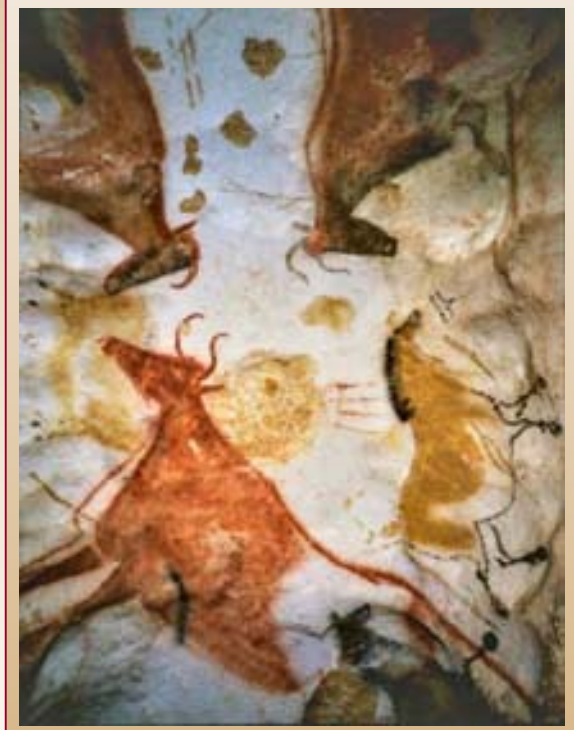
Perceptual and Artistic Principles for Effective Computer Depiction

Color in Art and Science

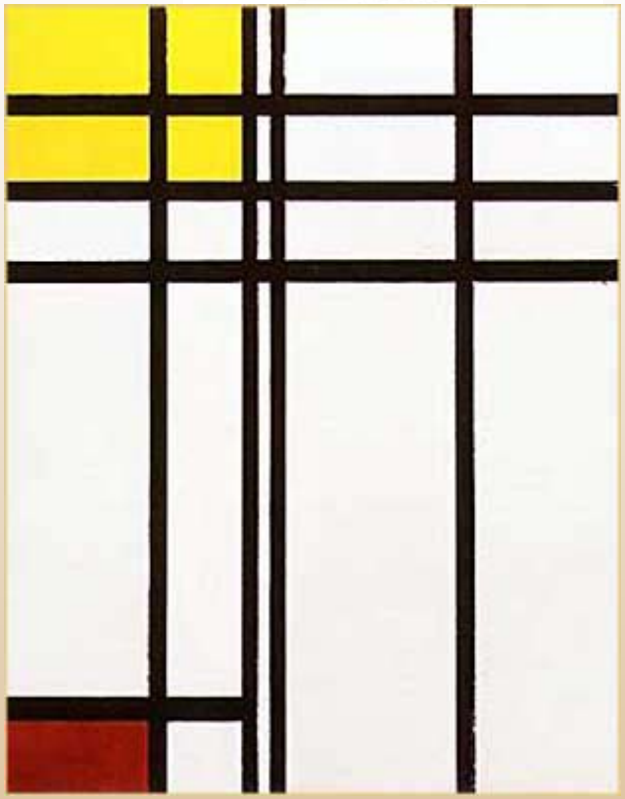
Victor Ostromoukhov

Université de Montréal



The cave of Lascaux
About 17000 BC

Vermeer
mid-XVII century

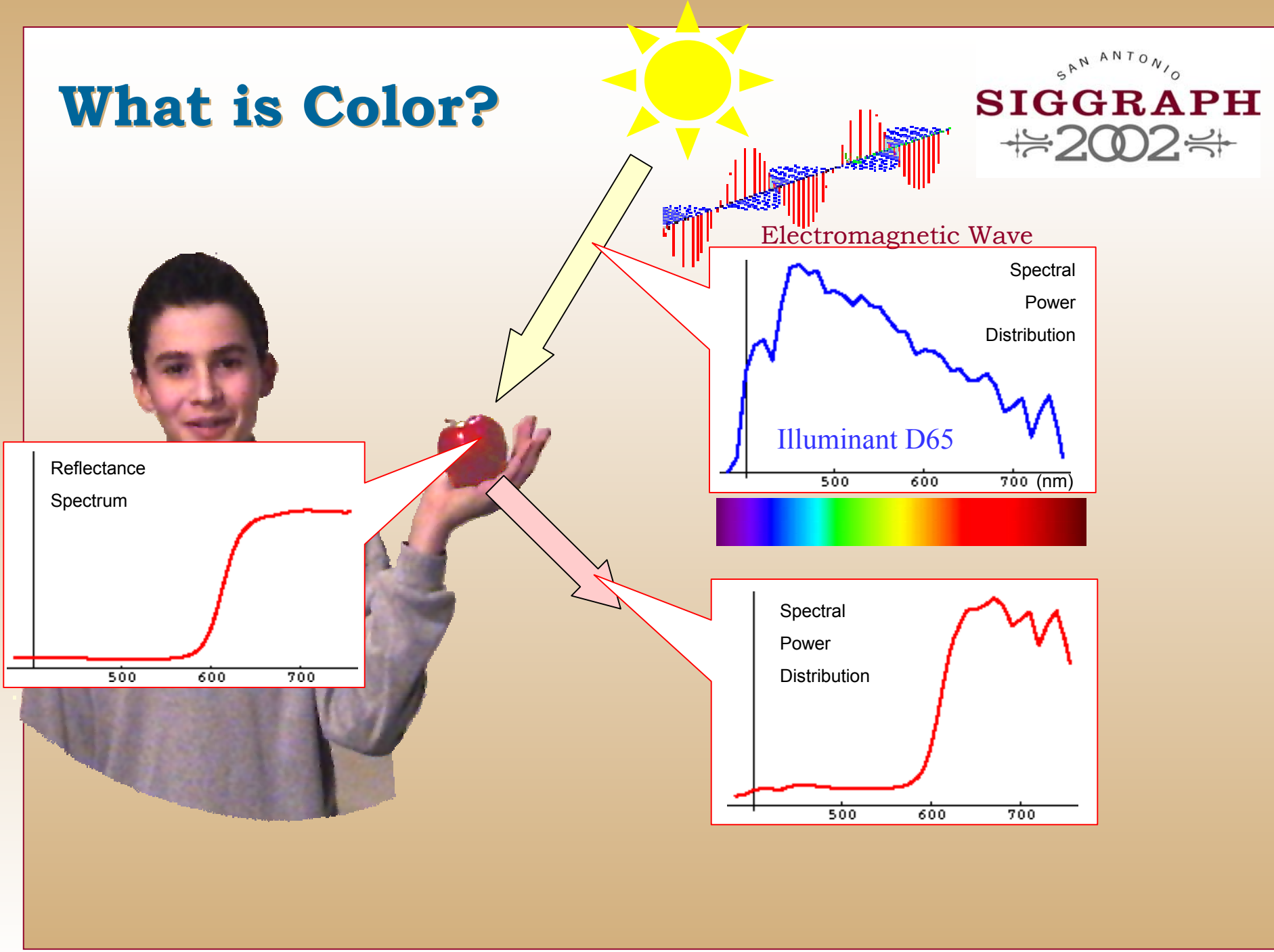


Mondrian
1921

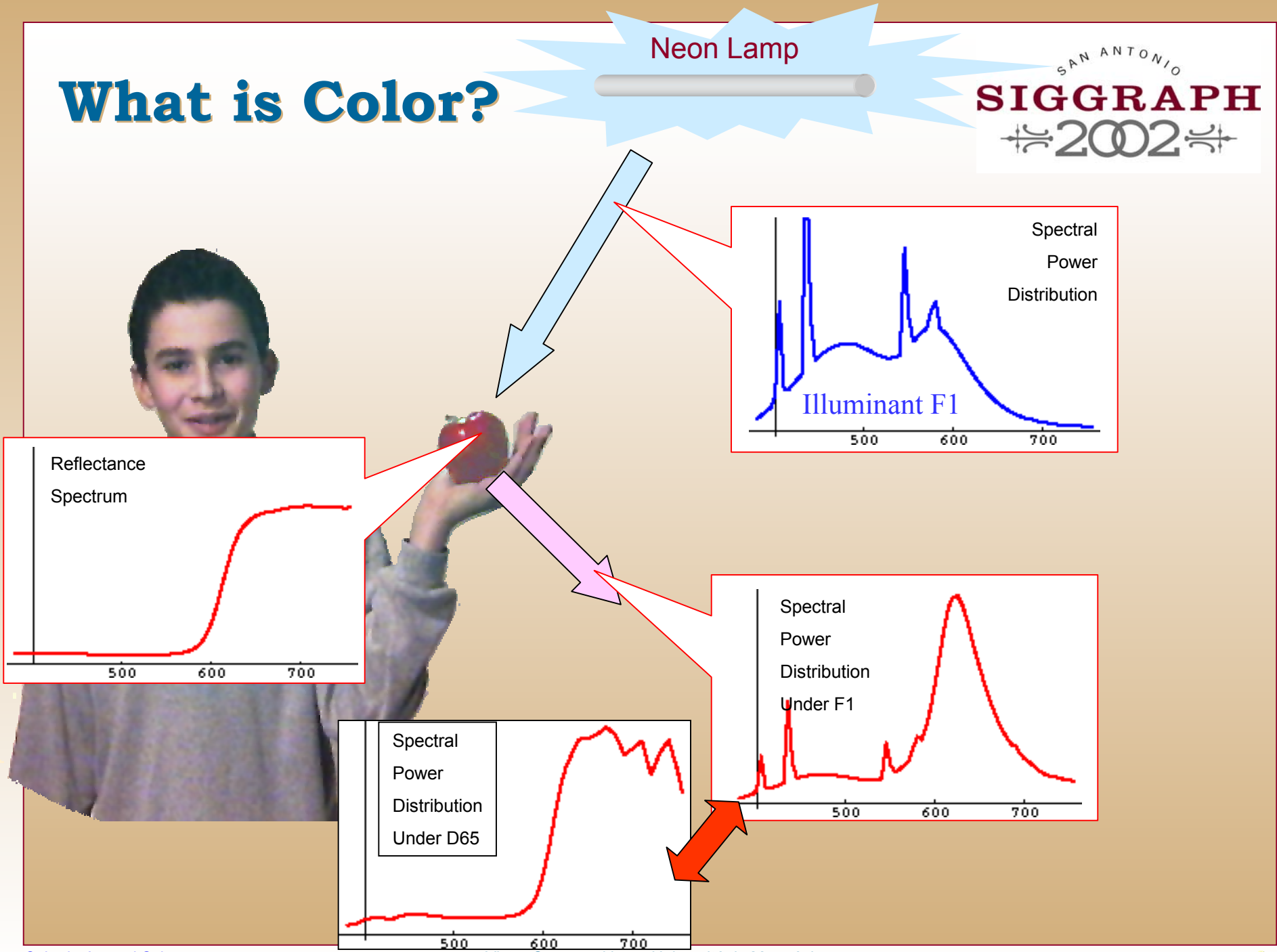
Outline

- 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

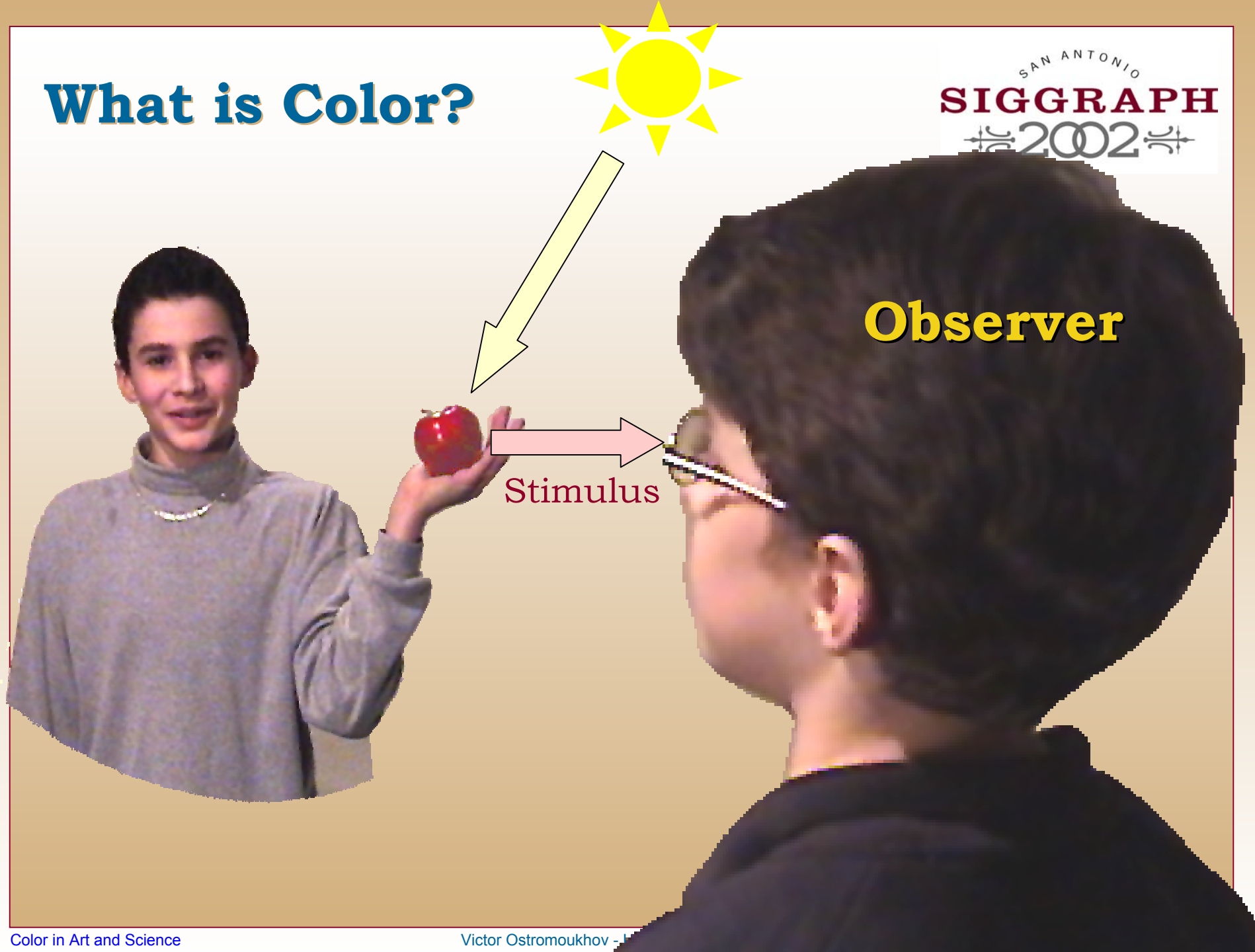
What is Color?



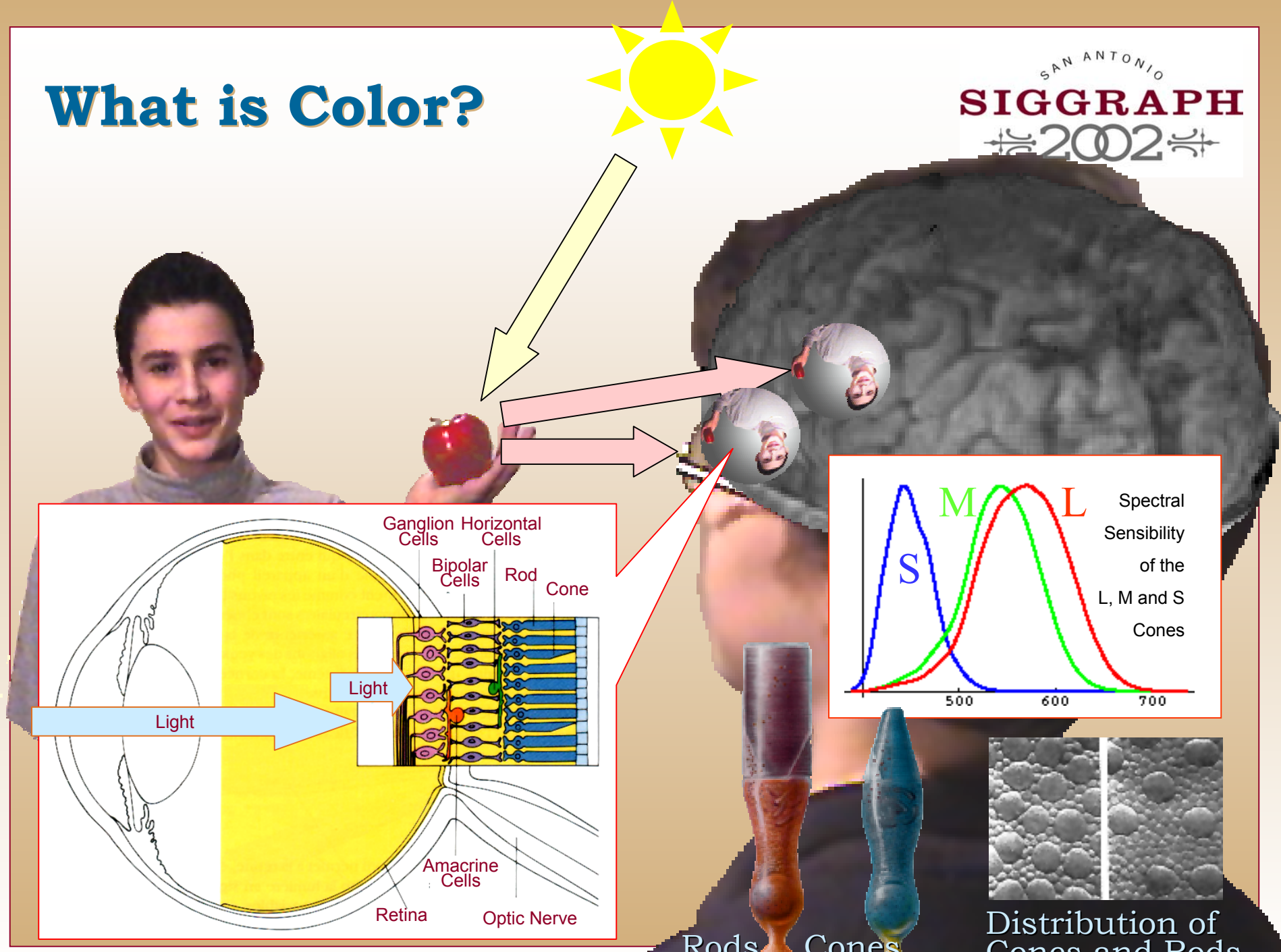
What is Color?



What is Color?



What is Color?



What is Color?

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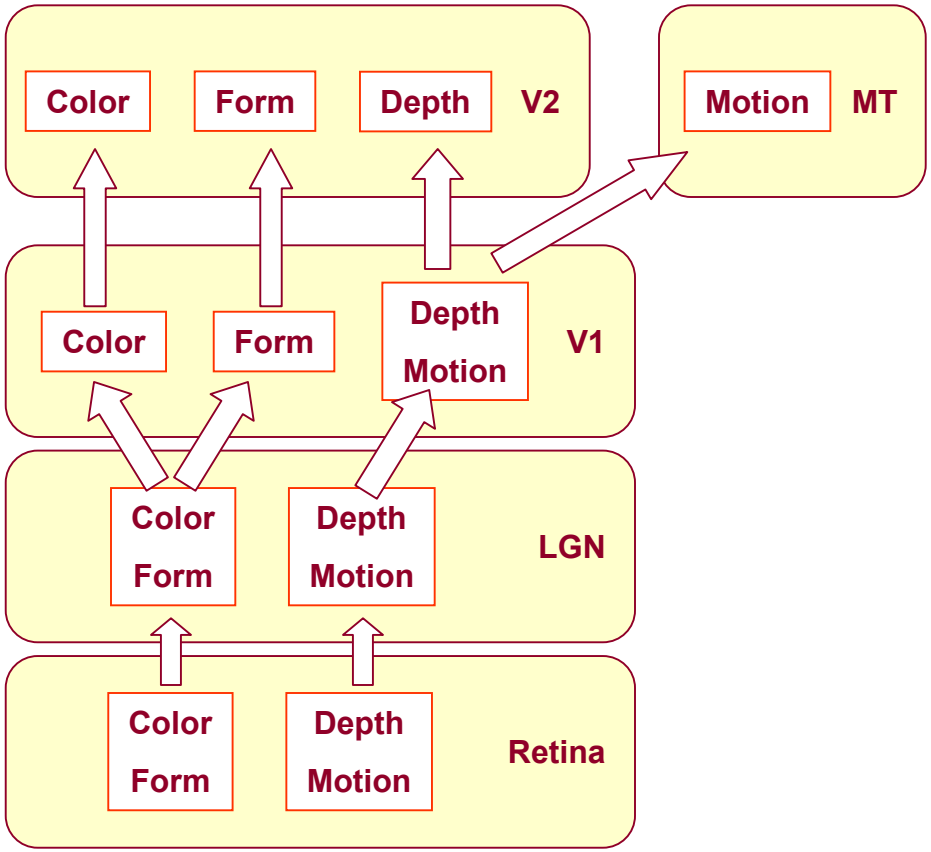
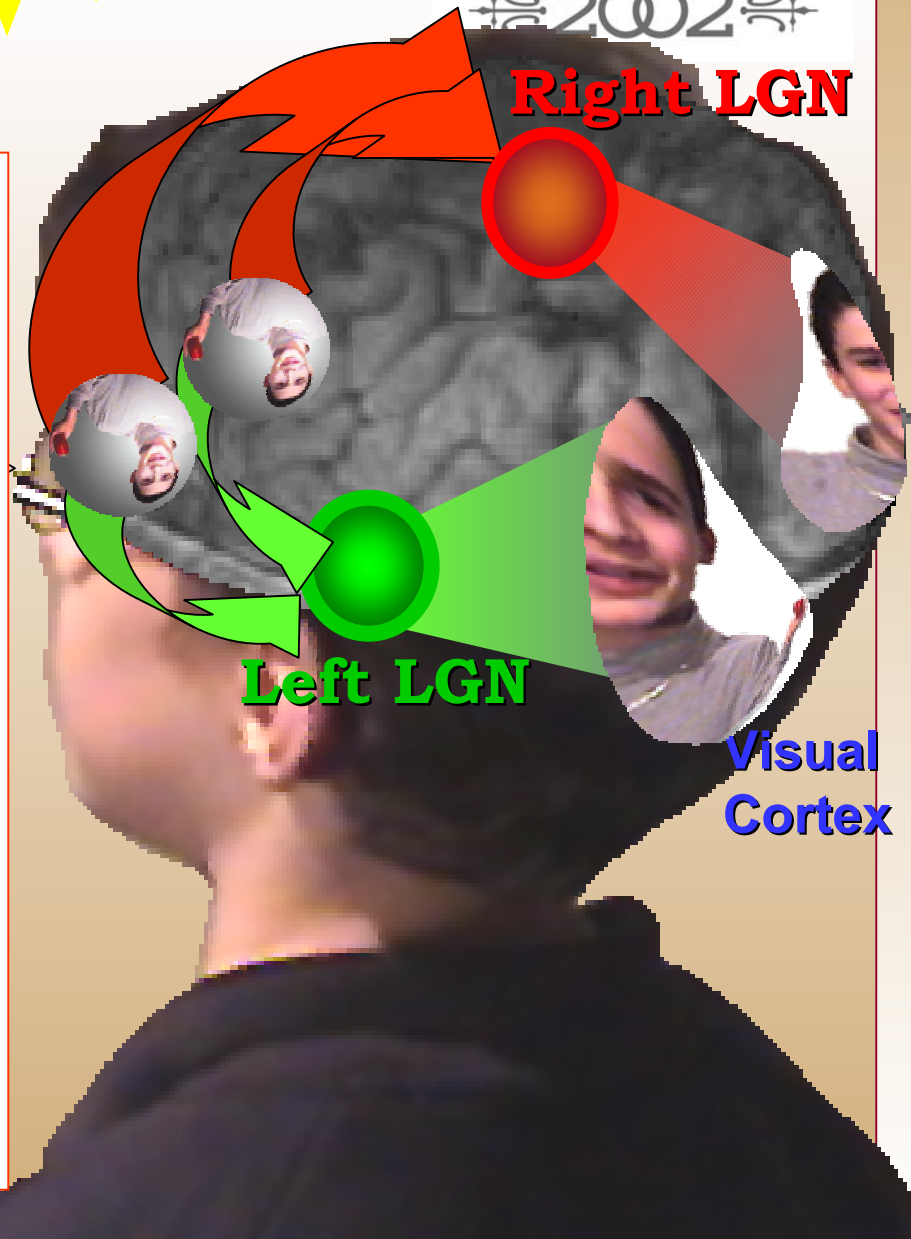
Visual Pathways [Palmer99]





What and Where Subsystems

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Where System:

Motion Perception

Depth Perception

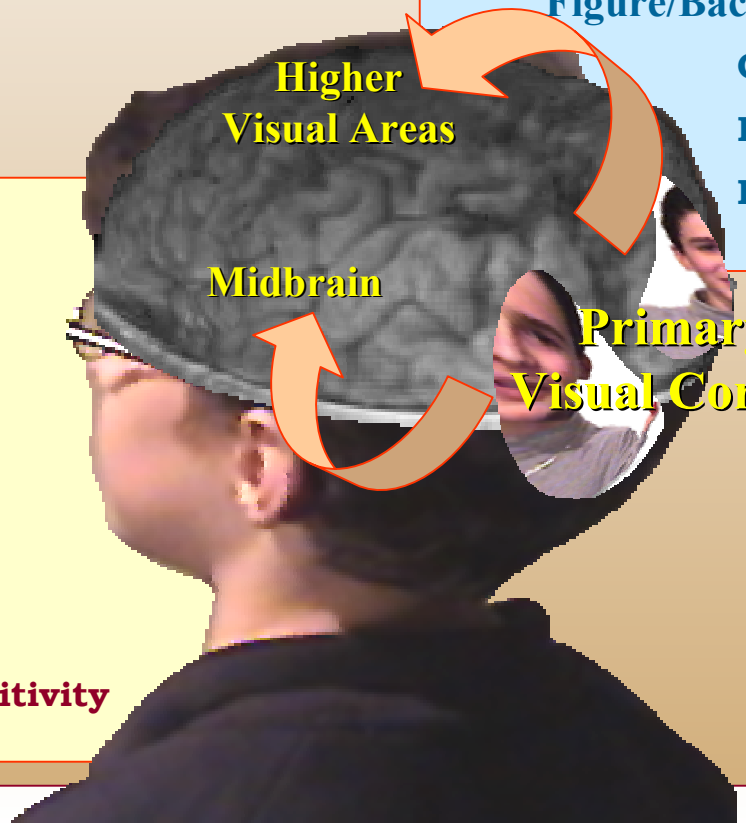
Spatial Organization

Figure/Background Segregation

Color Blind

Fast

High Contrast Sensitivity



What System:

Object Recognition

Face Recognition

Color Perception

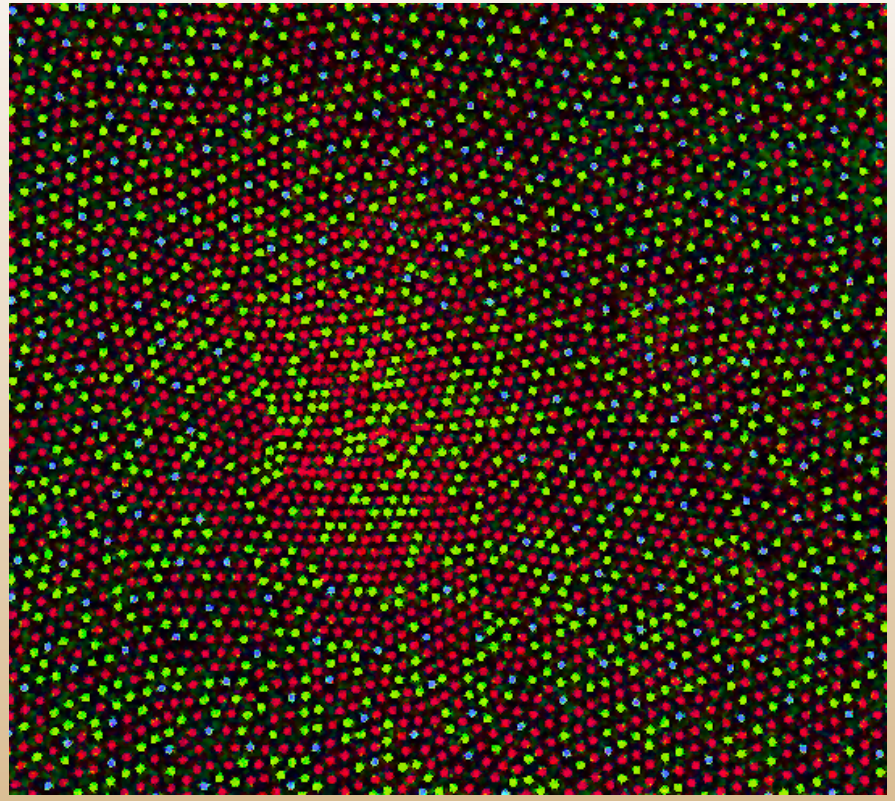
Color Selective

Slow

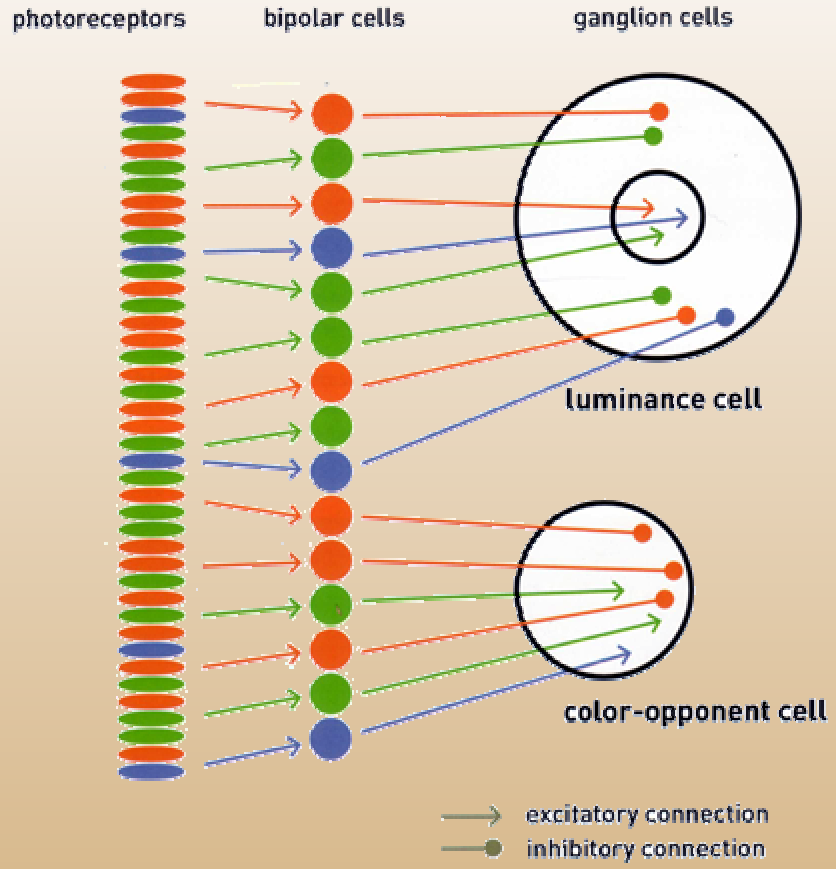
Low Contrast Sensitivity

[after Livingstone2002]

Summing and Subtracting Cone Signals



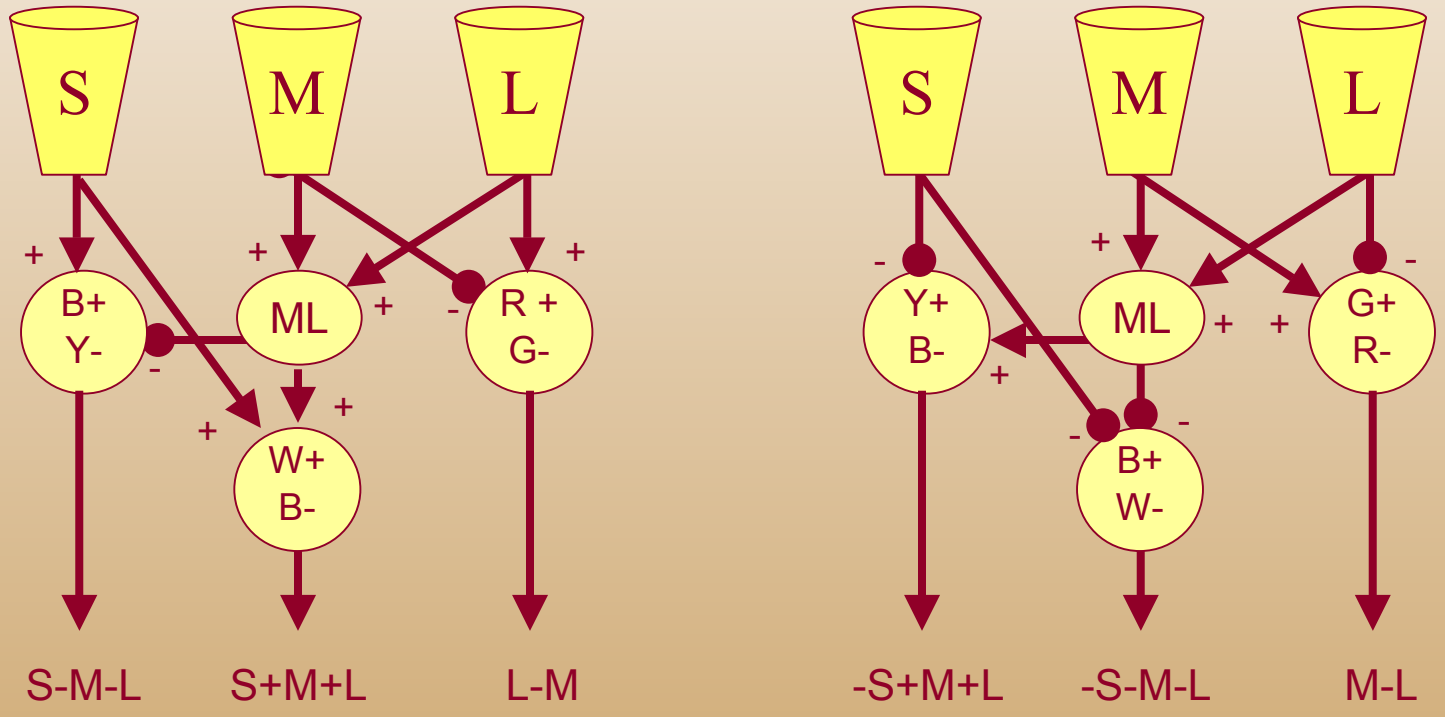
Distribution of S, M and L cones



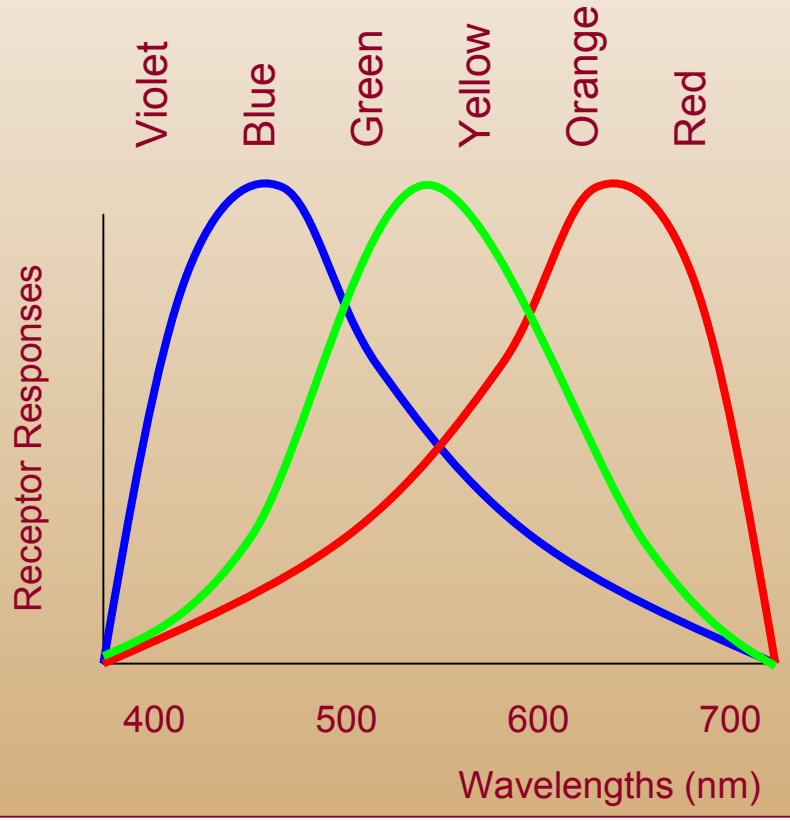
[Livingstone2002]

Color opponents wiring

- Sums for brightness
- Differences for color opponents



von Helmholtz 1859: Trichromatic color theory



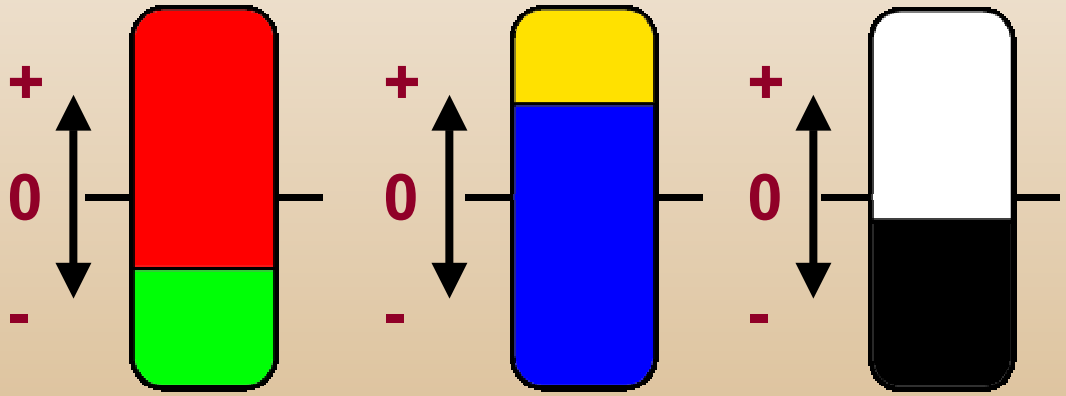
Short wavelength receptors

Medium wavelength receptors

Long wavelength receptors

Hering 1874: Opponent Colors

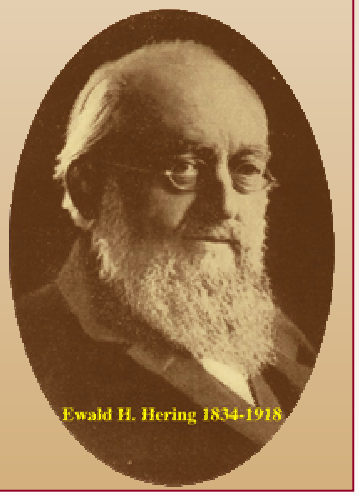
- Hypothesis of 3 types of receptors: Red/Green, Blue/Yellow, Black/White
- Explains well several visual phenomena



Red/Green Receptors

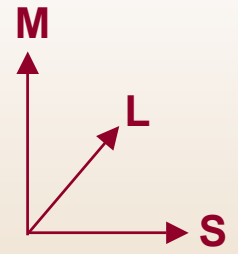
Blue/Yellow Receptors

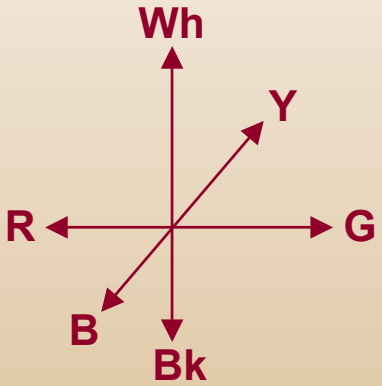
Black/White Receptors

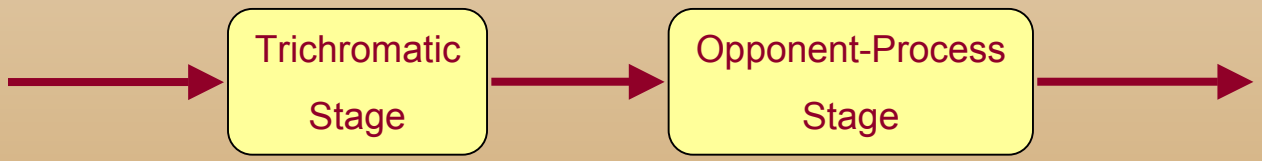


Dual Process Theory

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

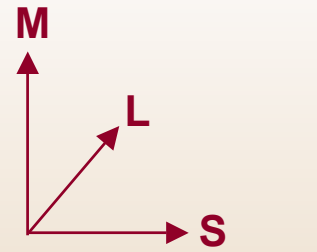


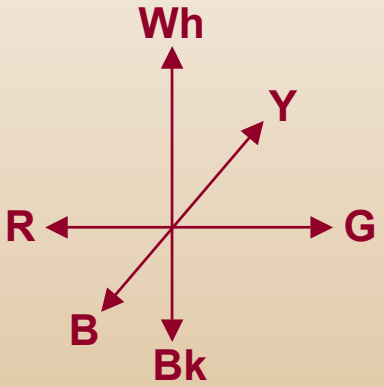


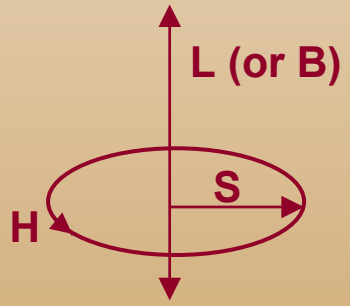


Color reparameterization

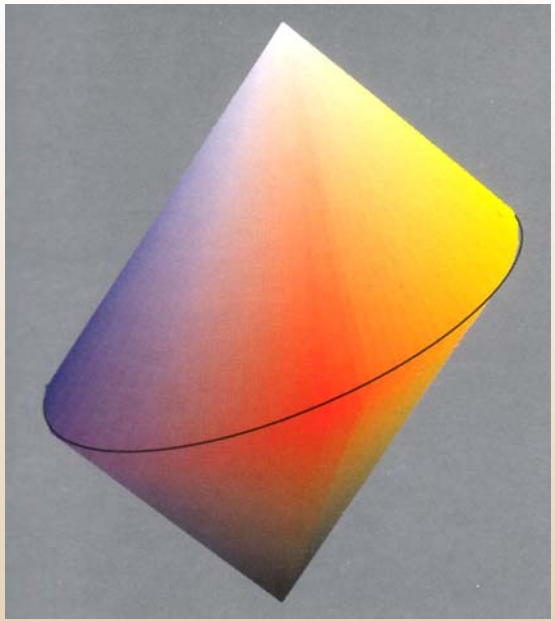
- The input is LMS
- The output has a different parameterization:
  - Light-dark
  - Blue-yellow
  - Red-green
- A later stage may reparameterize:
  - Brightness or Luminance or Value
  - Hue
  - Saturation

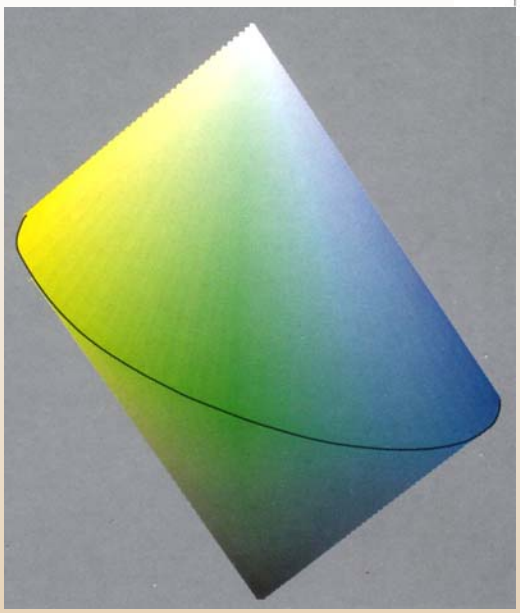


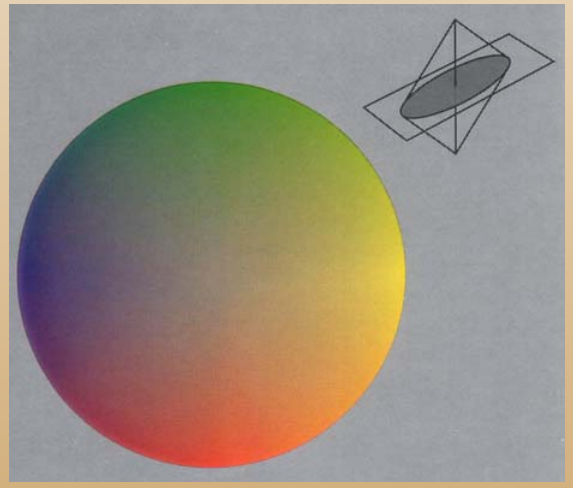


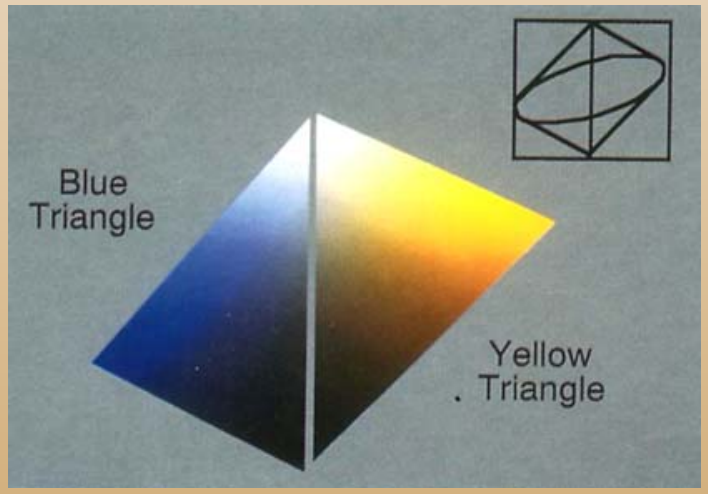


Hue Saturation Value



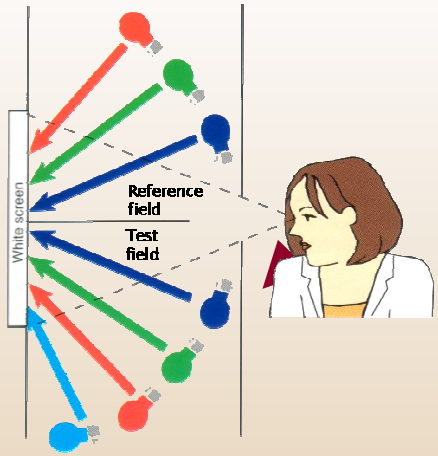


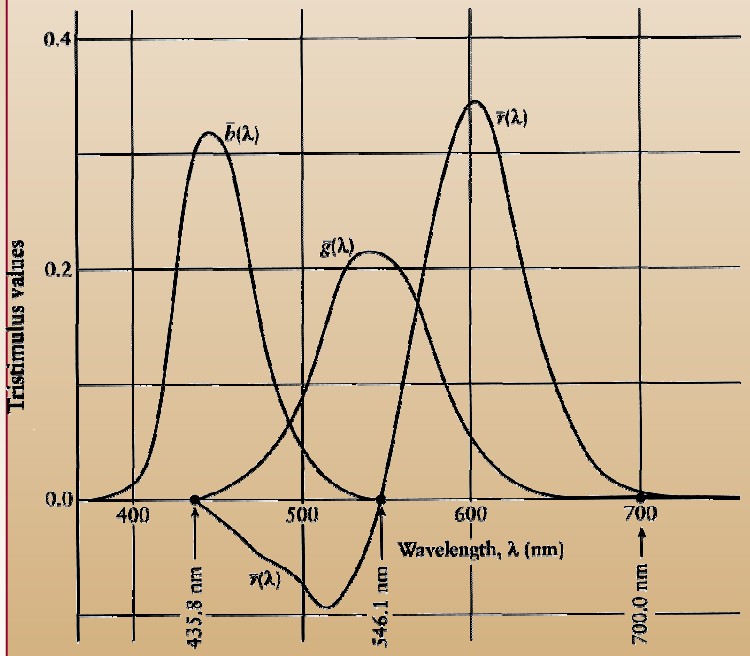


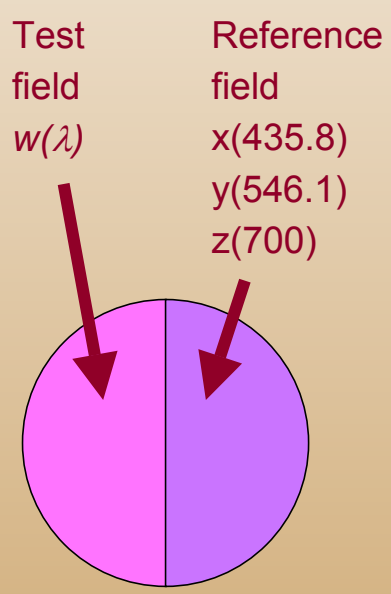


Colorimetry: CIE Color Matching

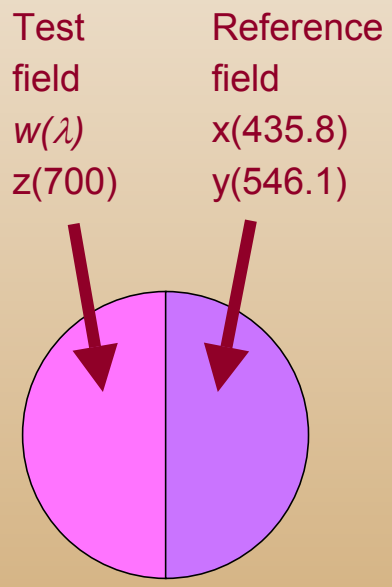
- Match a pure spectral test field $w(\lambda)$ with a reference field: a mixture of red $z(700)$, green $y(546.1)$ and blue $x(435.8)$ of variable intensity







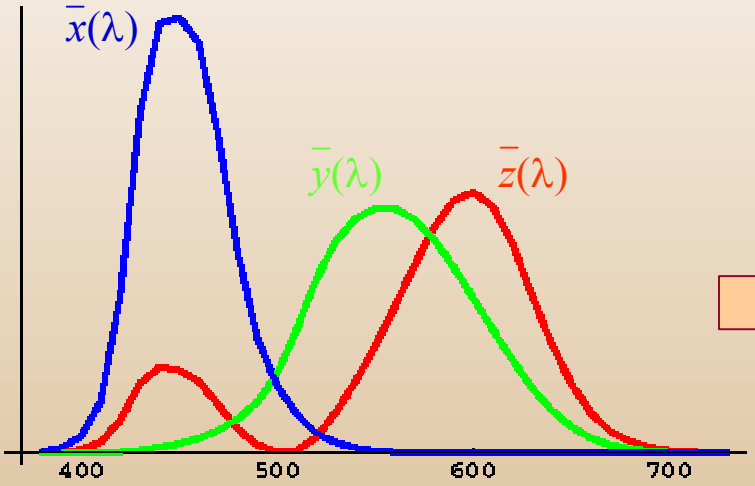
$T = A + B + C$



$T + C = A + B$

CIE-XYZ Color Space

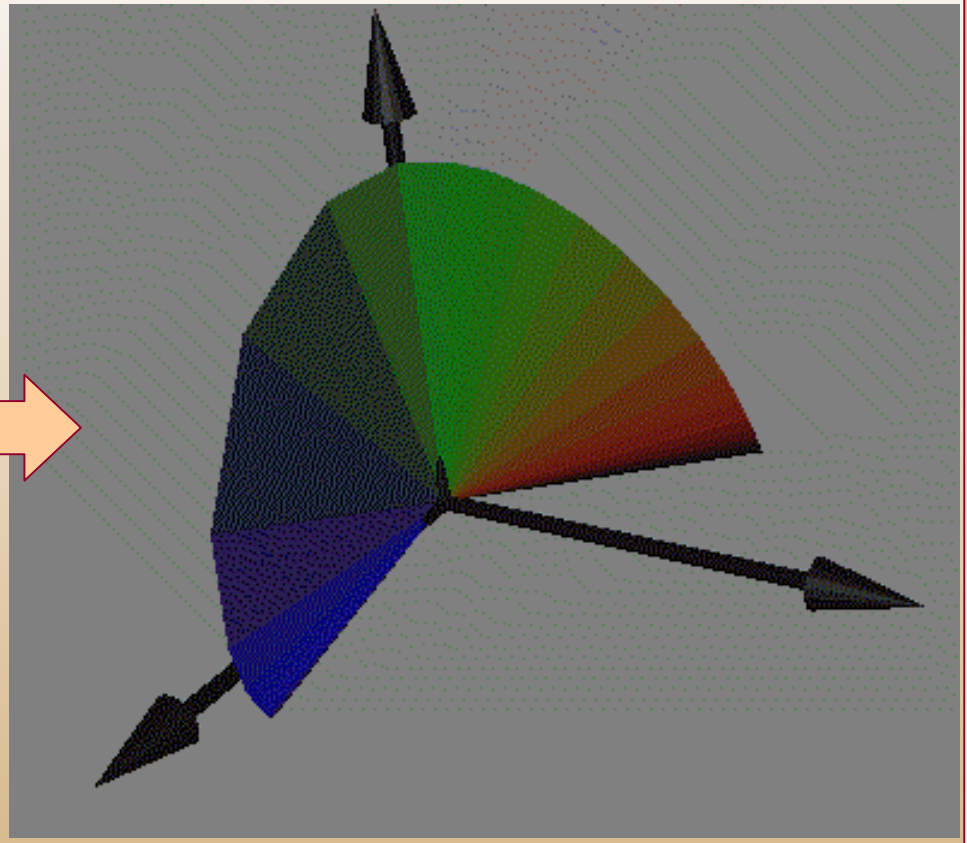
Color-matching curves



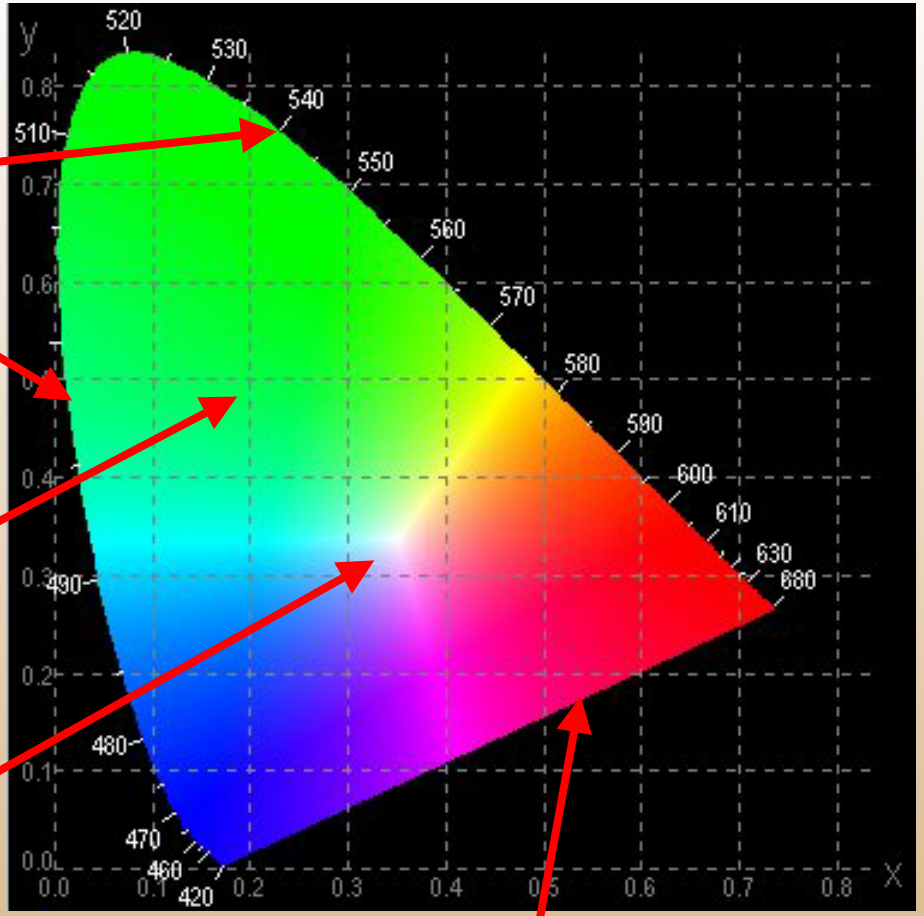
$$X = \int_{380}^{780} C(\lambda)\bar{x}(\lambda)d\lambda$$

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

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



The Colors in the Chromaticity Diagram



Spectrally pure colors (monochromatic or prismatic) on the contour

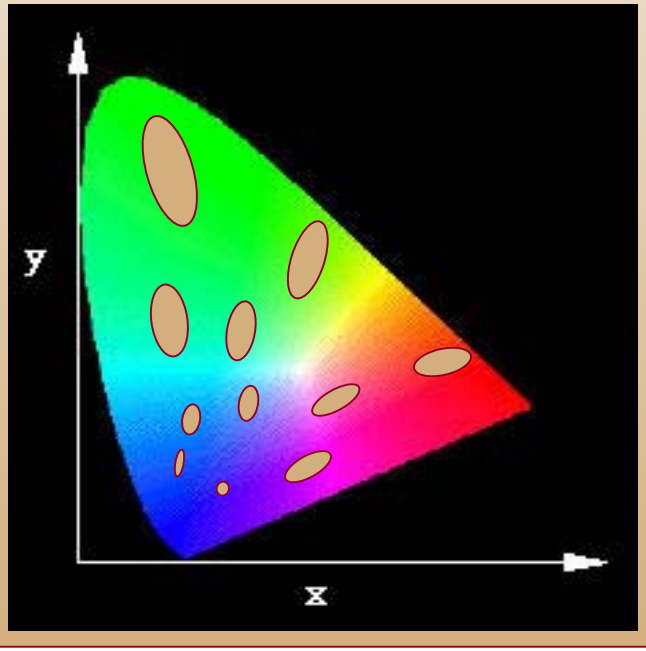
Visible spectrum

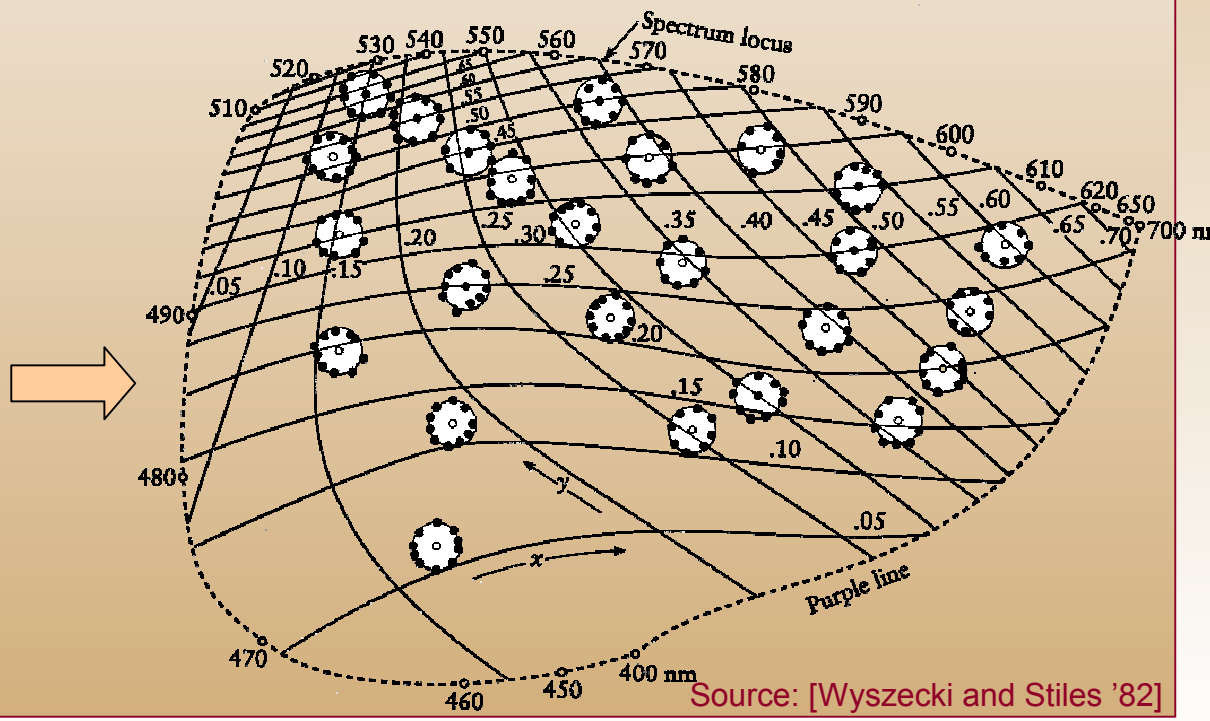
Neutral illuminant white

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

Perceptually Uniform Space: MacAdam

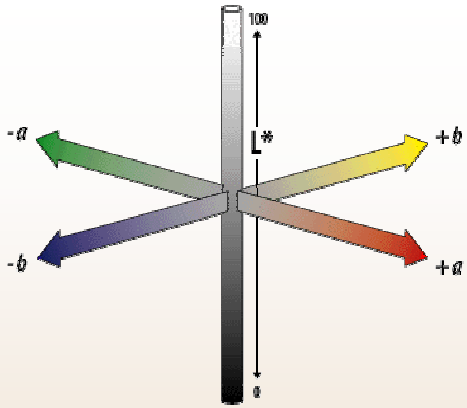
- In color space CIE-XYZ, the perceived distance between colors is not equal everywhere
- In perceptually uniform color space, Euclidean distances reflect perceived differences between colors
- MacAdam ellipses (areas of unperceivable differences) become circles

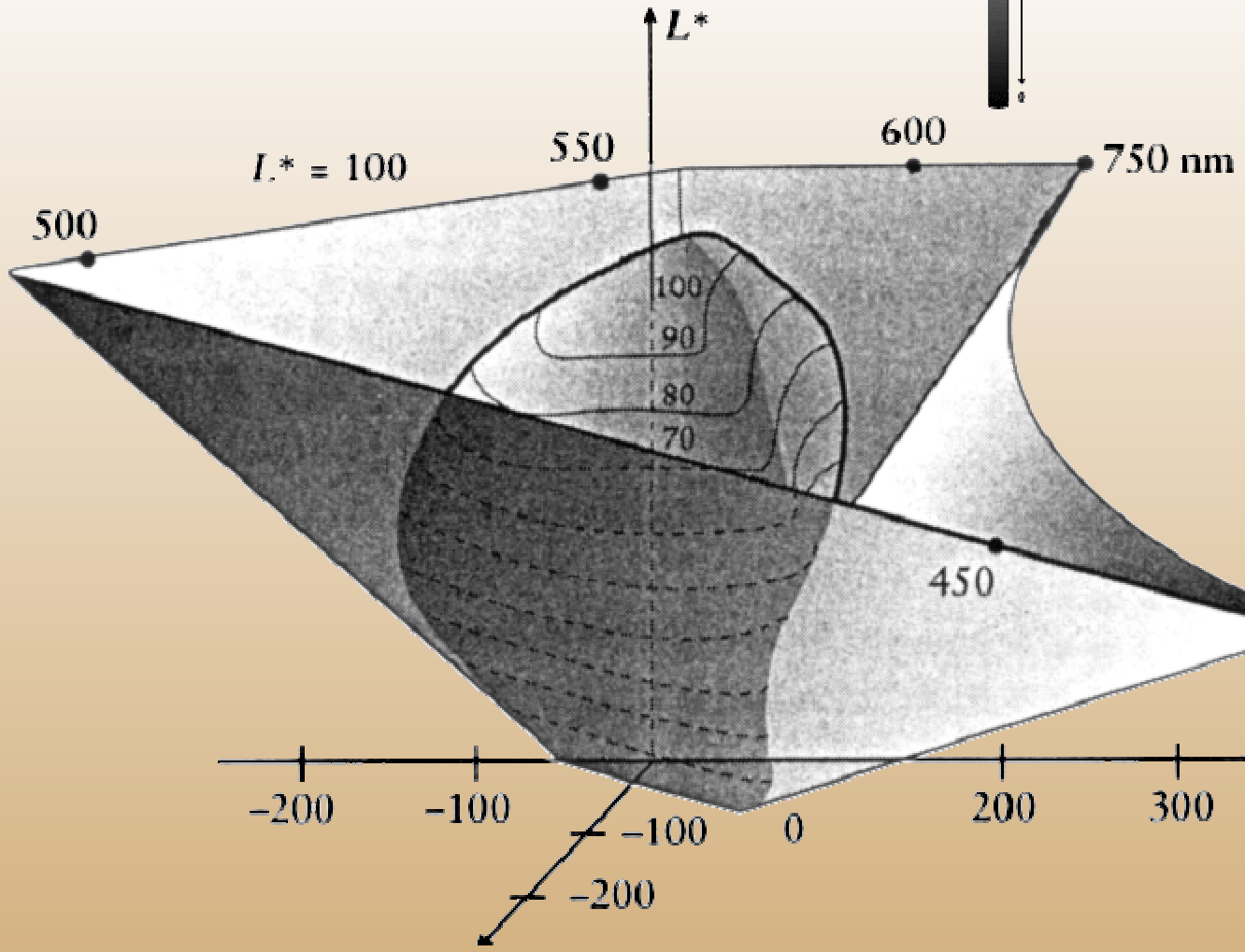




Source: [Wyszecki and Stiles '82]

CIE-LAB





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

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

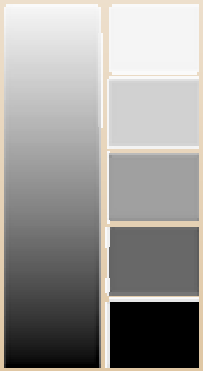
$$b = 200\left[\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3}\right]$$

Source: [Wyszecki and Stiles '82]

Perceptually Uniform Space
Munsell

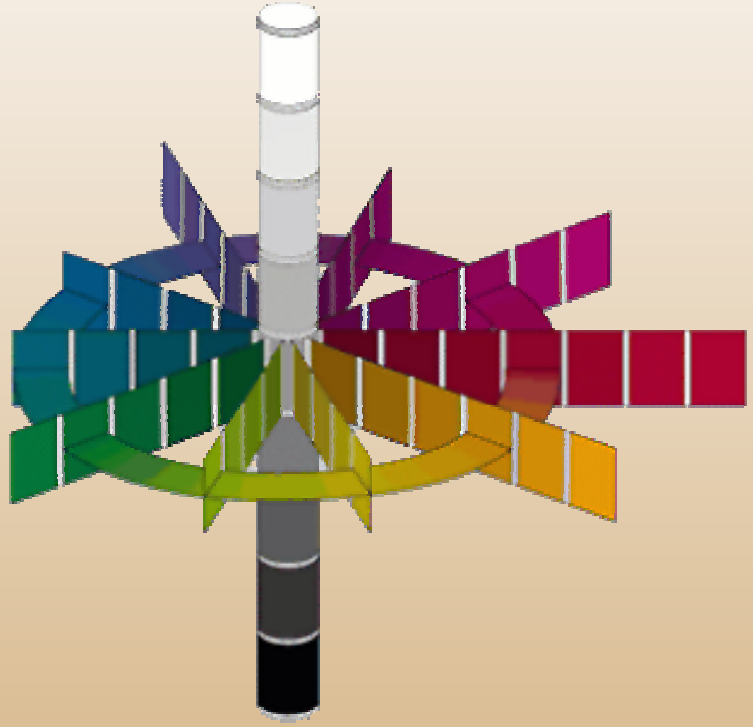
Hue

Value



Chroma

Munsell Color Space



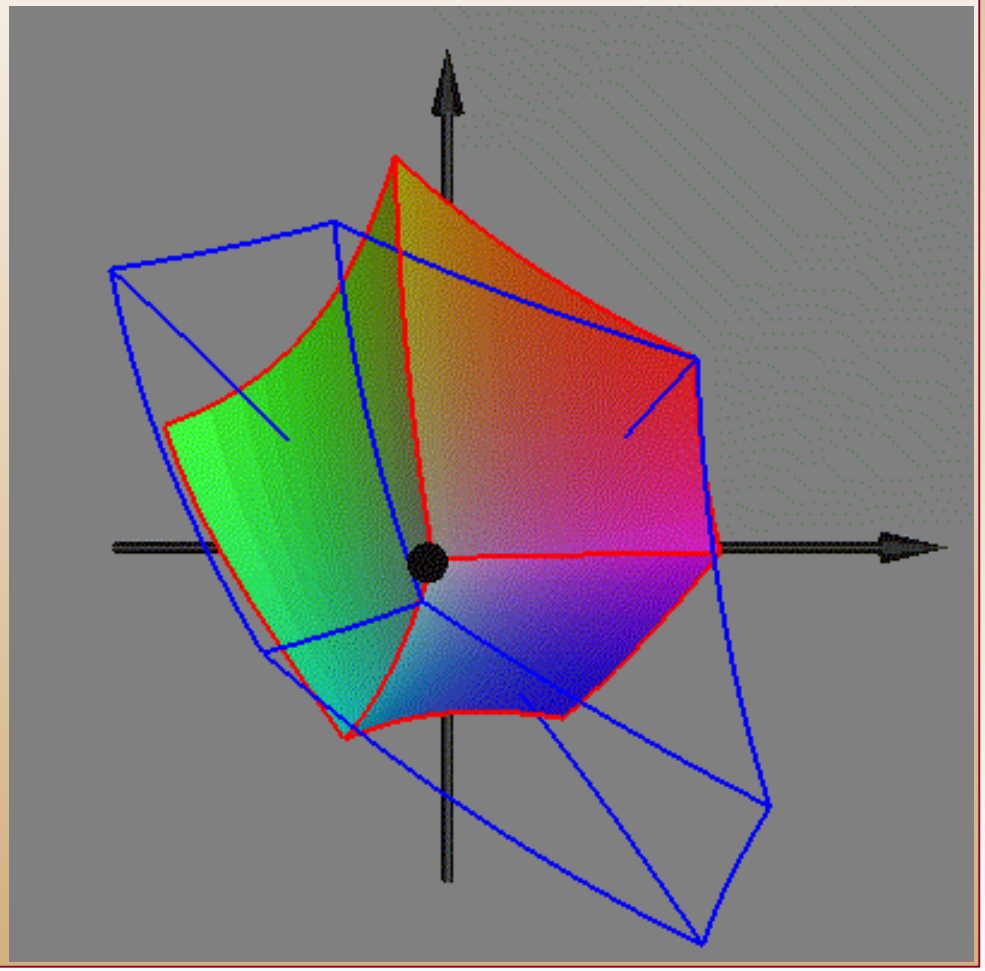
munsell.com

Gamut Mapping

CIE-LAB

Perceptually-uniform Color space

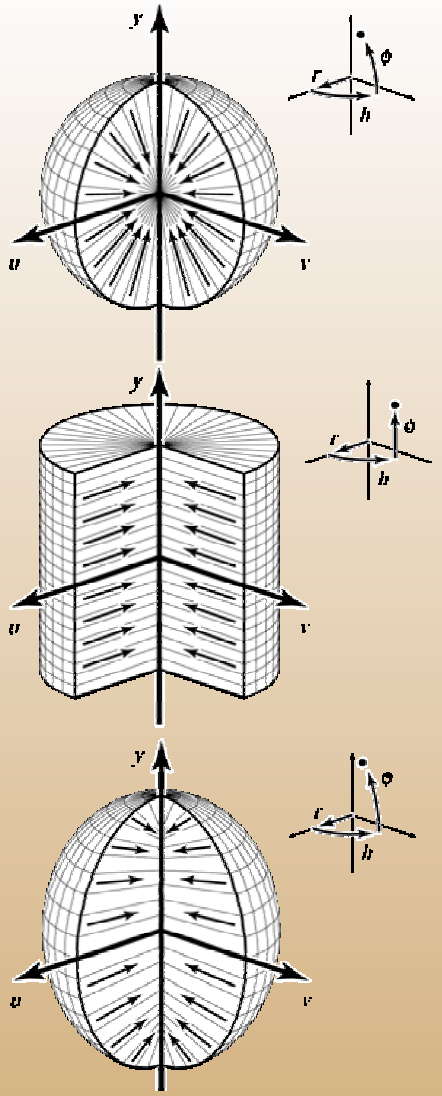
- Color gamut of different processes may be different (e.g. CRT display and 4-color printing process)
- Need to map one 3D color space into another

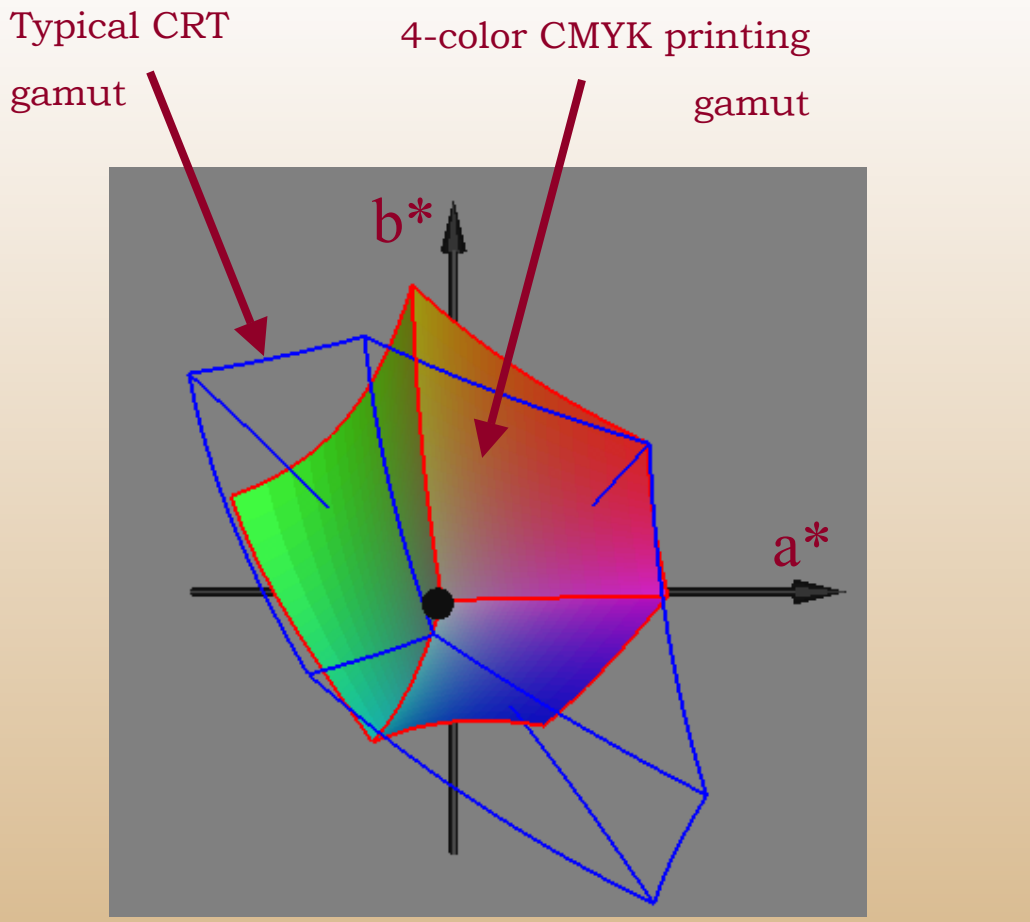


Typical CRT gamut

4-color printing gamut

Gamut Mapping





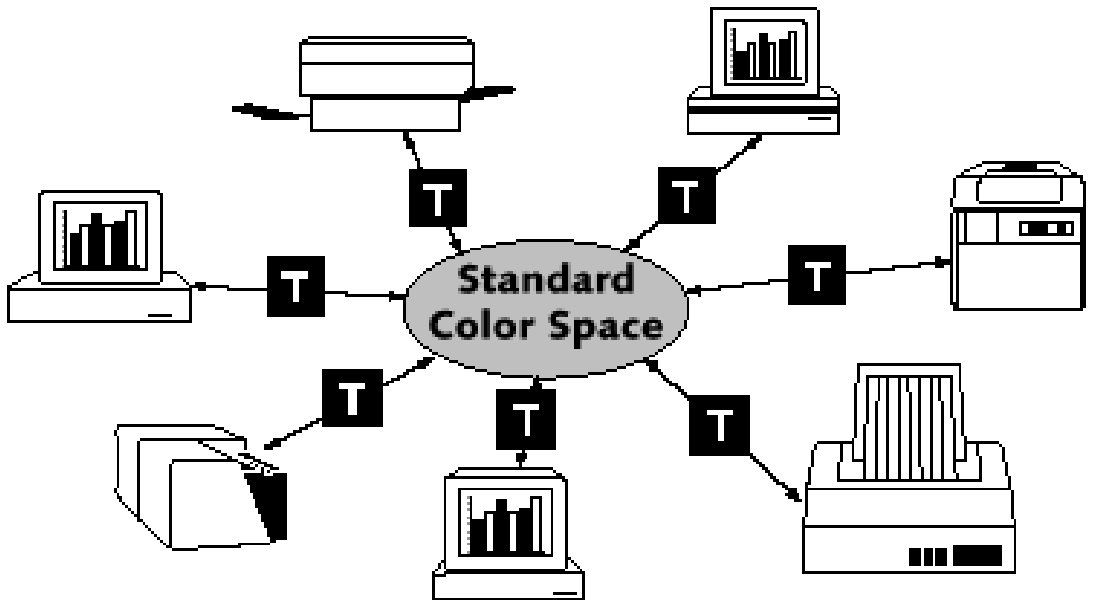
Gamut mapping is a morphing of 3D color space according to adopted scheme

ICC

International Color Consortium

SAN ANTONIO SIGGRAPH 2002

Device Independent Color



T each is a device-to-standard-color transform

http://www.color.org/

Color Perception and Art

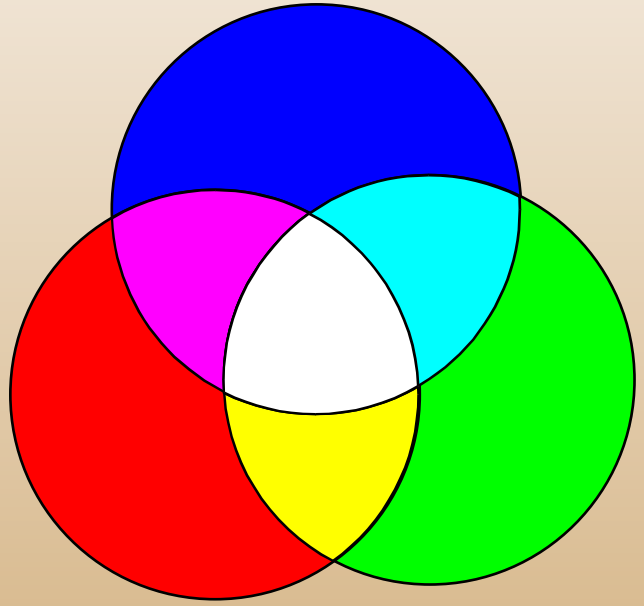
Basic Phenomena

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

Physical color mixture

Additive

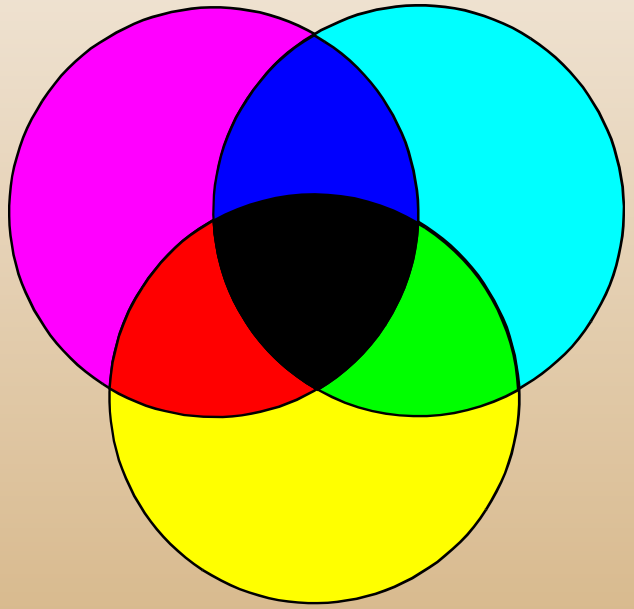
red, green, blue



Spot Lights

Subtractive

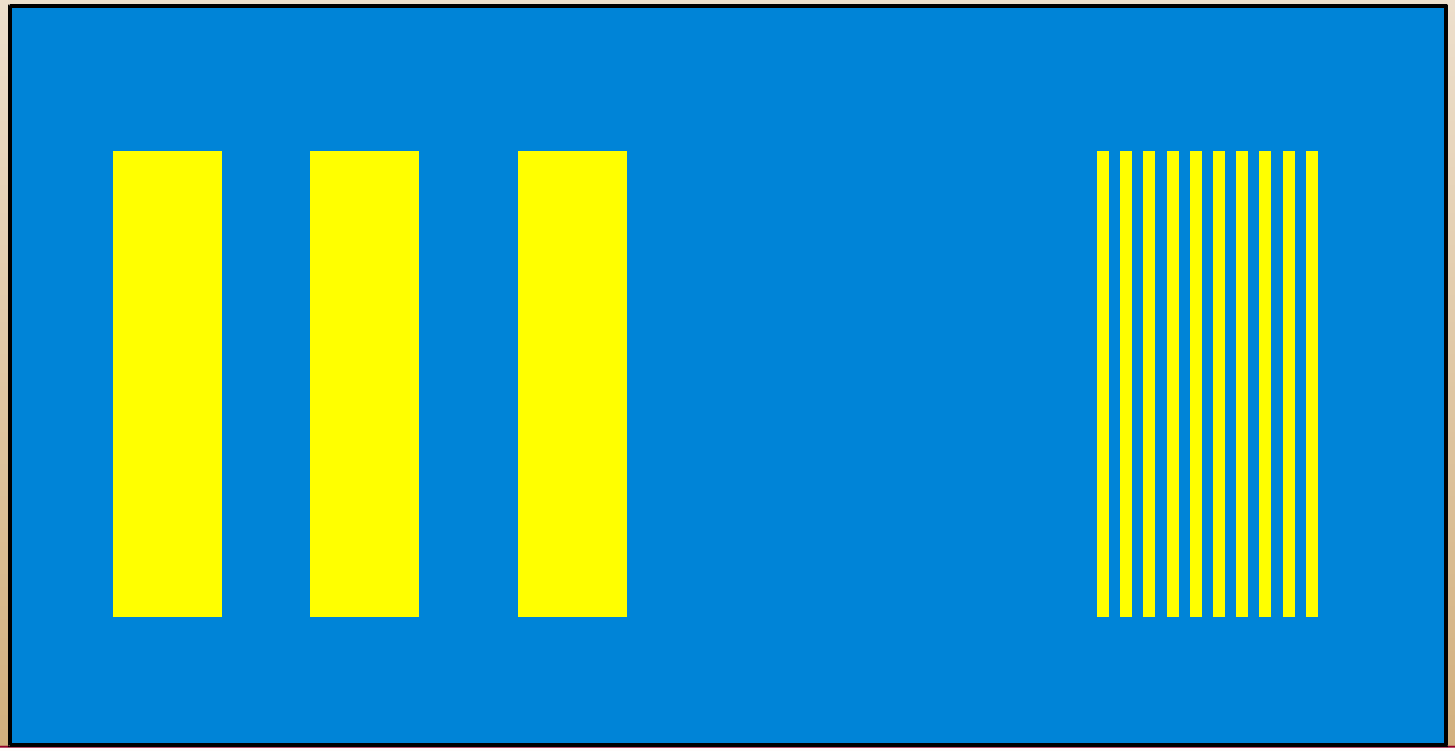
cyan, magenta, yellow



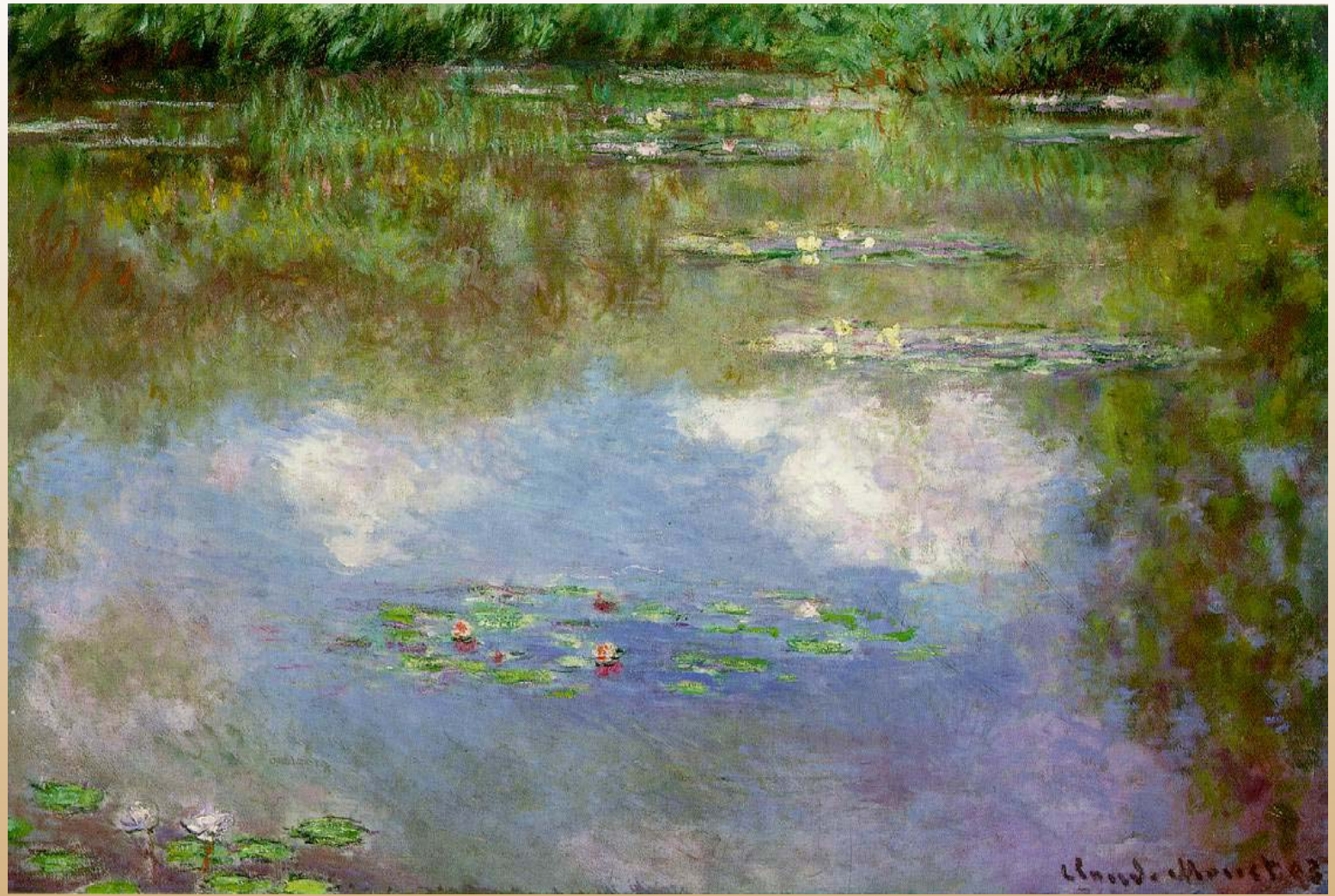
Inks

Optical color mixture

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



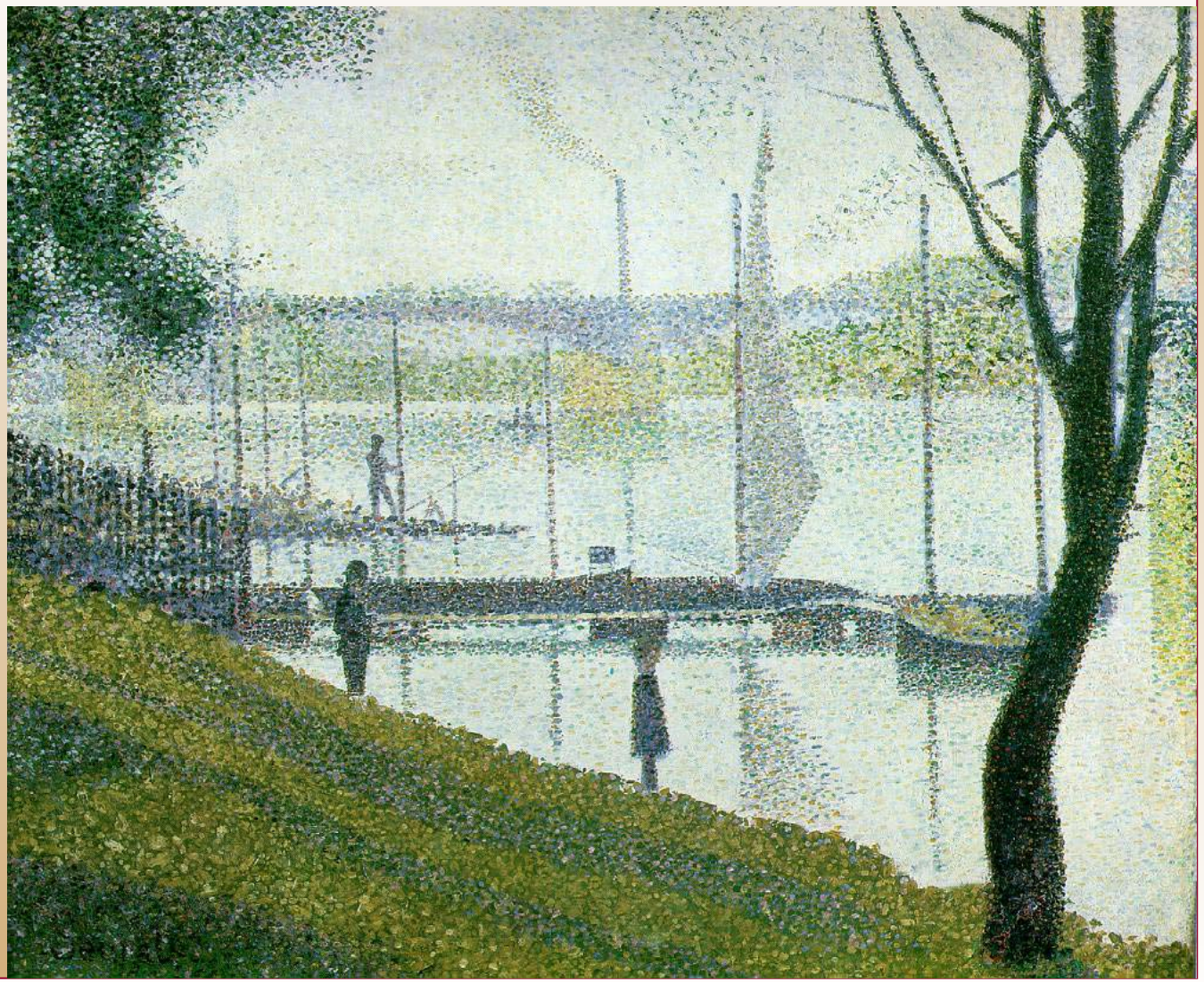
Impressionism



Claude Monet

Pointillism

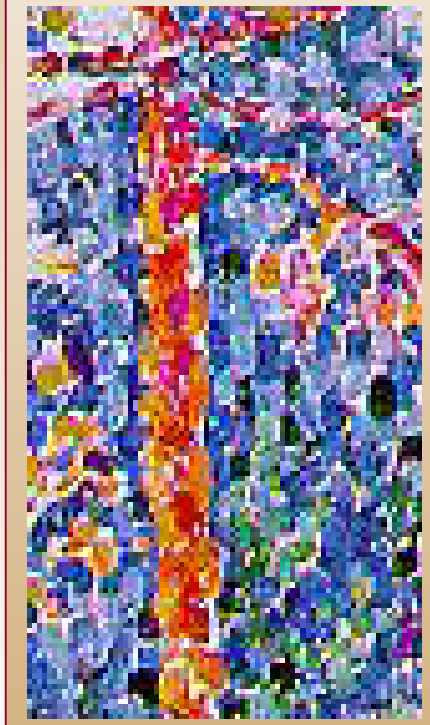
- Use of pure colors
- Reduced palette
- Additive rather than subtractive mixture

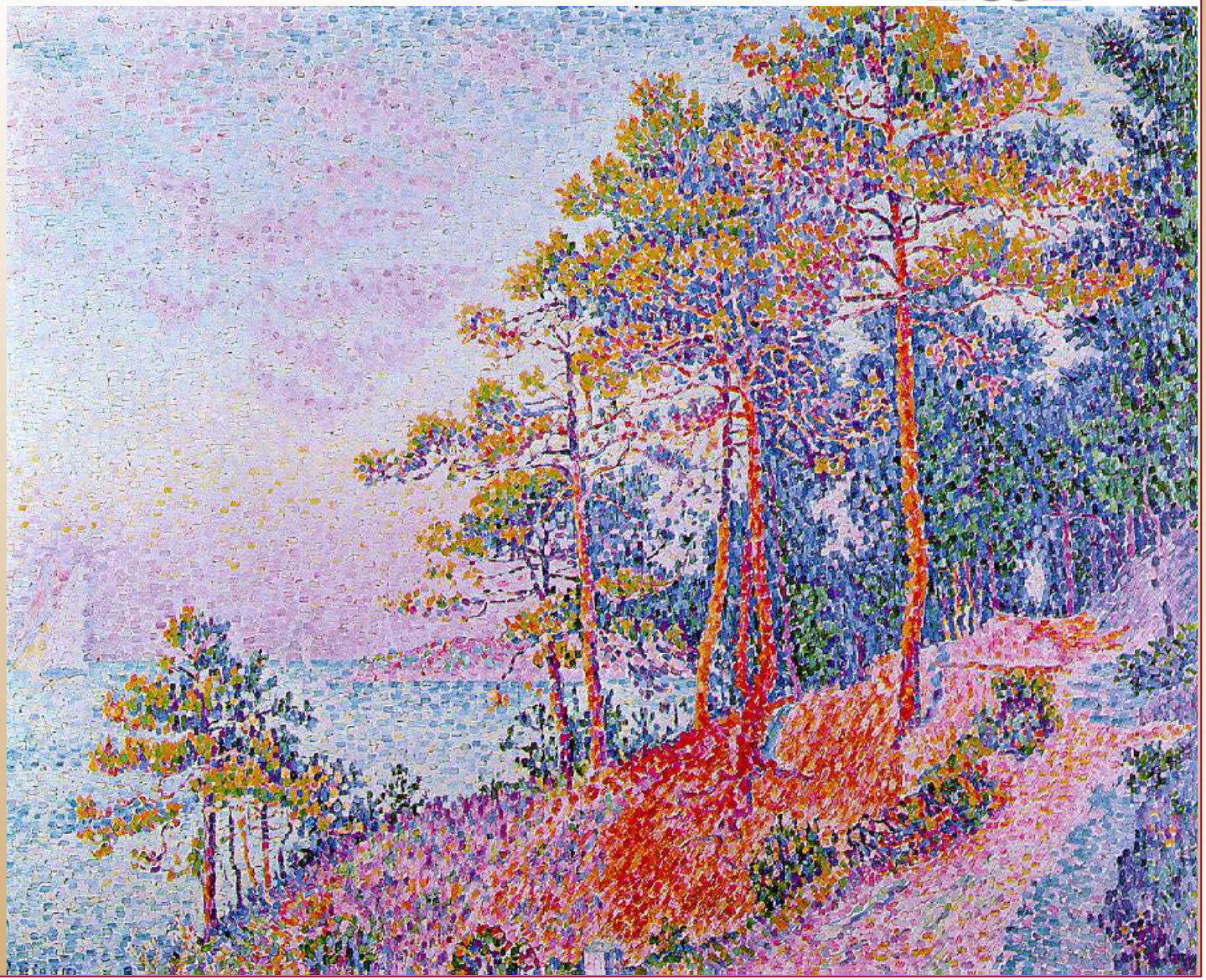


Georges Seurat

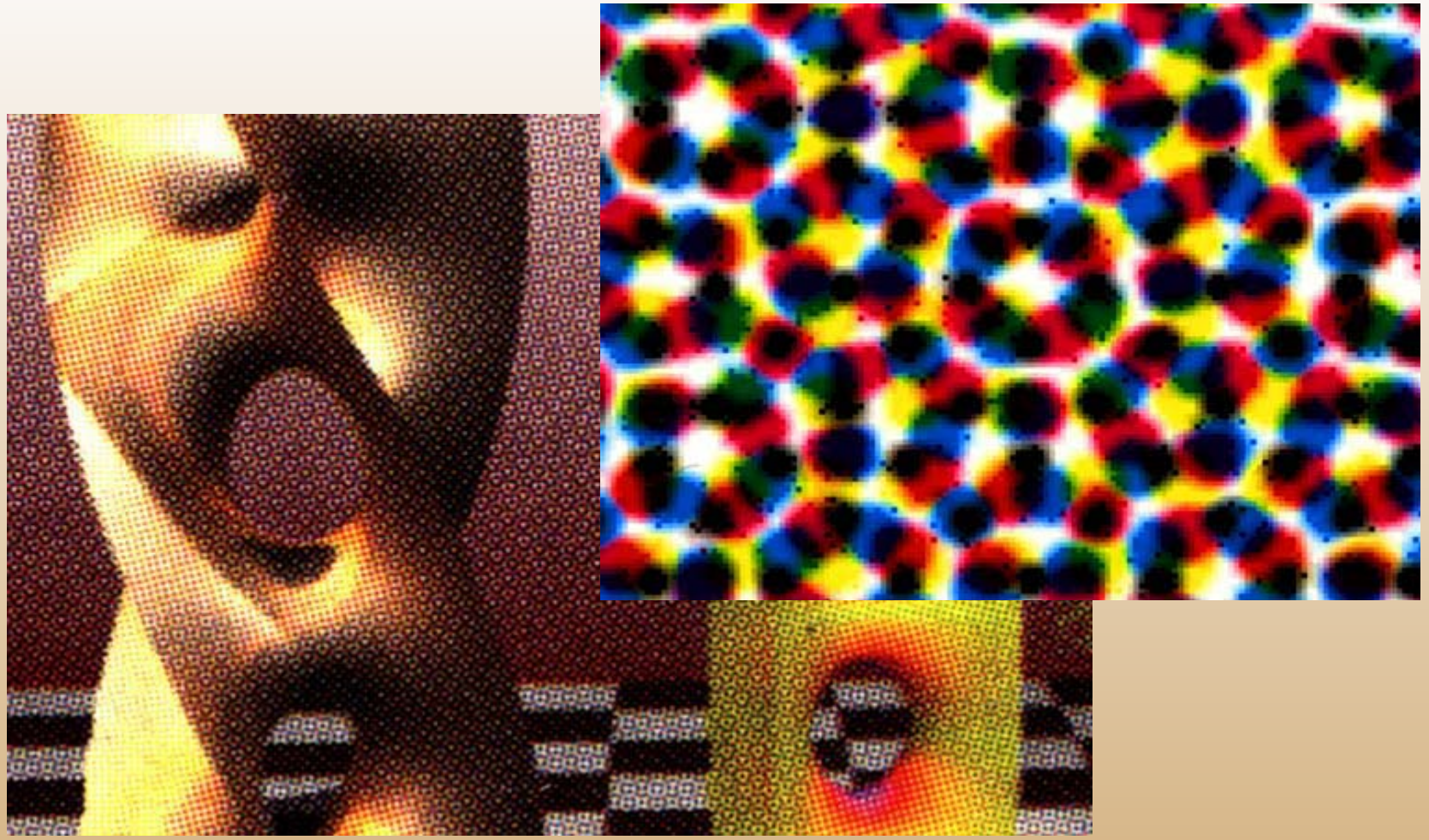
Post-Impressionism

- They obtain more pure, brilliant colors

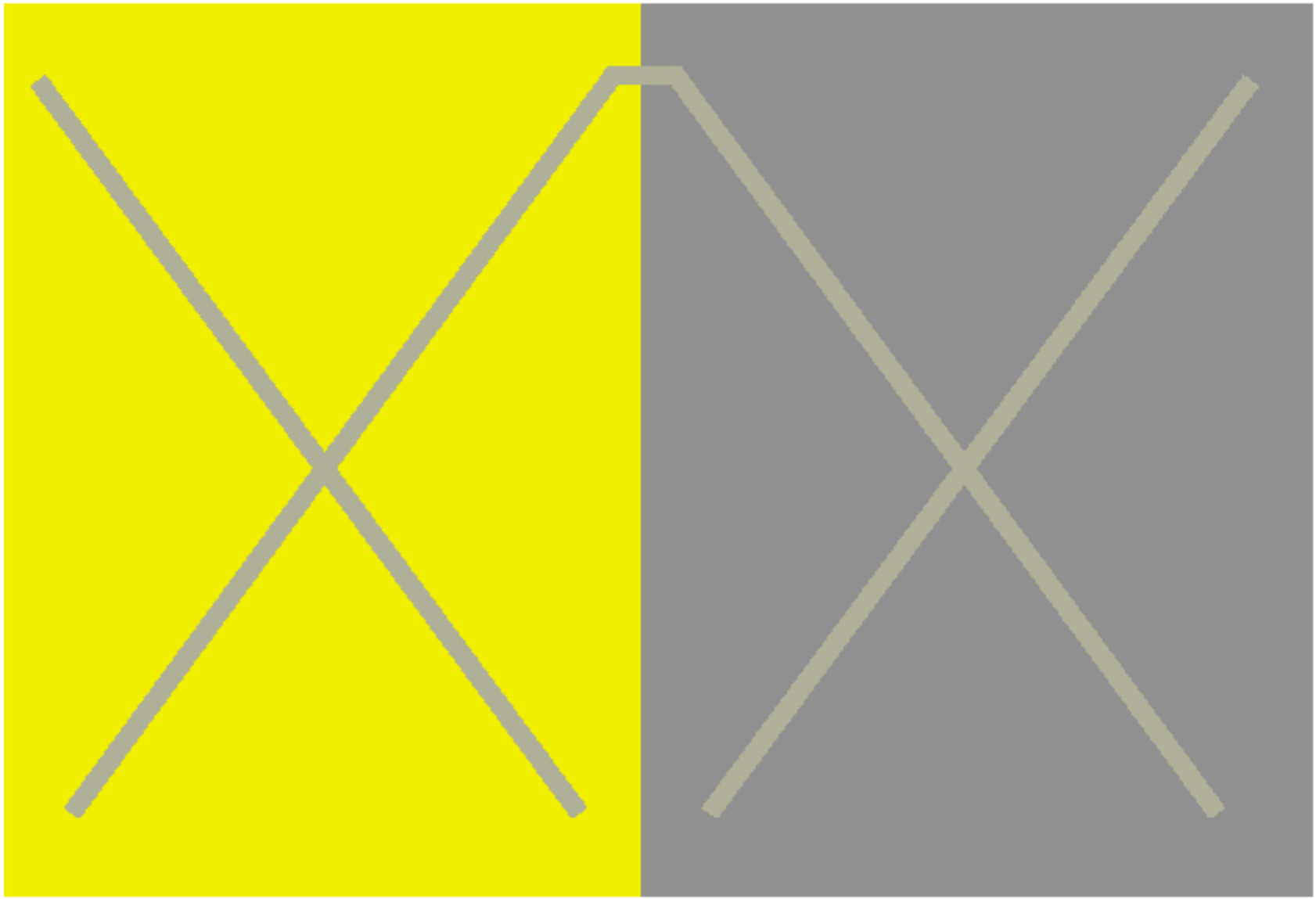




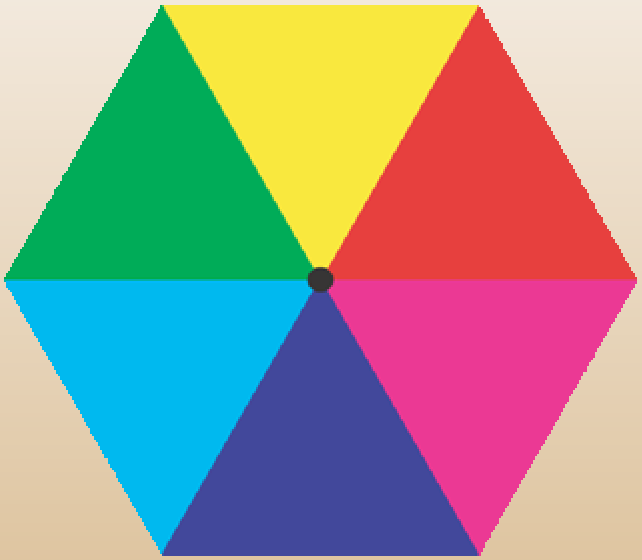
Color Printing

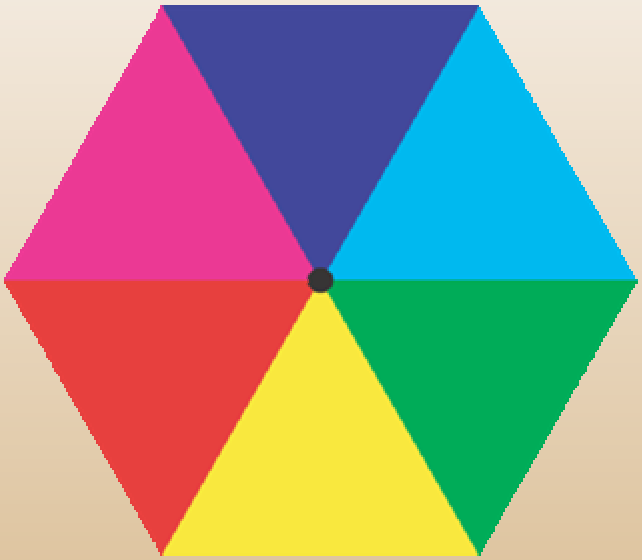


Simultaneous Color Contrast

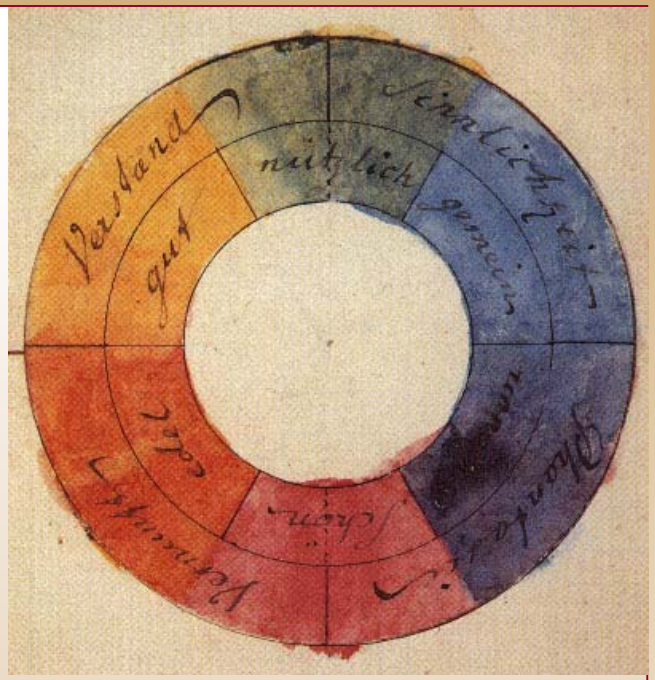


Opponent Colors





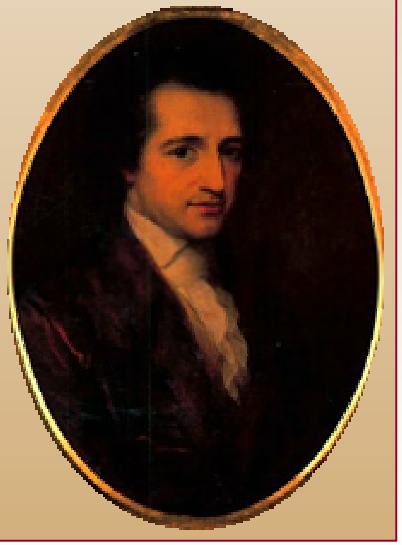
Goethe 1810



- Circular diagram:

  primary colors (red, blue and yellow) alternate with secondary colors (orange, violet and green)

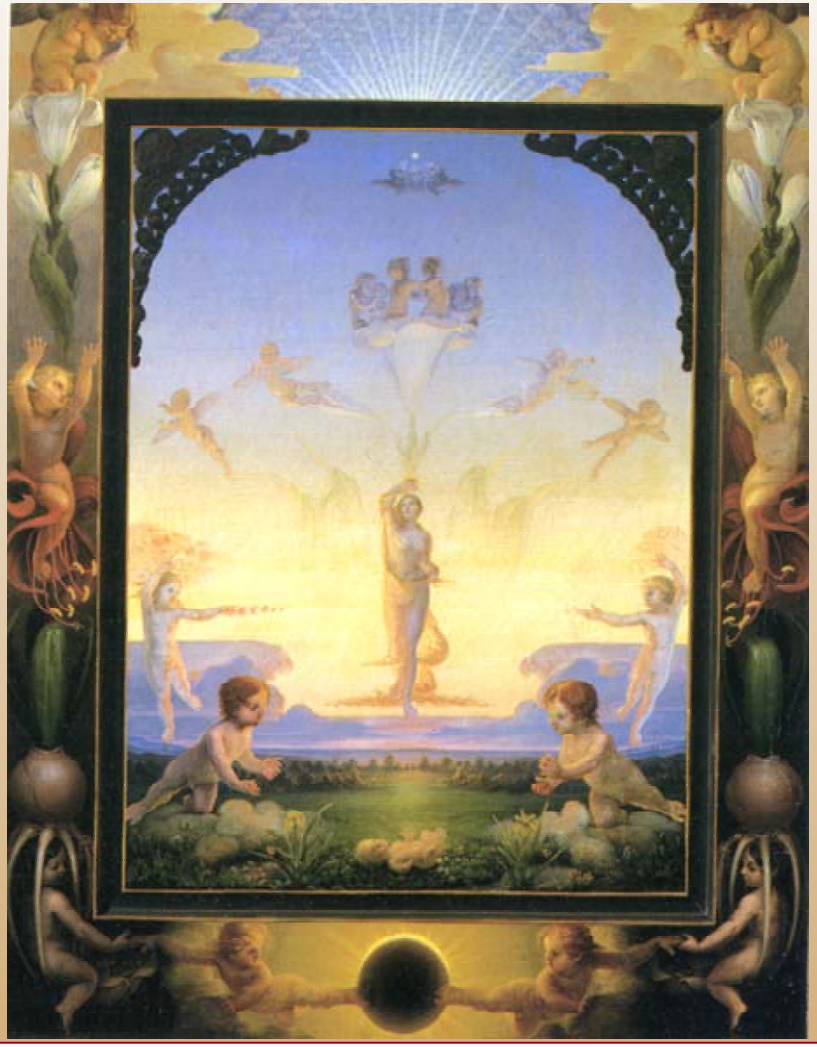
- Color opponents



- 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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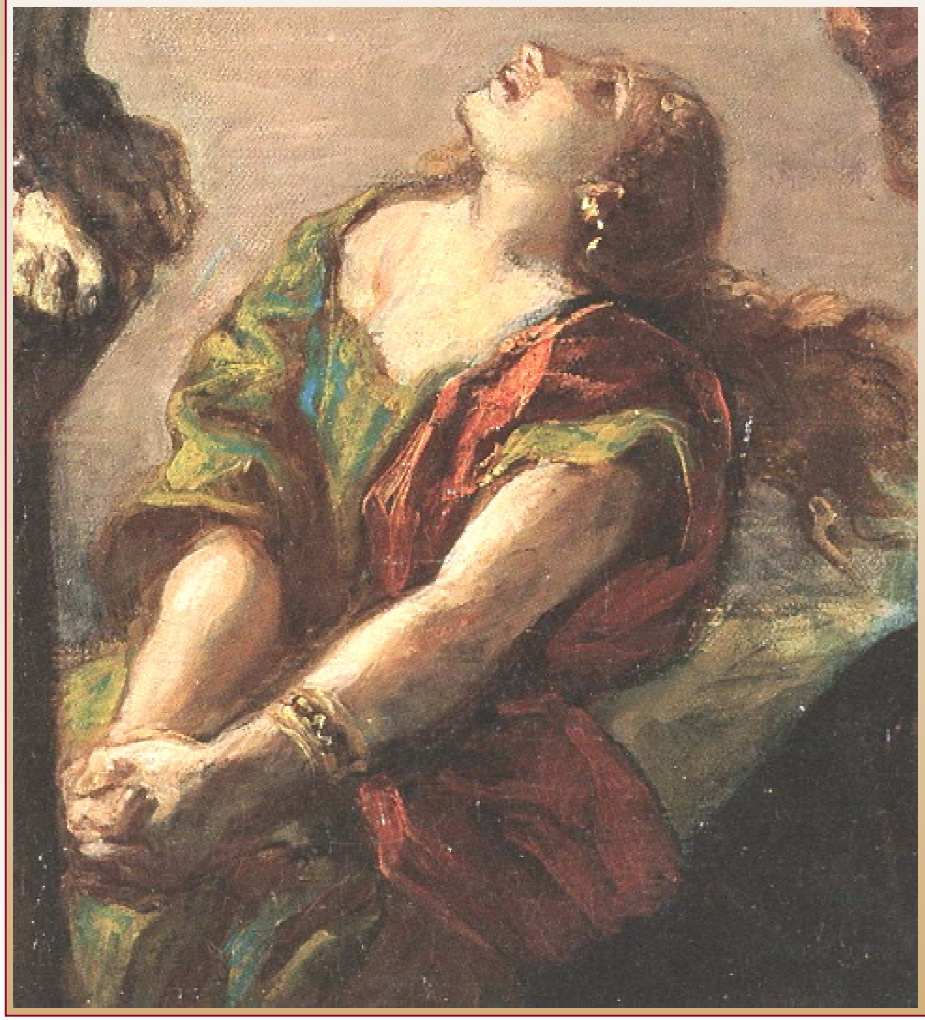
Turner, Delacroix



Post-Impressionism

Expressive Power of Complementary Colors

Vincent van Gogh

Chromatic Adaptation

Chromatic Adaptation

Claude Monet

Rouen Cathedral, 1894

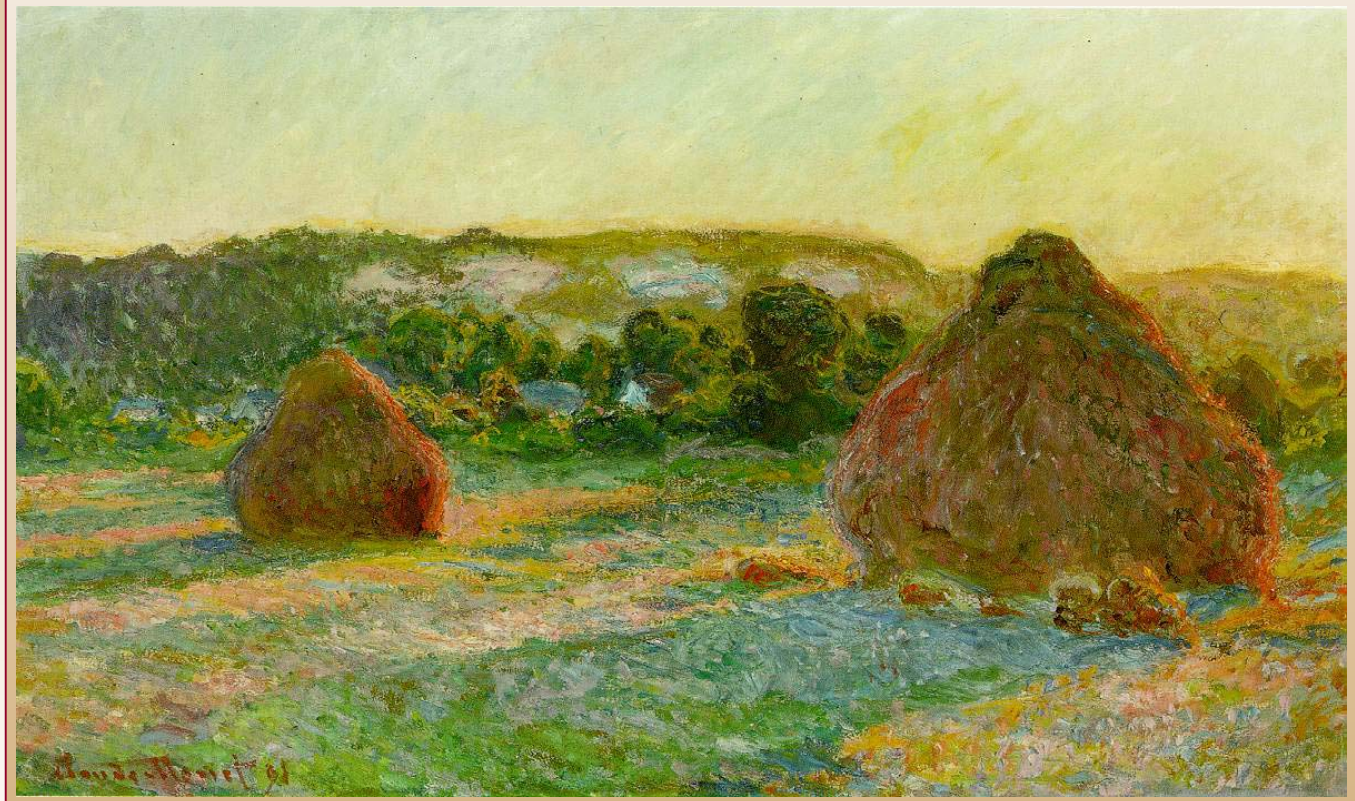
Chromatic Adaptation

Claude Monet

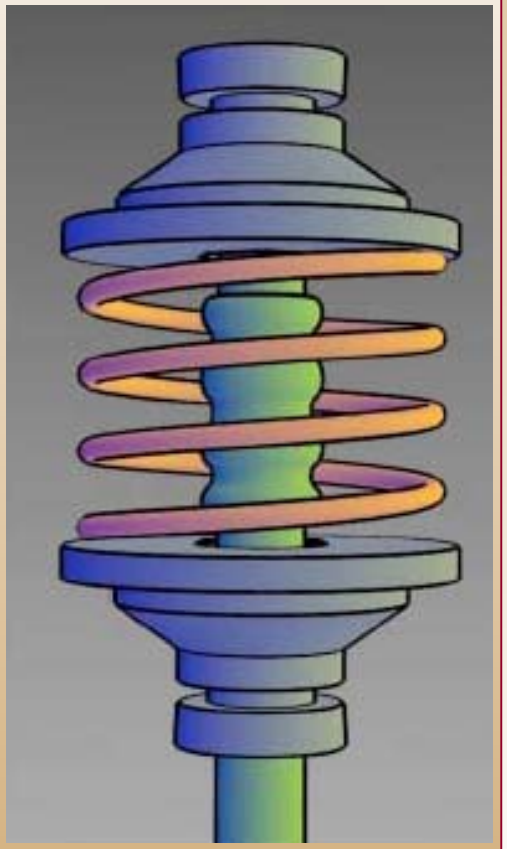
Rouen Cathedral, 1894

Color Shadows

- Usage of Warm and Cold Colors



Claude Monet, Grain stack in the morning, 1891



[Gooch and Gooch'98]

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,

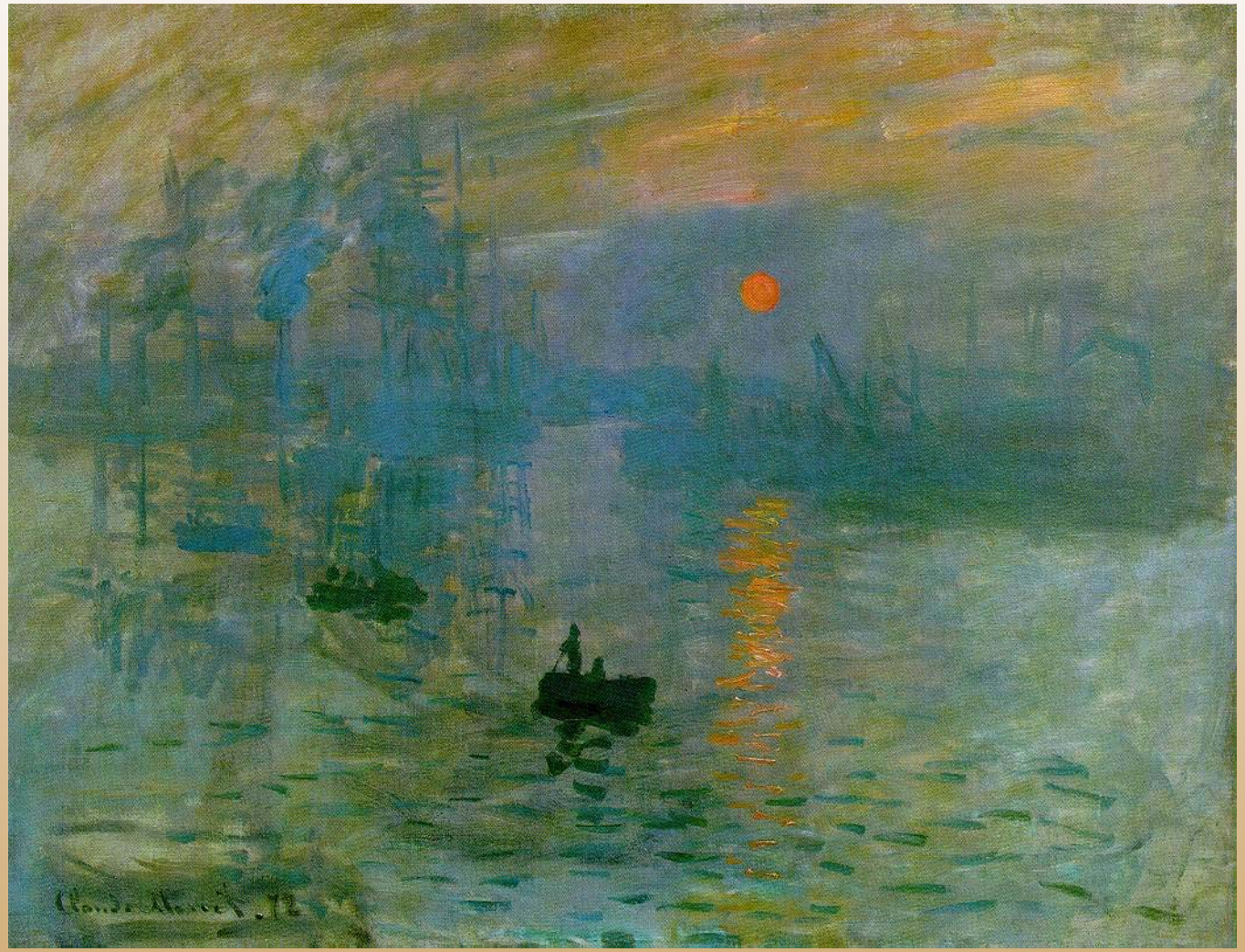
an anti-impressionist

critic, 1876

Auguste Renoir, Young Woman in the Sun, 1875

Perception of Space

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



Claude Monet,

Sunrise, 1872

Perception of Space

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

Claude Monet,

Sunrise, 1872

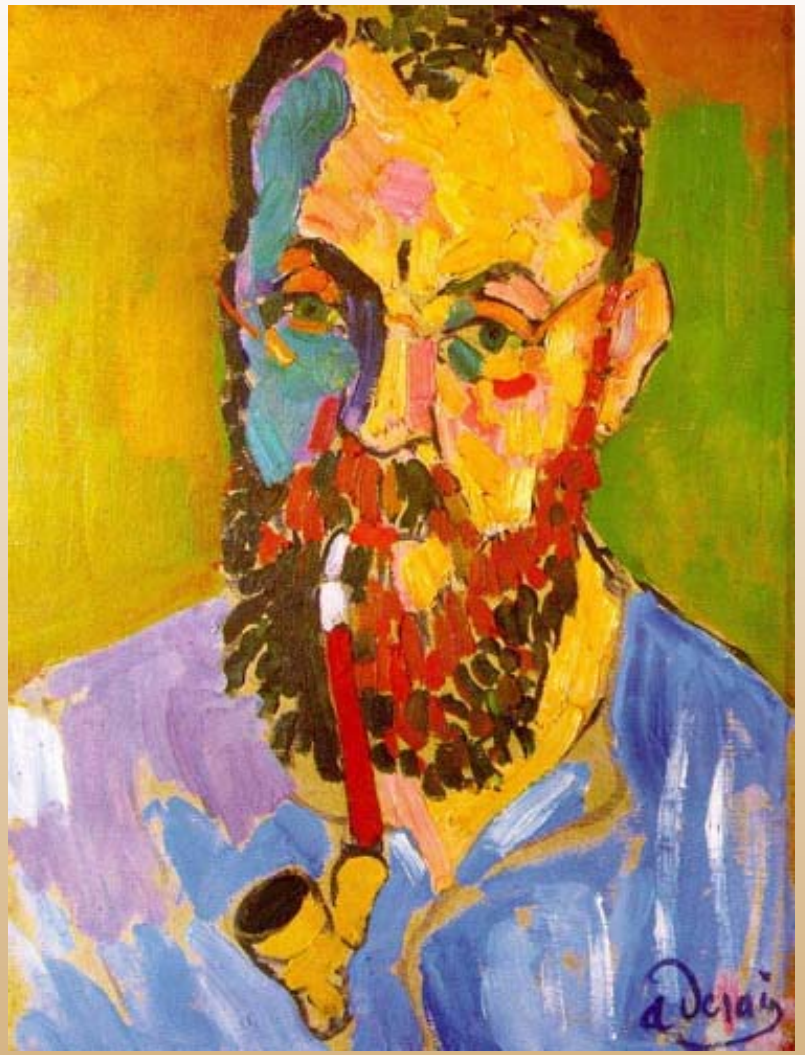
Perception of Depth

SAN ANTONIO SIGGRAPH 2002

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

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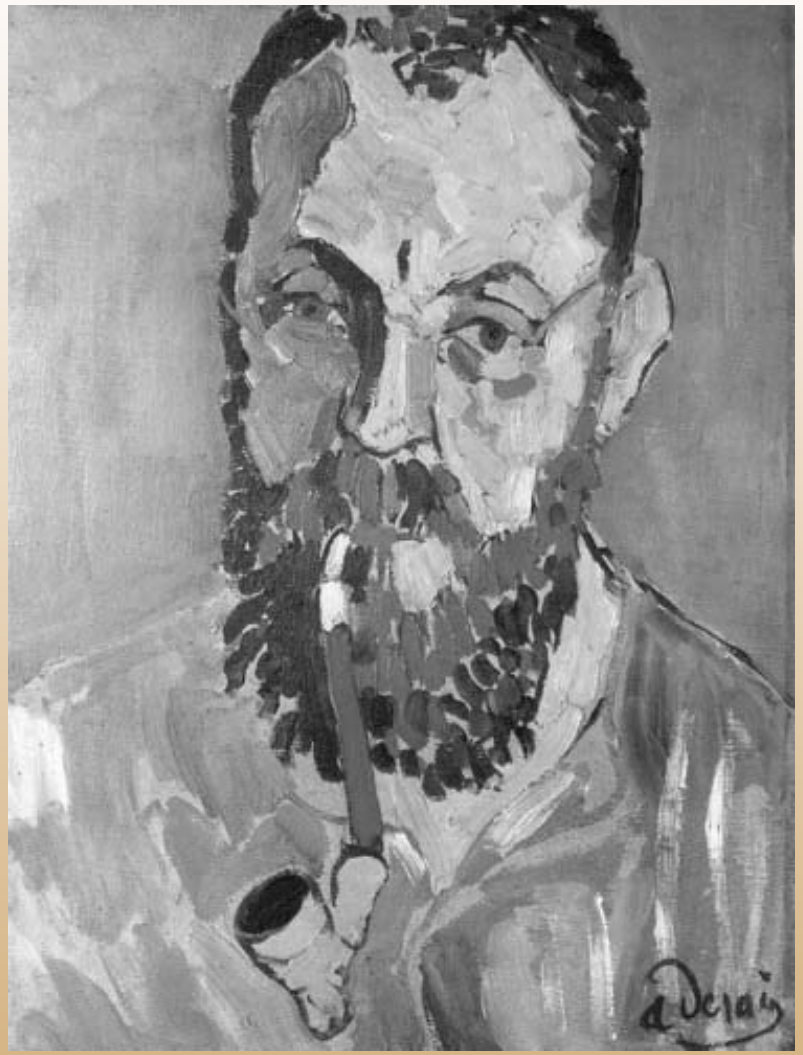


André Derain, Portrait of Henri Matisse, 1905

Perception of Motion

Claude Monet, Poppies, 1873

Perception of Motion

Claude Monet, Poppies, 1873

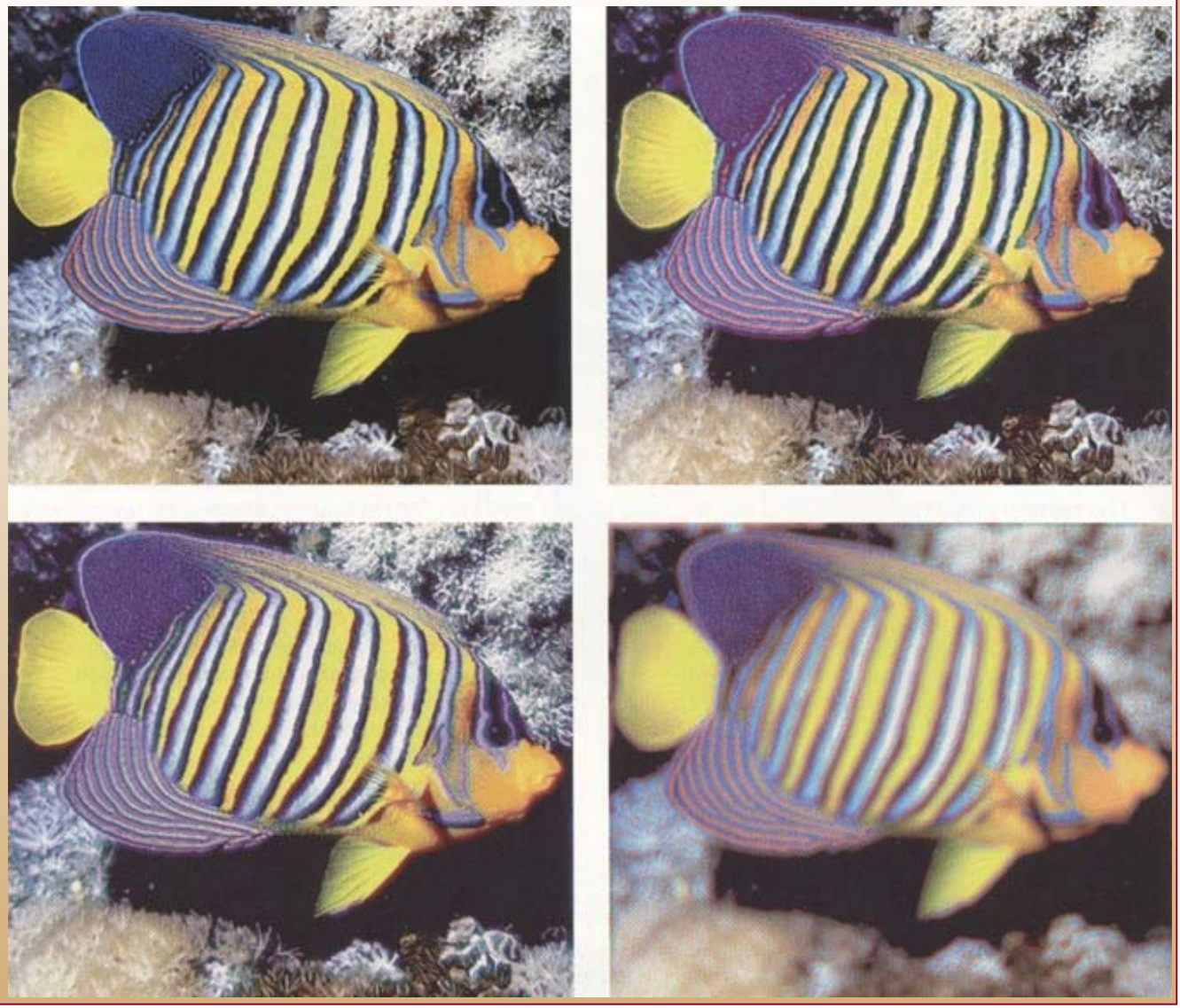
Chromatic and Achromatic Visual Acuity

Abraham Walkowitz, Isadora Duncan

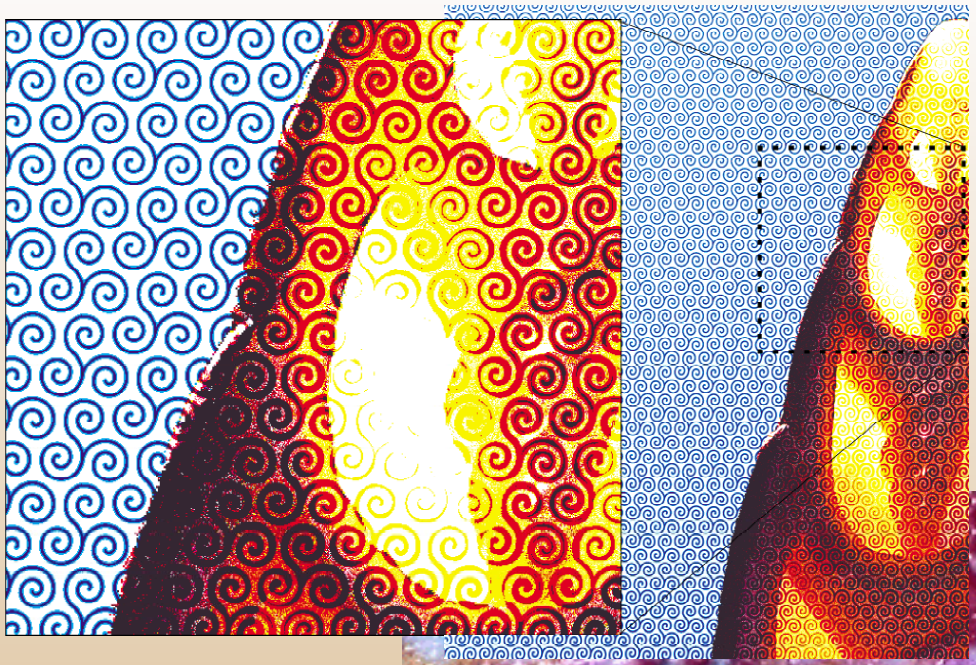
Raoul Dufy, Open Window

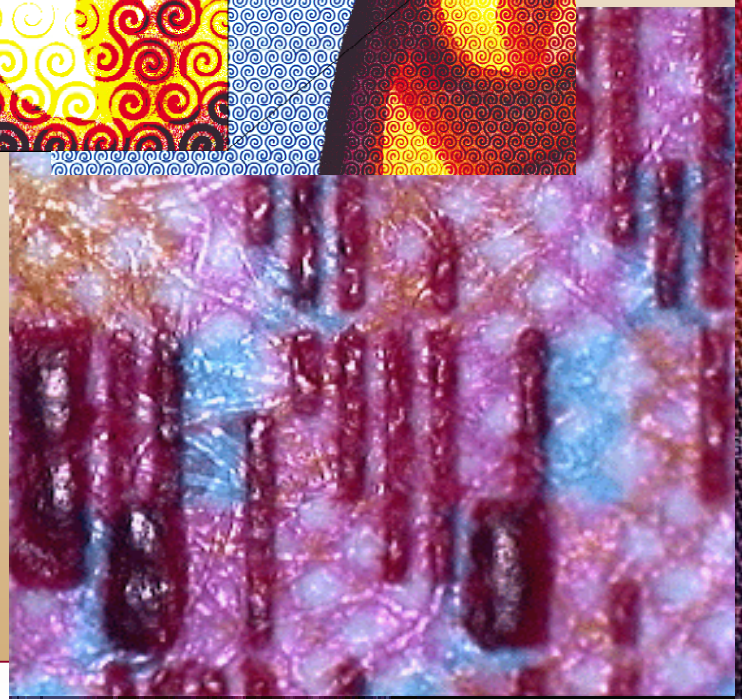
Chromatic and Achromatic Visual Acuity

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



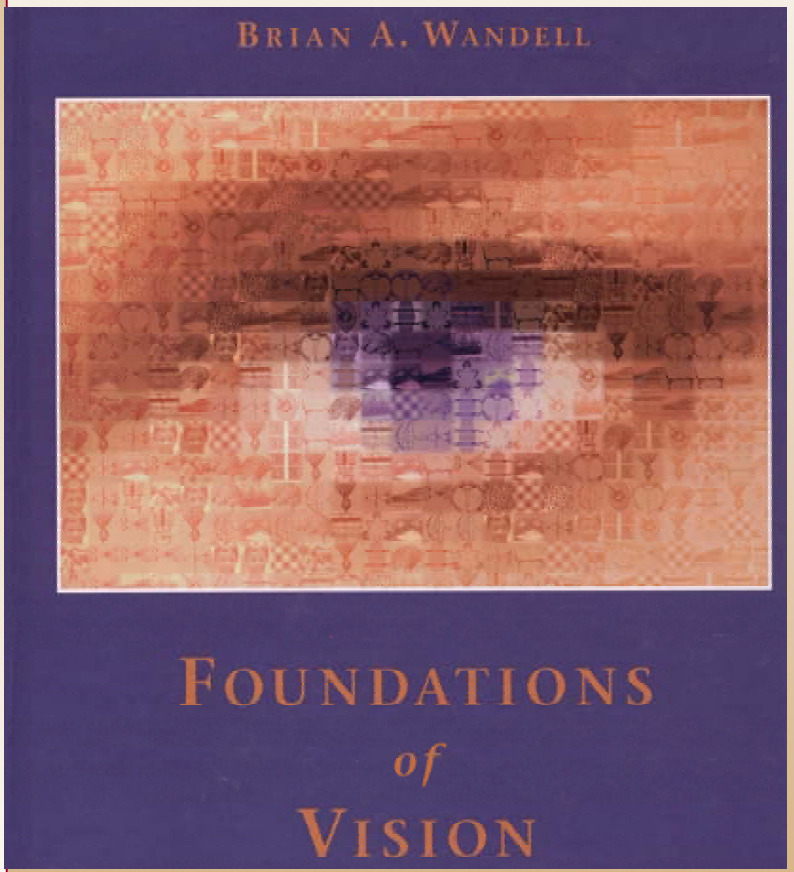
Artistic Halftoning

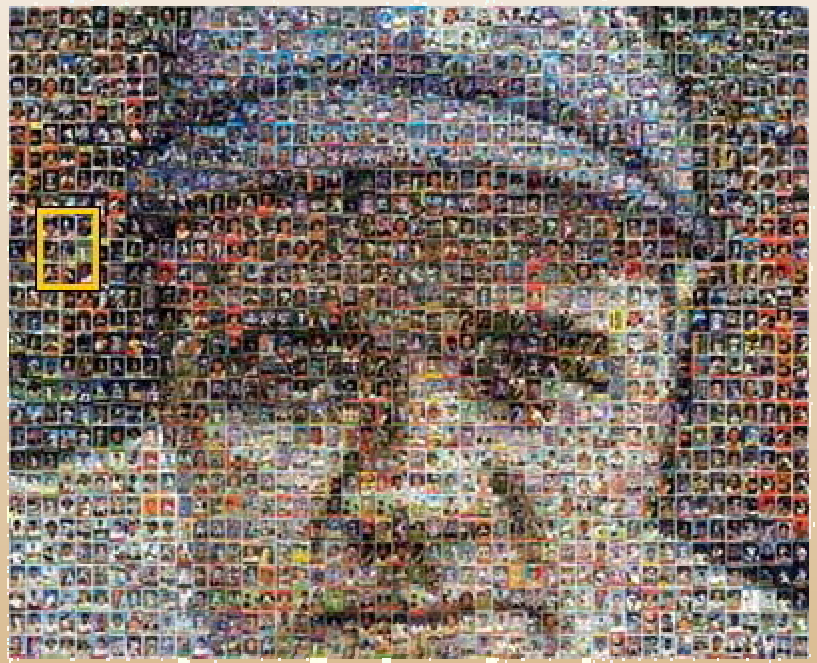


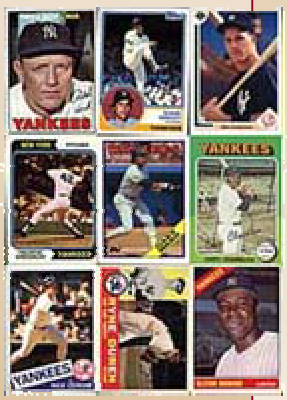


[Ostromoukhov and Hersch 1999]

Photo-Mosaics



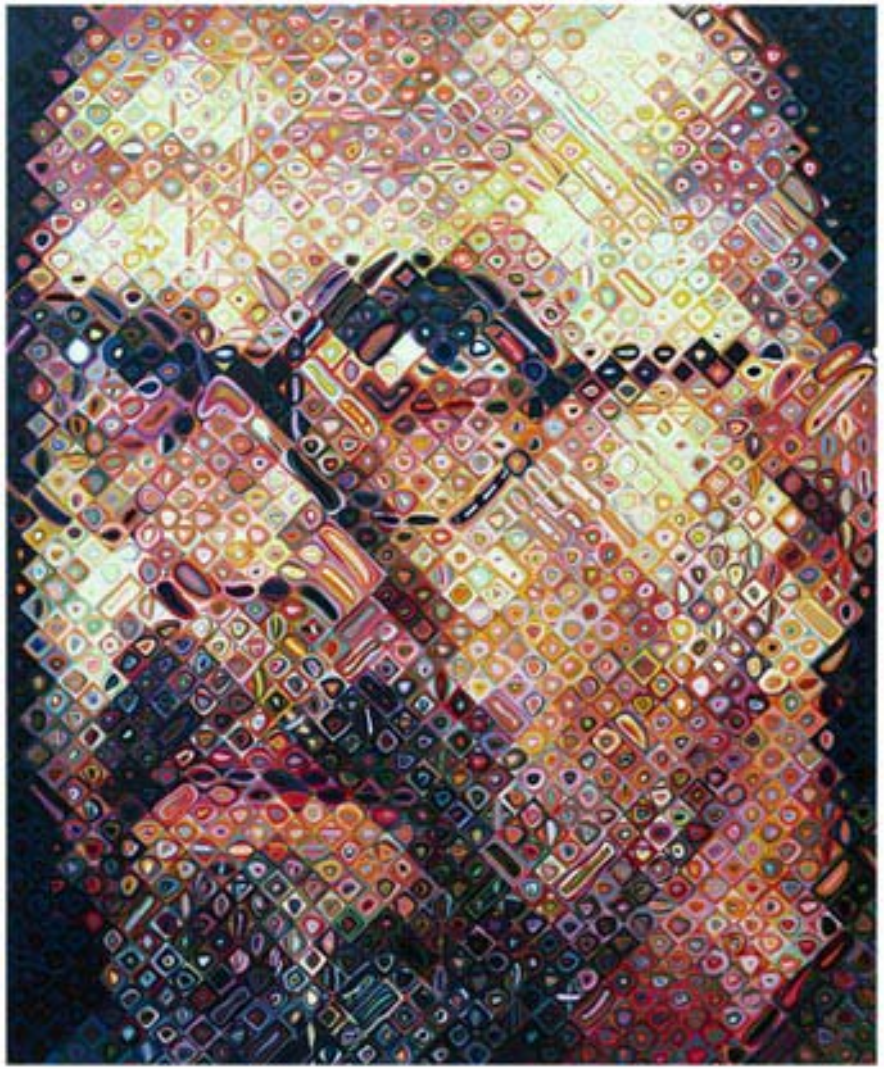




www.photomosaic.com

“Layered” pointillism

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

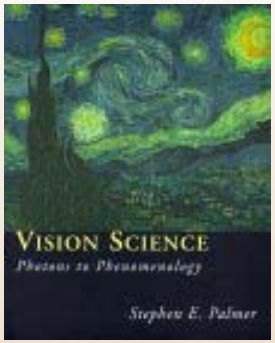


Chuck Close, *Self-Portrait, 2000*

Conclusions

- 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

Selected Bibliography



Vision Science
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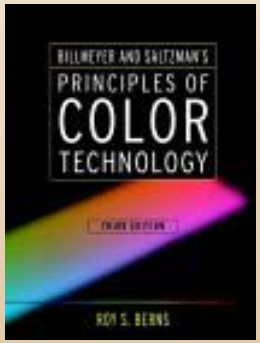
MIT Press; ISBN: 0262161834
760 pages (May 7, 1999)



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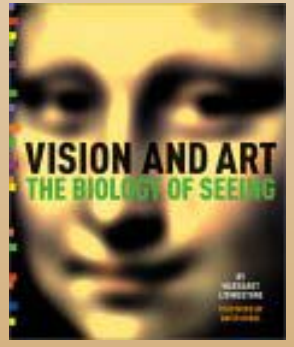
by Roy S. Berns, Fred W. Billmeyer, Max Saltzman
Wiley-Interscience; ISBN: 047119459X
304 pages 3 edition (March 31, 2000)



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Harry N Abrams; ISBN: 0810904063
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