CS 530 - Visualization

Color Perception

Thanks to Penny Rheingans (UMBC) and Chuck Hansen (Utah)

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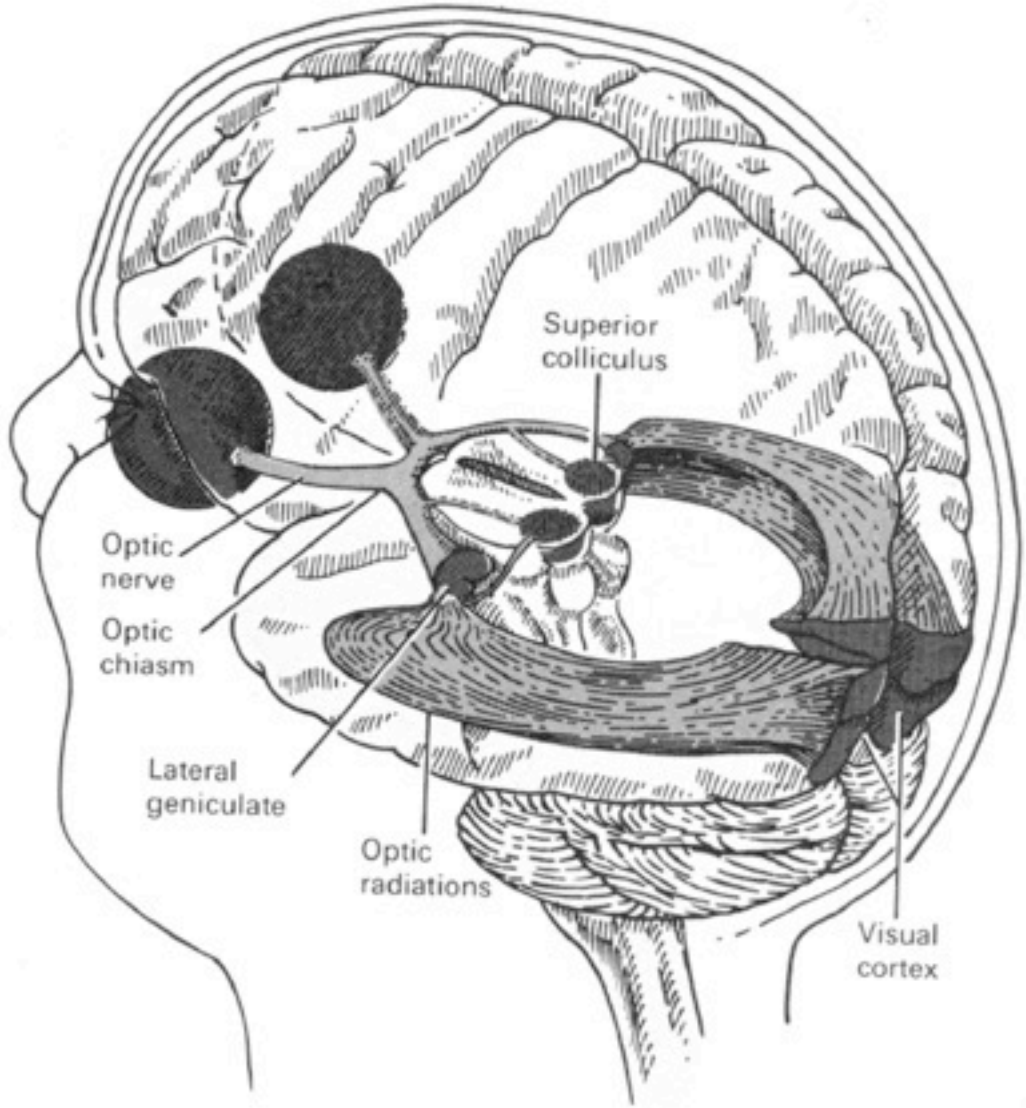
PURDUE UNIVERSITY

Characteristics of Color Perception

- Fundamental, independent visual process
  - after-images
  - Simultaneous color contrast
  - Chromatic Adaptation
- Relative, not absolute
- Interactions between color and other visual properties

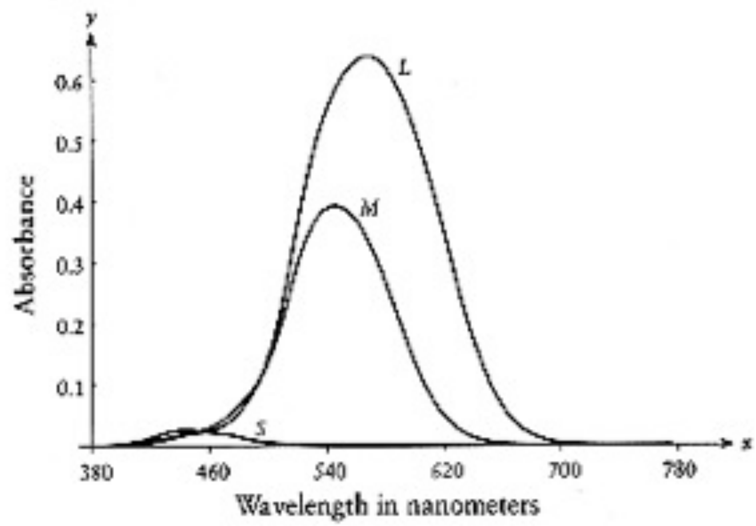
Color Pathway

- Red, green, and blue (roughly) cones
- Retinal ganglion cells
- Parvocellular layers in LGN
- Areas in visual cortex
  - V1: blobs
  - V2: thick stripes
  - V4: color


Superior colliculus
Optic nerve
Optic chiasm
Lateral geniculate
Optic radiations
Visual cortex

Physiology: Receptors

- Cones
  - active at normal light levels
  - three types: sensitivity functions with different peaks



Glassner '95

Physiology: Ganglia

- Transform incoming SML into <u>opponent</u> color responses
  - G - R
  - Y - B (Y = R+G)
  - W (W ≅ R+G)
- Characteristics
  - concentric receptive fields
  - logarithmic response of receptors
  - adaptation

Physiology: Brain

- Lateral geniculate nuclei
  - assemble data for single side of visual field
  - 2 monochromatic layers => magnocellular path
  - 4 chromatic layers => parvocellular path
- Visual cortex
  - visual area 1: blobs
  - visual area 2: thick stripes
  - visual area 4: color

Parvocellular Division

- Role in vision
  - discrimination of fine detail
  - color
- Characteristics
  - color: sensitive to wavelength variations
  - acuity: small RF centers
  - speed: relatively slow response

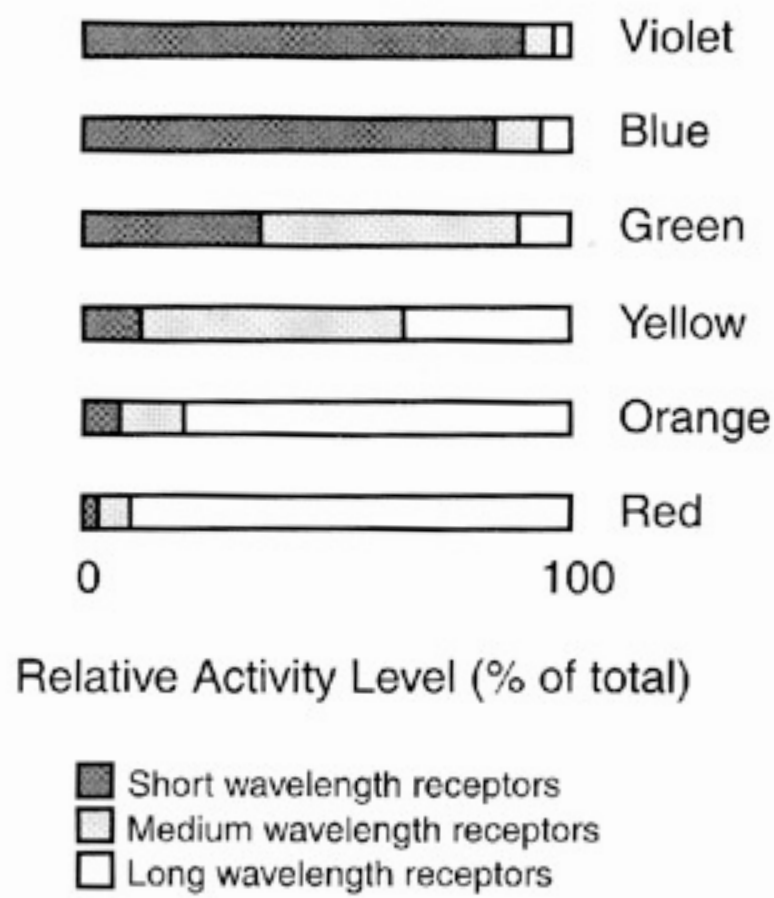
Models of Color Vision

- Tricolor theory
- Opponent process theory

Trichromatic Theory

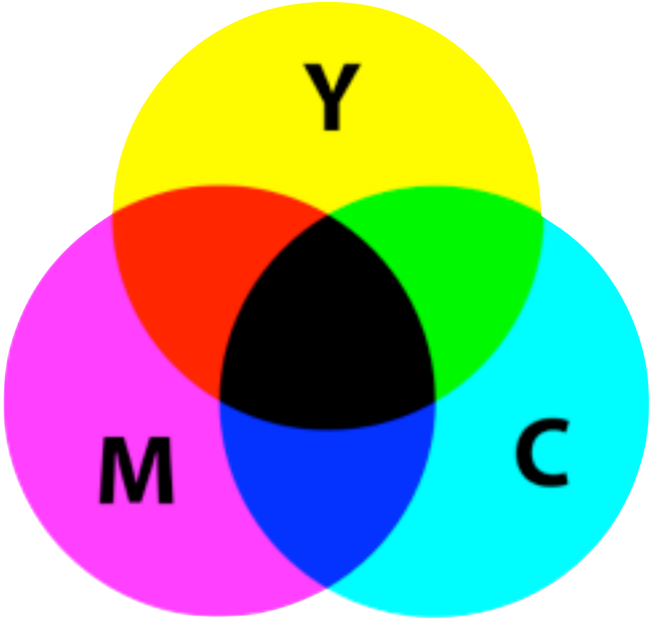
- Three types of cones – each with a characteristic wavelength
- Mixture of 3 responses defines color
- Explains some psychophysical data
  - 3D color space (i.e. 3 colors match any perceived)
  - Metamers: match of an apparent color with a different spectral distribution (3D basis)
  - Color blindness (different types)

Trichromatic Theory

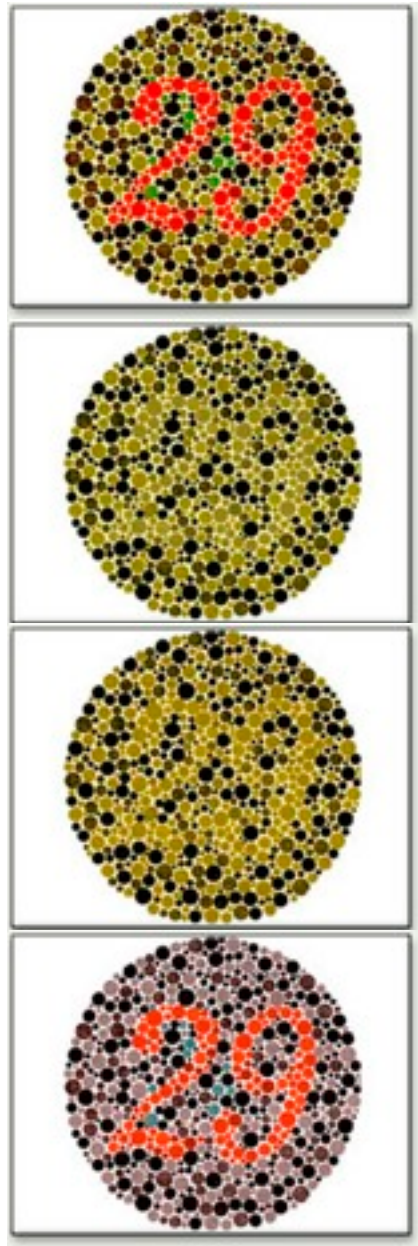


Trichromatic Theory Shortcomings

- Color blindness
  - R-G, B-Y, All
- Yellow seems primary
- Color constancy



Color Blindness



Normal

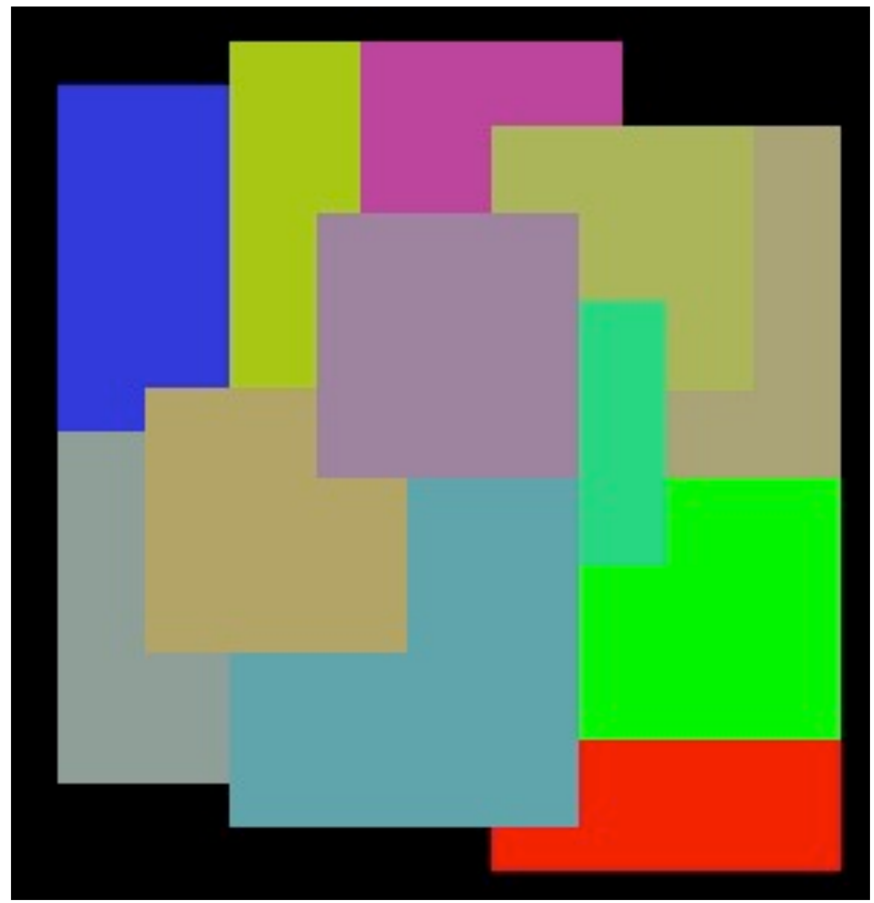
Protan (L-cone)

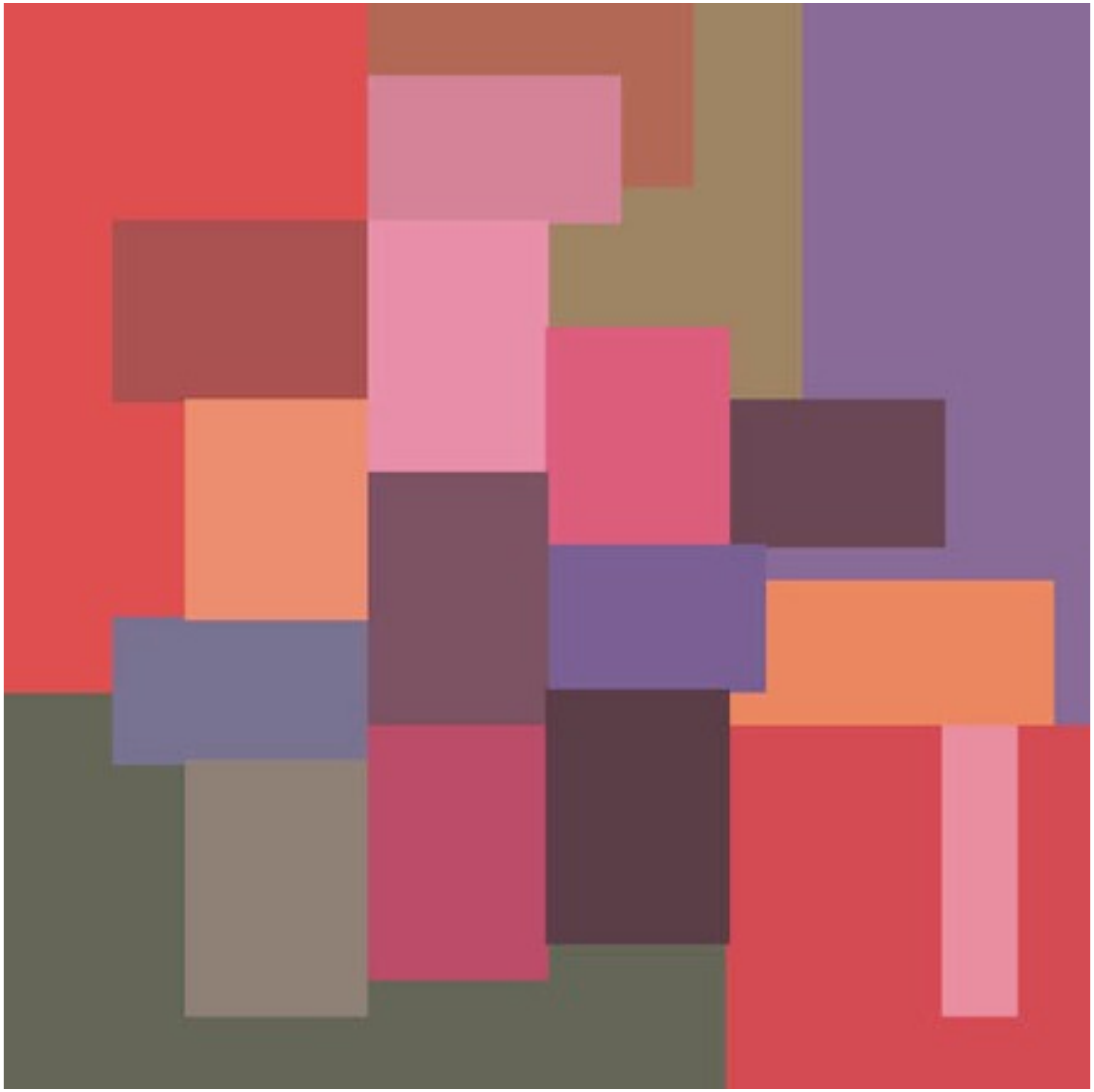
Deutan (M-cone)

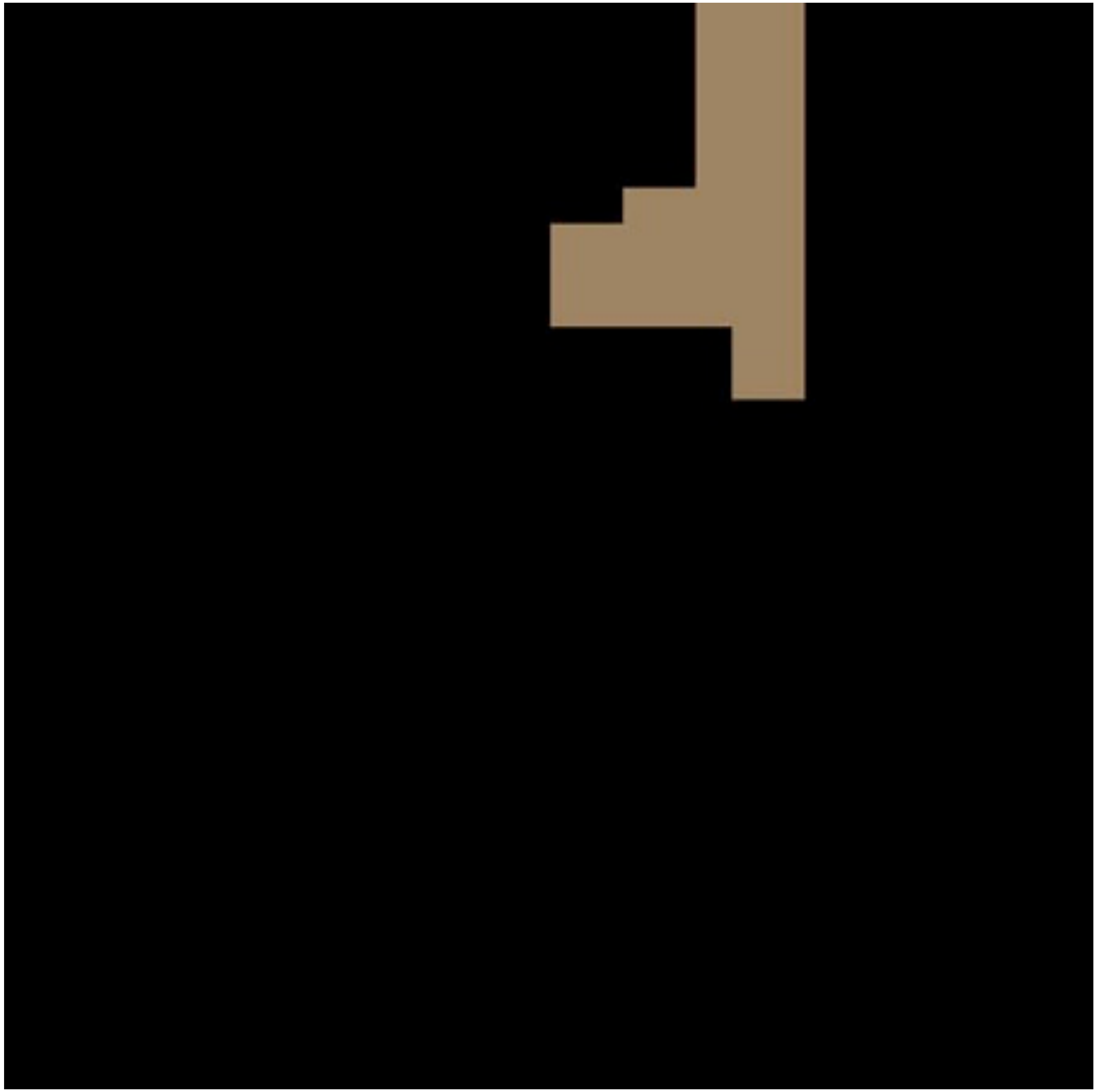
Tritan (S-cone)

Mondrian Color Patches

- Colors look different depending on their neighbors
- Adjacency/black lines
- Color edges are critical to color perception
- Can determine color in non-white lighting conditions

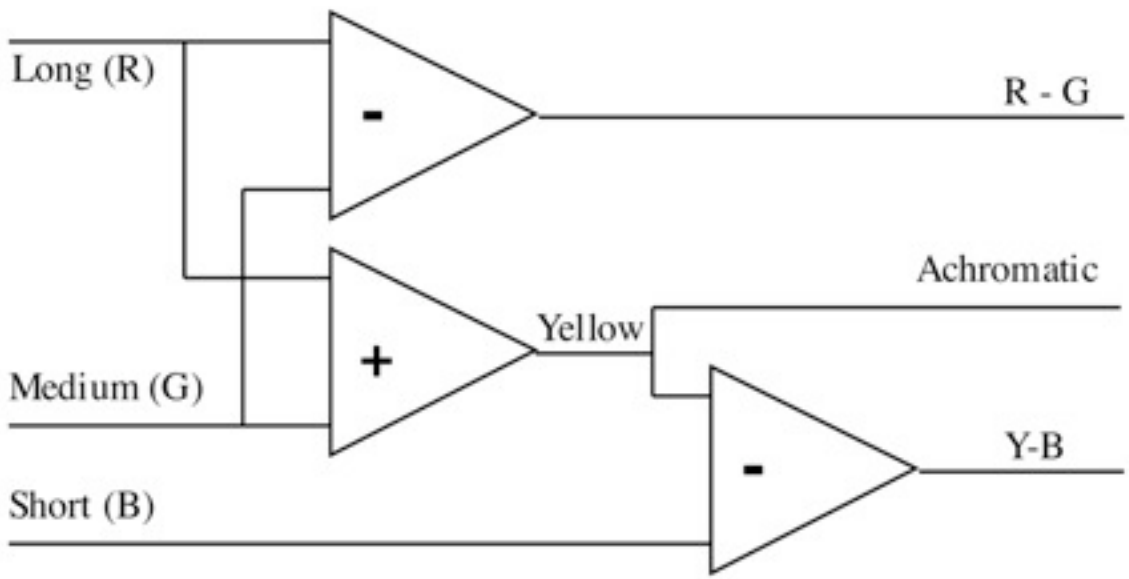






Opponent Color Theory

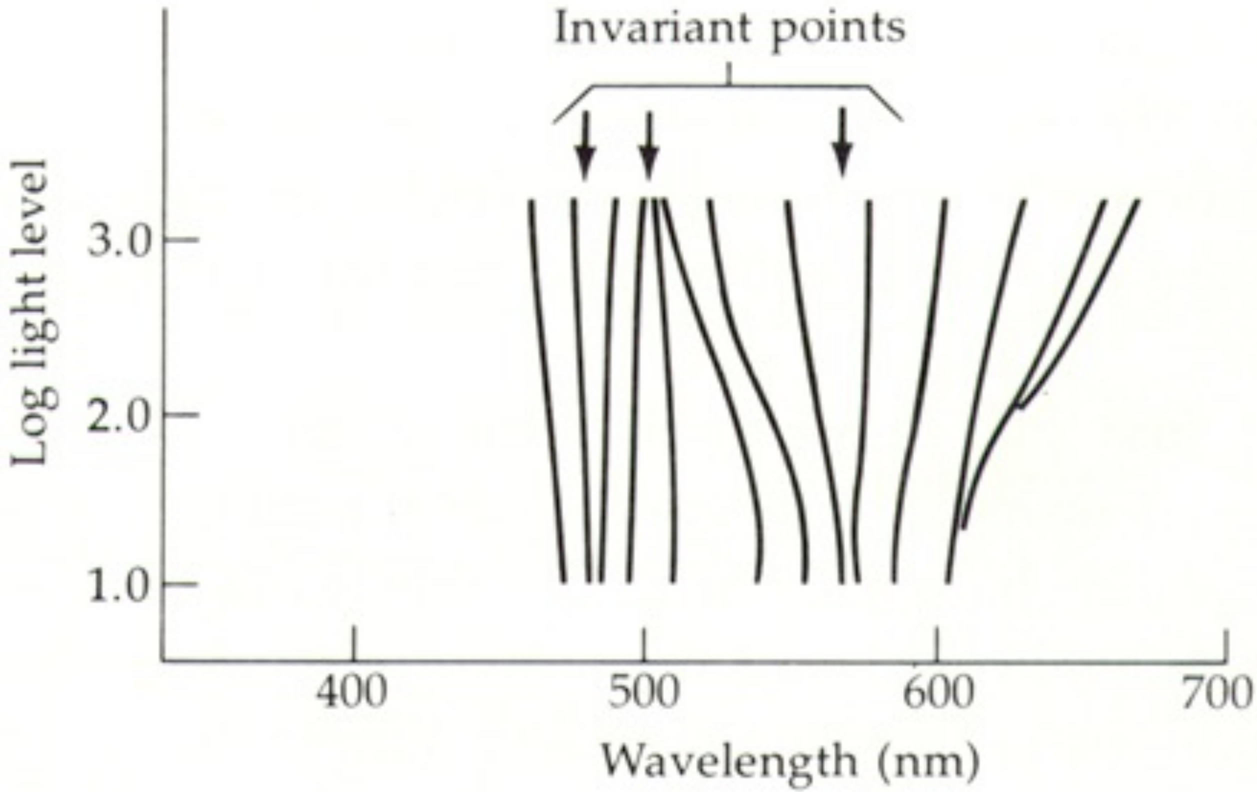
- Humans encode colors by differences
- E.g R-G, and B-Y Differences
  - Color blindness



Perceptual Distortions

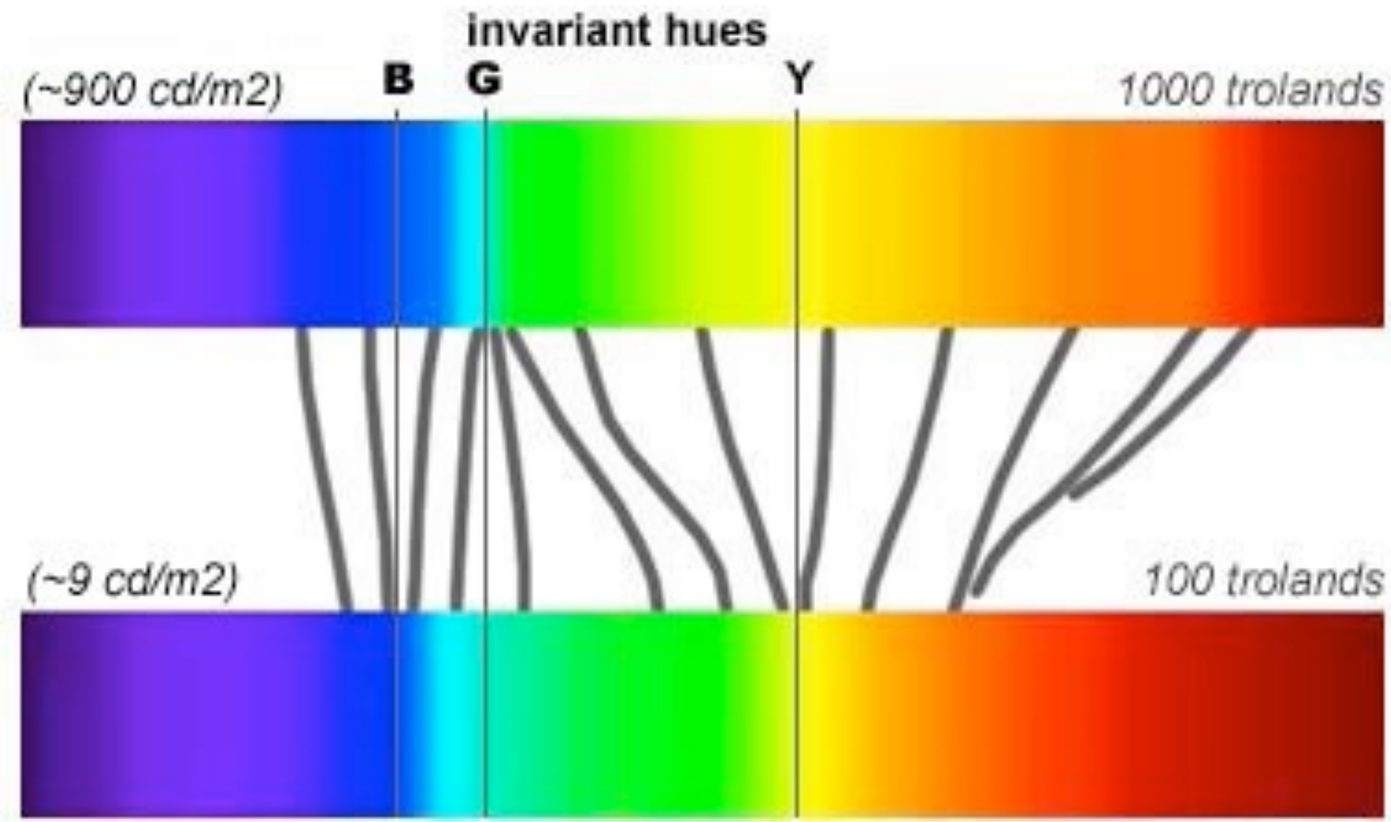
- Color-deficiency
- Interactions between color components
  - brightness - hue (Bezold-Brucke Phenomenon)
  - saturation - brightness (Helmholtz-Kohlrausch effect)
- Simultaneous contrast
  - brightness
  - hue
- Small field achrominance
- Effects of color on perceived size

Bezold-Brucke Phenomenon



Hurvich '81, pg. 73.

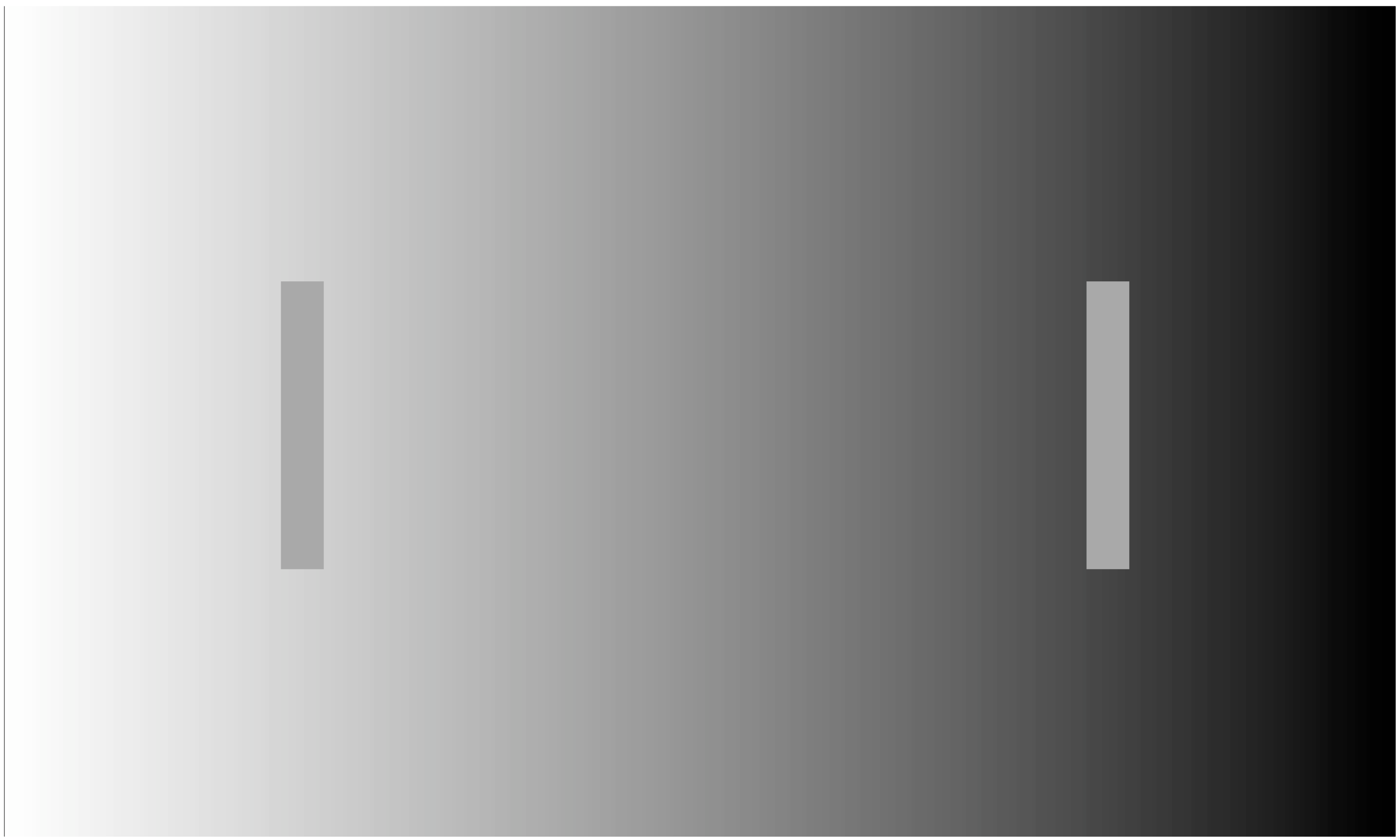
Bezold-Brucke Phenomenon



Hurvich '81, pg. 73.

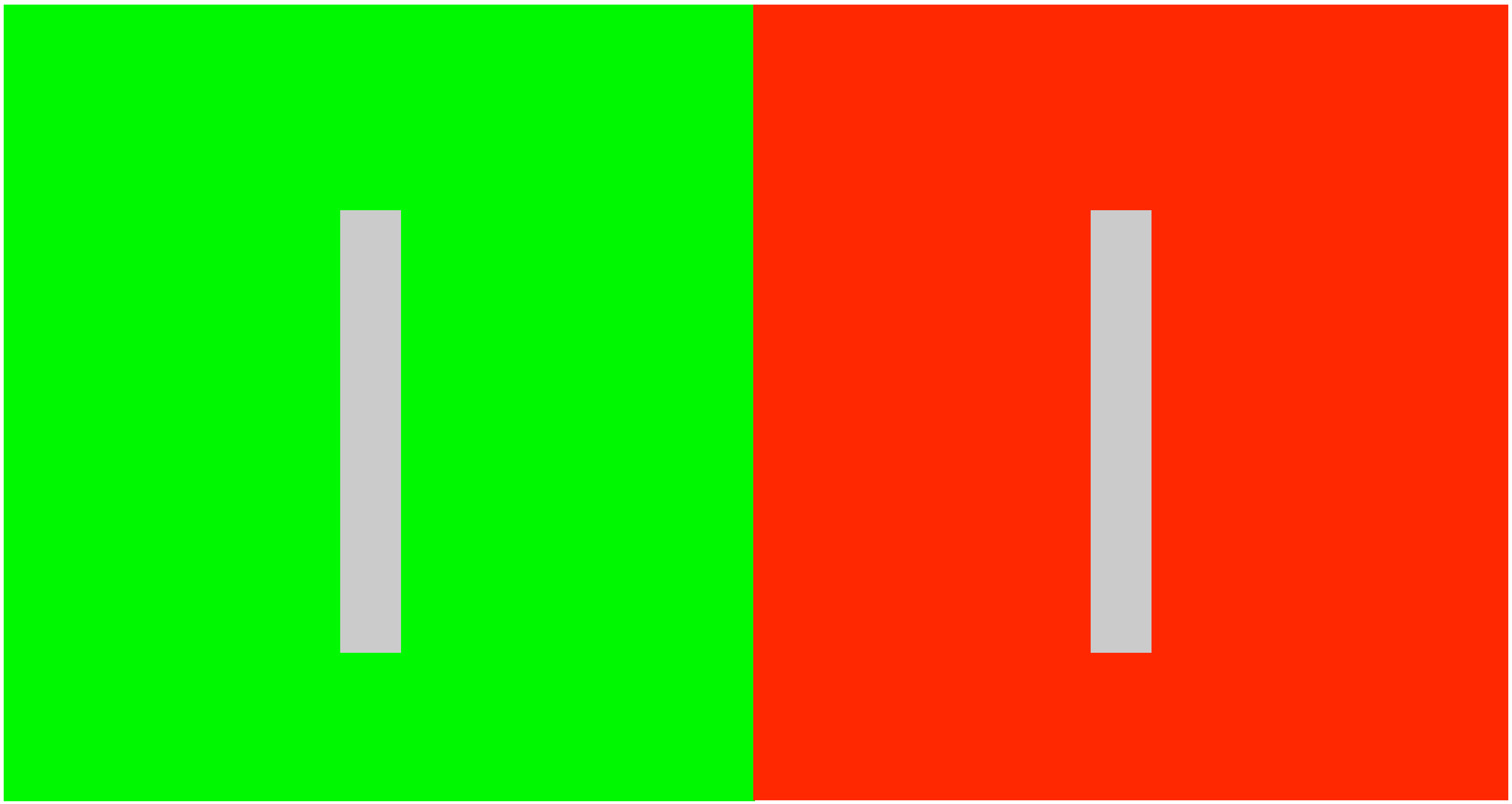
Helmholtz-Kohlraush effect

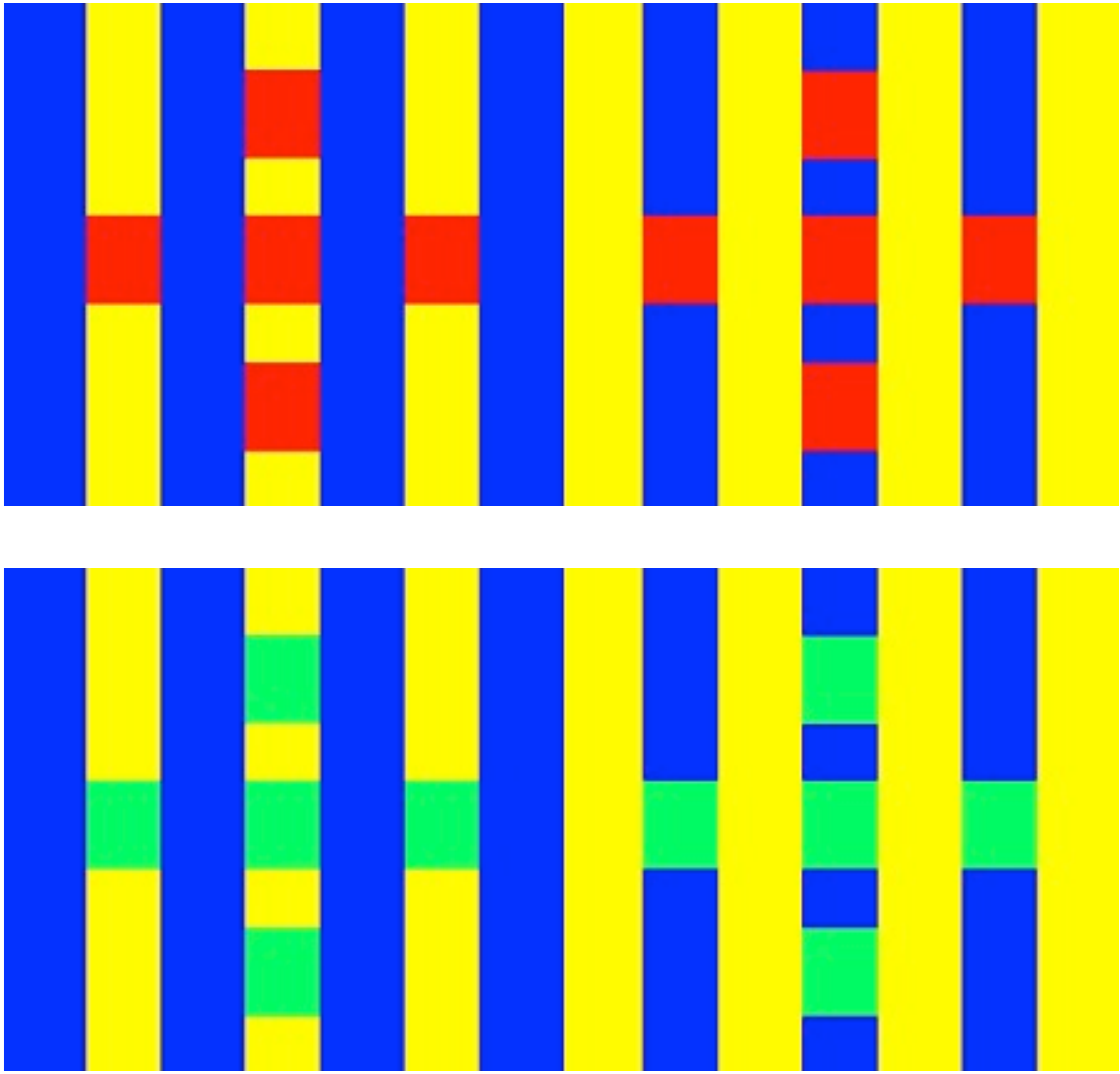
Simultaneous Contrast



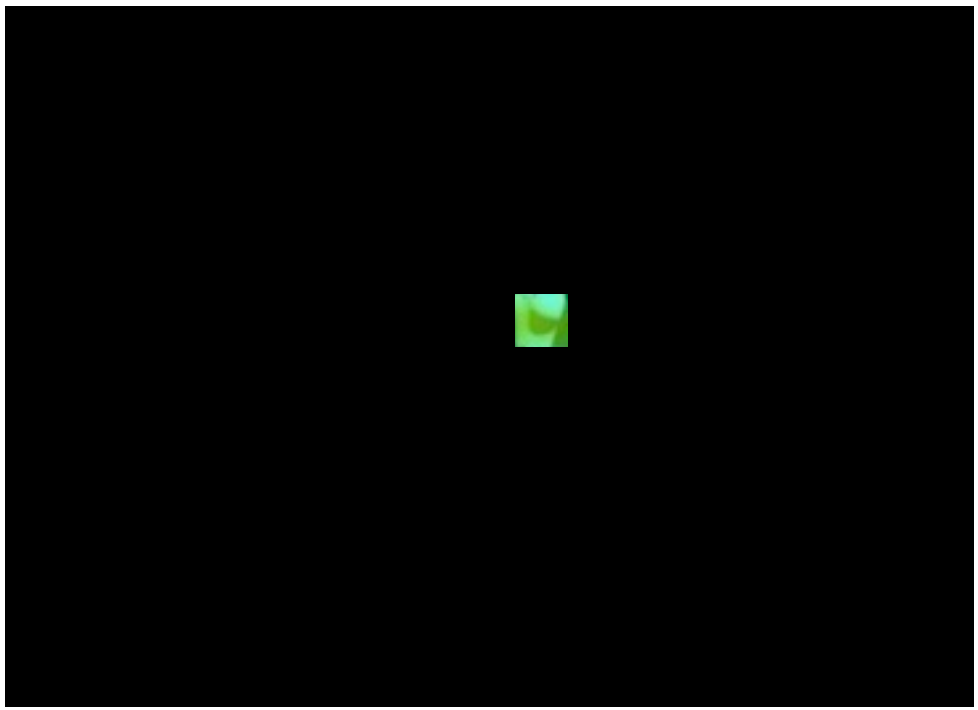
Simultaneous Contrast

Simultaneous Contrast

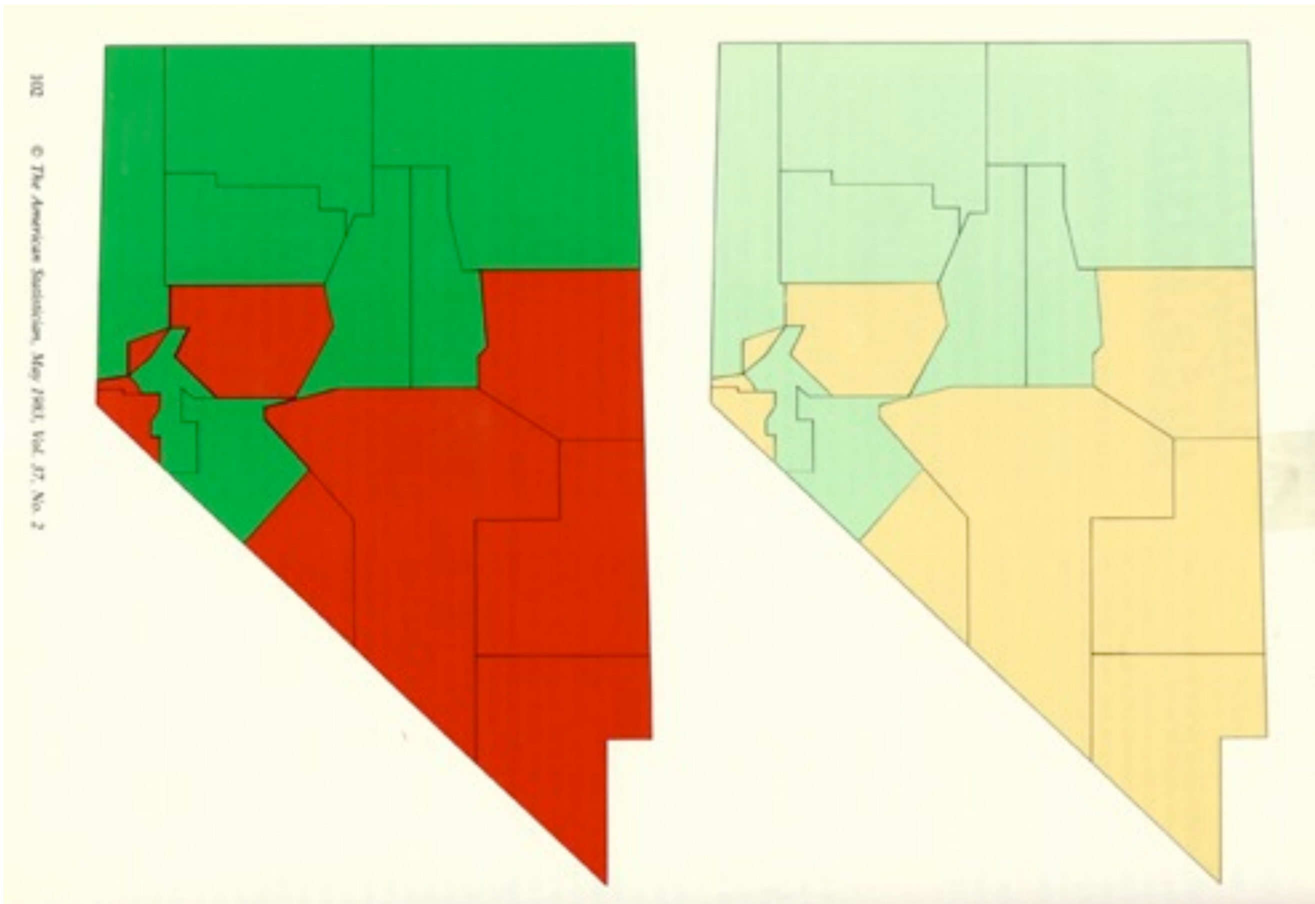




Chromatic Adaptation



Color-size Illusion

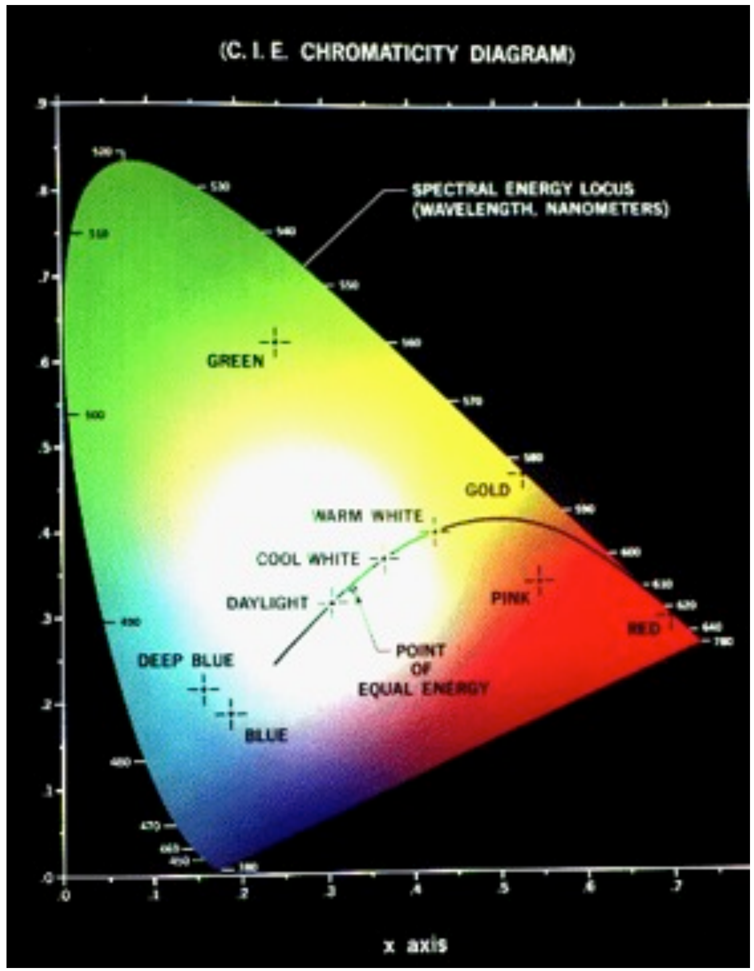


- Cleveland and McGill '83.

Color Spaces

- Perceptually based
  - device independent, perceptually uniform
  - CIELUV, CIELAB, Munsell
- Device-derived
  - convenient for describing display device levels
  - RGB, CMY
- Intuitive (transformations)
  - based in familiar color description terms
  - HSV, HSB, HLS

The Space of Human Color

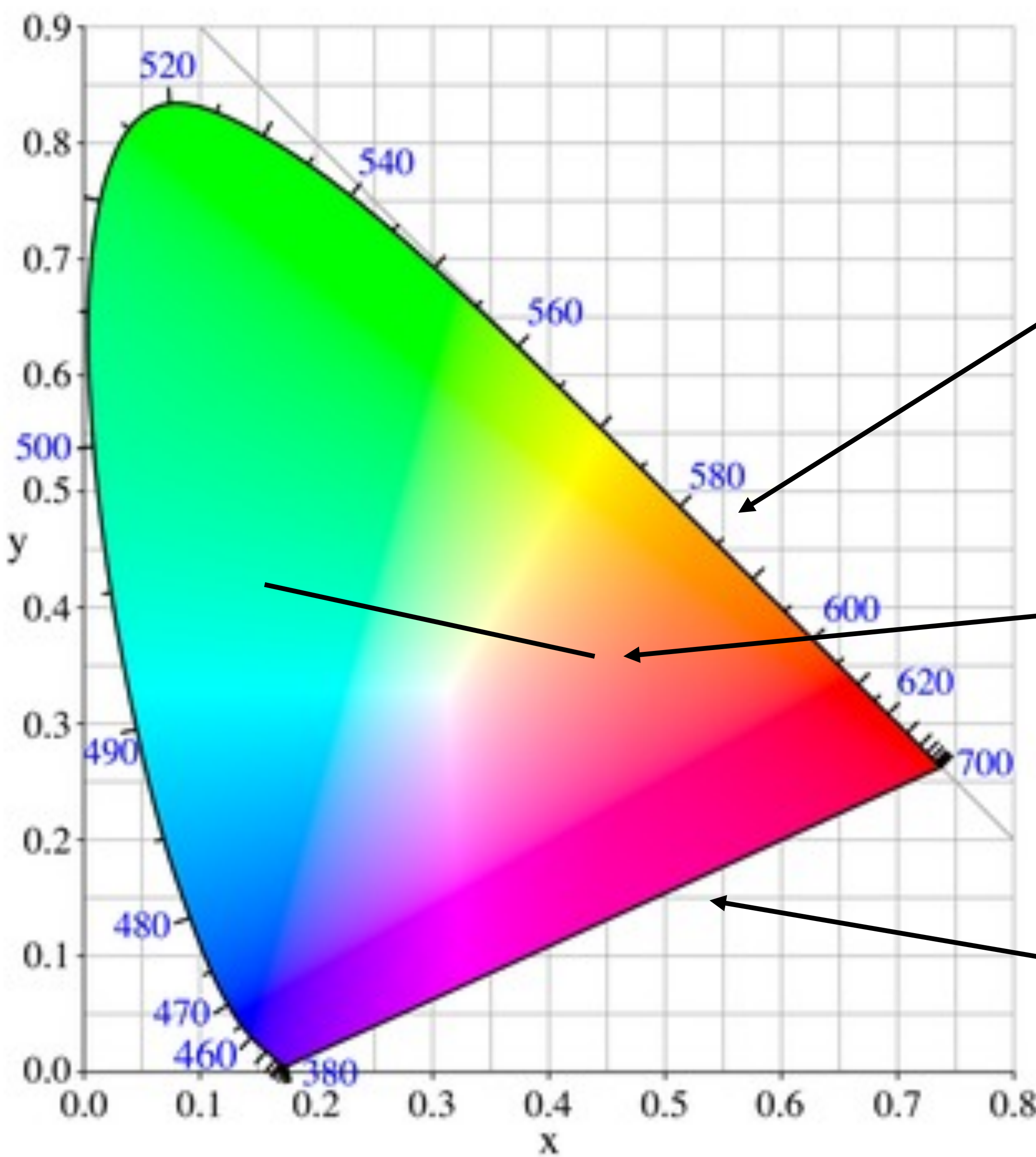


Gamut

CIE 1931 XYZ

xy plot

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$



spectral locus

Mixing colors

purple line

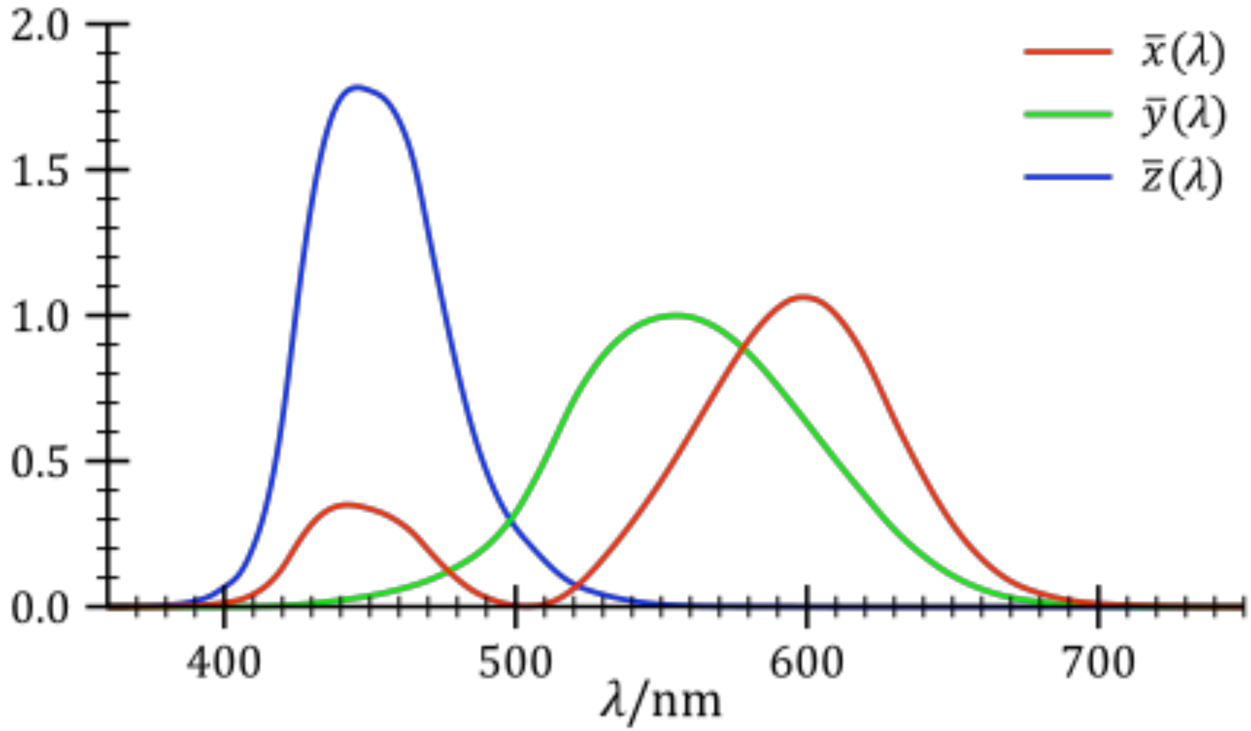
CIE Color Space

- Humans can mimic any pure light by addition (and subtraction) of 3 primaries
  - Color is a 3D space
- With R-G-B, addition and subtraction were required to get all wavelength

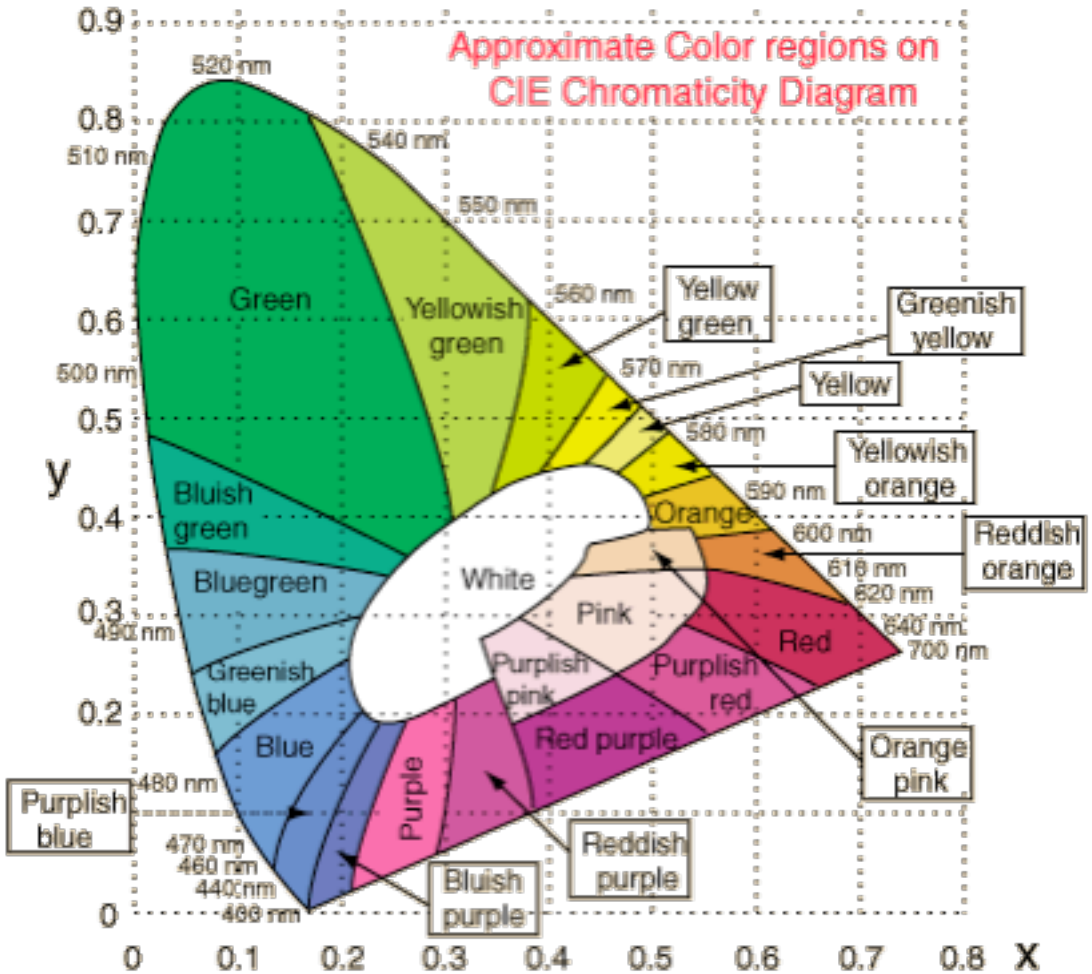
The CIE Color Space

- In nature, light adds (but does not subtract)
- Conversion to another coordinate system X-Y-Z is a convenience---they are not primary colors
- Any 3 primaries (additive) can produce only a subset of all visible colors

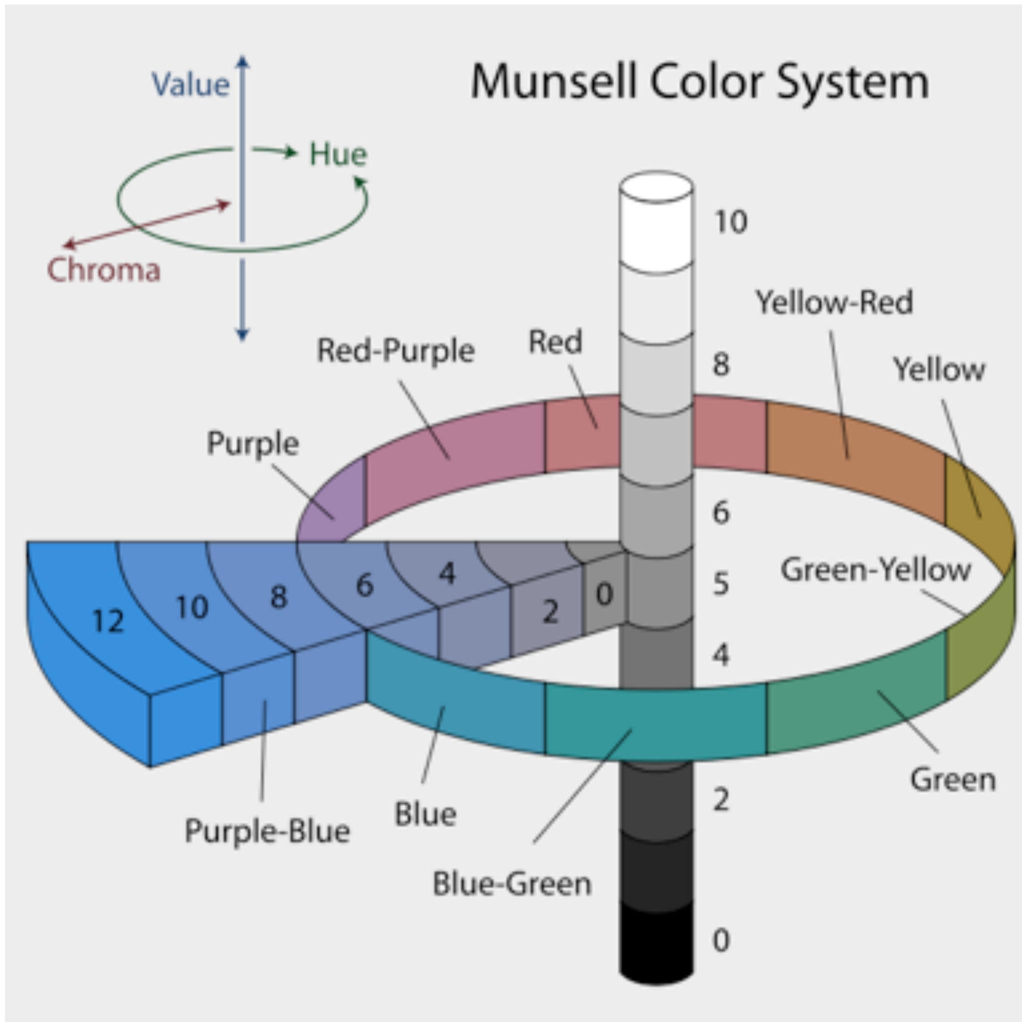
$$X = \int_0^\infty I(\lambda)\,\overline{x}(\lambda)\,d\lambda$$
$$Y = \int_0^\infty I(\lambda)\,\overline{y}(\lambda)\,d\lambda$$
$$Z = \int_0^\infty I(\lambda)\,\overline{z}(\lambda)\,d\lambda$$



The Chromaticity Diagram



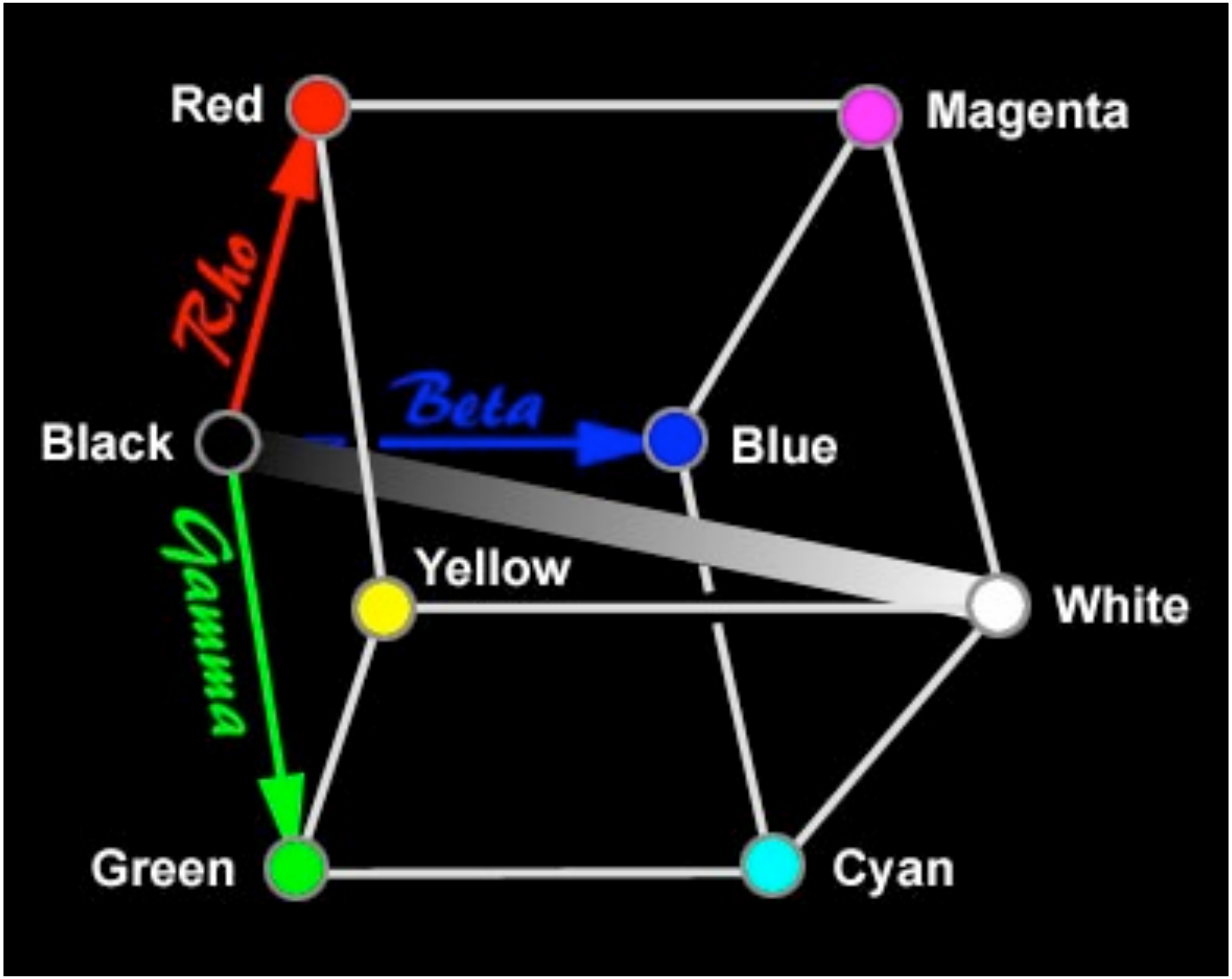
Munsell Color System



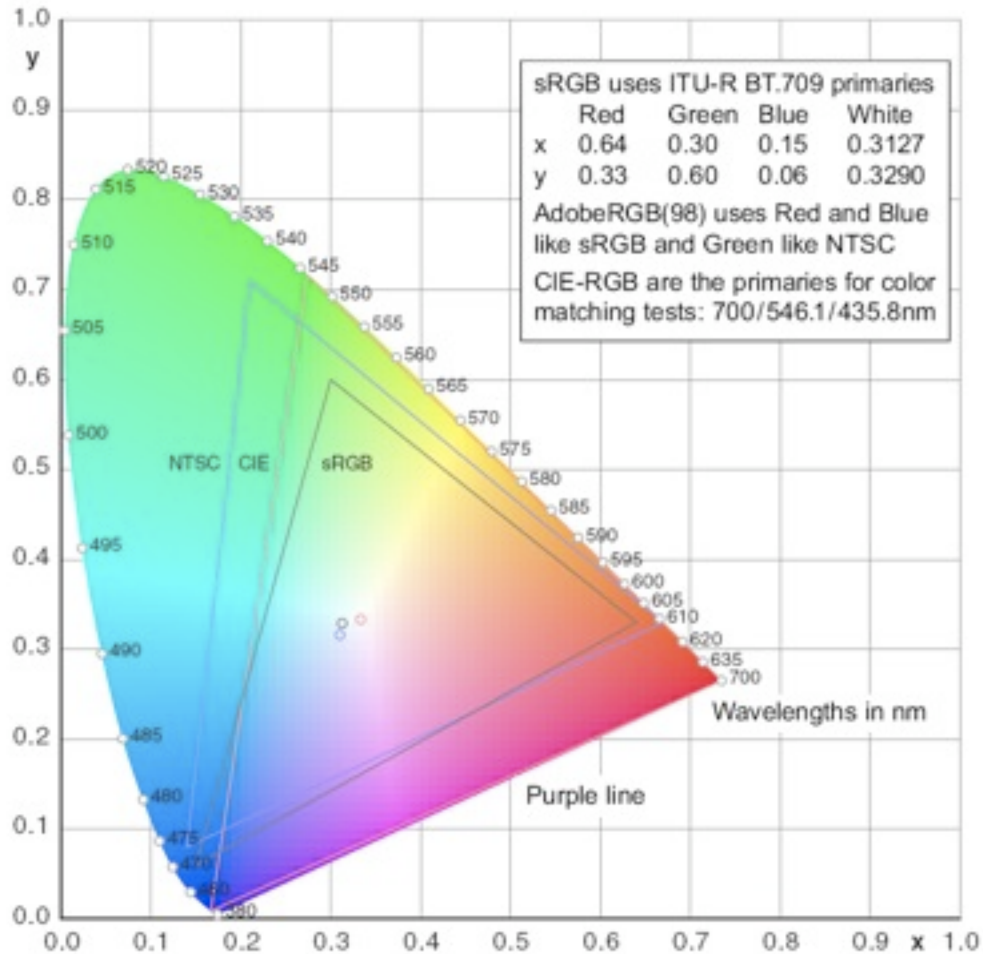
Munsell Color System

R-G-B Color Space

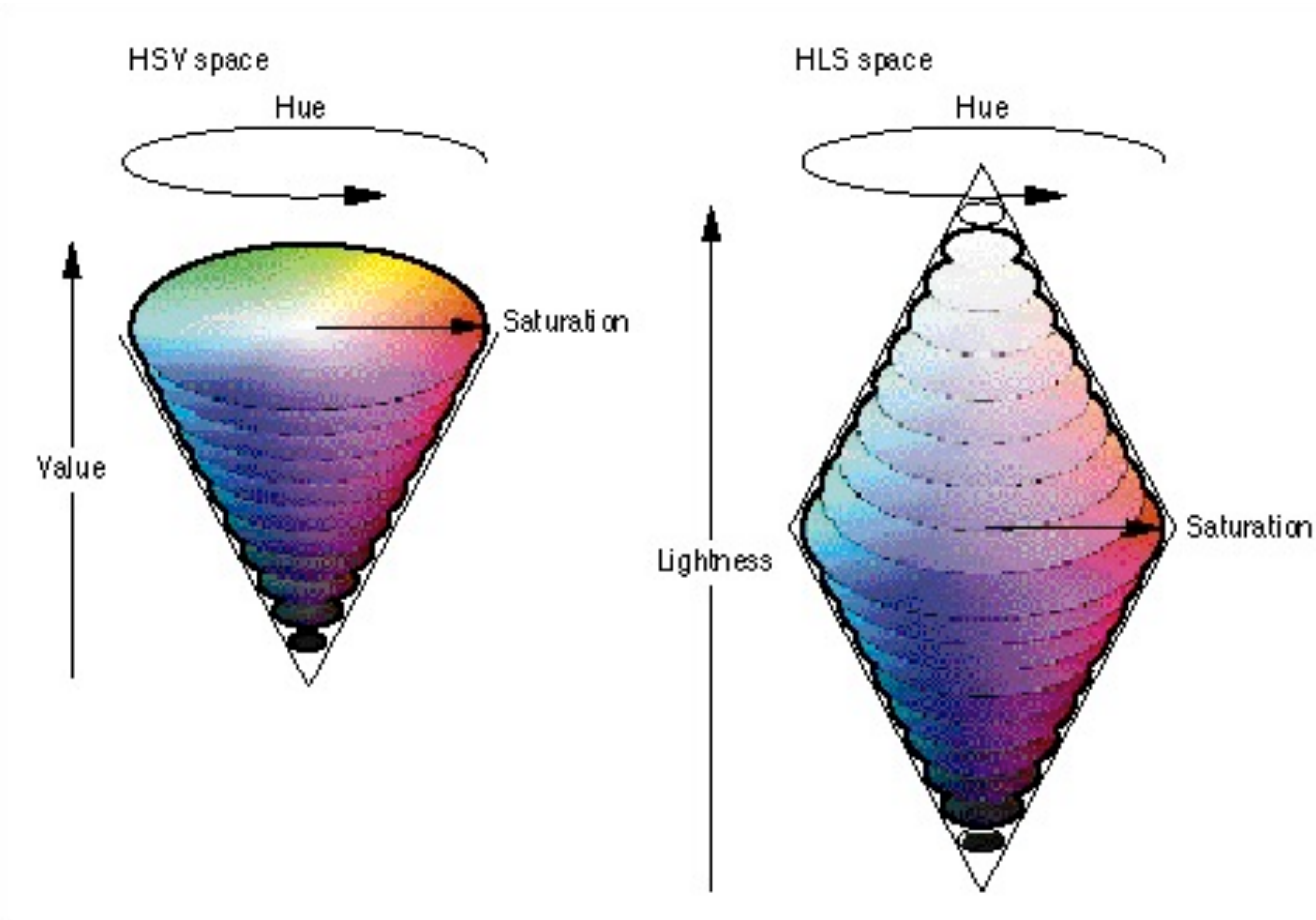
- Convenient colors (screen phosphors)
- Decent coverage of the human color
- Not a particularly good basis for human interaction
  - Non-intuitive
  - Non-orthogonal (perceptually)


Red
Magenta
Rho
Beta
Black
Blue
Gamma
Yellow
White
Green
Cyan

The Chromaticity Diagram



HSV/HSL


HSV space
Hue
Saturation
Value
HLS space
Hue
Saturation
Lightness

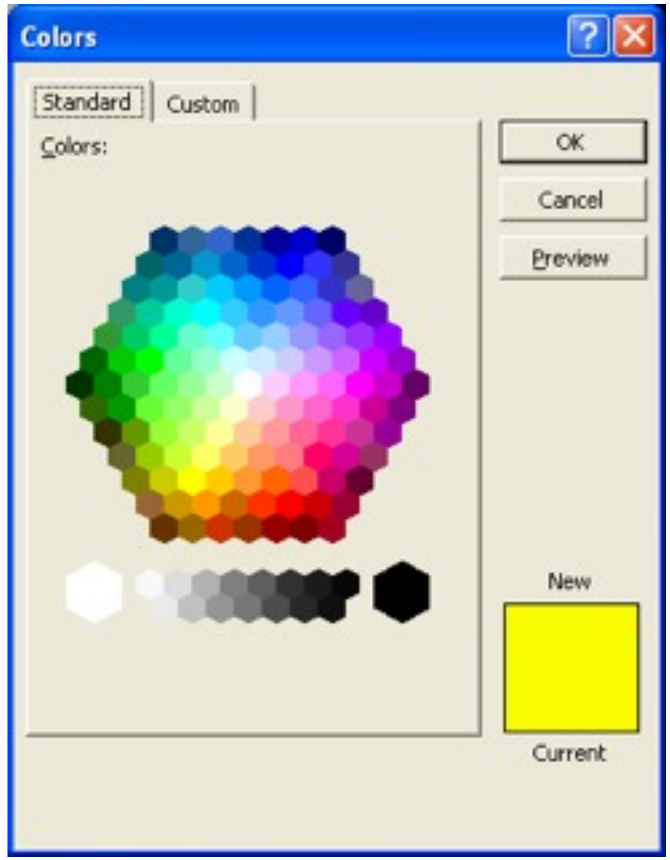
HSI/HSV

- Value/Luminance – total amount of energy
- Saturation – degree to which color is one wavelength
- Hue – dominant wavelength

HSV

- Max = max(R, G, B)
- Min = min(R, G, B)
- S = (max – min)/max
- If R==Max → h = (G-B)/(max-min)
- If G==Max → h = 2+(B-R)/(max-min)
- If B==Max → h = 4 + (R-G)/(max-min)
- If h<0 → H = h/6 + 1
- If h>0 → H = h/6

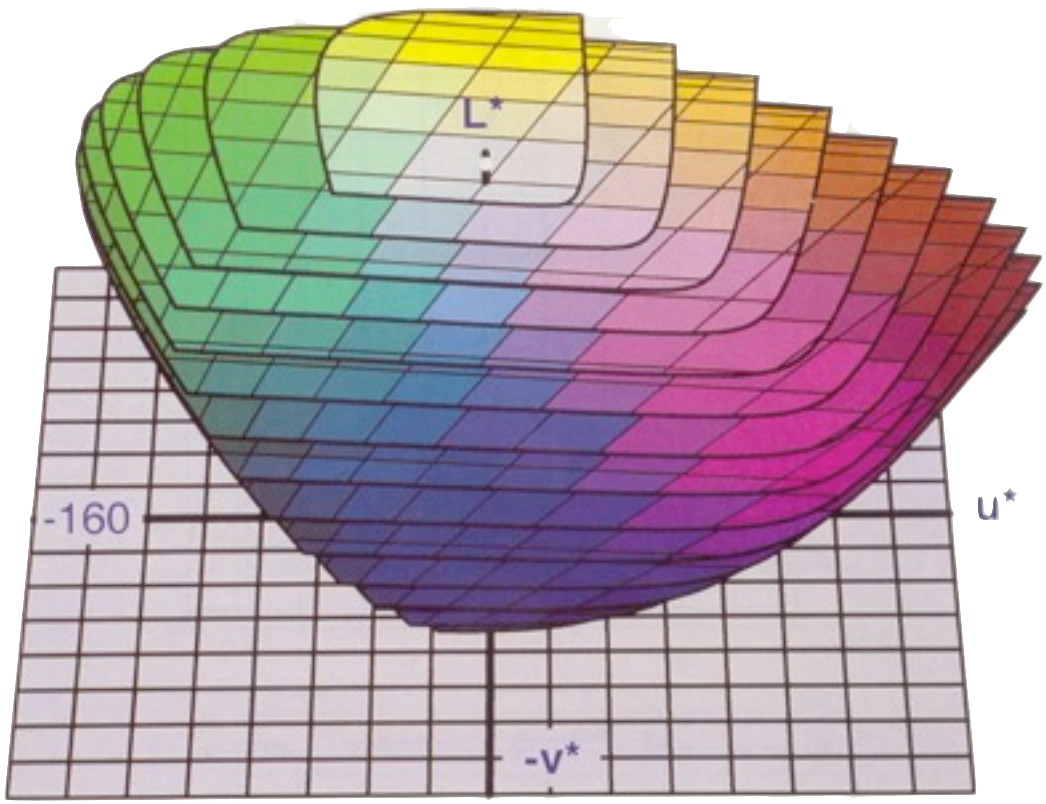
HSV User Interaction



HSI

- $S = \sqrt{\dfrac{(R-G)^2 + (R-B)^2 + (G-B)^2}{2}}$
- $I = \dfrac{R+G+B}{3}$
- $H = \dfrac{a - \arctan \frac{(R-1)b}{G-B}}{2\pi}$
- $a = \dfrac{\pi}{2}$ if G>B, $\dfrac{3\pi}{2}$ if G<B
- $H = 1$ if G=B
- $a = \sqrt{3}$

Perceptual Spaces



Hill et al. '97, pg. 136

Perceptual Spaces