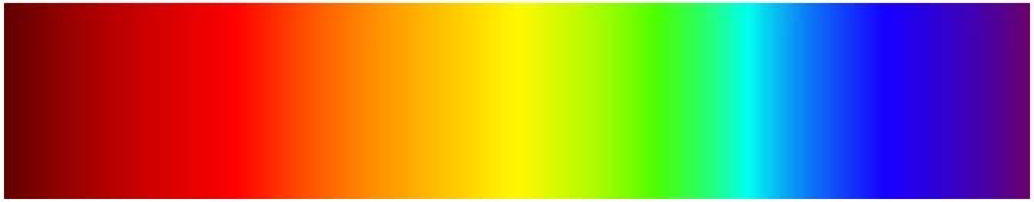
Image Processing

Color



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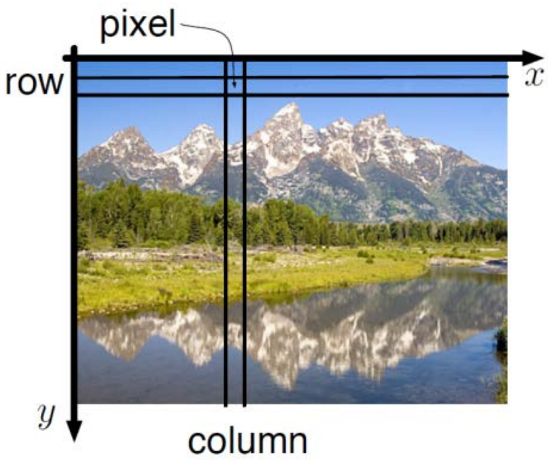
Material in this presentation is largely based on/derived from
presentation(s) and book: The Digital Image by Dr. Donald House at Texas A&M University

Lecture Objectives

- Previously
  - **Digital Images are Numbers**
    - **2D function f(x, y)**
      - **or a matrix**
      - f(x, y) = Pixel Intensity Value
        - » $f(x,y) \in [0, 255]$ or $f(x,y) \in [0, 1]$
    - Greyscale (scalar)
    - Color (3-vector)



- Today
  - Color
    - Perception
    - Representation

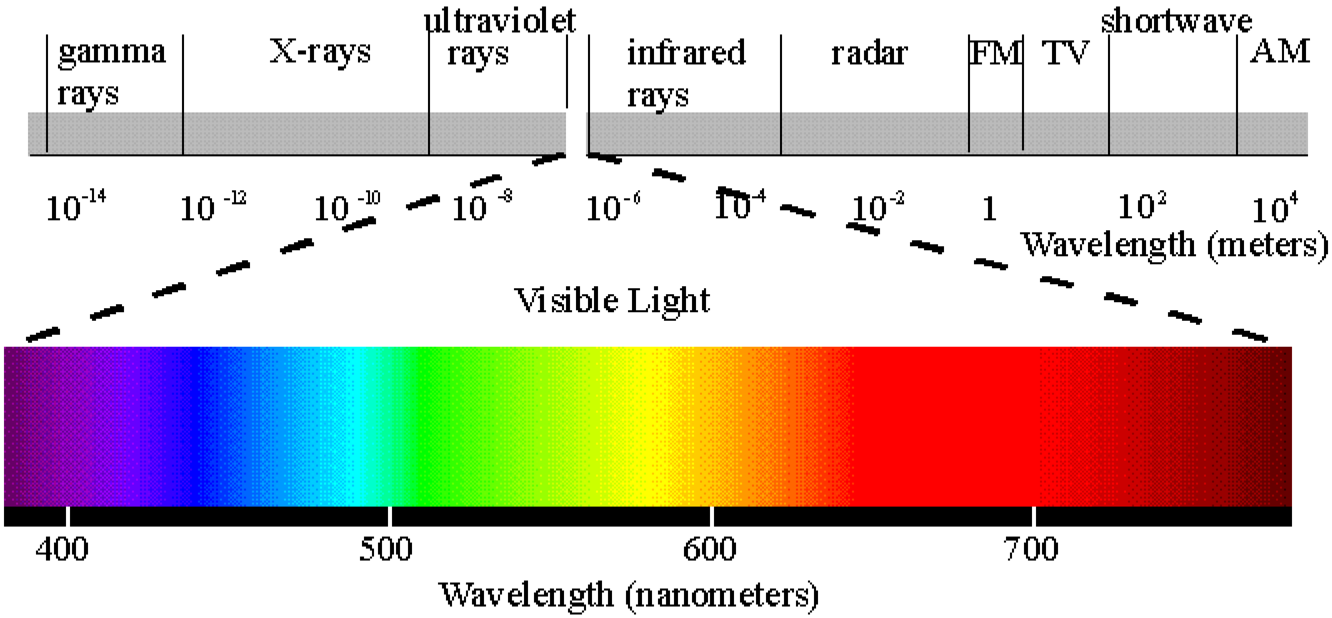
What is Color?

- Who should we ask?

  - physicist?
  - biologist?
  - artist?

Physical Color

- Color is directly related to the physical phenomenon of light
  - It is a way of describing distributions of light energy

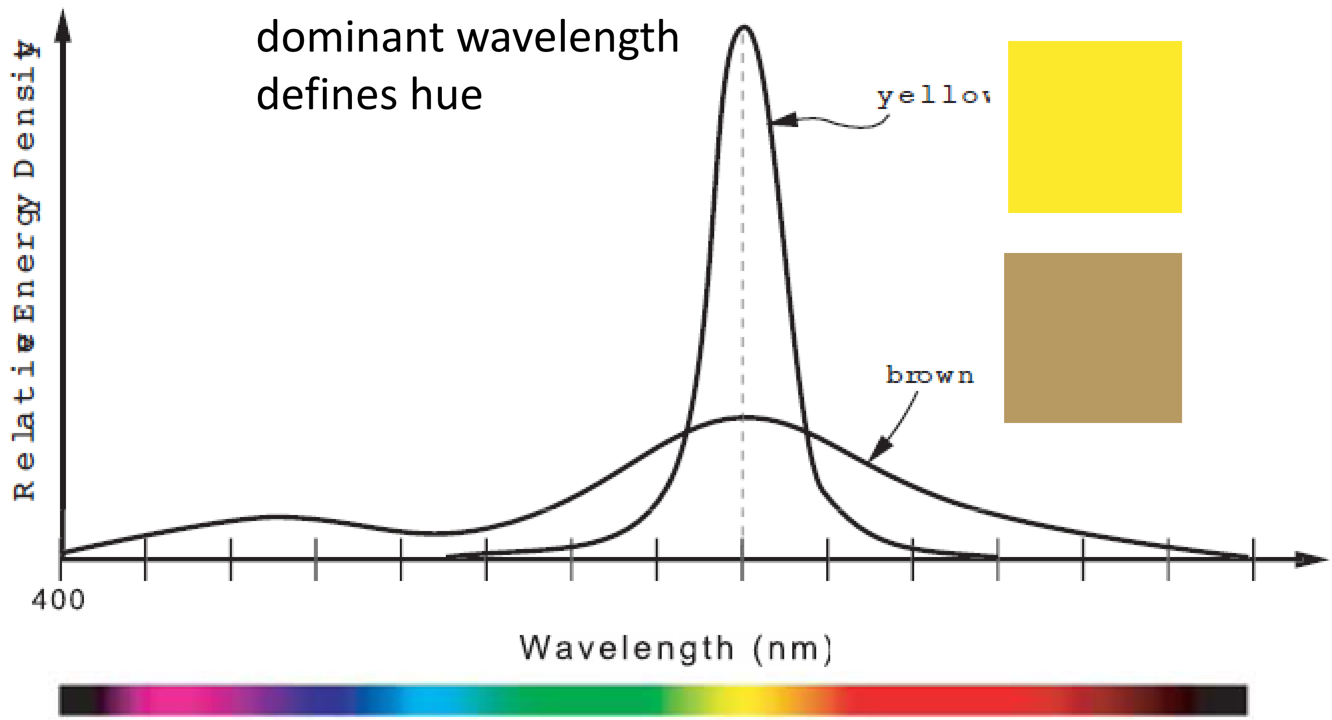


Electromagnetic Waves

Spectrum Defines Color

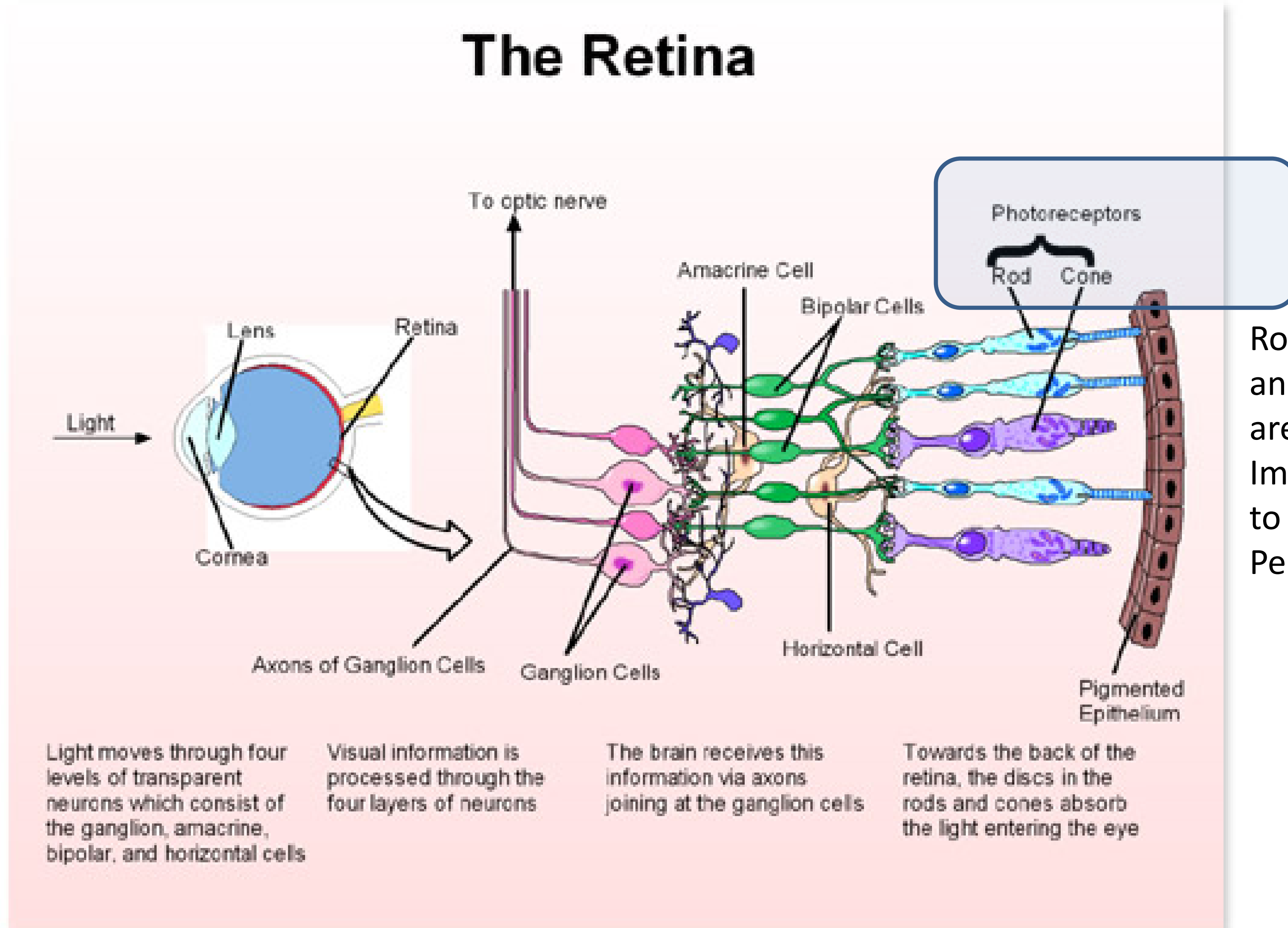
Think: spectral analysis

- speed of light = wavelength * frequency



total energy (area under curve) are the same
distributions are different… (so things will “appear” different)

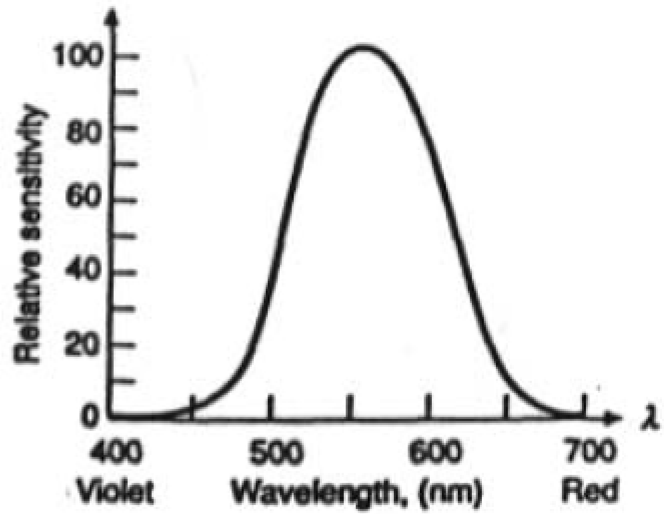
Biology



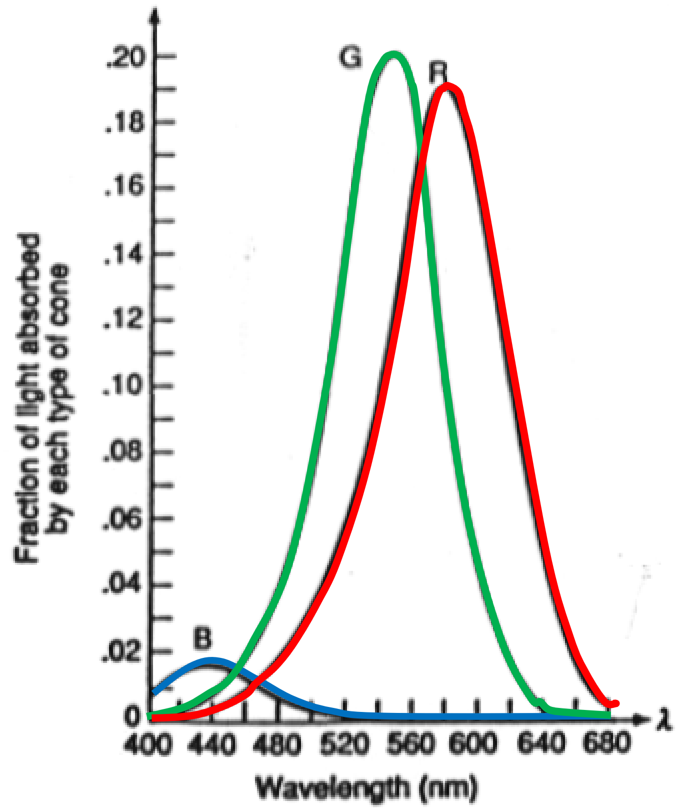
Rods and Cones are Important to Color Perception

Rod and Cone Response Curves

RODS:
- low light
- constant luminance varied wavelength



a) rods

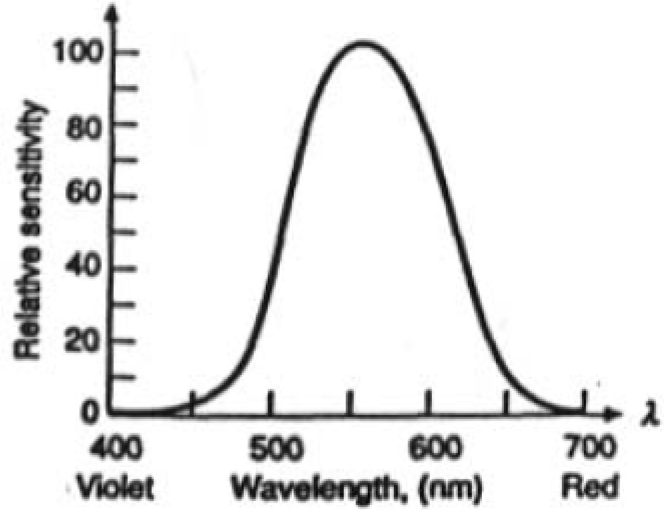


b) cones

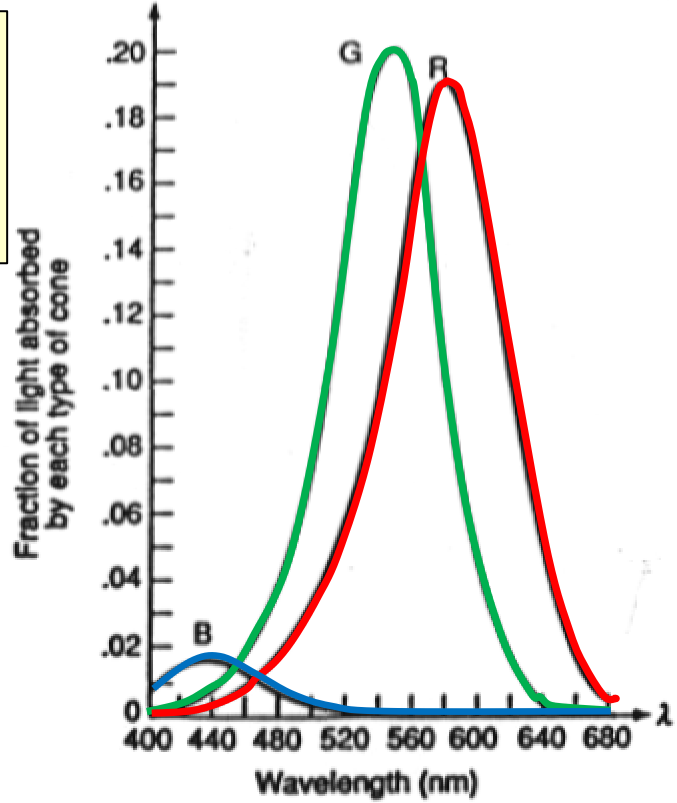
Figure 4.2: Spectral Sensitivity of Retinal Rod and Cone Cells copied from Foley, van Dam, Feiner and Hughes, *Computer Graphics Principles and Practice*, Addison-Wesley, 1990, pg. 577.

Rod and Cone Response Curves

CONES:
- high light
- 3 primary types
    - roughly R, G, B



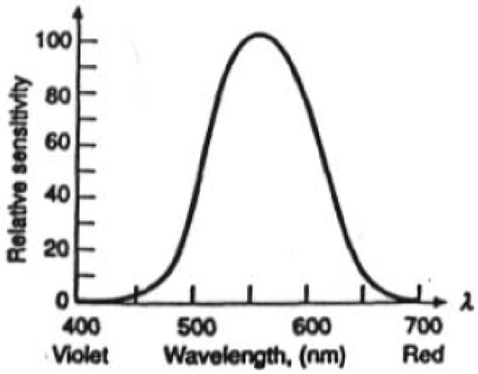
a) rods



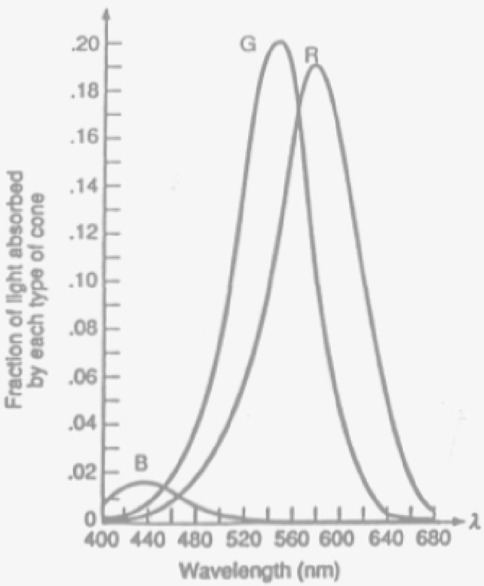
b) cones

Figure 4.2: Spectral Sensitivity of Retinal Rod and Cone Cells copied from Foley, van Dam, Feiner and Hughes, *Computer Graphics Principles and Practice*, Addison-Wesley, 1990, pg. 577.

Luminous Efficiency Function



a) rods



b) cones

By experimental evidence:

(a) is the sum of the 3 curves of (b)

So (a) is often called the **Luminous Efficiency Function**

Tri-Stimulus Theory of Color

- Additive Color Systems
  - RGB
  - HSV
  - CIE xyY
- Subtractive Color System
  - CMY
    - CMYK

Tri-Stim Theory of Color

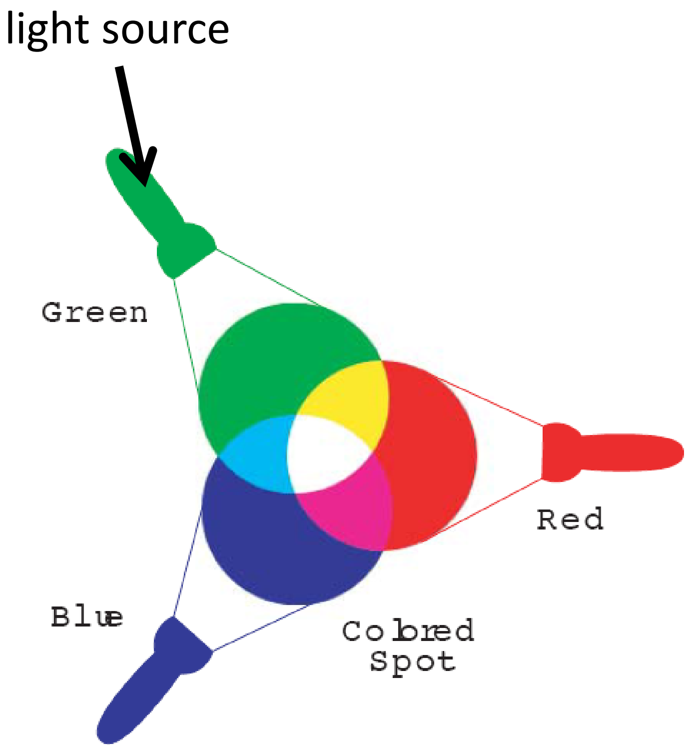
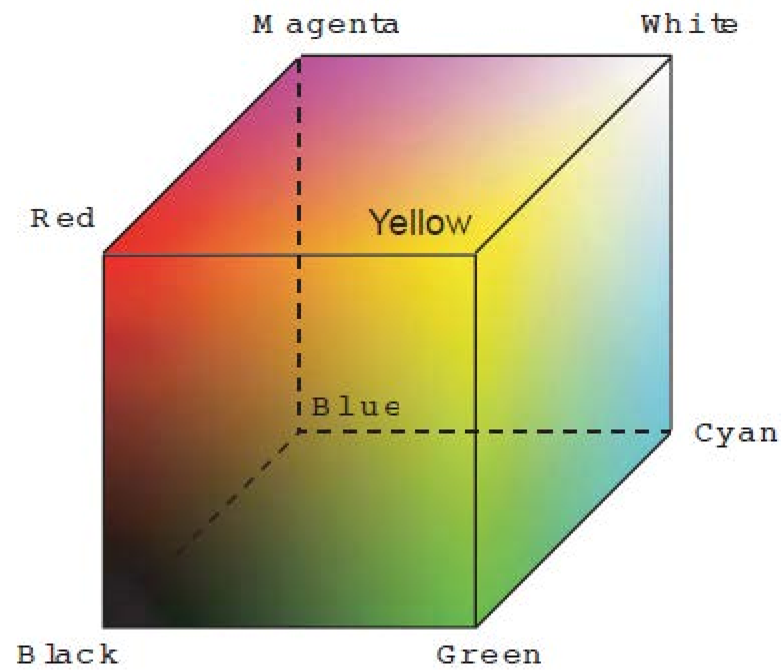


Figure 1.7: Additive Color Mixing for the Red-Green-Blue System

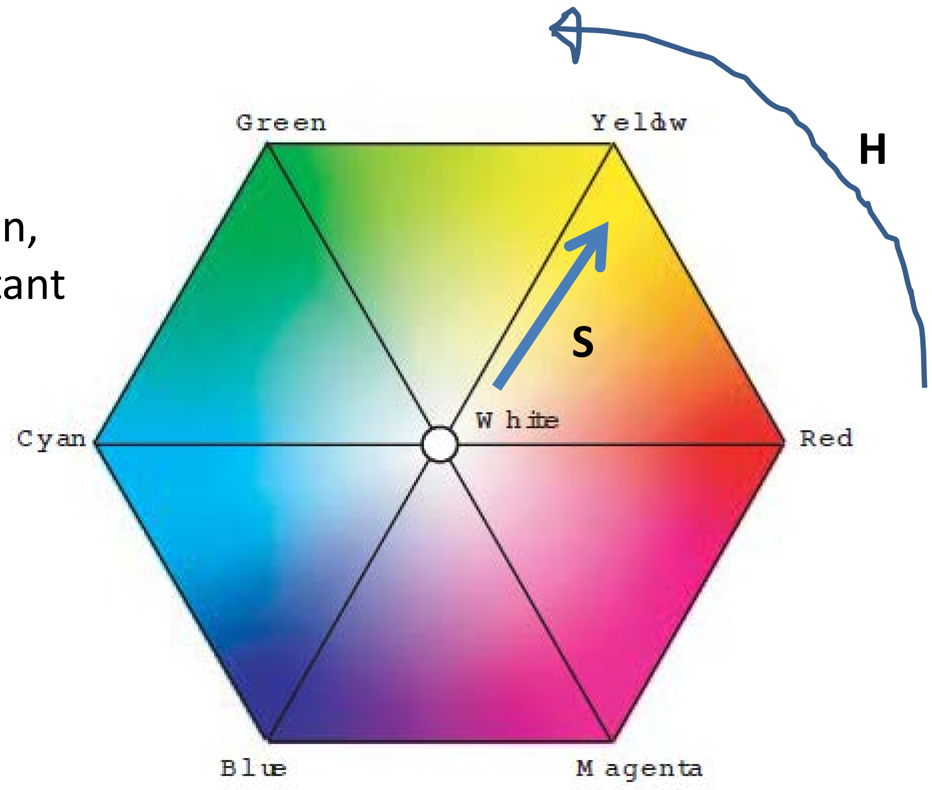


a) RGB

HSV Color Space (Artists)

Hue, Saturation, Value

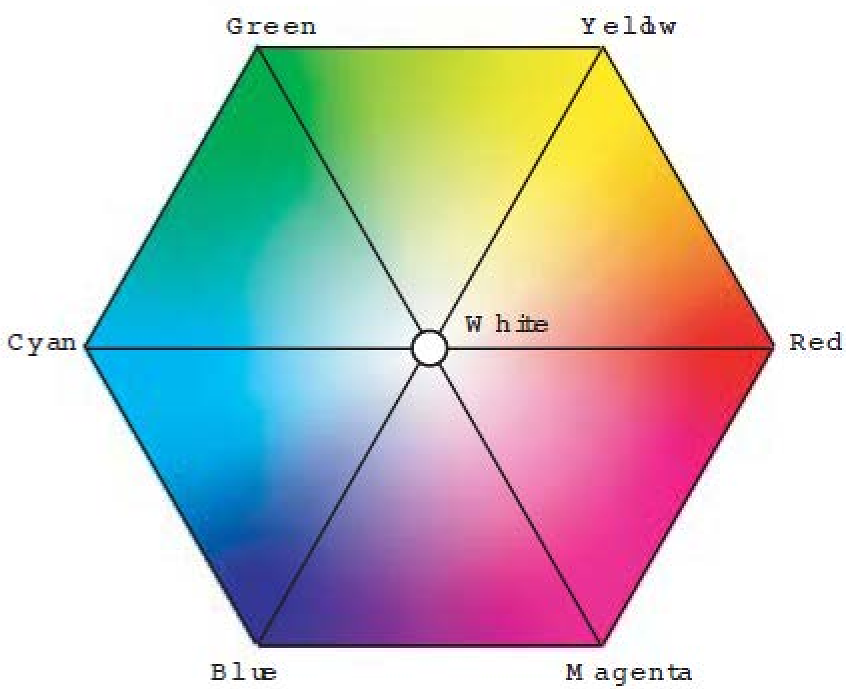
Cross-Section,
so V is constant

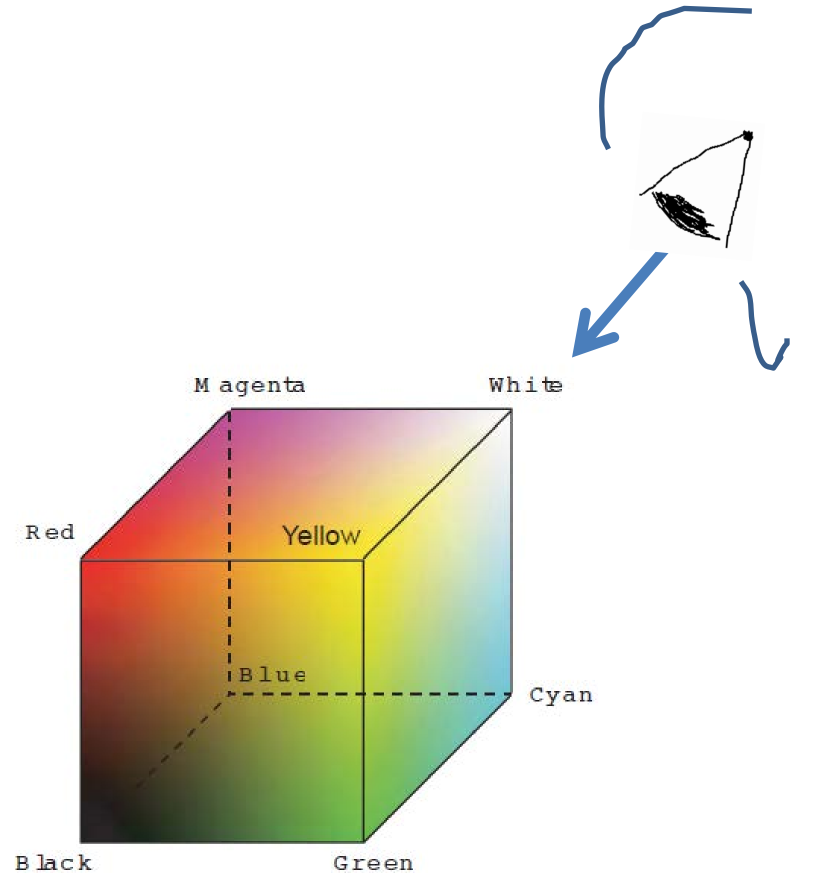


RGB versus HSV

RGB can be translated to HSV and back

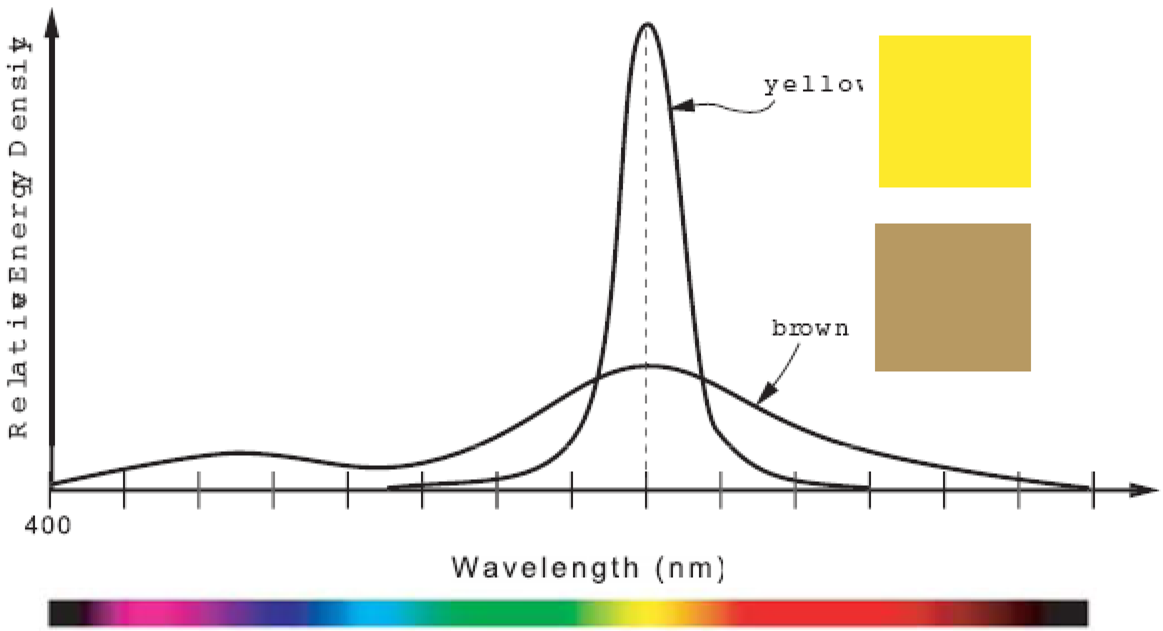
Orient the cube so you are looking down the diagonal from the white corner to the black corner of the cube





a) RGB

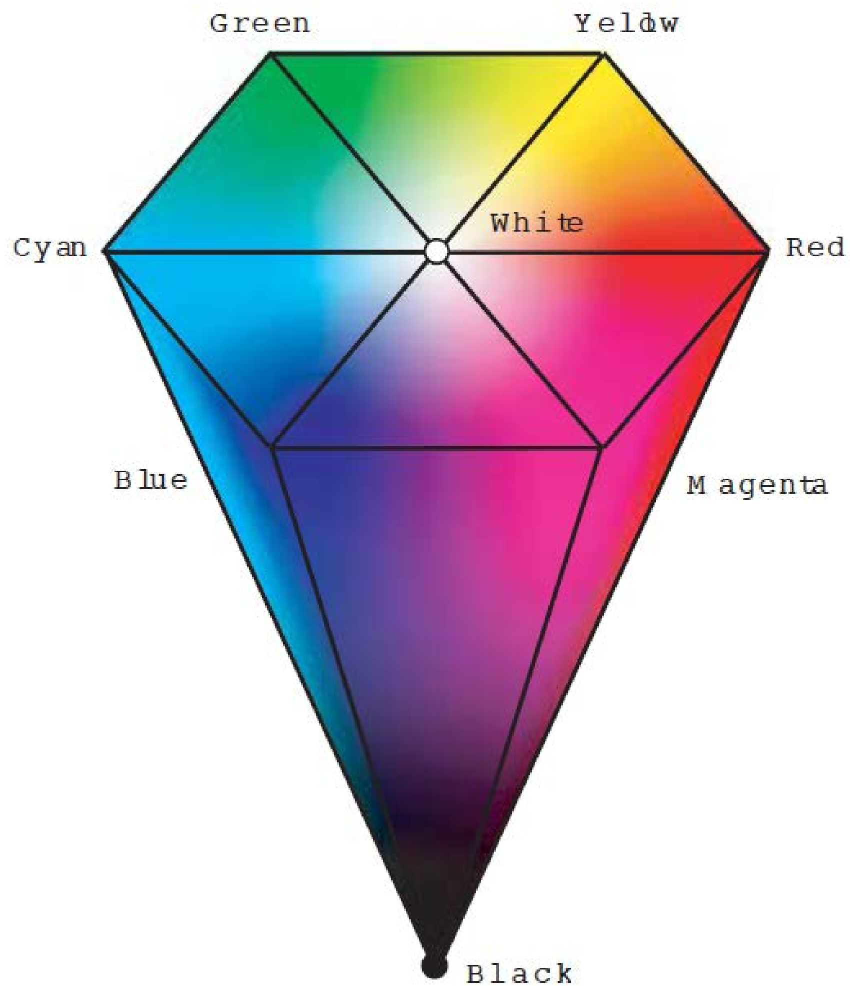
HSV: yellow versus brown



H is same
V is same
S is different

- Same Hue ←→ Same dominant wavelength
- Same Value ←→Same area under the curves
  - » different brightness due to response curve of eye
- Different Saturation ←→Different Spectral Distribution

HSV Color Hexcone



Using the Cone

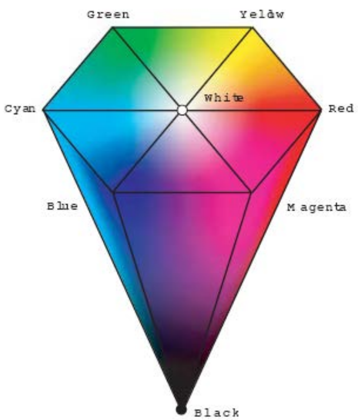
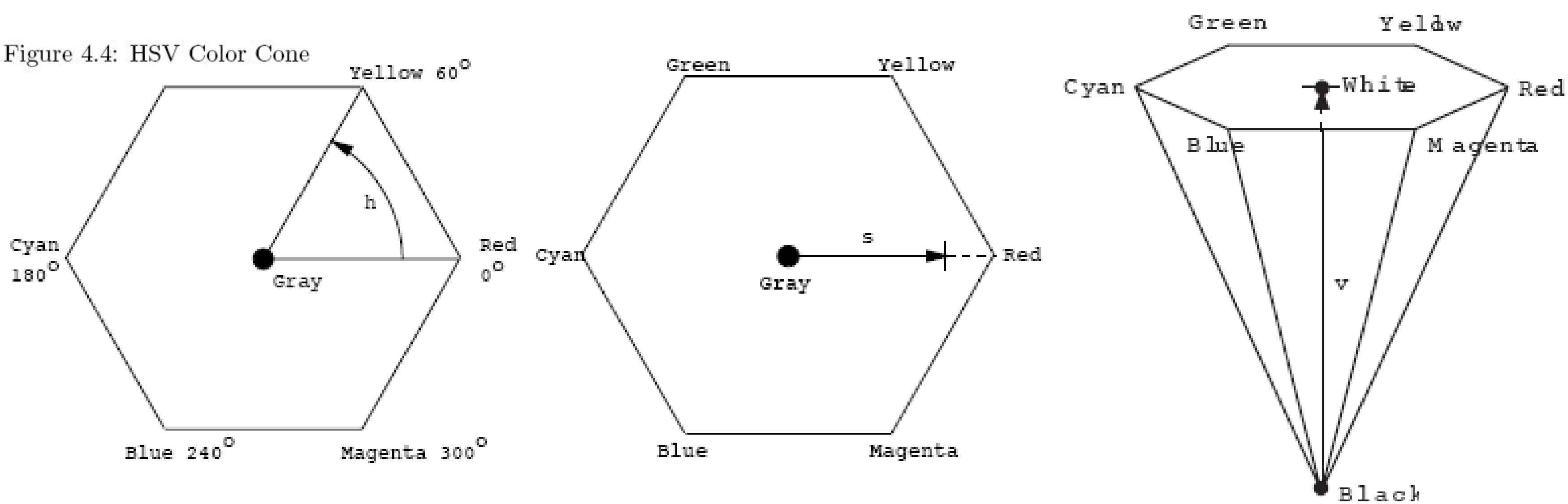


Figure 4.4: HSV Color Cone



a) hue

range here: [0, 360)

b) saturation

range here: [0, 1]

c) value

range here: [0, 1]

Figure 4.5: Parameterization of HSV Color Space

CIE Color Space

- CIE: International Commission on Illumination
  - Desire to: **Specify precise reproducibility**
  - Developed a color space to reflect desired mathematical properties
    - based on experimental results of human eye response/perception

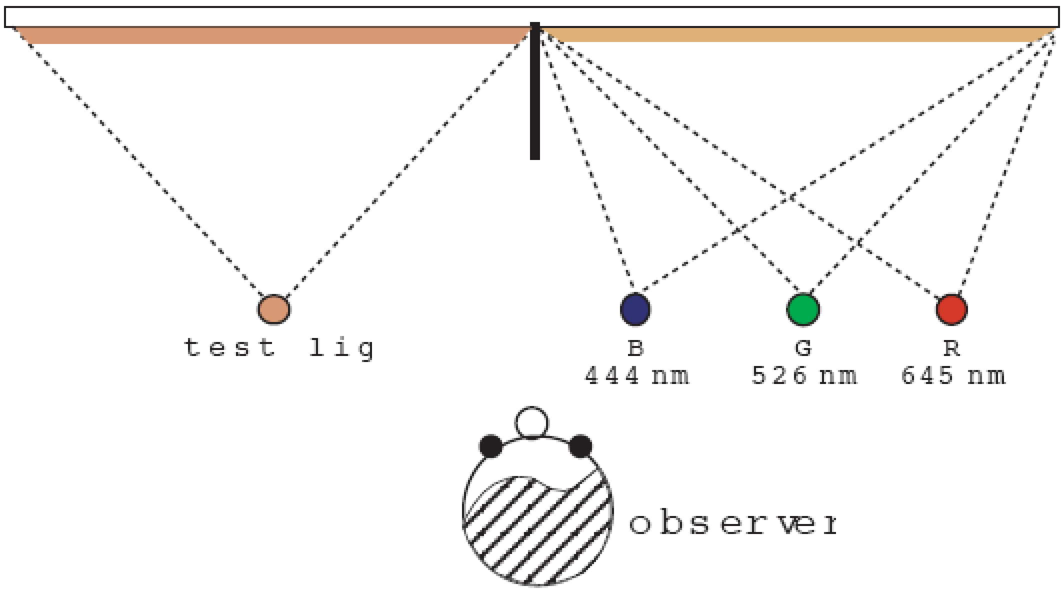


Figure 4.6: CIE Test Apparatus

Question to observer: does the left color match the right?

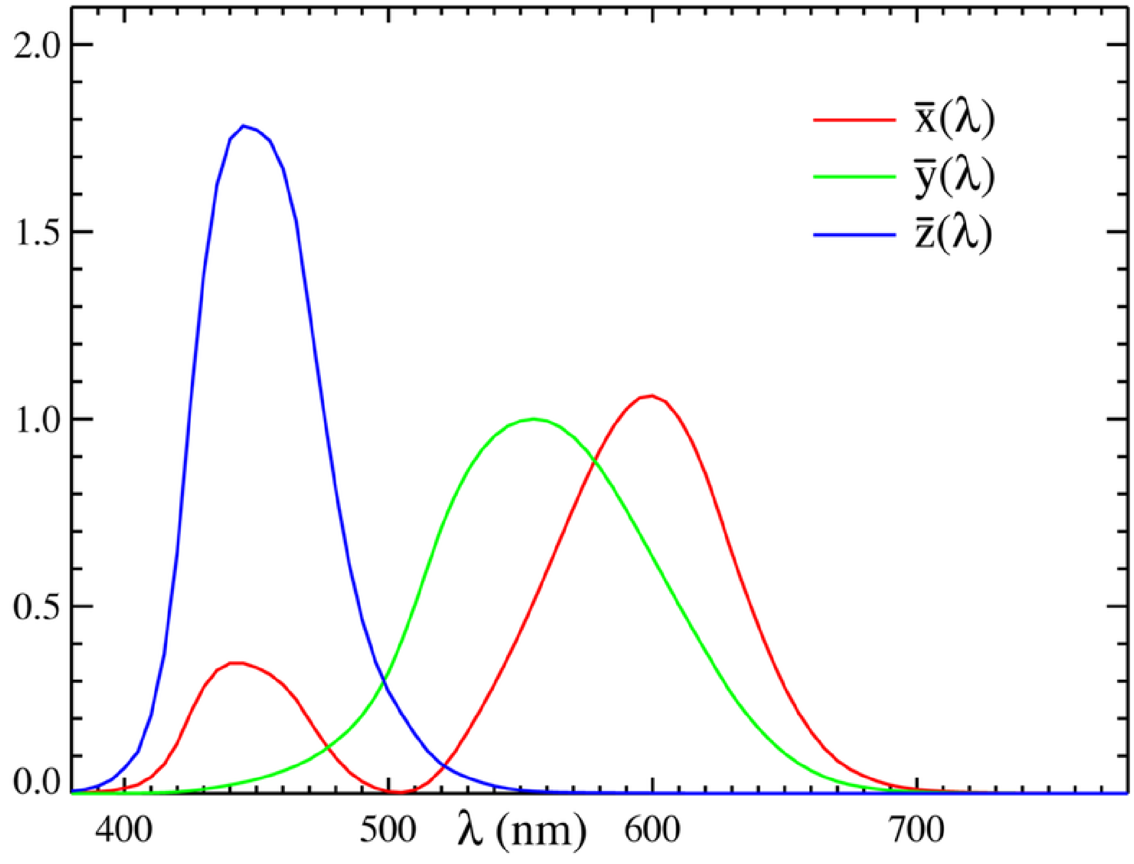
CIE Color Space: A space of desires

- CIE intent is to
  - Define a colored light using a mixture of 3 primaries
  - Three imaginary primaries are denoted: x, y, z
    - So each color can be made with positive combinations of x, y, z
  - New space is related to CIE RGB space by a linear transformation
    - R, G, B and x, y, z can be converted linearly
  - Assign Luminous Efficiency Curve to y (Choose y to be luminosity)

$$C = X\mathbf{x} + Y\mathbf{y} + Z\mathbf{z}$$

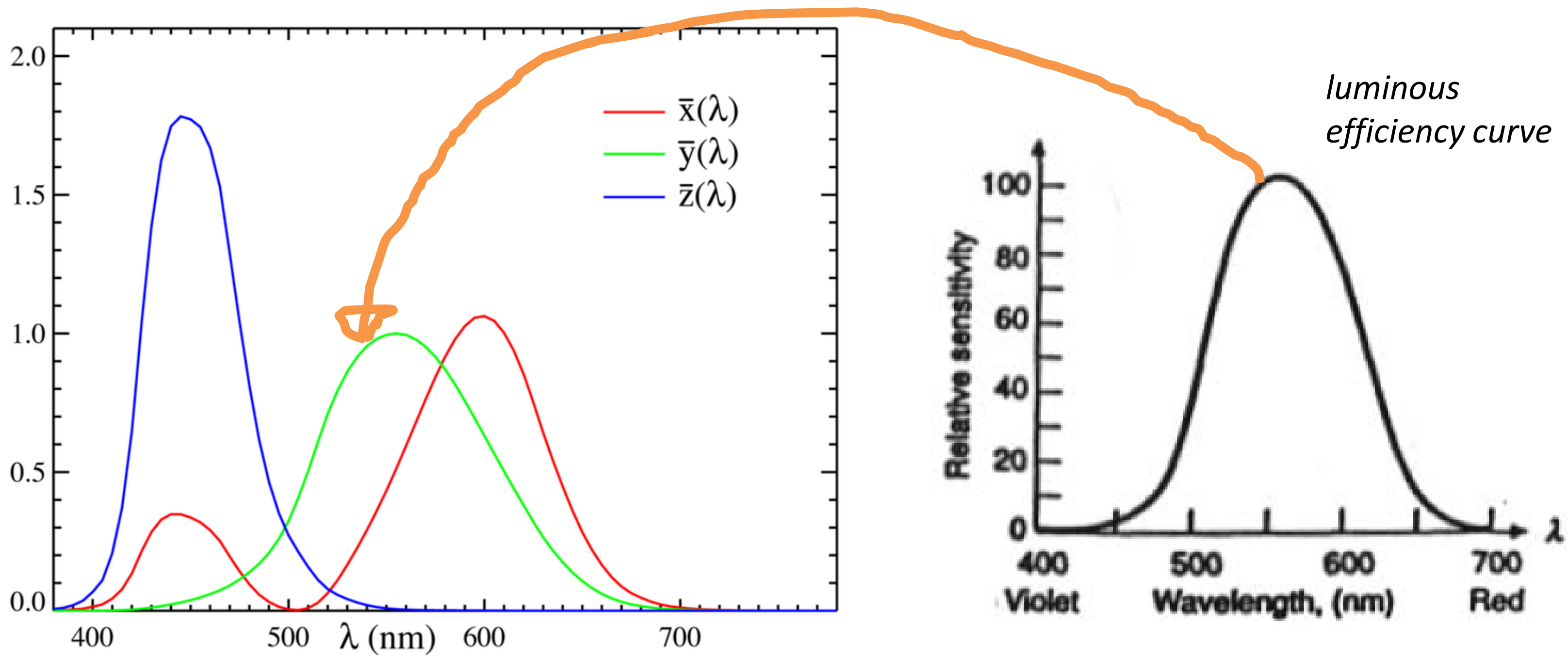
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

CIE Color Matching Functions



- Plots of x, y, z transformed from RGB
  - transform is LINEAR

CIE Color Matching Functions



- By design the y curve is just the luminous efficiency curve of the human eye

CIE xyY color specification

- Three imaginary color primaries: x, y, z

  $C = Xx + Yy + Zz$

- Normalizing X, Y, Z yields:

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

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

  $z = Z / (X + Y + Z) = 1 - (x + y)$

Choose Y to be luminance
i.e. sort of V in HSV

x, y can then represent all colors
i.e. sort of H, S in HSV

Color is then given by (x, y, Y)

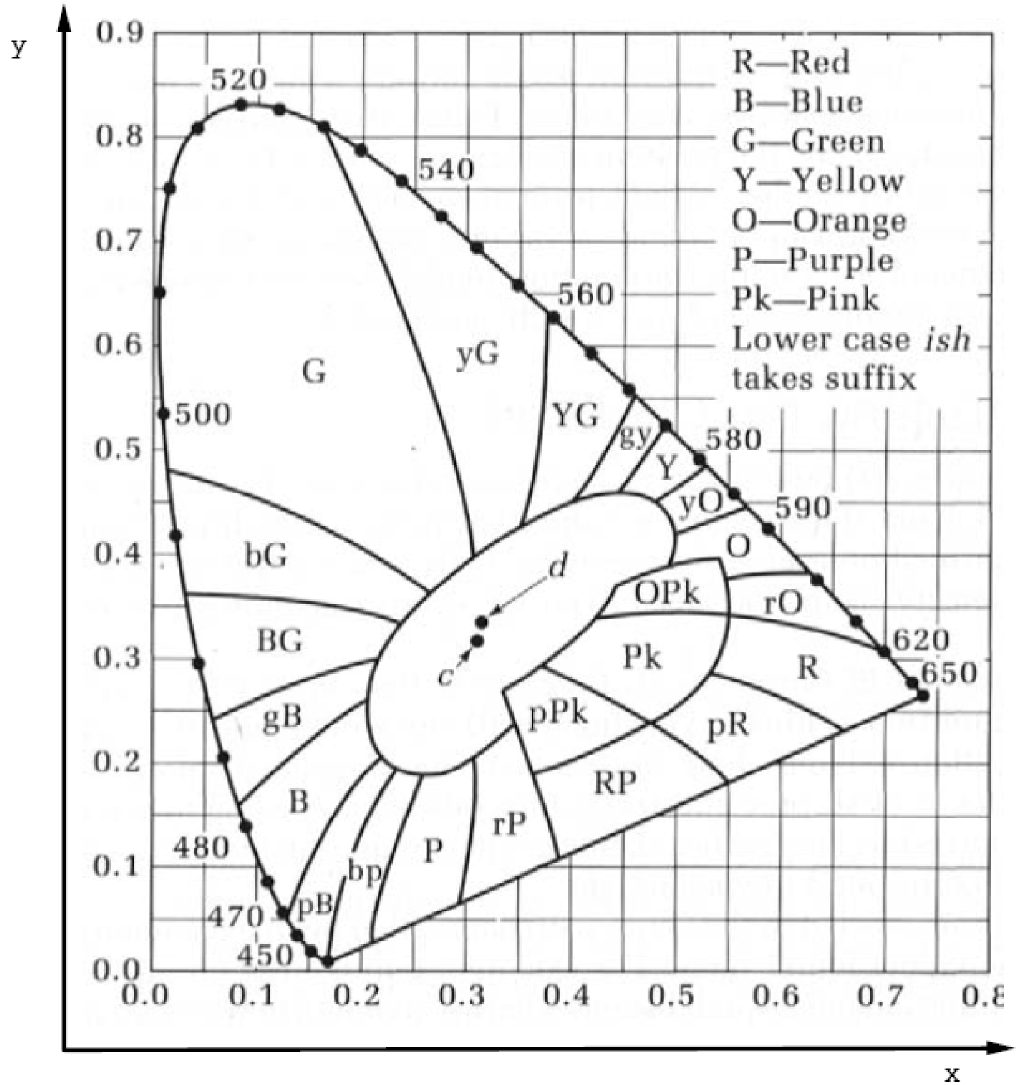
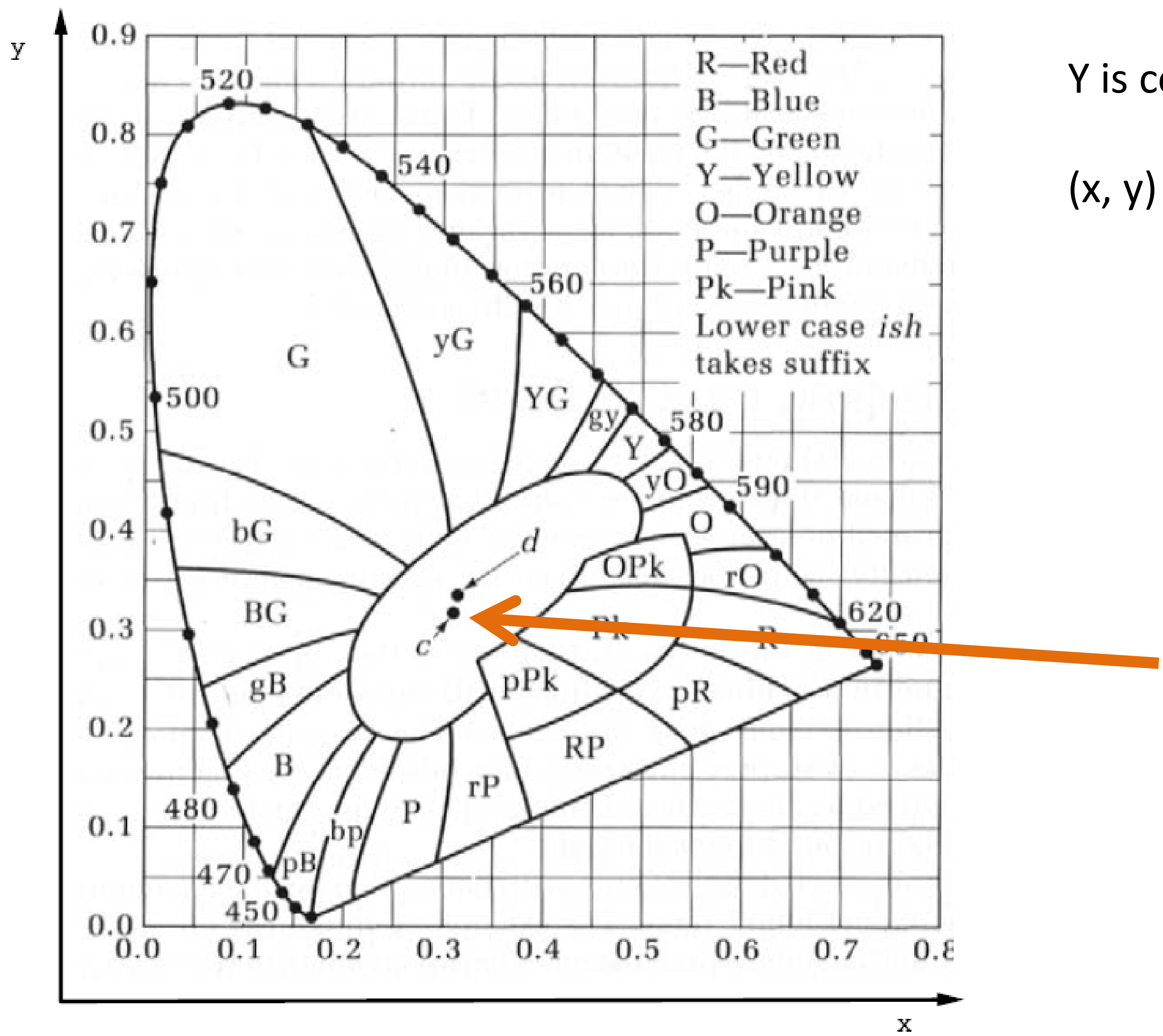


Figure 4.9: Cross Section of the CIE Space for Fixed Luminance Y copied from F.S. Hill, *Computer Graphics*, Macmillan, 1990, pg. 572.

Y is constant in this picture

(x, y) specifies the color



Y is constant in this picture

(x, y) specifies the color

c is white light

Figure 4.9: Cross Section of the CIE Space for Fixed Luminance Y copied from F.S. Hill, *Computer Graphics*, Macmillan, 1990, pg. 572.

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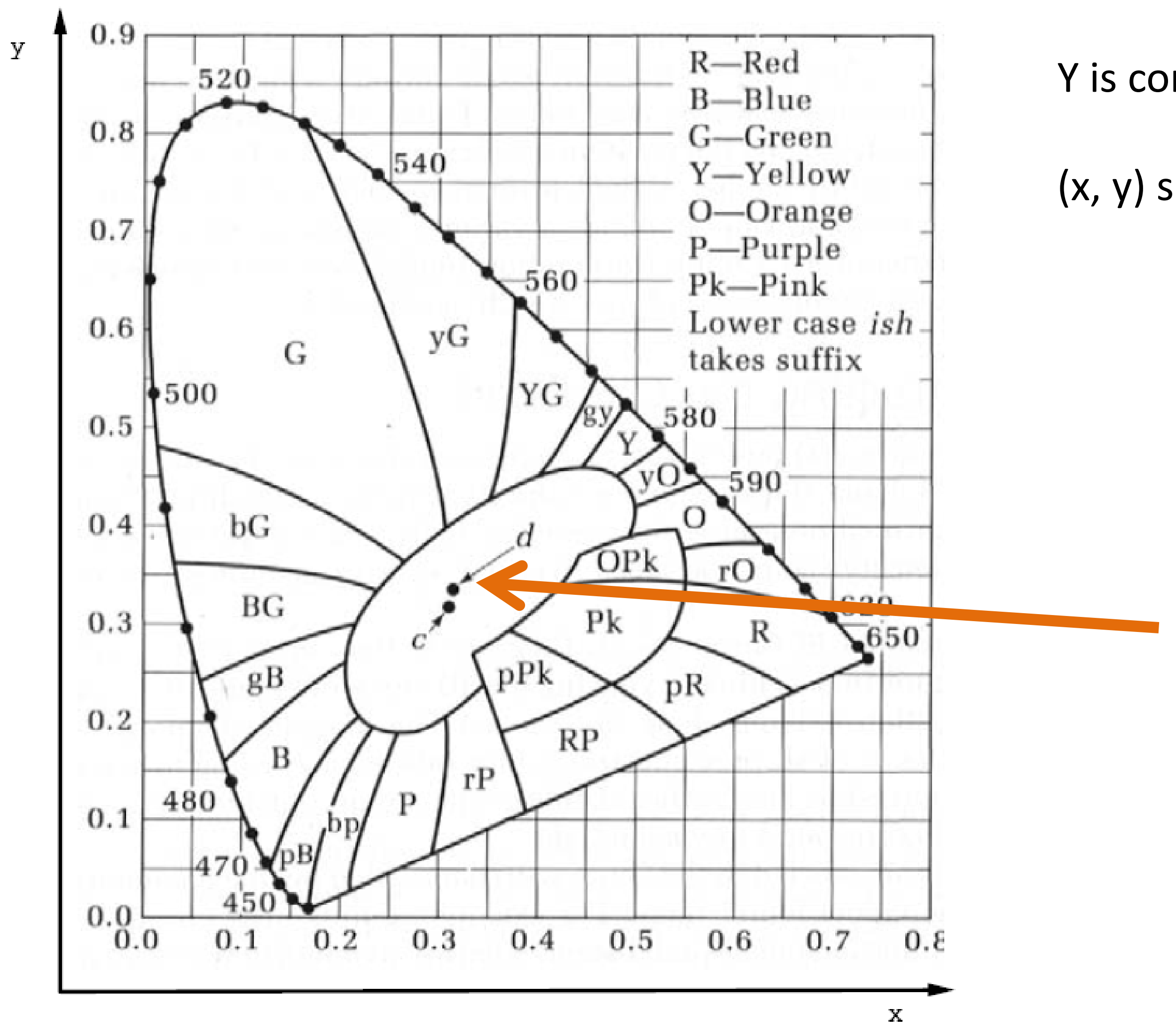

d is white light for NSTC

Figure 4.9: Cross Section of the CIE Space for Fixed Luminance Y copied from F.S. Hill, *Computer Graphics*, Macmillan, 1990, pg. 572.

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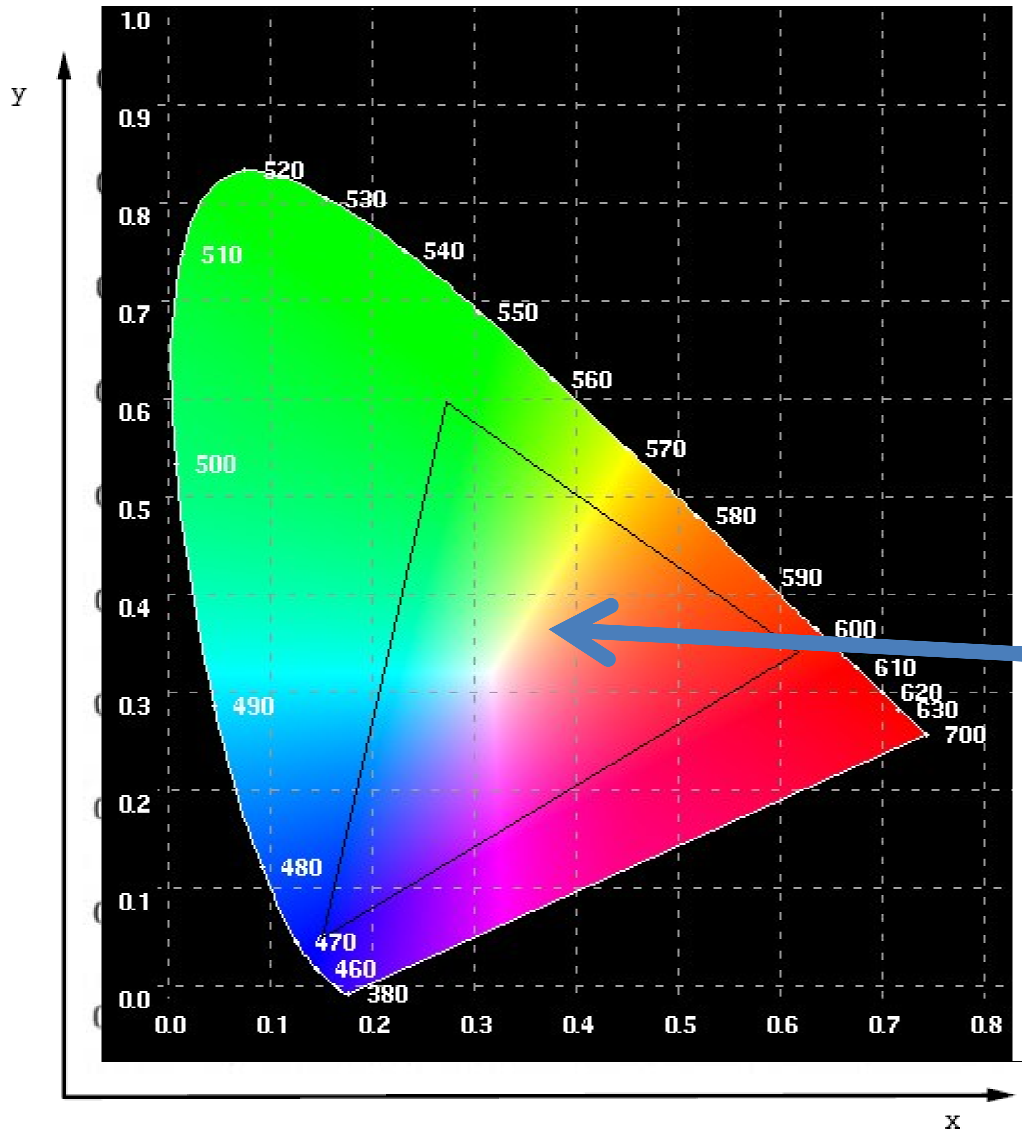
(x, y) specifies the color



Monitor display is limited to colors in this triangle (approximately)

This is called the monitor's GAMUT

Figure 4.9: Cross Section of the CIE Space for Fixed Luminance Y copied from F.S. Hill, *Computer Graphics*, Macmillan, 1990, pg. 572.

Summary

- Color
  - For humans
    - Tri-stimulus based
    - Many different color spaces
      - Examples: RGB, HSV, CIE xyY
    - Translation between them usually linear
      - *NOTE: HSV, HSL, HSI are NOT the same*
        - » *V = value, L = lightness, I = intensity*
  - Hardware has limitations too
    - only a GAMUT of colors can be displayed

Aside:
Color spaces themselves tend not be linear as they try to match human eye responses
See discussions on perception

- *Additional discussion on different color spaces and conversion between them can be found at*
  - *http://www.poynton.com/PDFs/coloureq.pdf*

Questions?

- Beyond D2L
  - Examples and information can be found online at:
    - *http://docdingle.com/teaching/cs.html*
    - *Continue to more stuff as needed*

Extra Reference Stuff Follows

Credits

- Much of the content derived/based on slides for use with the book:
  - *Digital Image Processing,* Gonzalez and Woods

- Some layout and presentation style derived/based on presentations by
  - Donald House, Texas A&M University, 1999
  - Bernd Girod, Stanford University, 2007
  - Shreekanth Mandayam, Rowan University, 2009
  - Igor Aizenberg, TAMUT, 2013
  - Xin Li, WVU, 2014
  - George Wolberg, City College of New York, 2015
  - Yao Wang and Zhu Liu, NYU-Poly, 2015
  - Sinisa Todorovic, Oregon State, 2015