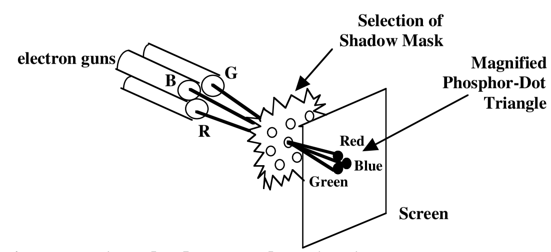
## Lecture Notes #3 - Perception & Color

- Reading: H&B Chapter 15 and Section 14-3. (Optional: Foley Chap. 13)
- Light
- Human color perception
- Color spaces for computer graphics
    - RGB, CIE, YIQ, HSV
- Color tables
- Gamma correction



## Color CRT



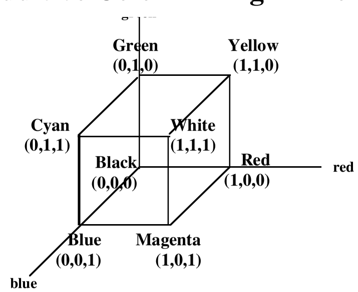

Most color monitors employ **shadow mask** technology

- Uses triads of red, green and blue phosphors at each pixel
- Uses three electron guns, one for each color
- Uses **shadow mask**

Such CRTs are also known as **RGB monitors**



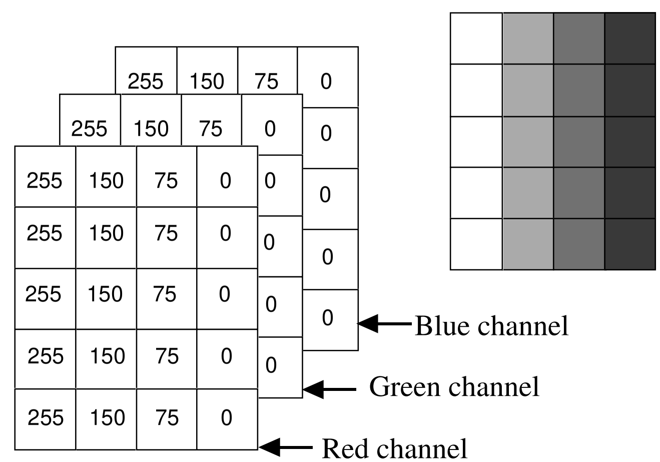
## Additive Color Mixing -- The RGB Cube




- All colors on a monitor are produced using combinations of red, green and blue.
- A monitor that allows 256 voltage settings for each of R,G, B is known as a **full color system.**
- The description of each color in framebuffer memory is known as a **channel.**

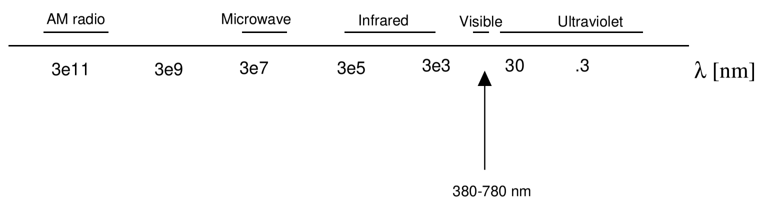


## RGB Displays



## Light

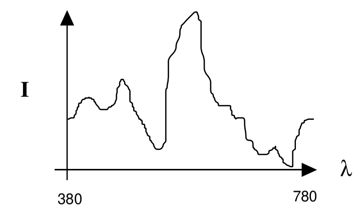
- Light is electromagnetic radiation
- EM spectrum organized by wavelength






## Light Sources

- Characterized by emission spectra

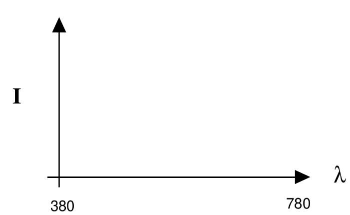



- Spectrum describes the energy at each wavelength.
- Light is "infinite dimensional"
  - It takes an infinite number of values to specify an emission spectrum.



## Color

- Light ≠ Color
- Many different spectra are perceived by humans as the same color.
  - Two spectra perceived as the same color are called "metamers".

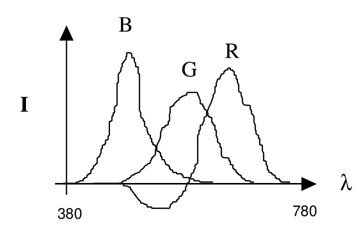





## Wright's Experiment

- In the late '20s Wright found that any *spectral color* X could be reproduced with combinations of three primaries at 650 (R), 530 (G), 460 (B) nm.

A spectral color is the color perceived due to emission at a single wavelength.

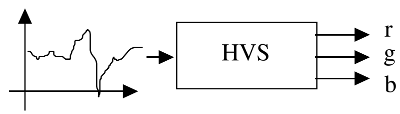



RGB color matching functions

Q: How to get negative red?

## Tristimulus Color Theory

- Wright's experiment led to tristimulus color theory.
- States that the human visual system maps each spectrum to three numbers.

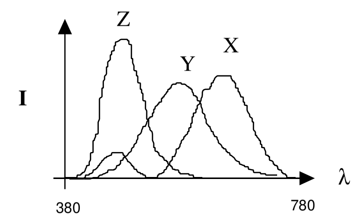



- Color space is therefore three dimensional.



## The CIE Color System

- Developed in the 30's by Commision Internationale de l'Eclairage (CIE)
- Based on three primaries X, Y, Z
- Every color X is a positive combination of X, Y, Z.




X,Y,Z color matching functions



## Chromaticity Coordinates

- X+Y+Z is the brightness or luminance of a color
- Factor luminance out by normalizing to 1:

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

- x and y are called chromaticity coordinates -- they describe the basic color.



## CIE chromaticity diagram

- (see Foley et al, Plate II.1 and II.2 (near page 616)

## YIQ

- The US television standard (NTSC) is based on the YIQ color coordinate system.
- Luminance encoded in Y channel.
- Chromaticity encoded in the I and Q channels.
- Conversion between RGB and YIQ specifications:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} .299 & .587 & .144 \\ .596 & -.275 & -.321 \\ .212 & -.528 & .311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.00 & .956 & .620 \\ 1.00 & -.272 & -.647 \\ 1.00 & -1.11 & 1.71 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

- The eye is most sensitive to changes in Y, least to Q.



## HSV

- H = hue -- chromaticity.
- S = saturation -- purity of the color.
- V = value -- how far from black.
- See H&B for conversion between RGB and HSV.



## Specifying color

The number of color choices depends on the amount of framebuffer storage allocated per pixel.

Q: How many colors can be displayed with:

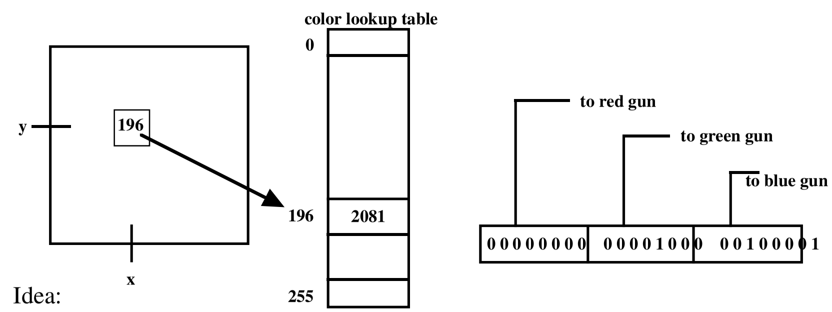
- 3 bits per pixel?
- 8 bits per pixel?
- 24 bits per pixel?



## Color tables

**Color tables** allow more color versatility when you only have a few bits per pixel.

Idea:




- Each framebuffer element stores an index into a color table, where the actual color is stored.
- Color table entries can be changed in software.

## Color tables, cont.

Example: What would be a "good" choice of colors to put into a color table if the hardware has 3-bit indices?



## Color tables, cont.

Example: What would be a "good" choice of colors for displaying a greyscale image in "color-mapped" hardware with 8-bit indices?



## Color tables, cont.

Example: How might you use a color table to animate a bouncing ball?



## Color tables on 24-bit systems

- Even "full color" systems with 24 bits per pixel often use color tables
- In this case, there is a separate color table for each 8-bit channel:

Our full-color Indy's are like this.

Q: Why would you want this capability?

## Perceptual light intensity

We perceive light intensity as we do sound: on a logarithmic scale.

Example: The perceived difference between 0.20 and 0.22 is the same as between 0.80 and

Ideally, to display n+1 equally-spaced intensity levels, the intensity levels should be spaced as

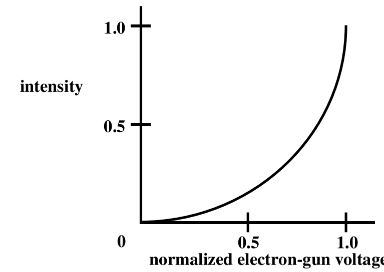
Example: Suppose I = 1/8, I = 1 and n=3. What are the four intensity levels to be displayed?

For color systems, the values of I and r may be different for each channel.



## Gamma correction

- Another problem with calculated intensities is related to the non-linearity of the monitor.
- A typical "monitor response curve" looks like this




Q: How would you check if your monitor is linear?

Q: How might you use a color table to correct for any non-linearity?



## Gamma correction, cont.

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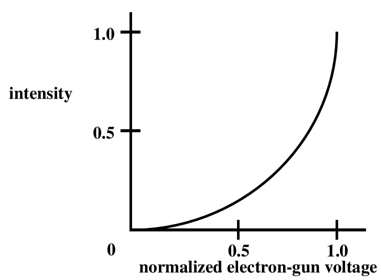


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