Lecture 4

Opponent Colors

Hue Cancellation Experiment
HUV Color Space

Opponent Colors

Ewald Hering (1905) - Pure colors R G B Y.
No such colors greenish-red, yellowish-blue

Boynton & Gordon (1965) -
With R G B Y can categorize all visible hues.

Jameson & Hurvich (1955, 1957) -
Hue Cancellation Experiments

Hue Cancellation Experiment

canceling light

Cancel the red-green content of the test light.
Cancel the blue-yellow content of the test light.
Hue Cancellation

Hurvich & Jameson (1957)

Red + Green cancellation lights
Blue + Yellow cancellation lights

Huff Cancellation

Hurvich & Jameson (1955)

Unique Hues :
yellow 573 nm, blue 472 nm, green 492 nm.
Unique Red has some ‘yellow’ (scarlet)

Figure From www.handprint.com/HP/WCL/color2.html

Physiological basis for Opponent Colors

Svaetichin & MacNichol ('58) - Horizontal cells
Boynton ('79), DeMonasterio ('78) - ganglion cells
DeValois & DeValois ('75) - LGN cells
Derrington et al ('84) - LGN cells

Opponent signals measured in LGN neurons

L-M

L+M-S

Derrington (1984)
Opponent process - possible neural connections:

- Ganglion cells / LGN cells
  - Color Contrast detectors
  - Color edge detectors

Opponent Cell - Neural Response

- Electrophysiological recordings midget ganglion cell in the monkey retina
- Opponent Cell - Neural Response
Mach bands for small changes in lightness (top) and hue (middle)
McCullough’s Effect - interaction between color and form

Why Opponent process?

A: Efficient Encoding

L and M cone sensitivities are highly correlated.

Cone responses to several Natural SPDs:

- L-cone absorption
- M-cone absorption
- S-cone absorption
Decorrelation:

\[
\begin{bmatrix}
O_1 \\
O_2 \\
O_3
\end{bmatrix} =
\begin{bmatrix}
1.00 & 0.00 & 0.00 \\
-0.59 & 0.80 & -0.12 \\
-0.34 & -0.11 & 0.93
\end{bmatrix}
\begin{bmatrix}
L \\
M \\
S
\end{bmatrix}
\]

Spectral sensitivities of three decorrelated sensors

(Decorrelated over the Macbeth color checker under mean daylight.)

Contrast Sensitivity
Contrast Sensitivity Function

Cambell Robson

Contrast Sensitivity Function

Spatial Frequency (cycles/degree)

Contrast Sensitivity

Visible Stimuli

Color Contrast Sensitivity

Asymmetric color matching experiment:

Opponent channels have different modulations:

(Poirson and Wandell 1993)

Opponent channels have different modulations:

Spectral Sensitivities

Contrast sensitivity

Spatial frequency (cpd)

Wavelength (nm)
YIQ - Color Space

NTSC = National Television Systems Committee

\[
\begin{bmatrix}
Y \\
I \\
Q
\end{bmatrix} =
\begin{bmatrix}
0.000 & 1.000 & 0.000 \\
1.407 & -0.842 & -0.451 \\
0.932 & -1.189 & 0.233
\end{bmatrix}
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

\[Y = \text{luminance}\]
\[I = \text{red-green}\]
\[Q = \text{blue-yellow}\]

YIQ - Color Space

Target display image is RGB, derived from camera

For transmission in the US, the image is converted into YIQ

\[Y = 0.299R + 0.587G + 0.114B\]
\[I = 0.596R + 0.275G + 0.321B\]
\[Q = 0.212R + 0.523G + 0.311B\]
Polar vs Opponent Color Spaces

Linear Color Spaces - Conversions

Conversion matrix....

<table>
<thead>
<tr>
<th>From</th>
<th>XYZ</th>
<th>LMS</th>
<th>RGB</th>
<th>OPP</th>
<th>YIQ</th>
</tr>
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<tbody>
<tr>
<td>XYZ</td>
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<tr>
<td>LMS</td>
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Y \\
Z
\end{bmatrix}
\]

Linear Color Spaces - Conversions

Conversion matrix....

\[
M_{XYZ2YIQ} =
\begin{bmatrix}
0.000 & 1.000 & 0.000 \\
1.407 & -0.842 & -0.451 \\
0.932 & -1.189 & 0.233
\end{bmatrix}
\]

\[
M_{XYZ2OPP} =
\begin{bmatrix}
278.7 & 721.8 & -106.5 \\
-448.7 & 289.8 & 77.1 \\
85.9 & -589.9 & 501.1
\end{bmatrix}
\]

\[
M_{LMS2OPP} =
\begin{bmatrix}
0.990 & -0.106 & -0.094 \\
-0.669 & 0.742 & -0.027 \\
-0.212 & -0.354 & 0.911
\end{bmatrix}
\]

\[
M_{RGB2XYZ} =
\begin{bmatrix}
12.2 & 44.4 & 6.5 \\
4.6 & 44.6 & 9.5 \\
0.5 & 4.6 & 44.8
\end{bmatrix}
\]

\[
M_{RGB2LMS} =
\begin{bmatrix}
0.895 & 0.2664 & -0.1614 \\
-0.7502 & 1.7135 & 0.0367 \\
0.0389 & -0.0685 & 1.0296
\end{bmatrix}
\]

\[
M_{XYZ2LMS} =
\begin{bmatrix}
0.895 & 0.2664 & -0.1614 \\
-0.7502 & 1.7135 & 0.0367 \\
0.0389 & -0.0685 & 1.0296
\end{bmatrix}
\]
Color Appearance

Whether modeled in

- XYZ Color Space
- HSV Color Space
- YIQ Color Space

Color Appearance - is much more complicated!

Color Differences are non Uniform

Color appearance is context dependent

All squares are matched on hue and chroma

Simultaneous Contrast

From:
http://personales.upv.es/gbenet/teoria%20del%20color/water_color/color3.html
Lateral Inhibition

Apparent color shifts in simultaneous color contrasts
Shifts are shown in contrast to a middle red color

From:
http://personales.upv.es/gbenet/teoria%20del%20color/water_color/color3.html
Simultaneous Contrast
Boundary Effects

Simultaneous Contrast
Boundary Effects

Simultaneous Contrast vs White’s Illusion

Color Induction

I Became a Singer!
Color Appearance

Color Appearance Depends On The Spatial Pattern (Spatial Frequency + Surround Color) Across The Cone Mosaic (Shevell and Monnier)

Immediate surround is not the main effect.

Monochromatic Effects

Vasarely effect

From: Michael's “Optical Illusions & Visual Phenomena”
www.michaelbach.de/ot/lum_pyramid/index.html
Chromatic Effects

Vasarely effect

Hues change steps along R-G

Craik-O’Brien-Cornsweet Effect

Spatial Sensitivity Varies With Mean Luminance Level

Spatial Sensitivity Varies From Fovea To Periphery
Low, but not High, Temporal Frequency Sensitivity Varies With Mean Level

Low Temporal Frequency Sensitivity Varies With Mean Level
High Temporal Frequency does Not

Measuring Color Differences