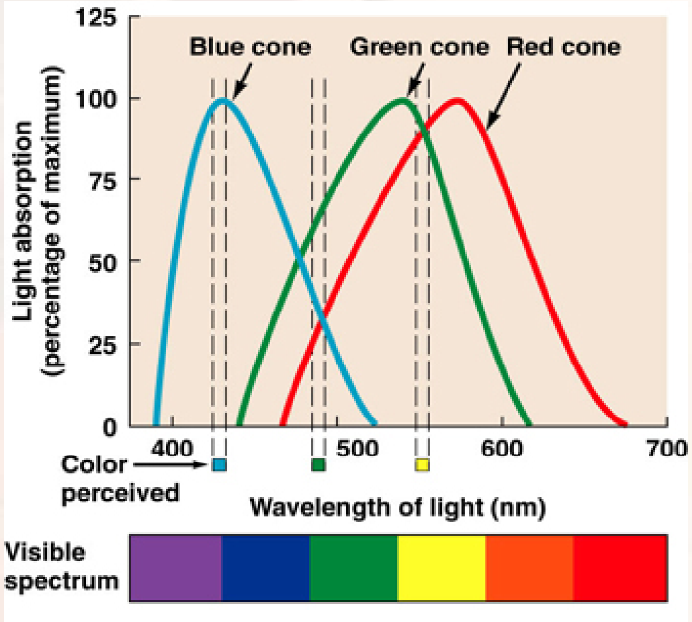
- ***The Human Visual System***



– The eye is an integrator

– Rods vs Cones

- Scotopic - Night vision, only Rods
- Mesopic - Dusk vision, both Rods and Cones
- Photopic - Day vision, only Cones

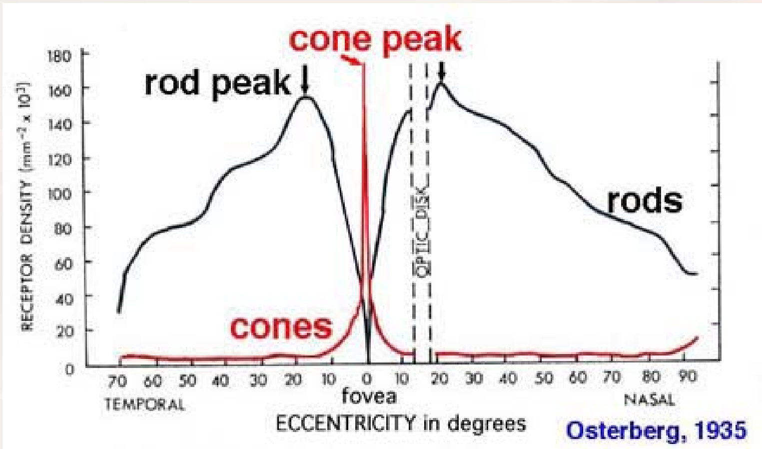


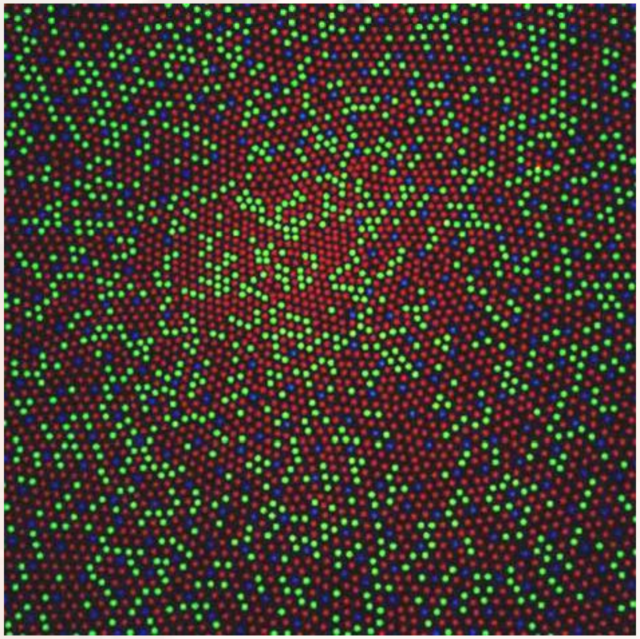
http://www.colorado.edu/intphys/Class/IPHY3730/image/figure6e.jpg

- ***Not all things are made equal***

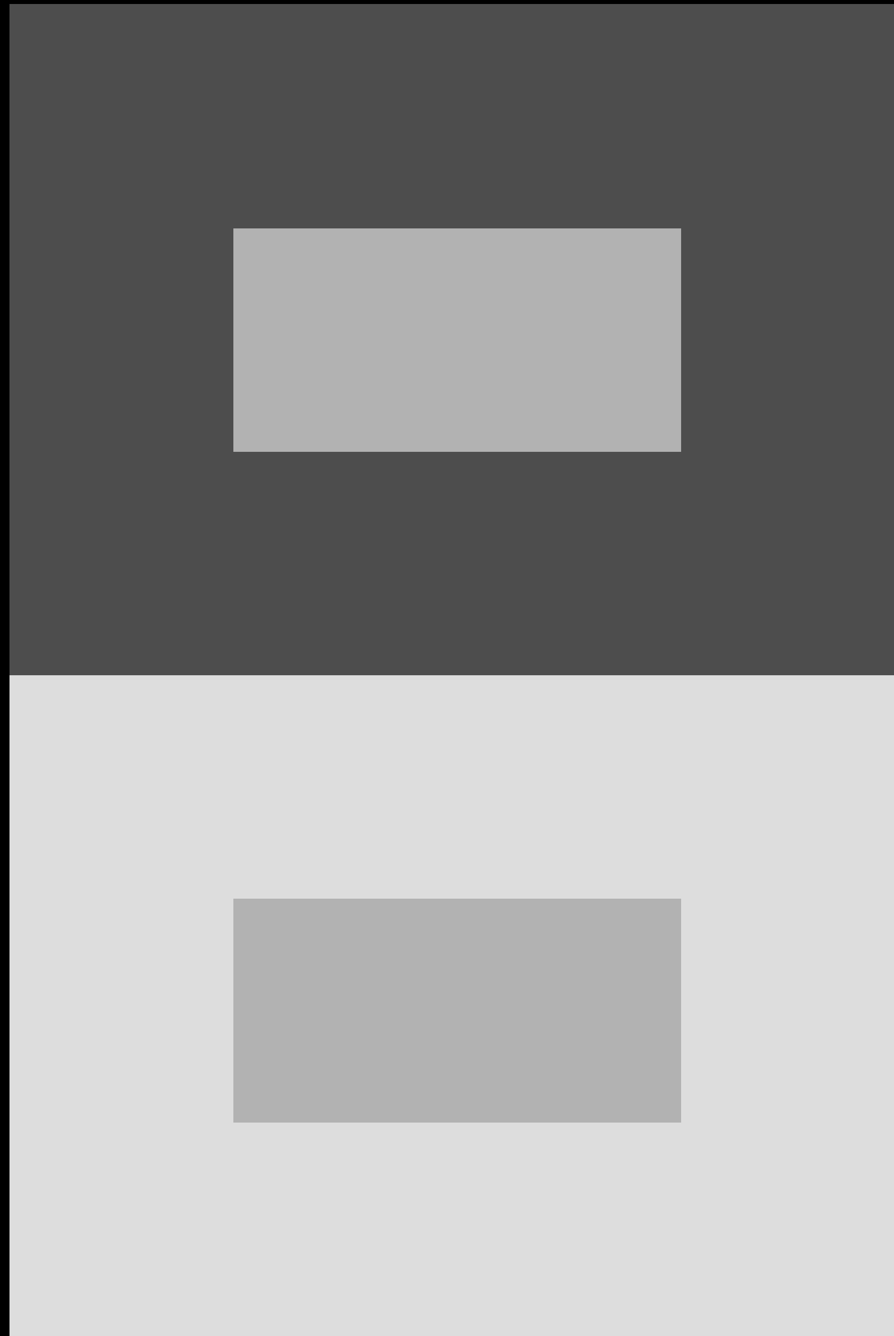
  – Foveal Density

    – 20 L Cones
    – 10 M Cones
    – 1 S Cones

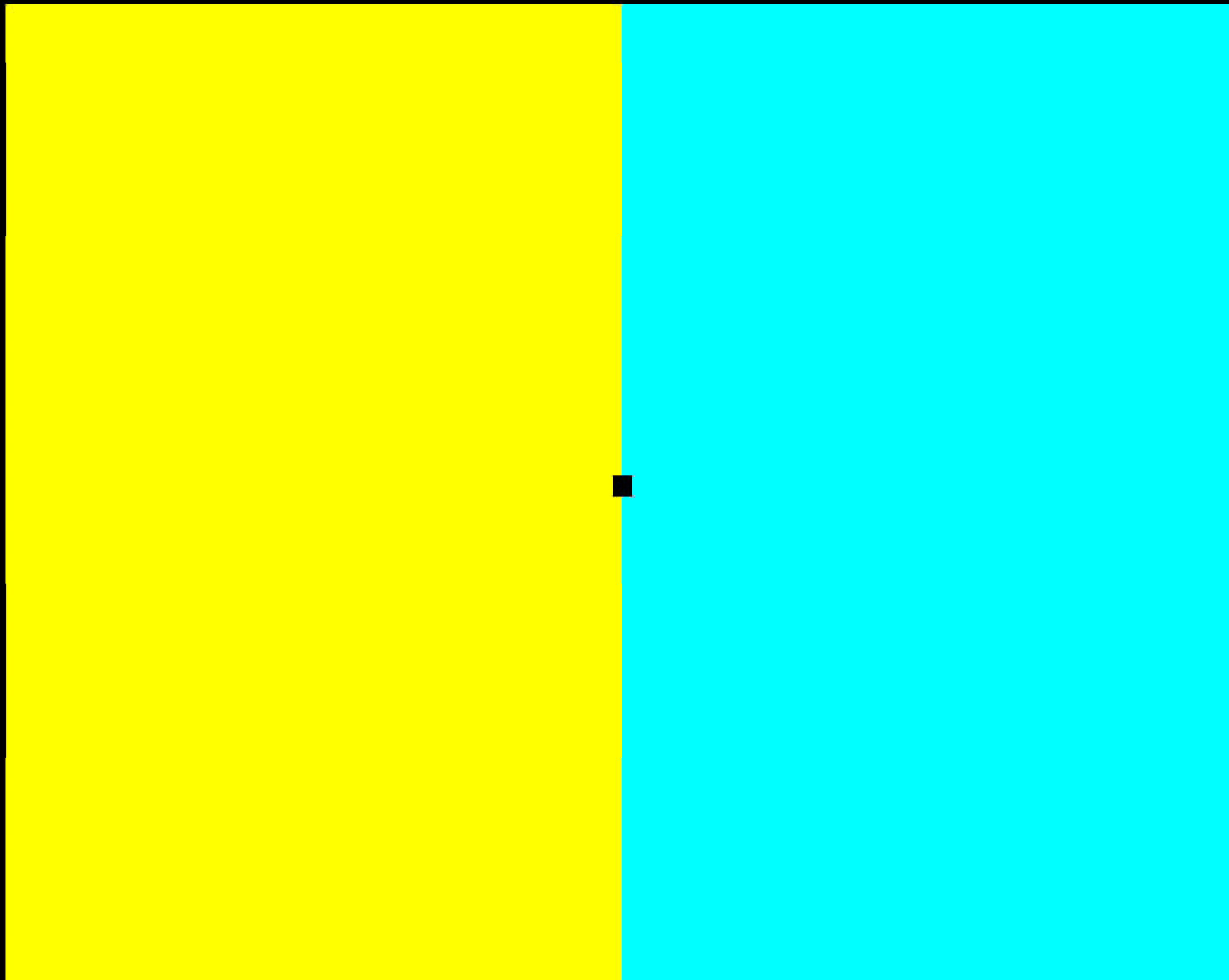




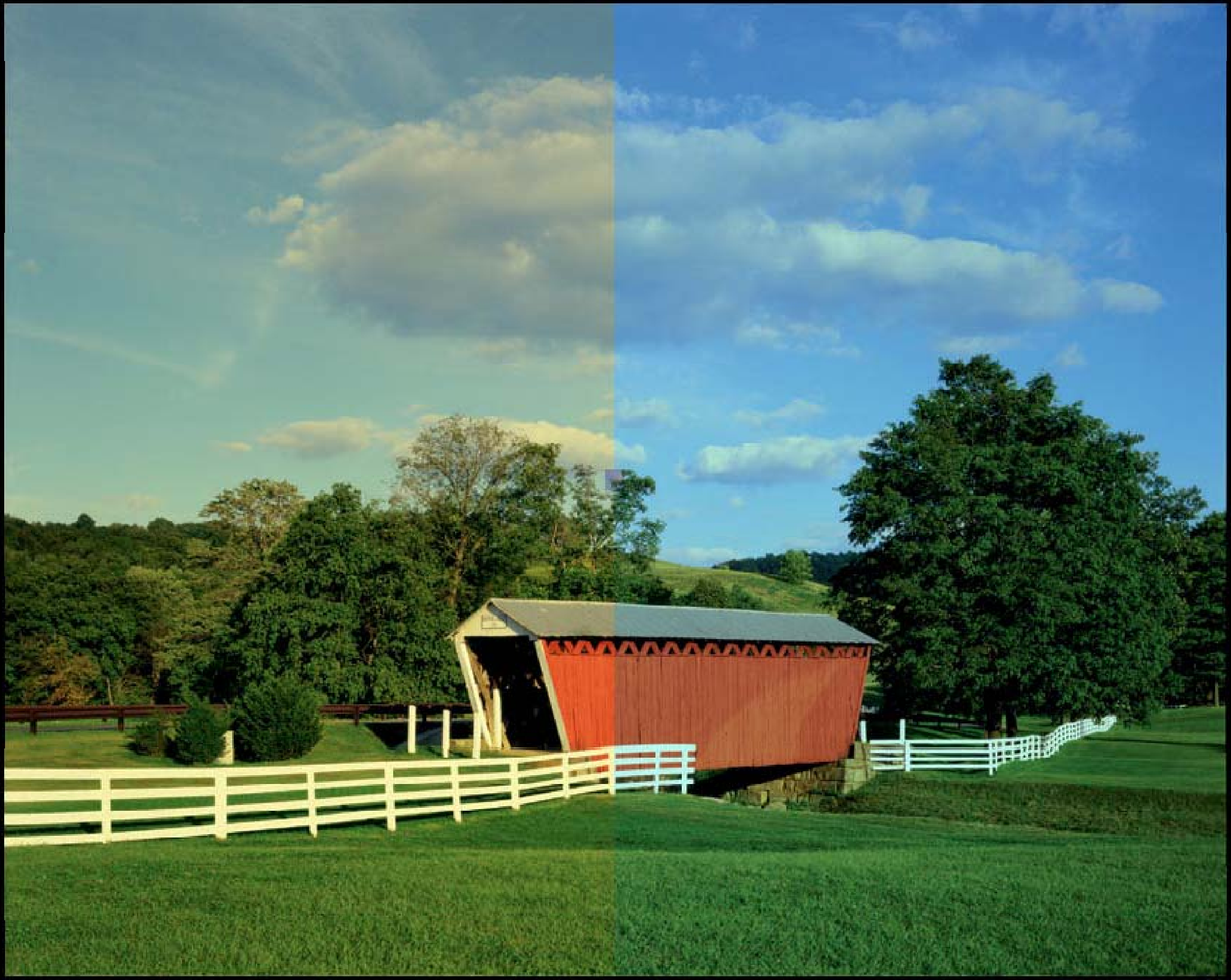
http://www.beercolor.com/color_basics1_files /image005.jpg



Color Constancy Demo

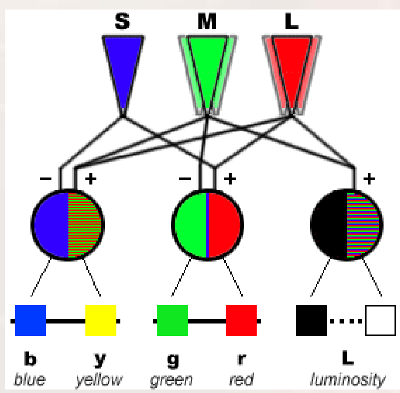


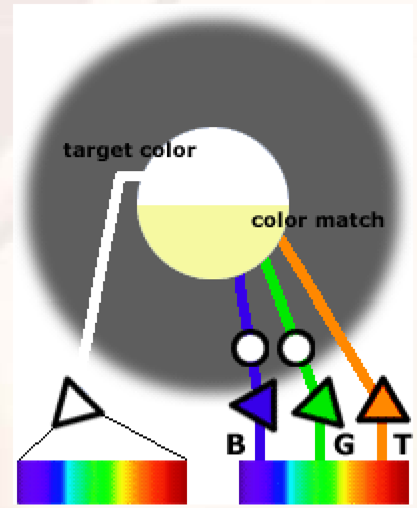
Look at the black square



COLOR THEORY

- ***Color Theory***
  - Trichromatic Theory — Young and Helmholtz (1800's)
  - Opponent Theory — Herring (Late 1800's)





www.handprint.com/HP/WCL/color2.html

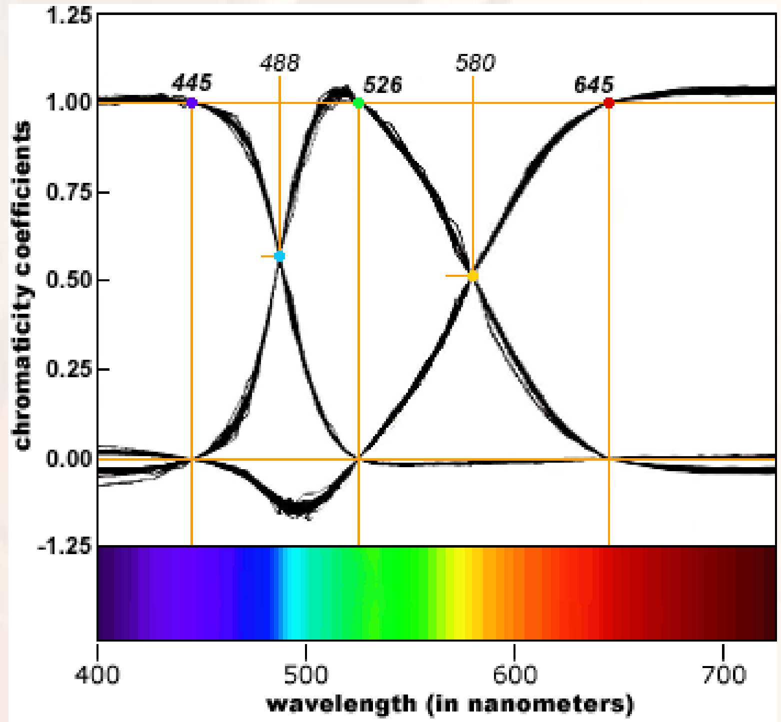
- ***Color Matching***

  – How do we get a color match?

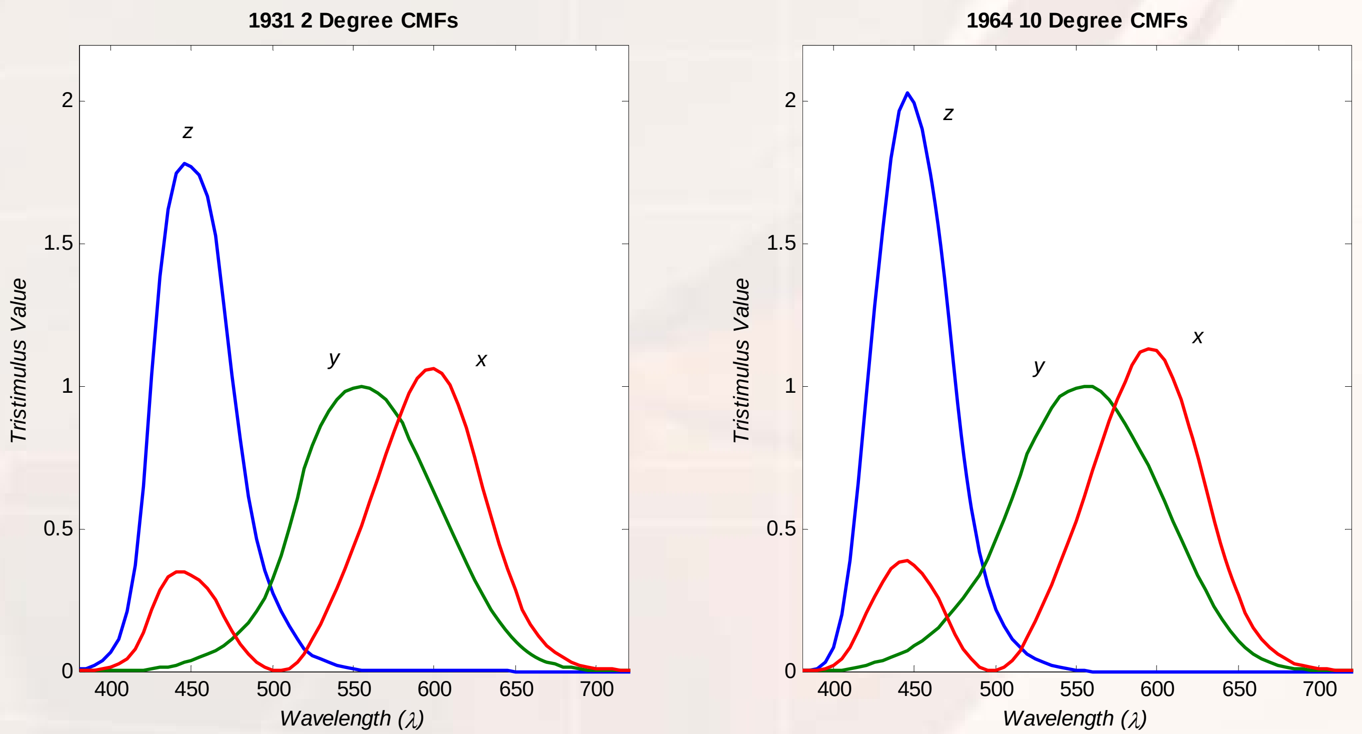
    - Subjectively
    - Quantatively

  – Every observer is slightly different

    - Work of Wright and Guild (1920's)
    - Achromatic mixing experiment
    - Negative lobes occurred because the third primary was needed in order to make a match, that primary essentially acts as a subtraction



- CIE Color Matching Functions (1931 2º Observer and 1964 10º Observer)



$$X = \int_{400}^{700} \Phi(\lambda)\,\bar{x}(\lambda)\,d\lambda \qquad Y = \int_{400}^{700} \Phi(\lambda)\,\bar{y}(\lambda)\,d\lambda$$

$$Z = \int_{400}^{700} \Phi(\lambda)\,\bar{z}(\lambda)\,d\lambda$$

Reflectance

$\Phi = S(\lambda)\, R(\lambda)$

S is the illuminant spectra
R is the reflectance factor of the object

Radiance

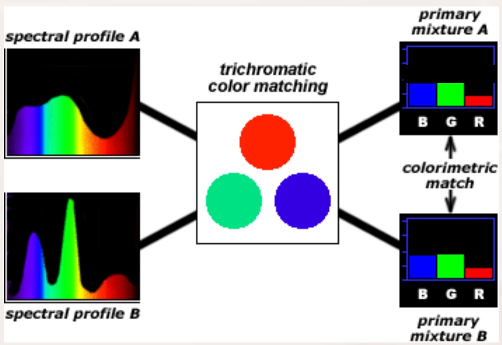
$\Phi = L(\lambda)$ or $E(\lambda)$

L is the Luminosity, also called
E (Emittance)

- A colorimetric match if …

Φ_1

Φ_2



$$X_1 = X_2$$

$$\int_{400}^{700} \Phi_1(\lambda)\bar{x}(\lambda)\,d\lambda = \int_{400}^{700} \Phi_2(\lambda)\bar{x}(\lambda)\,d\lambda$$

$$Y_1 = Y_2$$

$$\int_{400}^{700} \Phi_1(\lambda)\bar{y}(\lambda)\,d\lambda = \int_{400}^{700} \Phi_2(\lambda)\bar{y}(\lambda)\,d\lambda$$

$$Z_1 = Z_2$$

$$\int_{400}^{700} \Phi_1(\lambda)\bar{z}(\lambda)\,d\lambda = \int_{400}^{700} \Phi_2(\lambda)\bar{z}(\lambda)\,d\lambda$$

the tristimulus values match under specific conditions.

- ***Metamerism***

  – What does it mean if …

$$\int_{400}^{700} S_1(\lambda)R_1(\lambda)\bar{x}(\lambda)\,d\lambda = \int_{400}^{700} S_1(\lambda)R_2(\lambda)\bar{x}(\lambda)\,d\lambda$$

$$but$$

$$\int_{400}^{700} S_2(\lambda)R_1(\lambda)\bar{x}(\lambda)\,d\lambda \neq \int_{400}^{700} S_2(\lambda)R_2(\lambda)\bar{x}(\lambda)\,d\lambda$$

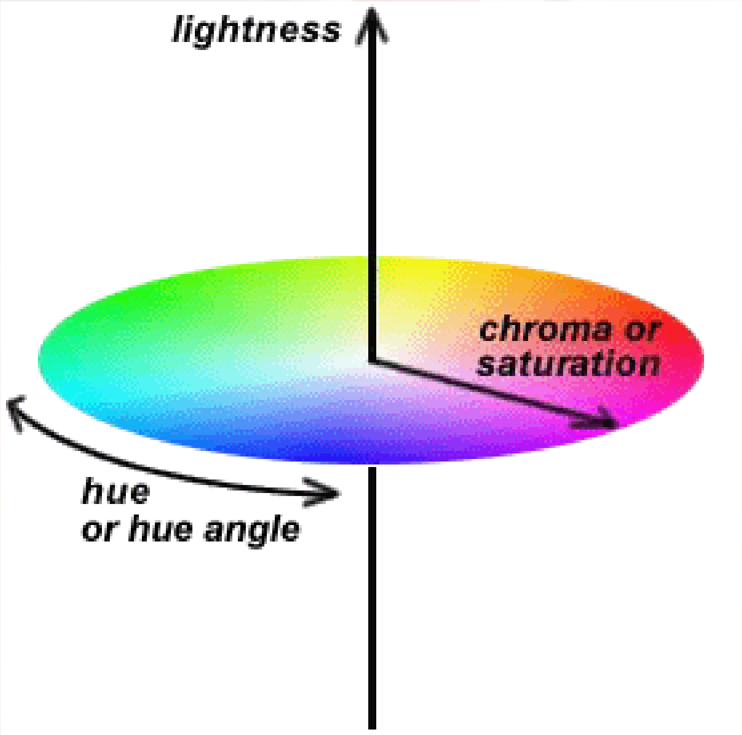
we have a metameric match under S_1 but not under S_2

- ***Observer Metamerism***
  - When two colors match for one observer but not for another
  - Color blindness is one example
- ***Illuminant Metamerism***
  - Two samples match under one light source, but not another

http://tqc.eu/images/products/150x150/colorbox_lightsources_animation.gif

COLOR APPEARANCE

- ***Color Appearance Modeling***
  - Absolute
    - Hue
    - Brightness
    - Colorfulness
  - Relative
    - Hue
    - Lightness
    - Chroma



– CIE 1976 (L*a*b*) Color Space - aka CIELAB

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]$$

Opponent Signals

$$X_n = \int_{400}^{700} S(\lambda)\bar{x}(\lambda)\,d\lambda$$

$$Y_n = \int_{400}^{700} S(\lambda)\bar{y}(\lambda)\,d\lambda$$

$$Z_n = \int_{400}^{700} S(\lambda)\bar{z}(\lambda)\,d\lambda$$

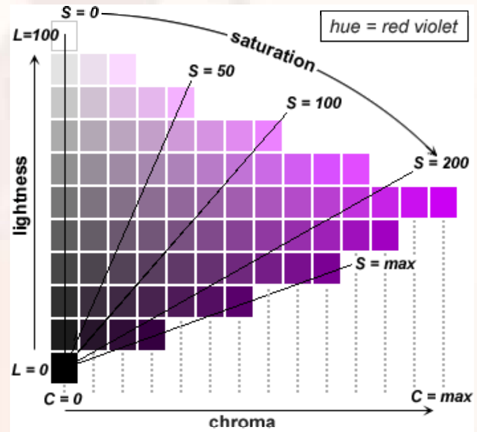
X_n Y_n Z_n are the tristimulus values of the white point

– Converting Cartesian co-ordinates into a Polar space

$$L^* = L^*$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

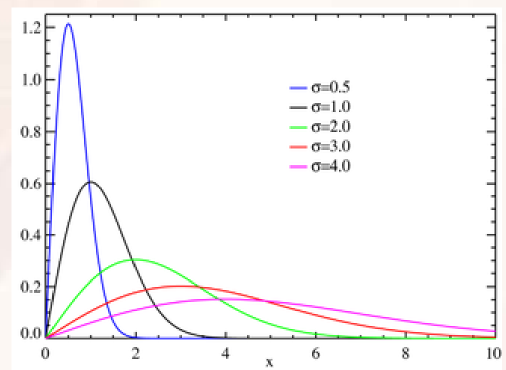
$$h_{ab}^* = \tan^{-1}\left(\frac{b^*}{a^*}\right)$$



– Calculating Color Differences

$$\Delta E_{76} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

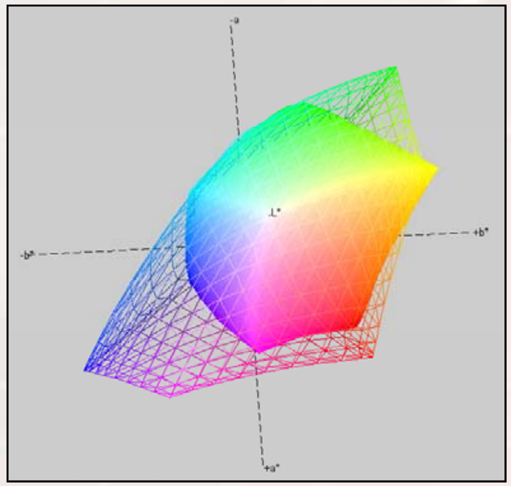
Color differences are not normally distributed



COLOR MODELING

- ***How does one map colors between devices?***

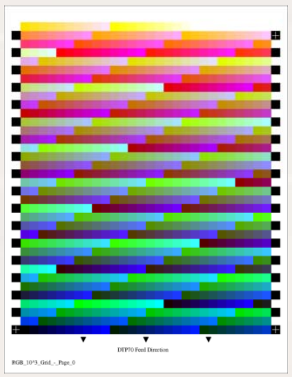
  - *First one must build colorimetric models of the source and destination devices*

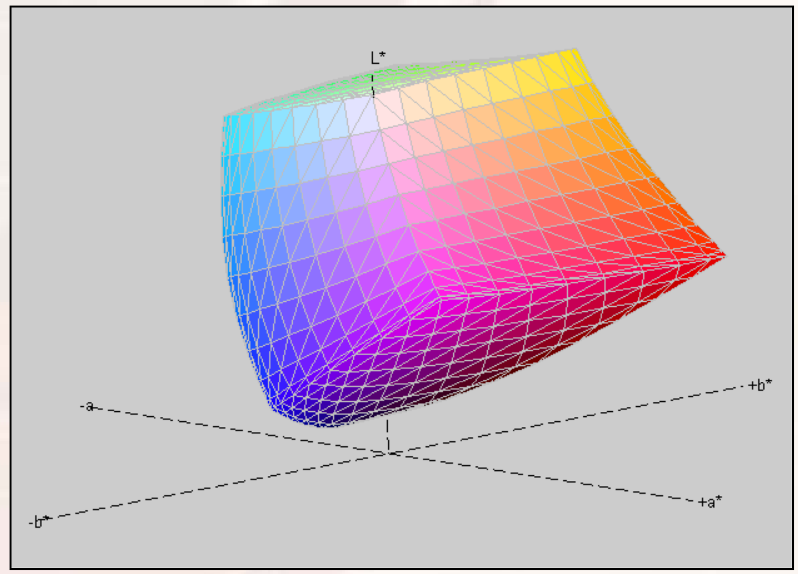


*The range of colors the device can create is called the "**Color Gamut**"*

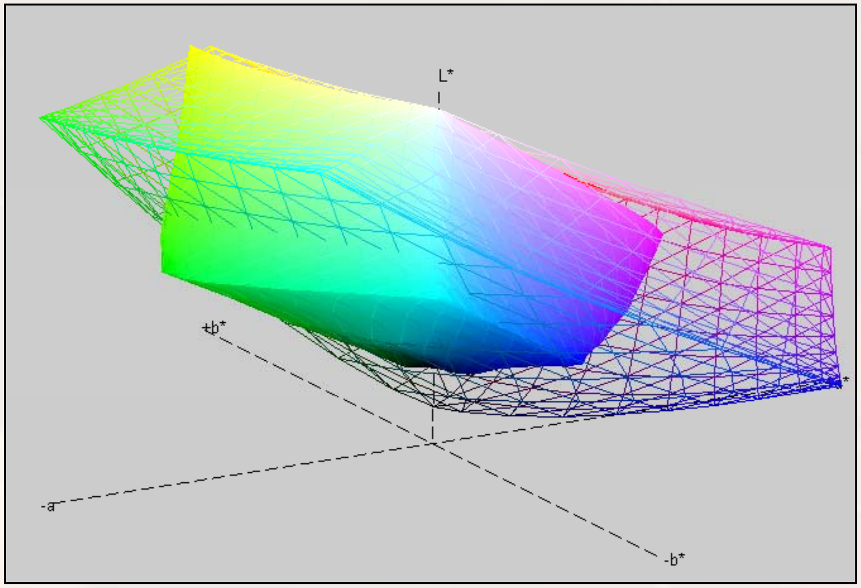
  - *Then one must map all colors from the source gamut to the destination gamut*

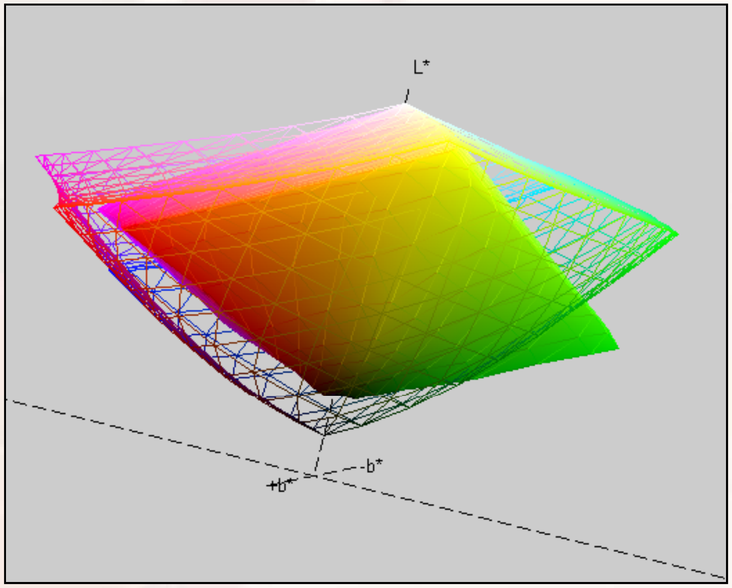
- ***How does one build a model of a device?***





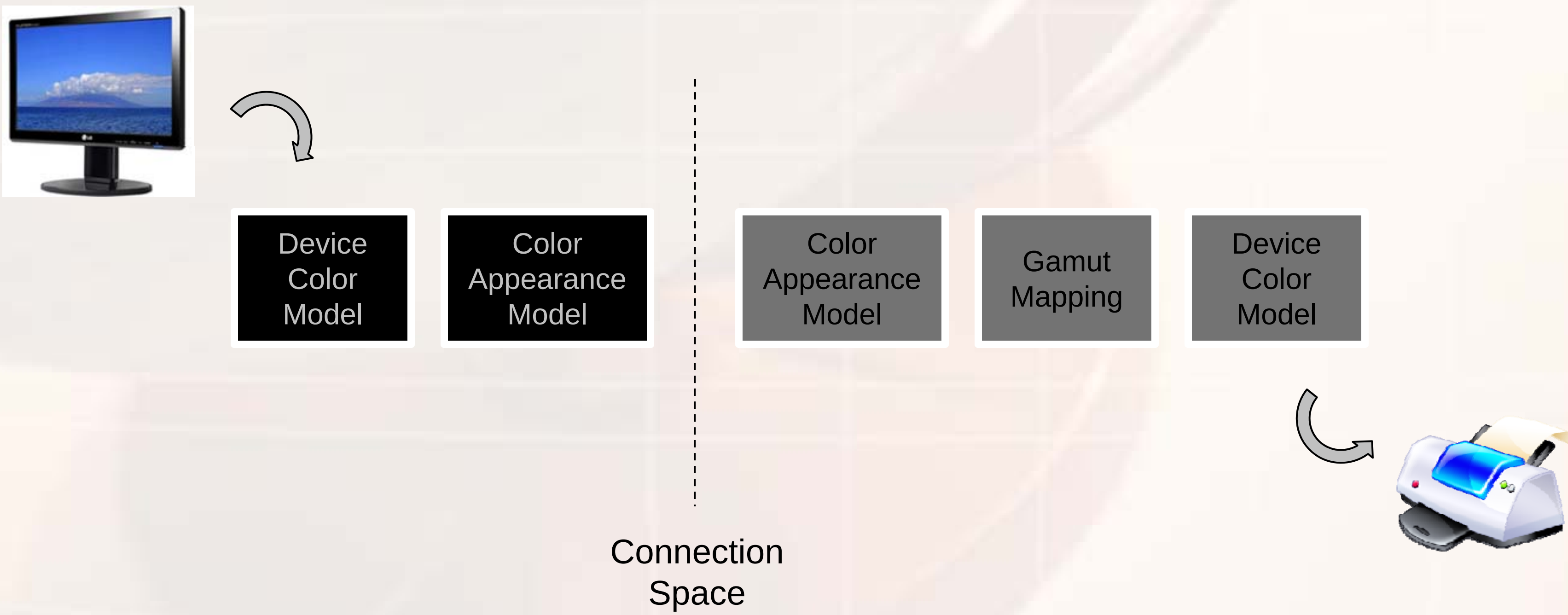
- ***Comparing Device Gamuts***





The process of mapping colors from one device to another is called ***Gamut Mapping***

- ***Color Conversion Workflow***



SUMMARY

- The Human Visual System is an integrator
- A colorimetric match only holds if the viewing conditions remain unchanged
- Metamerism is a very important concept
  - Most current imaging systems rely upon the a metameric match
  - Spectral matches would be ideal, but are currently prevented by technological limitations
- Color appearance models enable the communication of color in meaningful terms
- Color Modeling enables one to communicate color consistently