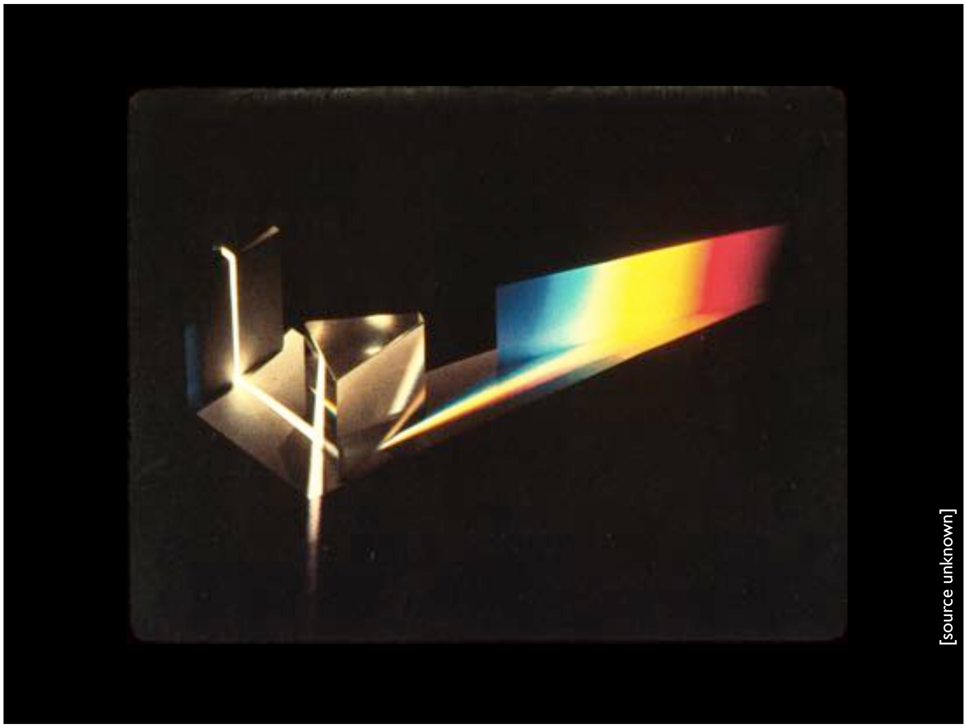

Displays

Stephen J. Guy

Sep 24, 2017

Recap

- What does alpha in an image represent
  - Partial coverage of the pixel
- You put a pixel of α=.5 on top of a pixel of α=.4 – What is the resulting alpha?
  - α=.7
- What is the resulting color (in terms of A and B)?
  - $C = \alpha_A A + (1-\alpha_A)\, \alpha_B B$ (not premultiplied)
  - $C' = A' + (1-\alpha_A)\, B'$ (pre-multiplied)
- What where the two steps in image morphing?
  - Warp two images to same shape
  - Then blend
  - Start with initial shape colors, move to final

3

Discussion

- Aliasing
  - You should be seeing it frequently in many applications, movies, media, images, etc.
- HW1
  - Start with just nearest neighbor sampling

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Overview

- Display Technologies
  - CRTs & Gamma Correction
- Image Storage
  - Frame Buffers
- Color Theory

Cathode Ray Tube

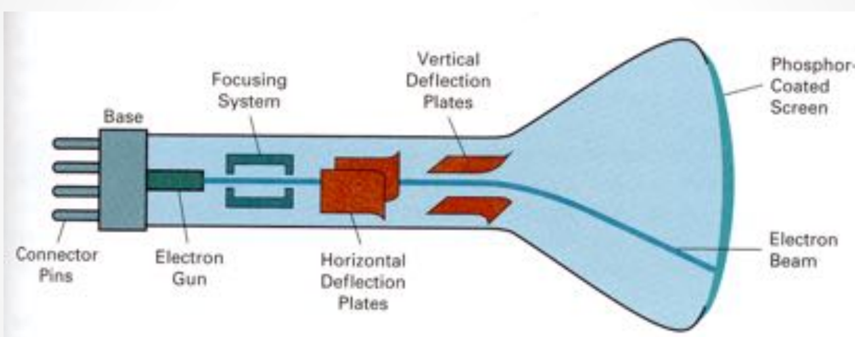
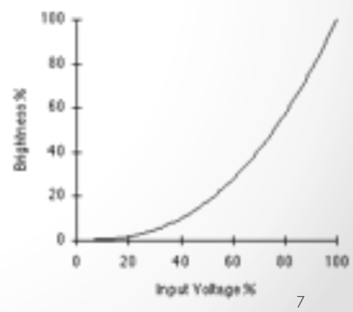


Figure 2.4 from H&B

6

Pixel Intensity (Gamma)

- The intensity of a pixel controls the gun's voltage
  - o Luminance (intensity) does not vary directly with voltage!
- Input voltage does not map linearly to output response
  - o Luminance = Voltage^{gamma}
  - o Non zero min luminance
  - o CRT with gamma of 2.5 ->



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Liquid Crystal Display

- (Used in both LCD TVs and LED TVs)

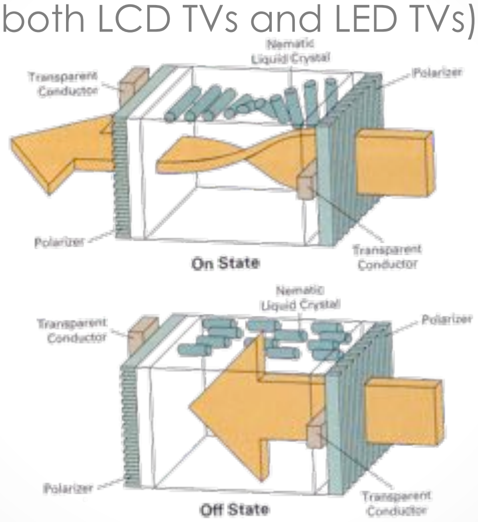
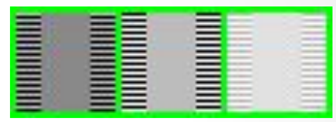


Figure 2.4 from H&B

Q: Does an exponential gamma model work well here?

Gamma Values

- Gamma varies by device
  - CRT monitors – 2.5
  - Inkjet Printers – 1.8
  - Old Macs – 1.8
  - sRGB standard – 2.2
  - NTSC TV – 2.2



Gamma = 2.2 (sRGB test)

- Television
  - Gamma precorrected at broadcast (or in camera)
- JPEG, MPEG
  - Gamma stored with the values
- sRGB – Web standard
  - Encoded with γ = 1/2.2 to get a linear response

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Gamma Correction

- If your storing a value as a integer image buffer:

$$\text{luminance} \propto \left(\frac{i}{255}\right)^{\gamma}$$

- To make a "gamma-corrected" image use this equation to convers (0.f – 1.f) to an int:

$$i = int(256 * f^{\frac{1}{\gamma}})$$

- γ = 2.2 is a safe value

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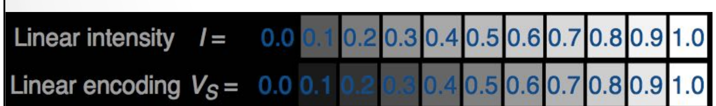
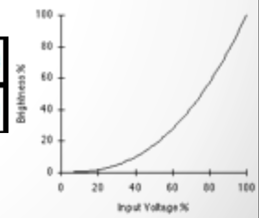
Gamma is Good!

- Humans eye sensitivity varies with brightness
  - Very sensitive to differences in dark tones
  - Insenstivite to differences in light tones
  - Approx. follows a power law!
- Bits are better used for darker regions
  - 70% of numbers used in bottom half of colors





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Raster Graphics System

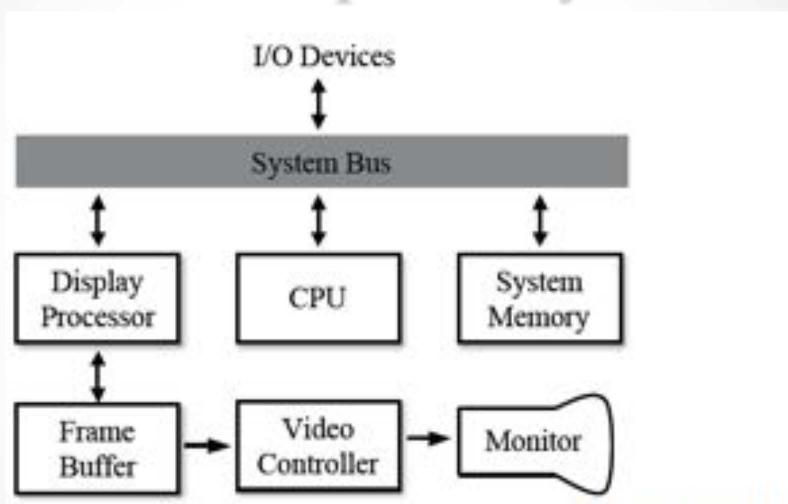


Figure 2.29 from H&B

Frame Buffer

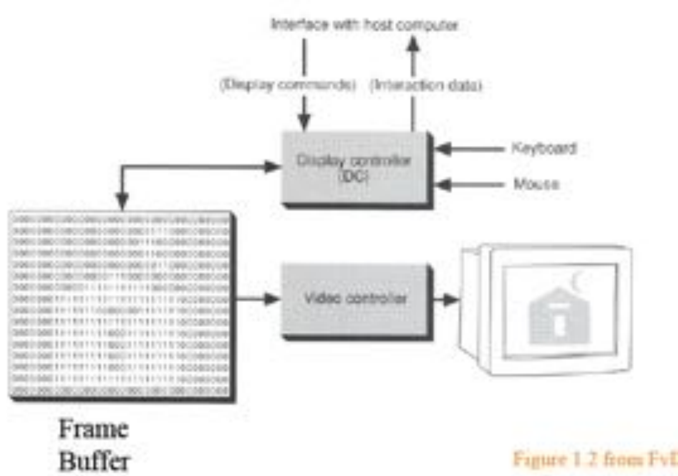
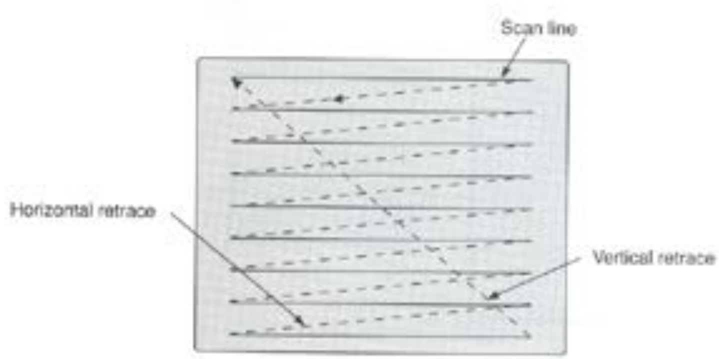


Figure 1.2 from FvDFH

Frame Buffer Refresh

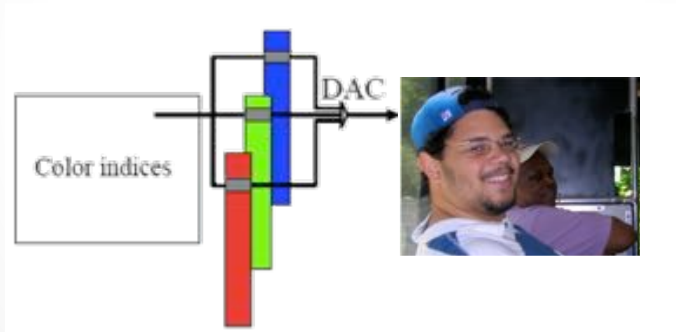


Refresh rate is usually 60-120 Hz

Figure 1.3 from FvDFH

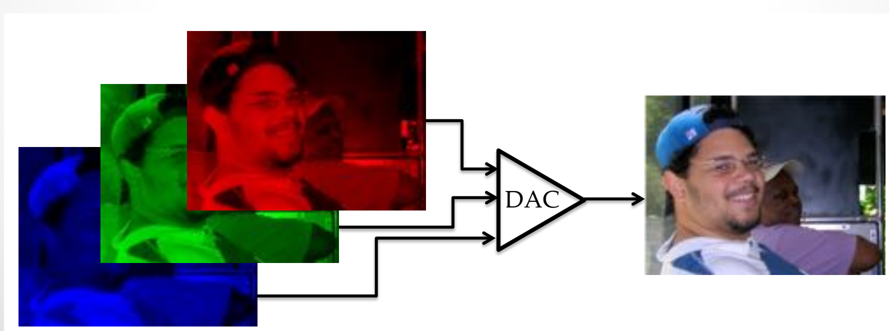
Color Lookup Framebuffer

- Store indices (usually 8 bits) in framebuffer
- Display controller looks up the RGB values to send

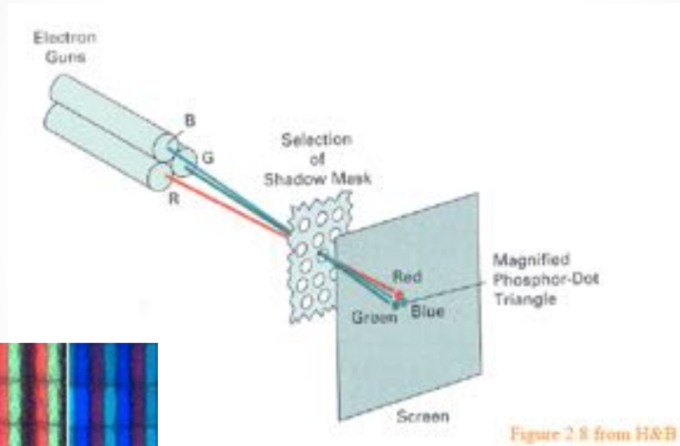


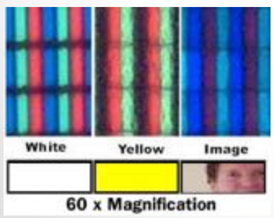
Direct Color Framebuffer

- Stores the actual intensities of R, G, B in framebuffer
- 24 bits per pixel = 8 bits red, 8 bits green, 8 bits blue
- 16 bits per pixel = ? bits red, ? bits green, ? bits blue



Color CRT



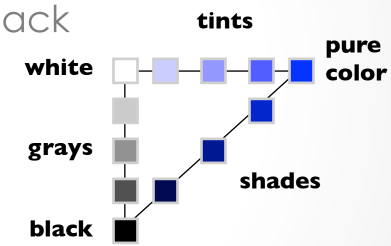


Overview

- Display Technologies
  - CRTs & Gamma Correction
- Image Storage
  - Frame Buffers
- **Color Theory**

What is Color?

- Artists often refer to colors as *tints*, *shades*, and *tones* of pure pigments
  - Tint: mixture with white
  - *Shade*: mixture with black
  - *Tones*: mixture with black and white
- *Gray*: no color at all (aka. neutral)
- This seems intuitive
  - tints and shades are inherently related to the pure color
    - “same” color but lighter, darker, paler, etc.



[after Foley et al.]

Describing Colors

- Color perception usually described with
  - **Hue**: Distinguishes between colors: red, green, yellow, etc.
  - **Saturation**: How far a color is from gray of equal intensity
  - **Lightness**: The perceived intensity reflected from an object
- Lightness also called *brightness* if the object is emitting light instead of reelecting it

Specifying Colors

- These are models, where does color come from?
    - Is Color a physical property of light?

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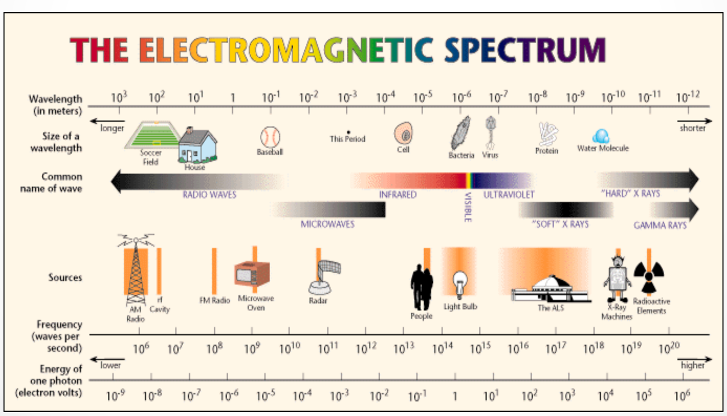
What is Light?

- Light is electromagnetic radiation
    - exists as oscillations of different frequency (or, wavelength)



[Lawrence Berkeley Lab / MicroWorlds]

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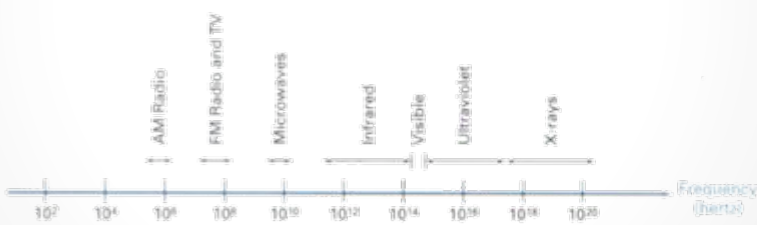
EM Spectrum

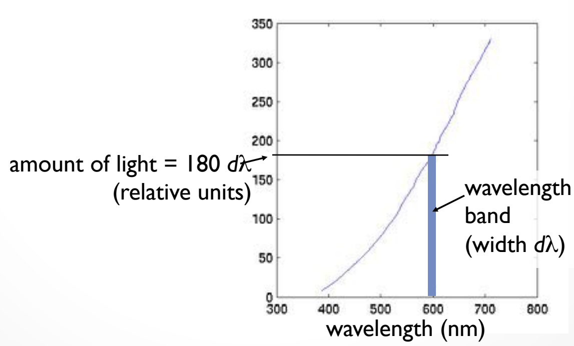
- Visible light frequencies range between ...
  - Red = 4.3×10^{14} hertz (700nm)
  - Violet = 7.5×10^{14} hertz (400nm)



Figures 15.1 from H&B

Measuring Light

- Salient property is the *spectral power distribution (SPD)*
  - the amount of light present at each wavelength
  - units: Watts per nanometer (tells you how much power you'll find in a narrow range of wavelengths)



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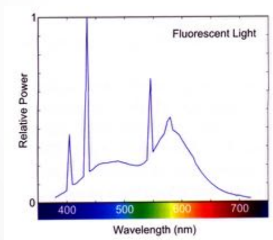
Color Science

- Color is a human perception
  - Not a property of light!
- Color Science studies how to map *Physical light description* to a *Perceptual color sensation*



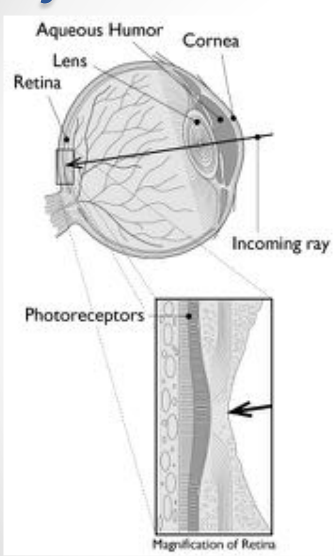
Physical

?

Perceptual

[Stone 2003]

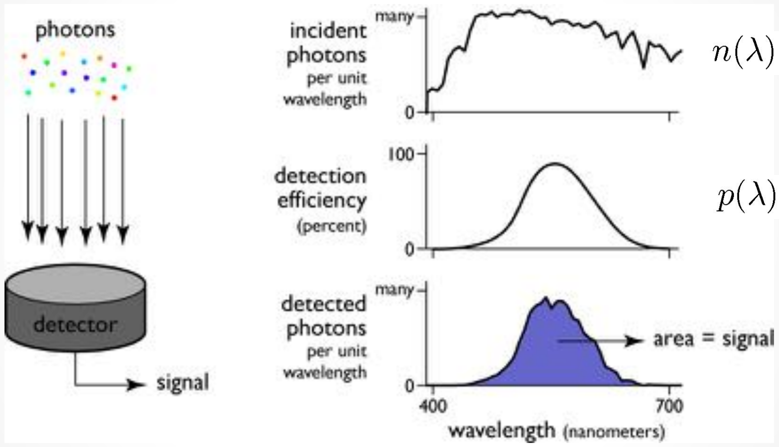
Eye as a measurement device



[Greger et al. 1995]

- Human eye very similar to camera
- Light is measured by the *photoreceptors* in the retina
  - Respond to visible light
  - Different types respond to different wavelengths

A simple light detector



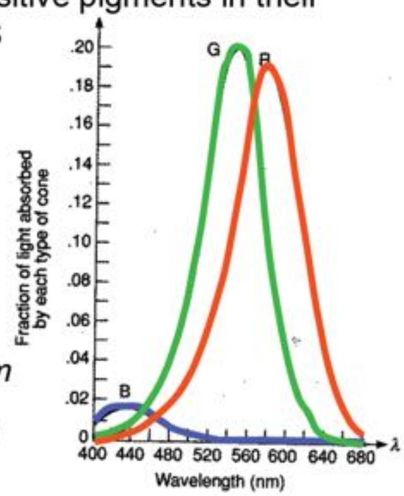
$$X = \int n(\lambda)p(\lambda)\, d\lambda$$

Human Color Vision

- Humans have 3 light sensitive pigments in their cones, called L, M, and S
- Each has a different *spectral response curve*:

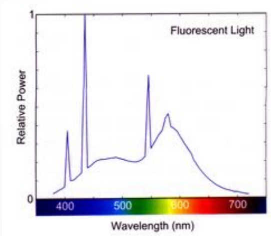
$$L = \int L(\lambda)E(\lambda)d\lambda$$
$$M = \int M(\lambda)E(\lambda)d\lambda$$
$$S = \int S(\lambda)E(\lambda)d\lambda$$

- This leads to *metamerism*
- "Tristimulus" color theory



Colorimetry

- Maps physical properties of lights to subjective values
- Much known since the 1930s
  - o But important refinements came latter



Physical

$$S = r_S \cdot s$$
$$M = r_M \cdot s$$
$$L = r_L \cdot s$$

Perceptual

[Stone 2003]

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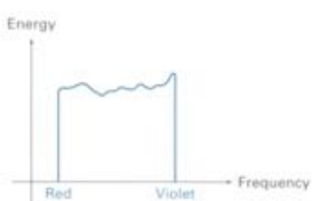
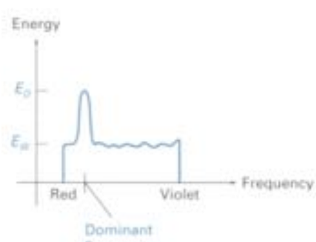
Visible Light

- Hue = dominant frequency (highest peak)
- Saturation = excitation purity (ratio of highest to rest)
- Lightness = luminance (area under curve)



White Light

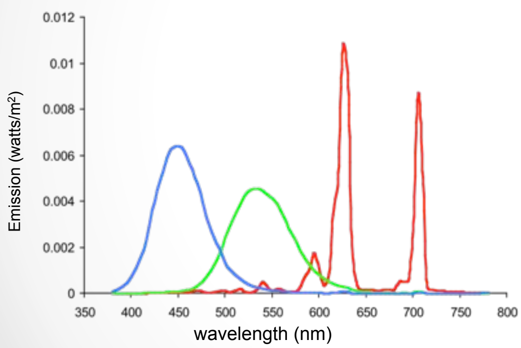


Orange Light

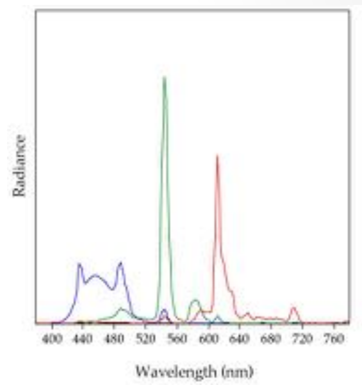
Figures 15.3-4 from H&B

Combining Colors

- Monitors display RGB values



CRT



LCD

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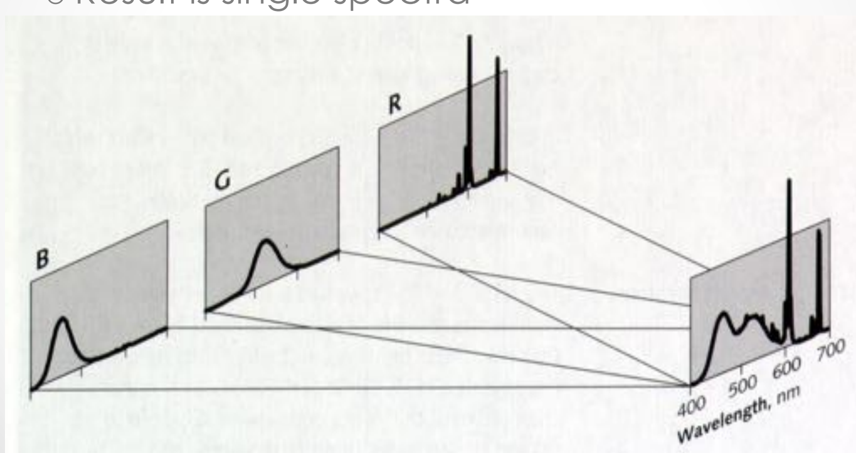
Combining Colors

- Spatial integration combines separate colors
  - Result is single spectra



[source unknown]

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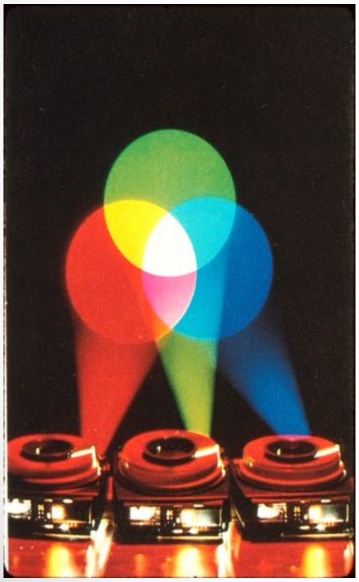
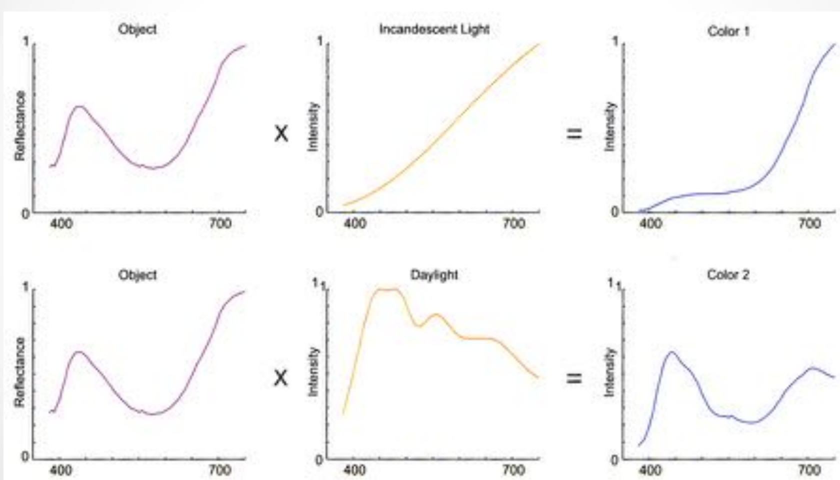
Additive v. Subtractive Colors



[source unknown]

Reflection from colored surface



[Stone 2003]

Subtractive color

- Produce desired spectrum by *subtracting* from white light (usually via absorption by pigments)
- Photographic media (slides, prints) work this way
- Leads to C, M, Y as primaries
- Approximately: 1 – R, 1 – G, 1 – B

Specifying Colors

- We need to represent colors with a number
  - Generally 3 points in a Color Space
- Examples:
  - RGB
  - HSV
  - CMY
- A point in the space specifies a linear combination of weights:
  - $s = R\mathbf{R} + G\mathbf{G} + B\mathbf{B}$ for some spectra **R**, **G**, **B**

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Color Spaces

- Why 3 dimensions?
  - Are you sure three is enough?
- What are the "best" color spaces?
  - Do they reflect the human visual system?

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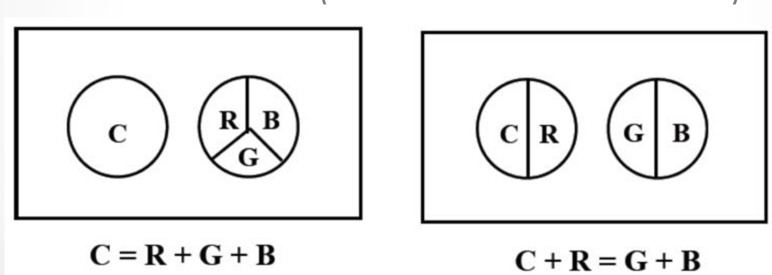
Color Matching

- Shine combinations of laser at two points
  - Allow users to adjust weights of lasers
  - C = Color to be matched
  - RGB = Lasers (700nm, 546nm, 435nm)



- Conclusion: Humans have *trichromatic* vision

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Linear Color Matching

Grassman's Laws:

1. Scaling the color and the primaries by the same factor preserves the match:

$$2C = 2R + 2G + 2B$$

2. To match a color formed by adding two colors, add the primaries for each color:

$$C_1 + C_2 = (R_1 + R_2) + (G_1 + G_2) + (B_1 + B_2)$$

RGB Spectral Colors

- Match each pure color in the visible spectrum (rainbow)
- Record the color coordinates as a function of wavelength

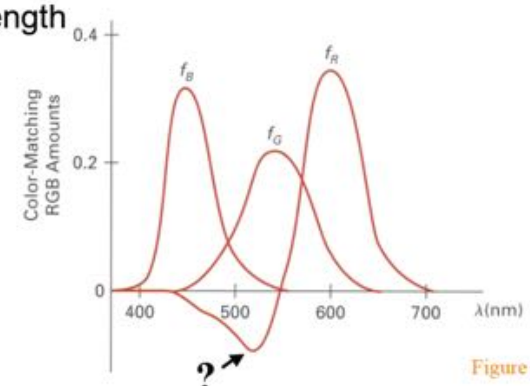
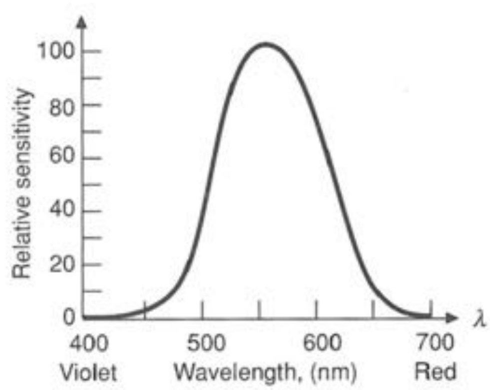


Figure 15.5 from H&B

Just Noticeable Differences

- The human eye can distinguish hundreds of thousands of different colors
- When two colors differ only in hue, the wavelength between just noticeably different colors *varies* with the wavelength!
  - More than 10 nm at the extremes of the spectrum
  - Less than 2 nm around blue and yellow
  - Most JND hues are within 4 nm.
- Altogether, the eye can distinguish about 128 fully saturated hues
- Human eyes are less sensitive to hue changes in less saturated light (not a surprise)

Luminance



Compare color source to a gray source

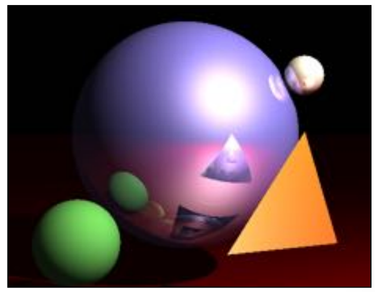
Luminance

$$Y = .30R + .59G + .11B$$

Color signal on a BW TV (Except for gamma)

Announcements

- HW1 is Due Monday 10/2
- HW2 will not be due until around 10/8 & 10/23
  - 3D Graphics
  - Ray-tracing



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