Lecture 10. Color Perception.

Reading Assignments:

Chapter 9

Color Vision

Computer vision systems that use color input are faced with the same problem as biological systems:

given the wide variability in illumination sources, how can we build a stable percept of an object's color?

Classic Color Vision Theory

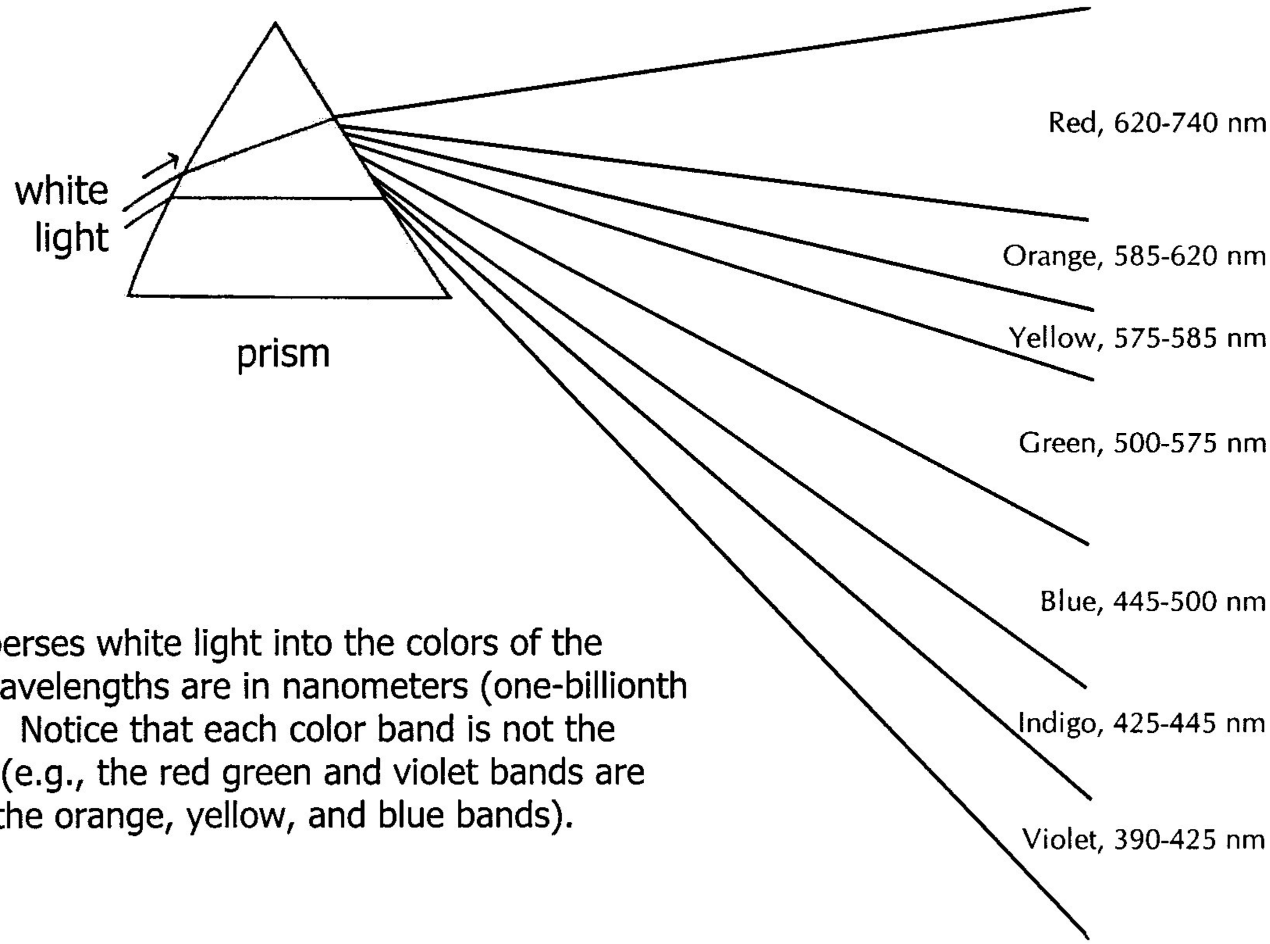


Fig. 1
A prism disperses white light into the colors of the rainbow. Wavelengths are in nanometers (one-billionth of a meter). Notice that each color band is not the same width (e.g., the red green and violet bands are larger than the orange, yellow, and blue bands).

White light contains energy at all visible wavelengths…

Classic Color Vision Theory

… and various objects absorb some of those wavelengths; those which are not absorbed but instead reflected contribute to our percept of the object's color.

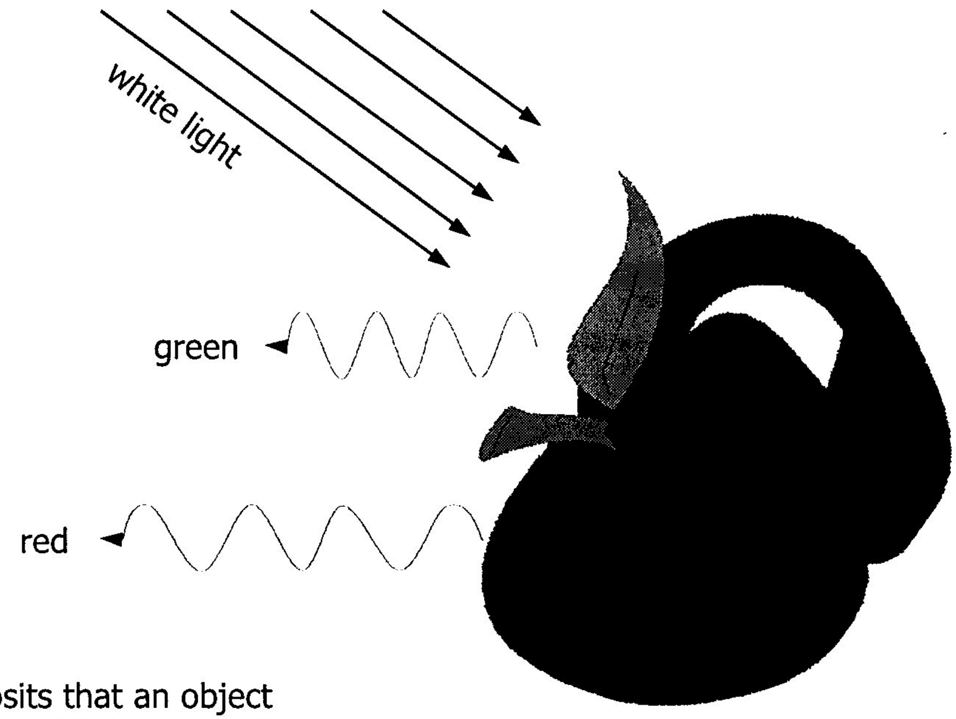


Fig 2.
Classic color vision theory posits that an object absorbs all of the wavelengths of light except its own color. Thus a red apple absorbs all of the colors in white light except red (which is reflected); a green leaf absorbs all of the colors in white light except green (which is reflected).

Edwind Land's Experiment

In the late 1950s, Edwind Land photographed (in grayscale) a scene through two colored filters and then projected both grayscale images through the same filters and superimposed. What did he see?

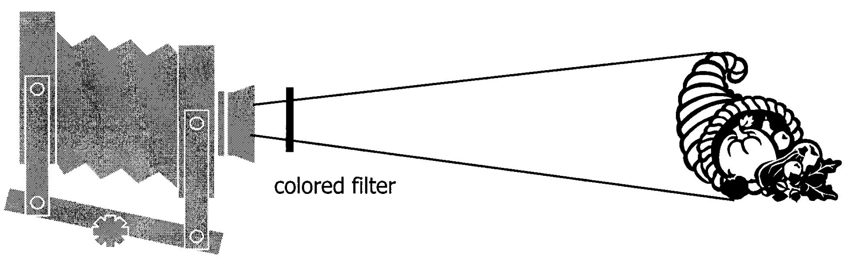


Fig. 3
Land used black-and-white transparency film to photograph a colorful still-life. The first picture was taken while a red filter was held in front of the camera lens; the next photo was taken with a green filter in front of the camera lens.

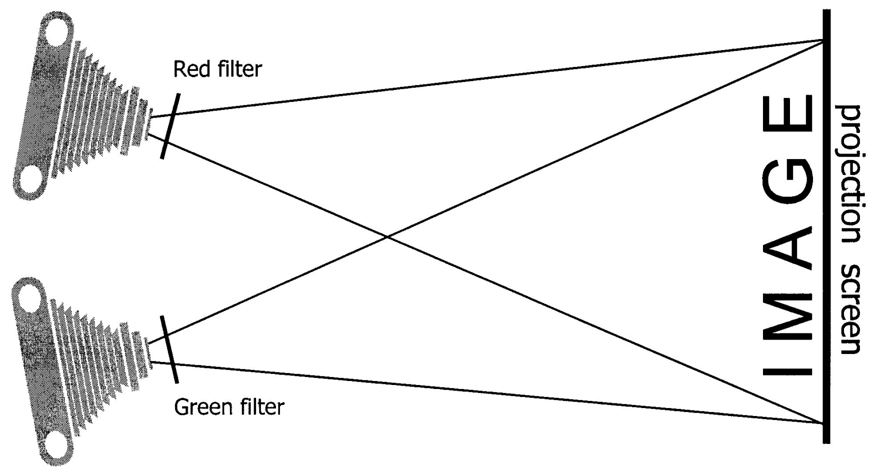


Fig. 4
Land projected the red-record with a red filter in front of the projector lens and the green-record with a green filter in front of the projector lens. (These were the same colored filters used in front of the camera when making the slides.) These two images were superimposed on a screen.

Edwind Land's Experiment

Classic color vision theory predicts:

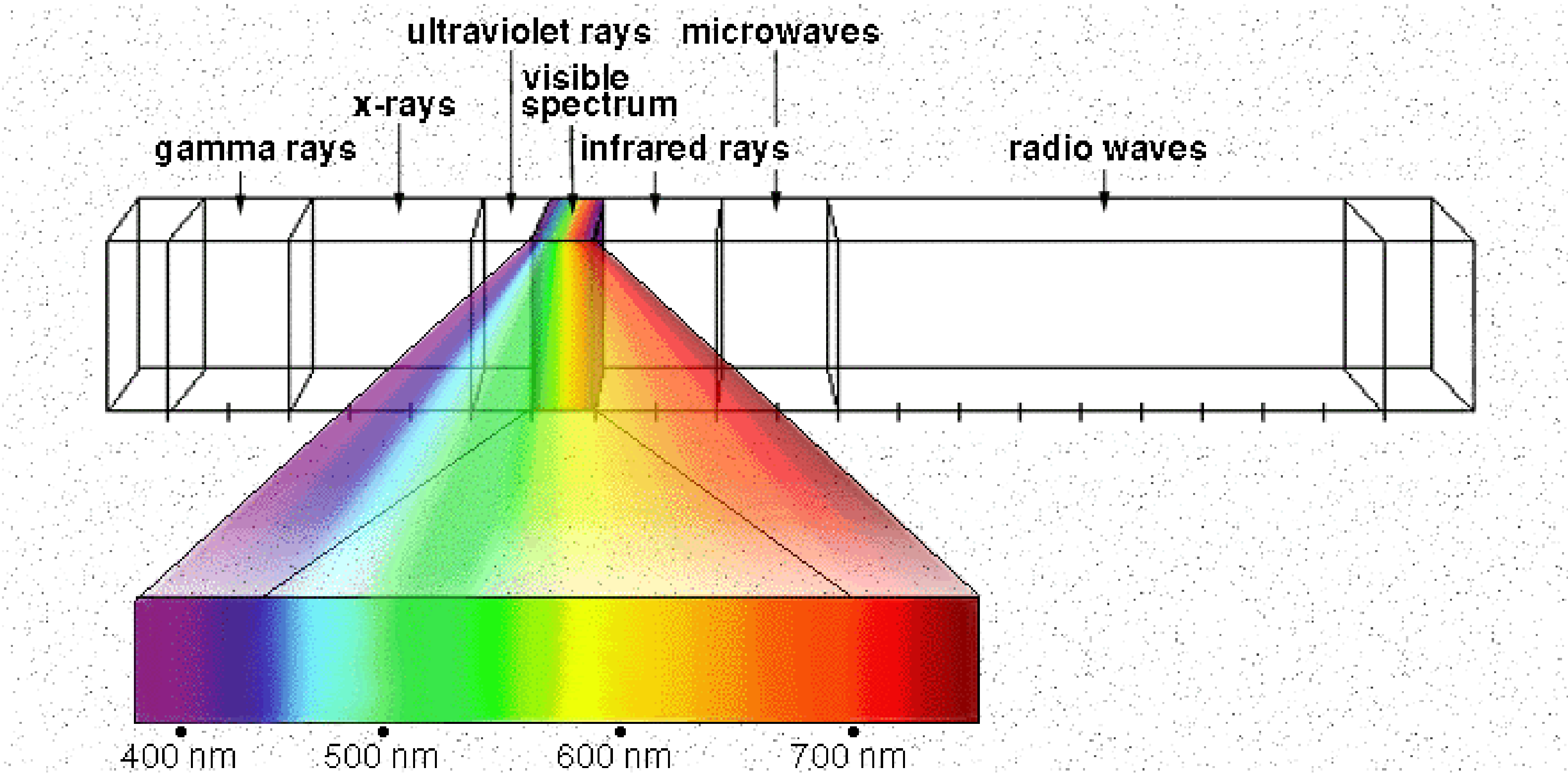
image 1: greyscale image through red filter => red shades

image 1: greyscale image through green filter => green shades

superimposition: yellow shades?

Result: color image!

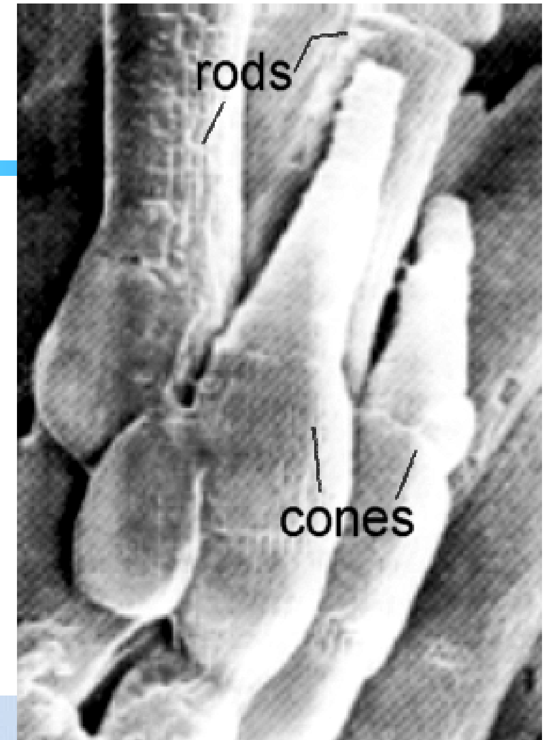
Origin of Color



Different wavelengths of light correspond to different "colors,"

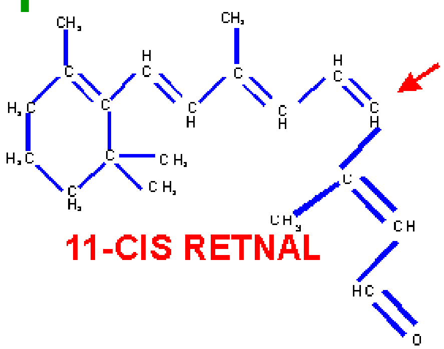
but… how can we measure such wavelengths? and are these all the colors we see?

Trichromacy

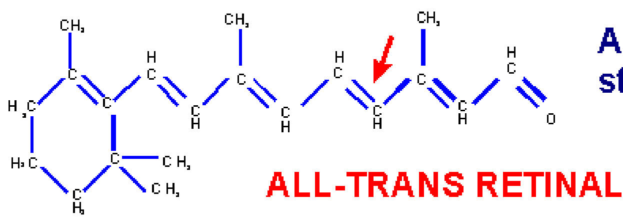


Humans: 3 types of "cone" photoreceptors tuned to different wavelengths.

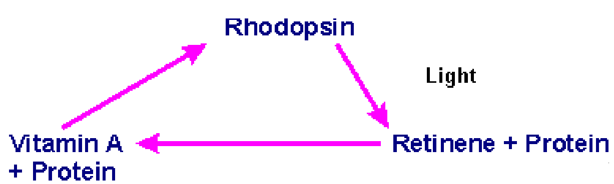
Photopigment molecules undergo a shape change as they absorb light. This triggers a cascade of events yielding a graded change in membrane potential.

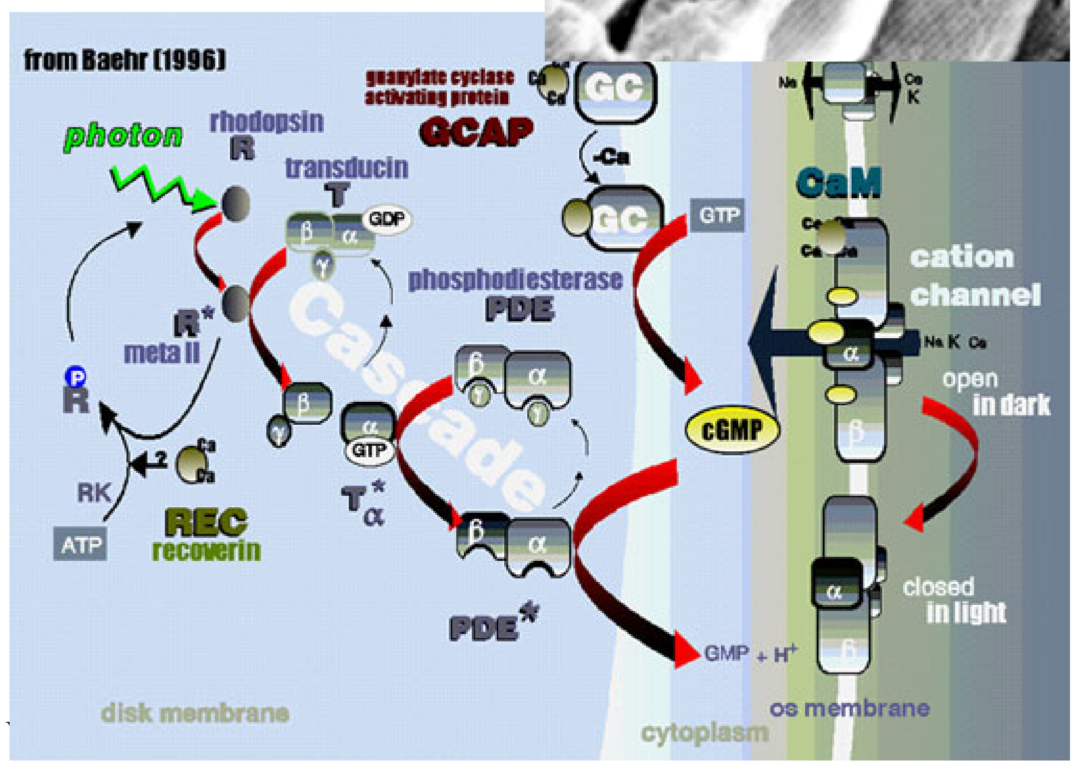


Prior to light stimulation



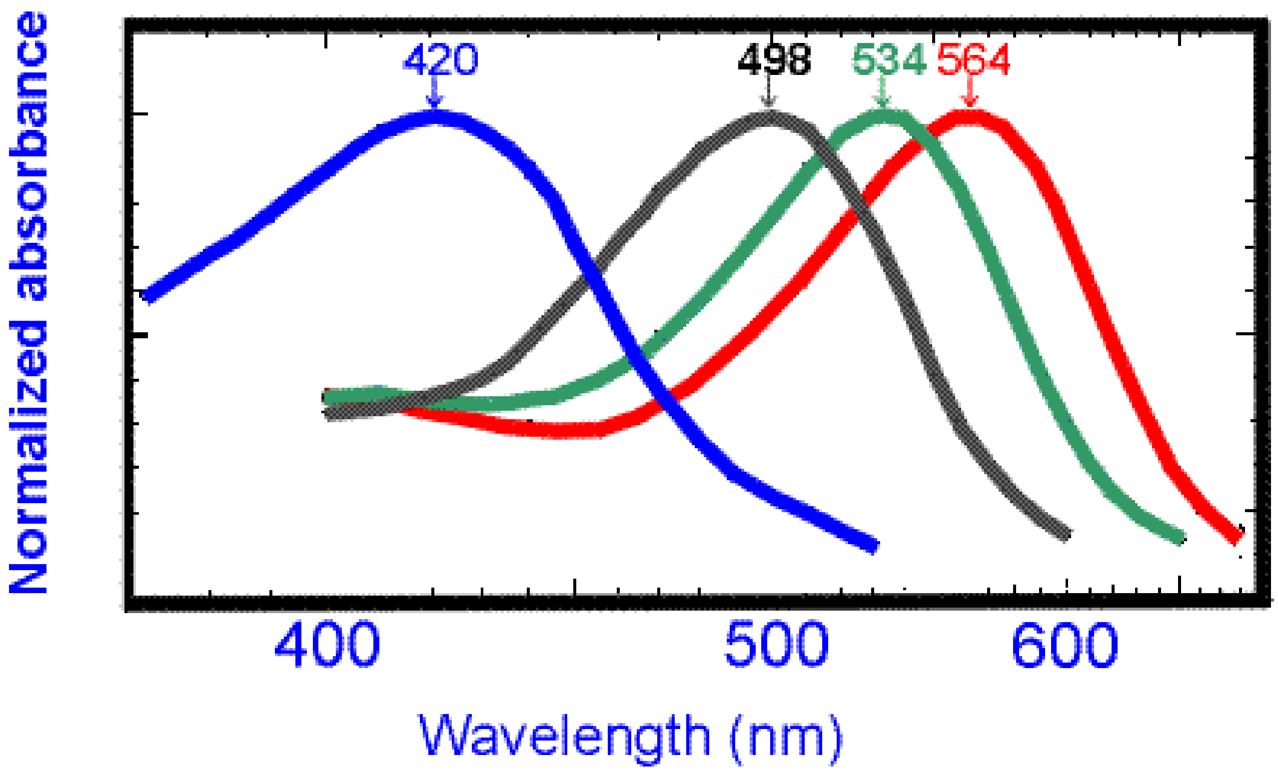
After light stimulation





Trichromacy

Bowmaker & Dartnall (1980) projected a known amount of light through the outer segments of retinal photoreceptors, and measured how much was absorbed.

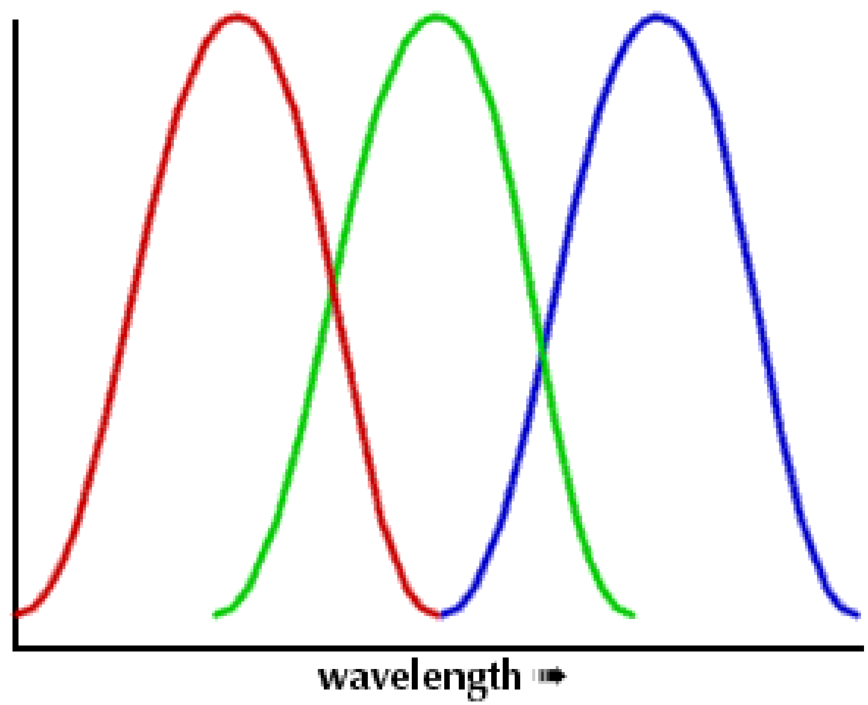


After Bowmaker & Dartnall, 1980

Why Several Types of Cones?

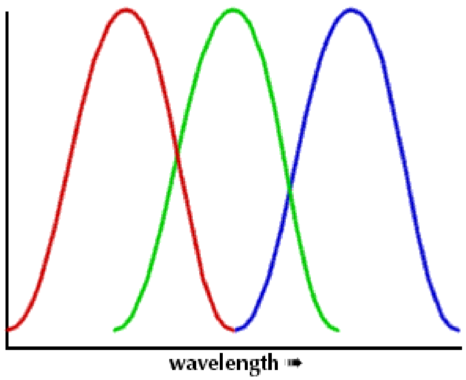
To decorrelate hue from intensity!

With just one type, ambiguity:
is the stimulus of a non-optimal
wavelength, or is it simply dim?



Normal Vision

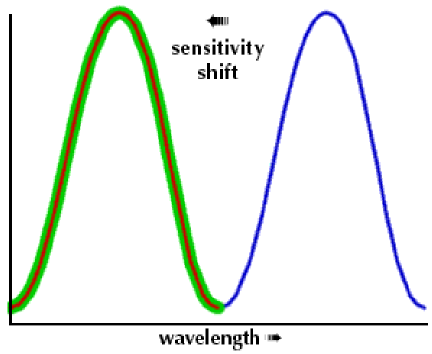
Normal daylight vision:

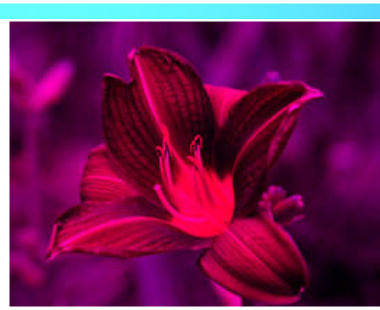


Response from 3 types of cones (short, medium and long-wavelength) yield color percept;

Rods are largely saturated and contribute little to daylight vision.

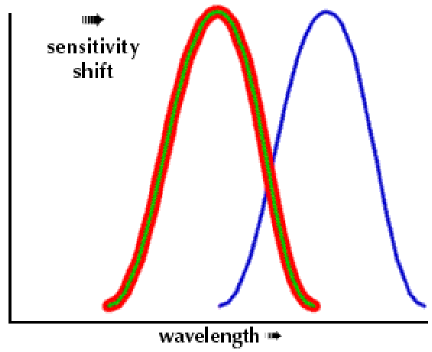
Common Pathologies

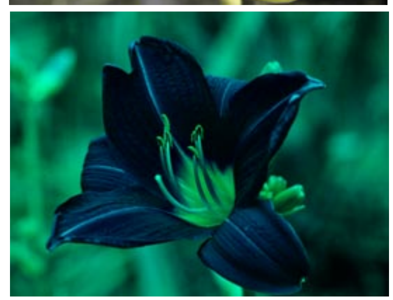




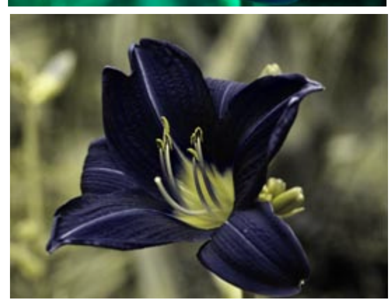
No green

Red perceived
as both red & green





No red



Green perceived as
both green & red.

Color Perception

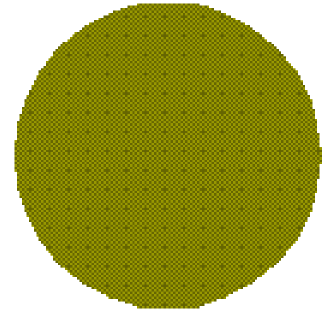
In summary,

the retina receives
a signal which contains
various amounts of
energy at various
wavelengths;

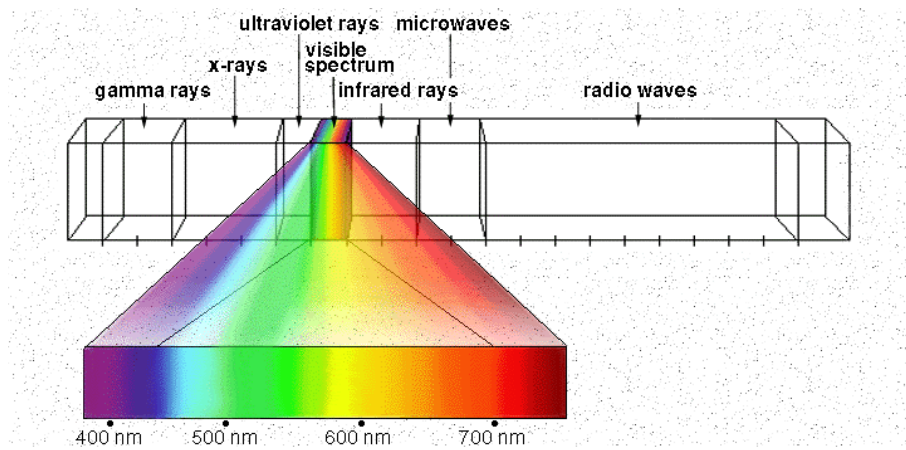
this signal is multiplied
by each of the three
cone sensitivity profiles;

the result is a triplet.

R=250
G=250
B=0



R=50
G=50
B=0



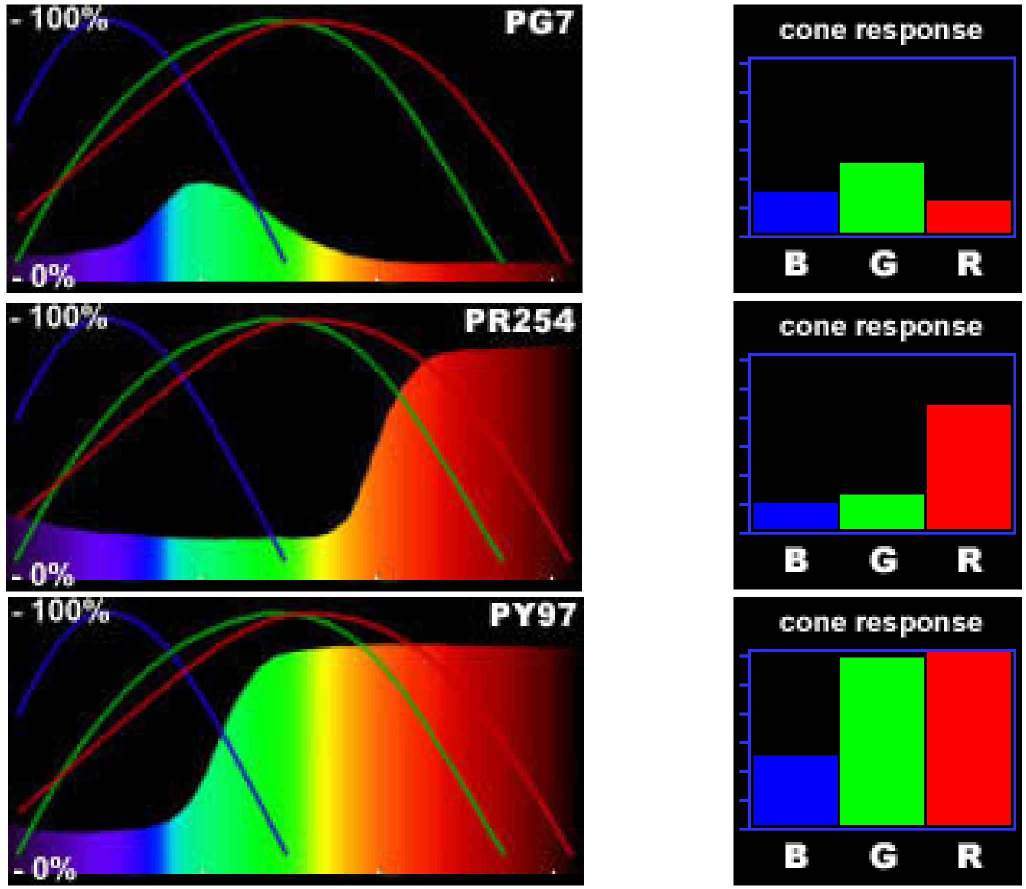
Different incoming wavelength distributions may yield identical triplets!

Relative Cone Absorption

phtalo green

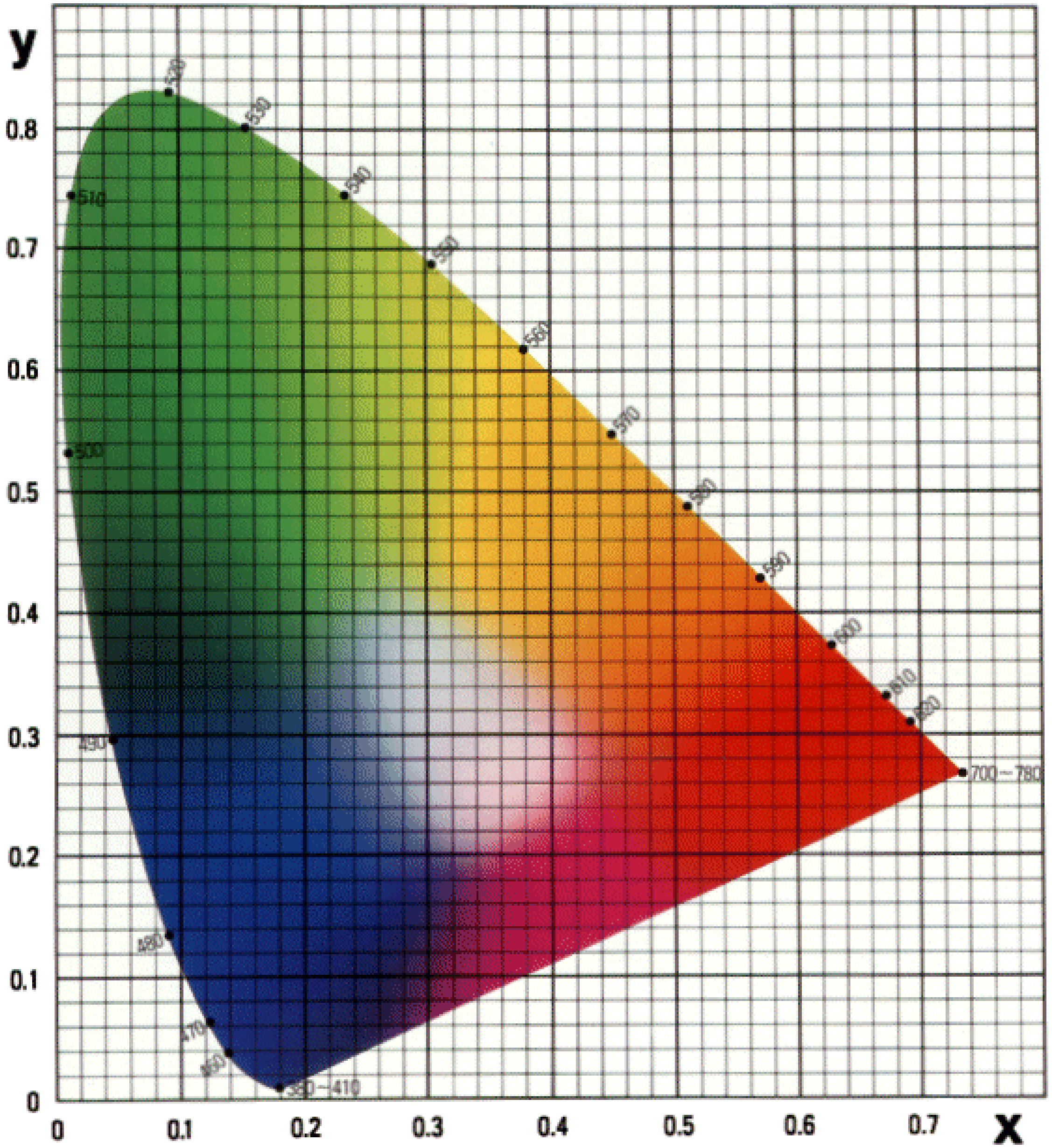
pyrrole red

hansa yellow



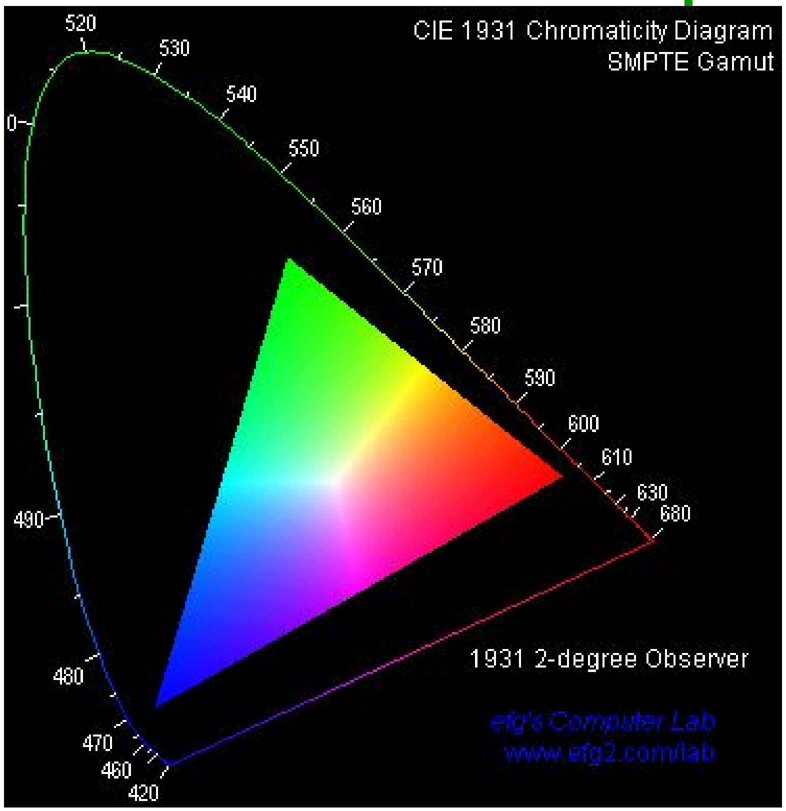
Metamers: different distributions of light that yield same response triplets.

CIE Color Space



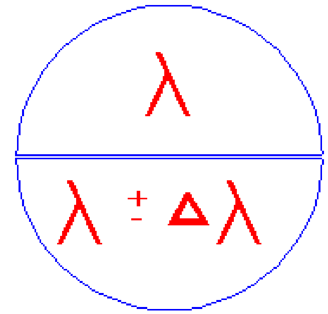
$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z}$$

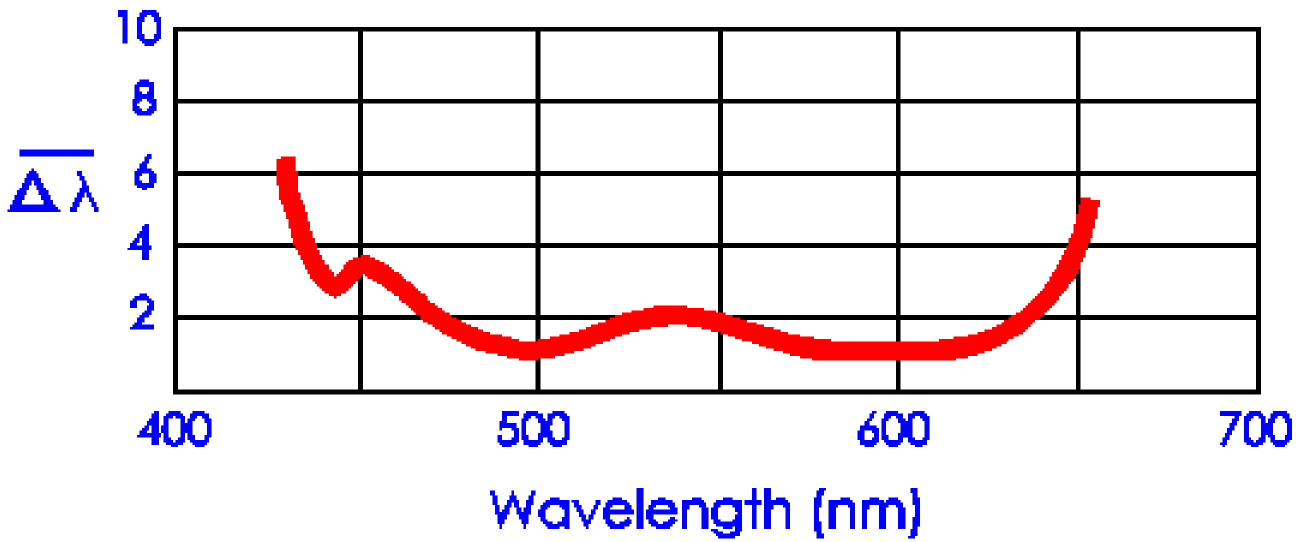
$$z = \frac{Z}{X + Y + Z} = 1 - x - y$$



Detection vs. Discrimination

Wright & Pitt, 1934. We can very accurately discriminate between two adjacent color patches.





but we will see that our percept of what color those two similar wavelengths correspond to can vary widely depending on viewing and illumination conditions.

Reflectance and Illuminant

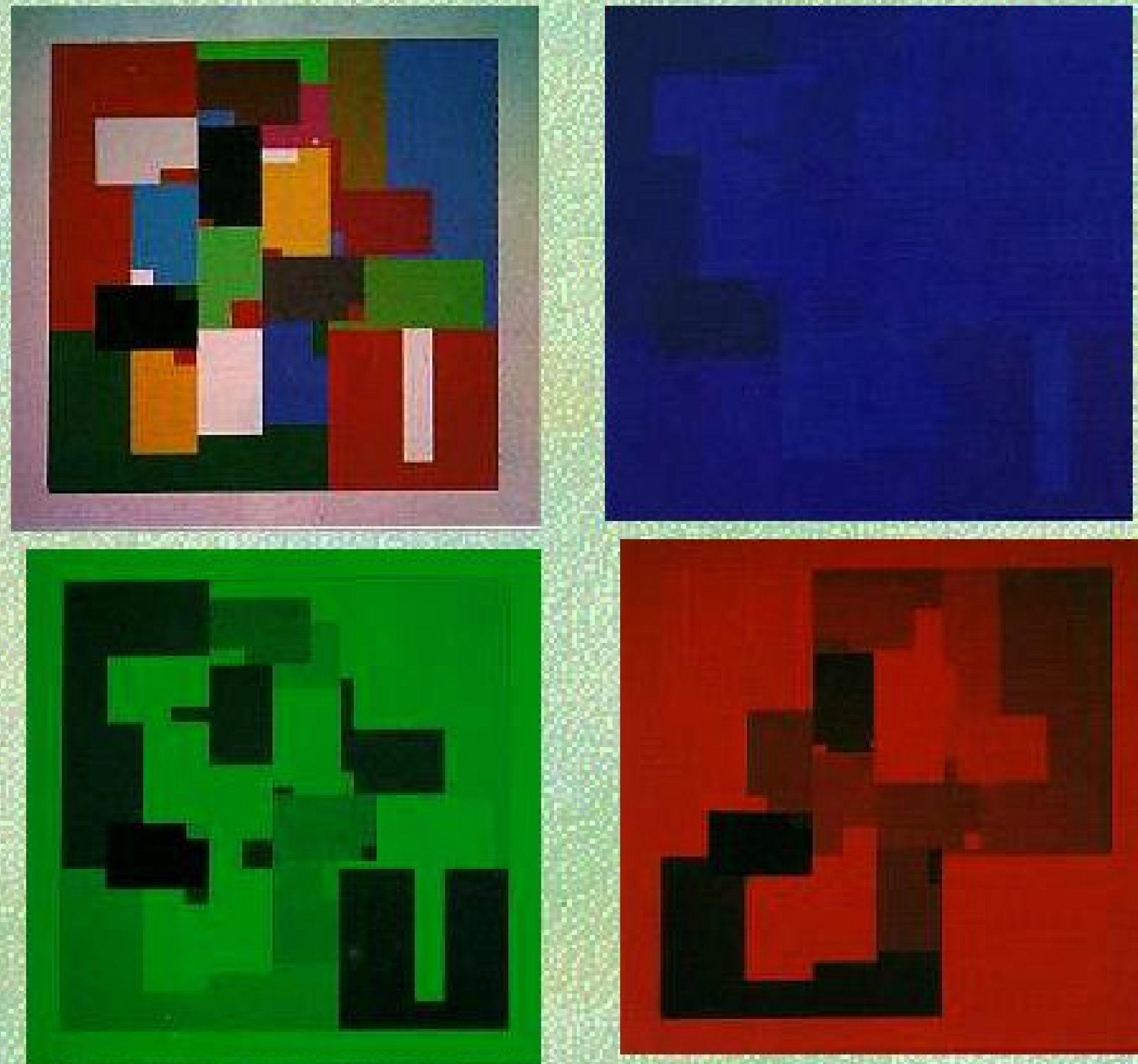
The light received at the photoreceptors is the product of:

- illuminant (i.e., light source and its spectral composition)
- surface reflectance (i.e., property of the object; percent of light of any wavelength that the object reflects).

Although this product varies with the illuminant, our color perception is largely insensitive to such variations, and dependent mainly on the surface reflectance.

This phenomenon is called "color constancy" and it makes good sense in terms of using vision as a signaling device to find preys and predators.

Any scene will have a different lightness record for each receptor's waveband



The light/dark pattern is different for each receptor

Constancy

Color appearance depends on local contrast rather than absolute level of cone absorption.

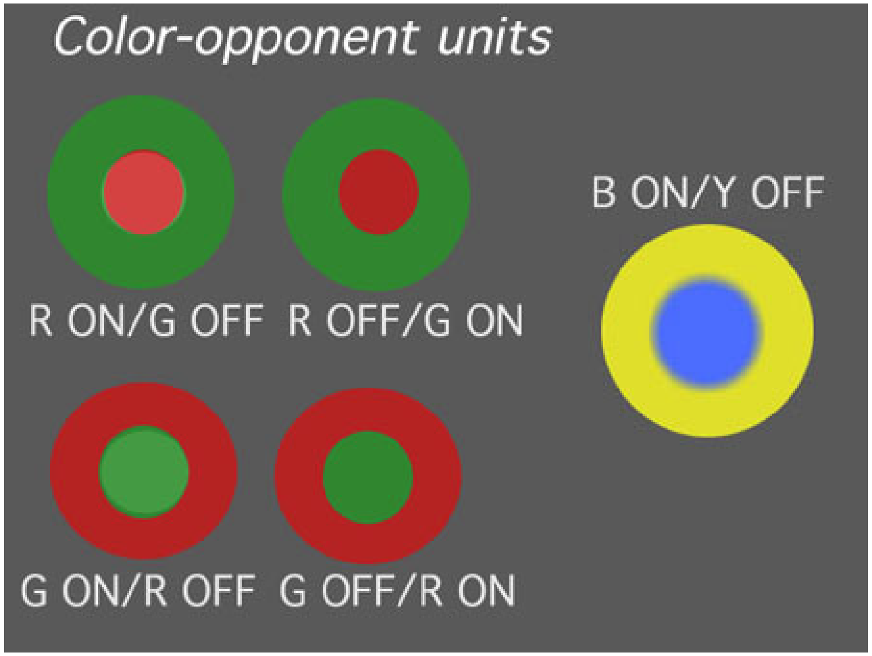
Example (Hering, 1964): read a book

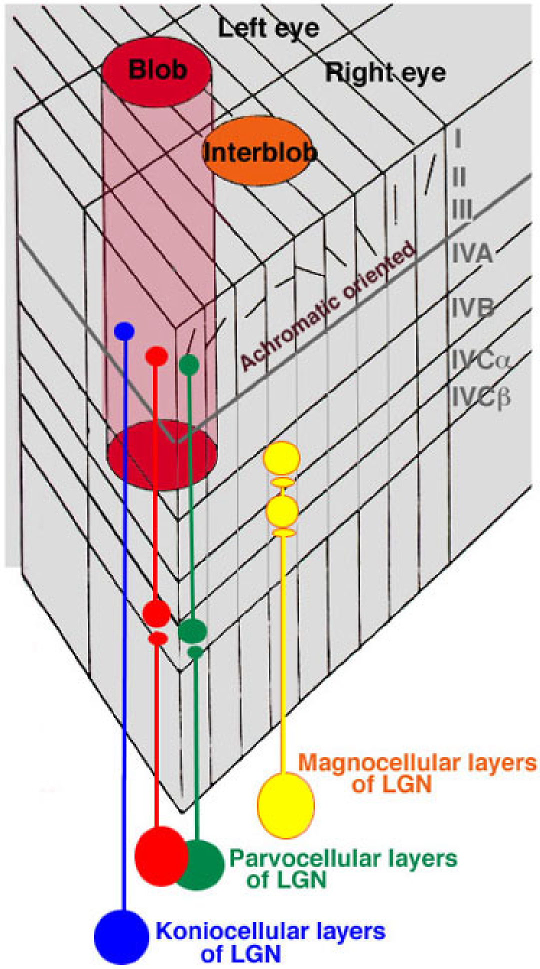
	reflects	indoors (illum. = 100)	outdoors (illum. = 10,000)
white paper	90%	90	9,000
black ink	2%	2	200

More light is received from the black ink outdoors than from the white paper indoors; yet the ink always looks black!

Cortical Processing

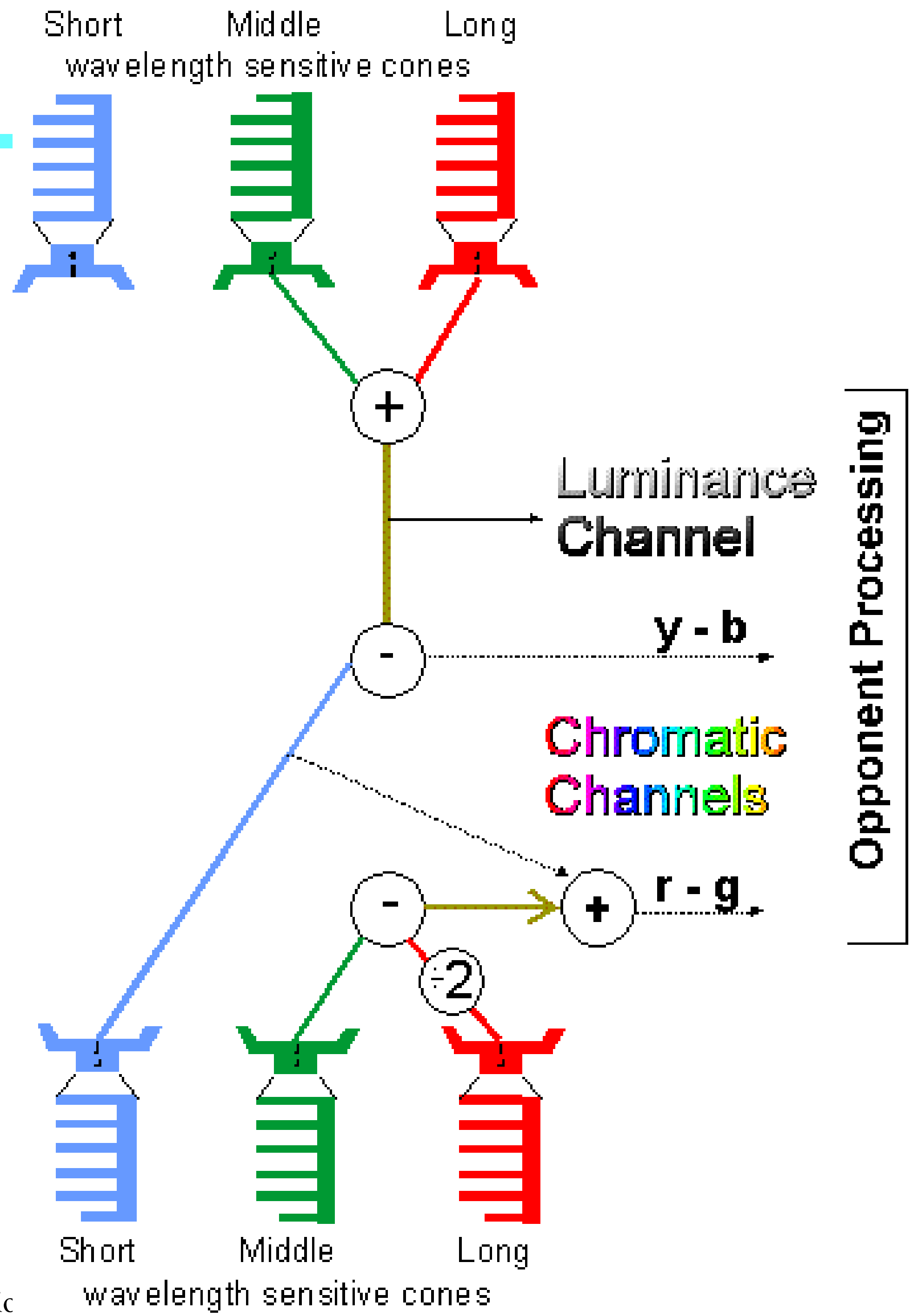
In V1, color-opponent neurons for red/green and blue/yellow.





In the monkey, V4 neurons are the first to respond to perceived color rather than wavelength.

Chromatic Channels



Basis Algorithms to Approximate Reflectance

Wandell et al, 1993. Macbeth ColorChecker (see chapter 9, p. 302)

derive a set of wavelets that will be used to decompose any reflectance profile into a vector of wavelet responses.

1st wavelet: captures light/dark

2nd wavelet: captures red/green

3rd wavelet: captures blue/yellow

…

then we have simple models of surfaces we may be interested in (for given computer vision applications) and can look for them in the image.

Surface & Illuminant Estimation

p points in image

3p measurements

if we have a 3-wavelet surface reflectance model, then we also have 3p unknowns (the wavelet coefficients for each location)

if the illuminant is known, we can solve the problem.

Otherwise, we need to estimate the illuminant from the image, and then solve the problem.

Lightness Algorithms

von Kries (1978) adaptation model: apply linear scaling to each channel to adapt to changing light conditions.

$$S^\lambda = E^\lambda R^\lambda; \qquad \lambda = r, g, b$$

with the correction factors K^λ computed as:

$$S_1^\lambda = E_1^\lambda R^\lambda$$
$$S_1^\lambda = K^\lambda S_2^\lambda = K^\lambda E_2^\lambda R^\lambda$$
$$K^\lambda = \frac{E_1^\lambda}{E_2^\lambda} \qquad \lambda = r, g, b$$

Problem: need to know the illuminant.

Recovering the Illiminant

Gray world assumption: average of surface reflectance is gray

White world assumption: every scene contains an object with white reflectance.

Uniform perfect reflector assumption: the brightest surface in the image is a perfect reflector.

Specularity-based: specularities typically reflect the illuminant perfectly; if we can find them, we will be able to recover the illuminant.

Lightness Algorithms

Helson & Judd (1936): empirical measurements yielded simple correction factors.

To discount the illuminant, they calculate the signal corresponding to a white patch and use it to correct the color of other patches in the scene.

$$N^\lambda = G^\lambda - k(G^\lambda - W^\lambda) \qquad \lambda = r, b$$

This white (N) is obtained by interpolating between the average signal over the whole scene (G) and a standard daylight white (W).

Land's Retinex Theory

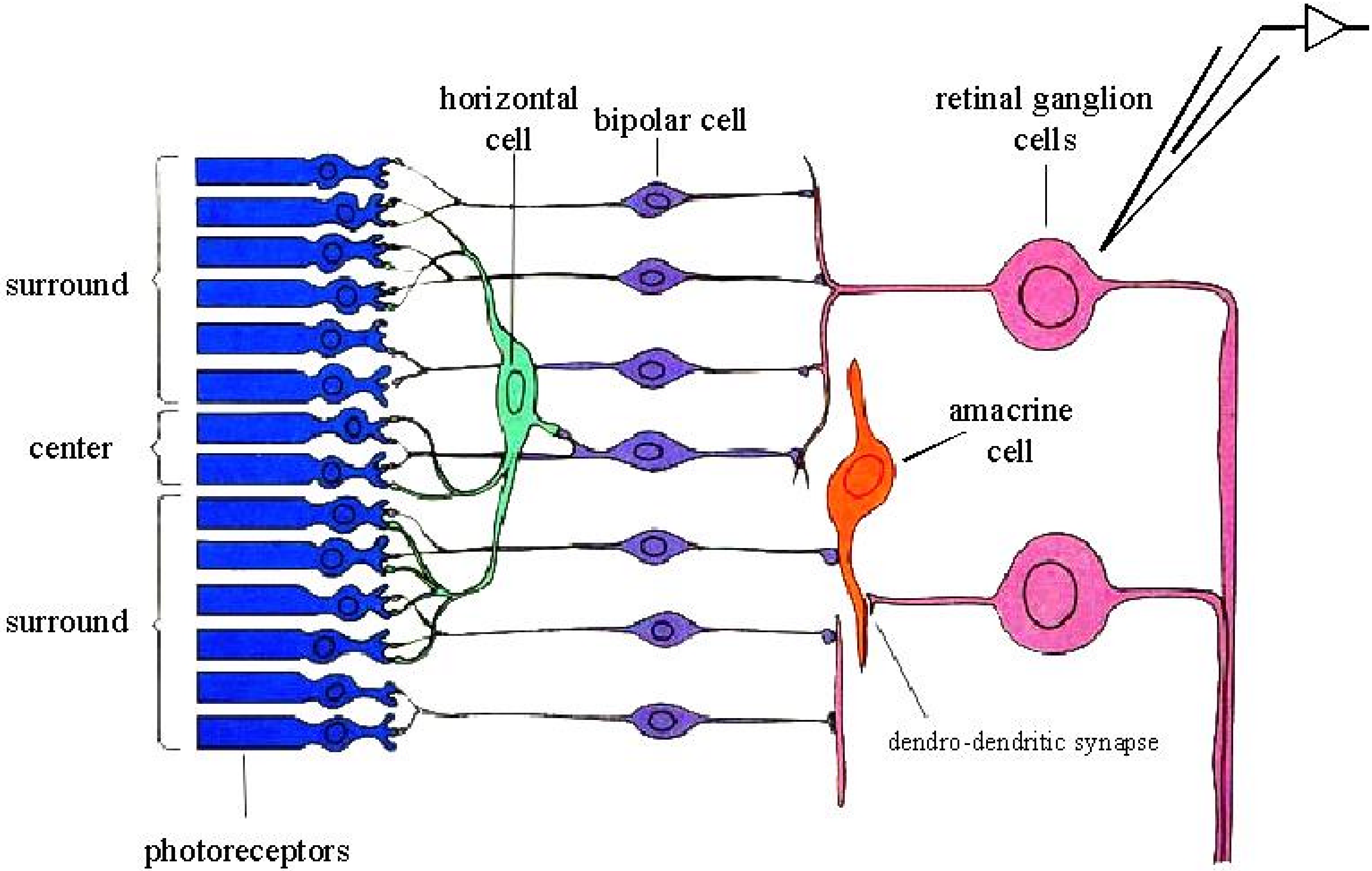
Our perception of color depends not directly on the wavelength of reflected light, but on the "interplay [contrast] between shorter and longer wavelengths over the entire scene."

(Land argues for a dichromatic theory of color perception).

Compare reflected light at one wavelength on one surface to reflected light at the same wavelength on neighboring surfaces; that way we should be able to discard the illuminant and extract the reflectance.

This can be done by center-surround mechanisms.

A circuit for center-surround?



Discounting the illuminant: Land's Retinex theory

- The visual system compares the reflectance (brightness) between surface patches for each waveband
- The visual system compares the proportion of each wavelength reflected by a single patch
- The results of the two comparisons are compared to obtain a color perception, corrected for spectral content of illuminant

Multiscale Retinex

- Dynamic range compression using log functions
- Center-surround normalization in each spectral band

2.1. The Multi-scale Retinex

For all (x, y) pixels in the multi-spectral image G, the multi-scale retinex (MSR)[4,5] can be compactly written as

$$F_j(x,y) = \sum_{n=1}^{N} W_n \cdot \{\log[G_j(x,y)] - \log[G_j(x,y) * H_n(x,y)]\}, \quad j = 1, \cdots, J \tag{1}$$

where J represents the number of spectral bands, N is the number of spatial scales being used, and W_n are the weighting factors for the scales.[6–8] The $H_n(x, y)$ are the surround functions (convolution kernels) given by

$$H_n(x,y) = I_n \exp[-(x^2 + y^2)/\sigma_n^2], \tag{2}$$

where σ_n are the spatial scale parameters that control the extent of the surround function and the I_n are selected so that $\sum\sum H_n(x, y) = 1$. Smaller values of σ_n provide more dynamic range compression, and larger values provide more lightness/color rendition. Each of the expressions within the summation represents a single-scale retinex (SSR).

The MSR combines the dynamic range compression of the small scale retinex with the tonal rendition of the large scale retinex to produce an output which encompasses both. The MSR reduces dependency on lighting conditions/geometry caused by such conditions as obscured foregrounds, and poor lighting caused by atmospheric conditions or defects in artificial illuminants.

Multiscale Retinex