CS 402:
Computer Graphics

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CS 402: Computer Graphics

Lecture Note 03

Colors in Computer Graphics

CS402: Computer Graphics

Lecture 3: Colors in Computer Graphics

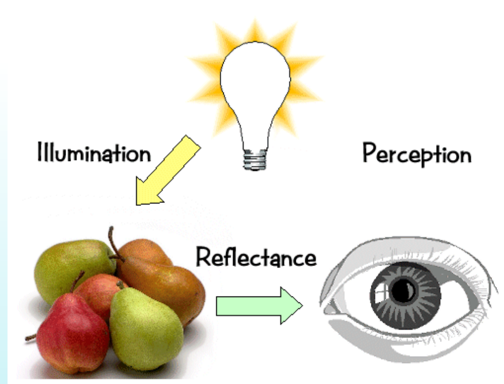
- **Color Perception**
- **Color Models**

Color Models

- **Hearn & Baker pp. 513-515, 565-581 (study)**

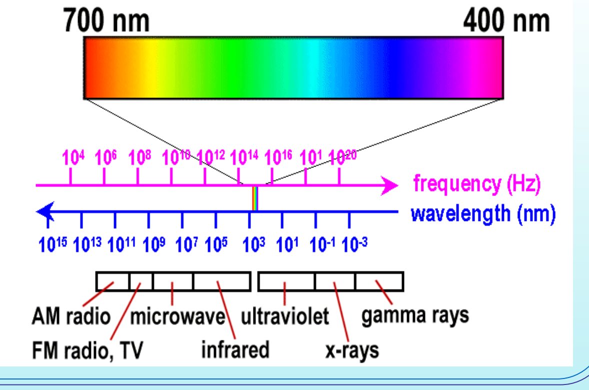
Elements of Color

- **Illumination**: The amount of light coming from the source.
- **Reflectance**: The amount of light reflected from the object.
- **Perception**: The sensation of the light by the eye.



The electromagnetic spectrum

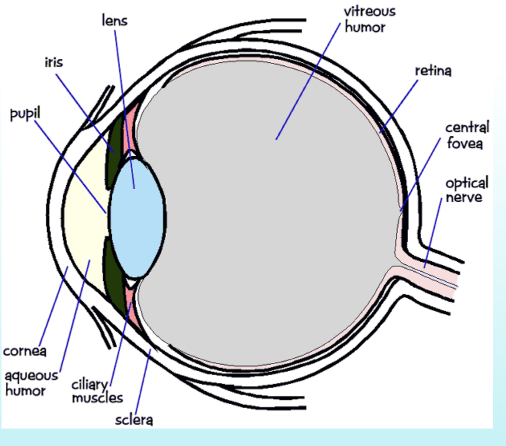
– **We perceive electromagnetic energy having wavelengths in the range 400-700 nm as a *visible light*.**



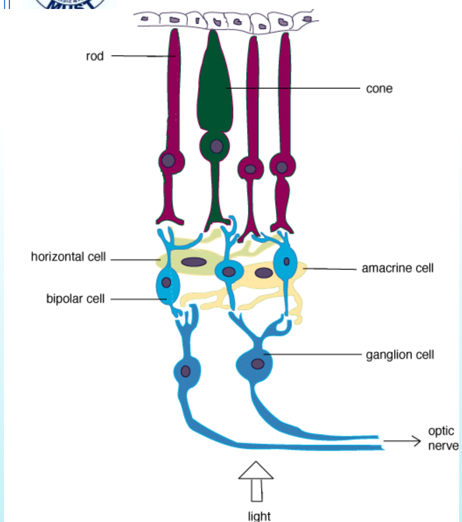
The Eye

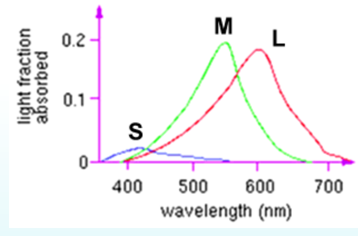
The photosensitive part of the eye is called the *retina*.

The retina is largely composed of two types of cells, called *rods* and *cones*. Only the cones are responsible for color perception.



The Fovea

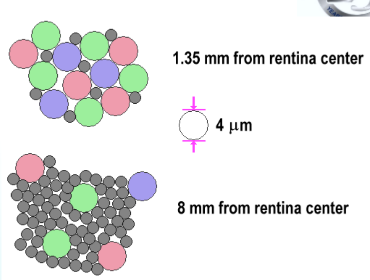


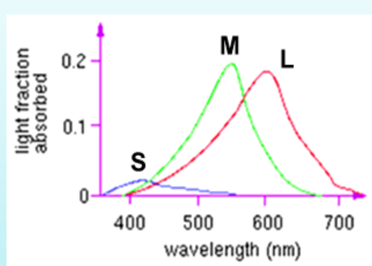


Colorblindness results from a deficiency of one cone type

The Fovea

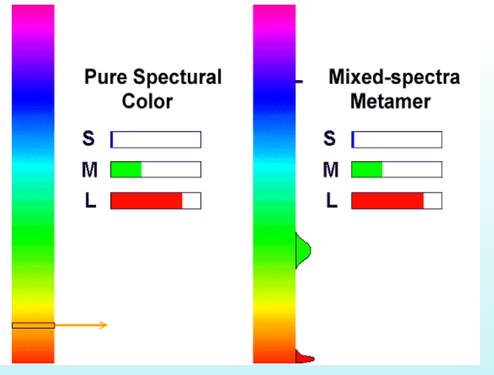
- **Cones are most densely packed within a region of the eye called the *fovea***
- **There are three types of cones, referred to as S, M, and L. They are roughly equivalent to blue, green, and red sensors, respectively. Their peak sensitivities are located at approximately 430nm, 560nm, and 610nm for the "average" observer.**





Color Perception

- Different spectra can result in a perceptually identical sensations called *metamers*
- Color perception results from the simultaneous stimulation of 3 cone types (*trichromat*)
- Our perception of color is also affected by surround effects and adaptation



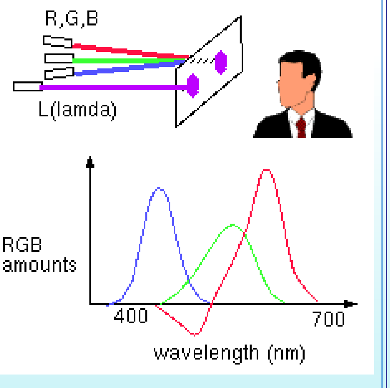
Color Modeling

- **Properties of Light:**
  - **Dominant Frequency (Hue or color):**
    - A light is a combination of some frequencies. The frequency close to which the resultant frequency is is called the dominant frequency, or the hue, or simply the color of the light.
  - **Brightness:**
    - The perceived **intensity** (the radiant energy per unit time) of light.
  - **Purity (Saturation):**
    - The perceived characteristics of the luminance of the source.
  - **Chromaticity:**
    - Refers collectively to the **purity** and the **dominant frequency**.

Color Matching

- In order to define the perceptual 3D space in a "standard" way, a set of experiments can (and have been) carried by having observers try and match color of a given wavelength, lambda, by mixing three other pure wavelengths, such as R=700nm, G=546nm, and B=436nm in the following example.

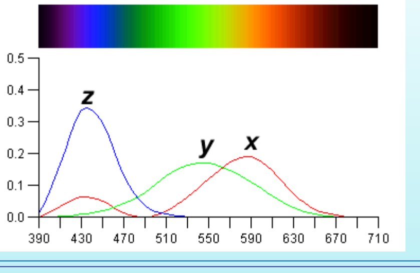
- Note that the phosphours of color TVs and other CRTs do not emit pure red, green, or blue light of a single wavelength, as is the case for this experiment.



CIE Color Space

In order to achieve a representation which uses only positive mixing coefficients, he CIE ("Commission Internationale d'Eclairage") defined three new hypothetical light sources, x, y, and z, which yield positive matching curves:

If we are given a spectrum and wish to find the corresponding X, Y, and Z quantities, we can do so by integrating the product of the spectral power and each of the three matching curves over all wavelengths. The weights X,Y,Z form the three-dimensional CIE XYZ space, as shown below.



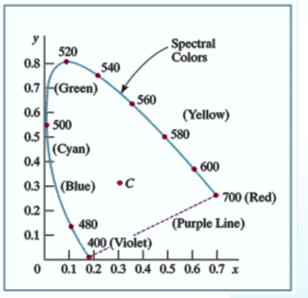
CIE Chromaticity Diagram

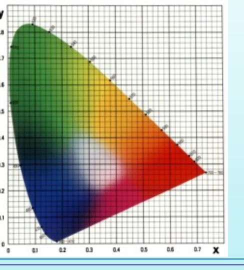
Often it is convenient to work in a 2D color space. This is commonly done by projecting the 3D color space onto the plane X+Y+Z=1, yielding a ***CIE chromaticity diagram.*** The projection is defined as:

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

$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

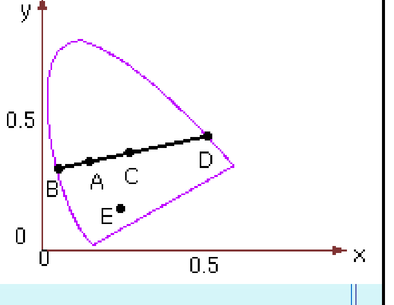
Giving the chromaticity diagram shown on the right.





Definitions

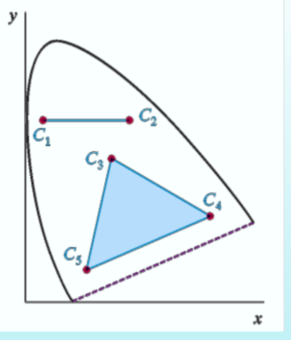
- **illuminant C**
  A standard for white light that approximates sunlight..
- **complementary colors**
  colors which can be mixed together to yiel white light. For example, colors on segmer CD are complementary to the colors on segment CB.

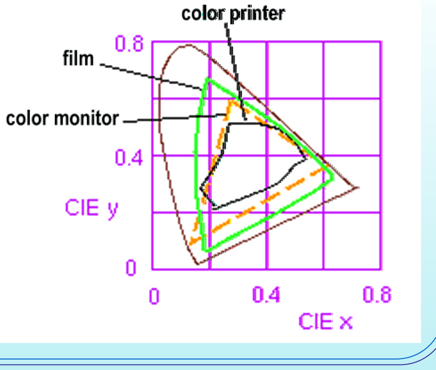


- **dominant wavelength**
  The spectral color which can be mixed wit white light in order to reproduce the desired color. color B in the figure is the dominant wavelength for color A.
- **non-spectral colors**
  colors not having a dominant wavelength. For example, color E in the above figure.

Color Gamuts

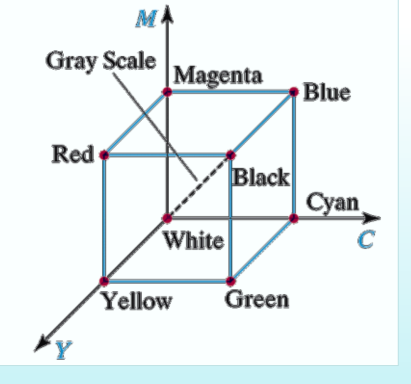
The chromaticity diagram can be used to compare the "gamuts" of various possible output devices (i.e., monitors and printers). Note that a color printer cannot reproduce all the colors visible on a color monitor.





The RGB Color Model

The **additive color model** used for computer graphics is represented by the RGB color cube, where R, G, and B represent the colors produced by red, green and blue phosphours, respectively.



Subtractive Color Model (Color for Printing)

- Green paper is green because it reflects green and absorbs other wavelengths. The following table summarizes the properties of the four primary types of printing ink.
- To produce blue, one would mix cyan and magenta inks, as they both reflect blue while each absorbing one of green and red. Unfortunately, inks also interact in non-linear ways. This makes the process of converting a given monitor color to an equivalent printer color a challenging problem.
- Black ink is used to ensure that a high quality black can always be printed, and is often referred to as to K. Printers thus use a CMYK color model.

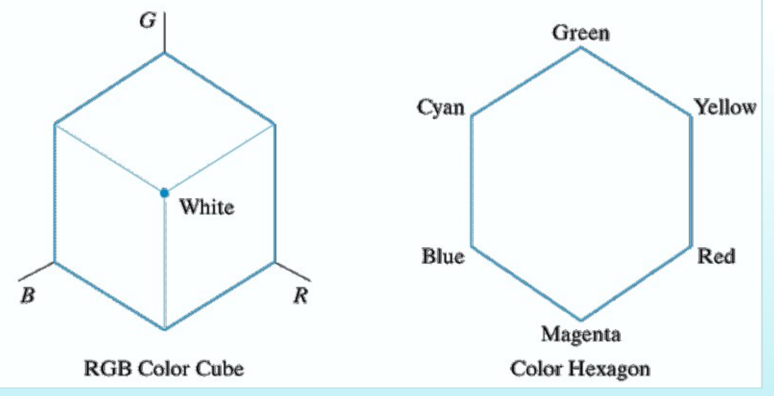
The CMY Color Model

dye color	*absorbs*	*reflects*
cyan	red	blue , green
magenta	green	blue , red
yellow	blue	red , green
black	all	none

Other Color Models

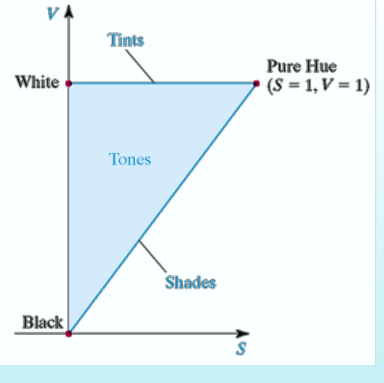
Several other color models also exist. Models such as **HSV** (hue, saturation, value) and **HLS** (hue, luminosity, saturation) are designed for intuitive understanding. Using these color models, the user of a paint program would quickly be able to select a desired color.

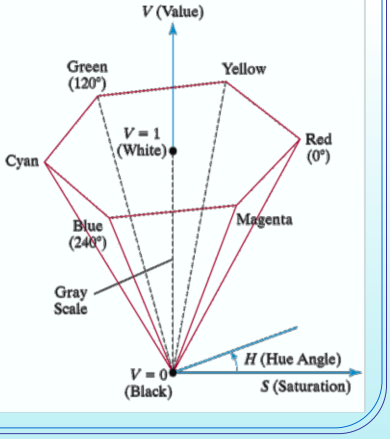
Other Color Models



Other Color Models

- **The HSV Color Model**





Homework

- Solve problems number:
  - 15.3, 15.8