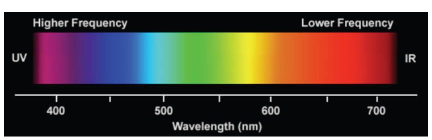
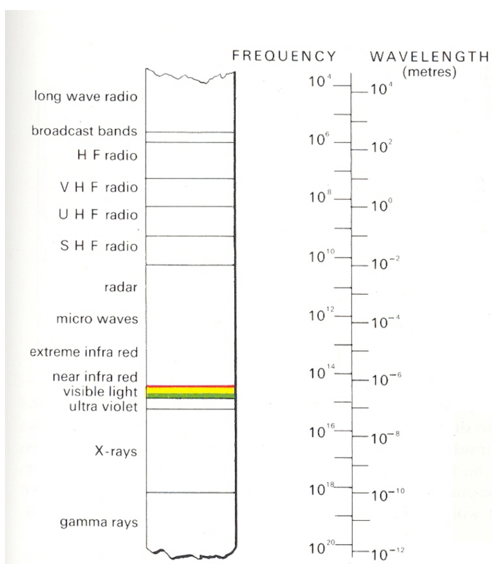
CSC 433/533
Computer Graphics

Lecture 05
Color and Perception

Recall: Light is Electromagnetic Radiation

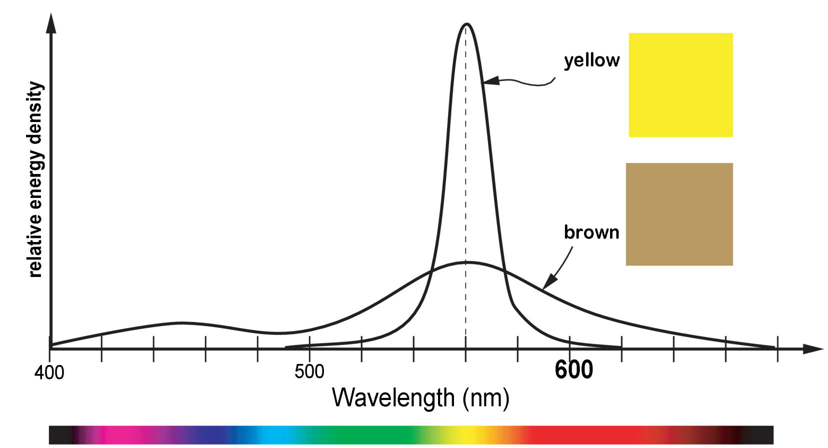
- Visible spectrum is "tiny"
- Wavelength range: 380-740 nm





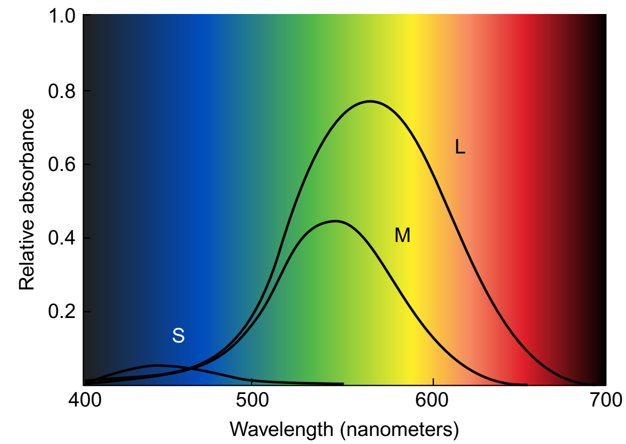
Recall: Color != Wavelength

- But rather, an integral over the wavelengths of the energy encoded of some **power spectrum**



Color and Perception

Recall: We have three types of cones (Short, Medium, and Long)



Colin Ware, Information Visualization: Perception for Design

Hunters

Gatherers

Trichromacy

- Our 3 cones cover the visible spectrum (theoretically, all we might are 2 though)
- Most birds, some fish, reptiles, and insects have 4, some as many as 12 (e.g. the mantis shrimp)
- This is a “reason” why many of our acquisition devices and displays use 3 channels, and why many of our color spaces are three dimensional

Key Idea:
Perception of color

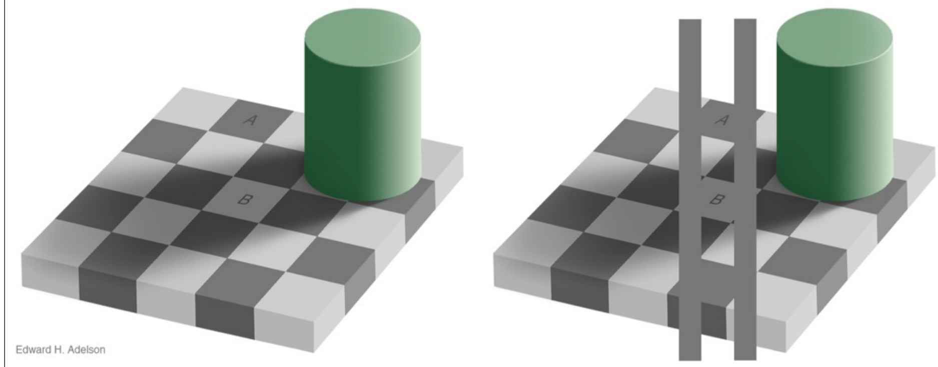
Ultimately, color is a perceptual phenomenon, we all perceive it differently

Color Models

Color Terminology

- **Color Model**
  - Is an abstract mathematical system for representing color.
  - Is often 3-dimensional, but not necessarily.
  - Is typically limited in the range of colors they can represent and hence often can't represent all colors in the visible spectrum
- **Gamut** or **Color Space**
  - The range of colors that are covered by a color model.

Simultaneous Contrast

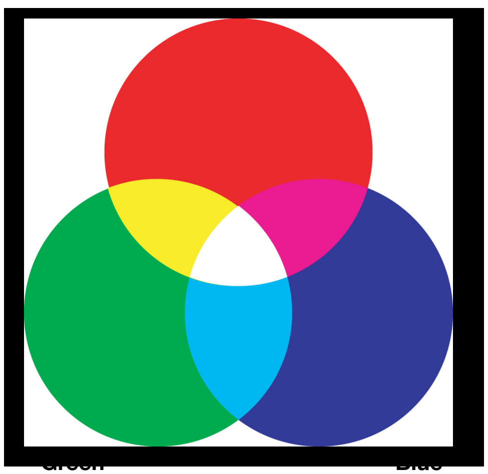


http://persci.mit.edu/_media/gallery/checkershadow_double_full.jpg

Simultaneous Contrast

Simultaneous Contrast

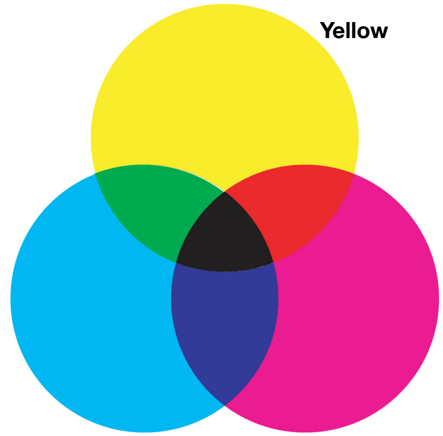
Light Mixing



- **Additive** mix of colored lights (start with black)
  - Add up wavelengths of light to make new colors
- Primary: RGB
- Secondary:
  CMY (cyan, magenta yellow)
- Neutral = R + G + B
- Commonly used by monitors, projectors, etc.

Ink Mixing

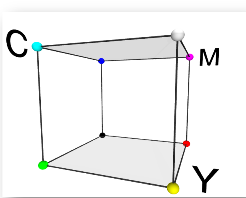
Different game, since we start with white page rather than a black screen
Each color filters the light that is reflected from the white page.



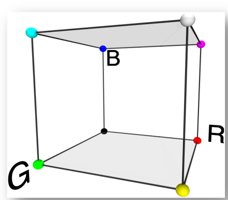
- **Subtractive** mix of transparent inks
  - Start with white and other wavelengths are selectively filtered.
  - The Yellow region does not completely prevent reflection of light from the white page. But it TENDS (depending on transparency) to filter others frequencies)
- Primary: **CMY (Cyan, Magenta, Yellow)**
- Secondary: RGB
- ~Black: C + M + Y
- In practice, we use **CMYK**, with some amount K of black ink, to get true black

Converting from RGB to CMY

- Assuming RGB values are normalized (all channels between [0,1]), the exact same color in CMY space can be found by inverting:



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

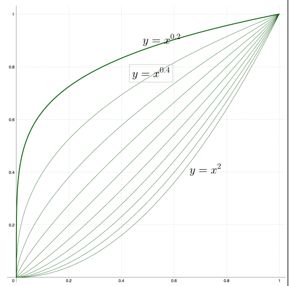


Color Spaces

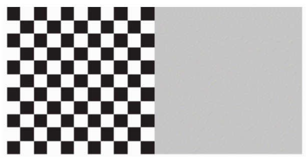
gamma-Correction

- Individual respond from the display (monitor) to every value of GrayScale
- Lets normalize the intensity by using float in [0,1] instead of 255 values of RGB
- such that
- 0 = black, and 1=white
- A pixel with input intensity 0.5 might look very different in different devices.
- Furthermore, the individual response is always monotonic but usually **not linear.**
- On top of it, viewer/illumination/other environmental factor
- So is there a subjective definition of what is gray (**middle** between white and black) ?
- Gamma-Correction. We will assume approximately that if the input is a then

$$\text{displayed intensity} = (\text{maximum intensity})a^{\gamma},$$



- a here is the input intensity to the monitor (between 0 to 1)
- γ is a constant the user could change,
- If no gamma-correction is needed, then the left and right should look the same (when viewed from a distance)
- Change a continuously to the right region, until the output a^{γ} looks like the left region.
- If this happens for some value a of input intensity, we deduce that
- $a^{\gamma} = 0.5$, or $\gamma = (\ln 0.5)/(\ln a)$
- Now every new image, with intensity a' , will be displayed using intensity $(a')^{1/\gamma}$

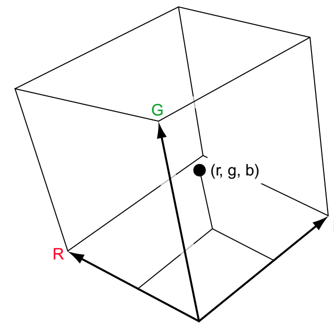


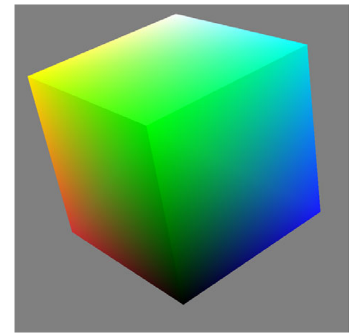
Chessboard of black/white pixels

Uniform region with grey pixels, all get input of 0.5 (before correction).

RGB Color Space

- Additive, useful for computer monitors
- Not perceptually uniform
  - For example, more "greens" than "yellows"





Converting from CMY to CMYK (less relevant to us)

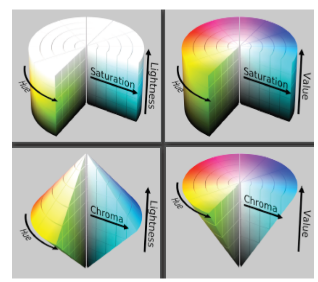
- Assuming CMY values are normalized (all channels between [0,1]), the exact same color in CMYK is

$$\langle C, M, Y, K\rangle = \begin{cases} \langle 0,0,0,1\rangle & \text{if } \min(C', M', Y') = 1, \\ \langle \frac{C'-K}{1-K}, \frac{M'-K}{1-K}, \frac{Y'-K}{1-K}, K\rangle & \text{otherwise where } K = \min(C', M', Y') \end{cases} \tag{3.2}$$

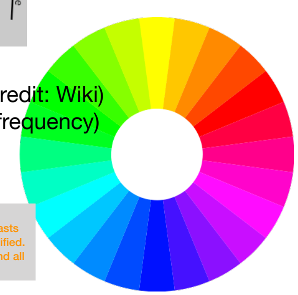
- K is a measure of the 'blackness' of the color and essentially serves as an offset after which the remaining amounts of cyan, magenta and yellow are 'added'

HSL, HSV Color Space

- **H**ue - what people think of as color (color, normalized by sensitivity)
- **S**aturation - purity, distance from grey
  - Also called **C**hroma
- **L**ightness - from dark to light (how many photons, alternatively, add more sources of light)
  - Also **B**rightness or **V**alue



Hue wheel (credit: Wiki)
(not a single frequency)



The HSL color space was invented for television in 1938 by Georges Valensi as a method to add color encoding to existing monochrome broadcasts, allowing existing receivers to receive new color broadcasts (in black and white) without modification as the luminance (black and white) signal is broadcast unmodified. It has been used in all major analog broadcast television encoding including NTSC, PAL and SECAM and all major digital broadcast systems and is the basis for composite video.

Conversion from RGB to HSB

- Assuming RGB values are normalized (all channels between [0,1]), the exact same color in HSB space can be found by first figuring out which channel (R,G, or B) has the max intensity

$$H = \begin{cases} \text{undefined} & \text{if } \max = \min, \\ 60 \times \frac{G-B}{\max - \min} & \text{if } \max = R \text{ and } G \geq B, \\ 60 \times \frac{G-B}{\max - \min} + 360 & \text{if } \max = R \text{ and } G < B, \\ 60 \times \frac{B-R}{\max - \min} + 120 & \text{if } \max = G, \\ 60 \times \frac{R-G}{\max - \min} + 240 & \text{if } \max = B. \end{cases} \quad (3.3)$$

$$S = \begin{cases} 0 & \text{if } \max = 0, \\ 1 - \frac{\min}{\max} & \text{otherwise} \end{cases}$$

$B = \max$. **// 'B' for "brightness". Not 'B' for "blue"**

Note: this method returns H as a value between 0° and 360°

Encoding Color Images

- Could encode 256 colors with a single unsigned byte. But what convention to use?
- One of the most common is to use 3 **channels** or bands
- Red-Green-Blue or RGB color is the most common -- based on how color is represented by lights.
- Coincidentally, this just happens to be related to how our eyes work too.

NOTE : There are many schemes to represent color, most use 3 channels, but the same idea extends to >3 channels