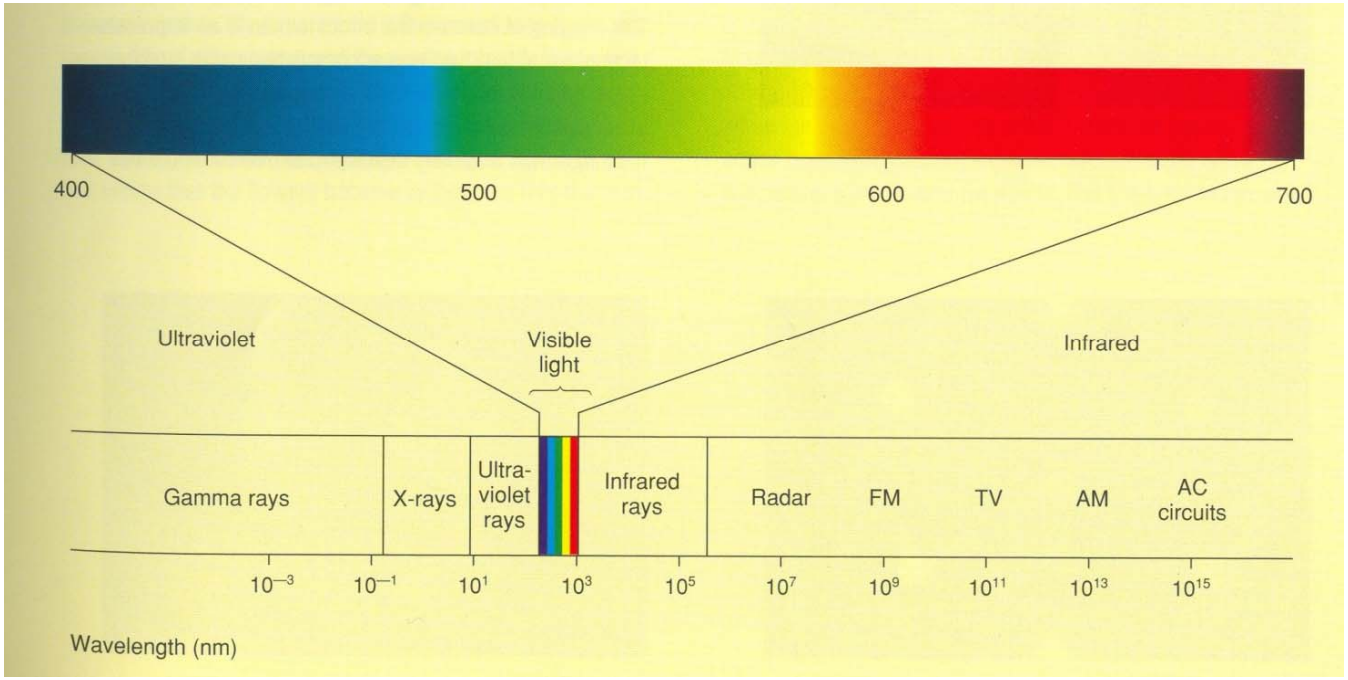
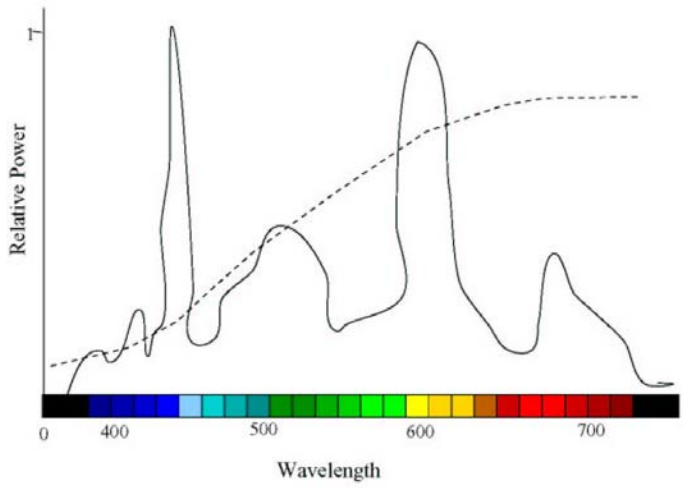
What is Color?

- Selective emission/reflectance of different wavelengths

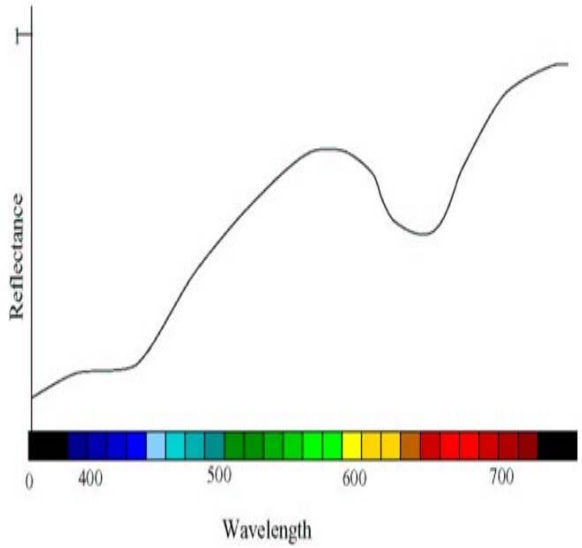


Color

- Left: illumination spectrum of a flouroscent (bold line) and tungsten lamp (dotted line) I(λ)
- Right: reflectance spectrum of a red apple R(λ)



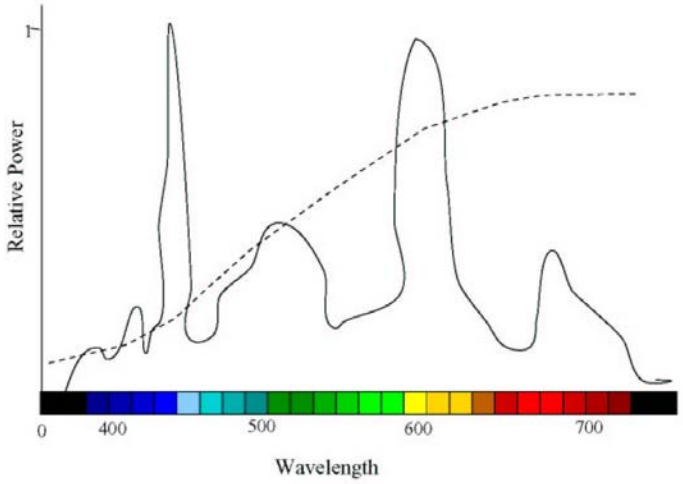
Illumination



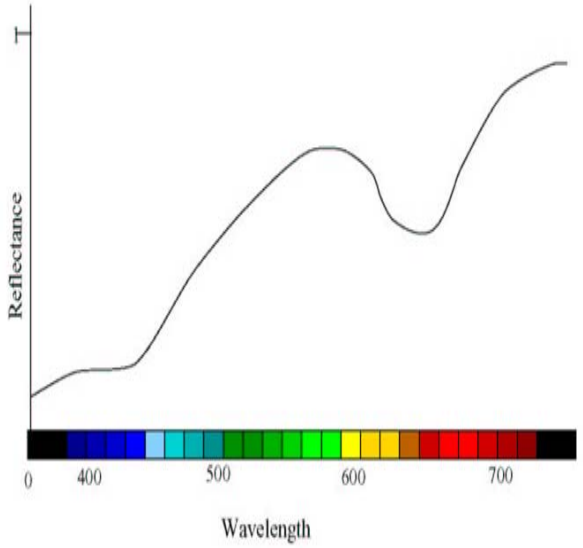
Reflectance

Color Stimuli

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



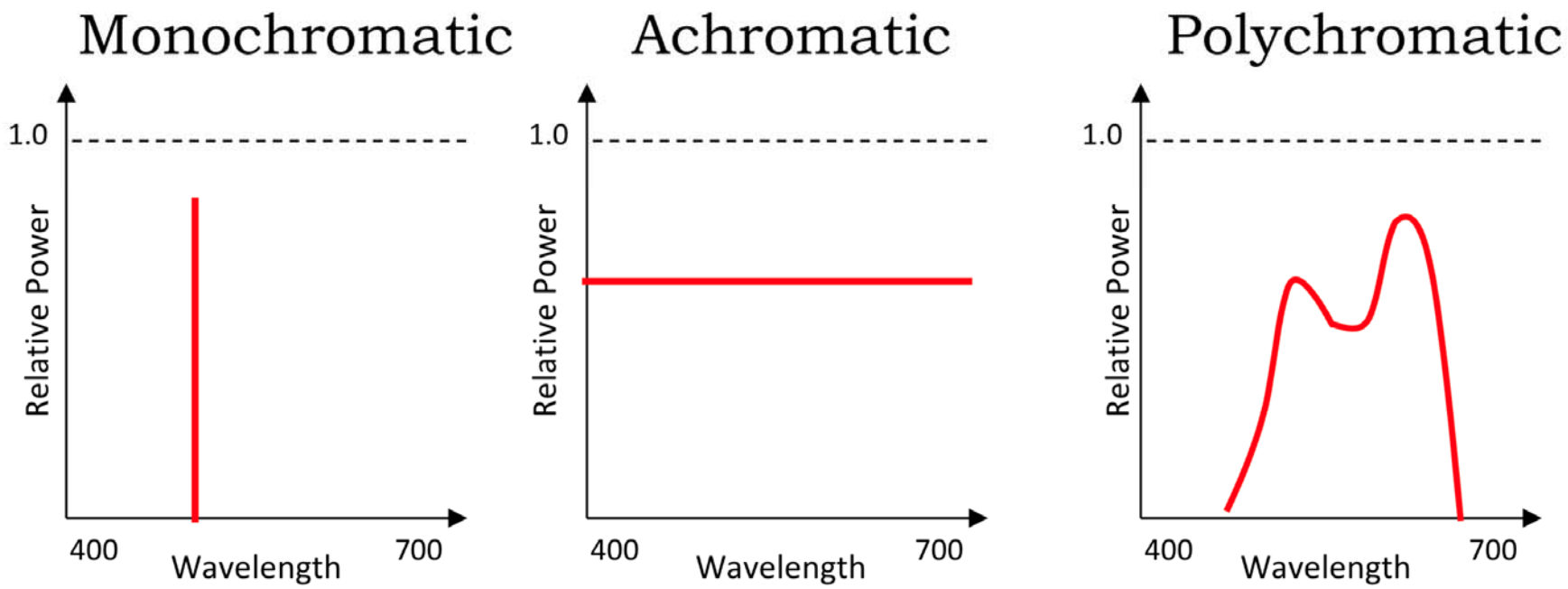
x



Illumination

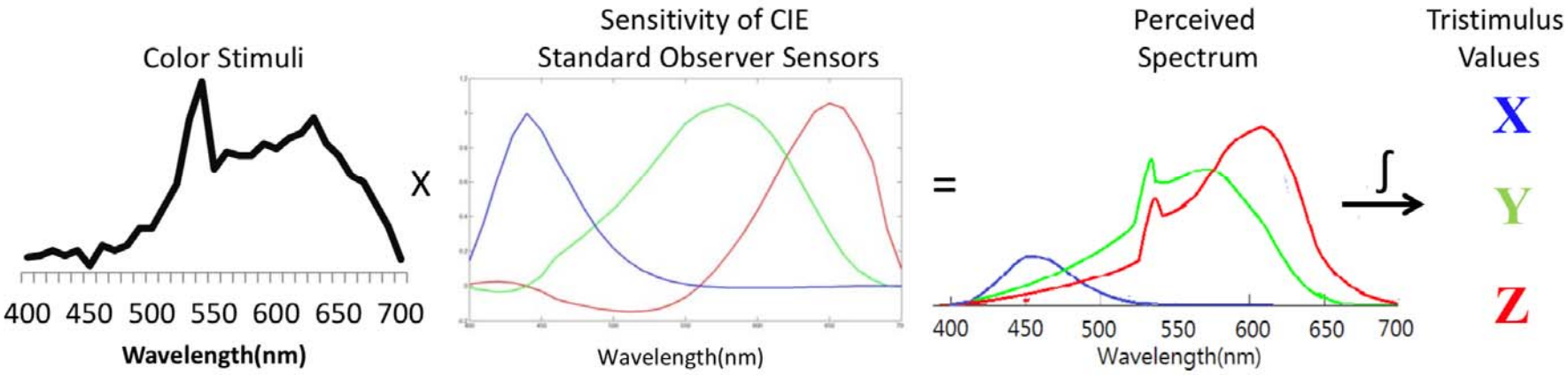
Reflectance

Types of Color Stimuli



Perceived Color

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



Computations on Color

- Very difficult using spectrums
- Can we have some sort of coordinate space to define color?

Tristimulus Values

- Integration over wavelength

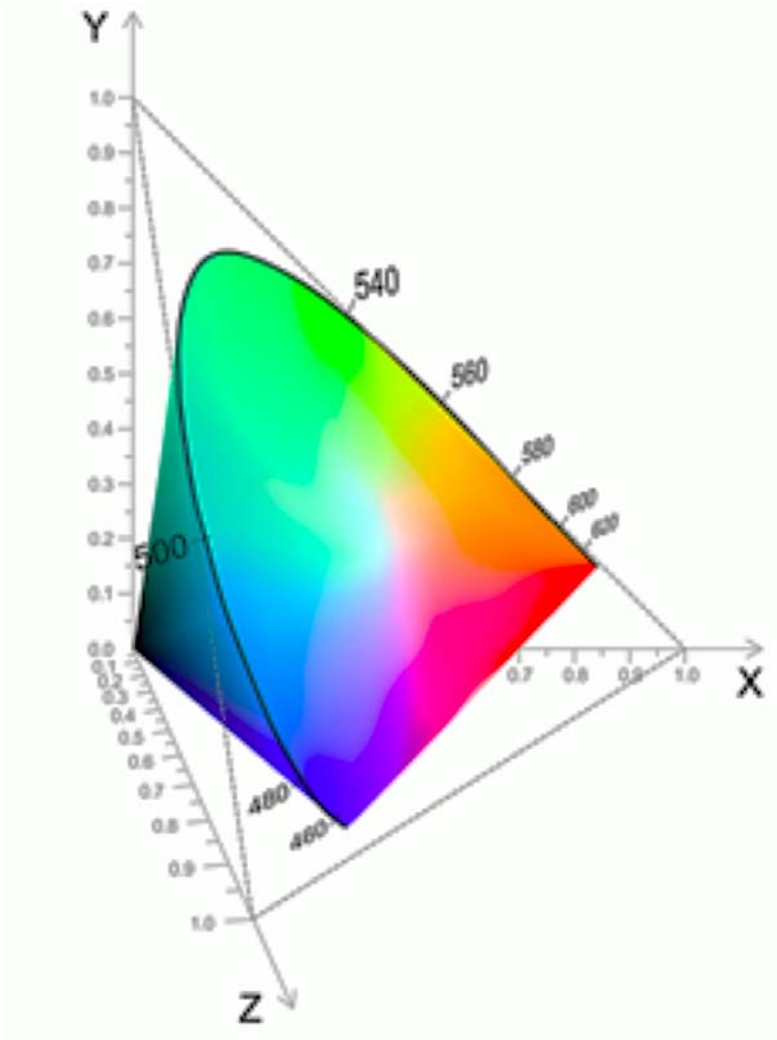
$$X = \int_{\lambda} C(\lambda)\bar{x}(\lambda)d\lambda = \sum_{\lambda=400}^{700} C(\lambda)\bar{x}(\lambda)$$

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

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

CIE XYZ Space

- Real colors span a sub-set of the XYZ space
- Two different stimuli can have same XYZ values
  - Metamerism



Perceptual Organization of CIE XYZ Space

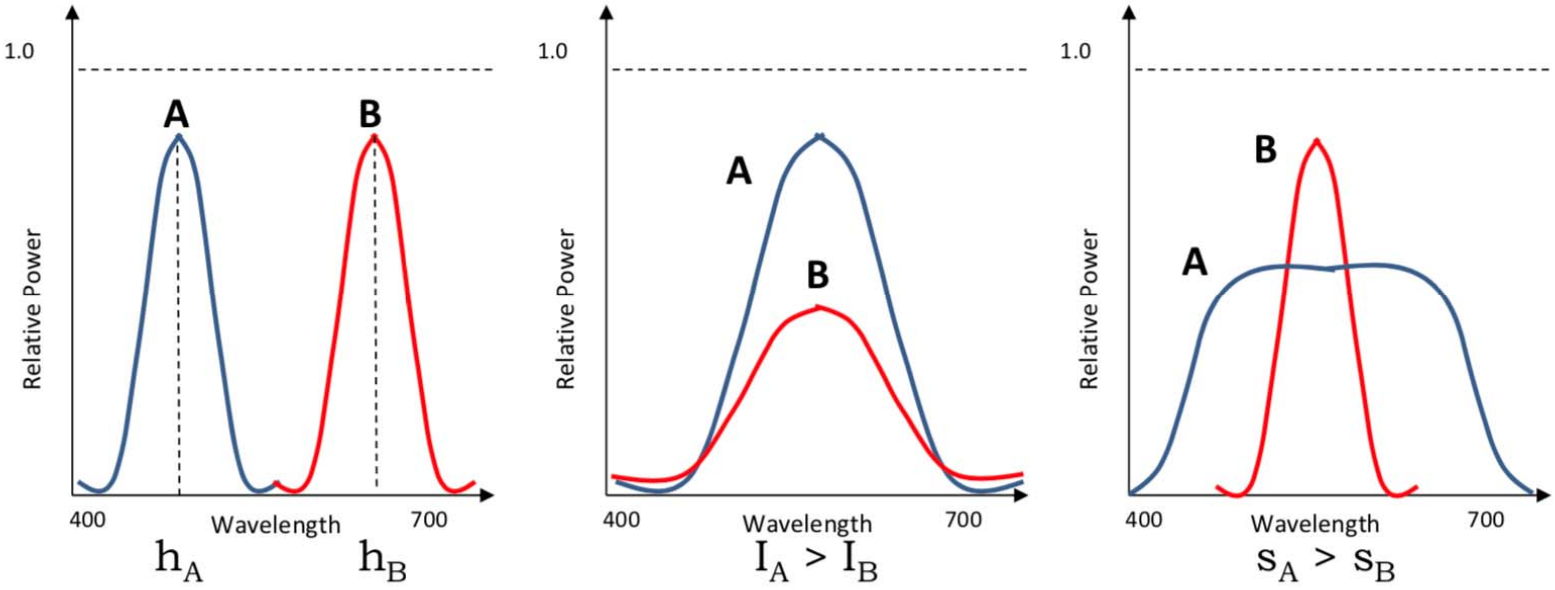
- No physical feel as to how colors are arranged
- How do brightness change?
- How does hue change?

What are the perceived properties?

- Intensity
  - Sum of the spectrum
  - Energy under the spectrum
  - I = X+Y+Z
- Hue
  - Mean wavelength of the spectrum
  - What wavelength sensation is dominant?
- Saturation
  - Standard deviation of the spectrum
  - How much achromatic/gray component?

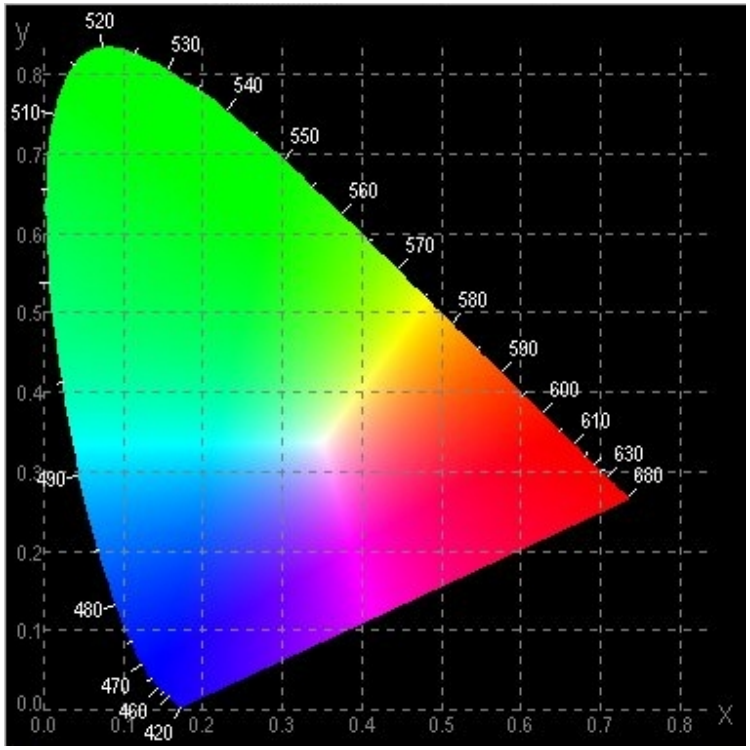
perceived properties

- Left: A and B have same intensity but different dominant wavelength and therefore different hues.
- Middle: A and B have the same hue but different intensities.
- Right: A and B have the same hue but different saturations.



Chrominance

- Chrominance – Hue and saturation
- Chrominance (x,y) = (X/I, Y/I)
  - Chromaticity chart
  - Projection on a plane with normal (1,1,1)
  - Reduction of dimension
  - Similar to 3D to 2D in geometry

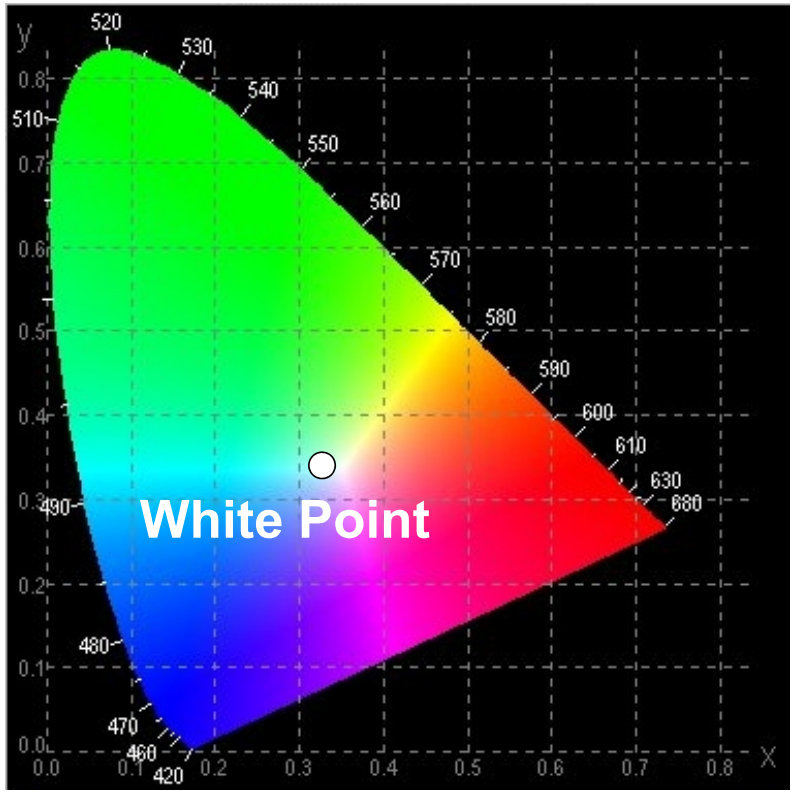


What does this mean?

- Scaling a vector (kX,kY,kZ)
  - (x,y) does not change
  - Each vector from (0,0,0) is an iso-chrominance line
  - Each vector map to a point in the chromaticity chart

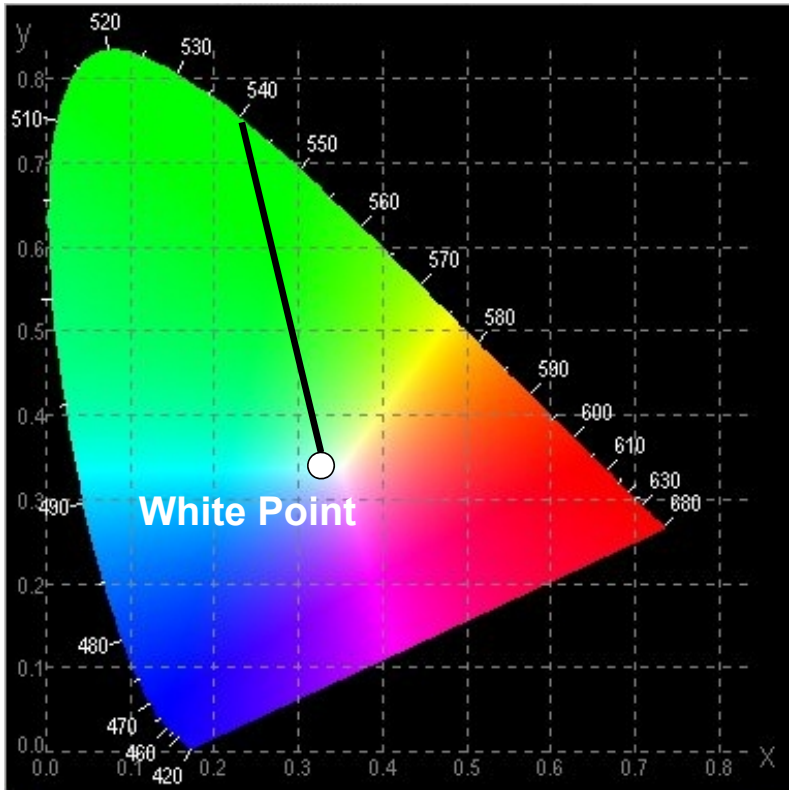
Chromaticity Coordinates

- 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



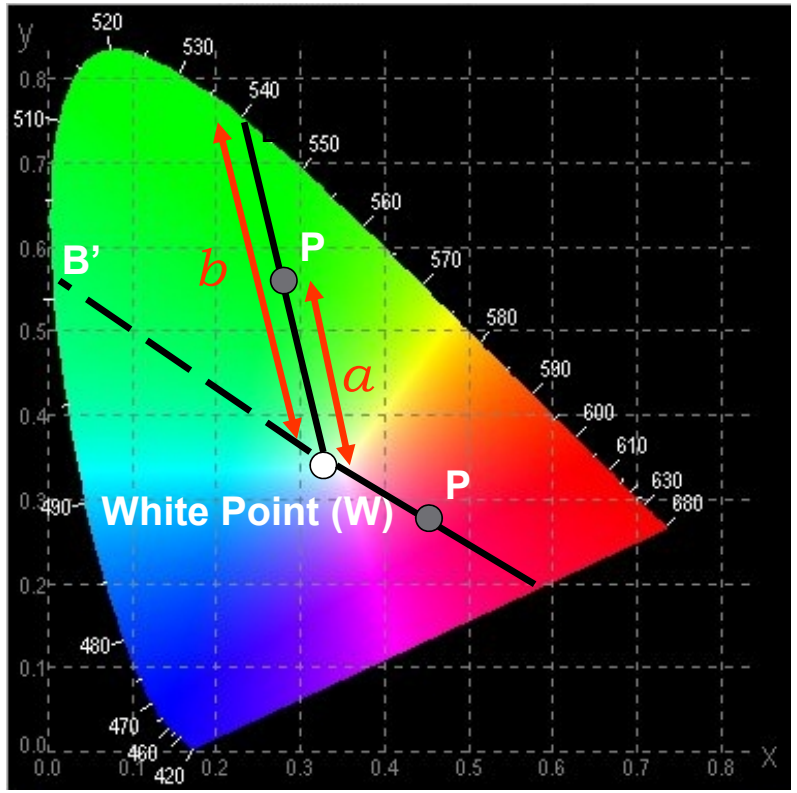
Chromaticity Chart

- 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

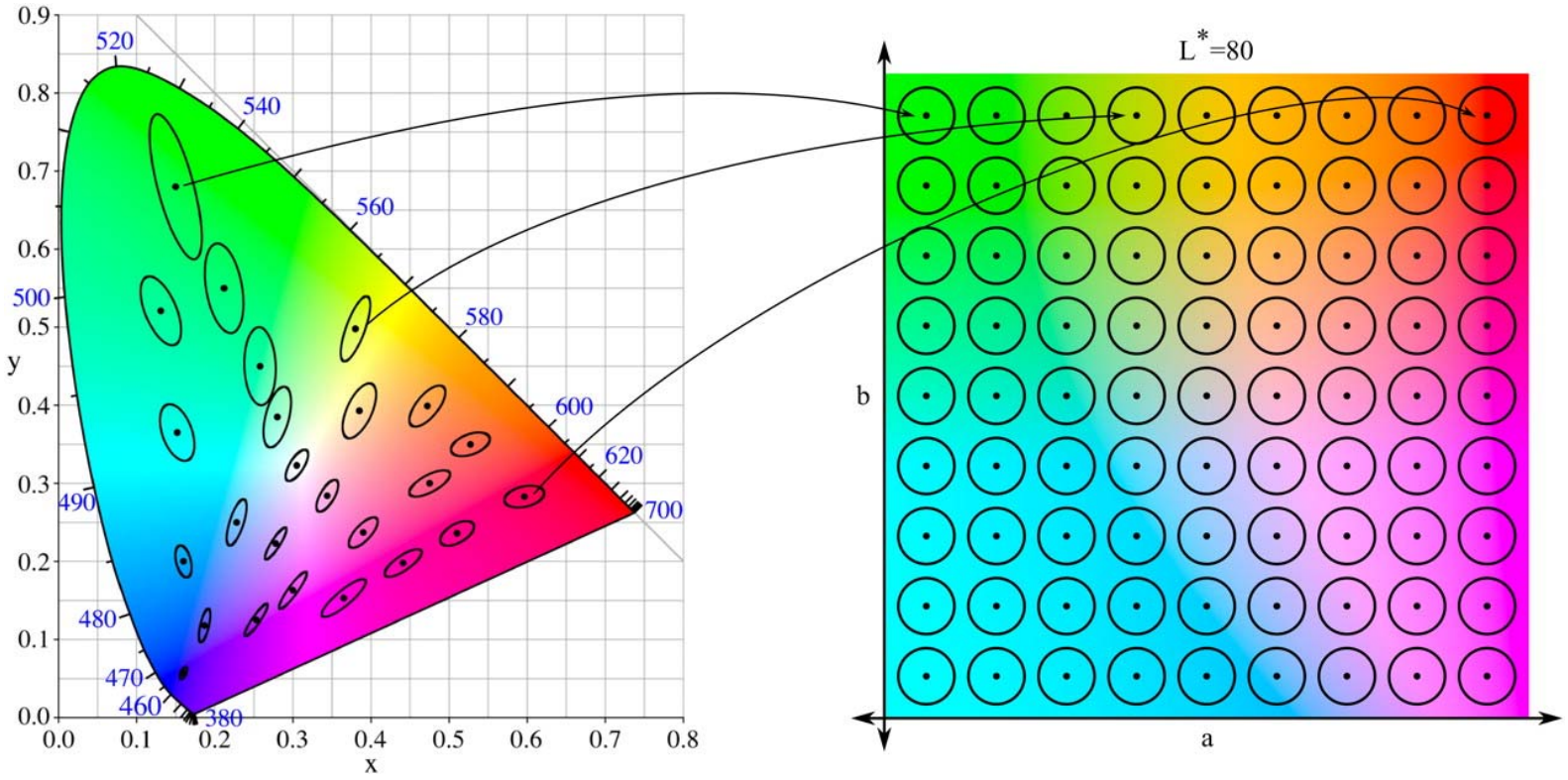
- What happens here?
  - Complimentary wavelength
  - When mixed generate achromatic color
- Purity (Saturation)
  - How far shifted towards the spectral color
  - Ratio of a/b
  - Purity =1 implies spectral color with maximum saturation



Luminance

- Perceived brightness
  - Based on eye's response
- Same brightness green looks brighter than blue or red
- This is proportional to Y

Perceptually Uniform Color Spaces



CIE 1931

CIELAB (CIE 1976 L*,a*,b*)