

Perceptual and Artistic Principles for
Effective Computer Depiction

Color in Art and Science

Victor Ostromoukhov
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The cave of Lascaux
About 17000 BC

Vermeer
mid-XVII century

Mondrian
1921

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Outline

- What is color?
- Basic Sensorial Process
- Objective Color Space
- Color Perception and Art
 - Light Mixture
 - Complementary (Opponent) Colors
 - Simultaneous Color Contrast
 - Chromatic Adaptation
 - Color Shadows
 - Depth/Motion Perception
 - Chromatic and Achromatic Visual Acuity

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What is Color?

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Electromagnetic Wave

Reflectance Spectrum

Illuminant D65

Spectral Power Distribution

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What is Color?

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Neon Lamp

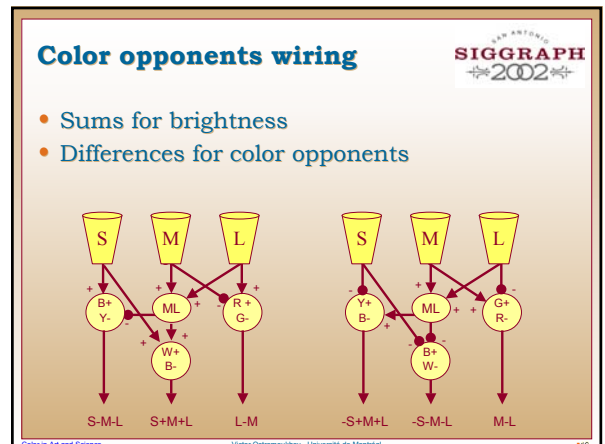
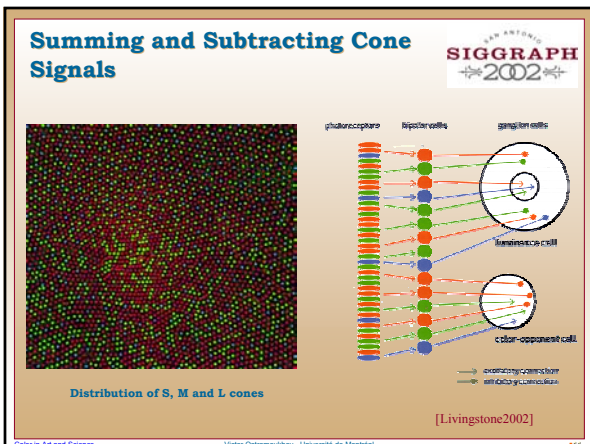
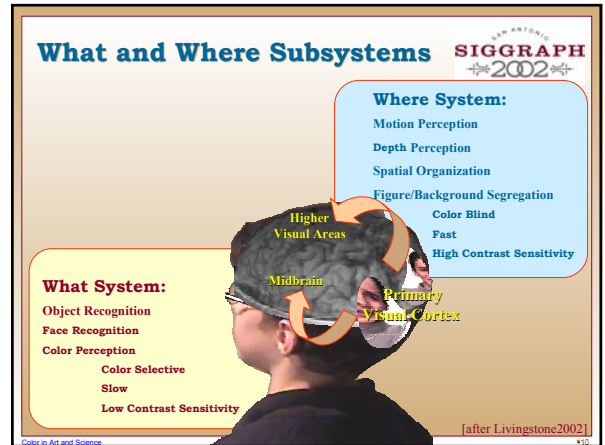
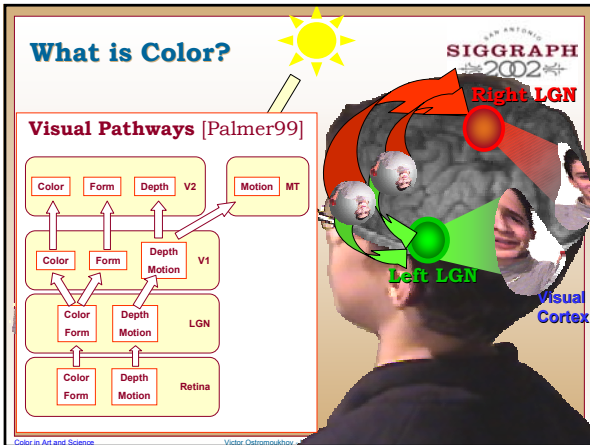
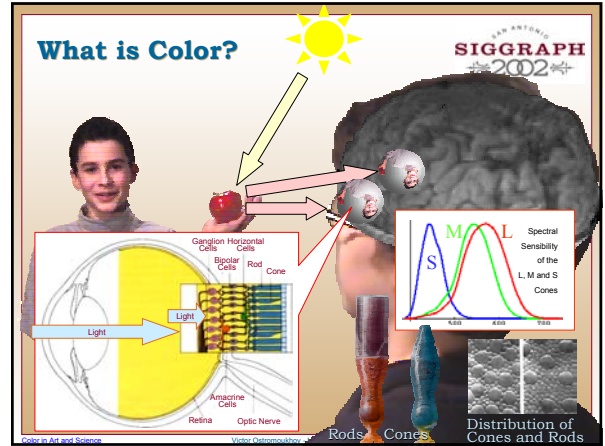
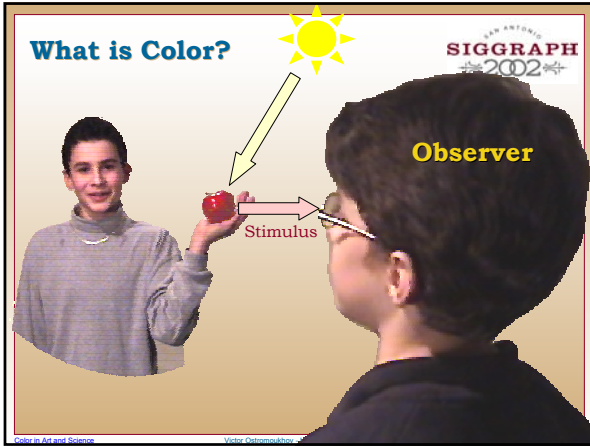
Reflectance Spectrum

Illuminant F1


Spectral Power Distribution Under F1

Spectral Power Distribution Under D65

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von Helmholtz 1859: Trichromatic color theory



Violet
 Blue
 Green
 Yellow
 Orange
 Red

Receptor Responses
 Wavelengths (nm)

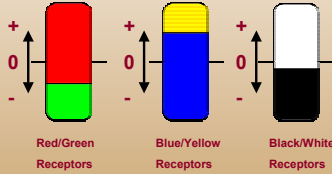
Short wavelength receptors
 Medium wavelength receptors
 Long wavelength receptors

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Hering 1874: Opponent Colors

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- Hypothesis of 3 types of receptors: Red/Green, Blue/Yellow, Black/White
- Explains well several visual phenomena



Red/Green Receptors
 Blue/Yellow Receptors
 Black/White Receptors

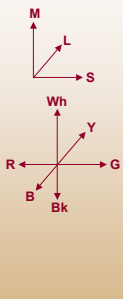


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Dual Process Theory

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- The input is LMS
- The output has a different parameterization:
 - Light-dark
 - Blue-yellow
 - Red-green

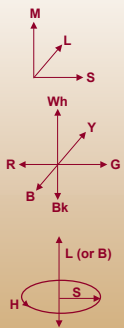


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Color reparameterization

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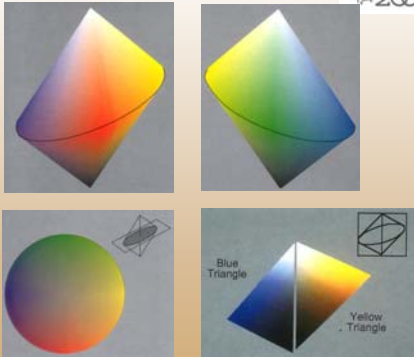
- The input is LMS
- The output has a different parameterization:
 - Light-dark
 - Blue-yellow
 - Red-green
- A later stage may reparameterize:
 - Brightness or Luminance or Value
 - Hue
 - Saturation



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Hue Saturation Value

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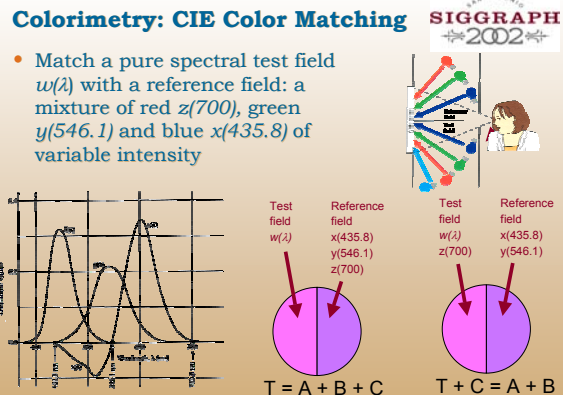
Blue Triangle
 Yellow Triangle

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Colorimetry: CIE Color Matching

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- Match a pure spectral test field $w(\lambda)$ with a reference field: a mixture of red $z(700)$, green $y(546.1)$ and blue $x(435.8)$ of variable intensity



$T = A + B + C$
 $T + C = A + B$

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CIE-XYZ Color Space

Color-matching curves

$$X = \int_{380}^{780} C(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = \int_{380}^{780} C(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = \int_{380}^{780} C(\lambda)\bar{z}(\lambda)d\lambda$$

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The Colors in the Chromaticity Diagram

Spectrally pure colors (monochromatic or prismatic) on the contour

Visible spectrum

Neutral illuminant white

Non-spectral colors (purples and magentas) no dominant wavelength

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Perceptually Uniform Space: MacAdam

- In color space CIE-XYZ, the perceived distance between colors is not equal everywhere
- In perceptually uniform color space, Euclidean distances reflect perceived differences between colors
- MacAdam ellipses (areas of unperceivable differences) become circles

Source: [Wyszecki and Stiles '82]

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CIE-LAB

$$L^* = 25 \left(100 \frac{Y}{Y_0} \right)^{1/3} - 16$$

$$a^* = 500 \left[\left(\frac{X}{X_0} \right)^{1/3} - \left(\frac{Y}{Y_0} \right)^{1/3} \right]$$

$$b^* = 200 \left[\left(\frac{Y}{Y_0} \right)^{1/3} - \left(\frac{Z}{Z_0} \right)^{1/3} \right]$$

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Perceptually Uniform Space Munsell

Hue

Value

Chroma

Munsell Color Space

munsell.com

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Gamut Mapping

CIE-LAB Perceptually-uniform Color space

- Color gamut of different processes may be different (e.g. CRT display and 4-color printing process)
- Need to map one 3D color space into another

— Typical CRT gamut

— 4-color printing gamut

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Gamut Mapping

Typical CRT gamut

4-color CMYK printing gamut

Gamut mapping is a morphing of 3D color space according to adopted scheme

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Device Independent Color

each is a device-to-standard-color transform

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Color Perception and Art

Basic Phenomena

- Light Mixture
- Complementary (Opponent) Colors
- Simultaneous Color Contrast
- Chromatic Adaptation
- Color Shadows
- Depth/Motion Perception
- Chromatic and Achromatic Visual Acuity

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Physical color mixture

Additive

red, green, blue

Spot Lights

Subtractive

cyan, magenta, yellow

Inks

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Optical color mixture

- Optical mix when spatial frequency increases
- But before fusion frequency
- Additive mix! (opposed to subtractive mix)

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Impressionism

Claude Monet

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Pointillism

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- Use of pure colors
- Reduced palette
- Additive rather than subtractive mixture





Georges Seurat

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Post-Impressionism

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- They obtain more pure, brilliant colors

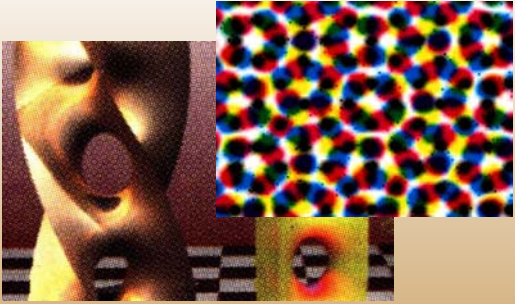



Paul Signac

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Color Printing

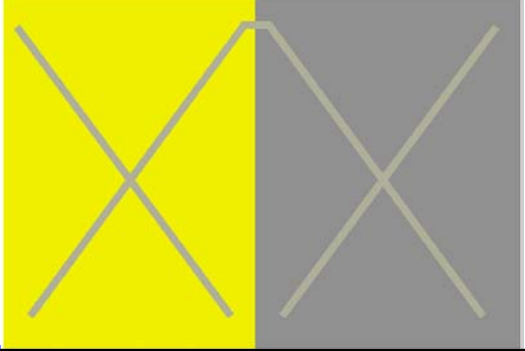
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Simultaneous Color Contrast

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Opponent Colors

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Image

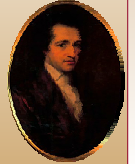


Afterimage



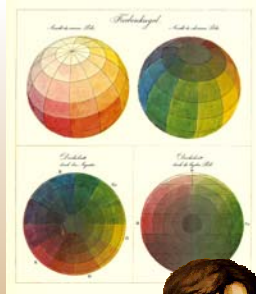
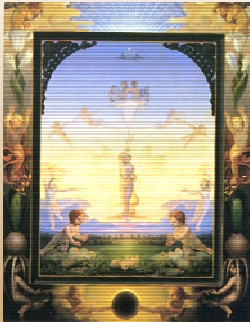
Goethe 1810

- Circular diagram:
primary colors (red, blue and yellow) alternate with secondary colors (orange, violet and green)
- Color opponents
- Exerted huge influence on generations of artists, scientists and philosophers



Runge 1803

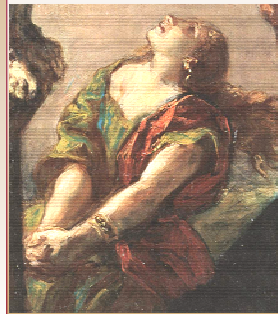
- Theorist and Romantic Painter



Romantic Painters of XIX century

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Turner, Delacroix



Post-Impressionism

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Expressive Power of Complementary Colors



Vincent van Gogh

Chromatic Adaptation

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Chromatic Adaptation

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Claude Monet
Rouen Cathedral, 1894

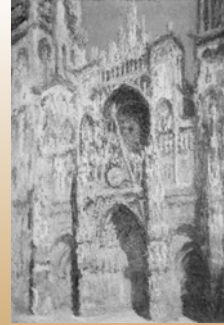
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Chromatic Adaptation

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Claude Monet
Rouen Cathedral, 1894

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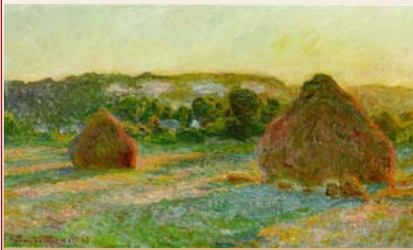
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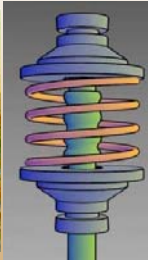
Color Shadows

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- Usage of Warm and Cold Colors



Claude Monet, Grain stack in the morning, 1891



[Gooch and Gooch '98]

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Color Shadows

Try to explain to Mr. Renoir that a woman's torso is not a heap of rotting flesh, with green and purple patches, like a corpse in advanced state of putrefaction.

Albert Wolf,
an anti-impressionist
critic, 1876



Auguste Renoir, Young Woman in the Sun, 1875

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Perception of Space

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Usage of unrealistic luminance to generate illusory sensation of brightness, depth, motion and transience.



Claude Monet,
Surrise, 1872

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Perception of Space

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Usage of unrealistic luminance to generate illusory sensation of brightness, depth, motion and transience.



Claude Monet,
Surrise, 1872

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Perception of Depth

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I understood that one could work with expressive colors which are not necessarily descriptive colors

Henri Matisse

The fact that depth is carried by a colorblind (Where) system permits such a dissociation between color and shape-from-shading



André Derain, Portrait of Henri Matisse, 1905

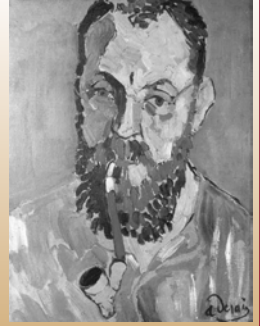
Perception of Depth

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I understood that one could work with expressive colors which are not necessarily descriptive colors

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André Derain, Portrait of Henri Matisse, 1905

Perception of Motion

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Claude Monet, Poppies, 1873

Perception of Motion

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Claude Monet, Poppies, 1873

Chromatic and Achromatic Visual Acuity

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Abraham Walkowitz, Isadora Duncan

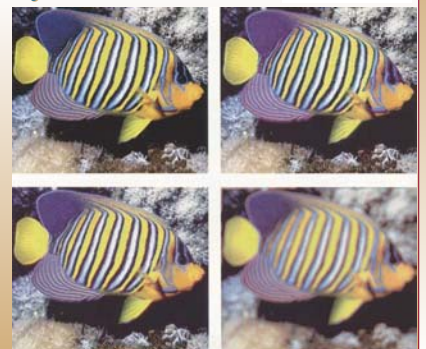


Raoul Dufy, Open Window

Chromatic and Achromatic Visual Acuity

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- JPG, MPG
- Color opponents instead of RGB
- Compress color more than luminance



Artistic Halftoning

[Ostromoukhov and Hersch 1999]

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 Schweizerische Nationalbank
 Banca Nazionale Svizzera
 Zwanzig Franken
 Vingt Francs

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Photo-Mosaics

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BRIAN A. WANDELL

FOUNDATIONS
 of
 VISION

www.photomosaic.com

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“Layered” pointillism

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- Dynamic tension between local and global patterns makes it so interesting
- Local and global percepts are inconsistent; sometimes we see the local percept, sometimes the global

Chuck Close, *Self-Portrait*, 2000

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Conclusions

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- Scientists and artists have developed their own techniques and interpretations of color
- They solved their respective limitations of the media
- Their influences were mutually beneficial
- Understanding of human perception may increase effectiveness of computer m depiction

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