# Johns Hopkins
# Engineering for Professionals

# 605.767 Applied Computer Graphics

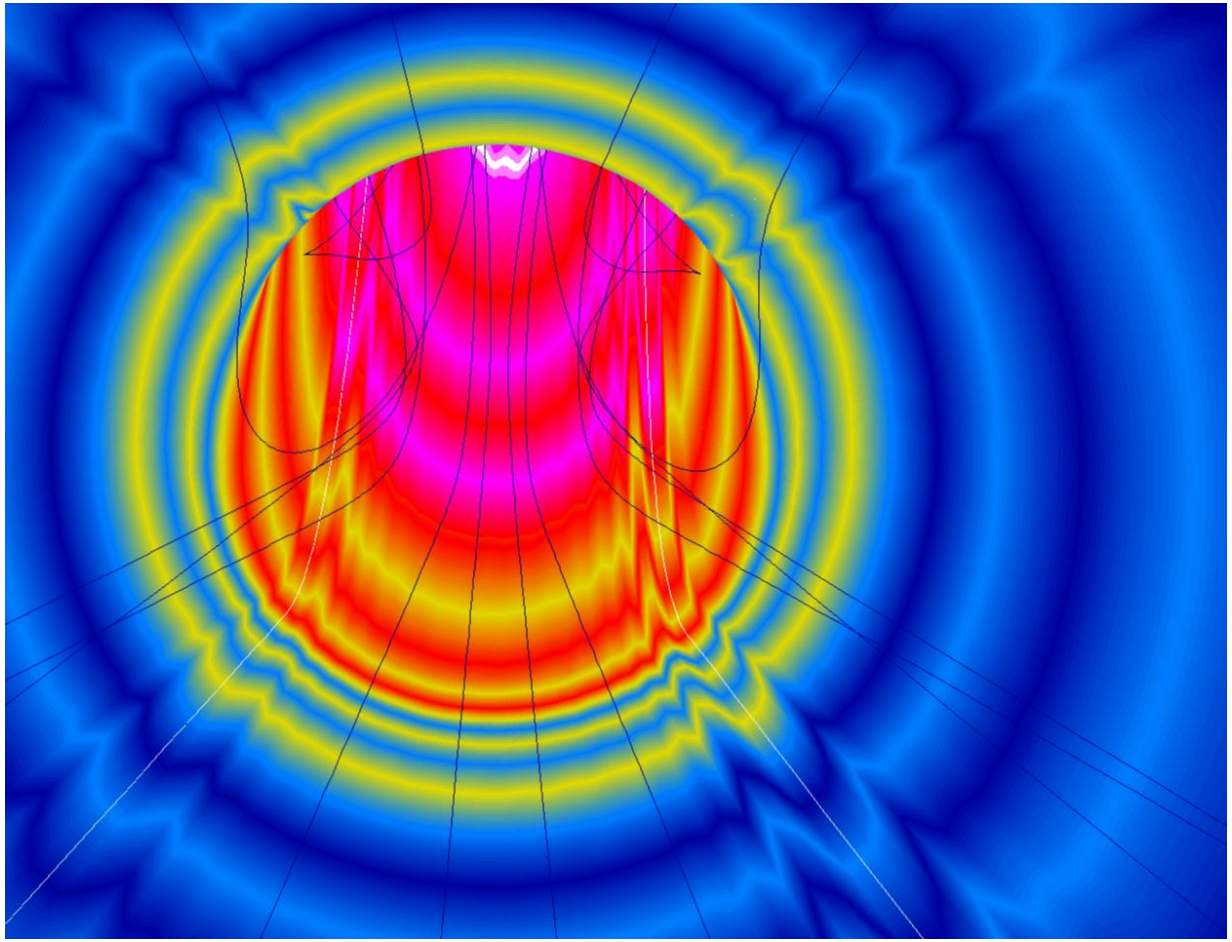
Brian Russin

# Module 4C
# Color Theory

# Color: Theory and Use in Computer Graphics

- Color and its use in computer graphics
  - Gamma correction
  - Physics and perception
  - Color spaces in computer graphics
  - Color usage guidelines
  - Color quantization

# Color: Theory and Use in Computer Graphics



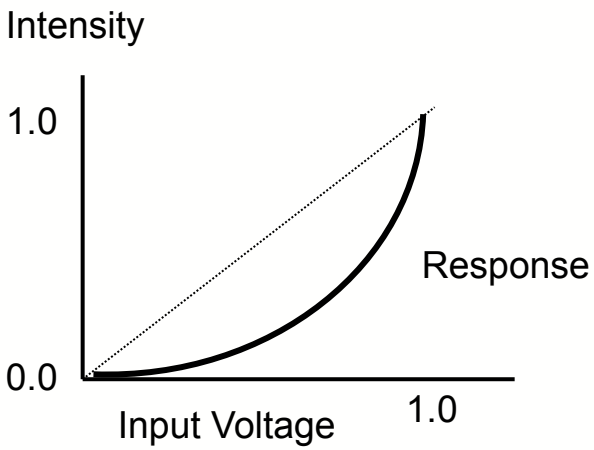
An inside look at the fluid flow in a bronchial tube.
Created by: Patty D. Seger, Mississippi State University - NSF Engineering Research Center

# Color and Display Devices

- Color capabilities depend on several factors:
  - Output levels from the framebuffer or color lookup table (CLUT)
  - Digital to analog (D/A) converter
    - Often less than the available colors from the framebuffer
      - e.g. 256 simultaneous colors from a palette of 16.7 million
        - 8 bit framebuffer / CLUT with 8 bit D/A converters (per R,G,B)
  - Physical characteristics of the display device
    - CRT monitors can produce many different intensities and colors at a pixel
    - Uses phosphor triads
      - Red, green, blue phosphor dots
- Differences in display devices
  - Color gamut, pixel density, resolution
- Printers and plotters produce 2 levels of intensity at a given point
  - Black (or ink color) on white (or paper color)

# Gamma Correction

- Display devices generally produce non-linear intensities in response to linear inputs
  - Response of CRT phosphors to electron gun voltages
- RGB specification is linear
  - Would like 0.5 red to produce half the intensity of 1.0
- Response curve is generally
  - I = intensity,
  - V = voltage input (normalized),
  - γ - typical gamma for a CRT is 2.2
  - a (max. intensity)
    - Depends on the display device
    - Can even vary between red, green, blue

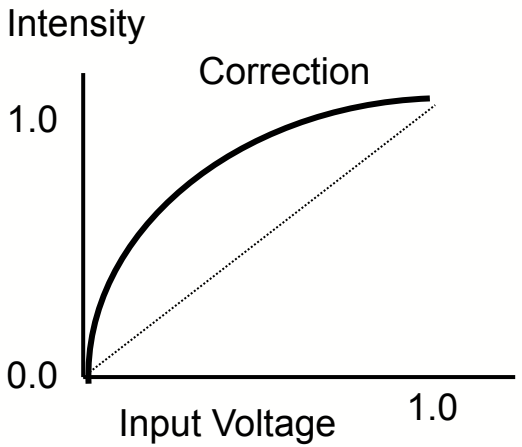


# Gamma Correction (cont.)

- To produce a linear response curve need to correct the input to

$$V = \left(\frac{I}{a}\right)^{\frac{1}{\gamma}}$$

- May want to store a table of corrections
  - Dynamic range slightly reduced as duplicate inputs may map to same intensity



# Color Theory

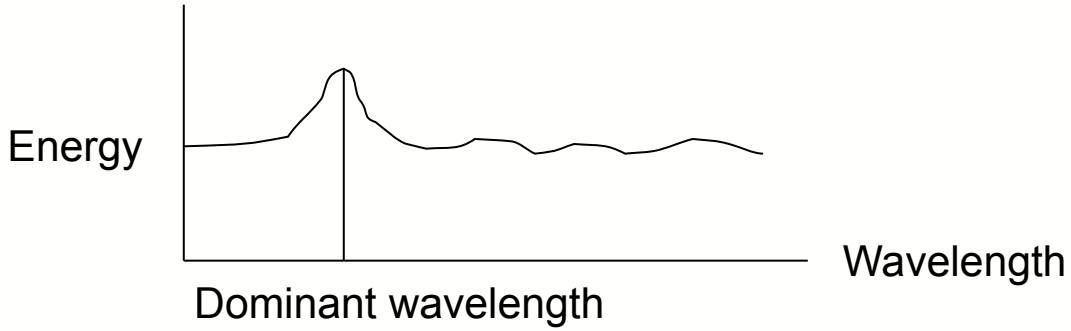
- Complex subject
  - Draws from concepts from physics, physiology, psychology, art, and graphics design
  - Confusion of terminology between reflected light (subtractive color), transmitted light (emissive devices such as CRTs), and perceptual terms
- Color of an object depends on many factors
  - Light source illuminating it
  - Color of surrounding areas
  - Human visual system
- Will introduce color theory and terms
  - Relate them to computer graphics

# Achromatic Light

- **Achromatic** light - black and white
  - Lack of color sensation
  - Quantity of light is only attribute
- Intensity or **luminance** describe the physical sense
  - Can be measured by photometer or luminance meter
  - Represents amount of light energy falling on an area
  - Units are candelas / $m^2$ or foot-lamberts
- **Brightness** refers to the perceived intensity
  - Psychological sense

# Physical Aspects of Color and Light

- Light is electromagnetic energy
  - Visible light: 400 (violet) - 700 (red) nanometers (10-7 cm) wavelength
- **Spectral energy distribution** shows the amount of energy present at each wavelength
- **Dominant wavelength** is the wavelength of color we see when viewing light
  - Corresponds to the perceptual term: hue
- **Excitation purity** corresponds to the saturation of the color
- **Luminance** is the intensity of the light
  - Area under the spectral energy distribution curve



# Perceptual Terms

- Color perception includes 3 quantities:
  - Hue, saturation, and lightness (brightness)
- **Hue** refers to color family: red, green, blue, yellow, purple, etc.
- **Saturation** refers to the color purity or strength
  - Compared to gray of equal intensity
  - Pink is relatively unsaturated while red is more saturated
  - Pastel colors are relatively unsaturated
- **Lightness** describes the perceived intensity of the color reflected from an object
  - **Brightness** refers to the perceived intensity of an emissive or self-luminous object (like a CRT or light bulb)

# CIE Standard Color Space

- CIE: Commission International de l'Eclairage (International Commission on Illumination)
- In 1931 CIE defined 3 standard primaries based on experimentally determined color matching functions
  - This space requires negative weights to produce some saturated colors
- CIE created a set of super-saturated primaries X, Y, Z
  - Corresponding color matching functions: x, y, z
  - Any perceivable color is achievable as a linear combination of X,Y,Z
- Y primary chosen to produce a color matching function y that matches the eye's **luminous efficiency function**
  - Experimentally determined
  - Peaks at yellow-green wavelength
    - Human visual system has poor response to blue wavelengths
- Any color expressed as C = aX + bY + cZ
  - All positive weights a,b,c
- See http://en.wikipedia.org/wiki/CIE_1931_color_space
  - For color matching curve diagrams

# CIE Chromaticity Diagram

- CIE created a common color space known as the **CIE Chromaticity Diagram**
  - x,y where x = X / (X+Y+Z) and y = (Y / X+Y+Z)
  - x,y produce chromaticity - combination of hue and saturation
  - Pure saturated colors or spectral colors are along the outside of the space
- CIE defined a **standard illuminant $D_{65}$**
  - Simulates sunlight
- Additive nature of colors can be demonstrated
  - Combination of two colors lies on the line between the colors
  - Complementary colors lie on opposite sides of a line through white
- The triangle formed by 3 primaries forms the gamut of colors attainable by combinations of the three primaries
  - Film has a larger gamut than CRTs which are larger than print inks