Return to Color

- Color
- Quality of Light
  - Has a wavelength – not just an amount
  - Each photon has a wavelength
- Lots of photons = spectra of frequencies
- Can measure the spectrum of light
  - Graph wavelength vs. amount at the measurement
- Different spectra give different “color impressions”

Is RGB good enough?
- Sortof – gets close to all colors
  - Need better gamut
- No
  - Inconvenient for talking about color
  - Perceptually non-linear
  - Inconsistencies in what RGB means = no matching
  - Can’t get really vivid colors
    - Purples are particularly bad
    - Can’t be RGV – since violet sensitivity isn’t good
    - Old film had different gamuts
      - Robin hood in technicolor

Before we go on…
What RGB means for this class
- We’ll do everything in RGB
- Can think about an image as 3 separate images
  - Intensity for R, G, for B
- Could store as 3 separate images RRRRR, GGG
- Could store RRGBRGBRGBRGB
  - Generally do the latter
- Analogy with film (3 layers vs. 1 layer)
- 4th color isn’t a color – its alpha, transparency
  - More on that next time

How do we talk about color?
- Want to understand the gamut of displays
- Want to compare displays
- Want to understand limits of RGB

Faking Colors
- Metamers allow for faking
- Two different overlapping cones respond
  - Some of each color?
  - Some of the in-between color
- Can fake responses using N “point” colors
  - 2 cones = 2 frequencies
- Get either cone, or anything in overlap
- Colors outside of overlap can’t be faked
Gamut
- The range of colors that a device can represent
  - Perceptual range
- Device only shows some primaries
- Can only fake some colors

(normal) Human Vision
- 3 types of Cones
  - S (short wavelength) cones
  - M (mid wavelength) cones
  - L (long wavelength) cones
- Sortof RGB, but not quite
- Lots of overlap
- Far fewer S cones than L and M

Limits of Color
- Limits on the colors you can see
  - Since some things will be equivalent
- Limits on the colors you can display
- Color matching
  - Try to give the same perceptual experience
- Problems:
  - All displays are going to be different
  - Different displays have different limits

How much color can you see
- Assuming trichromatic (not color blind)
  - Each type of cone gives a response
    - Range of sensation is 3D
- Imagine a color system with 3 primaries
  - Each exactly corresponds to one type of cone
- Amounts of each light = amounts of response
  - Color space is exactly perceptual

Tristimulus color spaces
- Good news: directly lets us describe all colors we can see (and only those colors)
- Bad news, not physically realizable
  - Because of cone overlap
  - Need negative amounts of light
    - Positive in main hump
    - Negative to cancel out others
- "Imaginary" light sources, good for analysis

Imaginary Primaries
- Can we excite just one type of cone?
  - No – there is overlap
  - Yes – shine 1 positive and 1 negative wavelength
    - Really need multiple wavelengths to do it
  - No – there’s no such thing as negative light
    - That’s why these are IMAGINARY primaries
- This is a thought experiment for analysis
- Could make LMS primaries (for LMS cones)
- But want to separate color from brightness
Perceptual Color Space

• Choose 3 primaries that do span human vision
  – Complete Gamut – can recreate any color
  – Not physically realizable (since has negative energies)

• CIE XYZ
  – Y is “lightness” – intensity w/o color
  – XZ are color directions
  – Look at 2D slices of constant brightness (since we’re just worried about color)
  – \( x = X/(X+Y+Z) \), \( y = Y/(X+Y+Z) \), \( x+y+z=1 \) (e.g. constant Y)

Determining Gamuts

• Gamut: The range of colors that can be represented or reproduced
• Overall range of colors has weird “tongue” shape (since xyz must be positive)
• Plot the matching coordinates for each primary: eg. R, G, B
• Region contained in triangle (3 primaries) is gamut
• Really, it’s a 3D thing, with the color cube distorted and embedded in the XYZ gamut

Gamut Analysis

• Space of colors a device can reproduce depends on primaries
• Device reproduce linear combinations of primaries = space inside of points
• Different devices have different ranges
  – Print with more inks
  – Films with different formulations

Other Color Systems: YCC

• \( Y \) = Luminence
  – Could be R+G+B
  – Better to be .3R + .6G + .1B
• Redundant – so send just 2 colors
  – Or send color differences: Y-R, Y-G

• Why?
  – Video: luminance is most important, subsample chroma
  – Perceptually more uniform since corrected for sensitivity
  – Start to separate color (direction in 2D)

Subtractive Color

• Printers combine inks that filter light
  – Remove colors

• So far additive
  – Black + red + green = yellow
• Ink is subtractive
  – White – red = cyan, White-green=magenta, white-blue=yellow
• Use “subtractive primaries”
  – Cyan, Magenta, Yellow

Artist – Centric Systems

• \( \text{Hue} \) = “name” of color
  – Red, orange, yellow, …
  – Color wheel
  – Complements add up to white
• Saturation = purity
• Value = luminence

• HSV (hexcone) vs. HLS (double hexcone)
  – RGB Color Cube viewed from the end
• Cone shape
  – Value is zero, hard to talk about color
• More convenient way to talk about color (for artists)
Where color gets messy…

- Color reproduction is hard
- When you see something on a monitor, does it look like the real thing? (shopping)
  - When you buy a real object?
  - When you print it?
- How do you make sure that what your camera sees is what you see on the screen is what you see when you print?
- How do you interpret RGB?
- Color Management
  - Turns out to be a nightmare since each piece doesn’t know what the other parts of the end-to-end chain are going to do
  - Often assume monitor is cheap, adjusted wrong,…