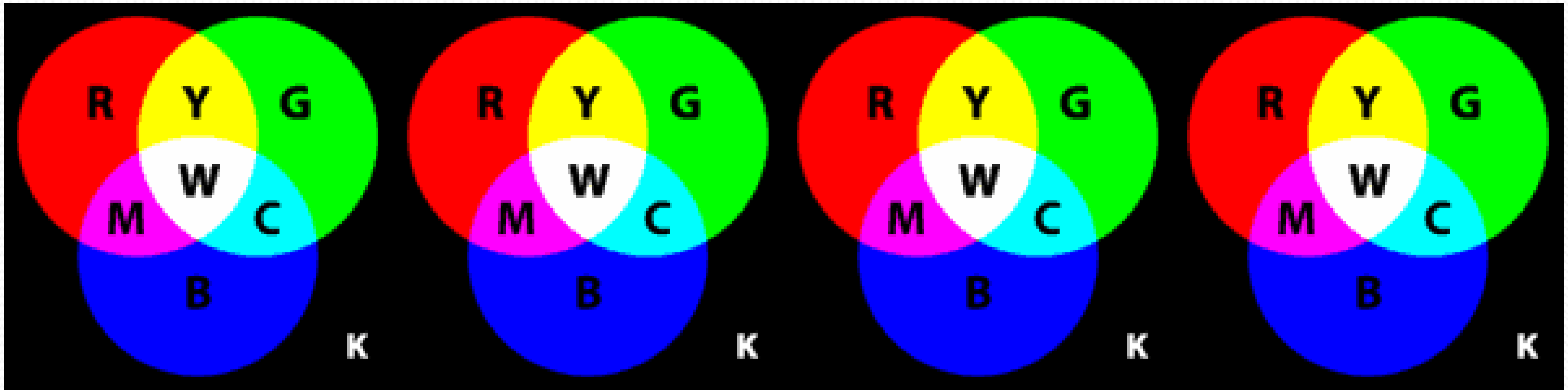
Color Models

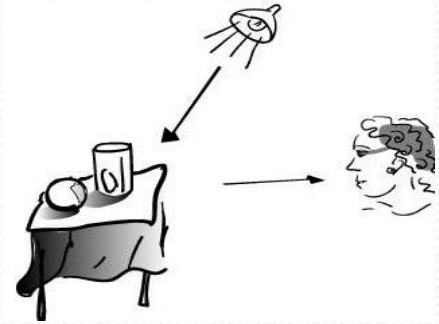
Why Study Color in Computer Graphics?

- **Measurement for realism** - what does coding an RGB triple mean?
- **Aesthetics** for selecting appropriate user interface colors
  - how to put on matching pants and shirt in the morning
  - what are the perceptual/physical forces driving one's "taste" in color?
- Understanding color models for providing users with easy color selection
  - systems for naming and describing colors
- Color models, measurement and color gamuts for converting colors between media
  - why colors on your screen may not be printable, and vice-versa



Why is Color Difficult?

- Color is an immensely complex subject drawing from physics, physiology, perceptual psychology, art, and graphic design
- There are many theories, measurement techniques, and standards for colors, yet no single theory of human color perception is universally accepted
- Color of an object depends not only on the object itself, but also on the light sources illuminating it, the color of surrounding area, and on the human visual system (the eye/ brain mechanism)
- Some objects reflect light (wall, desk, paper), while others also transmit light (cellophane, glass)

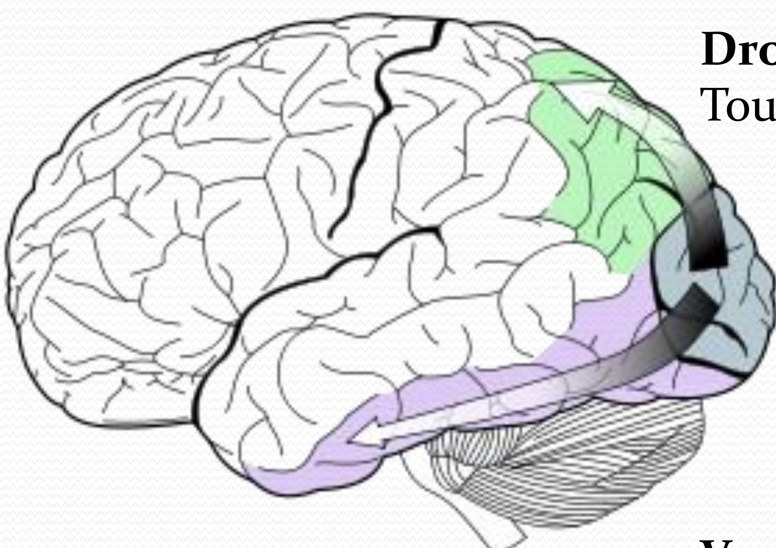


What is color?

- Color is a property of objects that our minds create – an interpretation of the world around us
- Color perception stems from two main components:
  - Physical properties of the world around us
    - electromagnetic waves interact with materials in world and eventually reach eyes
    - visible light comprises the portion of the electromagnetic spectrum that our eyes can detect (380nm/violet – 740nm/red)
    - photoreceptors in the eye (rods and cones) convert light (photons) into electro-chemical signals which are then processed by our brain.
  - Physiological interpretation of signals output by receptors
    - less well-understood and incredibly complex higher level processing
    - very dependent on past experience and object associations

What is color?

- A color model is a method for explaining the properties (visual perceptual) or behavior of color within some particular context.



Drosal Stream – Sight, Smell, Sound, Taste, Touch

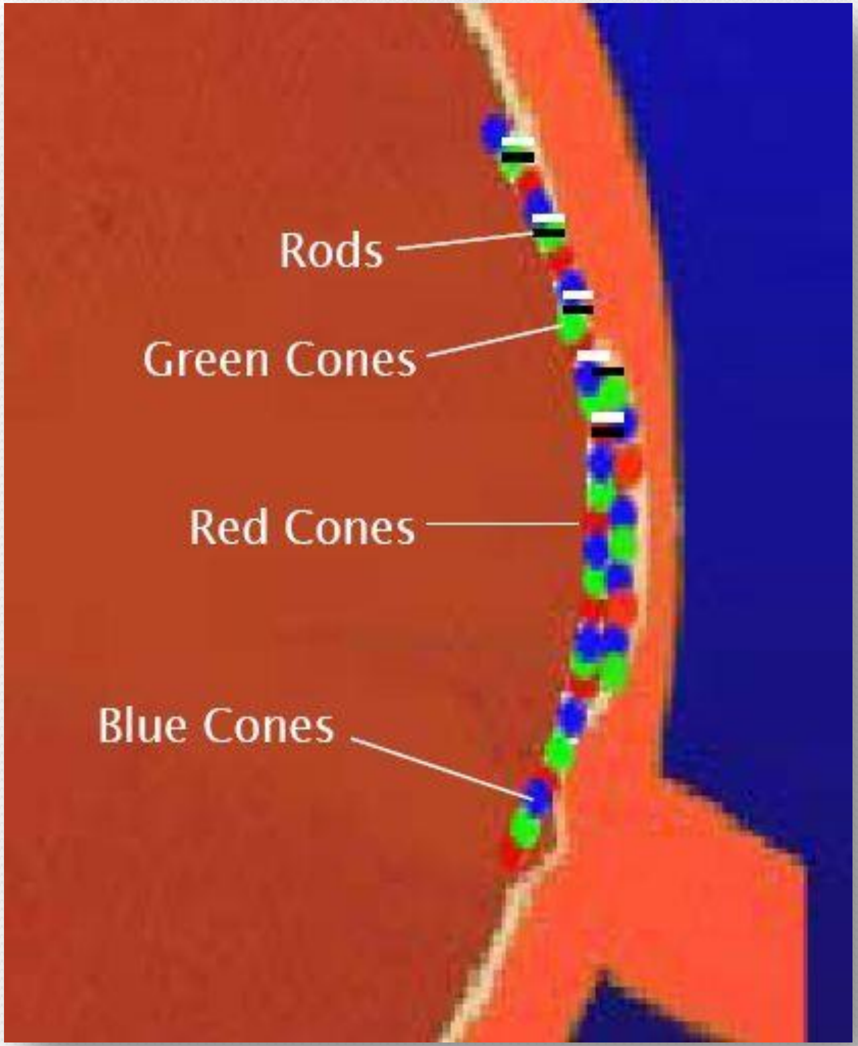
Cerebral Cortex

memory, attention, perceptual awareness, thought, language, and consciousness

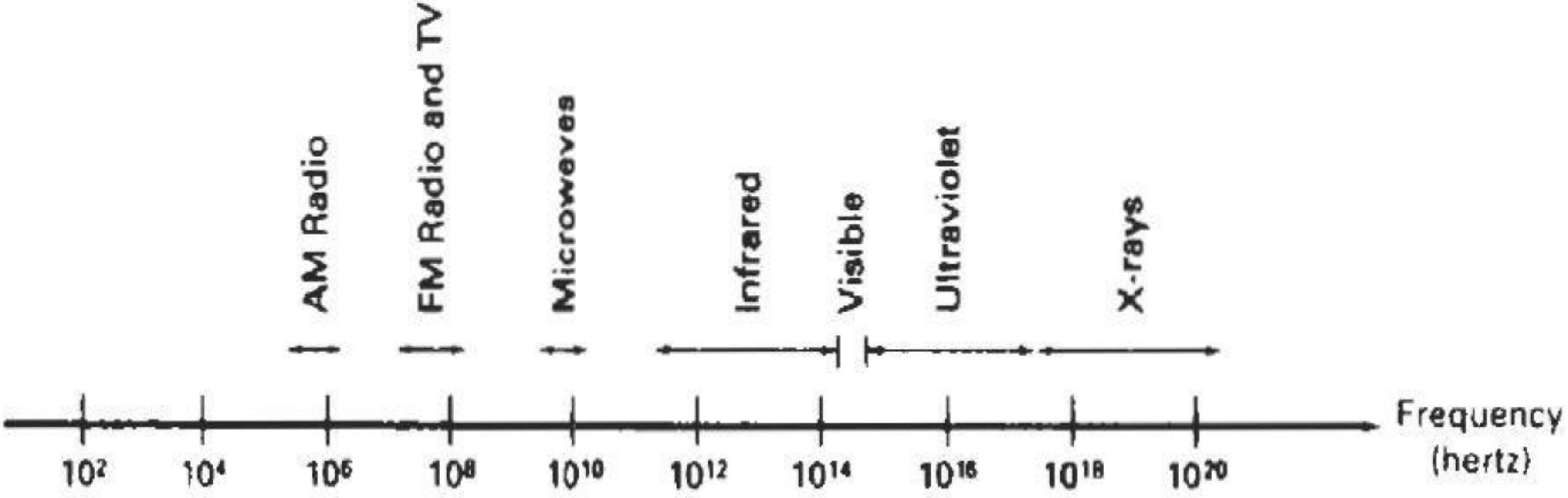
Ventral Stream – Color Perception

Cones and Rods

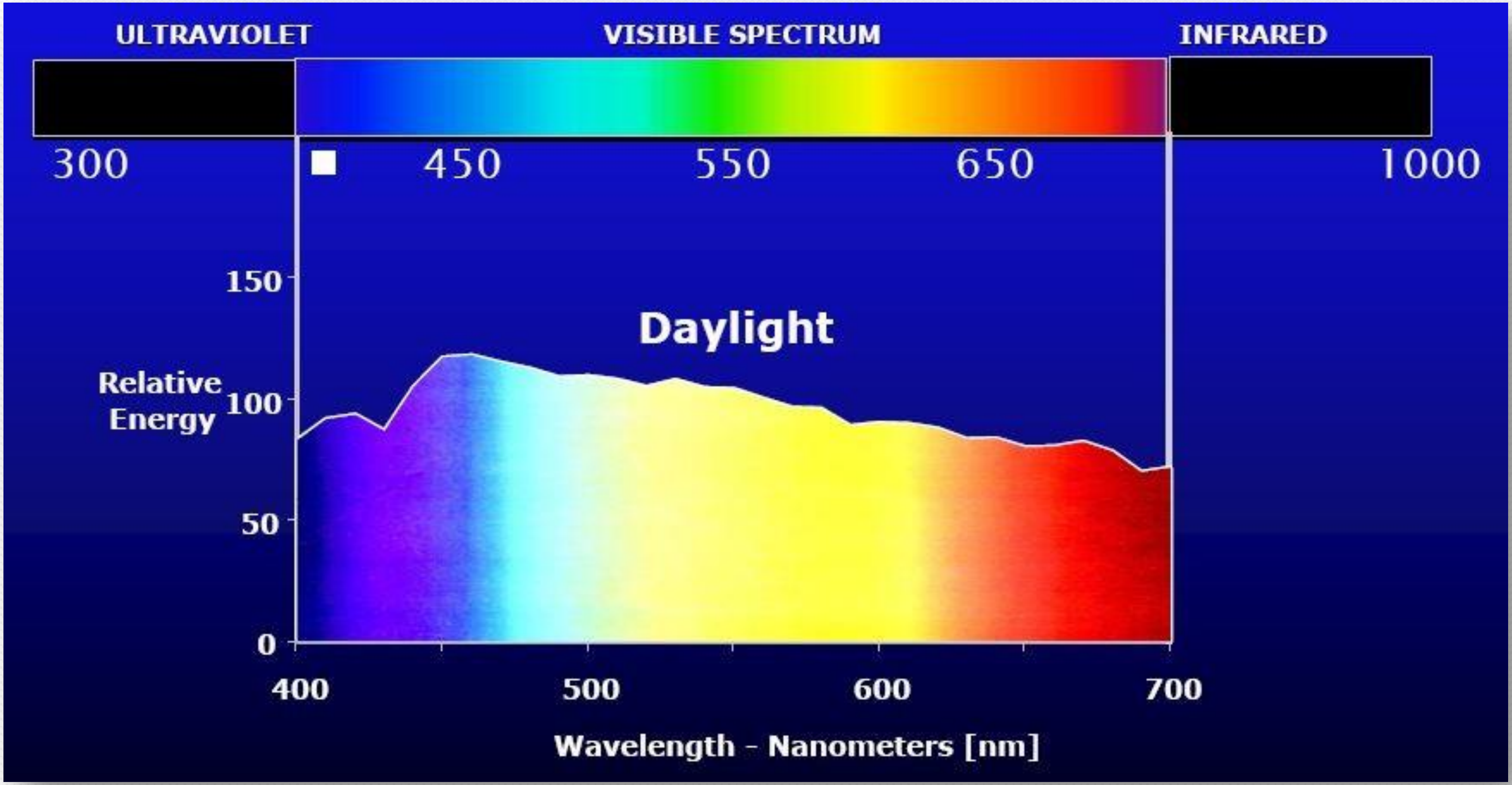
- Rod - Responsible for night vision.
- Cones – Responsible for daylight and color vision.



Electromagnetic Spectrum



Visible Spectrum



Color Classification

Color

Luminance

Chrominance

Brightness

Hue

Saturation

Properties of Color

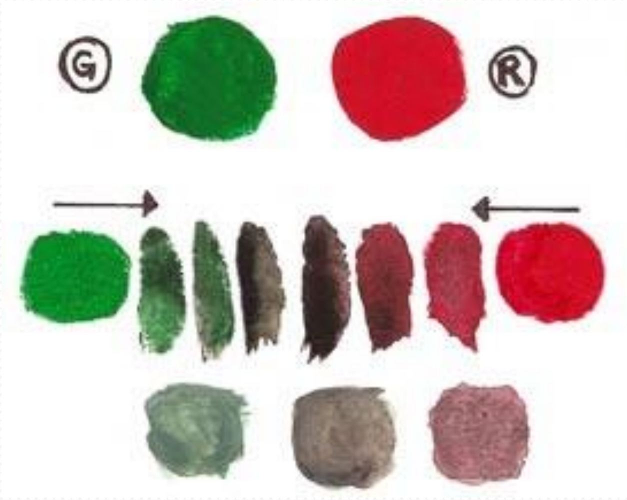
- What we perceive as **light or color** is a narrow frequency band within the electromagnetic spectrum.
- Lowest frequency is RED color (4.3×10^{14}).
- Highest frequency is Violet color (7.5×10^{14}).
- Since light is a electromagnetic wave, we measure the various colors in terms of frequency (f) or the wavelength (λ).

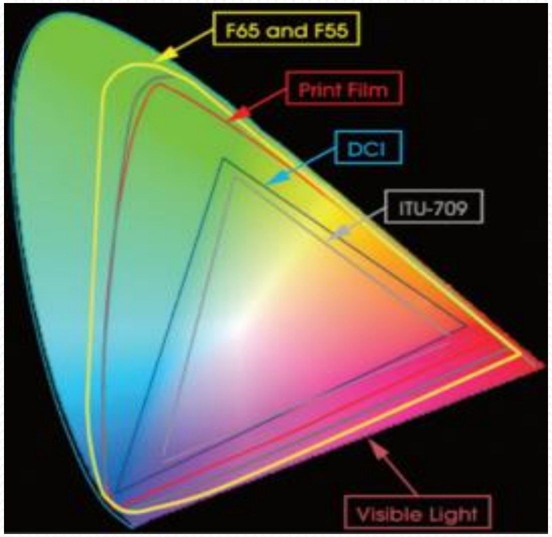
Properties of Color

- Light source emits all frequencies within the visible range to produce white light.
- When the white light is incident upon the object, some frequencies are reflected and some are absorbed by the object.
- The combination is what we see the object.
- If the low frequencies are predominant in reflects light, the object is described as RED.
- The dominant frequency is called HUE.

Properties of Color

- Primary Colors – R G B.
- Complimentary Colors.
- Intuitive Colors (Shades, Tint, Tones)
- Color Gamut.





Standard Primaries

- Three primary colors were defined in 1931 by the International Commission on Illumination referred to as CIE.
- The three primaries are imaginary.
- They are defined mathematically with positive color matching functions.
- Specifies the amount of each primary needed to describe any spectral colors.

XYZ Color Models

- Set of CIE primaries are referred to as xyz or (x,y,z) color model, where x,y,z represents vectors in 3D color space.
- Any color C_λ can be expressed as

$$C_\lambda = xX + yY + zZ$$

- x,y,z is the amount of standard color primitives to be added to match C_λ.

- Normalization Amount

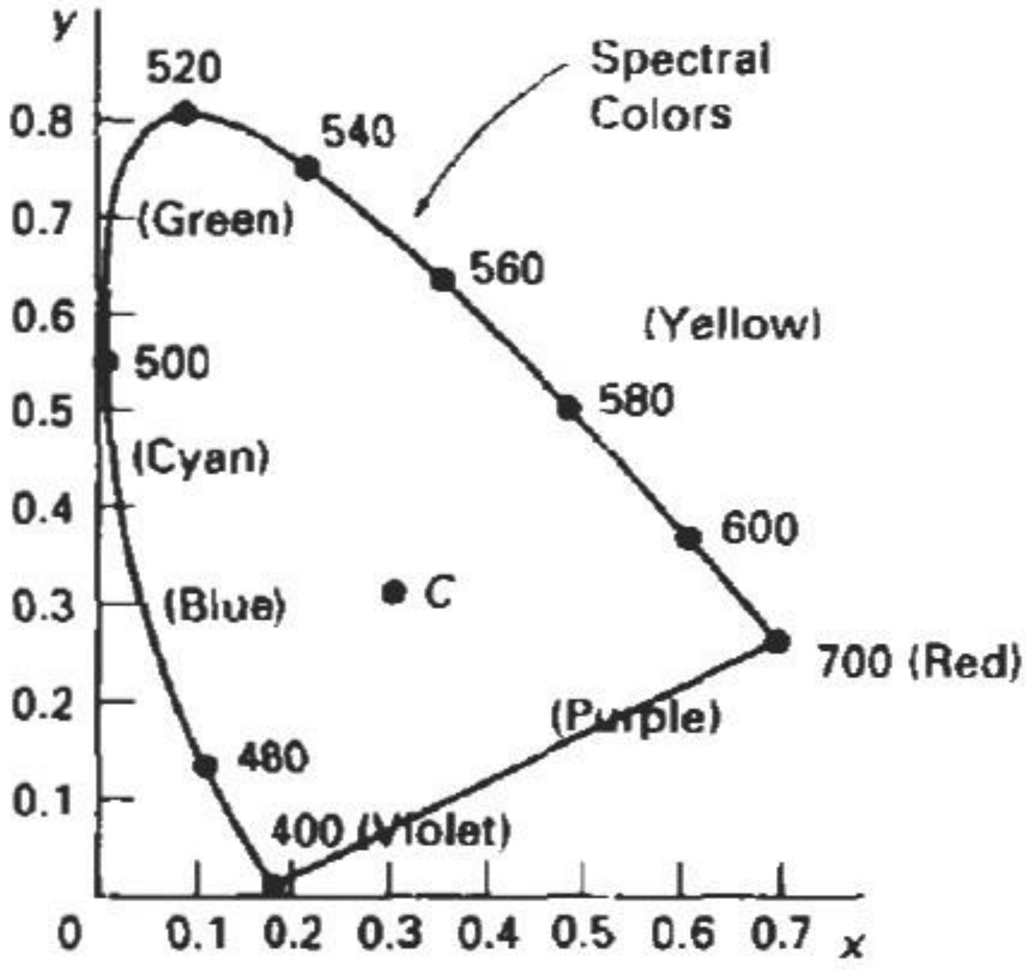
$$X = \frac{X}{X+Y+Z} \qquad Y = \frac{Y}{X+Y+Z} \qquad Z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1;\ z = 1 - x - y$$

CIE Chromaticity Diagram

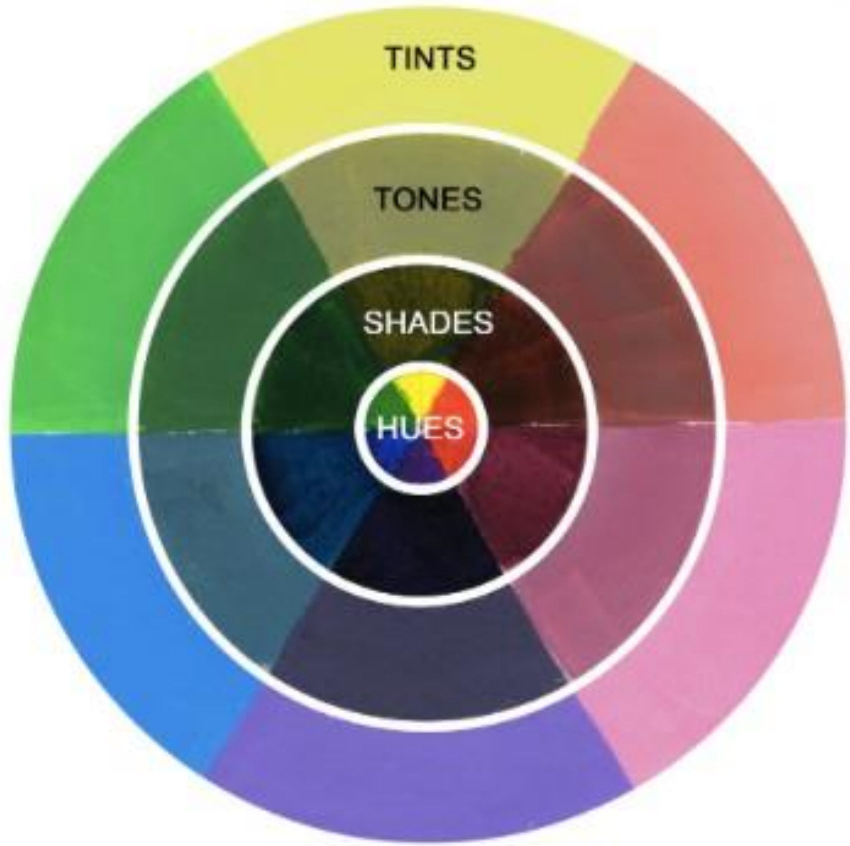
- When we plot the normalized amounts x and y for colors in the visible spectrum, we get a tongue-shaped curve, called the chromaticity diagram.
- Use
  - Comparing color gamut for different set of primaries.
  - Identifying complimentary colors.
  - Determining dominant wavelength and purity of a given color.

CIE Chromaticity Diagram



Intuitive Color

- An artist creates a color painting by mixing color pigments with white and black pigments to form various
  - Shades
  - Tint
  - Tones



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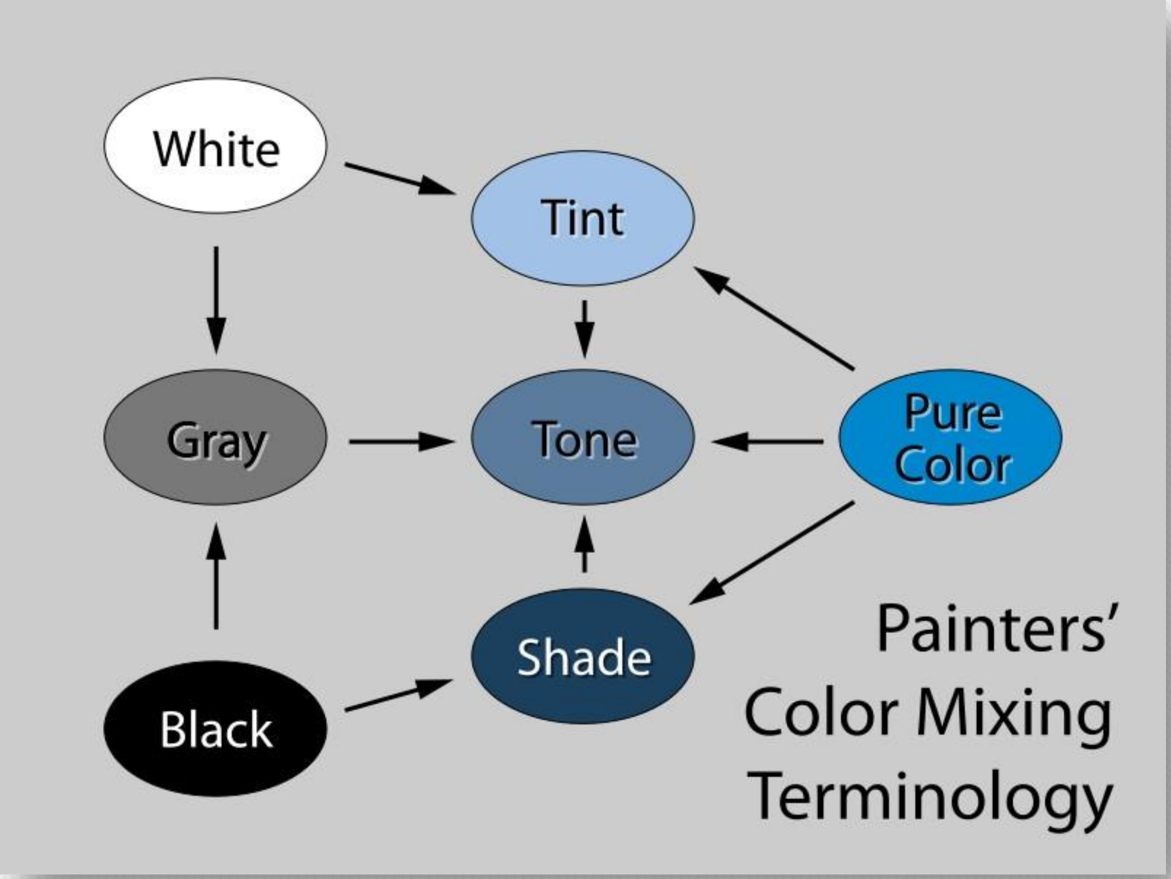
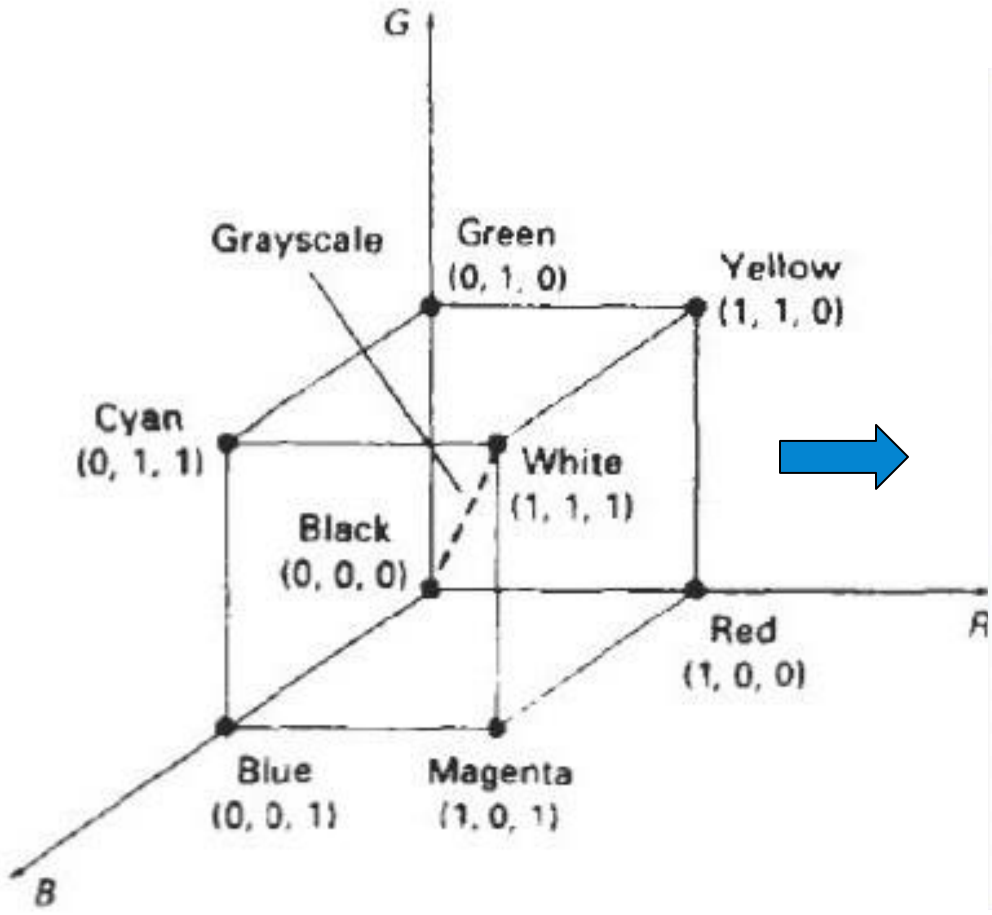
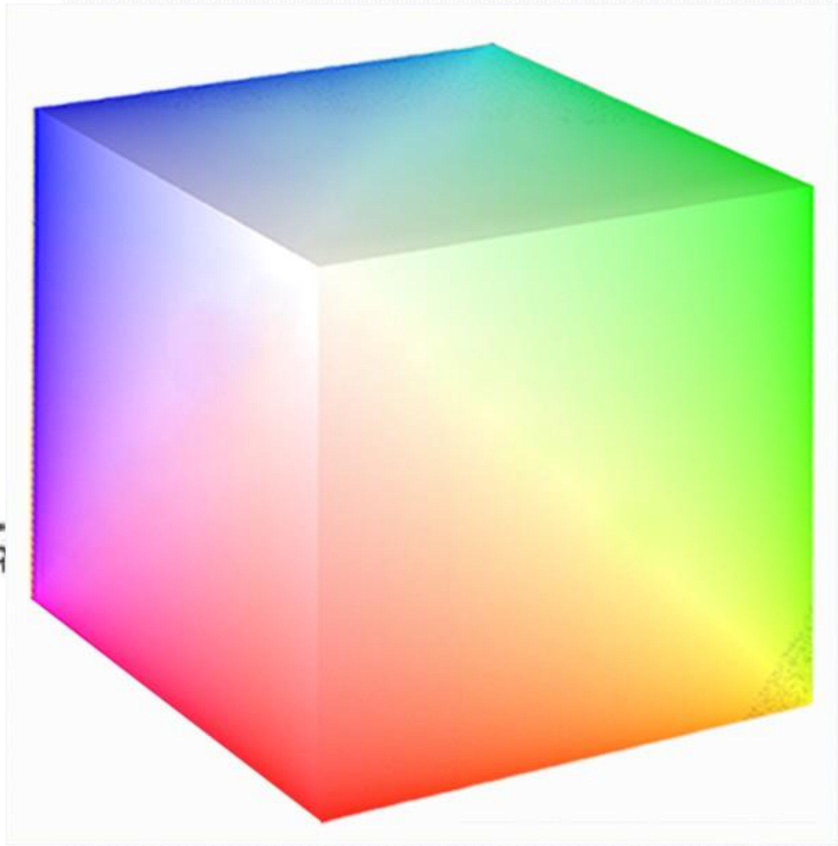


RGB Color Model

- Sensitivity of 3 Pigments
- Red - 630 nm
- Green - 530 nm
- Blue - 450 nm
- By comparing the intensities of light source, we perceive the color of light.
- $C_{\lambda} = {}_{R}R + {}_{G}G + {}_{B}B$

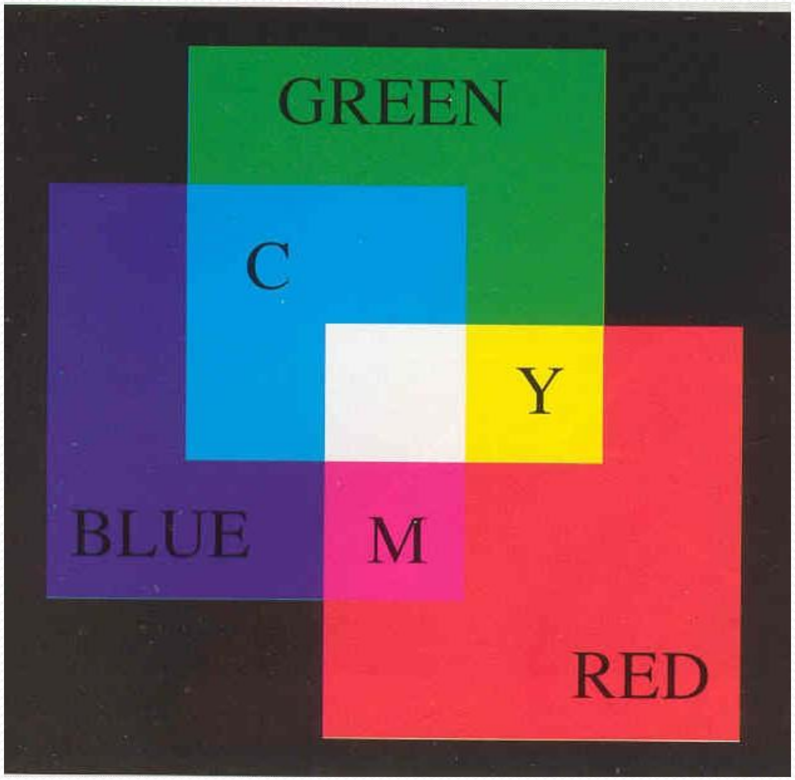
RGB Color Model





RGB Color Model

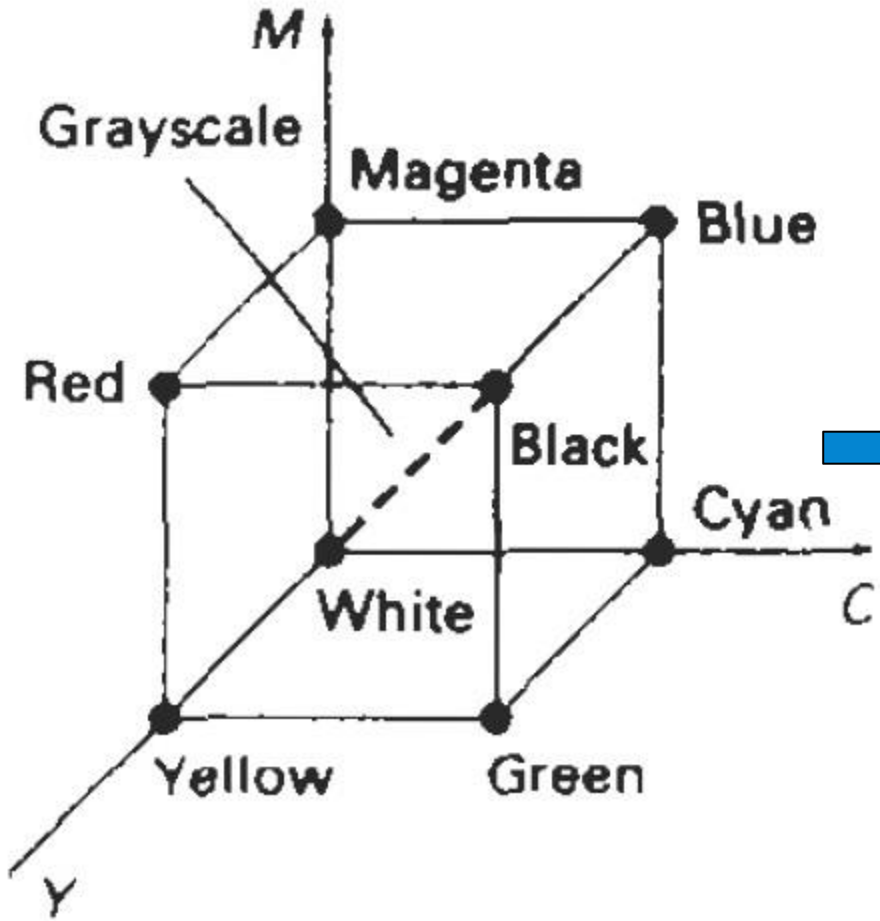
- Colors are additive nature

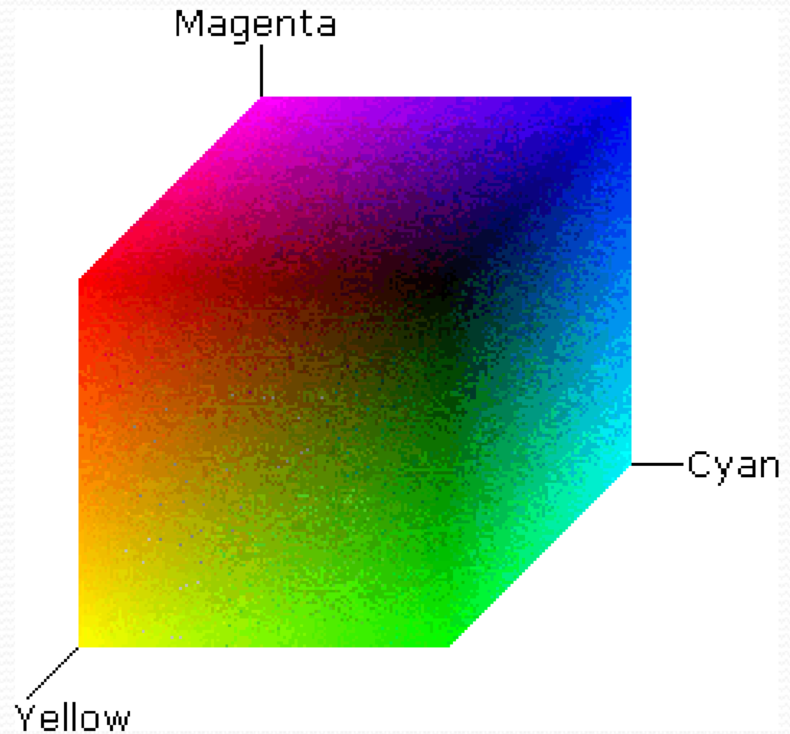


R	G	B	Color
0.0	0.0	0.0	Black
1.0	0.0	0.0	Red
0.0	1.0	0.0	Green
0.0	0.0	1.0	Blue
1.0	1.0	0.0	Yellow
1.0	0.0	1.0	Magenta
0.0	1.0	1.0	Cyan
1.0	1.0	1.0	White

CMYK Color Models

- Mainly for hard copy devices.
- All components of incident light is subtracted.





CMYK Color Model

- Colors are subtractive nature

C	M	Y	Color
0.0	0.0	0.0	White
1.0	0.0	0.0	Cyan
0.0	1.0	0.0	Magenta
0.0	0.0	1.0	Yellow
1.0	1.0	0.0	Blue
1.0	0.0	1.0	Green
0.0	1.0	1.0	Red
1.0	1.0	1.0	Black

CMYK Color Models

- Normalization.

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

YIQ Color Model

- Composite Component.
  - Y – Luminance
  - I,Q – Chrominance

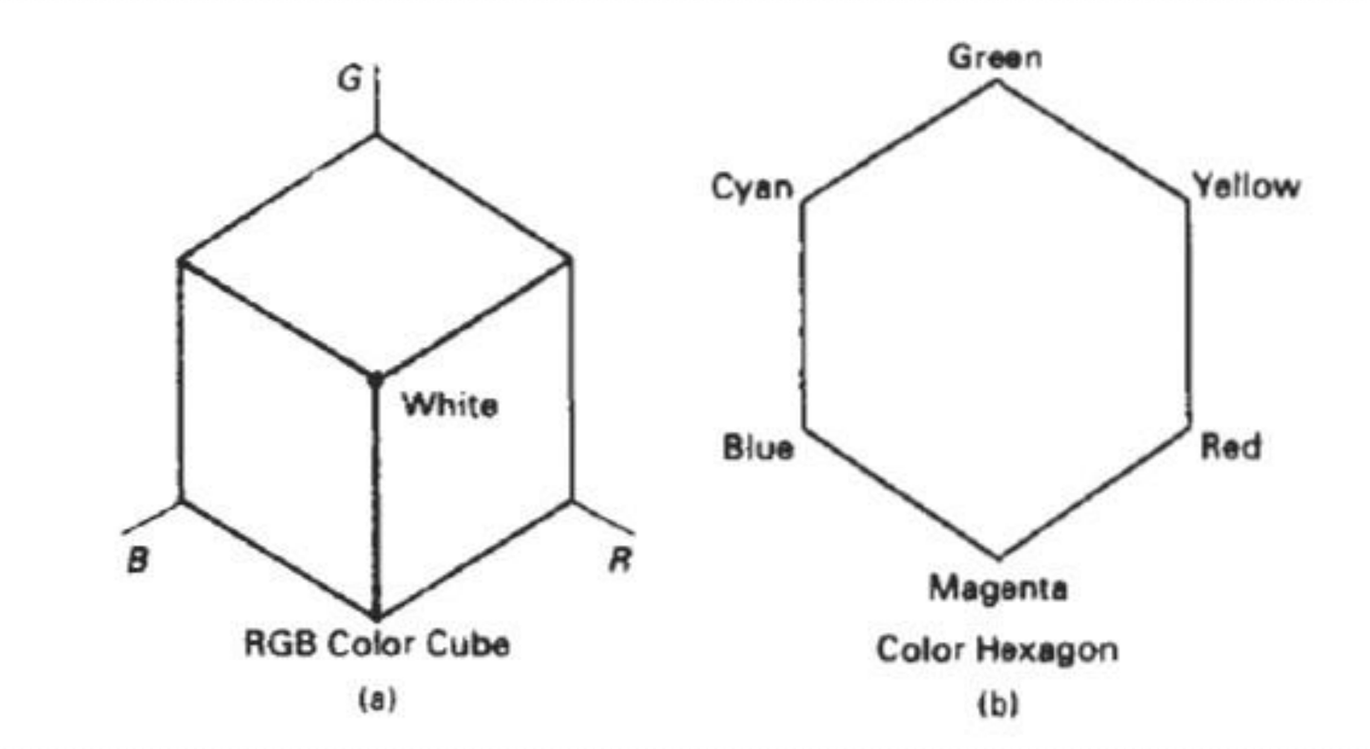
- NTSC
- Transformation Matrix based on NTSC

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.620 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.108 & 1.705 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

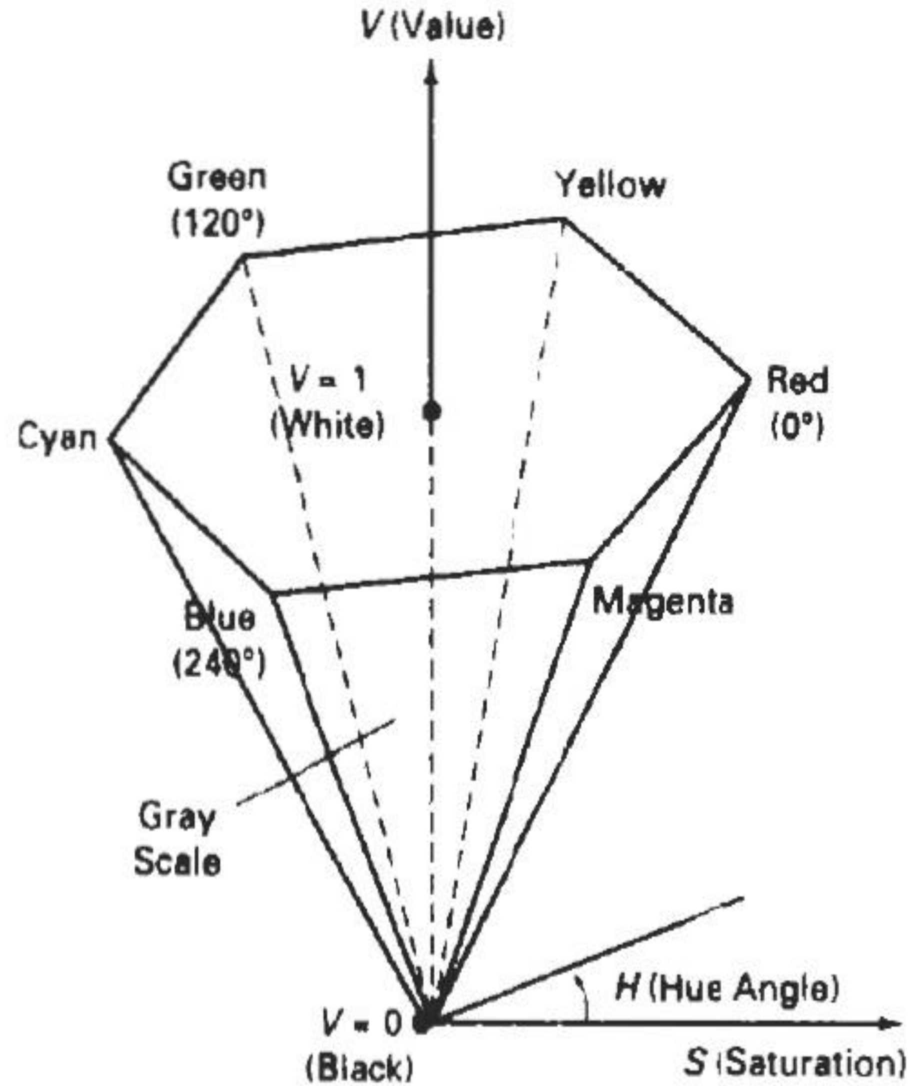
HSV Color Models

- HSV model uses color descriptions.
  - Shades, Tint, Tones
- Color Parameters
  - Hue
  - Saturation
  - Value



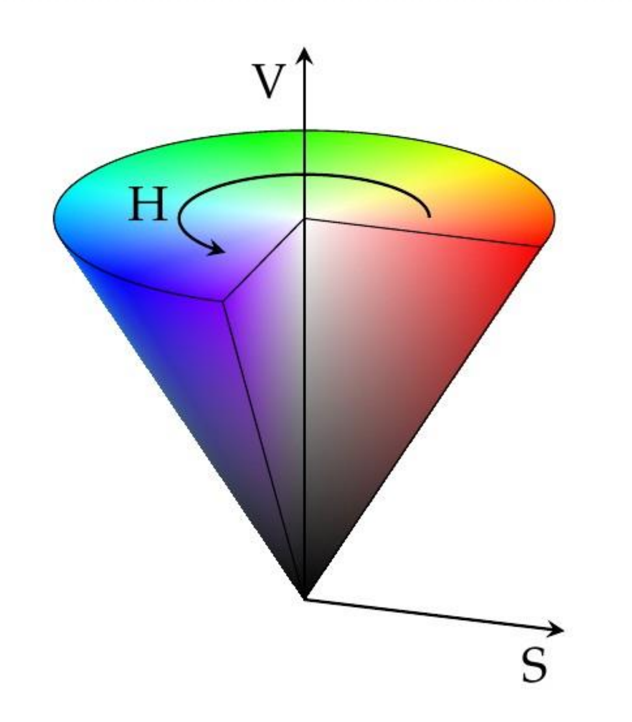
HSV Hexcone

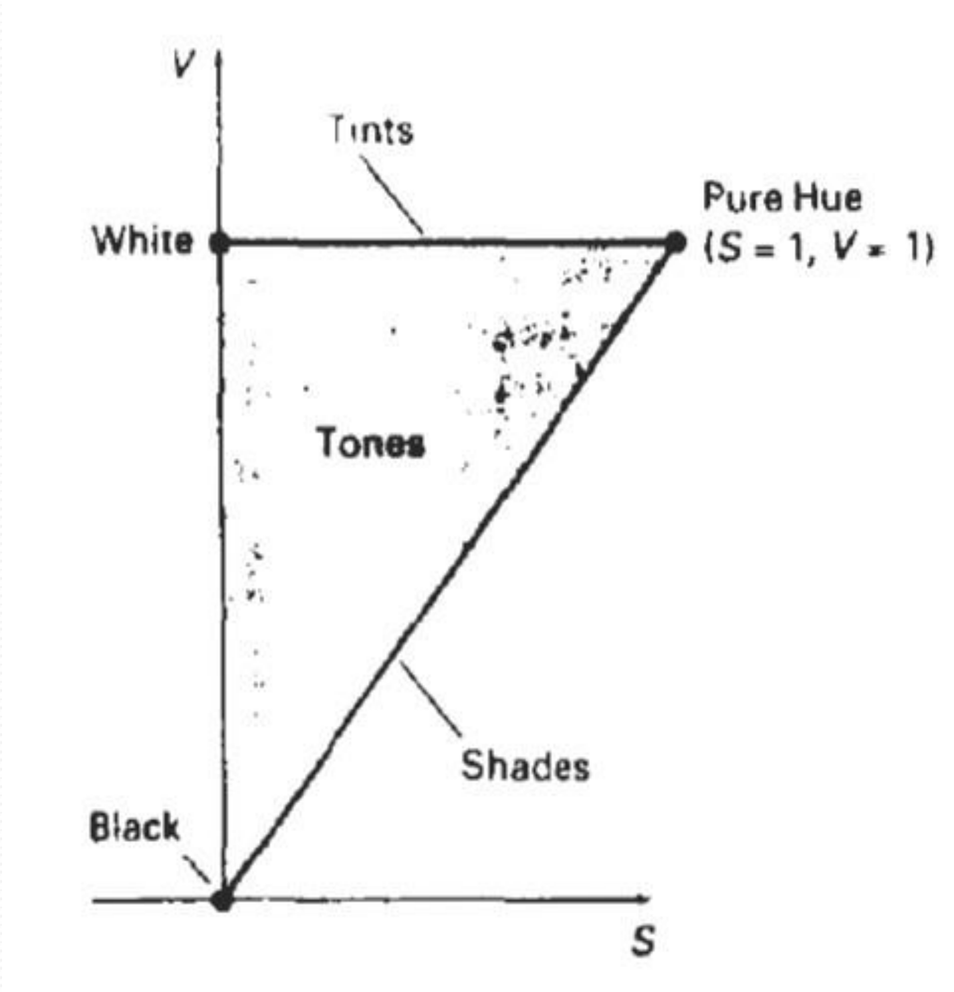
- **Saturation** is measured along a horizontal axis, and **value** is along a vertical axis through the center of the hexcone.
- **Hue** is represented as an angle about the vertical axis, ranging from 0 degrees at red through 360 degrees.



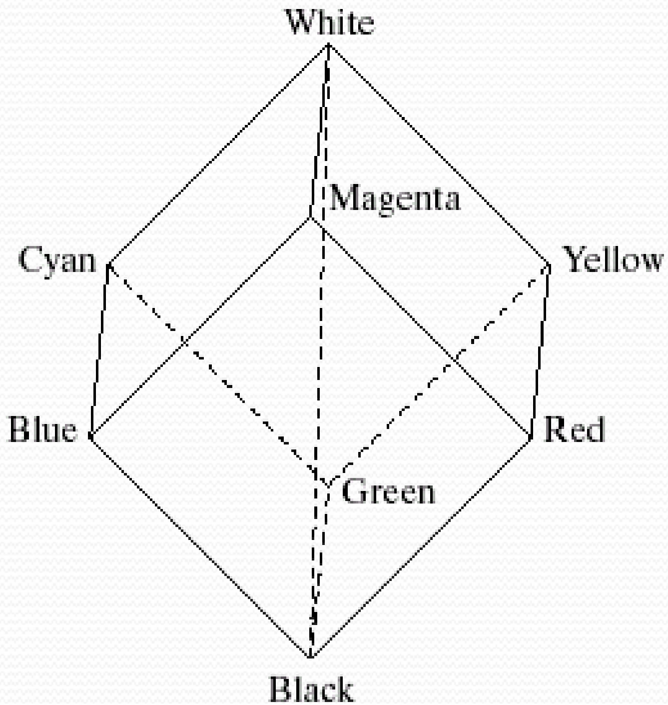
HSV Cross Section

- Saturation S varies from 0 to 1. It is represented in this model as the ratio of the purity of a selected hue to its maximum purity at $S = 1$.

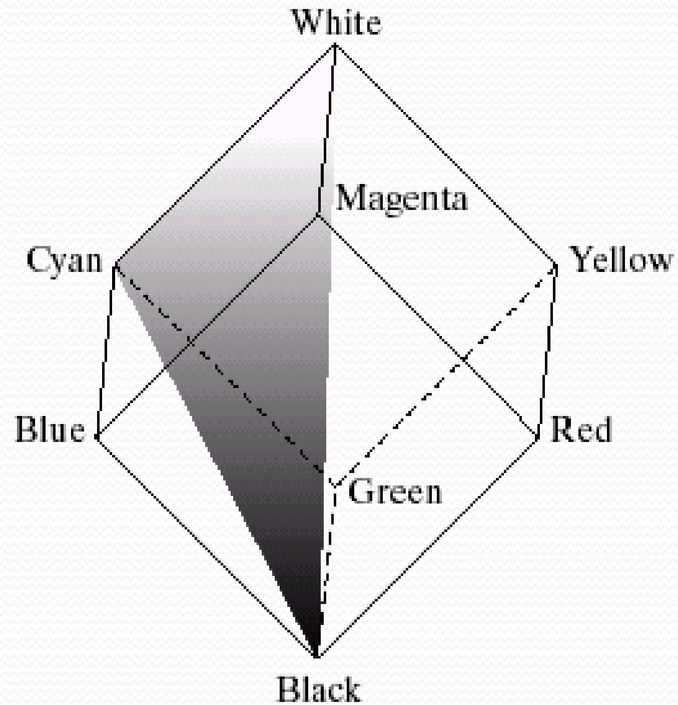




The HSI Color Models

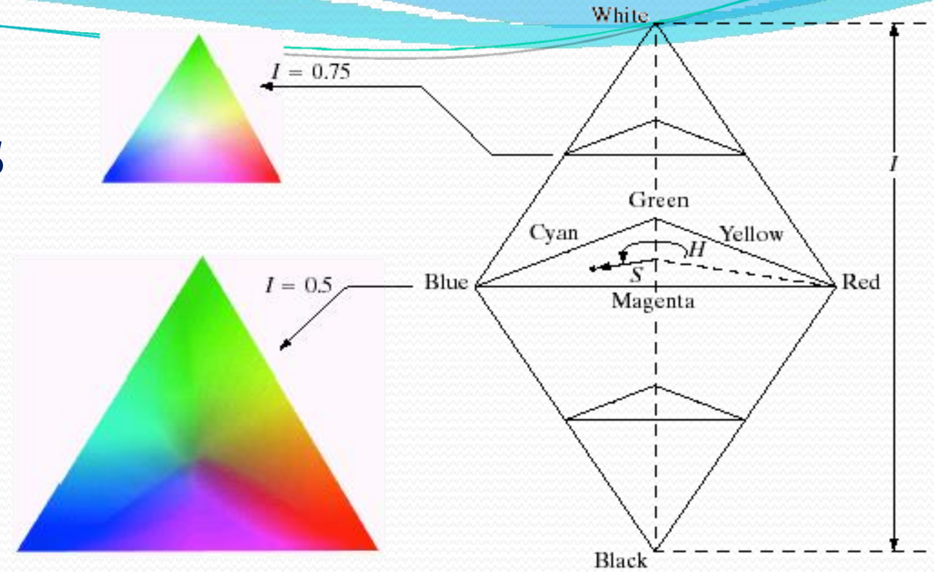


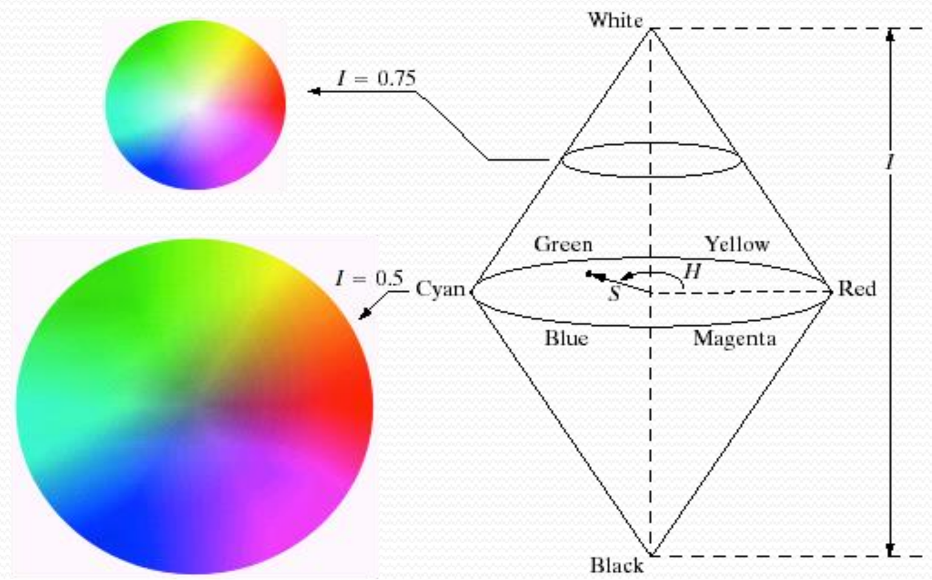
RGB



HSI

The HSI Color Models





The HSI Color Models

- **Converting colors from RGB to HSI**

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}} \right\}$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)]$$

$$I = \frac{1}{3}(R+G+B)$$