Part I: What is Light?

Part II: The Eye

Part III: Reflectance

Part IV: Lighting

Part V: Shadows

Shading
What are the patterns of light in this room?

- Projector as light source
- Light transmitted through windows
- Blue light reflecting from screen
- Blackboard is matte surface
- Edge of screen is shiny surface
- Shadows underneath the desks
Physics of Light and Color

Electromagnetic (EM) radiation

Different colors correspond to radiation of different wavelengths $\lambda$
Intensity of each wavelength specified by amplitude
Frequency $\nu = \frac{2 \pi}{\lambda}$
- long wavelength is low frequency
- short wavelength is high frequency

We perceive EM radiation with $\lambda$ in the 400-700 nm range
Color: What's There vs. What We See

- Human eyes respond to “visible light”
  - tiny piece of spectrum between infra-red and ultraviolet
- Color defined by the emission spectrum of the light source
  - amplitude vs wavelength (or frequency) plot
Part I: What is Light?

Part II: The Eye

Part III: Reflectance

Part IV: Lighting

Part V: Shadows

Shading
Part I: What is Light?

Part II: The Eye

Part III: Reflectance

Part IV: Lighting

Part V: Shadows

Shading
• The image is formed on the retina
• Retina contains two types of cells: rods and cones
• Cones measure color (red, green, blue)
• Rods responsible for monochrome night-vision
The Fovea

Cones are most densely packed within a region of the retina called the **fovea**

- 1.35 mm from retina center
- 8 mm from retina center
- 4 μm

Three types of cones: S, M, L
- Corresponds to 3 visual pigments
- Roughly speaking:
  - S responds to blue
  - M responds to green
  - L responds to red

Not uniform sensitivity
- Colorblindness: deficiency of one cone/pigment type
Color Filters

Rods and cones can be thought of as filters
Cones detect red, green or blue parts of spectrum
Rods detect average intensity across spectrum

A physical spectrum is a complex function of wavelength
But what we see can be described by just three numbers—the color filter outputs
How can we encode a whole function with just three numbers?
We can’t—we can’t distinguish certain colors—*metamers*
Saccades
Vision and the brain

The retina is part of the central nervous system
2 million fibers from retina to lateral geniculate nucleus (LGN),
10 million from there to brain.

Primary connection is *Primary Visual Cortex or V1*
2 cm² on back of brain
Hypothesis: V1 gets used as a sort of image buffer for higher processing in the rest of the brain

Steps:
- Saccade ends
- Retina accumulates image
- LGN opens connections, image gets written to V1
- Rest of brain accesses that info
- Meanwhile, a point of interest is being generated for next saccade
- Next saccade happens perhaps 250ms later; go back to step 1

All automatic; eye tracking systems can discern attention but pointing with eyes doesn’t work very well for user interfaces.
Color Models

Okay, so our visual system is quite limited, but maybe this is good news...

We can avoid computing and reproducing the full color spectrum since people only have three color channels:

- everything would be much more complex if we perceived the full spectrum
- transmission would require much higher bandwidths
- display would require much more complex methods

Real-time color 3D graphics is feasible

Any scheme for describing color requires only three values:

- lots of different color spaces--related by matrix transformations
Color Spaces

Spectrum
allows any radiation (visible or invisible) to be described
usually unnecessary and impractical

RGB
convenient for display (CRT uses red, green, and blue phosphors)
not very intuitive

HSV
an intuitive color space
H is hue - what color is it? S is saturation or purity - how non-gray is it? V is value - how bright is it?
H is cyclic therefore it is a non-linear transformation of RGB

CIE XYZ
a linear transform of RGB used by color scientists
HSV

Hue: color
Saturation: how non-grey
Value: brightness

From mathworks
Better Color Models?

Figure 11: A painting created with IMPaSTo, after a painting by Vincent Van Gogh.

source:
IMPaSTo: a realistic, interactive model for paint
William Baxter, Jeremy Wendt, Ming C. Lin
Tetrachromacy
Additive vs. Subtractive Color

• Working with light: additive primaries
  – Red, green and blue components are added by the superposition property of electromagnetism
  – Conceptually: start with black, primaries add light

• Working with pigments: subtractive primaries
  – Typical inks (CMYK): cyan, magenta, yellow, black
  – Conceptually: start with white, pigments filter out light
  – The pigments remove parts of the spectrum

<table>
<thead>
<tr>
<th>dye color</th>
<th>absorbs</th>
<th>reflects</th>
</tr>
</thead>
<tbody>
<tr>
<td>cyan</td>
<td>red</td>
<td>blue and green</td>
</tr>
<tr>
<td>magenta</td>
<td>green</td>
<td>blue and red</td>
</tr>
<tr>
<td>yellow</td>
<td>blue</td>
<td>red and green</td>
</tr>
<tr>
<td>black</td>
<td>all</td>
<td>none</td>
</tr>
</tbody>
</table>

– Inks interact in nonlinear ways--makes converting from monitor color to printer color a challenging problem
– Black ink (K) used to ensure a high quality black can be printed
What about displays?

Humans can’t see most of the spectrum but displays can’t display most of what we can see.

Human Overall Luminance Vision Range
(14 orders of magnitude, scale in log cd/m2)

-6 -4 -2 0 2 4 6 8

starlight moonlight indoor lighting sunlight

Human Simultaneous Luminance Vision Range

5 orders of magnitude

2-3 orders

Today’s Devices

BrightSide Technologies

5 orders of magnitude
What about displays?

Conventional CRTs have 600:1 dynamic range
Flat-panel LCDs are 500:1.
BrightSide's HDR displays achieve 200,000:1

10 times higher brightness than any commercially available display while at the same time delivering a black that is over 10 times darker than that of conventional displays.

http://www.brightsidetech.com

HDR image, range, conventional display, HDR display
Part I: What is Light?

Part II: The Eye

Part III: Reflectance

Part IV: Lighting

Part V: Shadows

Shading