Visual Imaging and the Electronic Age

Color Science Color Spaces for User Interaction

> Lecture #8 September 29, 2020 Prof. Donald P. Greenberg

Computing Tristimulus Values with the Response Matching Functions

• For each test lamp we can compute the equivalent RGB tristimulus values using the color matching functions

$$R(P) = \int P(\lambda)\bar{r}(\lambda)d\lambda$$
$$G(P) = \int P(\lambda)\bar{g}(\lambda)d\lambda$$
$$B(P) = \int P(\lambda)\bar{b}(\lambda)d\lambda$$

Response Matching Functions



Response Matching Functions

R = 650 nm G = 530 nm B = 460 nm



Transformations Between RGB and XYZ

$$\begin{cases} X \\ Y \\ Z \end{cases} = \begin{bmatrix} +0.607 & +0.174 & +0.200 \\ +0.299 & +0.587 & +0.114 \\ +0.000 & +0.066 & +1.111 \end{bmatrix} \begin{cases} R \\ G \\ B \end{cases}$$

$$\begin{cases} R \\ G \\ B \end{cases} = \begin{bmatrix} 1.909 & -0.532 & -0.288 \\ -0.985 & +1.997 & -0.028 \\ 0.058 & -0.119 & +0.902 \end{bmatrix} \begin{cases} X \\ Y \\ Z \end{cases}$$

R= 700nm, G= 546.1nm, B= 435.8nm

Three Identical Disks



Receptive Fields



http://droualb.faculty.mjc.edu/Course%20Materials/Physiology%20101/Chapter%20Notes/Fall%202007/figure_10_39_labeled.jpg



The most deeply shadowed regions of the church's white siding project luminances to the eye almost equal to the luminances projected by the black shingles in the direct sunlight. Yet they look very different.

- Irvin Rock. PERCEPTION, 1984 Scientific American Books, Inc., p.22.

- "The eye has evolved to see the world in unchanging colors,... regardless of shifting and uneven illumination."
- "The fact remains that objects retain their color identity under a great variety of lighting conditions."

-Edwin Land, Scientific American 1977





Claude Monet (1840-1926)



http://translate.google.com/translate?hl=en&sl=fr&u=http://www.snof.org/art/monet. UTF-8%26oe%3DUTF-8%26sa%3DG



Extracted lenses of humans at various ages:

A) Six months B) Eight years C) 12 years D) 25 years E) 47 years F) 70 years G) 82 years H) 91 years

The bottom 3 are different types of cataracts.

Werner G. K. Backaus, Reinhold Kliegl, John S. Werner. Color Vision, 1998 by Walter de Gruyter & Co.

Claude Monet





The basin with the Nymphea, 1899 (without cataract)

The basin with the Nymphea, 1923 (with cataract)

http://translate.google.com/translate?hl=en&sl=fr&u=http://www.snof.org/art/monet.html&prev=/search%3Fq%3Dla%2Bcataracte%2Bet%2Bla%2Bpeinture%26hl%3Den%26lr%3D%26ie%3D UTF-8%26oe%3DUTF-8%26sa%3DG



Claude Monet (1925) *La maison vue du jardin aux roses*. [*House Seen from the Rose Garden*]. Oil on canvas, 89 x 100 cm. Musée Marmottan, Paris.



Claude Monet (1925) *La maison vue du jardin aux roses*. [*House Seen from the Rose Garden*]. Oil on canvas, 81 x 92 cm. Musée Marmottan, Paris.



Monet in his studio at Giverny in front of one of the *Nymphéas* panels for the Orangerie (Room 1, South Wall)

Musée de l'Orangerie. "The Nymphéas of Claude Monet," Editions de la Réunion des musée nationaux, Paris 2006.

Musée de l'Orangerie. "The Nymphéas of Claude Monet," Paris 2006



Musée de l'Orangerie. "The Nymphéas of Claude Monet," Editions de la Réunion des musée nationaux, Paris 2006.

Musée de l'Orangerie. "The Nymphéas of Claude Monet," 1920-26



A cycle of Monet's water-lily paintings, known as the *Nympheas*, was arranged on the ground floor of the Orangerie in 1927. The Orangerie was renovated (1999-2006) and the paintings are now available under direct diffused light.

Interaction of Color - Josef Albers

Yale University Press - 1971

Albers drawing Structural Constellations





Josef Albers, Interaction of Color, 1963 Yale University, Plate XIII-1.



Josef Albers, Interaction of Color, 1963 Yale University, Plat V-1.



Color Spaces for User Interaction

- RGB Cube
- Hexacone Model
- HSL Biconical Solid (Hue, Saturation, Lightness)
- Munsell Color System
- Others

RGB Cube



Hexacone Model



Hexacone Model



Hexacone Model



Alvy R. Smith

HSV Hexagon



HSL Double Hexagon















Billmeyer



Meyer







Meyer



Meyer

Perceptually Uniform Color Spaces

- Chromaticity specifies the basic color (hue) of an object.
- Comparing chromaticities gives the best indicator of the color differences between two objects.
- A chromaticity diagram where equal physical distances (on the diagram) indicate equal perceptual differences would be useful.
- Why?

MacAdam Experiments

- Subjects were shown colors of known chromaticity (luminance was held constant) and were asked to match the sample using an adjustable color source.
- Each chromaticity point studied is surrounded by an ellipse proportional in size to the standard deviation of the difference between the actual and match chromaticities.
- The ellipse indicate how rapidly the color change is perceived.

Just Noticeable Differences (JND's) MacAdam Ellipses



Note the varying size and orientation of the ellipses.

MacAdam Ellipses - Nonlinear Color Spaces (uvw)



Basis for the CIELUV and CIELab systems

Opponent Color Theory

Hering 1892



Figure 12.1– Foundations of Sensation and Perception, George Mather

Opponent Color Theory

Hering 1892

- Four particular colors appear to be "unique".
 - Red, Green, Blue, and Yellow
- He considered these to be the "cardinal directions" of chromaticity
- All other colors seem to be intermediate between these four



Opponent Color Theory

Hering 1892

There are three types of color receptive fields called *opponent channels*.

Black – White (luminance) channel M + L

Green – Red channel M - L

Yellow – Blue channel

M + L - S

Opponent Color Theory

Hering 1892



Figure 12.9– Foundations of Sensation and Perception, George Mather



Cones interconnect in the retina, eventually leading to opponenttype signals. Roy S. Berns. "Billmeyer and Saltzman's Principles of Color Technology, 3rd Ed. 2000, John Wiley & Sons, Inc. p. 16.



Image from "Eye, Brain, and Vision," David Hubel, 1988

Full Color Image



YIQ http://en.wikipedia.org/wiki/YIQ

Luminance Image (Y)



Color Addition (Red/Green Axis)(I)



Color Addition (Yellow/Blue Axis)(Q)



Full Color Image



YIQ http://en.wikipedia.org/wiki/YIQ





