Lecture: Color

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Notes – not for display
Based on old slides

Return to Color

- Took color for granted (assumed RGB)
- 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?

- Need to understand why
- 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

Colors

- One dominant wavelength = pure color
- No dominant wavelength = “white” (or black/gray)
- What do we perceive?
  - Luminence (amount of light)
  - Color (dominant)
  - Purity of Color
- Complications
  - Differences in perception
  - Artist notions vs. physics vs. psychology

Sensing Color

- Different sensors have different sensitivities
  - Spectrum of sensor
  - Convolution with spectrum gives response
- Ideal photo sensor / real photo sensor
- Cameras – wide range sensor
  - Put filters in front of each CCD element
  - Different parts of spectra (R,G,B)
  - Bayer Mosaic (need to interpolate)
  - Foveon

Color Vision in Animals

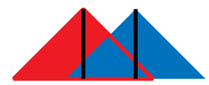
- Rods = all the same
  - No color vision
- Cones = have different kinds
  - 1-chromat (can’t see color) -> Dogs
  - bi-chromat (2 different types) -> large mamals
  - Tri-chromat -> humans ***
    - Color blindness = lack of 1 type
    - Rare genetics condition gives a 4th type
  - Some birds have 4 or 5 types of cones
    - Ducks&Pigeons have 5, European starlings have 4

Distinguishing colors

- 1 sensor
  - All colors look the same
  - Combination of colors looks like any color
- Metamers – perceptually indistinguishable
- 2 sensors
  - Non-overlap case (what differences?)
  - Overlap case
    - Middle vs. combination of sides

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

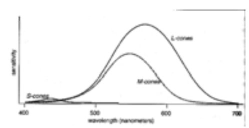


Gamut

- 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



Different Sensitivities

- Convert to gray requires scaling for sensitivities
- R = 0.212671 * Y
- G = 0.715160 * Y
- B = 0.072169 * Y.

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, for G, for B
- Could store as 3 separate images RRRRR, GGGG
- Could store RGBRGBRGBRGB
  - Generally do the latter
- Analogy with film (3 layers vs. 1 layer)
- 4^{th} 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

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

Imaginary Primaries

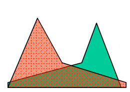
- Can we excite just one type of cone?
  - No – there is overlap
  - Yes – shine 1 positive and 1 negative wavelength
    - Really need multiple wavelengths to do it
  - No – there's no such thing as negative light
  - That's why these are IMAGINARY primaries
- This is a thought experiment for analysis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

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

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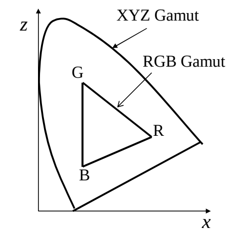
Perceptual Color Space

- 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)

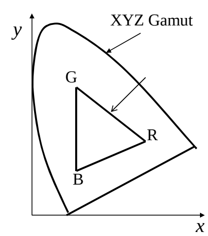
Determining Gamuts



- 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

- 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, …