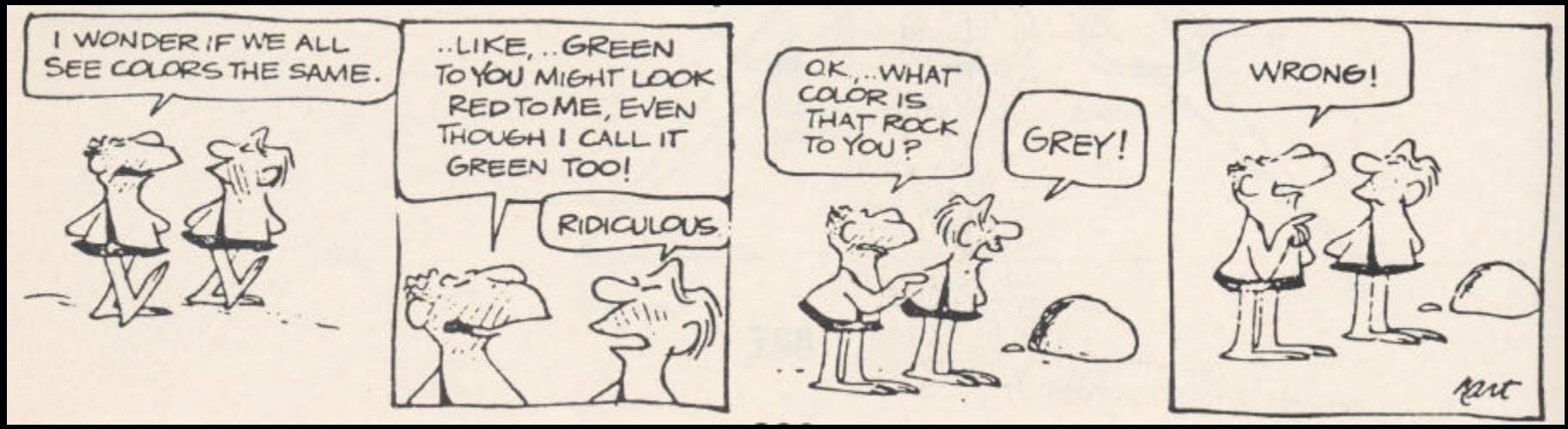
The Art and Science of Depiction

Introduction to Color Vision

Fredo Durand

MIT- Lab for Computer Science

Introduction to color vision

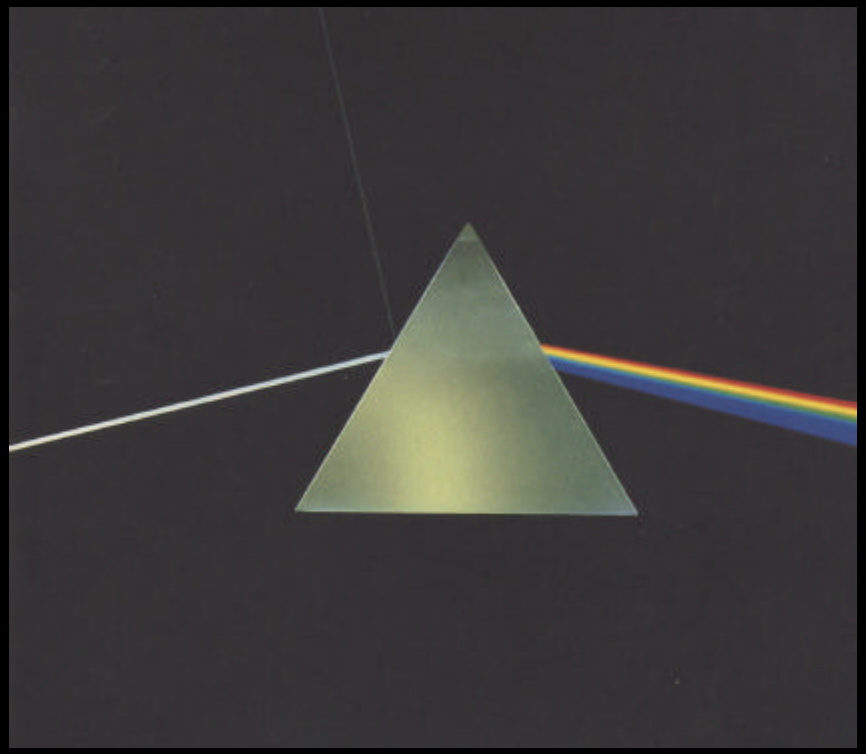


Plan

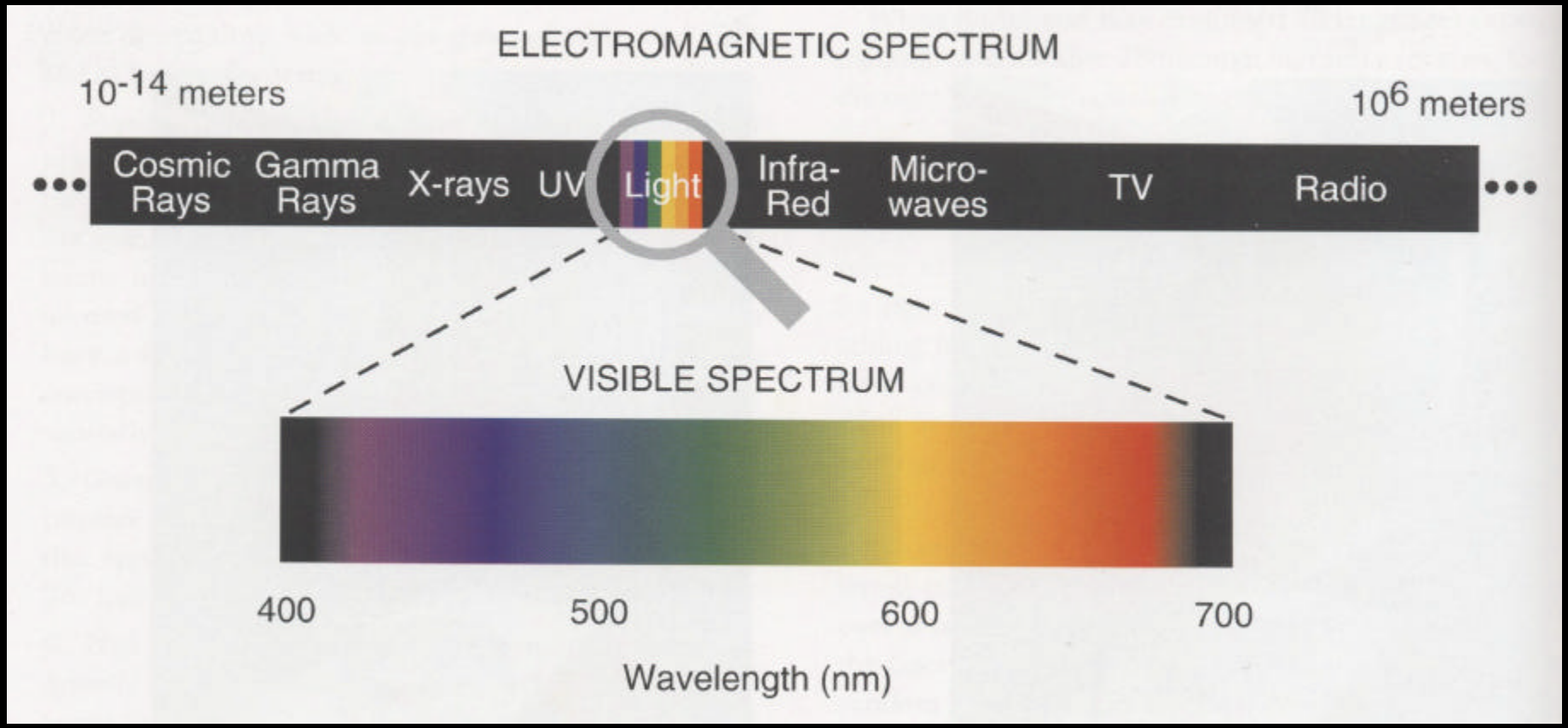
- Physical spectrum
- Trichromatic vision
  - Cones
  - Metamerism
  - Chromatic adaptation
  - Color blindness
- Color Opponents

Physical spectrum

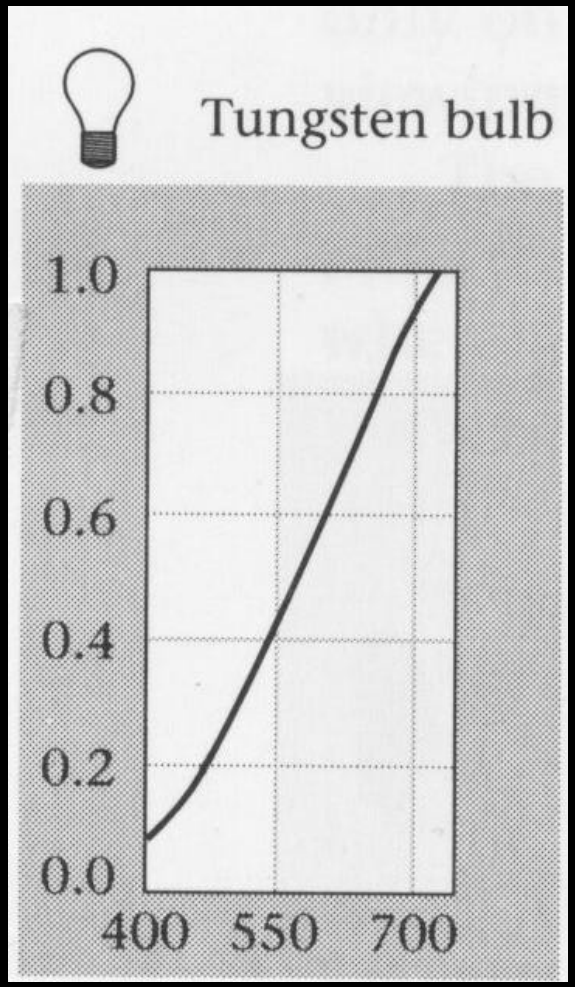
- 1666, Newton
- Pittoni, *Allegory*, 1925

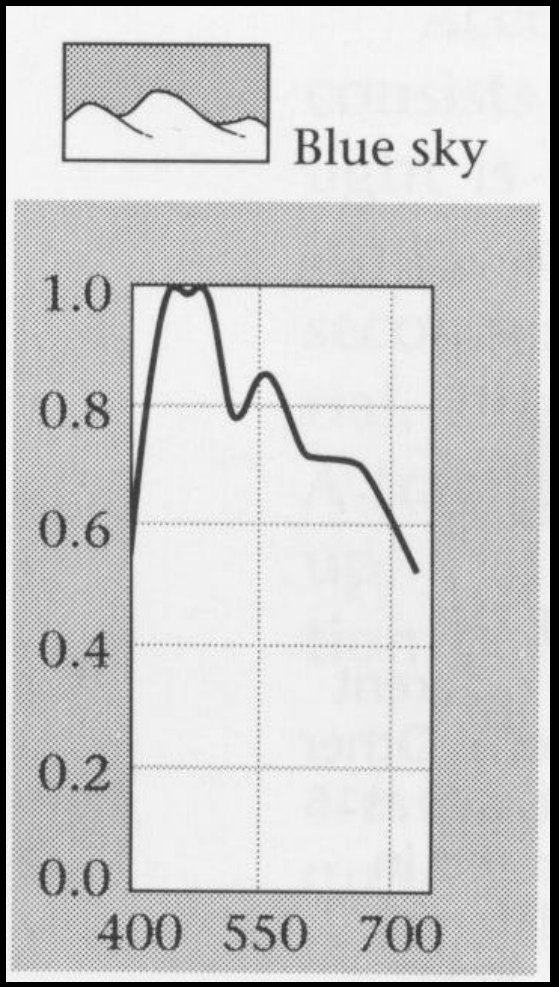


Physical spectrum



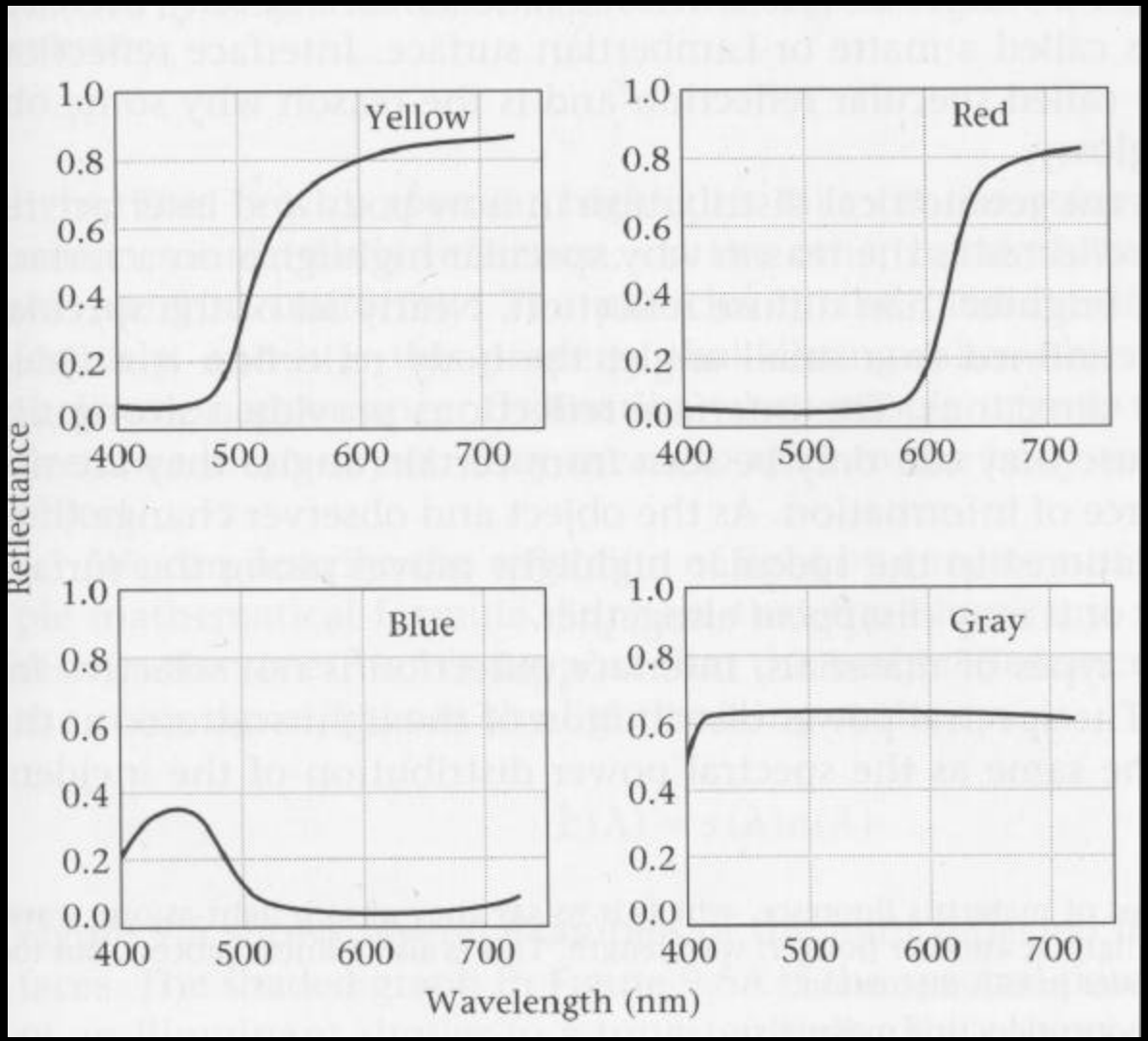
Light source spectrum





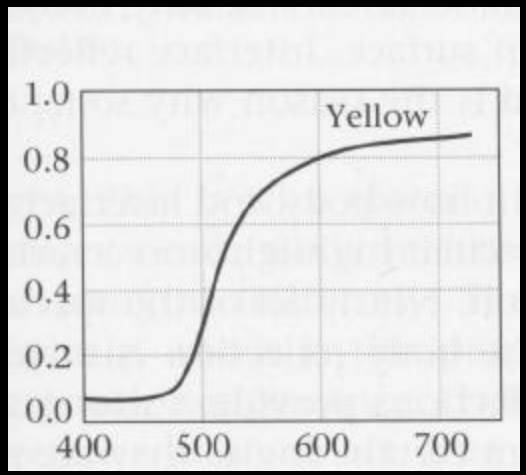
Reflectance Spectrum

- Objects do not have a “color”
- They have a reflectance spectrum

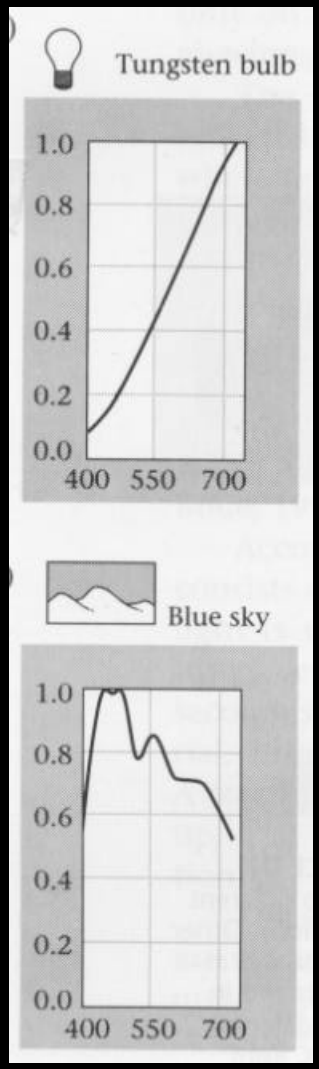


Reflected spectrum

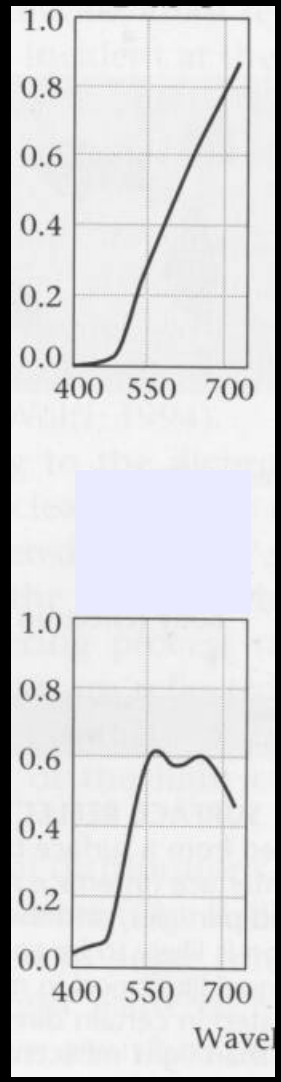
- Depends on light source and reflectance
- Multiply



*



=



Plan

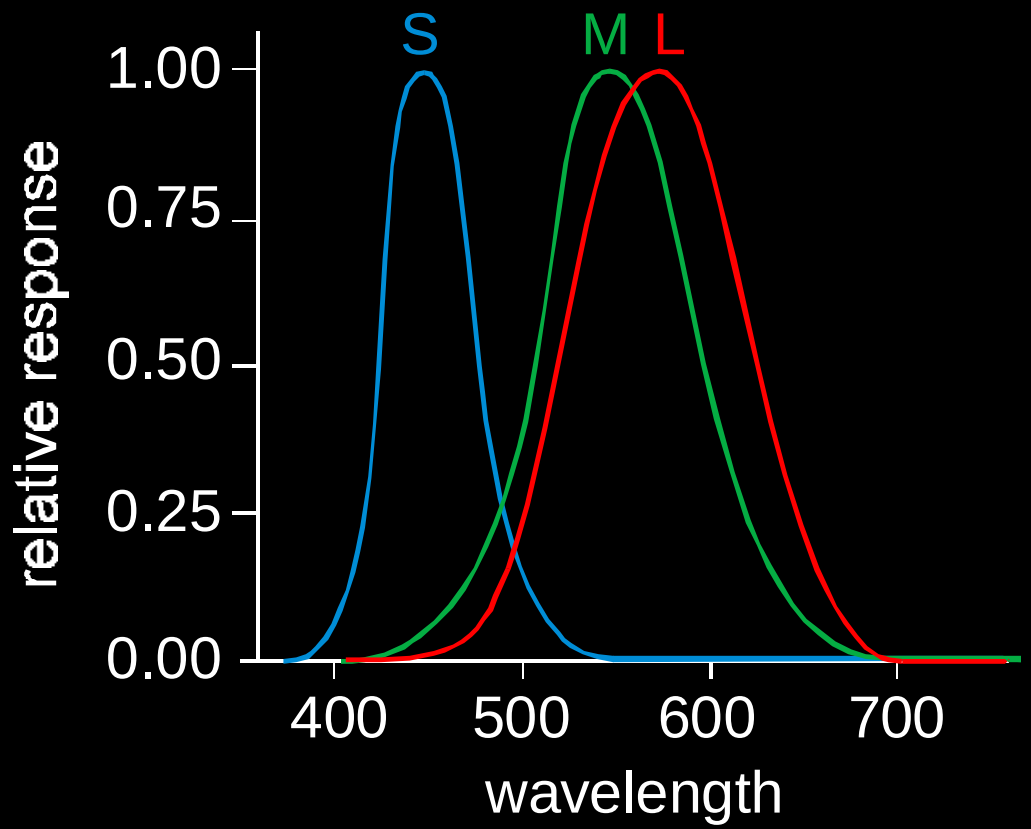
- Physical spectrum
- Trichromatic vision
  - Cones
  - Metamerism
  - Chromatic adaptation
  - Color blindness
- Color Opponents

Trichromatic vision

- Maxwell, Young, Helmholtz
- Cones

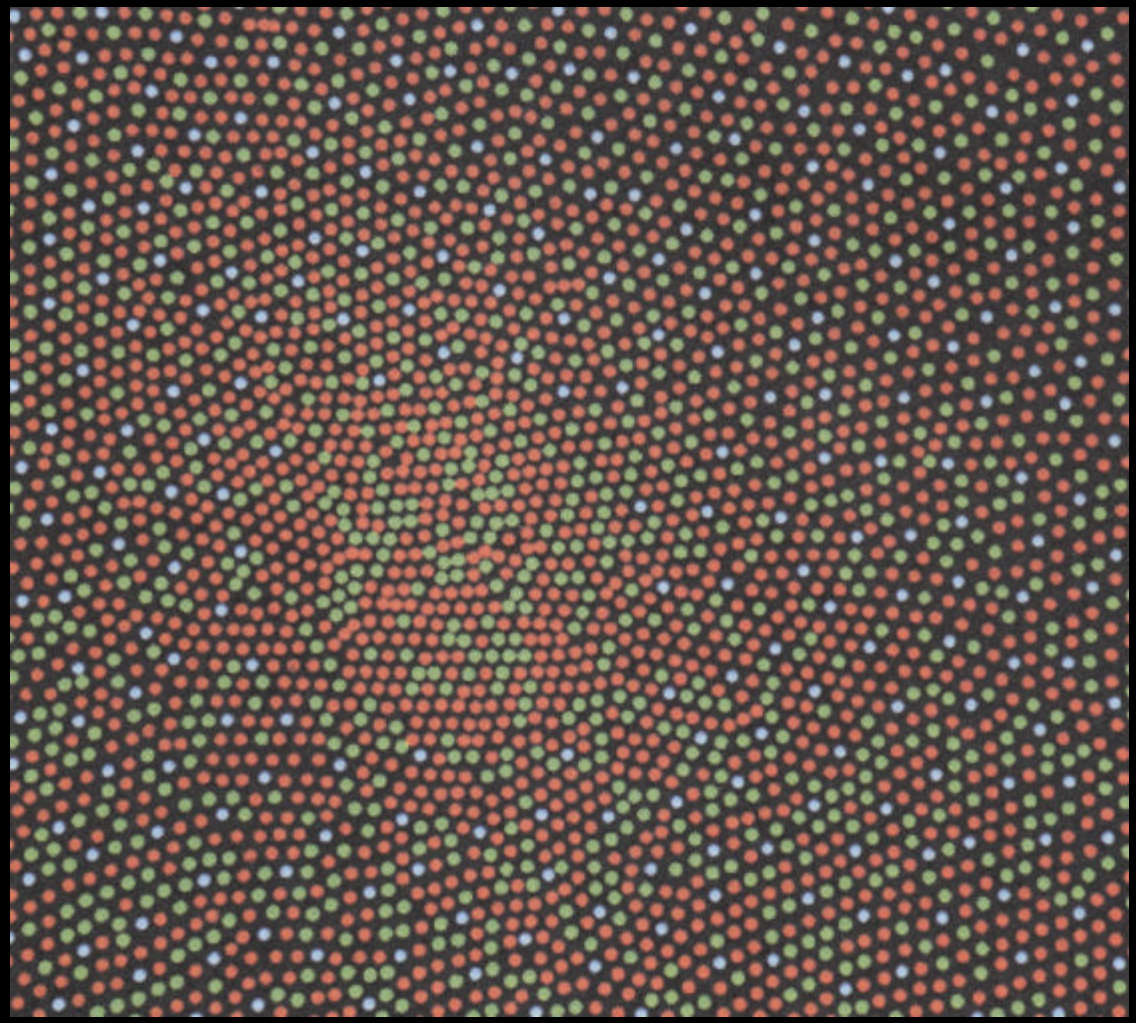
Cone spectral sensitivity

- Short, Medium and Long wavelength

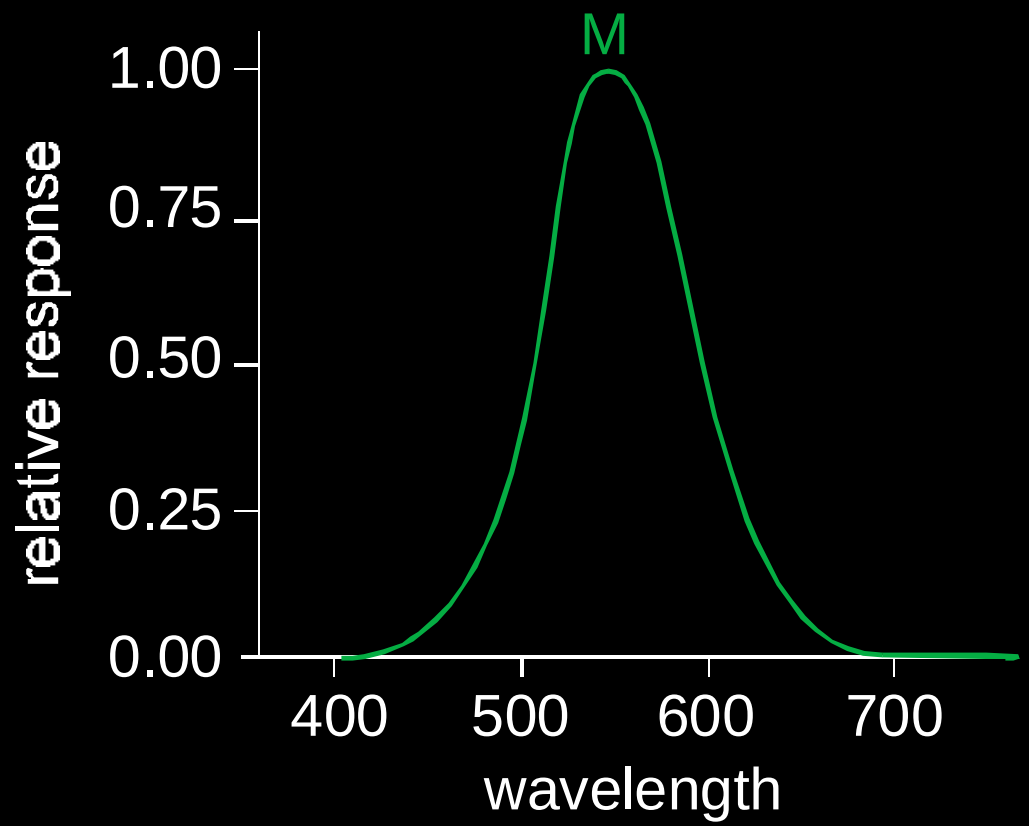


Cones distribution

- LMS 40:20:1
- No S (blue) in retina center

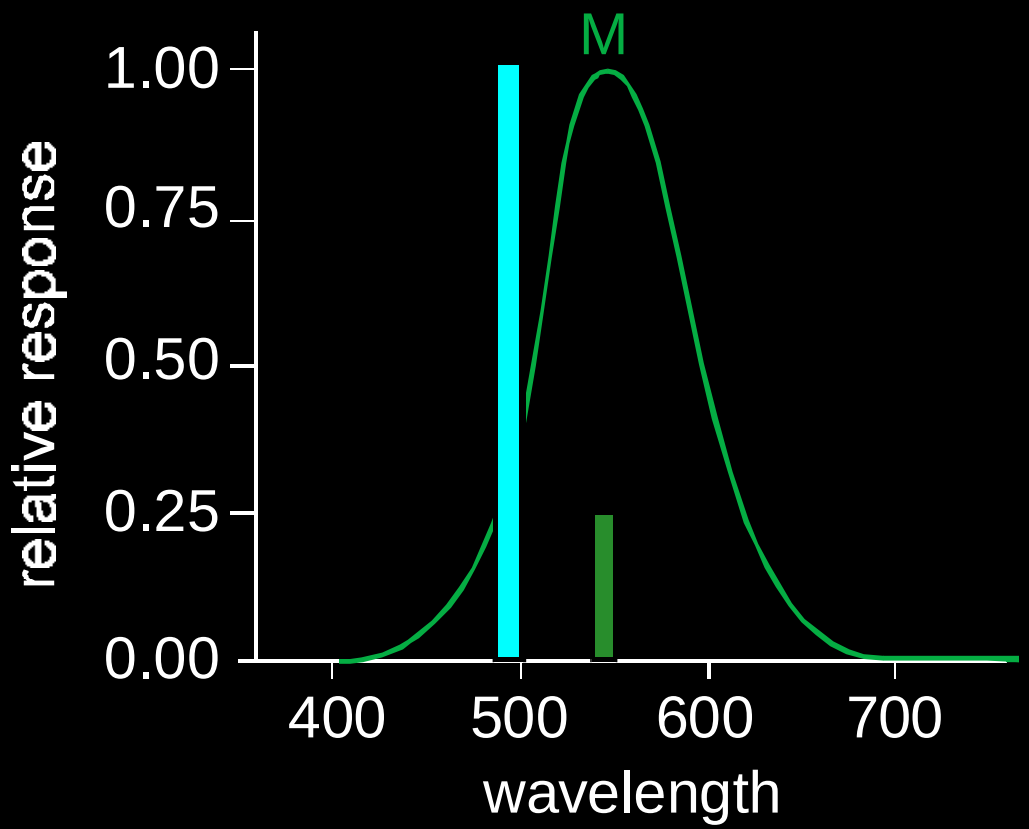


Cones do not "see" colors



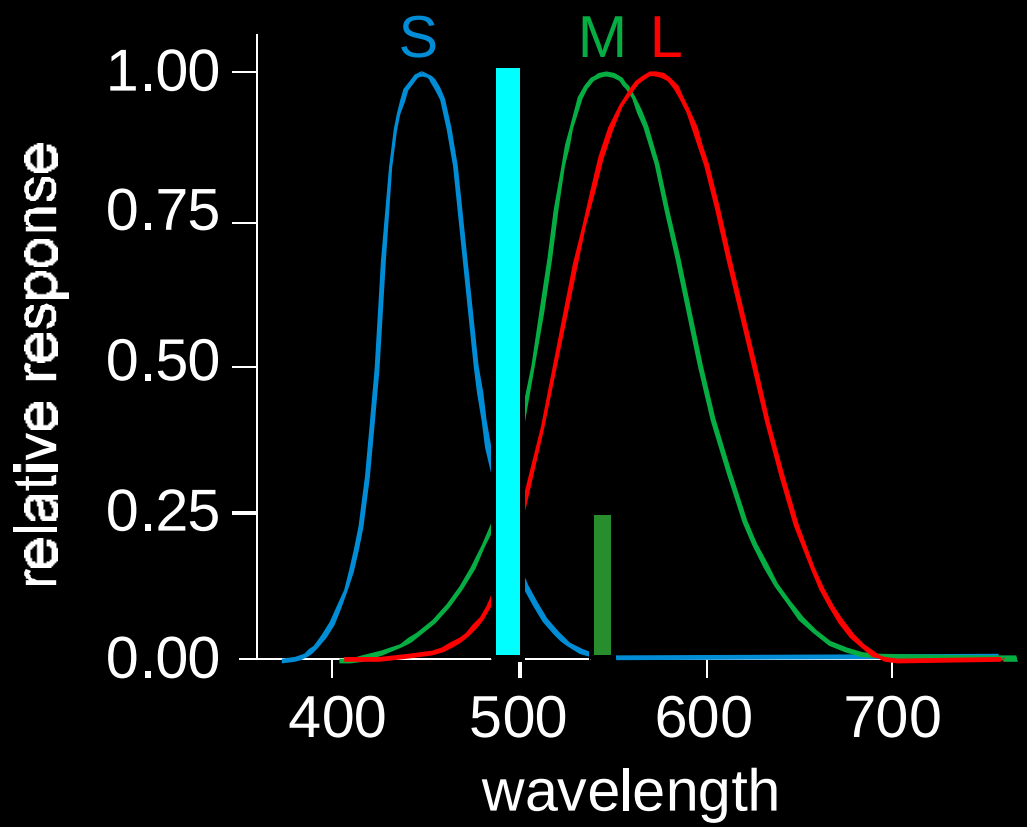
Cones do not "see" colors

- Different wavelength, different intensity
- Same response

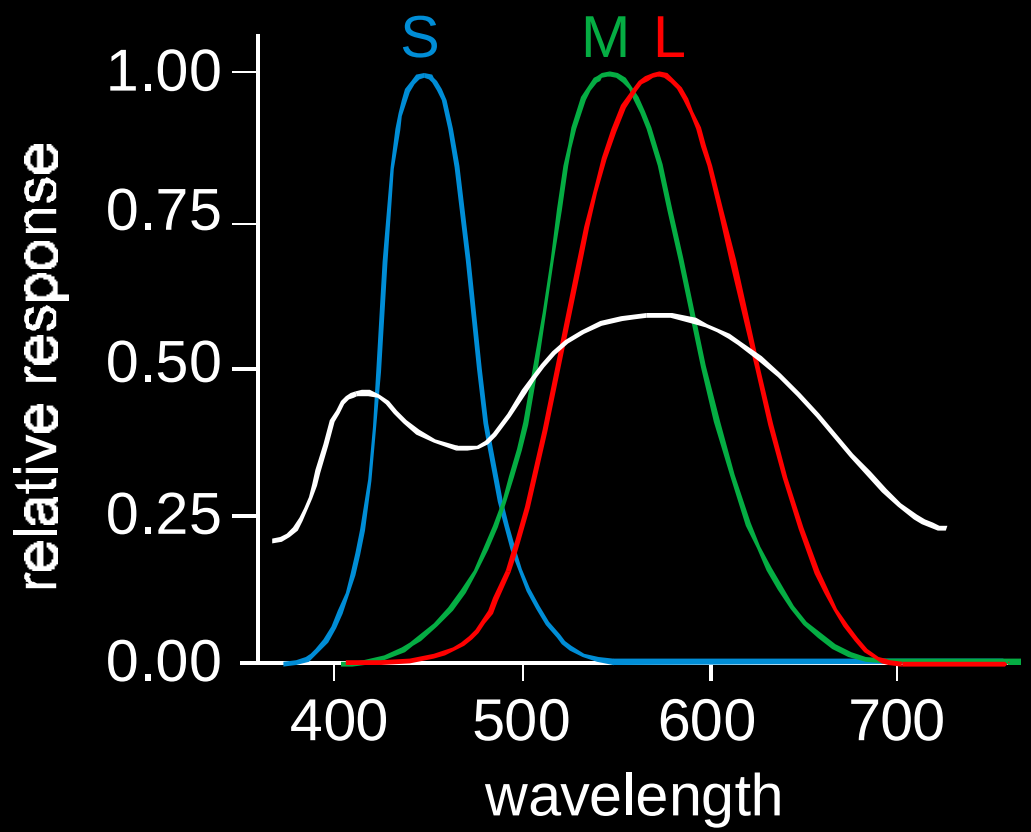


Response comparison

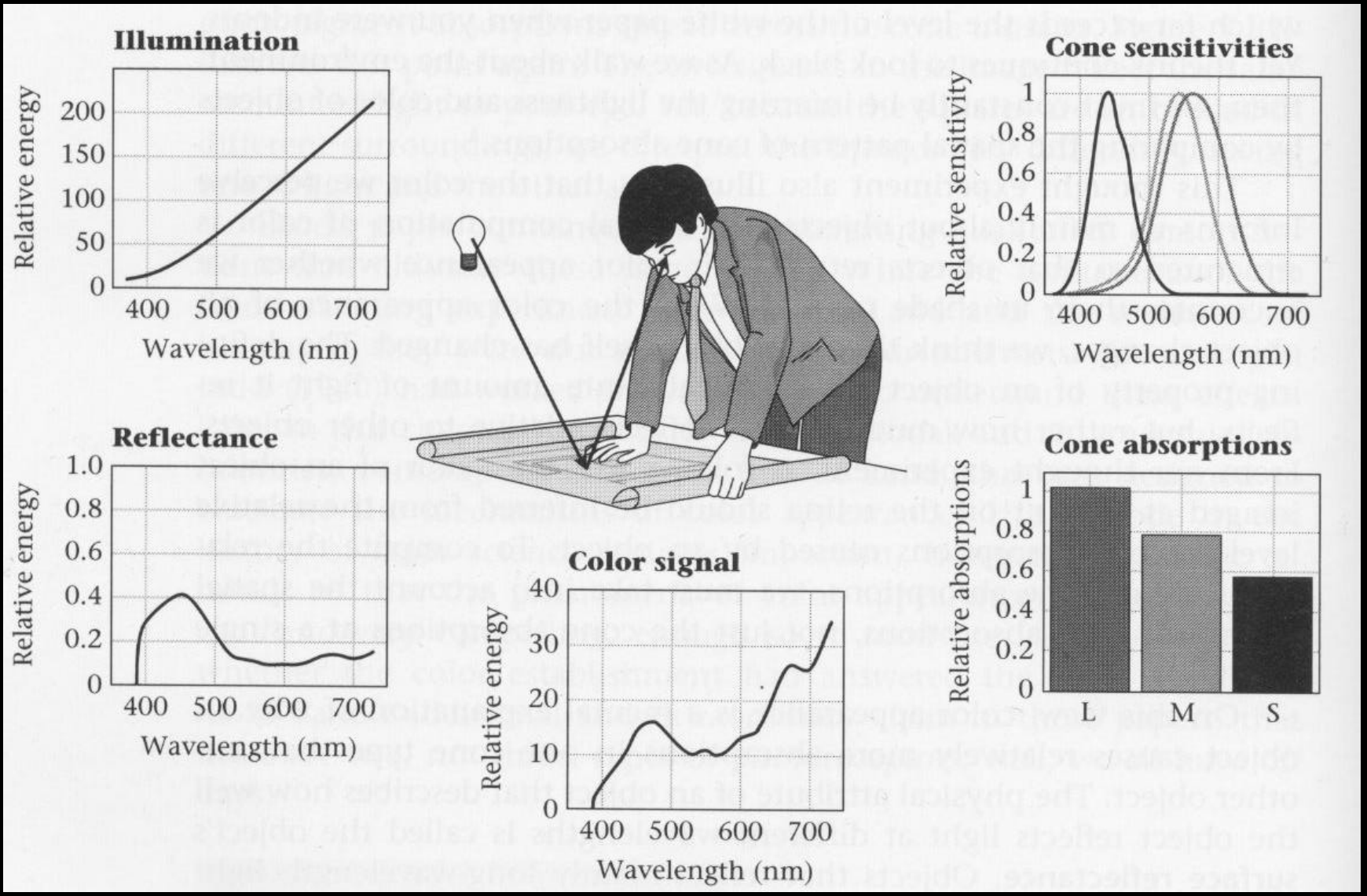
- Different wavelength, different intensity
- But different response for different cones



Complex spectrum



Summary

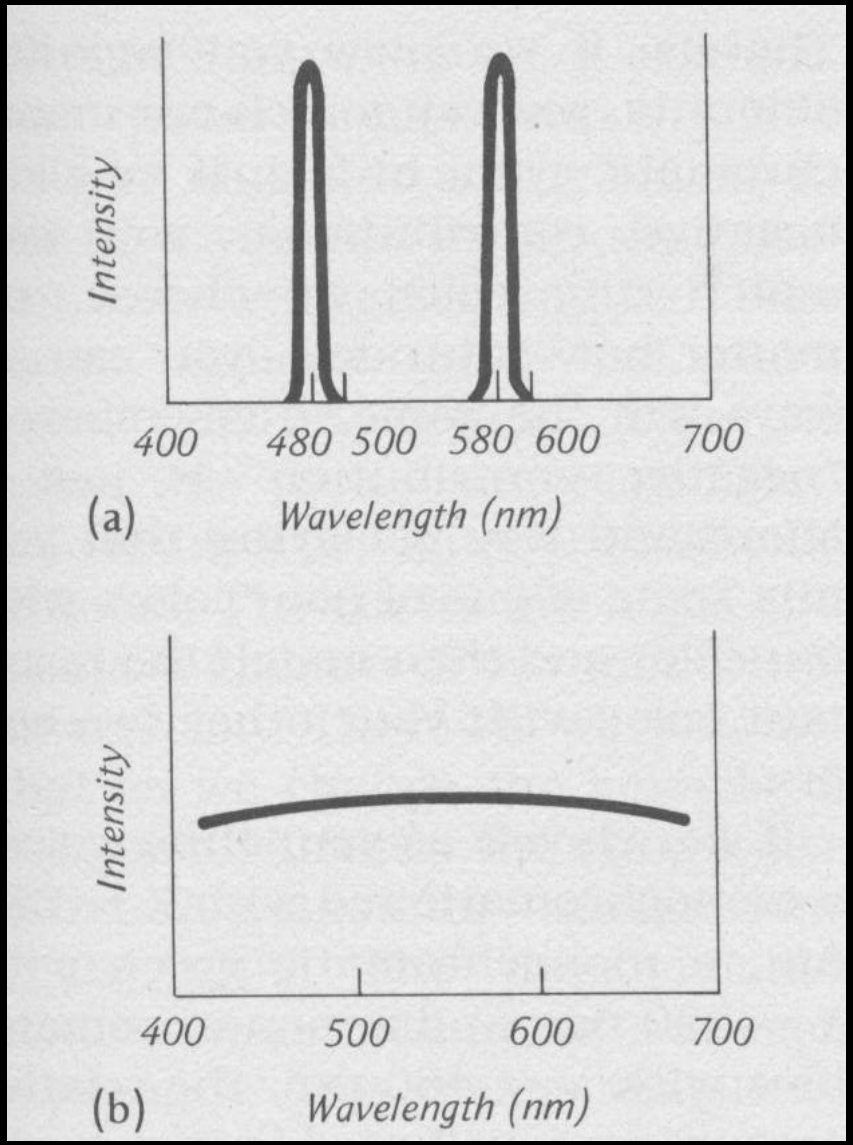

Illumination
Relative energy
200
150
100
50
0
400 500 600 700
Wavelength (nm)
Cone sensitivities
Relative sensitivity
1
0.8
0.6
0.4
0.2
0
400 500 600 700
Wavelength (nm)
Reflectance
Relative energy
1.0
0.8
0.6
0.4
0.2
0
400 500 600 700
Wavelength (nm)
Color signal
Relative energy
40
30
20
10
0
400 500 600 700
Wavelength (nm)
Cone absorptions
Relative absorptions
1
0.8
0.6
0.4
0.2
0
L M S

Plan

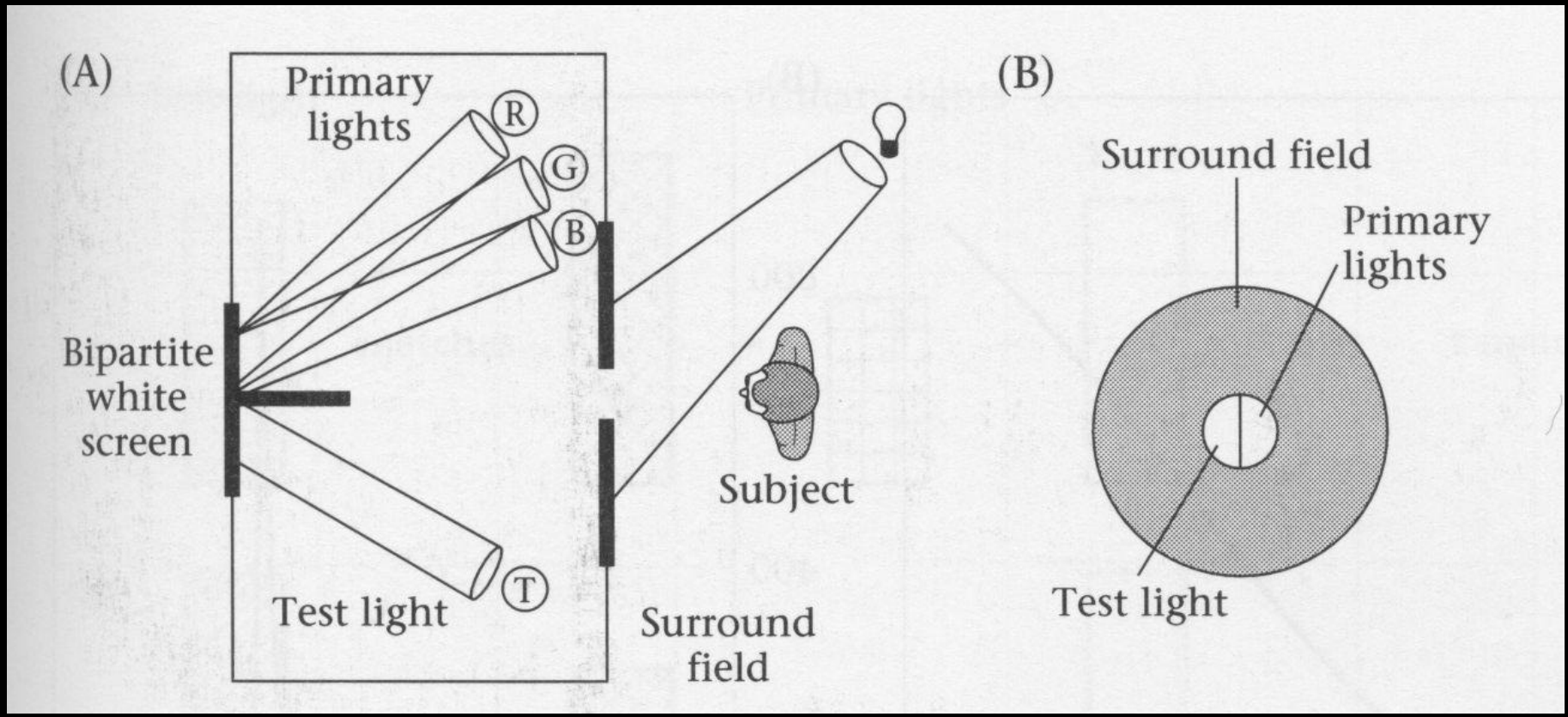
- Physical spectrum
- Trichromatic vision
  - Cones
  - Metamerism
  - Chromatic adaptation
  - Color blindness
- Color Opponents

Metamerism

- Different spectrum
- Same response



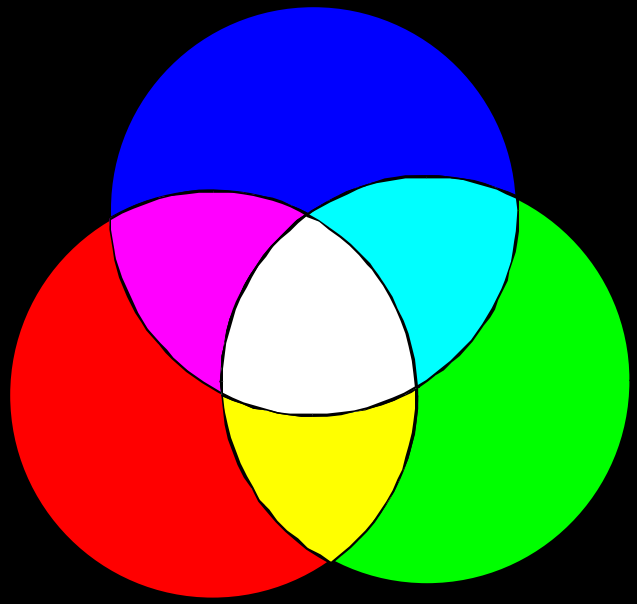
Color matching



Color synthesis

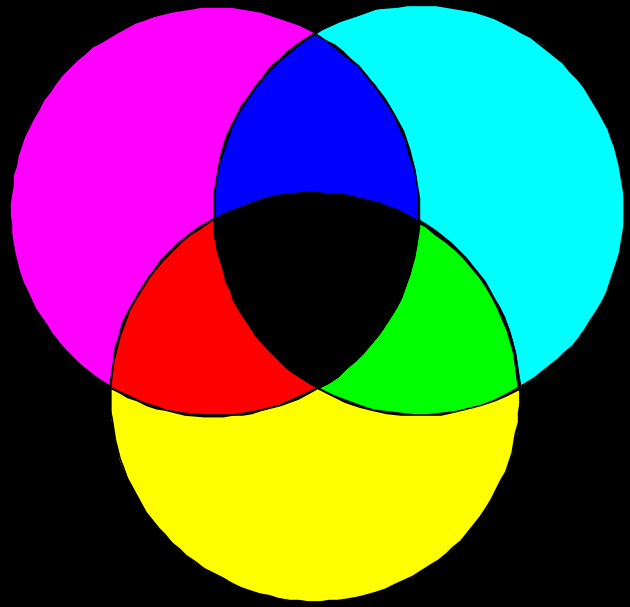
Additive

red, green, blue



Subtractive

cyan, magenta, yellow



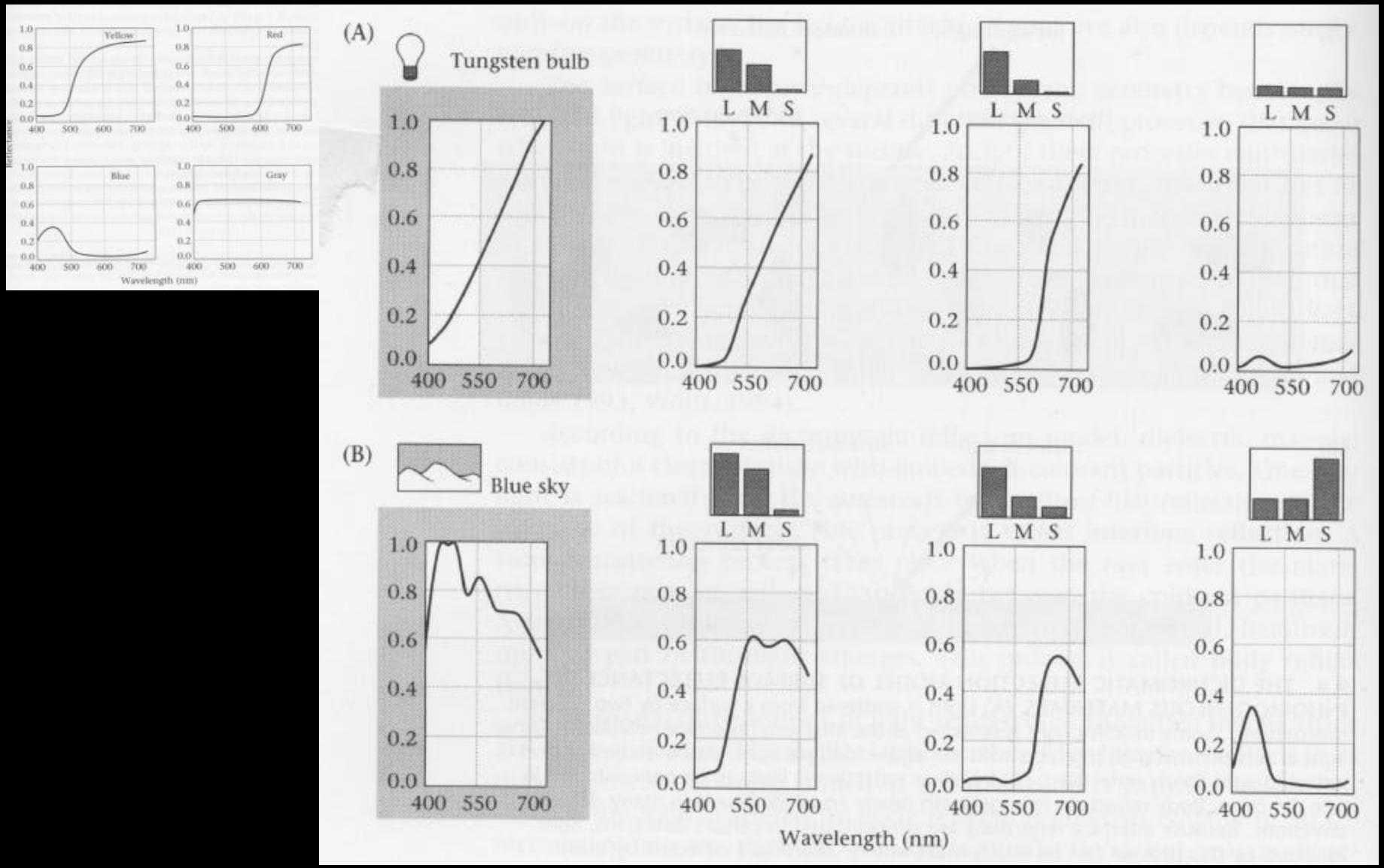
Future discussion

- Limited gamut

Metamerism & light source

- Metamers under a given light source
- May not be metamer under a different lamp
- Because different spectrum

Metamerism & light source



Metamerism & light source

- Metamers under a given light source
- May not be metamer under a different lamp
- Because different spectrum

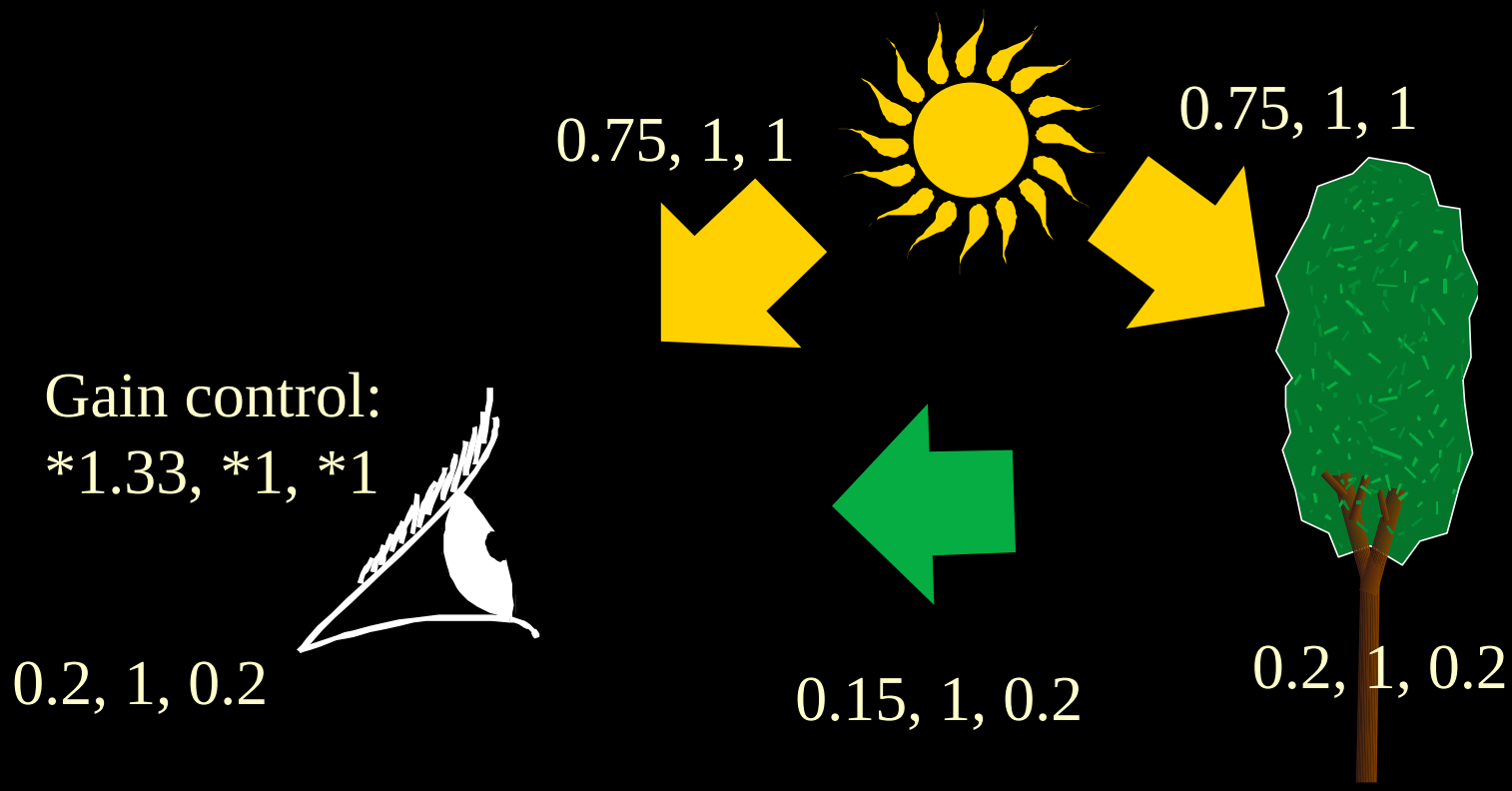
- Problem when buying cloths under neon lighting

Plan

- Physical spectrum
- Trichromatic vision
  - Cones
  - Metamerism
  - Chromatic adaptation
  - Color blindness
- Color Opponents

Chromatic adaptation

- Von Kries adaptation
- Different gain control on L, M, S

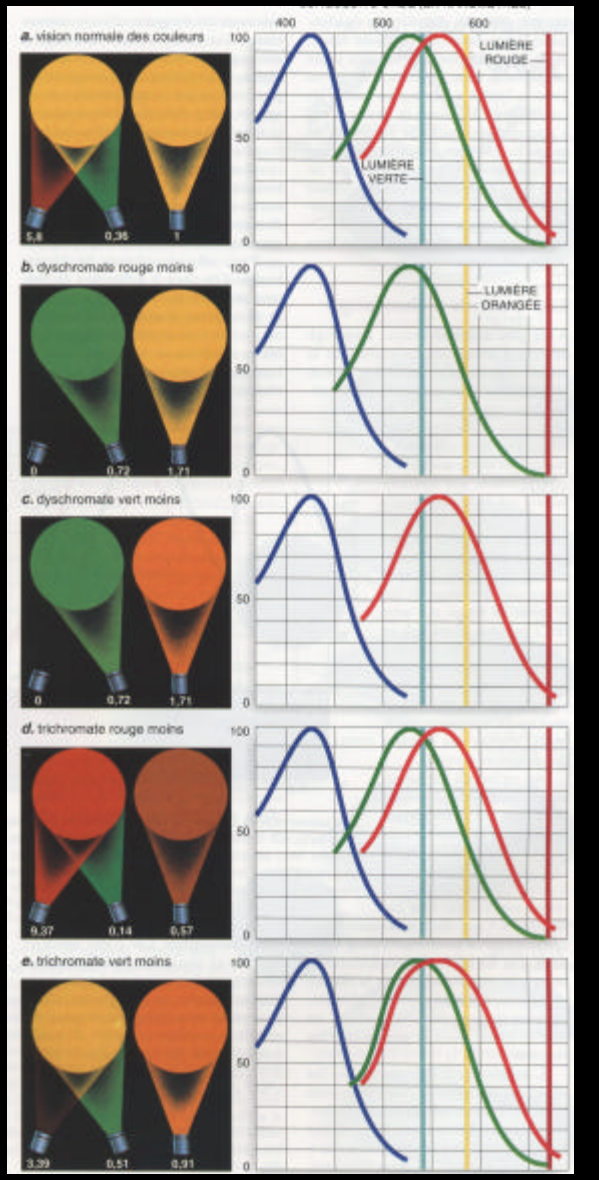


Plan

- Physical spectrum
- Trichromatic vision
  - Cones
  - Metamerism
  - Chromatic adaptation
  - Color blindness
- Color Opponents

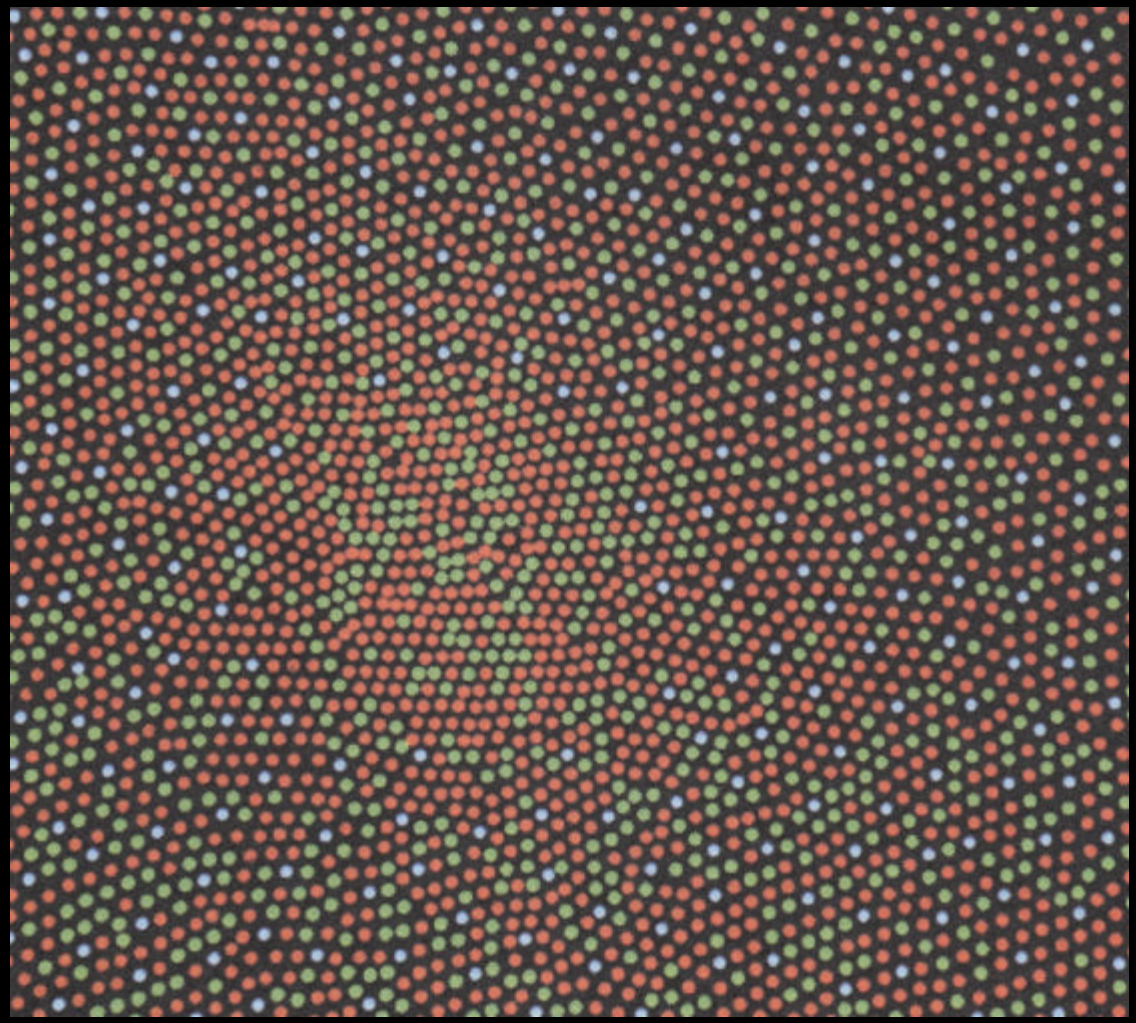
Color blindness

- Dalton
- 8% male, 0.6% female
- Genetic
- Dichromate (2% male)
  - One type of cone missing
  - L (protanope), M (deuteranope), S (tritanope)
- Anomalous trichromat
  - Shifted sensitivity

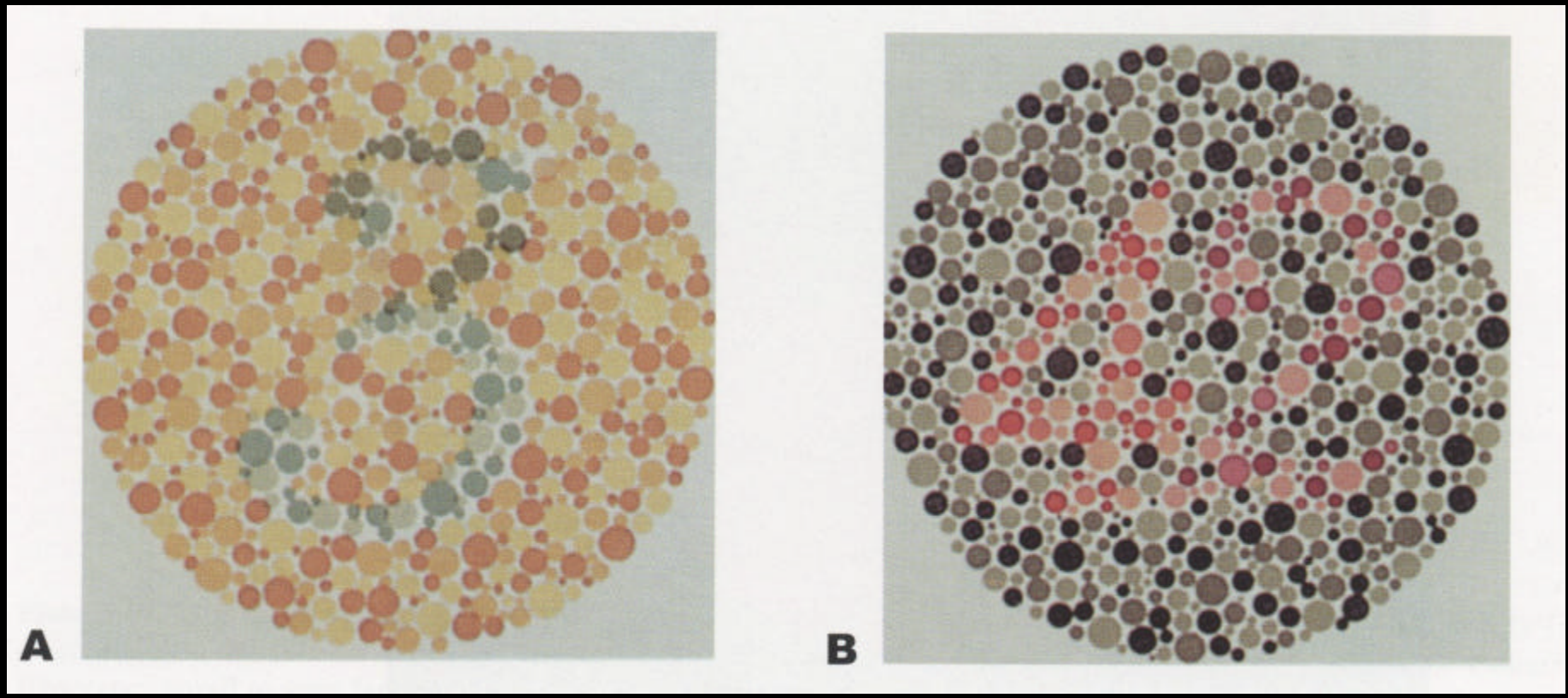


We are all color blind

- Center of retina
- No S (blue)
- We compensate via gaze movement
- Not well understood

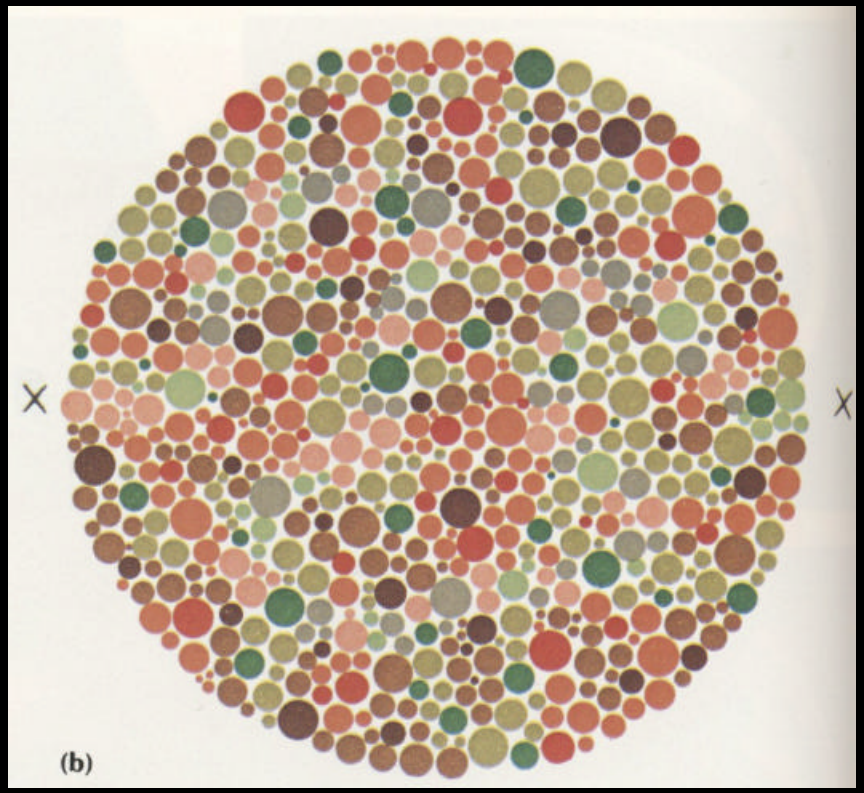


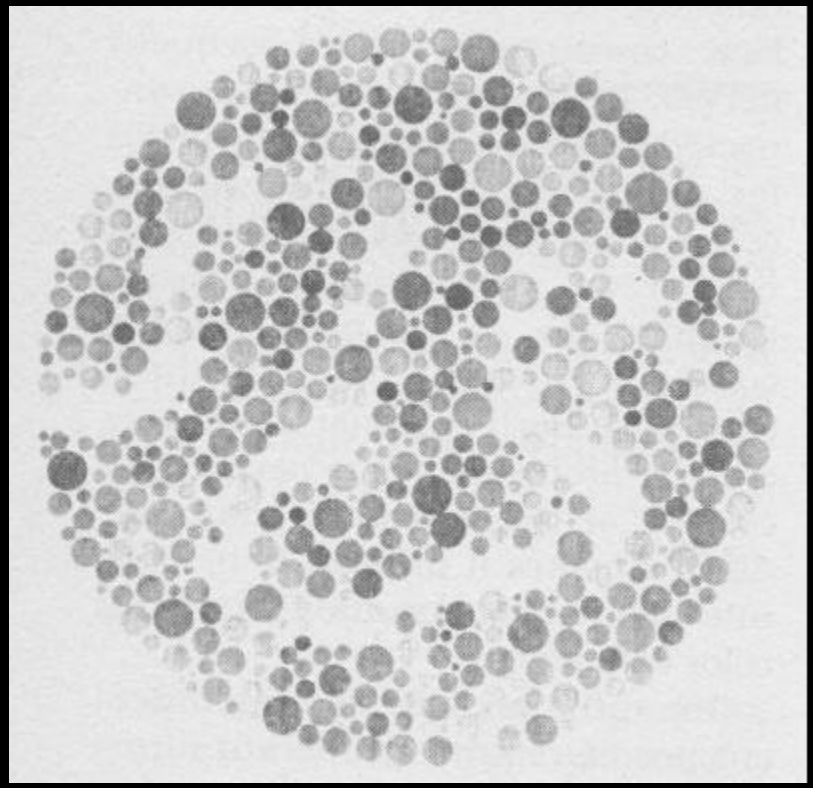
Color blindness test



Color blindness test

- Maze in subtle intensity contrast
- Visible only to color blinds
- Color contrast overrides intensity otherwise



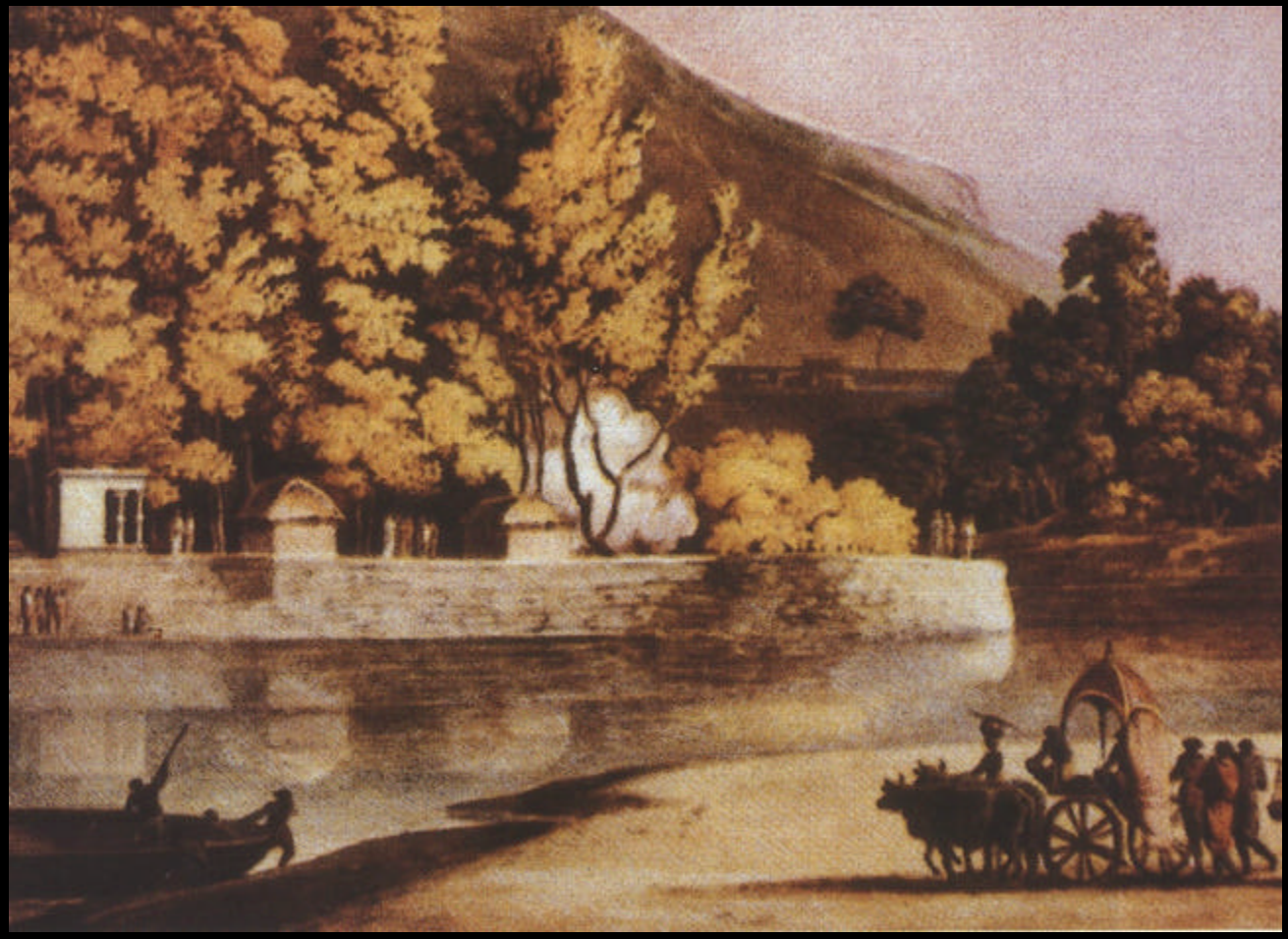


Color blind impressions

- A normal scene
- B
  protanope L
- C
  deuteranope M
- D
  tritanope S

Color blindness & Painting

- Restricted to blue-yellow



Goethe after a color-blind

Color blindness & Painting

- Restricted to blue-yellow

Meryon, *Le Vaisseau Fantôme*

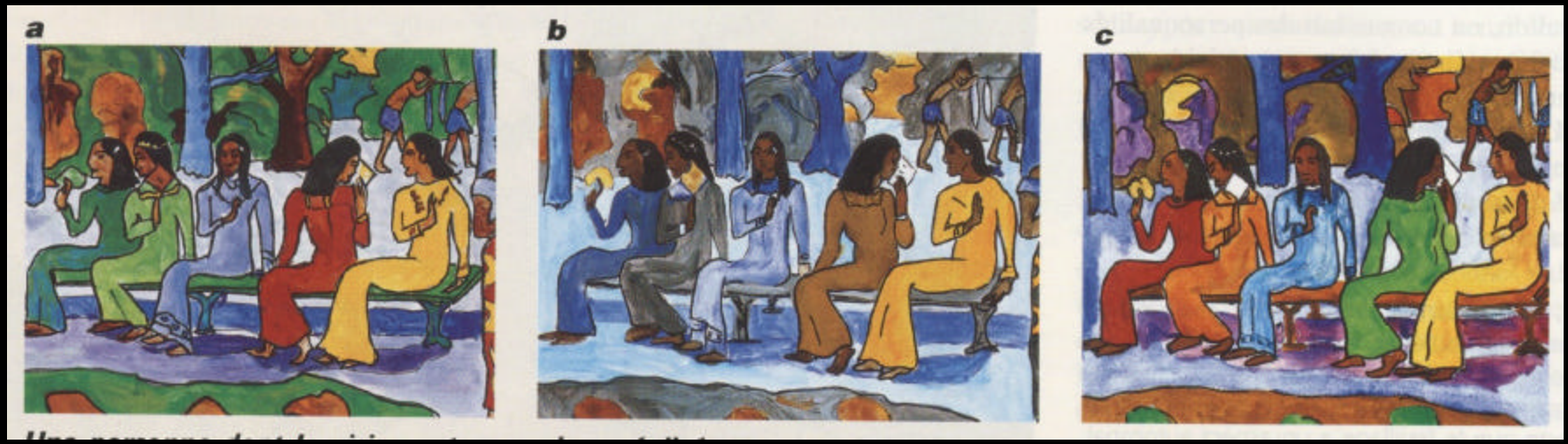
Color blindness & Painting

- Restricted to blue-yellow

J. J.

Color blindness & Painting

- Image reproduction (after Gauguin)
- Different strategies



Normal color vision

Color blind (perceived)

Color blind (confusion)

Plan

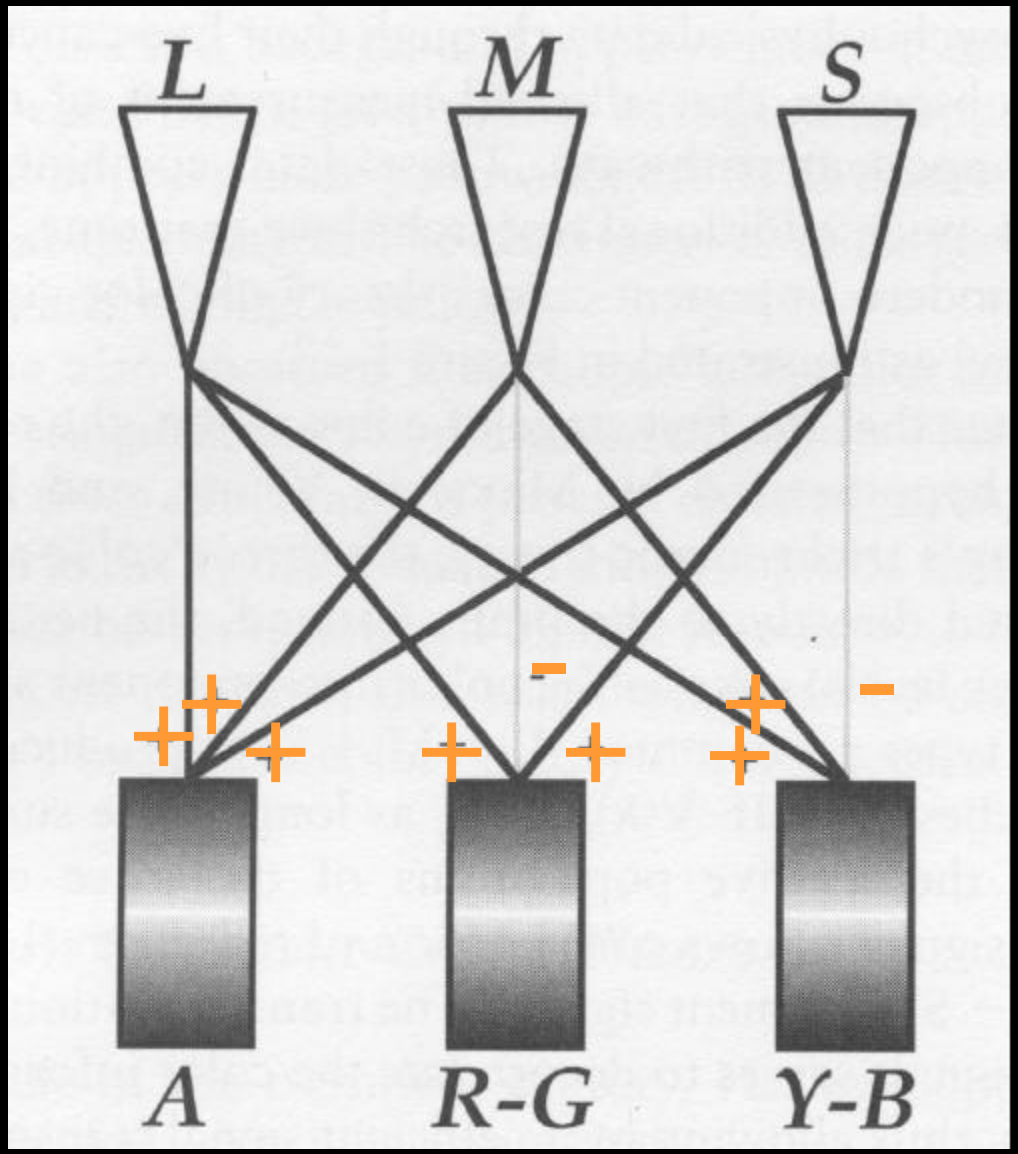
- Physical spectrum
- Trichromatic vision
  - Cones
  - Metamerism
  - Chromatic adaptation
  - Color blindness
- Color Opponents

Color Opponents

- Hering
- A color can be “blue-green”, “yellow-red”, “yellow-green”, etc
- But never “yellow-blue” or “red-green”
- Suspected two opponents:
  - Blue-yellow axis
  - Red-Green axis

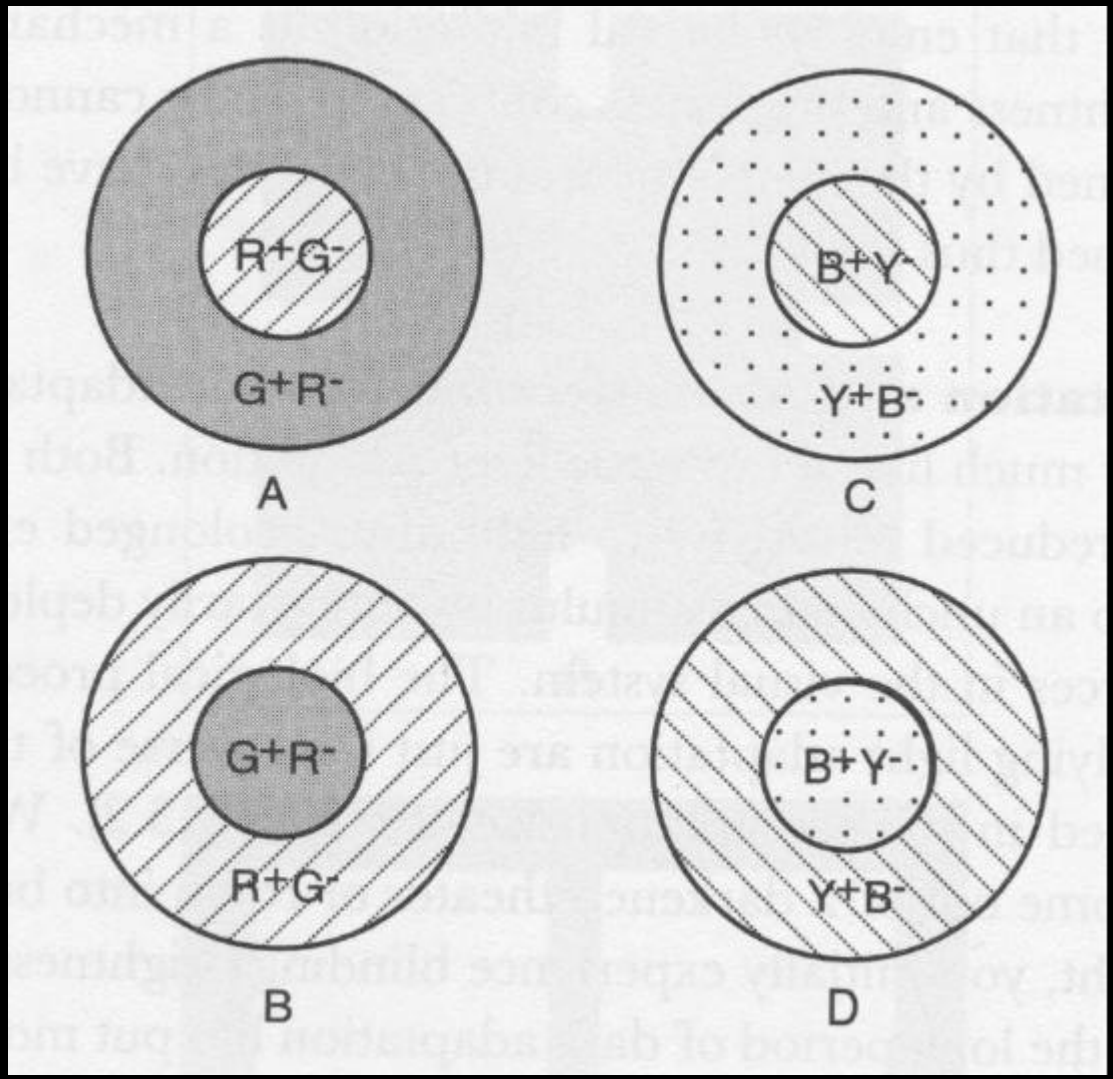
Color opponents wiring

- Sums for brightness
- Differences for color opponents



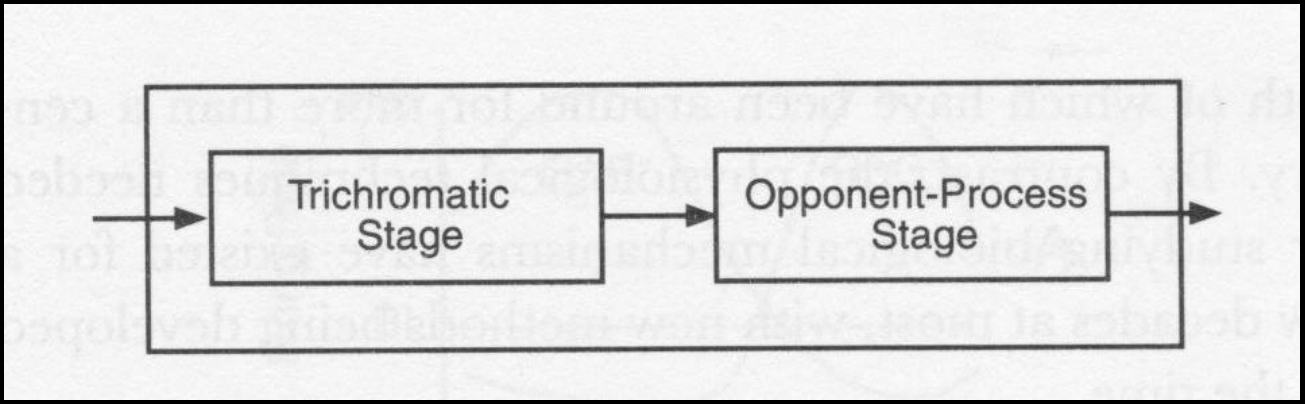
Double center surround opponents

- Center-surround
- Color opponents



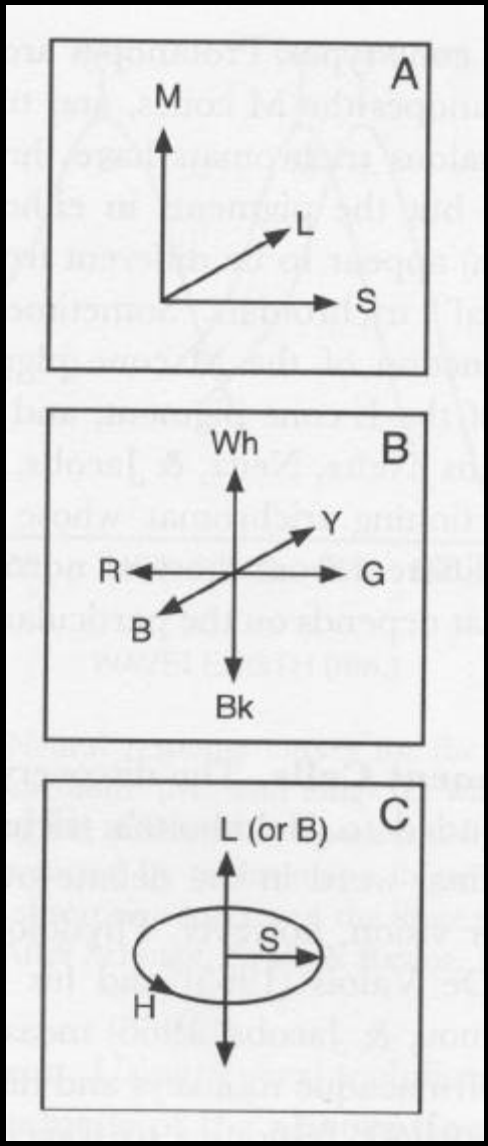
Color reparameterization

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



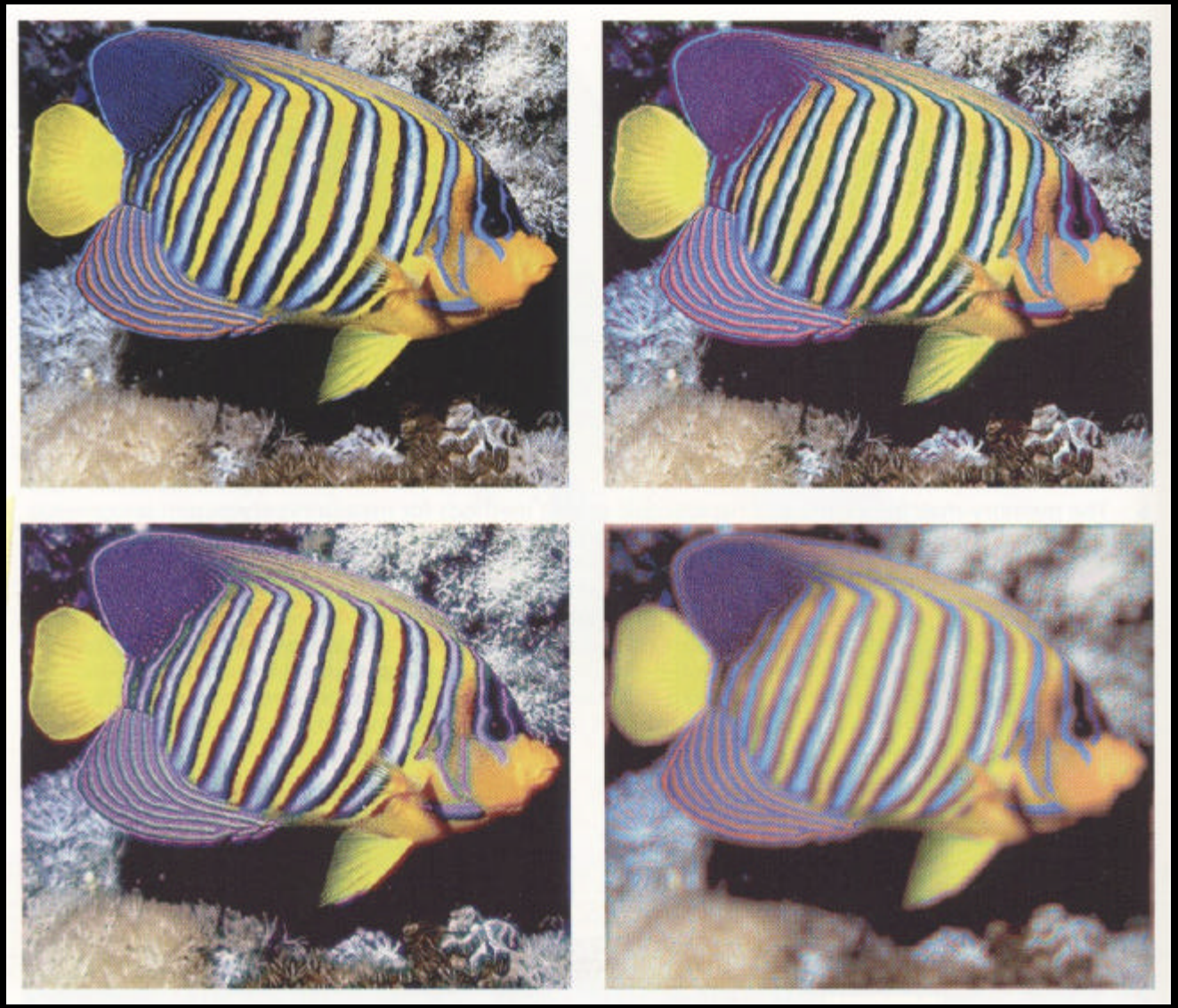
Color reparameterization

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



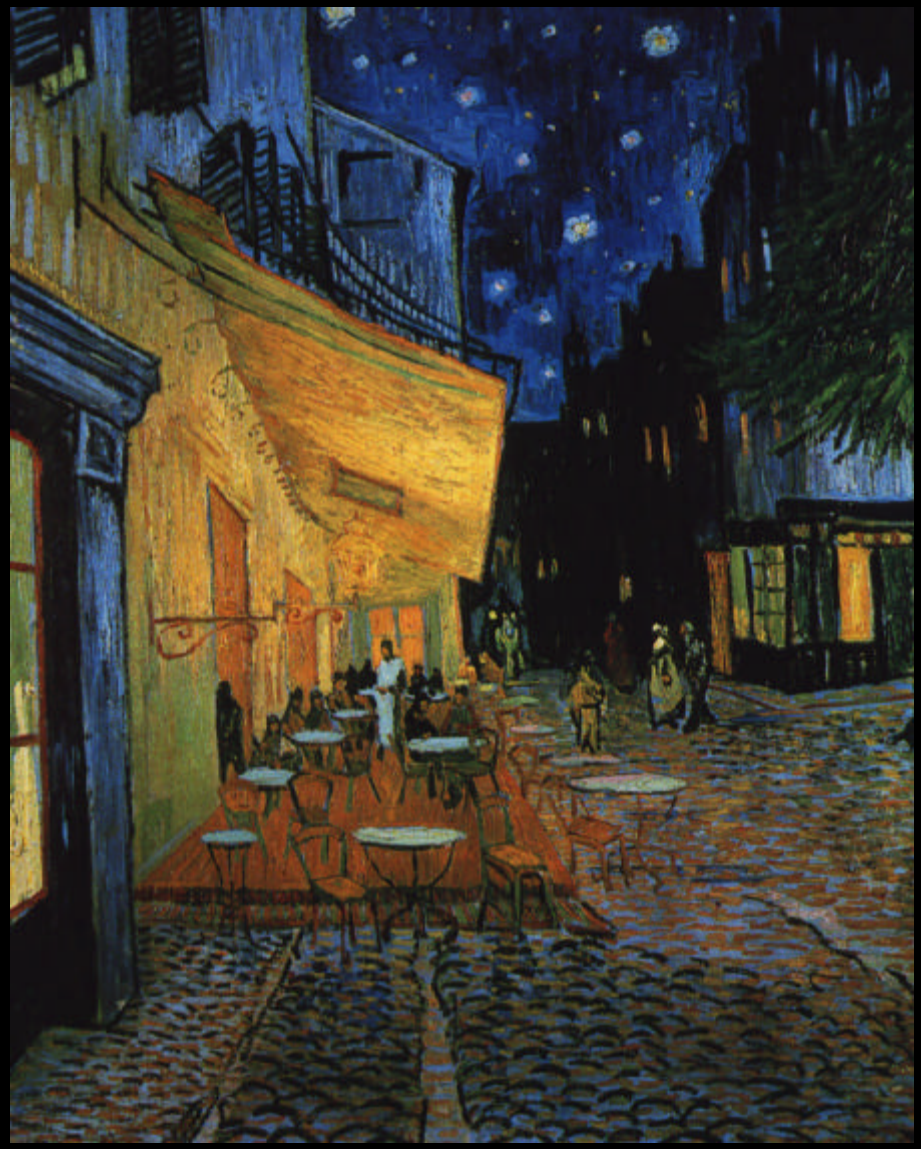
Opponents and image compression

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



Blue-yellow opponent and painting

- Often used to depict night
- (S cones share properties with rods…)
- Van Gogh
  Café at Night



Red-green opponent and painting

- Jawlensky

Opponent and painting

- Degas