Department of Computer Science
National Tsing Hua University

CS 5263: Wireless Multimedia Networking Technologies and Applications

Color Models

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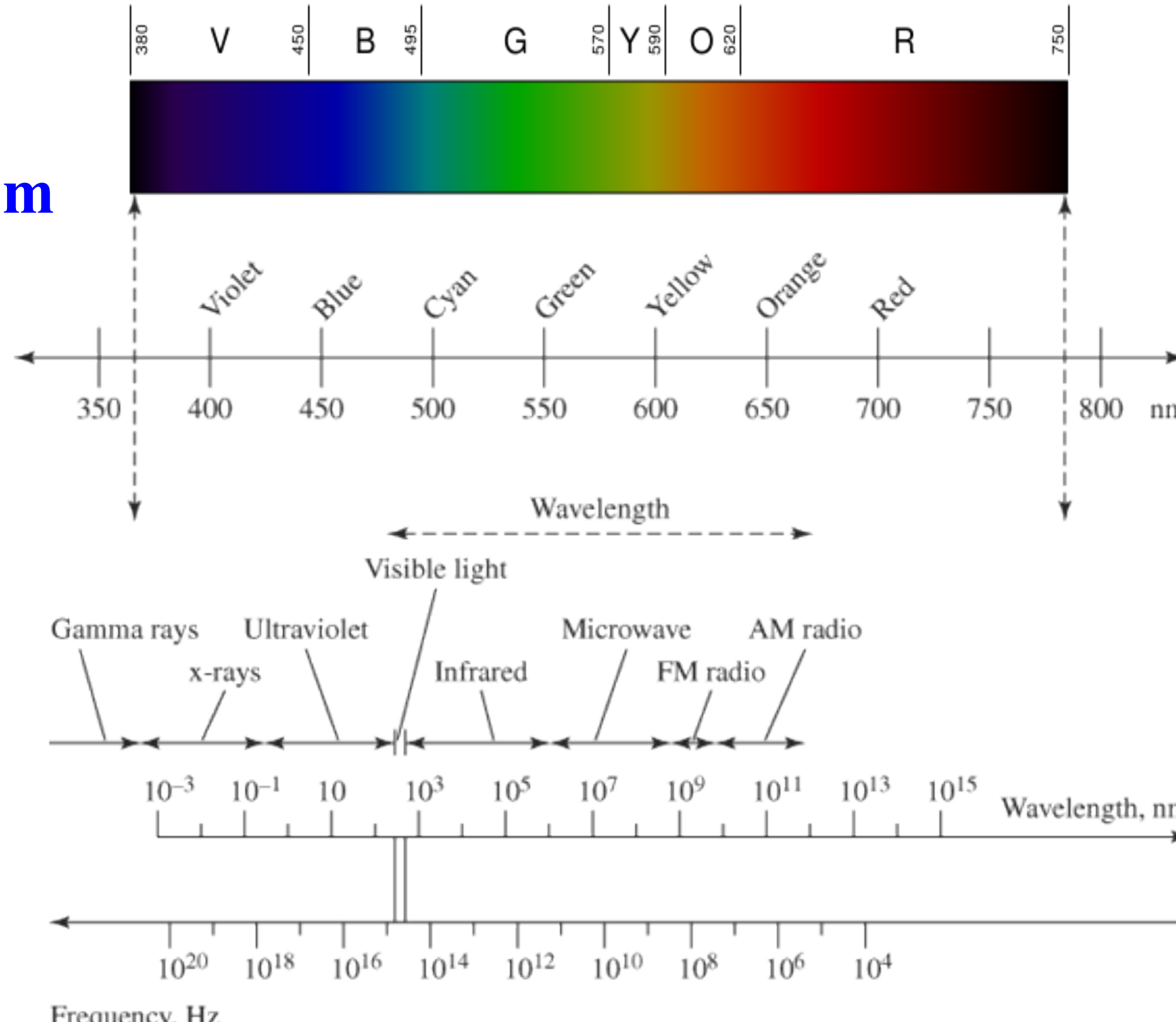
Colors & Color Models

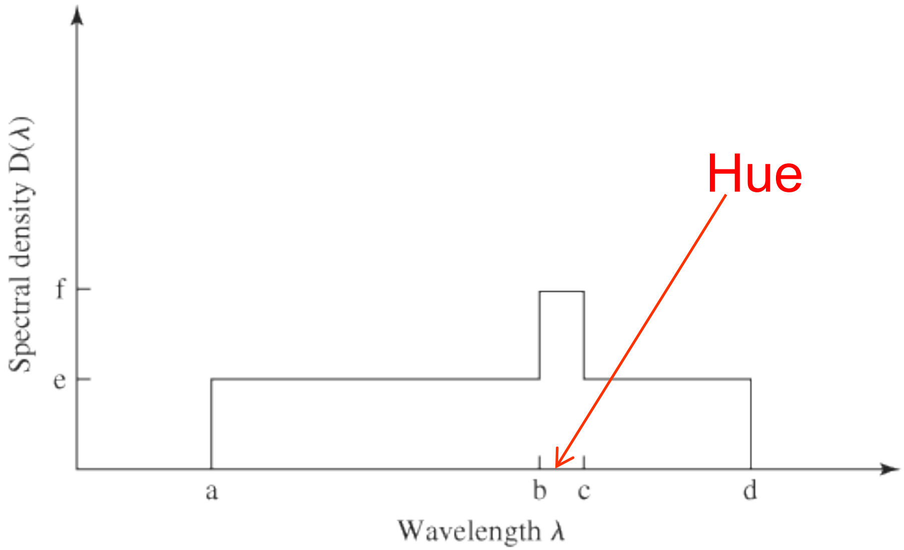
- **Color is composed of electromagnetic waves**
- **Humans: visible colors: 370 – 780 nm**



- **Frequency spectrum**

Colors

- Pure color has a single wavelength
  - Could be generated for example by laser
- Typically, we see a combination of wavelengths
  - Spectral analysis shows contribution of each wavelength
- A color could be represented by
  - Hue: dominant wavelength
    - Wavelength at the spike
  - Saturation: color purity
    - Area under spike over total area
  - Luminance: ~brightness
    - Area under curve (power)

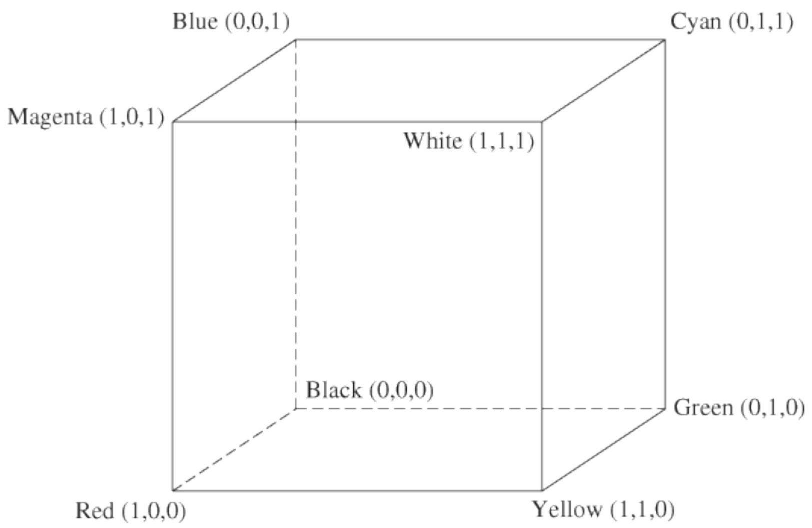


Color Models

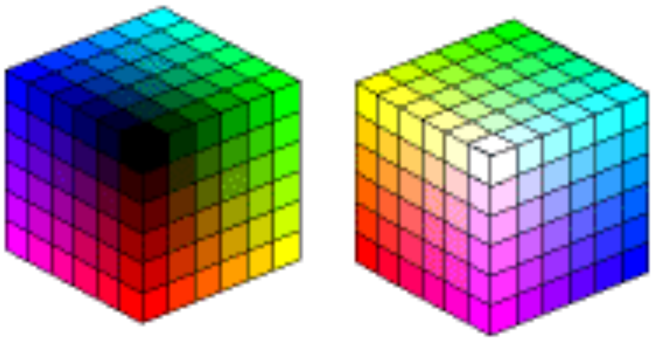
- The hue, saturation, luminance representation is not well suited for computer monitors
  - CRT monitors use three phosphors beams Red, Blue, Green (RGB) of varying intensities
  - LCD: use Red, Blue, Green pixels
- Common method to create wide range of colors is to combine three primary colors
    - Primary = cannot be generated from each other
- RGB are good choices because the color receptors in the eyes are specially sensitive to them

RGB Color Model

- Increasing each component with same ratio ➔ increases brightness
  - (0.64, 0.96, 0.78) is brighter shade of green than (0.32, 0.48, 0.39)
- Grayscale values on the cube's diagonal from (0,0,0) to (1,1,1)
  - Same value for R,G,B



- RGB to grayscale conversion: (R, G, B) ➔ (L, L, L)
  - L = 0.30 R + 0.59 G + 0.11 B
- Eyes are most sensitive to green, and least sensitive to blue

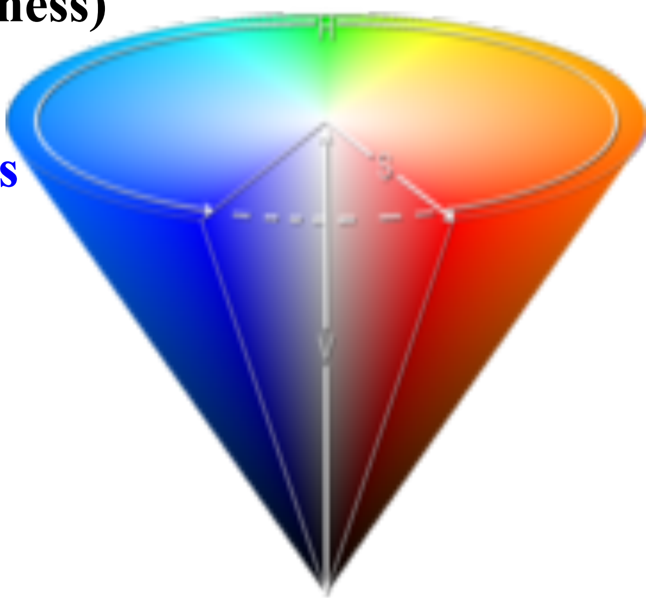


CMY Color Model

- RGB is called additive model
- CMY (Cyan, Magenta, Yellow) are complements of R,G,B
  - C = 1 - R; M = 1 – G; Y = 1 - B
- ➔ CMY is a subtractive model, i.e.,
  - The origin of the cube is White (not Black), and
  - (C, M, Y) means how much Red, Green, Blue are subtracted out
- CMY is used in color printer
  - Typically with a fourth color: Black (K) ➔ CMYK
    - To give better clarity and save ink, because
    - (1,1,1) results in muddy brown not true black

HSV and HLS Color Models

- We mentioned before that a color can be represented by its
  - Hue (essential color)
  - Saturation (purity of color)
  - Luminance (or value or lightness or brightness)
- ➔ HSV (also called HSB) color model
- Usually used in computer graphics applications
- HLS is similar to HSV
- Non linear transformations from RGB to HSV (or HLS) and vice versa



HSV model

Luminance & Chrominance Color Models

- Yet another method to represent color
  - Put all luminance information in one value (Y)
  - All color (chrominance) information in other two (IQ)
- Why?
  - More convenient for television broadcast (in early days)
    - All black & white info in one value (luminance) ➔
    - same transmission for black & white and color TVs
  - Allows us to treat components differently
    - Humans more sensitive to Y than IQ
- YIQ used for TV in North America (NTSC)
- YUV for TV in Europe (PAL)
- YCbCr (similar to YUV): Used in JPEG and MPEG

YIQ Model

- Y: weighted sum of R,G,B
  - Brightness in the image
  - Black & white image

- I & Q add the color aspects

Original image

Y Component

I Component

Q Component

Luminance & Chrominance Color Models

- **YIQ ⇔ RGB using linear transformation**

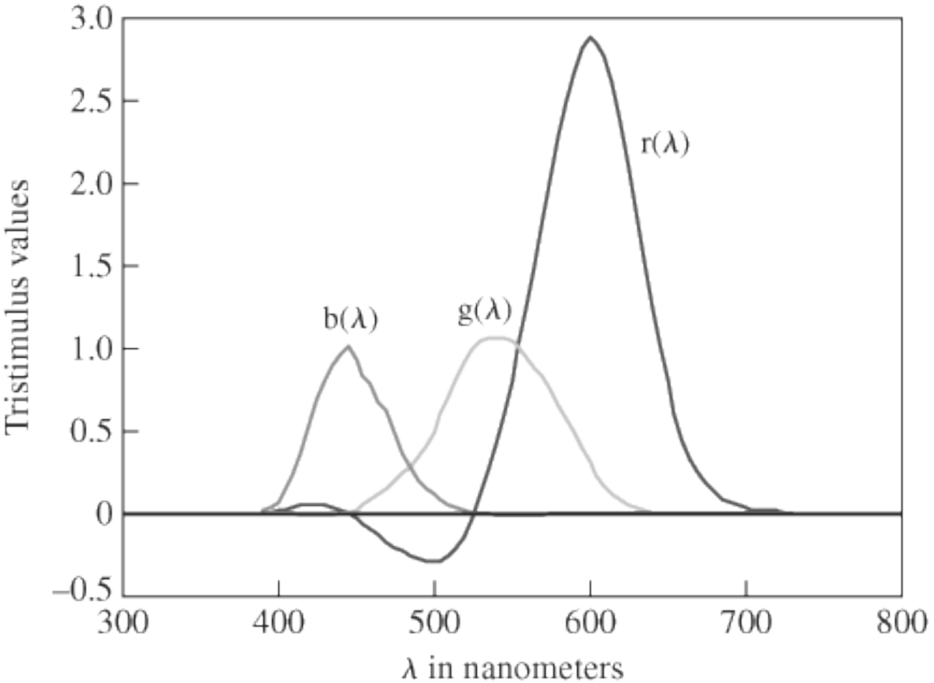
$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- **Note: Values in matrix depend on the choice of the primaries for RGB**

CIE XYZ Model and Color Gamut

- **RGB does not capture all visible colors**
  - Some visible colors cannot be produced by adding RGB components

$$C(\lambda) = r(\lambda)R + g(\lambda)G + b(\lambda)B$$



- **Color matching experiment**
  - Produce pure colors
  - Ask observers to vary r, g, b mix till match
  - Some visible (pure) colors could not be matched unless we added R to them, i.e., subtract R from the mix

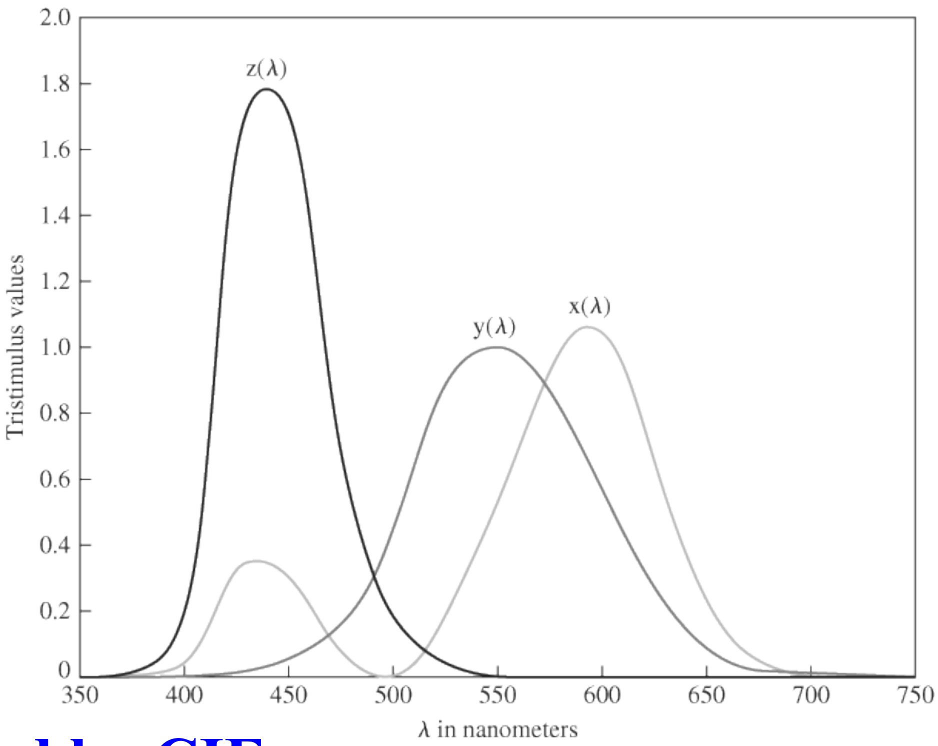
CIE XYZ Model and Color Gamut

- This means systems that use RGB model (e.g., monitors) may not able to produce all visible colors
- Similarly for systems that use CMYK model (e.g., color printers)
- ➔ some colors can be produced on monitors but not on printers and vice versa
- Color Gamut (or scope): is the range of colors that can be produced (displayed or printed)
- CIE: Commission Internationale de l'Eclairage (illumination in French)
  - Goal: define a model to represent <u>ALL</u> colors
  - Used to compare color gamut of different color models

CIE XYZ Color Model

- **CIE defines three virtual primaries (X, Y, Z) from which all colors can be composed by positive amounts**
- **Color given by**

$$C(\lambda) = x(\lambda)X + y(\lambda)Y + z(\lambda)Z$$

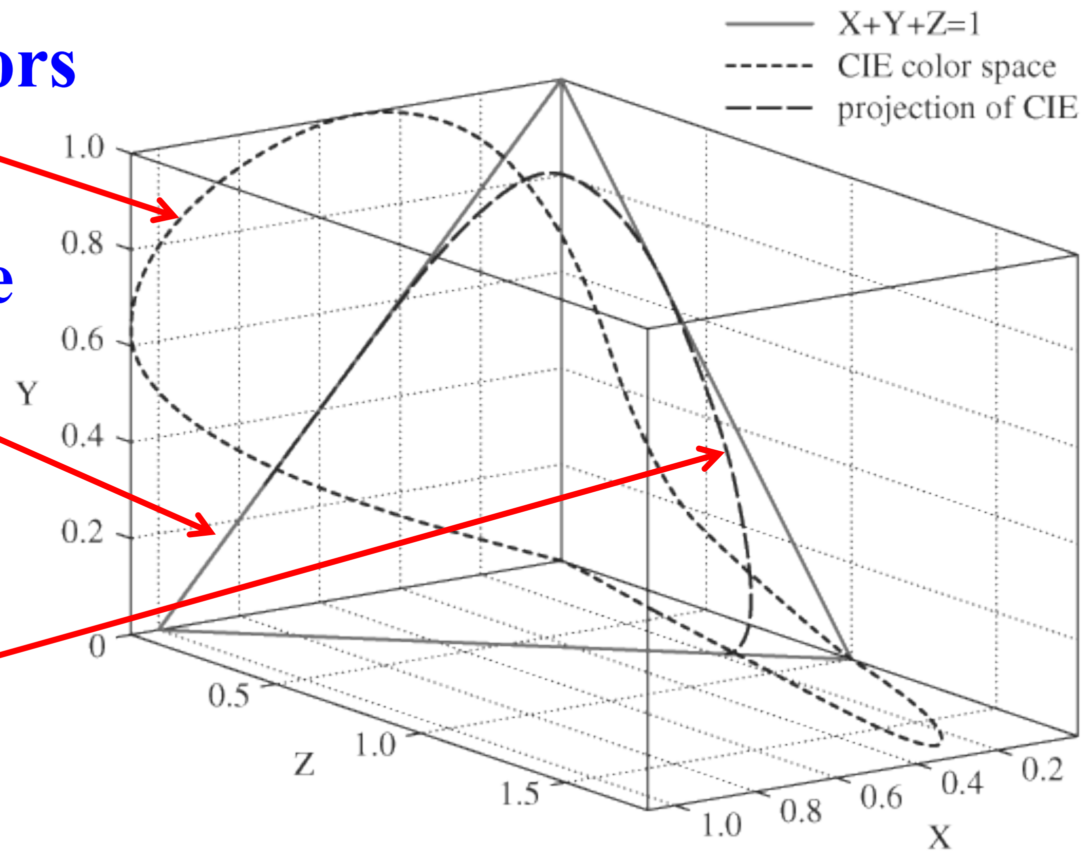


- **X, Y, Z are constants defined by CIE**
- **For simplicity, we normalize:**

$$x'(\lambda) = \frac{x(\lambda)}{x(\lambda)+y(\lambda)+z(\lambda)};\; y'(\lambda) = \frac{y(\lambda)}{x(\lambda)+y(\lambda)+z(\lambda)};\; z'(\lambda) = \frac{z(\lambda)}{x(\lambda)+y(\lambda)+z(\lambda)}$$

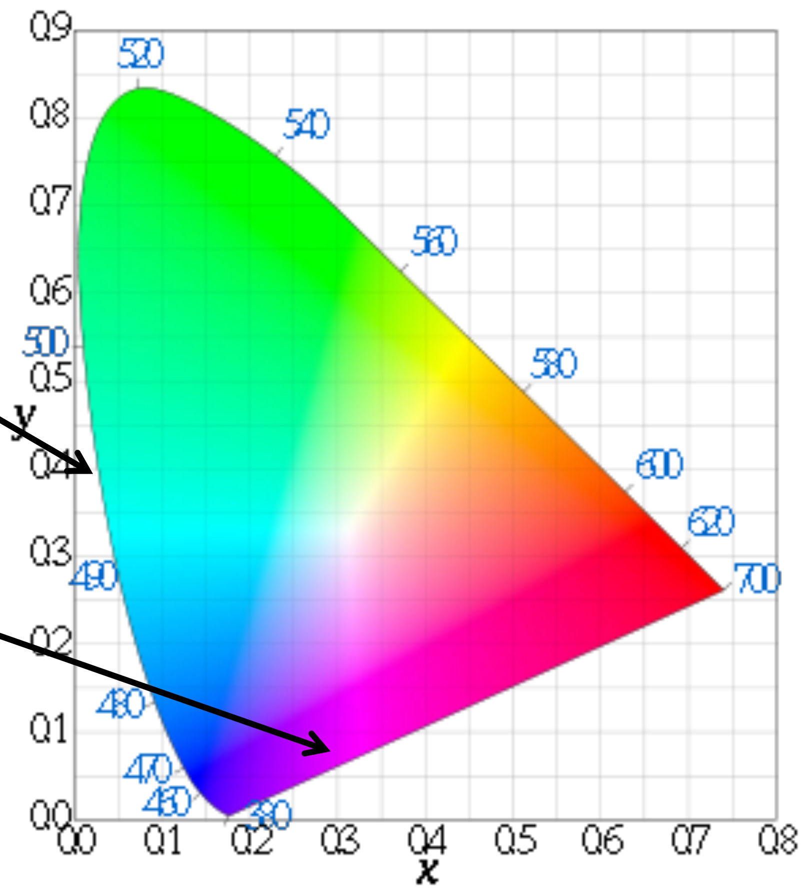
CIE XYZ Color Model

- **Thus, we have:** $x'(\lambda) + y'(\lambda) + z'(\lambda) = 1$
- **All perceived colors**
- **Normalized plane**
- **Projection**
  Horseshoe shape



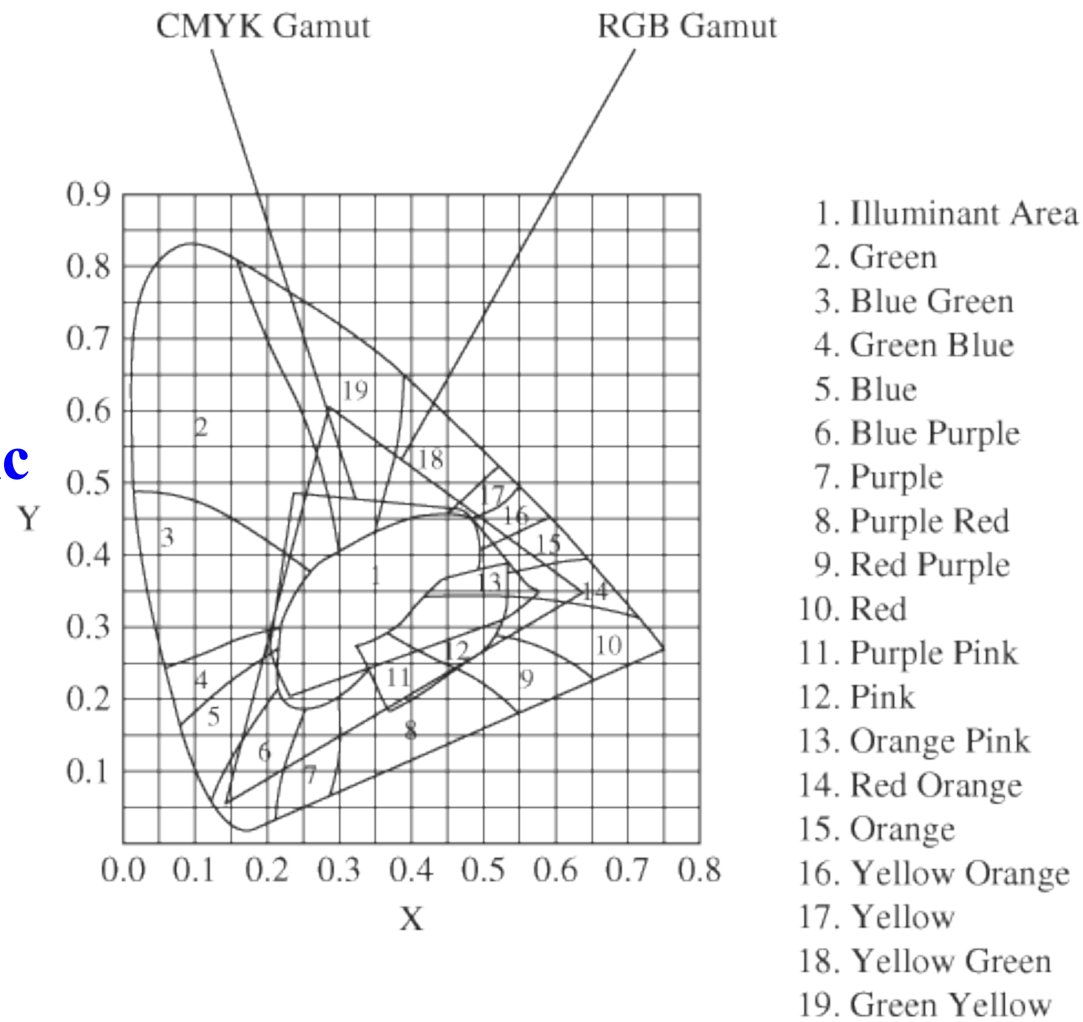
CIE Chromaticity Diagram

- Projection on X,Y ➔
  CIE Chromaticity Diagram
  - Represents all visible colors at unit energy
- On the curved edge, fully saturated (pure, spectral) colors
- On straight line base, colors that cannot be produced by a single wavelength (nonspectral)
- A line joining any two colors represents colors that can be created by combining these two colors



RGB vs. CMYK on Chromaticity Diagram

- RGB range is larger, but it does not fully contain CMYK
- Note: exact gamut depends on the specific constants used for RGB & CMYK



RGB ←→ CIE XYZ

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.24 & -1.54 & -0.50 \\ -0.97 & 1.88 & 0.04 \\ 0.06 & -0.20 & 1.06 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

- **Again depends on the specific constants for RGB**

Color Models: Summary

- **Different methods for representing colors**
  - **Additive** (three primary colors: R, G, B)
    - Used in digital cameras, monitors, TVs
  - **Subtractive** (three primary colors: C, M, Y Plus K)
    - Good for printers
  - **Luminance & Chrominance:** YIQ, YUV, YCbCr
    - Luminance component (Y) and two chrominance components
    - YIQ & YUV used in B&W and color TV (same signal)
    - YCbCr used in JPEG and MPEG compressions
  - **HSV & HSL:** Hue, Saturation, Value (or Lightness)
    - Usually used in computer graphics applications
  - **CIE XYZ:**
    - Theoretical, comprehensive, used for comparing gamut