Color Constancy

Lecture 11
Chapter 5, Part 3

Jonathan Pillow
Sensation & Perception (PSY 345 / NEU 325)
Princeton University, Spring 2015
Color Constancy

The visual system uses a variety of tricks to make sure things look the same color, regardless of the illuminant (light source)

- **Color constancy** - tendency of a surface to appear the same color under a wide range of illuminants

- To achieve color constancy, we must discount the illuminant and determine the object’s surface properties
Illusion illustrating Color Constancy

Same yellow in both patches

Same gray around yellow in both patches

(the effects of lighting/shadow can make colors look different that are actually the same!)
Exact same light coming to your eye from these two patches

But the brain infers that less light is hitting this patch, due to shadow

CONCLUSION: the lower patch must be reflecting a higher fraction of the incoming light (i.e., it’s brighter)
Color Constancy
Color Constancy

Beau Lotto
• Visual system tries to discount the effects of the illuminant: it cares about the properties of the surface, not the *illuminant*.

(on last slide: brain discounts the cone responses by taking into account information about much light is hitting different surfaces)

• still unknown how the brain does this: believed to be in cortex (V1 and beyond).
• *but:* color-constancy is not perfect

• possible to fool the visual system by:

  – using a light source with unusual spectrum
    (most light sources are broad-band; narrow-band lights
    will make things look very unusual)

  – showing an image with little spectral variation
    (e.g., a blank red wall).
or in rare cases we can fool 2/3 of the population
(and sow division and hostility across the internet!)
So what’s going on?

- Object of interest
  - Energy
    - Reflectance
      - Surface reflectance function
      - Illuminant power spectrum

= Light hitting eye

400, 700, Wavelength
Possibility #1: dress in blueish light (or shadow)

- blueish light source
- white stripe!

\[ \text{blueish light source} \times \text{reflectance} = \text{energy} \]

\[
\begin{array}{c}
\text{energy} \\
400 \quad \text{wavelength} \quad 700 \\
\end{array}
\]
Possibility #2: dress in yellow light

- yellowish light source
- blue stripe!

\[
\text{energy} \times \text{reflectance} = \text{energy}
\]
So: percept depends on inferences about the light source!
So: percept depends on inferences about the light source!

Of course: we have no idea (so far) why people are making such radically different inferences about light
one possibility: where did you look first?

Top
one possibility: where did you look first?

Bottom
Color mixing

• Mixing of lights (additive) vs Mixing of paints (subtractive)
Mixing of lights:

- **Additive color mixing**
- If light A and light B both arrive at the eye, the effects of those two lights add together
- (that is, the power spectra add)
Georges Seurat’s painting *La Parade* (1888)
• illustrates the effect of *additive* color mixture
• reflected light from nearby dots adds together when blurred by the optics of the eye

This is the same effect we get from a TV monitor with 3 kinds of phosphors
Mixing of paints:

- **Subtractive color mixing**
  - If pigment A and B mix, some of the light shining on the surface will be subtracted by A and some by B. Only the remainder contributes to the perception of color.
Example of *subtractive* color mixture: “white”—broadband—light is passed through two filters

1. Take “white” light that contains a broad mixture of wavelengths.

2. Pass it through a filter that absorbs shorter wavelengths. The result will look yellowish.

3. Pass that through a bluish filter that absorbs all but a middle range of wavelengths.

4. The wavelengths that make it through both filters will be a mix that looks greenish.

This is the same result we’d get from mixing together yellow & blue paints.
color blindness

- About 8% of male population, 0.5% of female population has some form of color vision deficiency: Color blindness

- Mostly due to missing M or L cones (sex-linked; both cones coded on the X chromosome)
Types of color-blindness:

**dichromat** - only 2 channels of color available (contrast with “trichromat” = 3 color channels).

Three types, depending on missing cone:

- **Protanopia**: absence of L-cones
- **Deuteranopia**: absence of M-cones
- **Tritanopia**: absence of S-cones

Frequency:

<table>
<thead>
<tr>
<th>Cone Type</th>
<th>Frequency: M / F</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-cones</td>
<td>2% / 0.02%</td>
</tr>
<tr>
<td>M-cones</td>
<td>6% / 0.4%</td>
</tr>
<tr>
<td>S-cones</td>
<td>0.01% / 0.01%</td>
</tr>
</tbody>
</table>

includes true dichromats and color-anomalous trichromats
Scene Viewed by Protanope

Same Scene Viewed by Normal Trichromat
Scene Viewed by Tritanope

Same Scene Viewed by Normal Trichromat
Other types of color-blindness:

- **Monochromat**: true “color-blindness”; world is black-and-white
- **cone monochromat** - only have one cone type (vision is truly b/w)
- **rod monochromat** - visual in b/w AND severely visually impaired in bright light
Rod monochromacy
normal trichromat

protanope

deuteranope

tritanope

monochromat

scotopic light levels
Color Vision in Animals

• most mammals (dogs, cats, horses): dichromats
• old world primates (including us): trichromats
• marine mammals: monochromats
• bees: trichromats (but lack “L” cone; ultraviolet instead)
• some birds, reptiles & amphibians: tetrachromats!
Color vision doesn’t work at low light levels!
Two Regimes of Light Sensitivity

- **Photopic**: Light intensities that are bright enough to stimulate the cone receptors and bright enough to “saturate” the rod receptors
  - Sunlight and bright indoor lighting

- **Scotopic**: Light intensities that are bright enough to stimulate the rod receptors but too dim to stimulate the cone receptors
  - Moonlight and extremely dim indoor lighting
Other (unexplained) color phenomenon:

- watercolor illusion
- neon color spreading
- motion-induced color: *Benham’s top*
Watercolor illusion
Watercolor illusion
Watercolor illusion
Neon Color-Spreading
Neon Color-Spreading
Neon Color-Spreading
Neon Color-Spreading
Benham’s top:

motion-induced color perception

http://www.michaelbach.de/ot/col_benham/index.html

- not well-understood; believed to arise from different color-opponent retinal ganglion cells having different temporal latencies.
- the flickering pattern stimulates the different color channels differently (although this is admittedly a crude theory)
Summary

• color constancy
• photopic / scotopic light levels
• additive / subtractive color mixing
• color blindness