

**CS 5263: Wireless Multimedia Networking
Technologies and Applications**

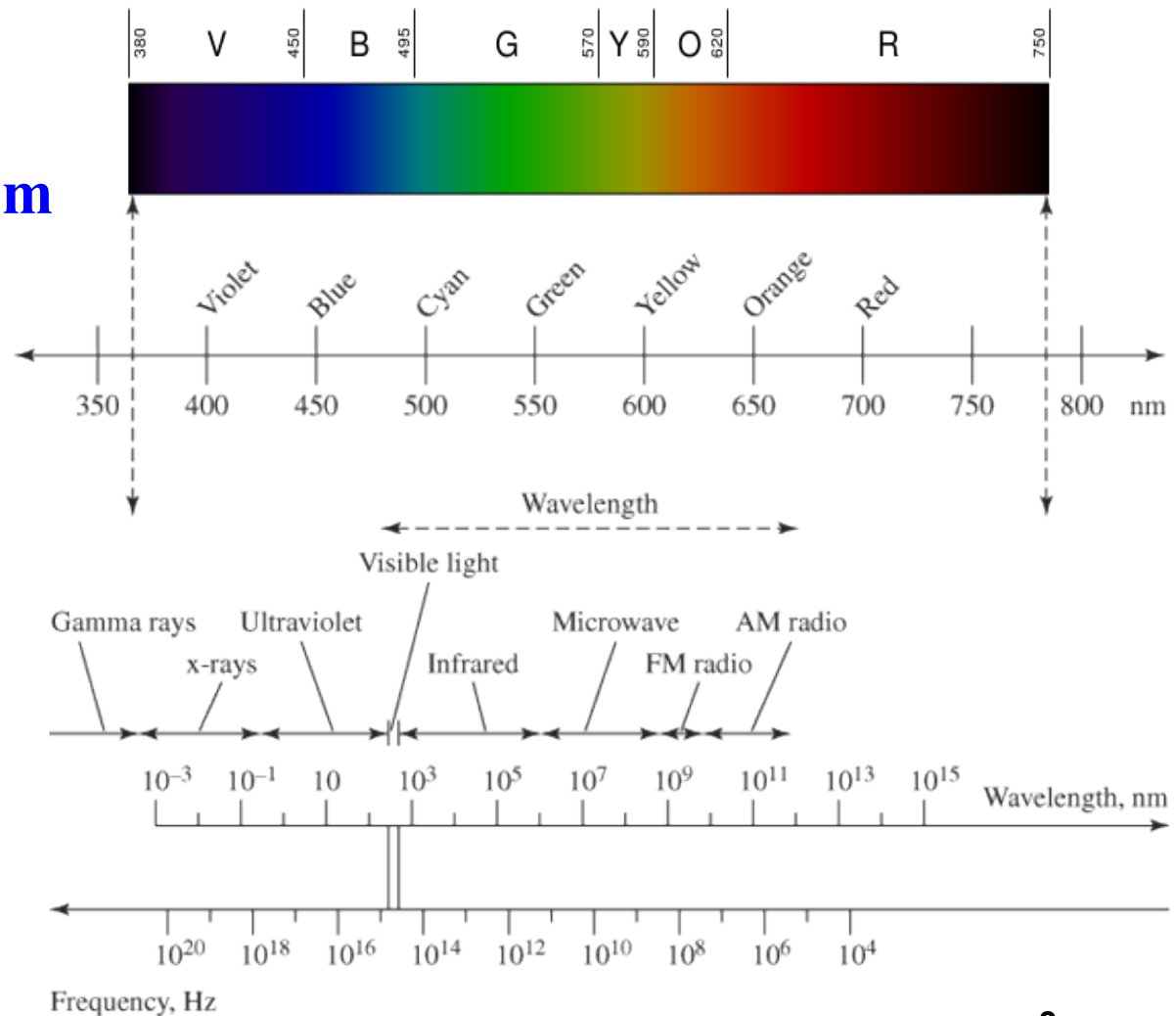
Color Models

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**Acknowledgement: The instructor thanks Prof. Mohamed Hefeeda at
Simon Fraser University for sharing his course materials**

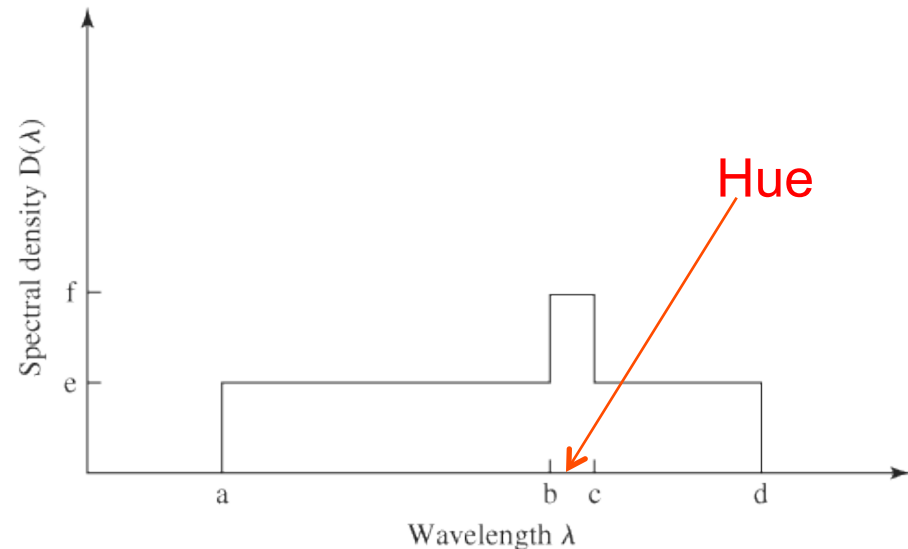
Colors & Color Models

- 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)

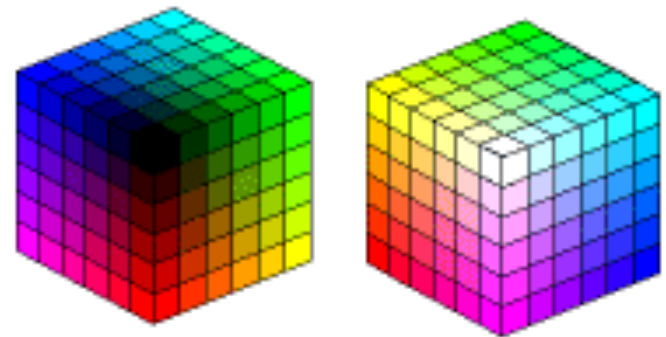
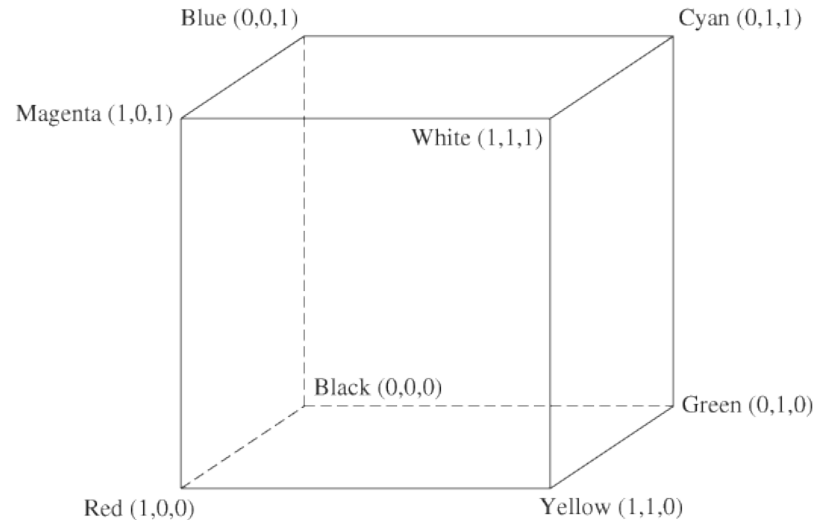


Color Models

- 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

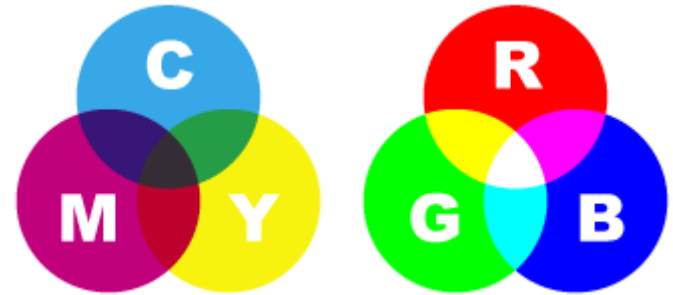
RGB Color Model

- 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: $(R, G, B) \rightarrow (L, L, L)$
 - $L = 0.30 R + 0.59 G + 0.11 B$
- Eyes are most sensitive to green, and least sensitive to blue



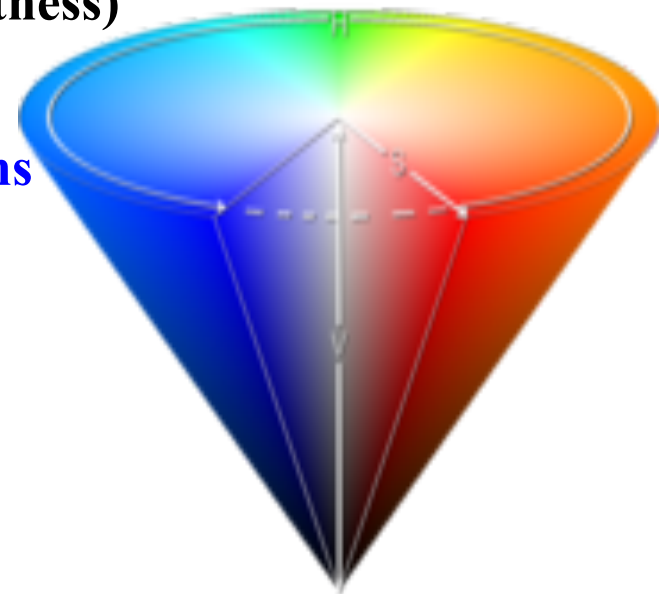
CMY Color Model

- 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 $\leftrightarrow$ 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

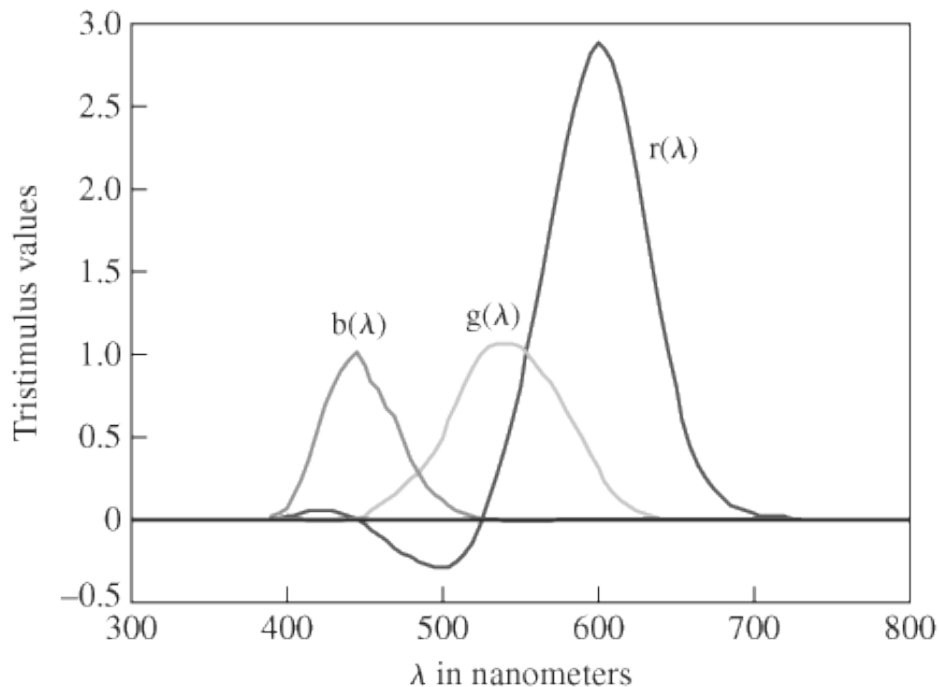
- RGB does **not** capture all visible colors

- 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



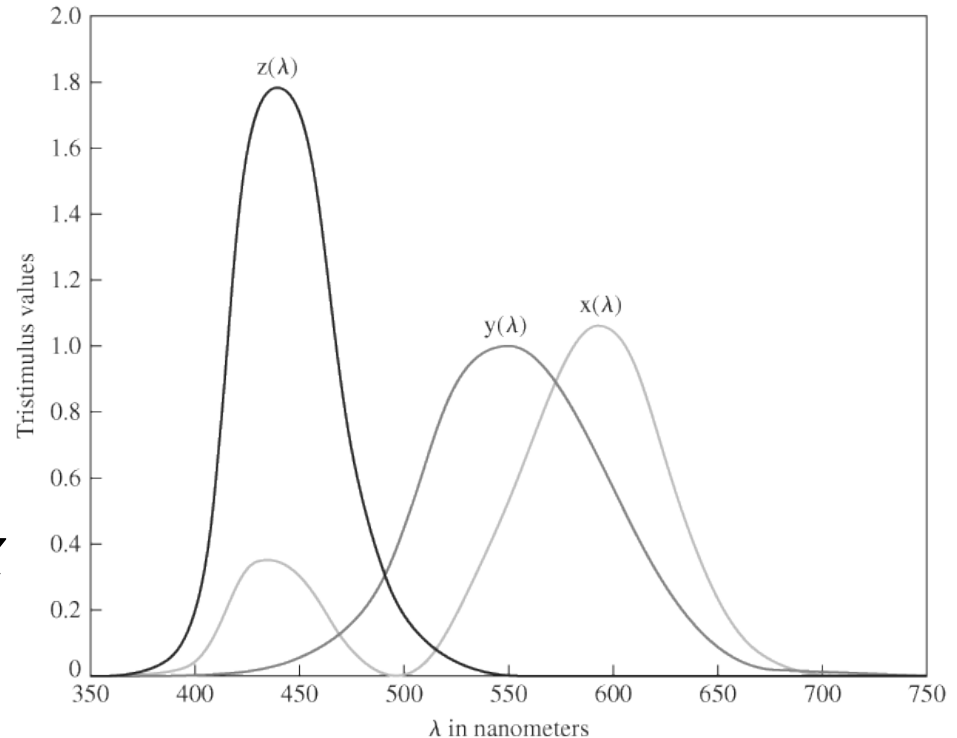
CIE XYZ Model and Color Gamut

- This means systems that use RGB model (e.g., monitors) may not be 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 ALL 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:

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

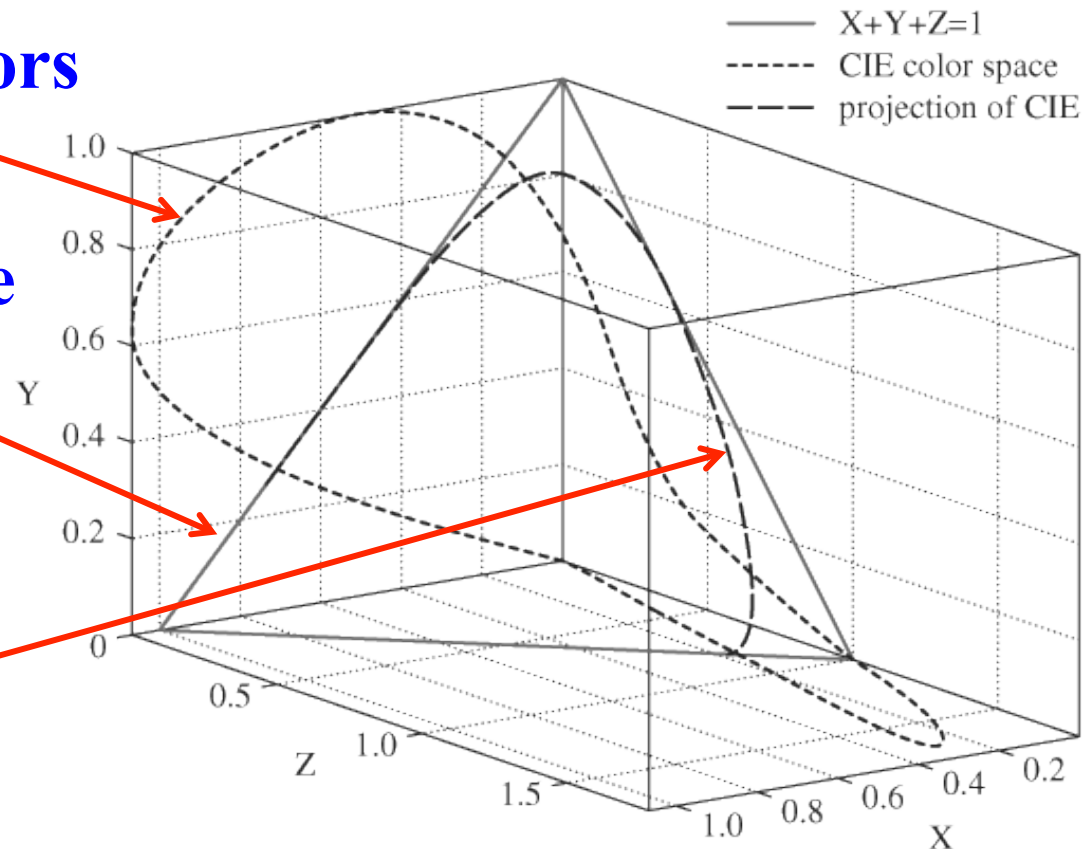
CIE XYZ Color Model

- Thus, we have: $x'(\lambda) + y'(\lambda) + z'(\lambda) = 1$

- All perceived colors

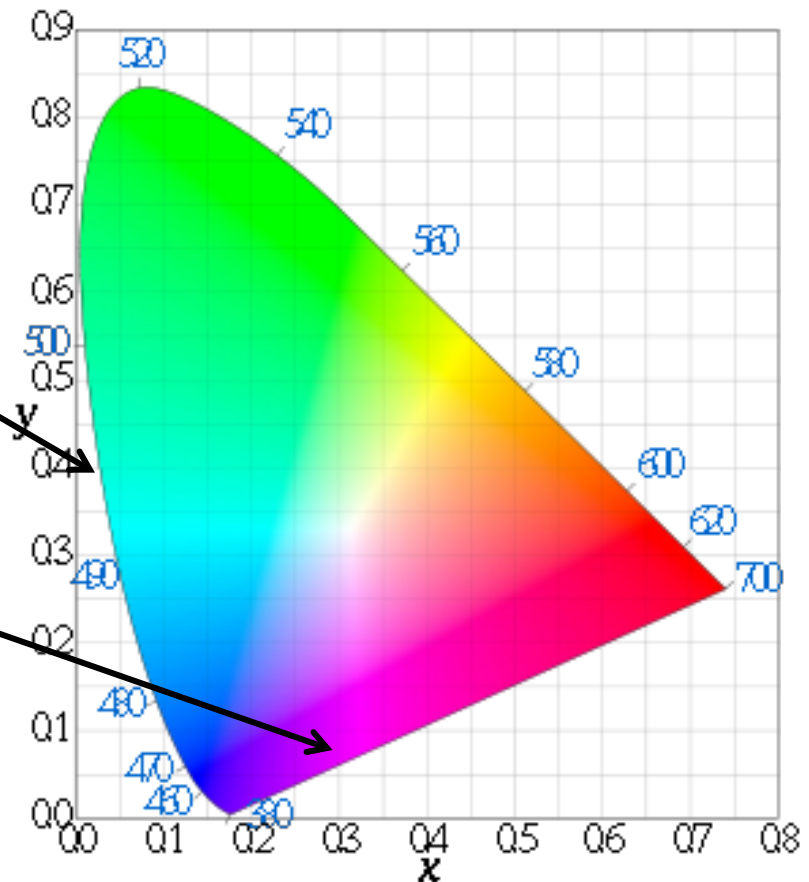
- Normalized plane

- Projection
Horseshoe shape



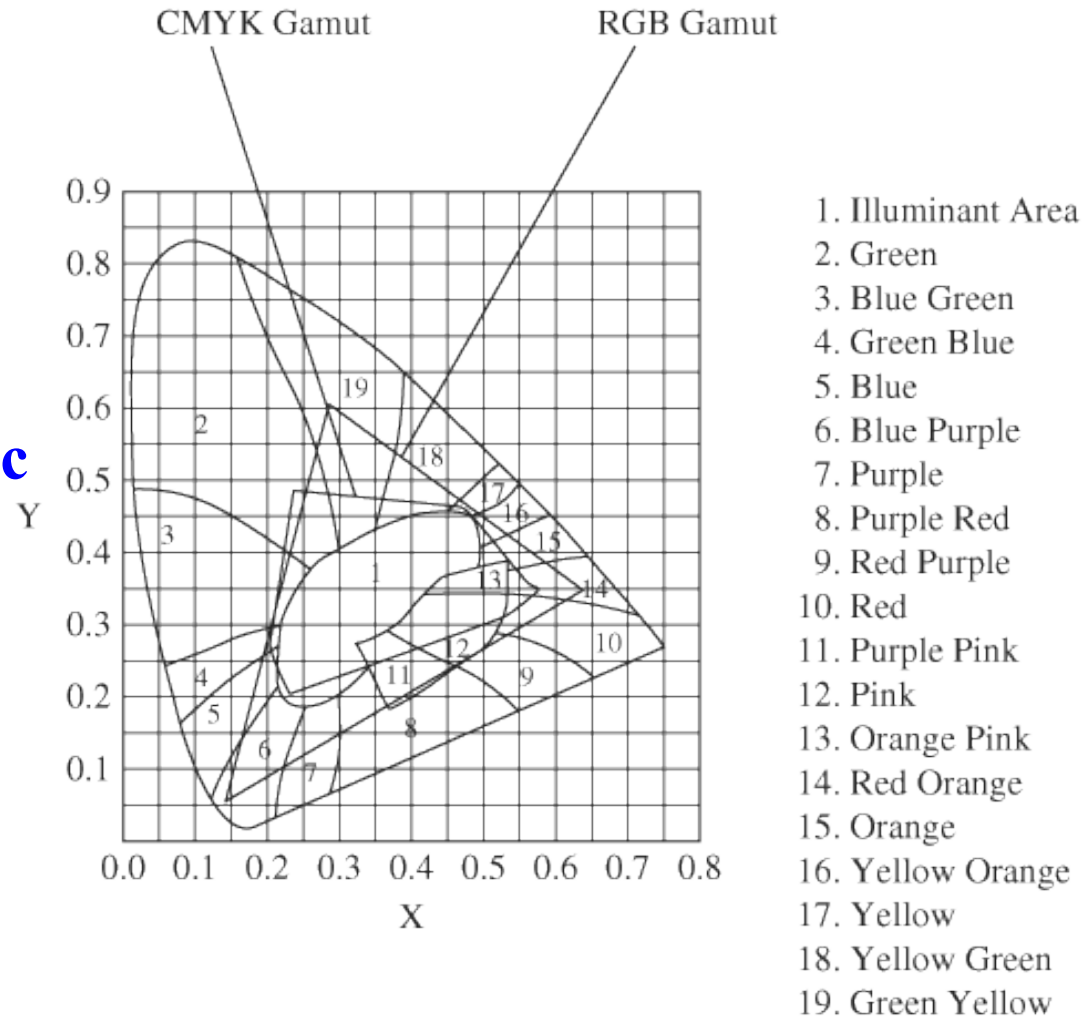
CIE Chromaticity Diagram

- 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 $\leftrightarrow$ 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