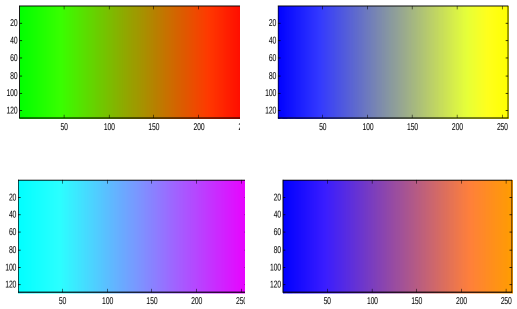
Lecture 4

Opponent Colors

Hue Cancellation Experiment
HUV Color Space

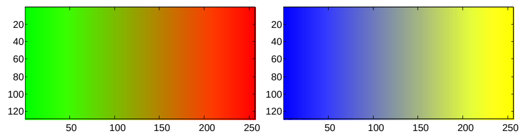


Opponent Colors

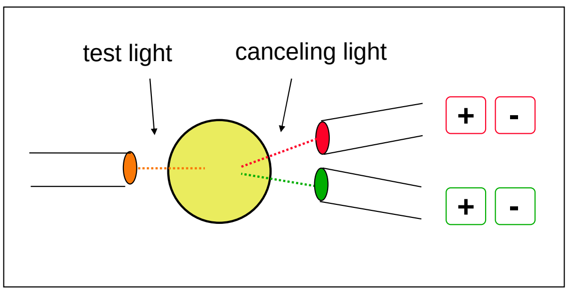
Ewald Hering (1905) - Pure colors R G B Y.
No such colors greenish-red, yellowish-blue

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

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



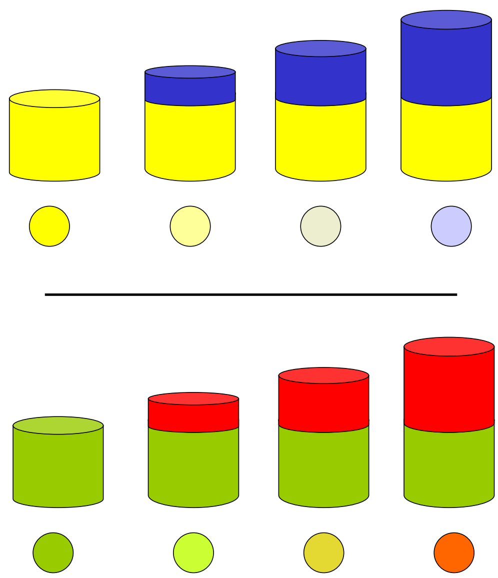
Hue Cancellation Experiment



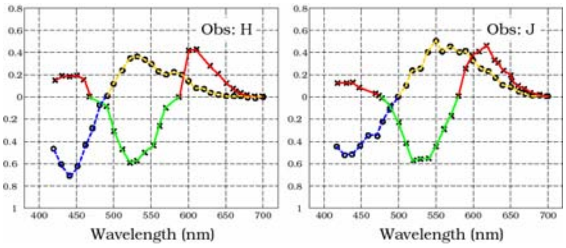
Cancel the red-green content of the test light.

Cancel the blue-yellow content of the test light.

Hue Cancellation Experiment



Hue Cancellation

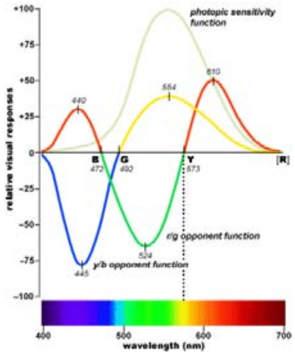


Hurvich & Jameson (1957)

Red + Green cancellation lights

Blue + Yellow cancellation lights

Hue 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

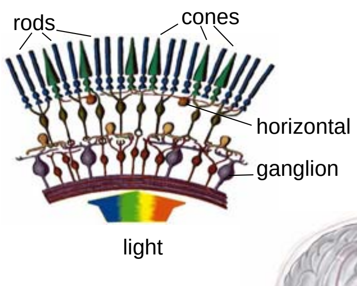
Physiological basis for Opponent Colors

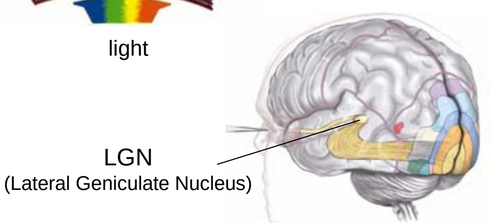
Svactchin & MacNichol (‘58) - Horizontal cells

Boynton (‘79), DeMonasterio (‘78) - ganglion cells

DeValois & DeValois (‘75) - LGN cells

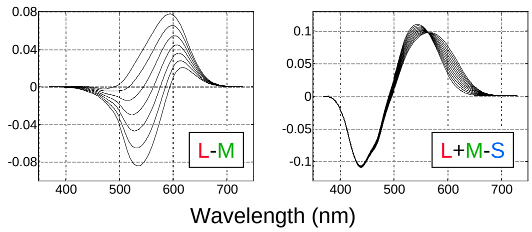
Derrington et al (‘84) - LGN cells





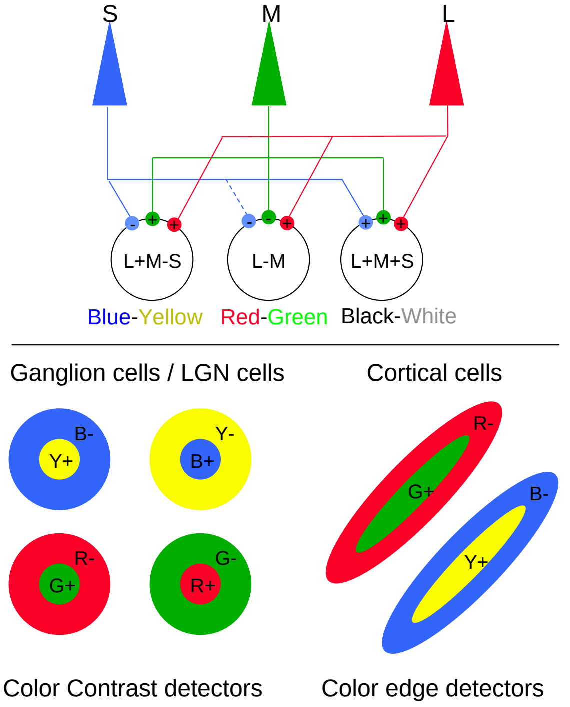
Physiological basis for Opponent Colors

Opponent signals measured in LGN neurons

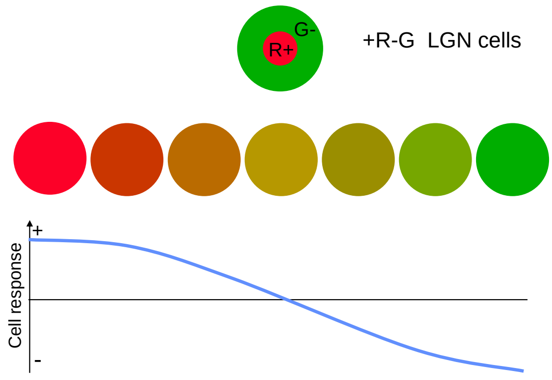


Derrington (1984)

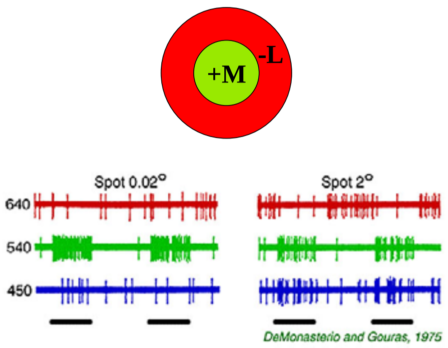
Opponent process - possible neural connections:



Opponent Cell - Neural Response



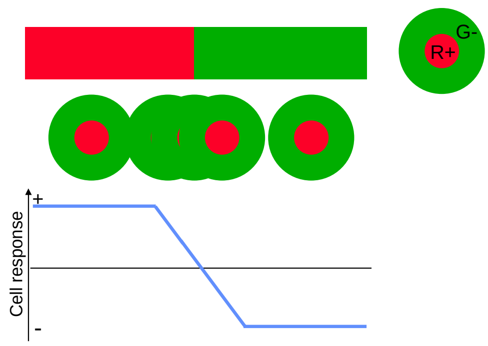
Chromatic On/Off Cells in Monkey Retina



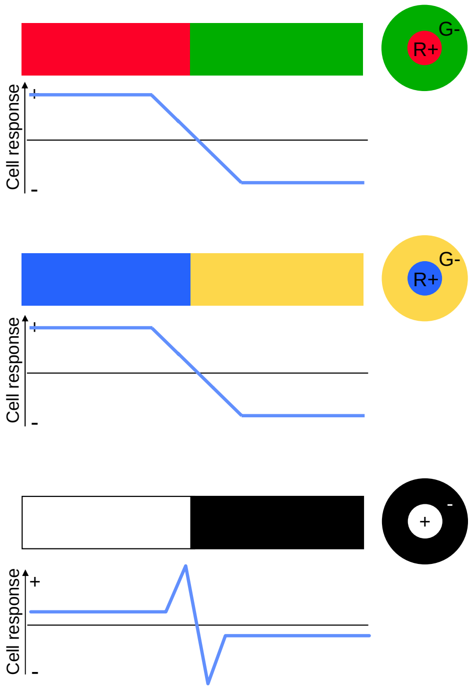
Green On/Red OFF

Electrophysiological recordings
midget ganglion cell in the monkey retina

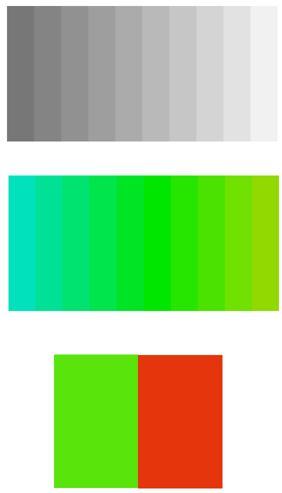
Opponent Cell - Neural Response



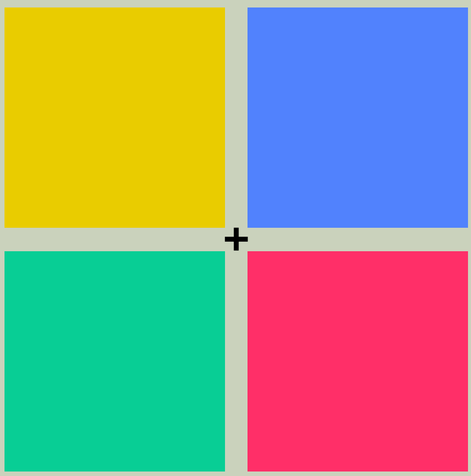
Opponent Cell - Neural Response



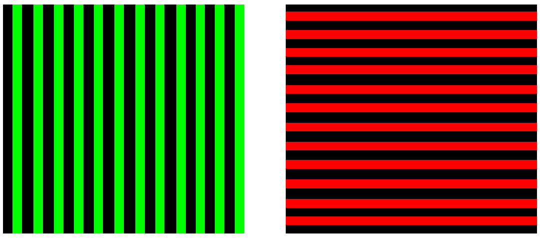
Mach Bands in Opponent Color Space



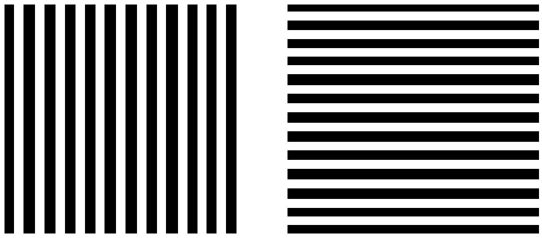
Mach bands for small changes in lightness (top) and hue (middle)

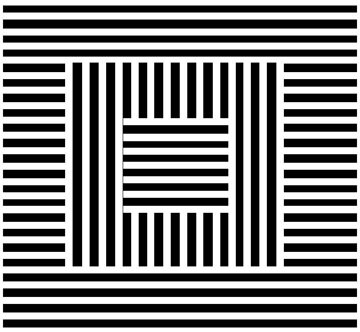


McCullough's Effect -
interaction between color and form



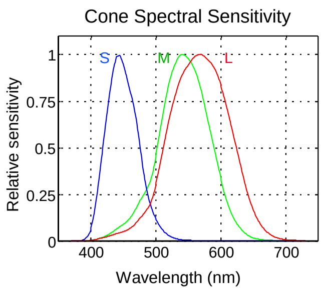
McCullough's Effect -
interaction between color and form





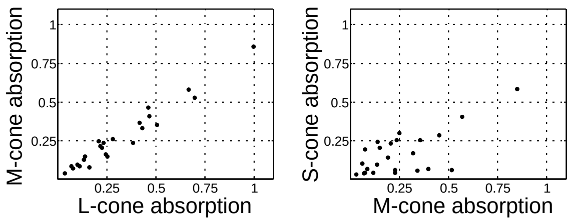
Why Opponent process ?

A: Efficient Encoding



L and M cone sensitivities are highly correlated.

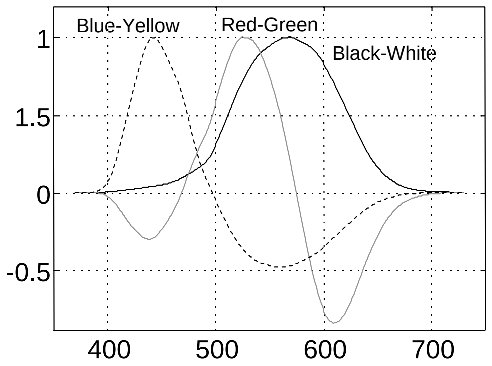
Cone responses to several Natural SPDs :



Decorrelation:

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

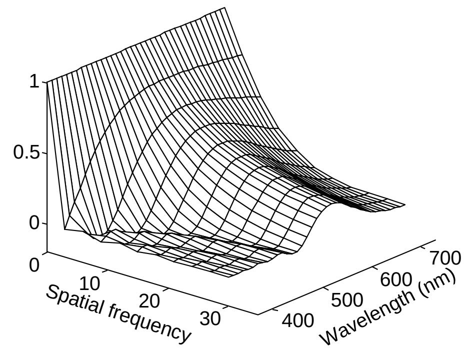
Spectral sensitivities of three decorrelated sensors



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

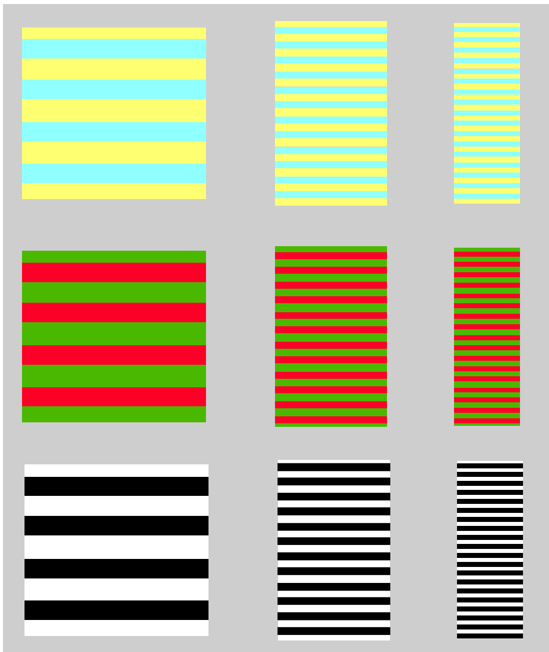
B: Compression

Human MTF

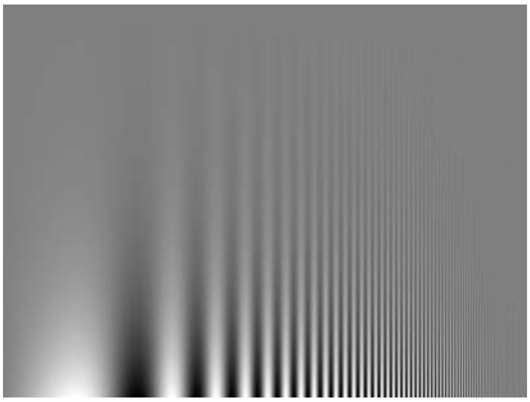


Contrast Sensitivity

Contrast Sensitivity

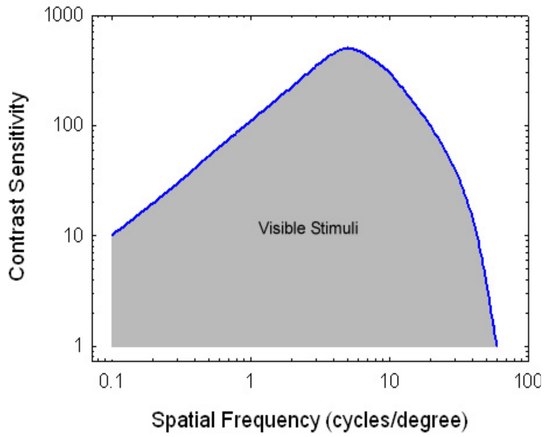


Contrast Sensitivity Function



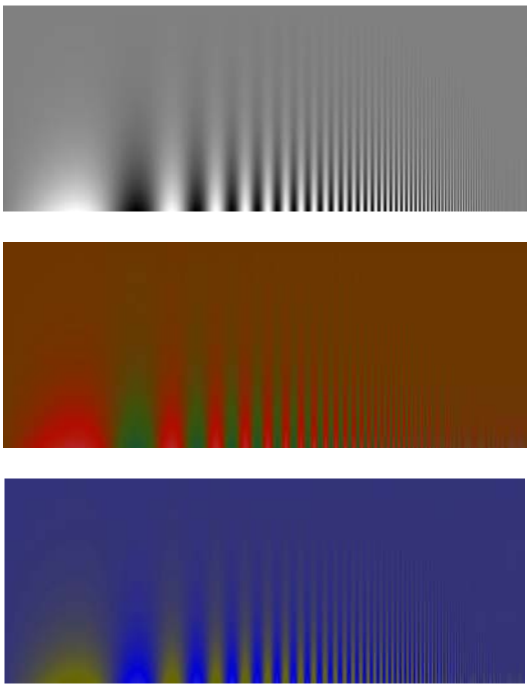
Cambell Robson

Contrast Sensitivity Function

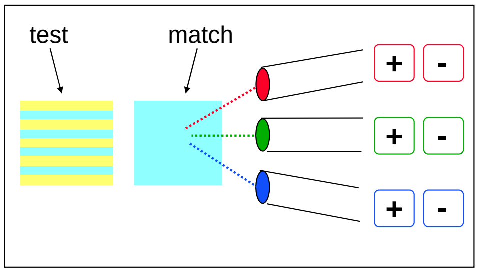


Cambell Robson

Color Contrast Sensitivity

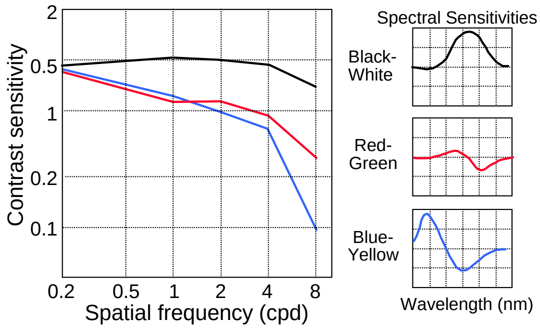


Asymmetric color matching experiment:



(Poirson and Wandell 1993)

Opponent channels have different modulations:



YIQ - Color Space

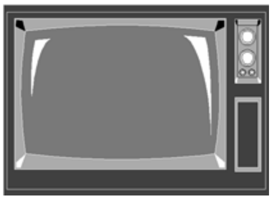
NTSC = National Television Systems Committee

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

Y = luminance

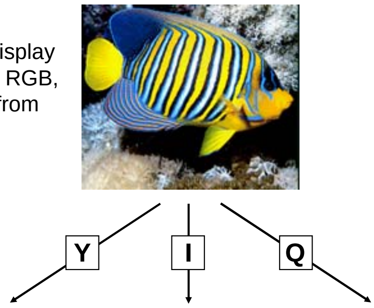
I = red-green

Q = blue-yellow



YIQ - Color Space

Target display image is RGB, derived from camera



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

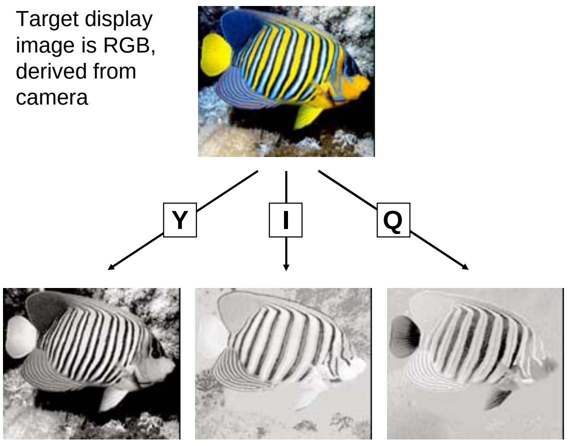
$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$

$$I = 0.596\,R + 0.275\,G + 0.321\,B$$

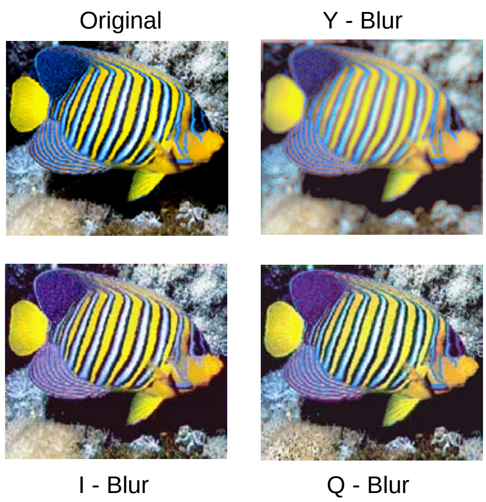
$$Q = 0.212\,R + 0.523\,G + 0.311\,B$$

YIQ - Color Space

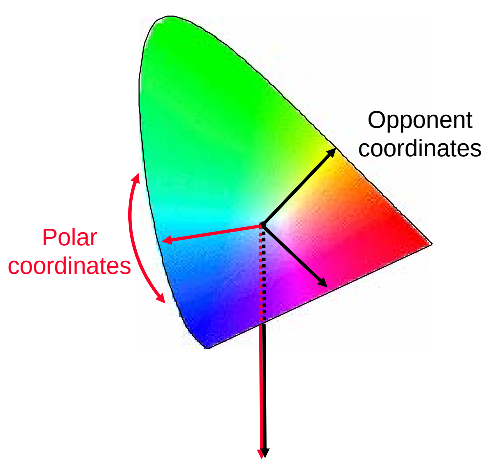
Target display image is RGB, derived from camera



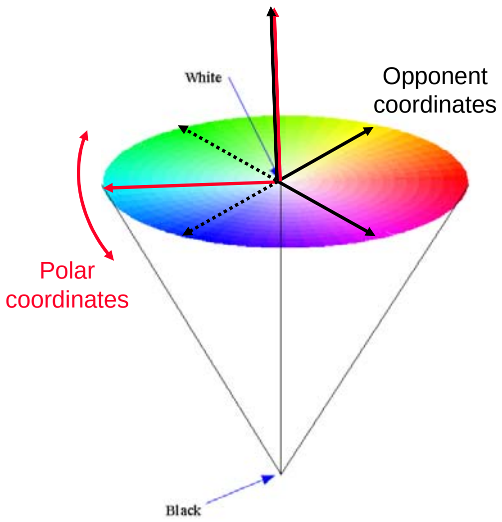
YIQ - Color Space



Polar vs Opponent Color Spaces



Polar vs Opponent Color Spaces



Linear Color Spaces - Conversions

Conversion matrix....

From \ To	XYZ	LMS	RGB	OPP	YIQ
XYZ				278.7 721.8 -106.5 -448.7 289.8 77.1 85.9 -589.9 501.1	0.000 1.000 0.000 1.407 -0.842 -0.451 0.932 -1.189 0.233
LMS				0.990 -0.106 -0.094 -0.669 0.742 -0.027 -0.212 -0.354 0.911	
RGB	16.9 23.6 15.0 9.6 45.8 7.5 0.9 8.0 78.2	12.2 44.4 6.5 4.6 44.6 9.5 0.5 4.6 44.8			
OPP					
YIQ					

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

Linear Color Spaces - Conversions

Conversion matrix....

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

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

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

$$M_{RGB2XYZ} = \begin{bmatrix} 16.9 & 23.6 & 15.0 \\ 9.6 & 45.8 & 7.5 \\ 0.9 & 8.0 & 78.2 \end{bmatrix}$$

$$M_{RGB2LMS} = \begin{bmatrix} 12.2 & 44.4 & 6.5 \\ 4.6 & 44.6 & 9.5 \\ 0.5 & 4.6 & 44.8 \end{bmatrix}$$

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

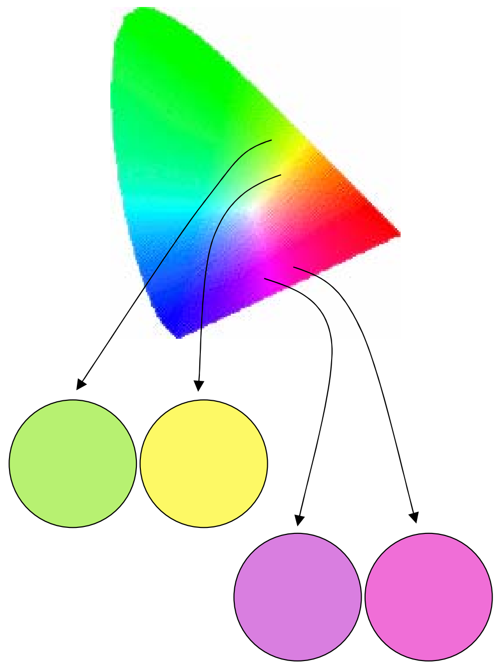
Color Appearance

Whether modeled in

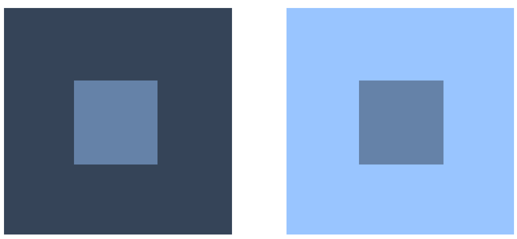
XYZ Color Space or
HSV Color Space
YIQ Color Space

Color Appearance - is much more complicated!

Color Differences are non Uniform



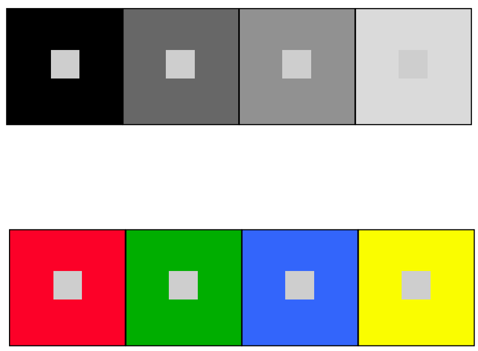
Color appearance is context dependent



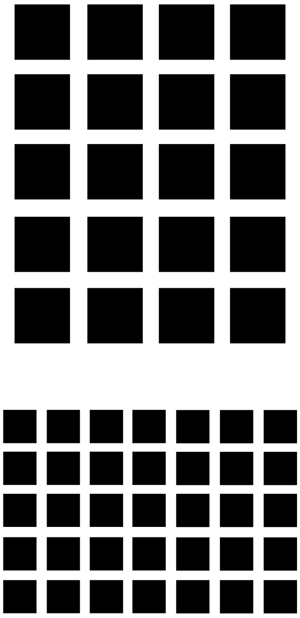
All squares are matched on hue and chroma

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

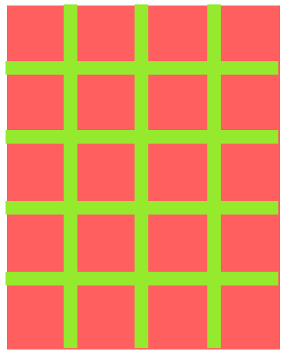
Simultaneous Contrast



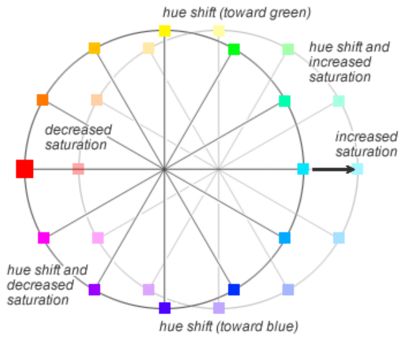
Lateral Inhibition



Lateral Inhibition



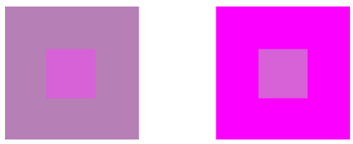
Simultaneous Contrast



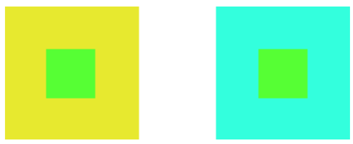
Apparent color shifts in simultaneous color contrasts
Shifts are shown in contrast to a middle red color

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

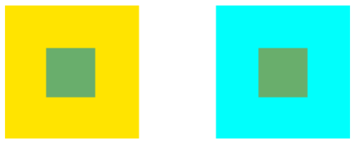
Simultaneous Contrast



color shift in a simultaneous chroma contrast
all squares are matched on hue and lightness



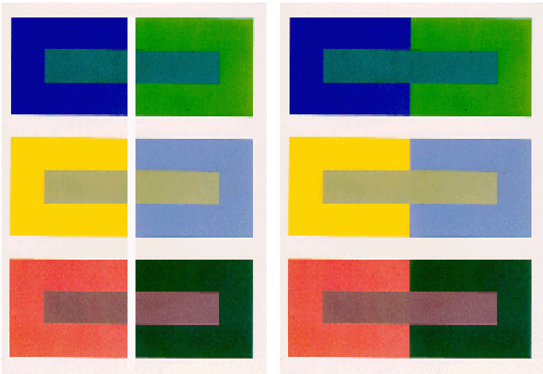
color shift in a simultaneous hue contrast
all squares are matched on chroma and lightness



color shift in a simultaneous hue contrast
central squares set to low chroma and mid value; outer squares are both at lightness of 91 and 100% chroma

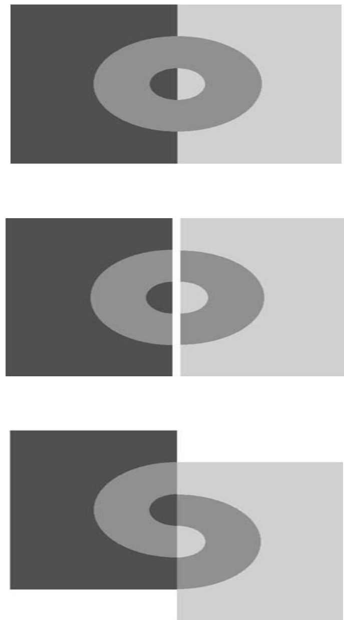
Simultaneous Contrast

Boundary Effects



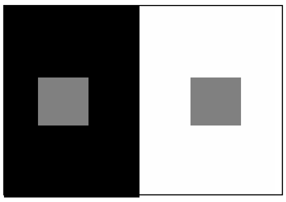
Simultaneous Contrast

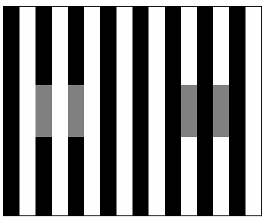
Boundary Effects



Simultaneous Contrast vs White's Illusion

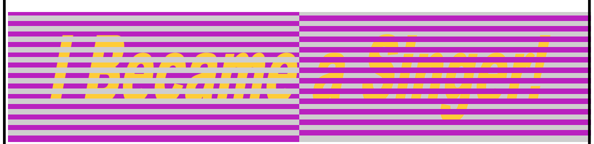
Simultaneous Contrast





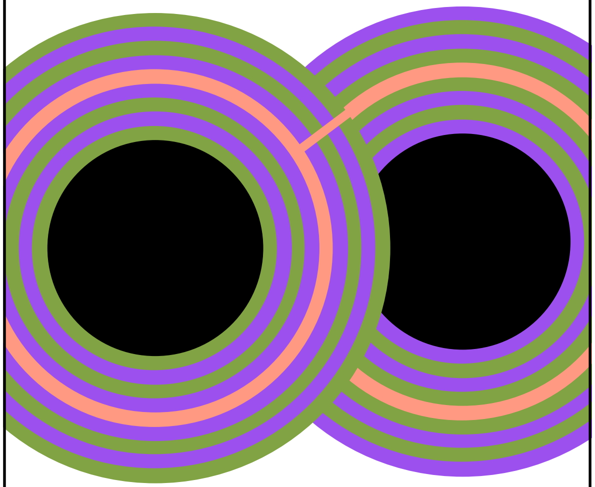
White's illusion

Color Induction



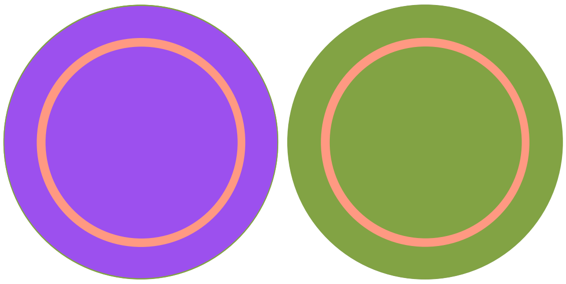
Color Appearance

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



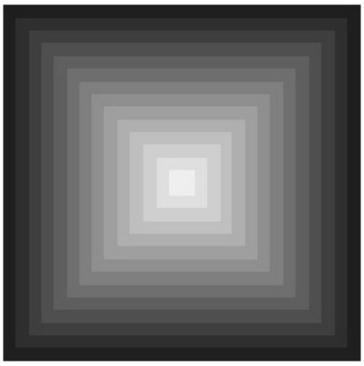
Color Appearance

Immediate surround is not the main effect.



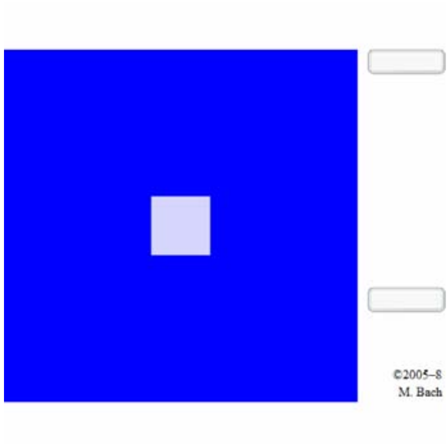
Monochromatic Effects

Vasarely effect



Monochromatic Effects

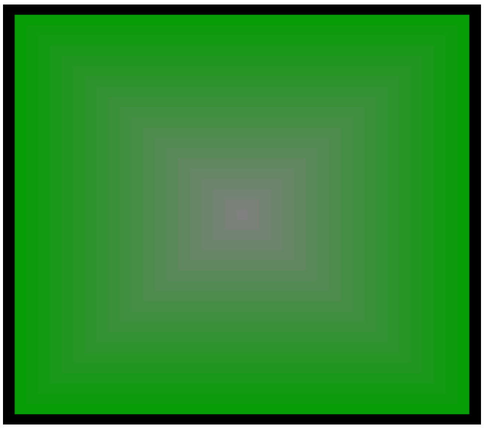
Vasarely effect



From:
Michael's "Optical Illusions & Visual Phenomena"
www.michaelbach.de/ot/lum_pyramid/index.html

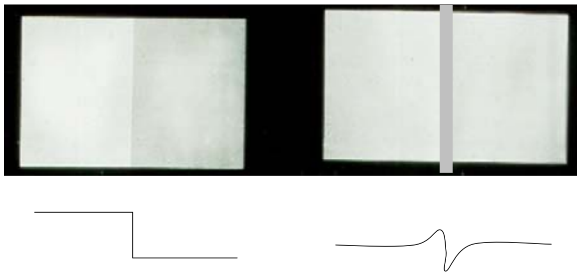
Chromatic Effects

Vasarely effect

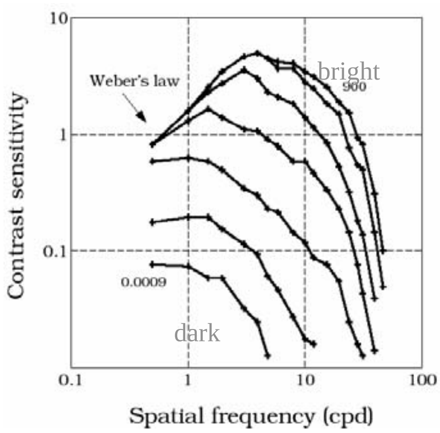


Hues change steps along R-G

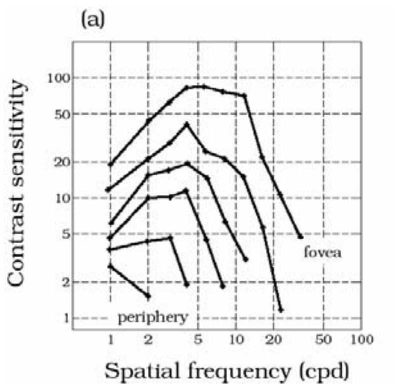
Craik-O'Brien-Cornsweet Effect



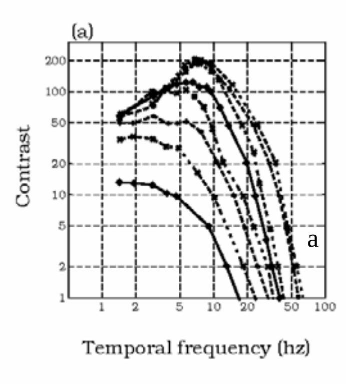
Spatial Sensitivity Varies With Mean Luminance Level



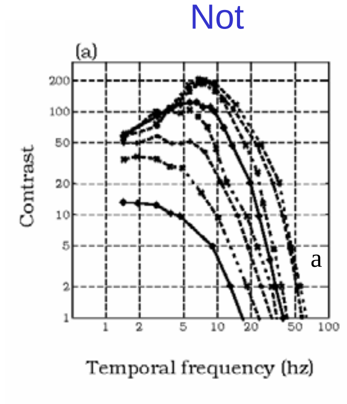
Spatial Sensitivity Varies From Fovea To Periphery



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