Lecture 16
Color

October 20, 2016
Where are we?

• You can intersect rays surfaces

• You can use RGB triples

• You can calculate illumination:
  – Ambient, Lambertian and Specular

• But what about color, is there more to know
  – Yes …
Basics: What is Color?

• Eyes, films and CCD/CMOS cameras all convert light into electrical energy
  – More intensity => higher (brighter) value

• This is sufficient for black-and-white (i.e. intensity) images

• What about color?
The Physics View

• Coherent light has a wavelength
  – Visible range typically described as:
    – 380nm (deep purple) to 780 nm (pure red)

• Natural light mixes many frequencies
  – Roughly equal across the spectrum ‘white’
  – Prisms split light by frequency (rainbows)

• Wavelengths ≠ perceptual colors
  – Metamers: wavelength combinations appearing the same to normal human observers
Eye Can See

- Human Receptors 101
- Rods = grayscale
  - Generally RGB
- Cones = color
- Both ‘count’ photons
- Rods highly sensitive
- Cones need a lot of light

Illustration from Anatomy & Physiology, Connexions via Wikipedia

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For Most People – 3 Flavors

Illustration from OpenStax College - Anatomy & Physiology, Connexions Web site. [http://cnx.org/content/col11496/1.6/](http://cnx.org/content/col11496/1.6/) via Wikipedia
Integration Over Time

Catch photons in a bucket – a metaphor.

First simple model, photons in 3 flavors

But: what about a 551 nm photon?
Spectral Power Density

• An illuminated object throws off an entire festival of different wavelength photons.

Your eye takes all this rich information and transduces it through essentially three accumulators, your RGB cones.
Displays: Clever Fakes?

• So how does a display create color images?
  – By stimulating R, G and B cones
• This is (was) easy to explain for TVs

1. Electron guns
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Mask for separating RGB beams
7. Phosphor layer with red, green, and blue zones
8. Close-up of the phosphor-coated inside

This image and associated numeric key to the right is from wikimedia. https://commons.wikimedia.org/wiki/File:CRT_color_enhanced.png
Do Others Do It Differently?


Our displays are specifically tuned to fools standard human color perception.

All color perception of this type subject to confusion: Metamers
Why Dogs Don’t Like TV?
Related Concepts (III)

- Perceptual Color
- Based roughly on opponent colors
  - Red – green
  - Blue – yellow
- Described in terms of Hue, Saturation and Intensity (or value)
  - Blue “wraps around” to red

More Human Color Vision

• Reality is complex
• Some women are quadchromatic
• Three different genes code for red pigment
  – … with slightly different wavelengths
• Distribution of color receptors is a function of eccentricity
  – … and then there is macular pigmentation
• White & Black are comparative, not colors
  – In a dark cave, you will see gray, not black
Graphics = Trichromatic Color

• Our displays produce trichromatic colors
  – Simple red, green and blue
• Every pixel has three values (R, G, B)
• 8-bit values: 0 to 255
• We will model light & reflectance in terms of (R,G,B) triples (vectors)
There is a lot to consider and there is value in learning more, not less, about using colors. Many computer scientists favor high levels of saturation – not such a good thing.
RGB Bits and Hex

• Get used to easily shifting from two views
• 8 bits per color

Red  Green  Blue
00110110 11110001 00110110

54 241 54

Sample

• 2 digit hex number.

Red  Green  Blue
00110110 11110001 00110110

36 F1 36
RGB values as floats

- When we move to illumination – bits byte 😊
- Want an easier way to blend and combine.
- Shift to floating point numbers.
- Constrained to the range 0.0 to 1.0

Red: 0 0 1 1 0 1 1 0
Green: 1 1 1 1 0 0 0 1
Blue: 0 0 1 1 0 1 1 0

Sample: 0.212 0.945 0.212
One more thing - Transparency

- Modern systems store a 4\textsuperscript{th} value
- $\alpha$ controls transparency of a color.
- means color below can be seen beneath.
Alpha Channel - Pragmatics

- A good way to use the last byte :-)  
- Consider a 32 bit word ...

<table>
<thead>
<tr>
<th>Alpha</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 0 0 0 0 0 0 0</td>
<td>0 0 1 1 0 1 1 0</td>
<td>1 1 1 1 0 0 0 1</td>
<td>0 0 1 1 0 1 1 0</td>
</tr>
</tbody>
</table>

Alpha controls blending
- Alpha = 0 (000) - transparent.
- Alpha = 1 (255) - completely covers.
- Alpha = 0.5 (128) - 50/50 mix with underneath.
Not all RGBs are Equal

• In the capture of color things are getting exciting. Read that as more complicated
  – Start with sRGB, but there is more
  – Adobe RGB,
  – Camera RAW, with complex sensing filters
  – Extended output displays

• I was searching for a personal metaphor
  – Next slide
Sound, Sight and Being Picky

• Are there ‘audiofiles’ of color?
• I grew up steeped in ‘golden ears’
• What is a ’golden eye’?

http://www.stereophile.com/content/beveridge-2sw-loudspeaker-system#kVx50V6YADZ6ve7x.97
Better Color ...?

A similar issue to that faced by audiofiles will emerge, how much does the average person care/notice.

One certainty – what we teach about color generation will be changing now displays seem to be moving forward at a more rapid clip.