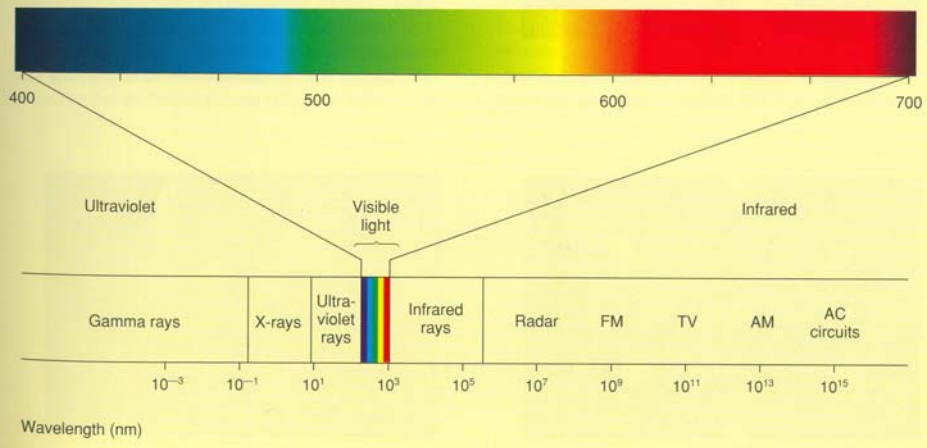
PERCEIVING COLOR

ICS 280: Visual Perception

Functions of Color Vision

- Object identification
  - Evolution : Identify fruits in trees
- Perceptual organization
- Add beauty to life

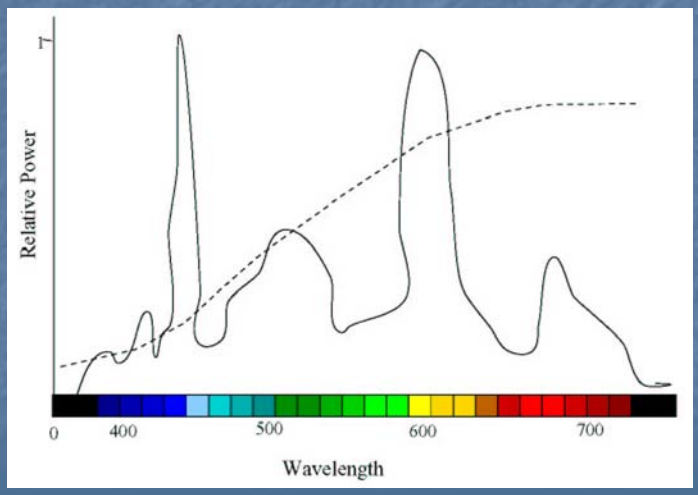
Visible Light Spectrum



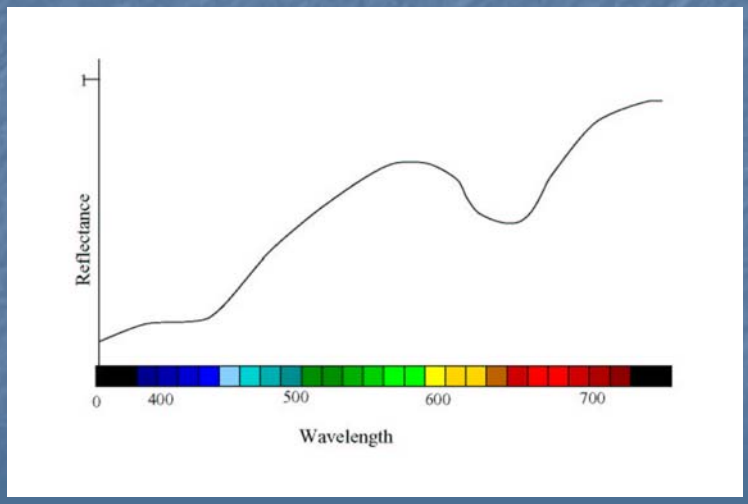
Color is due to..

- Selective emission/reflection of different wavelengths by surfaces in the world
- Different response to different wavelengths of the eye

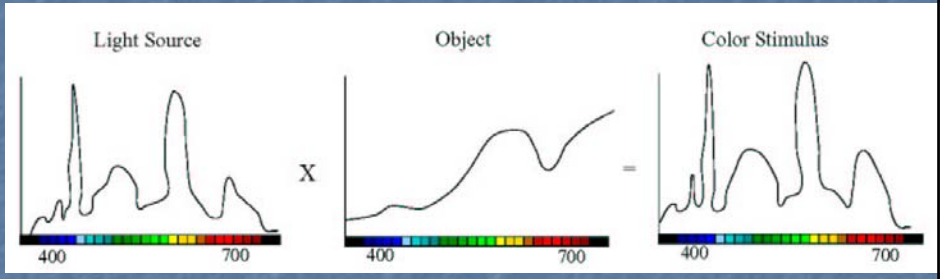
Illumination – I(λ)



Reflectance – R(λ)



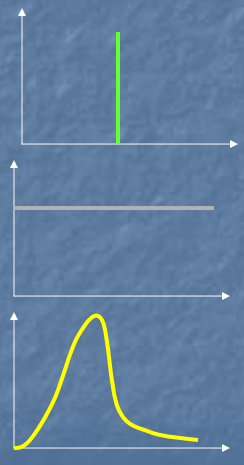
Color Stimuli – C(λ)



$$I(\lambda) \times R(\lambda) = C(\lambda)$$

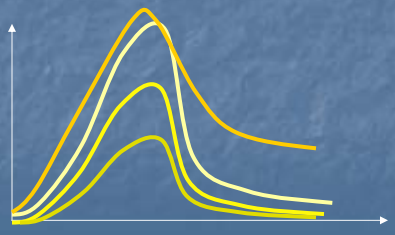
Different Types of Stimuli

- Monochromatic
  - Laser
- Achromatic
  - Sunlight (close to)
- Polychromatic
  - Most common



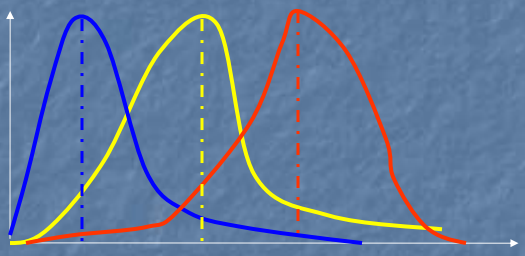
Properties of Stimulus

- Luminance
  - Amount of stimulus in cd/m^2
  - Perceived as brightness
  - Governed by the area under the curve



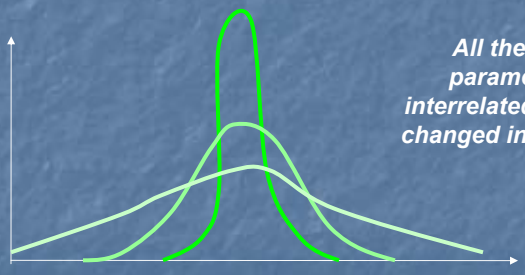
Properties of Stimulus

- Hue
  - Predominant wavelength
  - Mean



Properties of Stimulus

- Saturation
  - Amount of Achromatic light
  - Variance from the mean



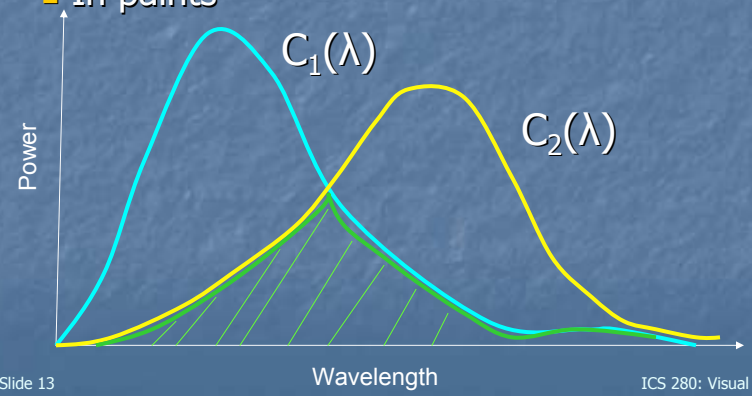
All these three parameters are interrelated. Cannot be changed independently

Lightness

- Relative amount of light reflected
- A black ball does remains black both outside and inside
  - Relative amount of light reflected remains same
  - Absolute amount of light reflected changes
  - Lightness remains same, brightness changes

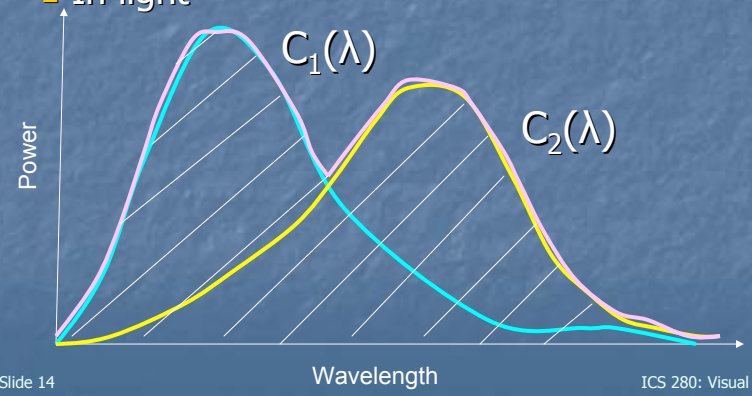
Color Mixtures

- Subtractive –
  - Intersection of two spectrums $C_1(\lambda)$ and $C_2(\lambda)$
  - In paints



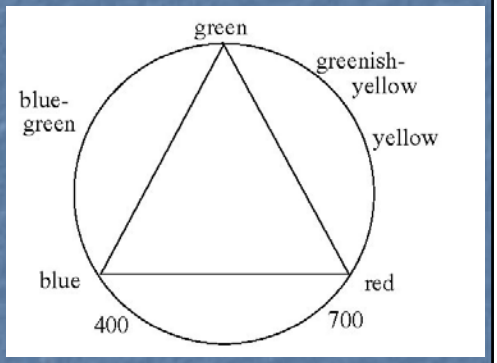
Color Mixtures

- Additive
  - Union of two spectrums $C_1(\lambda)$ and $C_2(\lambda)$
  - In light



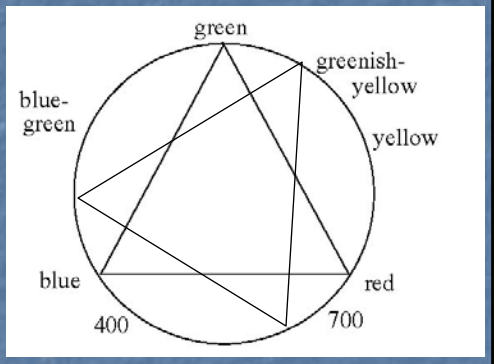
Newton's Additive Color Wheel

- Boundary is saturated color
  - Unsaturated colors in the interior
- Combination of two colors generate a color on the line joining them

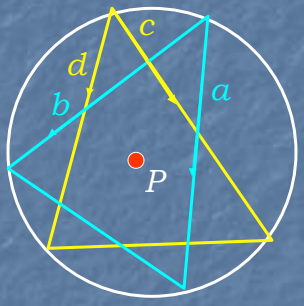


Newton's Additive Color Wheel

- Three colors to create a reasonable subset
  - Devices
  - Even Eye
- Same color can be created by a different set of primaries



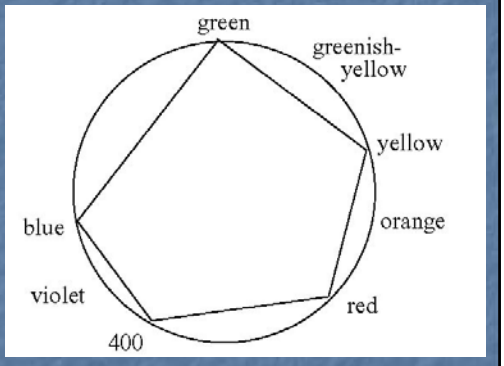
Linear Transformation of Primaries



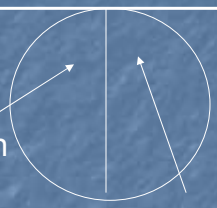
- A set of primaries is a linear transformation of another set of primaries
  - Since they define different 2D coordinates
- Board Work:
  - P can be transformed from one coordinate system to another by a linear transformation

Newton's Additive Color Wheel

- Increasing the number of primaries
- More colors can be represented



Helmholtz/Maxwell's Color Matching Experiment



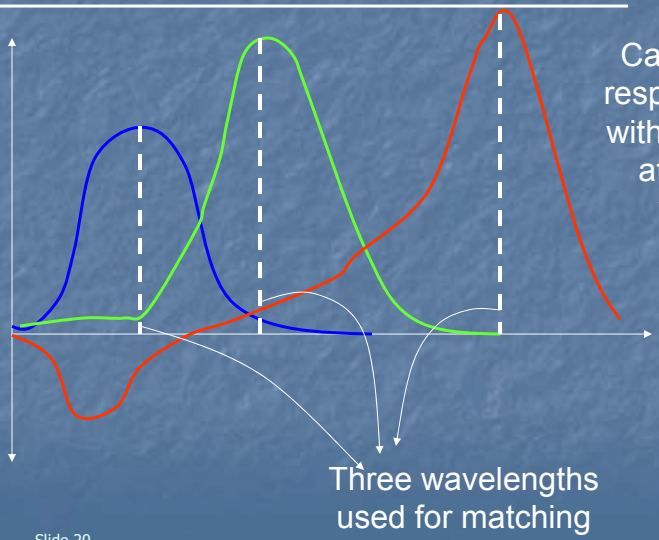
Present each visible wavelength

Add the wavelength here

Match by adjusting amounts of three wavelengths (420nm, 560nm, 640nm)

- All colors can be produced by different amounts of three wavelengths
- Cannot match certain wavelengths
- Register as negative amount

Color Matching Functions

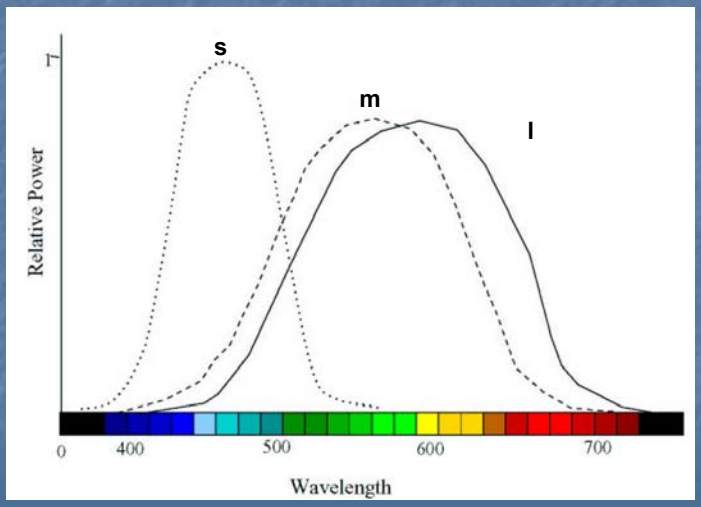


Can be thought of response of sensors with peak sensitivity at the matching wavelengths

Why do we need at least three?

Three wavelengths used for matching

Human Visual Response

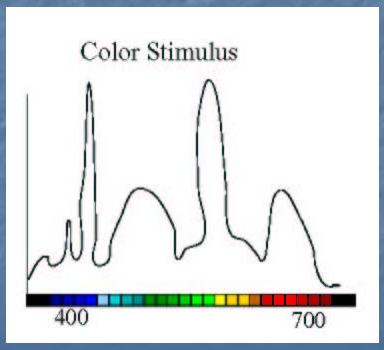


Human Visual Response

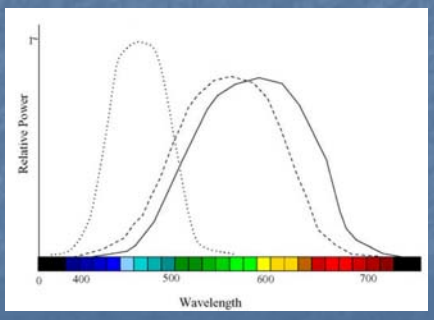
- Trichromatic Theory
  - Proposed by Thomas Young
  - Eye has three kinds of receptors
  - Produce psychologically similar sensations of red, green and blue

Color Percieved

- The response generated by a stimulus in the cones gives the perceived color



x



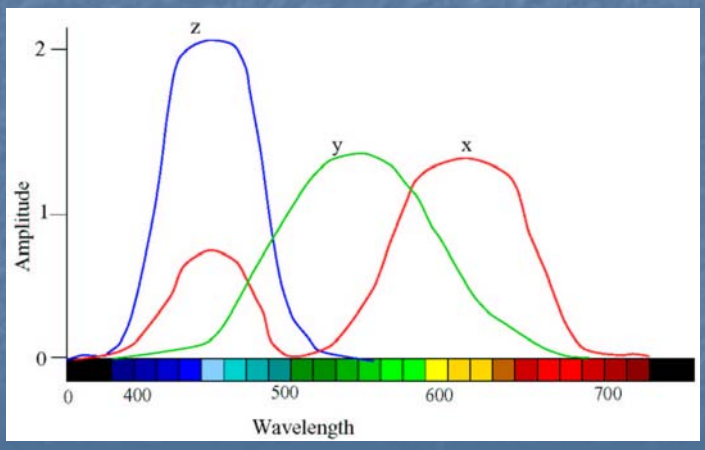
Metamerism

- Because of this selective response
  - Two dissimilar stimuli can generate equal strength of *s, m* and *l*
  - Phenomenon is called metamerism
  - The two stimuli are called the metamers
  - So, we experience all the metamers similarly

CIE Standard Color Matching Functions

- Negative weights do not make sense
- Humans perceive the entire range
  - But cannot be reproduced by just three primaries
- Need some color matching functions that would be able to span the entire range
  - With only positive weights
- Imaginary color matching functions
  - Can be found by linear transformations
  - Does not correspond to real colors

CIE Functions for Standard Observer



Tristimulus Values

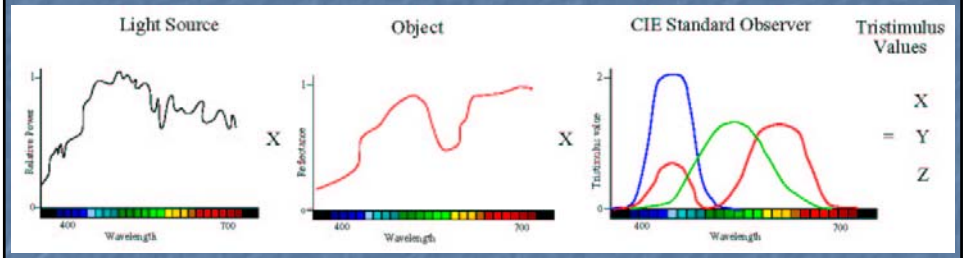
- Integration over wavelength

$$X = \int_{\lambda} C(\lambda)x(\lambda) = \sum_{\lambda=400}^{\lambda=700} C(\lambda)x(\lambda)$$

$$Y = \int_{\lambda} C(\lambda)y(\lambda) = \sum_{\lambda=400}^{\lambda=700} C(\lambda)y(\lambda)$$

$$Z = \int_{\lambda} C(\lambda)z(\lambda) = \sum_{\lambda=400}^{\lambda=700} C(\lambda)z(\lambda)$$

Tristimulus Values



- XYZ forms a three dimensional space to define color
- Two colors added by just adding the XYZ coordinates

Problem with the XYZ representation

- No physical feel as to how colors are arranged
- How are saturated hues arranged?
- How are unsaturated hues arranged?
- Perceptually not easy to deal with
- Experiment with color palette

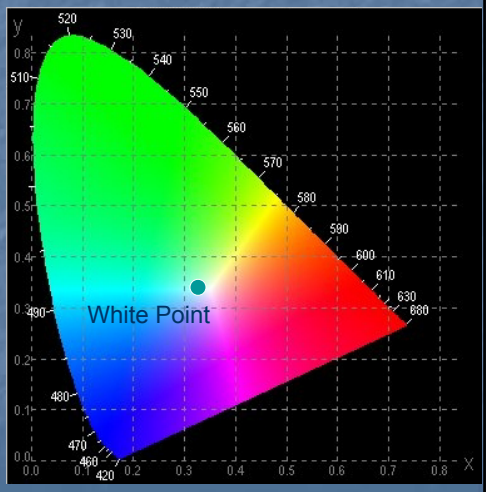
Chromaticity Chart

- Relative proportions of X, Y, and Z are more important
- For example, equal proportions of each signifies an achromatic color
- Chromaticity Diagram

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

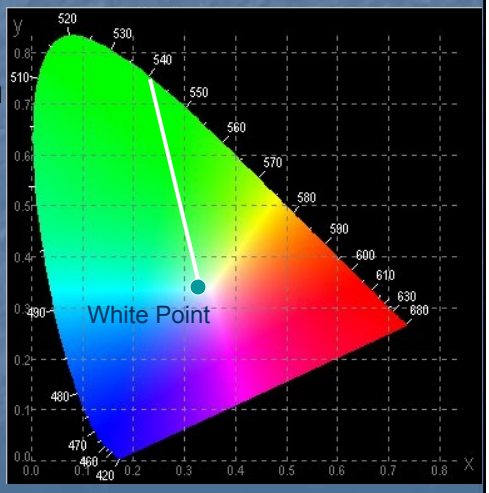
Chromaticity Coordinates

- Shows all the visible colors
- Achromatic Colors are at (0.33,0.33)
  - Why?
  - Called white point
- The saturated colors at the boundary
  - Spectral Colors



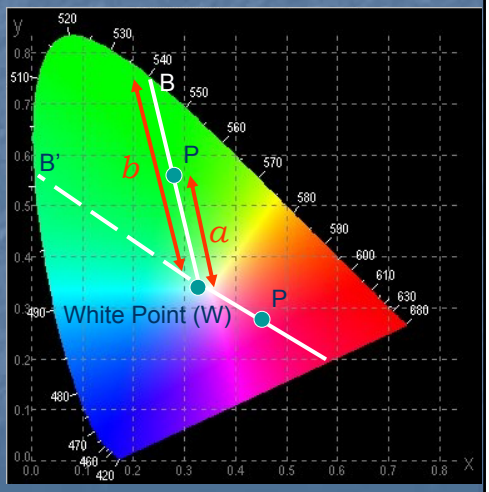
Chromaticity Chart

- Exception is purples
  - Non-spectral region in the boundary
- All colors on straight line from white point to a boundary has the same spectral hue
  - Dominant wavelength



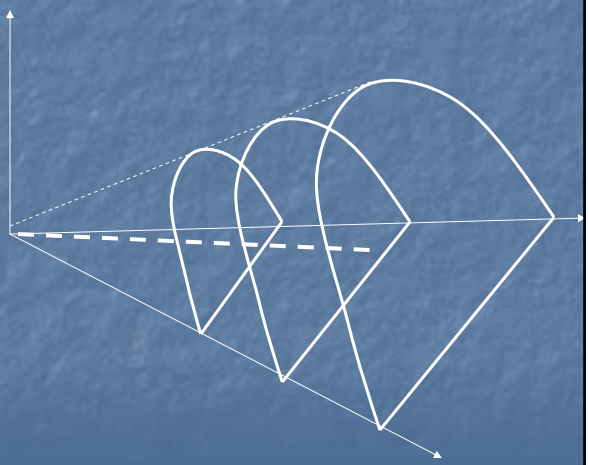
Chromaticity Chart

- What happens here?
  - Complimentary wavelength
  - When mixed generate achromatic color
- Purity (Saturation)
  - How far shifted towards the spectral color
  - Ratio of a/b
  - Purity =1 implies spectral color with maximum saturation



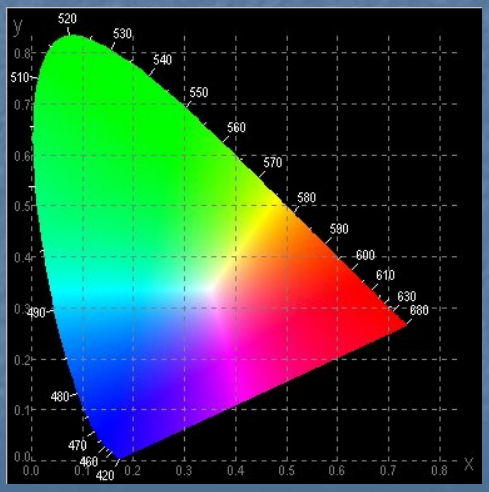
Relationship to XYZ space

- Plane through $X+Y+Z = c$
- Colors on this straight line have same hue but different luminance ($X+Y+Z$)



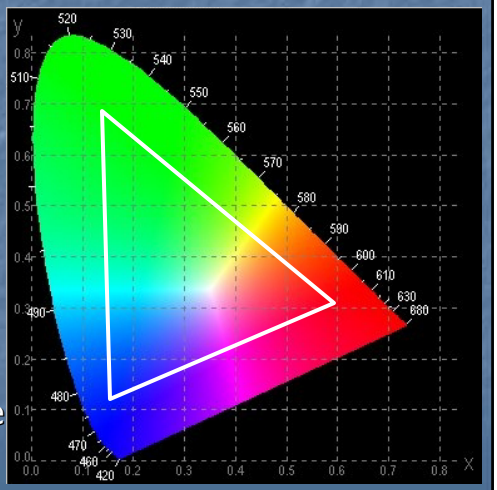
How to combine colors?

- Board Work
  - Using just XYZ
  - Using hue, saturation and luminance
- What happens when add two colors of same hue and saturation?



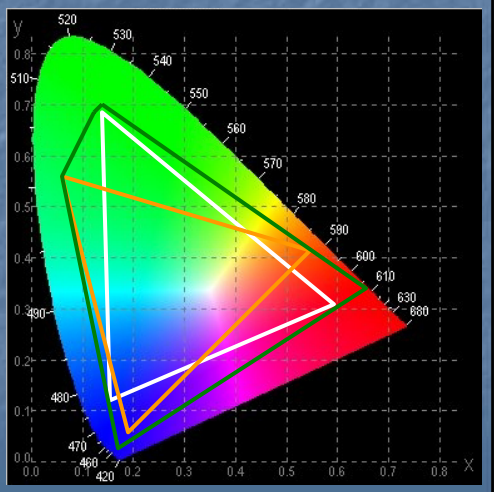
Eye and Devices

- Difference between the eye and the devices
  - Eye has unique properties
  - Devices cannot reproduce that
- Gamut
  - Any color within the gamut can be reproduced by the device



Eye and Devices

- Gamut Matching Problem
  - Gamut Mapping
- More primaries can give wider gamut
- Why not?
  - Underconstrained system
  - No unique solution



Trichromatic Theory

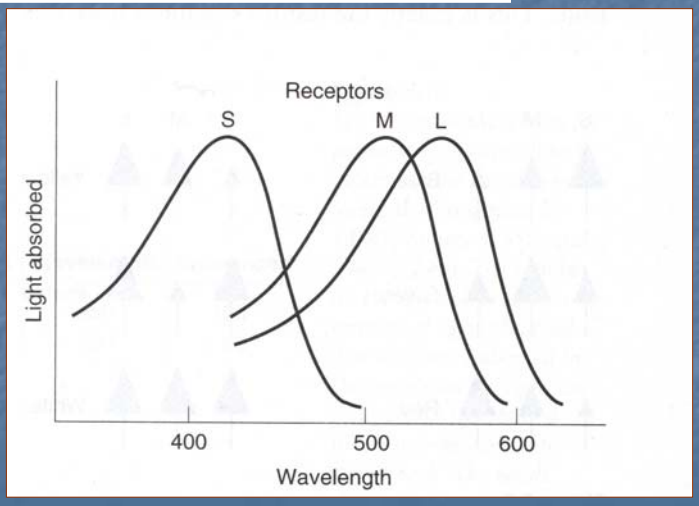
Color Matching Experiments

- All colors can be produced by mixing various proportions of three wavelengths
  - 420nm, 560nm and 640nm
  - Young Helmholtz theory of color vision
- Three types of receptors excited
  - Pattern of excitation depends on the color or the wavelength of the light

Physiological Explanation

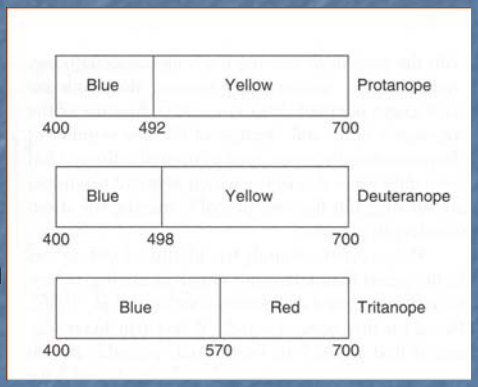
- Three different types of cone
  - Different pigment with different absorption spectra
- Pigments have different amino acids in their opsins
  - Causes the different absorption spectra
- S, M, L
  - S and M are 44% similar, peaks 112nm apart
  - M and L are 96% similar, peaks 27nm apart

Response of Cones



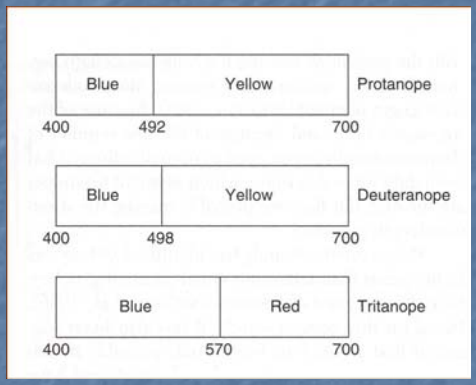
Color Deficiency

- Monochromat
- Dichrromat
- Color weakness
- Cerebral achromatopsia



Reasons

- Monochromat
  - No cones
- Dichrromat
  - No L, No M, and No S
- Color weakness
  - S,M and L not very sensitive
- Cerebral achromatopsia
  - Cones are fine but problem in visual cortex



Dichromatism

- Why more males?
  - Resides in X chromosome
  - Both X's need to have the defect in women
  - Can be passed on by women with one deficient X to the male offspring