Sensation & Perception

Ch. 9: Perceiving Color

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Main topics
Functions of color
Trichromatic theory
Color deficiency
Lightness constancy
A Sunday afternoon on the island of :La Grande Jatte: G. Seurat

Alfalfa field, Saint-Denis: G. Seurat
Water Lilies: C. Monet

Sisley
Aristotle contemplating a bust of Homer: Rembrandt (1653)

Bridge at Villeneuve-la-Garenne: Sisley
Why are impressionists’ paintings so bright?

• Subject matter
  – Landscape, not much mythological figures

• Scientists discovered the mechanism underlying the perception of color
Color

• Physiologists:
  – Helmholtz (1821-1894)
    • http://en.wikipedia.org/wiki/Hermann_von_Helmholtz
  – Hering (1834-1918)

• Impressionist painters:
  – Monet (1840-1926)
  – Seurat (1859-1891)
  – Pissarro (1830-1903)
  – Sisley (1839-1899)
• Impressionists were influenced by the theory of color perception
Colors, what are they?

- A brief review on vision
What we see is electromagnetic energy
What does the eye do?

- Capturing electromagnetic energy.
  - As the radio and TV do
  - Discerning different wave lengths
What does the eye do?

→ Transducing light energy into neural energy
Two types of photo receptors

• Cones and Rods
• Cones are for color vision
Eye

- Photo receptors
- Two types of photo receptors – rod & cone
3 types of cones

- There are three types of cones that are selectively tuned to three different lengths of electromagnetic waves (Short, Medium, and Long).
• Short:
  – These cones react primarily to the waves whose length are about 419 nm (nano-meter)
• Medium:
  – These cones react primarily to the waves with 531 nm
• Long
  – These cones react primarily to the waves with 558 nm
Color perception is produced by combinations of these 3 types of cones:

- Blue
- Green
- Red

Demonstration:

VL 9-4
Different objects reflect light in a different manners.

Some objects (tomato) absorb short waves while reflect long waves → create a red surface.

Absorb short waves but reflect long waves
Mixing paints

Blue paint

Yellow paint

Blue paint + Yellow paint
Demonstration: Mixing lights (VL 9-1)
What the computer does is the same thing

- Pixel
- Bit
- Illuminating the phosphor with three different electron guns.
- Illuminate each pixel with red, green, and blue electron guns
3 types of electron guns: a red gun, a green gun, and a blue gun
Why do the impressionists’ paintings so bright?

➔ They did the same thing.

➔ Computer scientists and impressionists developed their ideas based on the psychological theory of color perception.
My paintings
After Image
Why do we get after-images?

• After-images have something to do with adaptation.
• What is adaptation?
  – Motion
  – Spatial frequency
• Look at the demonstration of motion adaptation
Simultaneous Color Contrast

• Why do the X’s look different in the two rectangles?
• Some sort of inhibitory mechanism is going on?
More Phenomenological Observations

• Visualize something red (apple, fire engine)
  – Now reddish-yellow
  – Now reddish-green

• Visualize something blue (sky, pool)
  – Now bluish-green
  – Now bluish-yellow

• Which is hardest to visualize?

• Note – very little overlap in color sensation of blue and yellow, and of red and green

• People who are color-deficient for red also lack green; same with blue and yellow
Figure 6.13
The results of a color-scaling experiment. After viewing each stimulus light, the subject rates her or his color sensation by assigning percentages to blue, green, yellow, or red so that they add up to 100 percent. These data, which are averages from a number of subjects, indicate very little overlap between blue and yellow and between red and green. Even this small amount of overlap decreases when we consider the results of individual subjects. (Adapted from Gordon & Abramov, 1988; see also Abramov & Gordon, 1994.)
Trichromatic $\rightarrow$ Opponent-process

Trichromatic stage:
3 kinds of cone receptors
(S, M, L)

Opponent process
At the bipolar or ganglion cells, the difference between S and (M+L) (Circuit 1) and the difference between M and L (Circuit 2) is assessed.
The first circuit (Circuit 1) processes the blue-yellow difference.
The second circuit (Circuit 2) processes the red-green difference.
Opponent-process theory
(Hering/Hurvich & Jameson)

• Color vision is caused by opposing responses generated by blue and yellow, and by red and green.
After images:
Red $\rightarrow$ Green
Green $\rightarrow$ Red
Blue $\rightarrow$ Yellow
Yellow $\rightarrow$ Blue
adaptation

After image

adaptation

After image
Trichromatic → Opponent-process

Two stages in color perception
Trichromatic stage:
   3 kinds of cone receptors
     (S, M, L)

Opponent process
   At the bipolar or ganglion cells, the difference between S and (M+L) (Circuit 1) and the difference between M and L (Circuit 2) is assessed.
   The first circuit (Circuit 1) processes the blue-yellow difference.
   The second circuit (Circuit 2) processes the red-green difference.
Responses of opponent cells in the monkey’s LGN

<table>
<thead>
<tr>
<th></th>
<th>B+Y−</th>
<th>G+R−</th>
<th>Y+B−</th>
<th>R+G−</th>
</tr>
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<tbody>
<tr>
<td>Spontaneous</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>450 nm (blue)</td>
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<tr>
<td>510 nm (green)</td>
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<tr>
<td>580 nm (yellow)</td>
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<tr>
<td>660 nm (red)</td>
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Fig. 7-20, p. 155
Figure 3.2.14 Neural response curves of opponent process cells. The relative firing rates for $R^+G^-$, $G^+R^-$, $B^+Y^-$, $Y^+B^-$, $Wh^+Bk^-$, and $Bk^+Wh^-$ cells in macaque monkey LGN are plotted as a function of wavelength. (After De Valois, et al., 1966.)
Opponent-process theory

S, M, and L cones have inhibitory and excitatory connections at LGN.

Inhibitory

Excitatory

55
Opponent-process theory

- The opponent-process is more like a mechanism to detect the different responses in the three types of cones.

- This allows the visual system to record *differences* between the responses of cones, rather than each type of cone's individual response.
Why is this process efficient?

- Distinguishing the two wavelengths, 1 and 2 is very hard using just the M and L receptors.

- Opponent process create two categorical responses $\rightarrow +$ or $-$
Huichol masks (Mexican Indian tribe)
Color blindness

• Can be caused by the disorder in cone receptors, optic nerves, and/or other higher brain areas responsible for color perception (e.g., V4).

• Most problems in color vision is associated with problems with the cone receptors in the retina.
• Monochromat
  – Cannot distinguish any color from gray. (all or two of the cone systems are compromised)

• Dichromat
  – Only one cone system is compromised.
Constancy

- Color constancy
  - We perceive the colors of objects as being relatively constant even under changing illumination.
  - A green sweater is green no matter where you see it.
  - How come?
• Background knowledge and your memory contribute to color constancy.
• You compare the color of your sweater with other surrounding things.

• Adaptation
Lightness constancy

• Both top-down and bottom-up processes are going on.
Different amounts of light are reflected from the same surface in (a) and (b).

But our perception of lightness is pretty much the same (lightness constancy)

How come?
Lightness constancy

• Constancy is so prevalent that we even don’t notice that.

• My skin reflects much less light in this room than in outside.

• But people don’t think that my skin color changes every time I enter a building.
Ratio principle

Perceive lightness of an object with respect to the surrounding area.

E.g.,

– When I enter a building, everything loses illumination, so perceived lightness of my face remains the same.
How does the visual system distinguish reflected light from illuminated light?
• The LGN is the first stop in the visual pathway.
• The LGN receives more input back from the cortex than from the retina.