Physiology of vision_3

Neurophysiology

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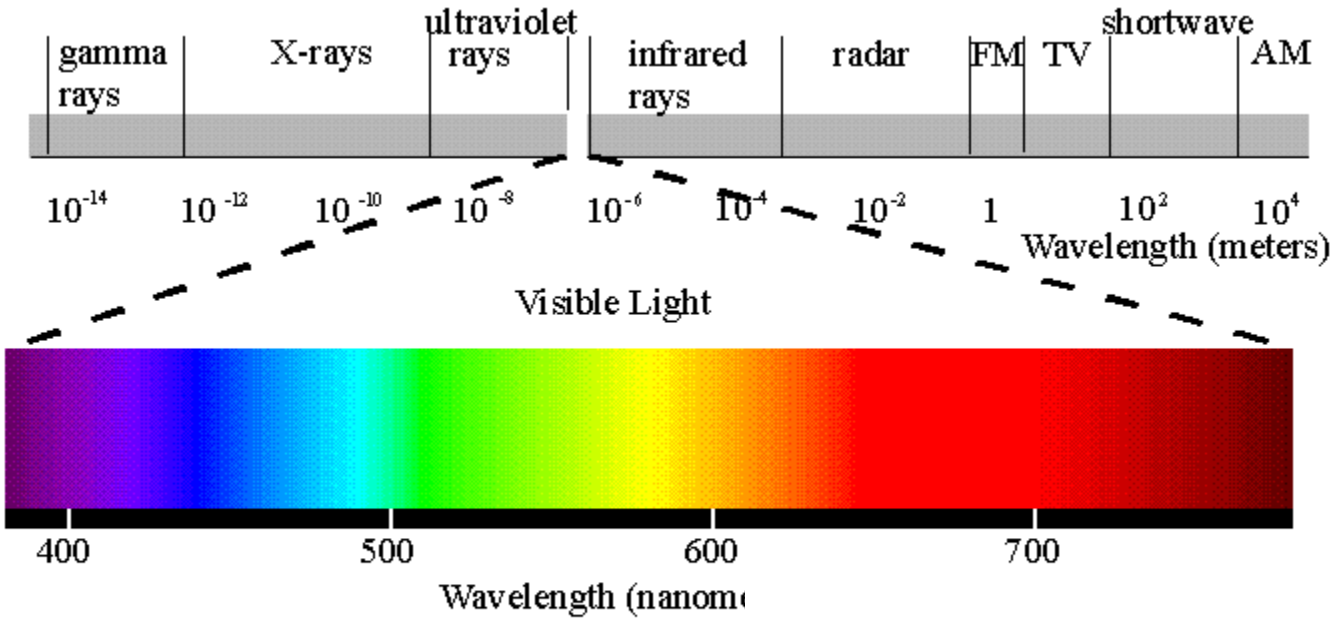
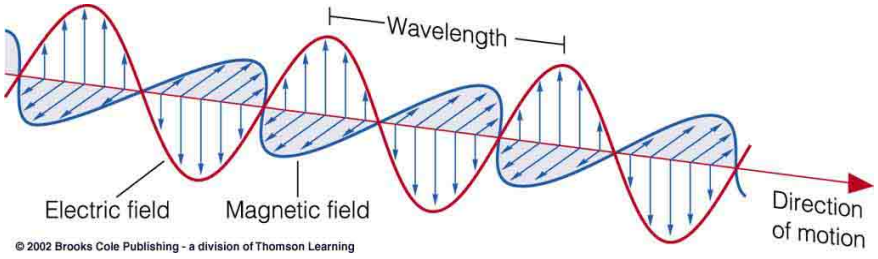
COLOR VISION

Black-white: luminance contrast (Q of reflected light)
Chromatic vision: analysis of light wave lengths
Color vision allows adding info to objects > enhanced discrimination


gamma rays
X-rays
ultraviolet rays
infrared rays
radar
FM
TV
shortwave
AM
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
Wavelength (meters)
Visible Light
400
500
600
700
Wavelength (nanom


Wavelength
Electric field
Magnetic field
Direction of motion
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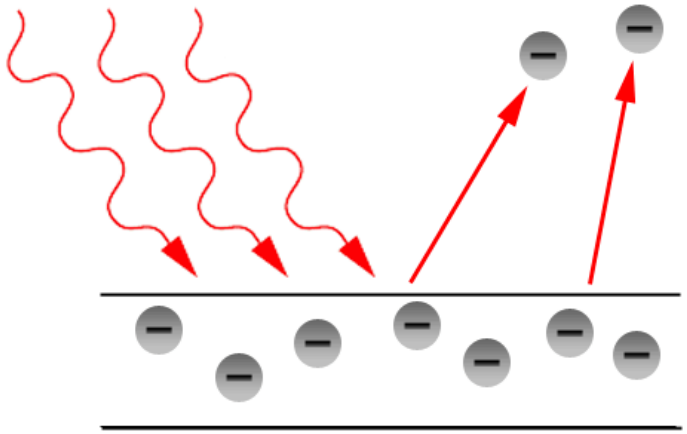
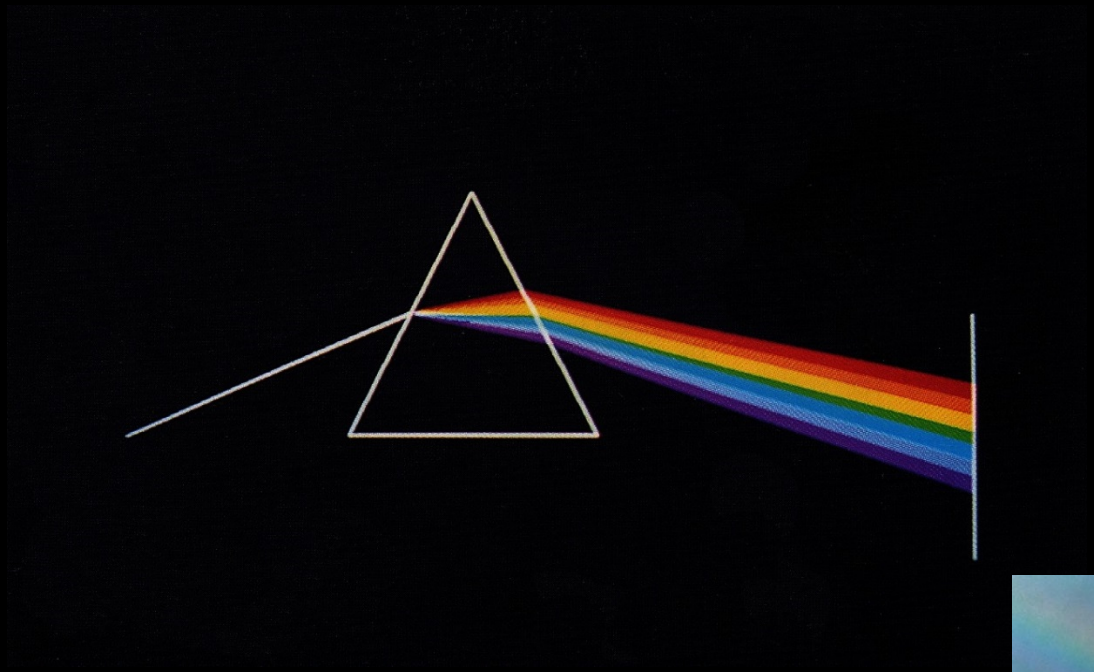


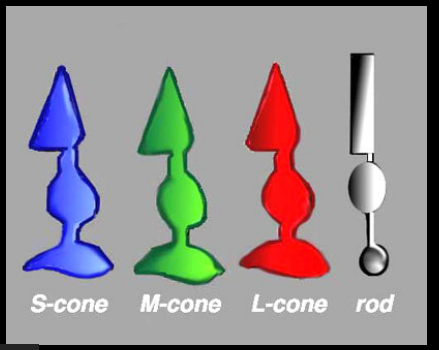
Newton's Prism:
White ligth is the sum of all wavelengths (colors) of visible light together



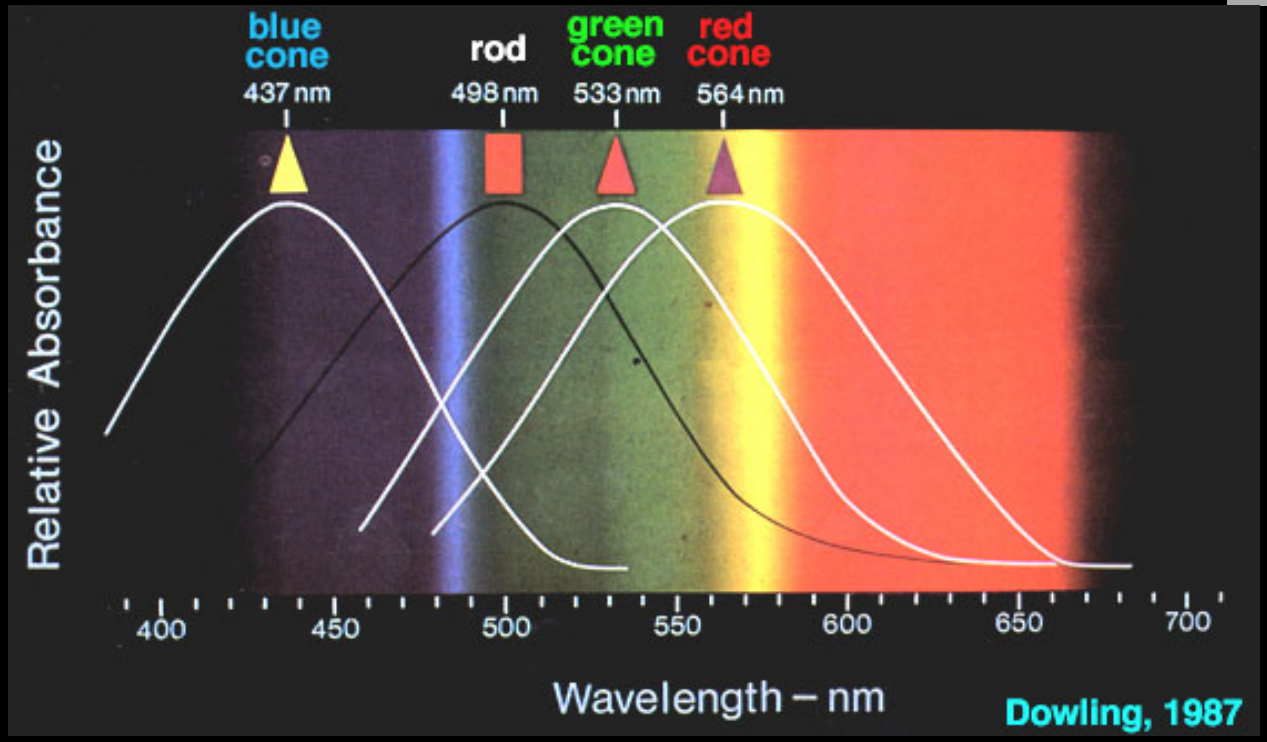
Photopigments

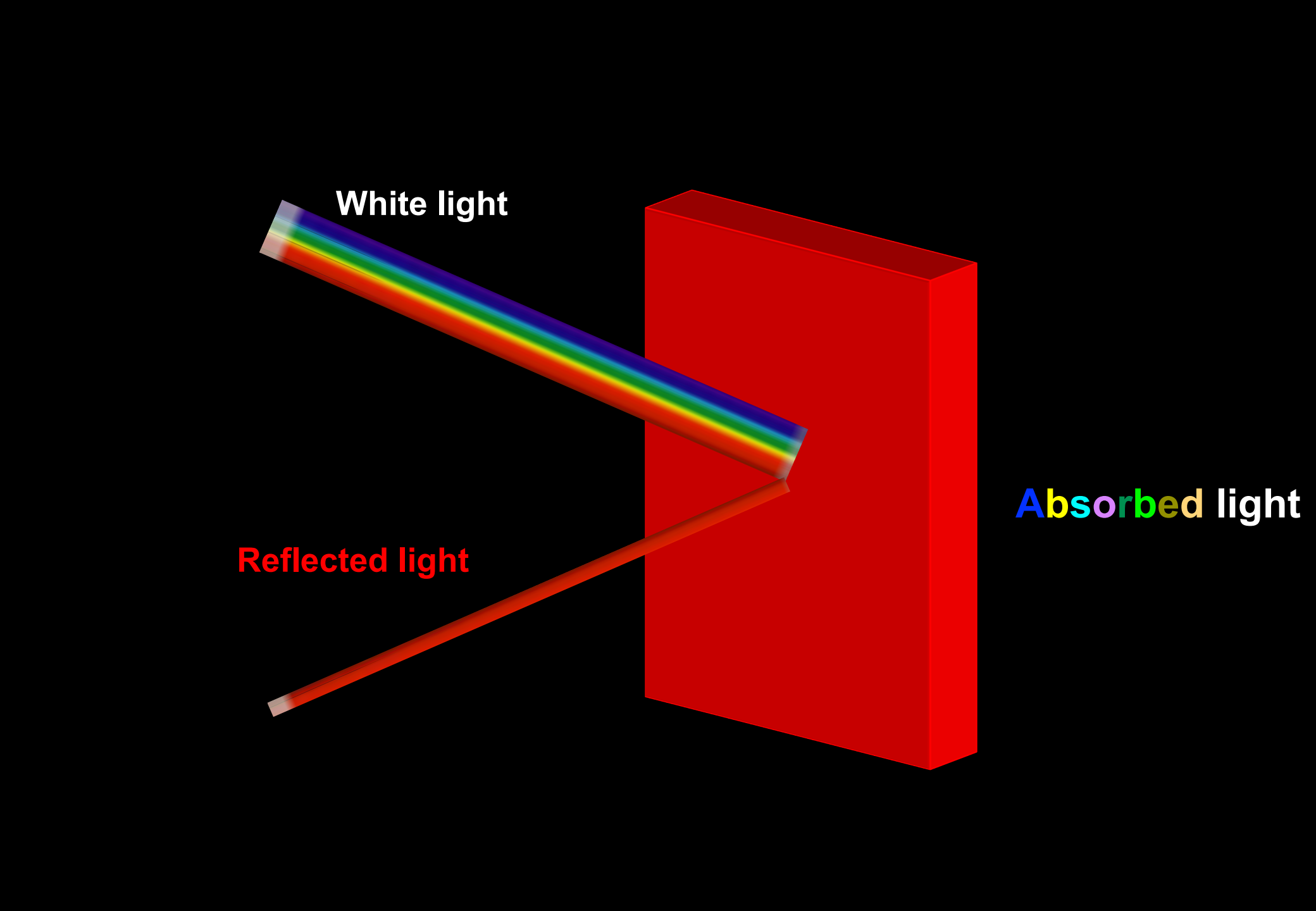
RODS: rhodopsin (rod)

<u>3 types of CONES</u>: each type contains a specific opsin sensitive to a defined wavelength range



Cone S: short wavelengths (Small: S)
Cone M: medium wavelengths (Medium: M)
Cone L: long wavelengths (Long: L)




White light
Reflected light
Absorbed light

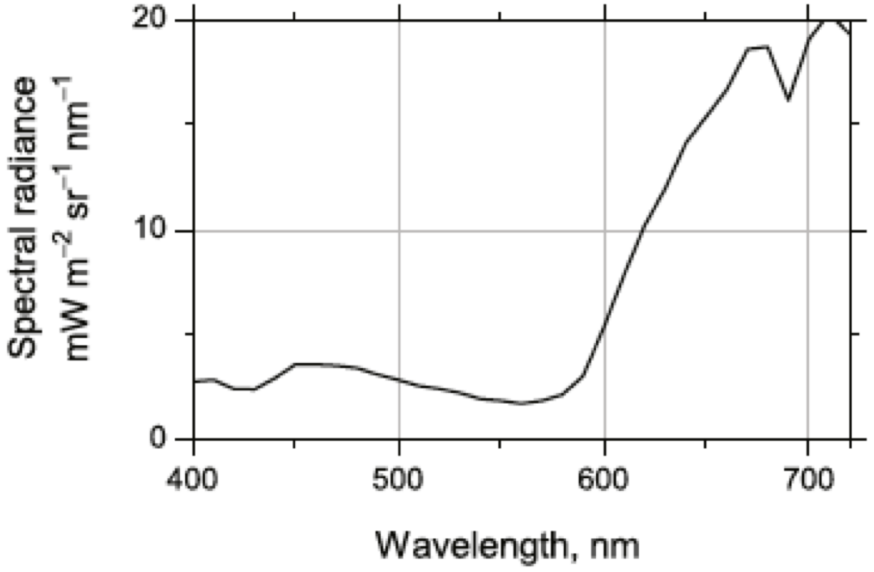
Sunlight

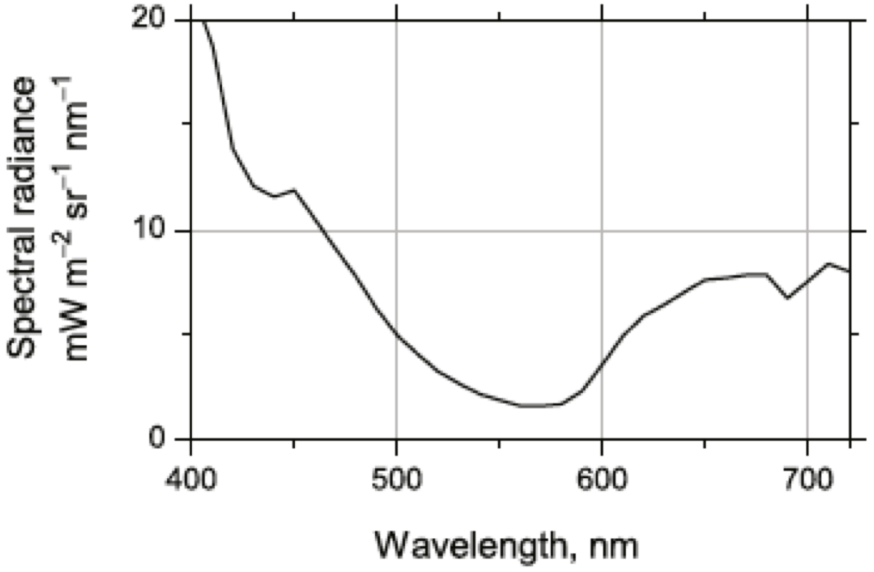
Skylight

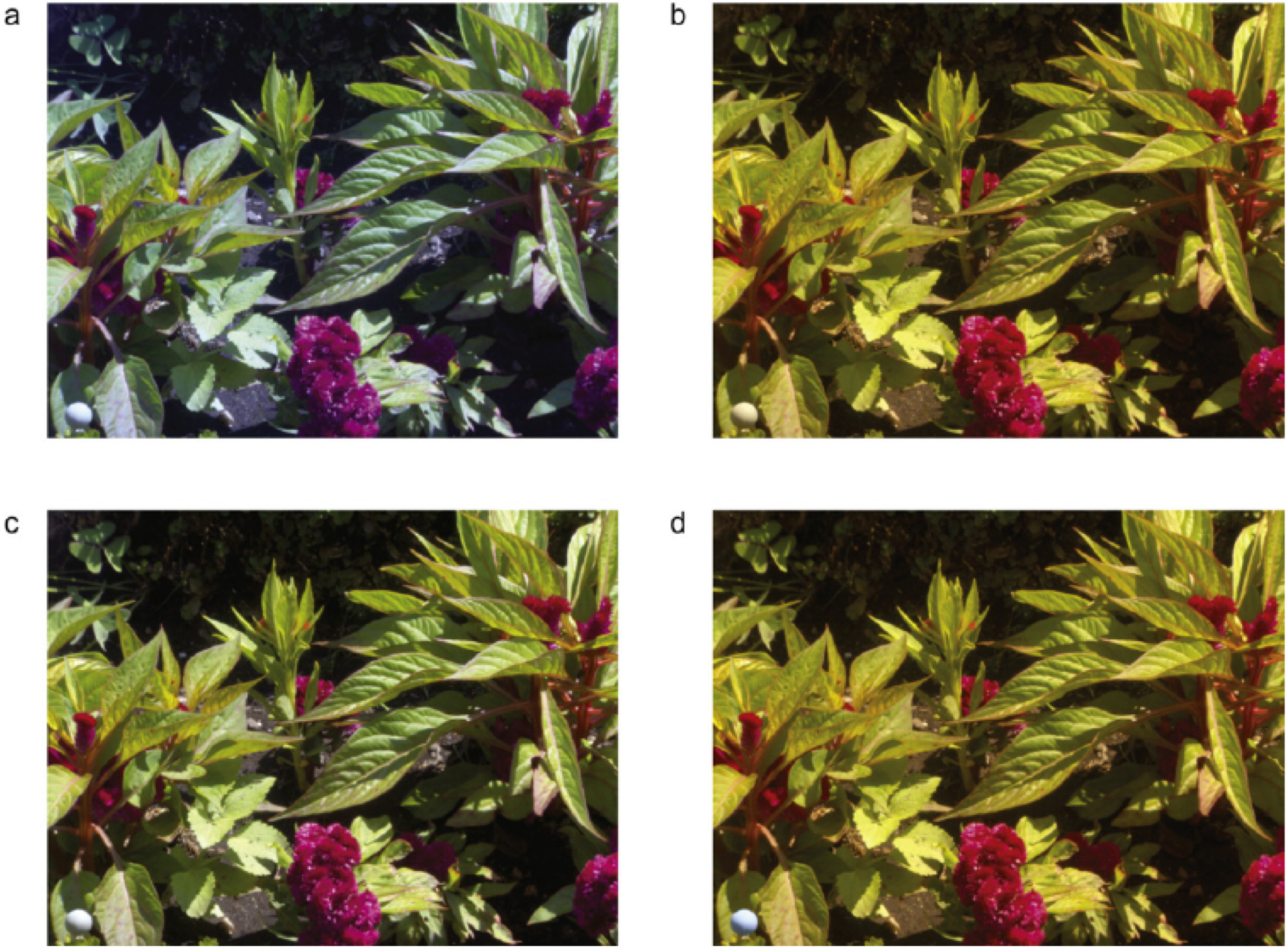
a

b

Radial spectra reflected by regions pointed by arrows






a
b
c
d

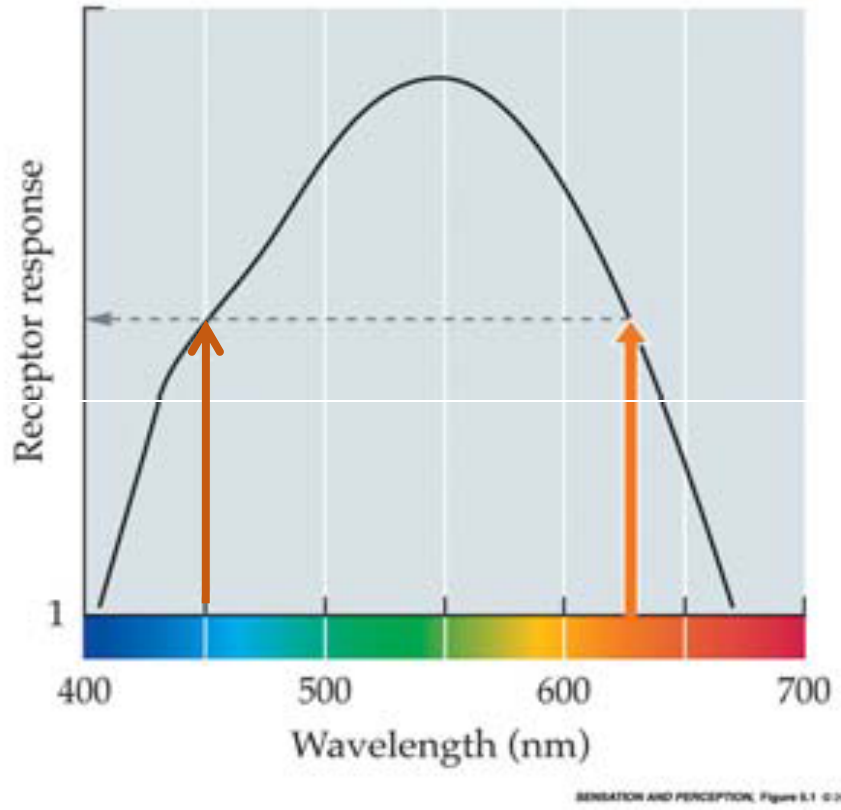
Perceived color constancy

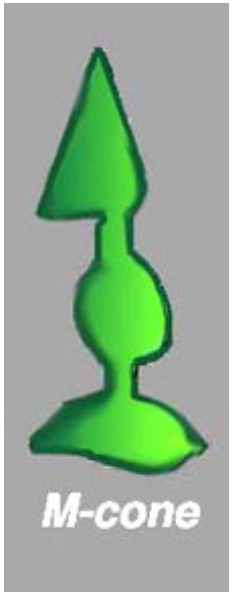
Perceiving a familiar object as having consistent color despite changes in illumination

But reflectance has changed!

Color Constancy

Photoreceptors are color blind!





The principle of Univariance

The same visual receptor cell can be excited by different combinations of wavelength and intensity, so that the brain cannot know the color of a certain point of the retinal image.

One individual photoreceptor type can not differentiate between a change in wavelength and a change in intensity.

Thichromacy and dichromacy

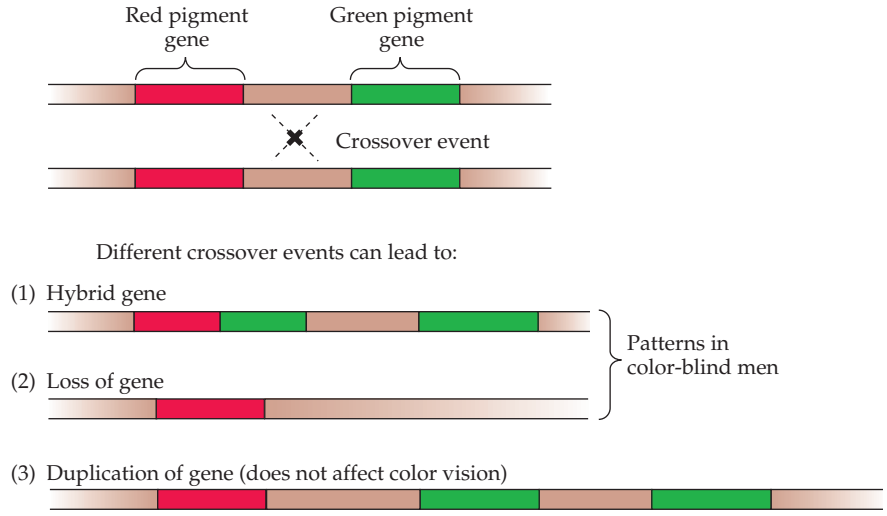
3 bandwidths needed to match all colors

2 bandwidths needed to match all colors (5-6%)

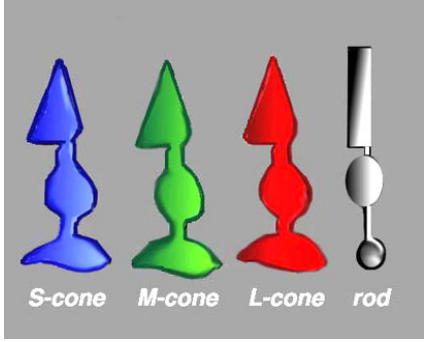
Protanopia (green and blue light)

Deuteranopia (blue and red light)

Anomalous trichromats (all bands needed, but in anomalous proportions)

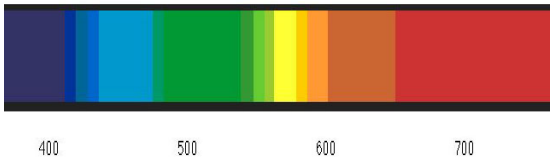


Jeremy Nathans



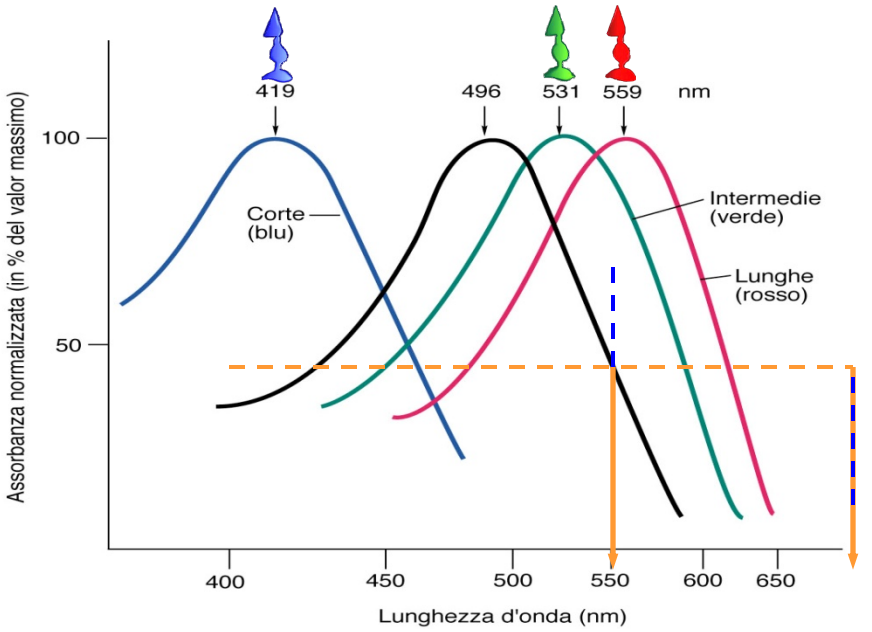
Cone evolution:

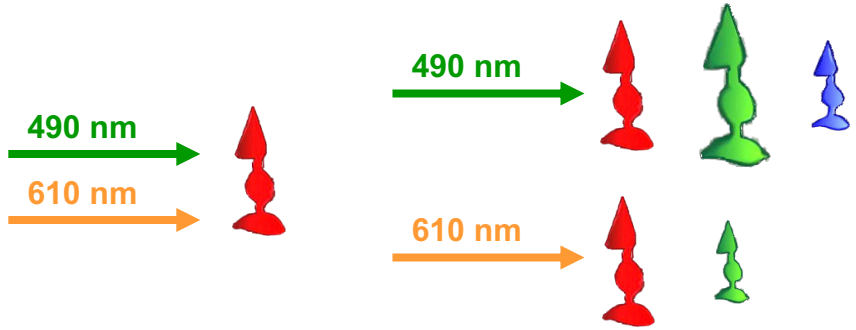
- Birds have 4 types of clones (+UV)
- Mammals often 2 types (dogs and cats included): blu and yellow
- In primates a mutation occurred in the pigment for yellow:
- Cones M, L > 3 types of clones)

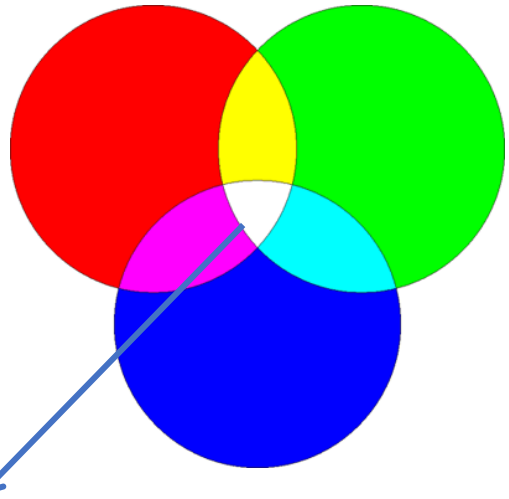


Genes of photopigments M and L are on the X chromosome

Daltonism (alterations in genes for M L pigments) - more frequent in males







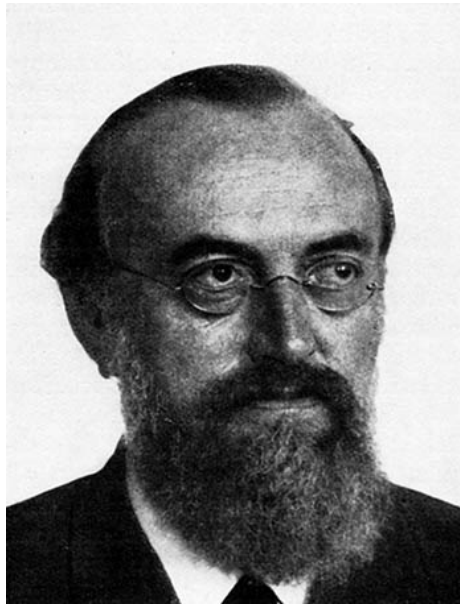
Thrichromatic theory (Young-Helmholtz)

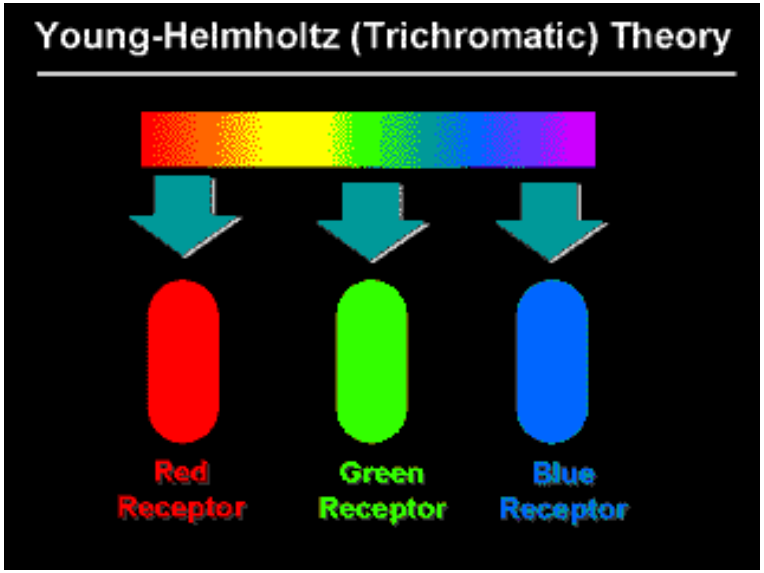
White derives from the maximal stimulation of S M L cones

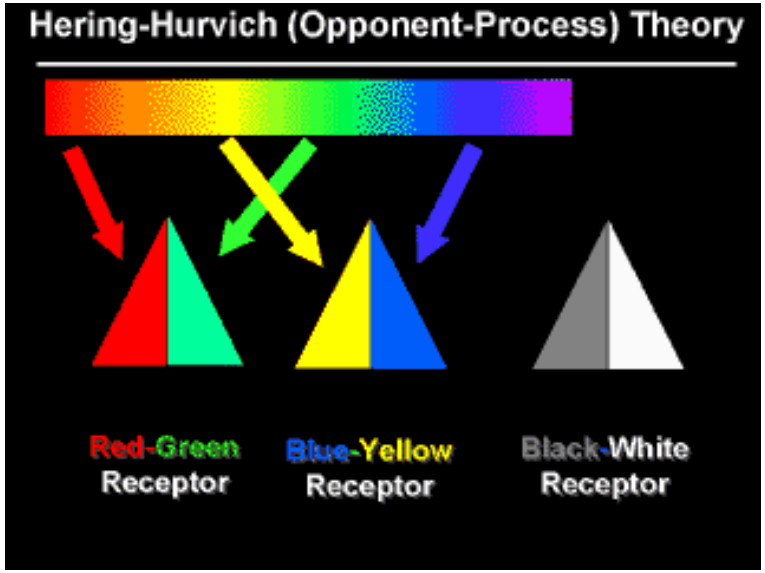
For chromatic vision all the three photopigments are necessary

The wavelength information can be extracted only by comparing the responses across different types of receptors

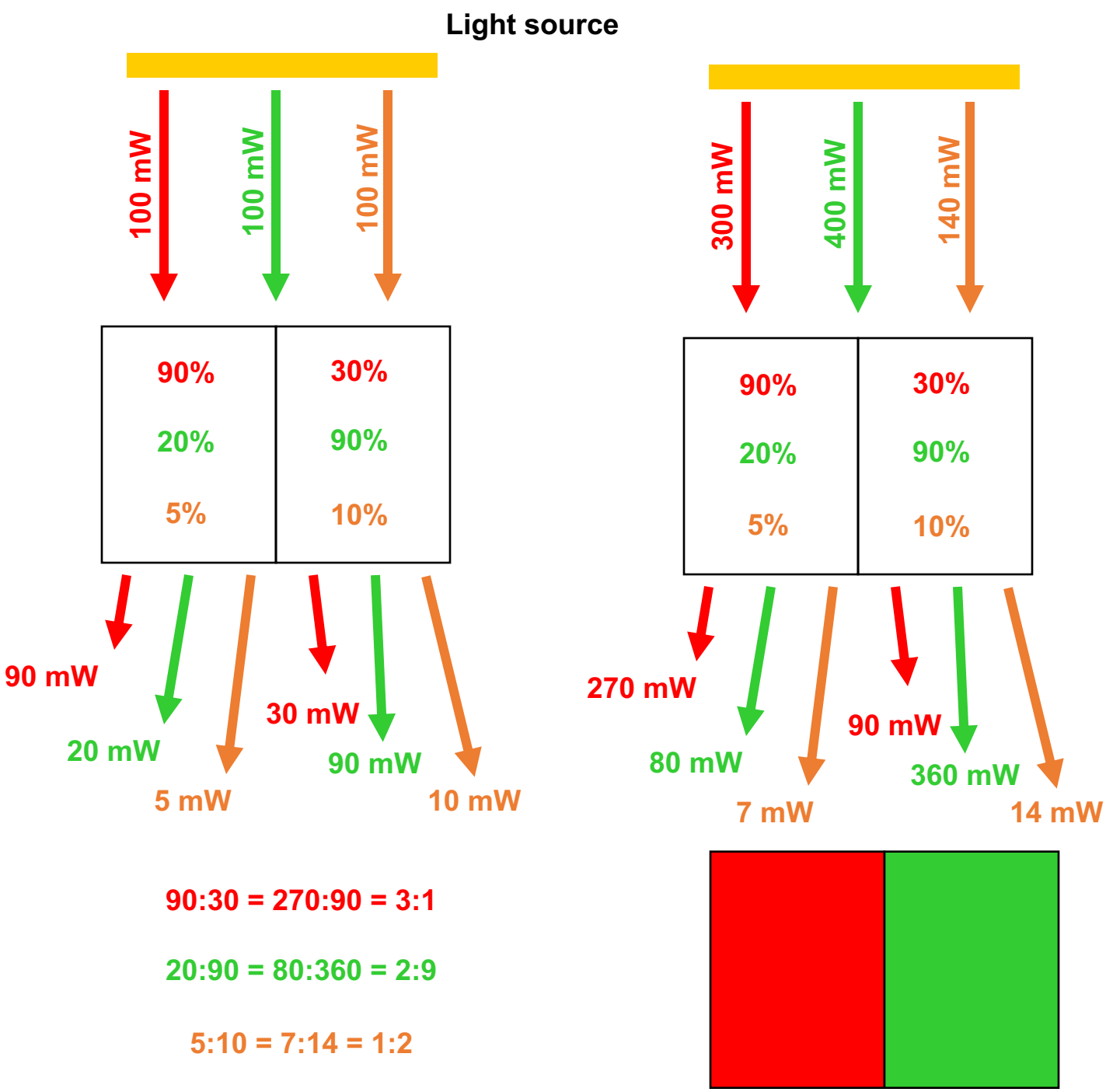
comparison of spectral components

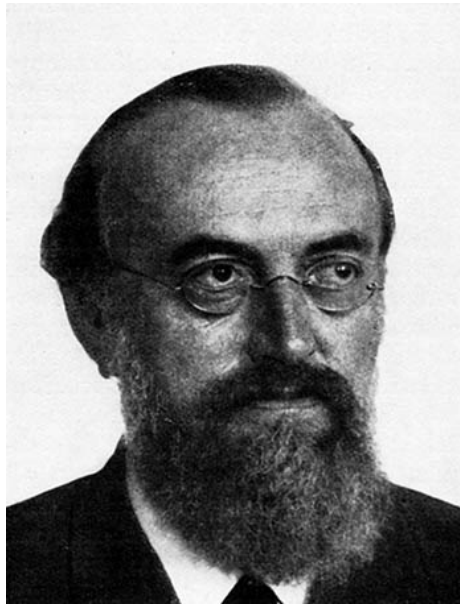


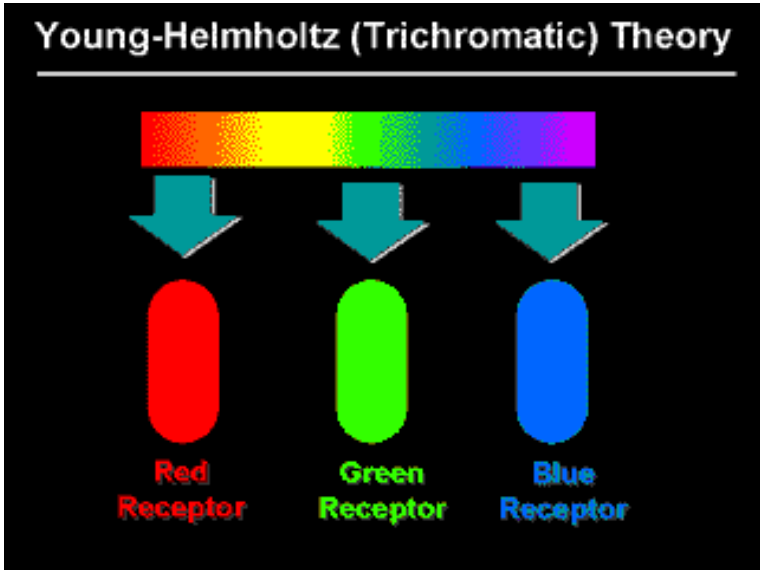

Young-Helmholtz (Trichromatic) Theory
Red Receptor
Green Receptor
Blue Receptor

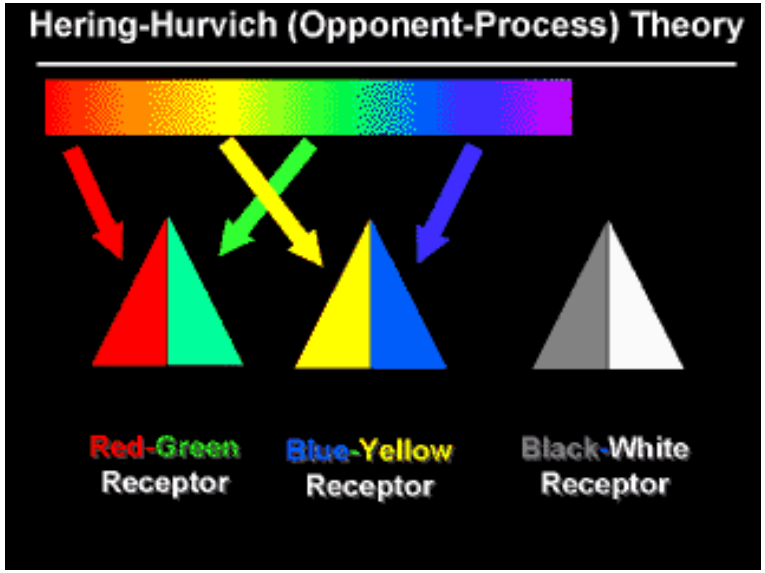

Hering-Hurvich (Opponent-Process) Theory
Red-Green Receptor
Blue-Yellow Receptor
Black-White Receptor

Night vision: in dim light cones are poorly active
Lower capability to perceive colors


Light source
100 mW
100 mW
100 mW
90%
20%
5%
30%
90%
10%
90 mW
20 mW
5 mW
30 mW
90 mW
10 mW
300 mW
400 mW
140 mW
90%
20%
5%
30%
90%
10%
270 mW
80 mW
7 mW
90 mW
360 mW
14 mW
90:30 = 270:90 = 3:1
20:90 = 80:360 = 2:9
5:10 = 7:14 = 1:2



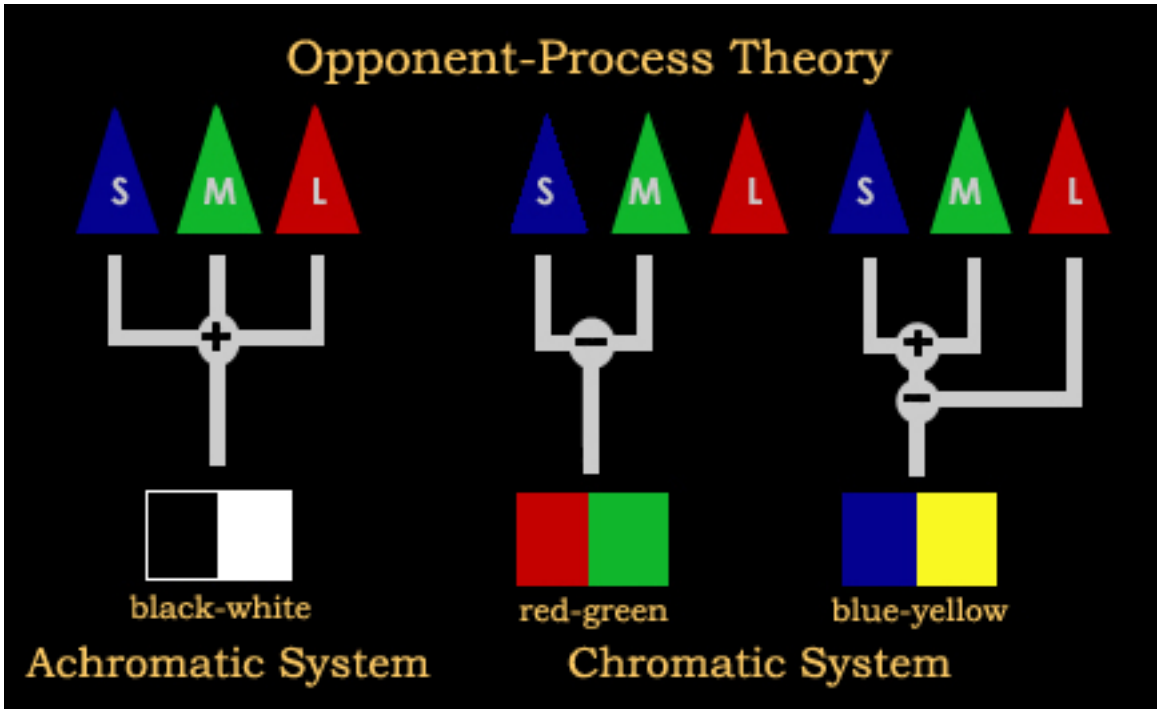

Young-Helmholtz (Trichromatic) Theory
Red Receptor
Green Receptor
Blue Receptor


Hering-Hurvich (Opponent-Process) Theory
Red-Green Receptor
Blue-Yellow Receptor
Black-White Receptor

Opponent Process theory

The cone photoreceptors are linked together to form three opposing colour pairs: blue/yellow, red/green, and black/white. Activation of one member of the pair inhibits activity in the other.

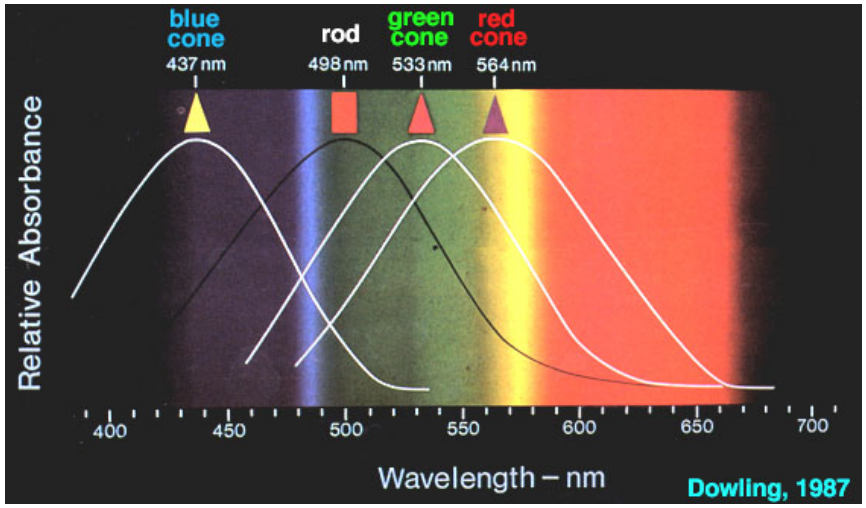
Consistent with this theory, no two members of a pair can be seen at the same location

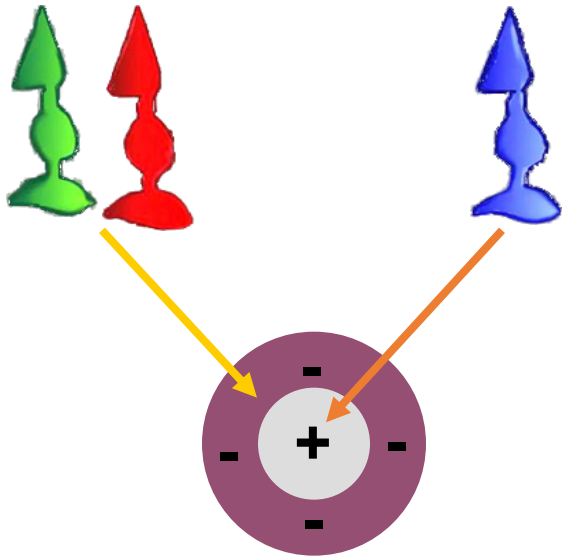


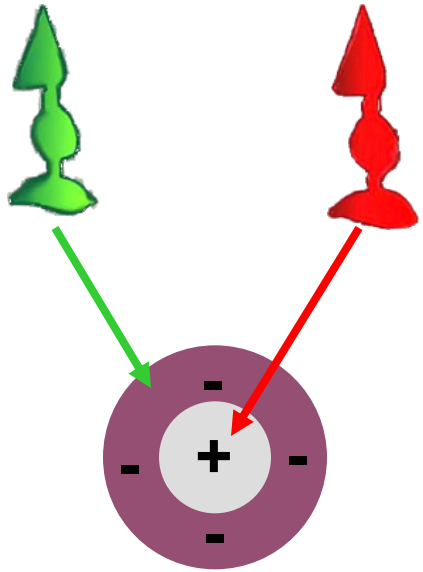
How is yellow seen if there is no yellow cone?

It results from the excitatory and inhibitory connections between the three cone types. Specifically, the simultaneous stimulation of red (L cones) and green (M cones) is summed and in turn inhibits B+Y-, which results in the perception of yellow. However, when blue light is present, the S cone is activated, the B+Y- cell receives excitatory input and blue is perceived.

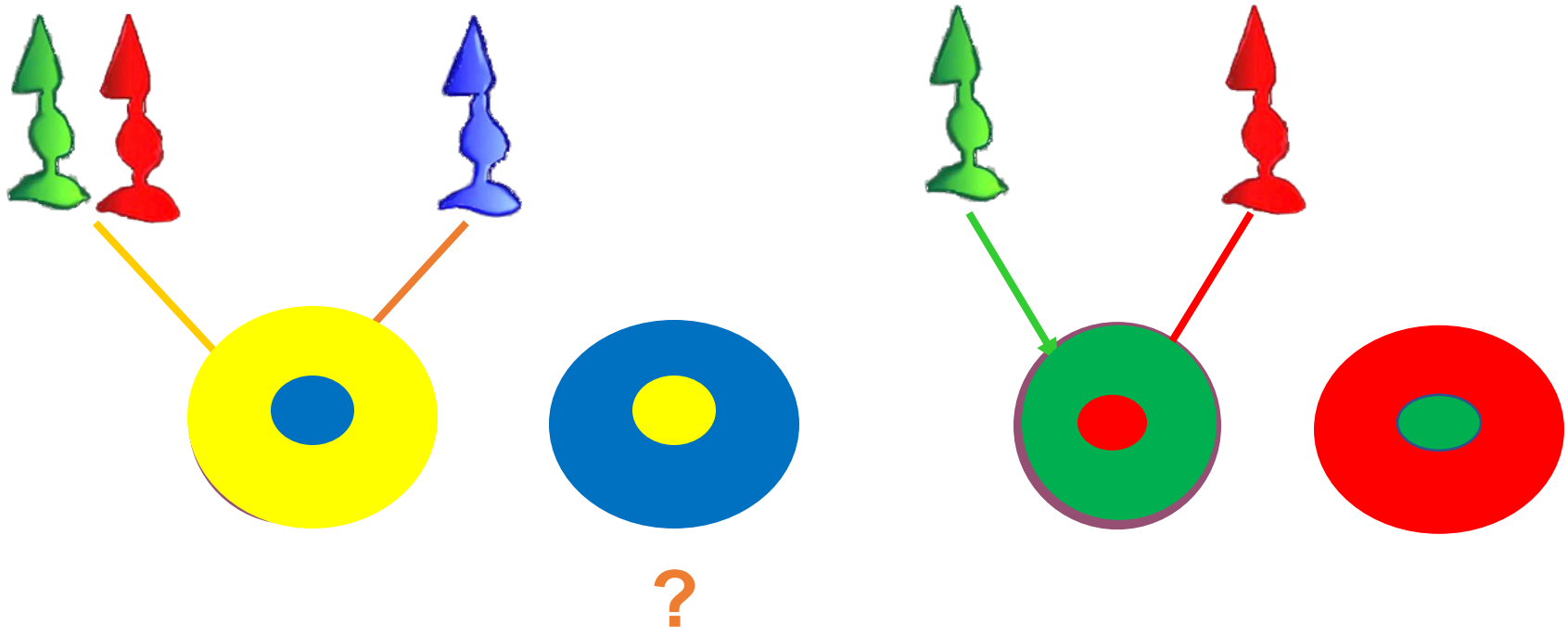
Bipolar and retinal ganglion cells (P)







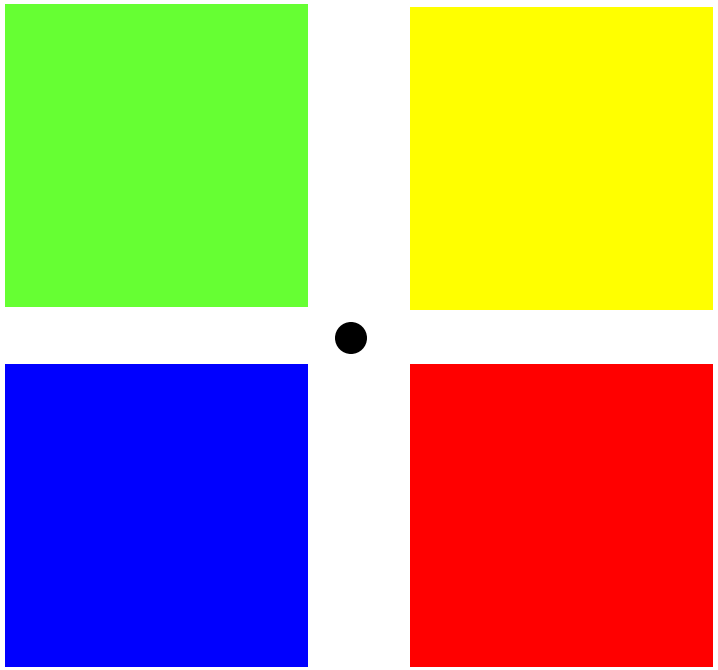
Cones transmit information to bipolar cells and ganglion cells on-center or off-center



Cells with chromatic opponence

Red, green and yellow, blue are fundamental hues and seem to be related in mutually exclusive pairs (eg reddish green is an impossible color)

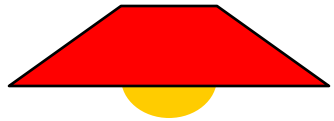
Opponent colors

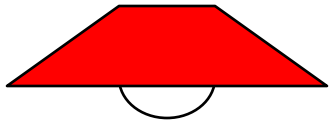


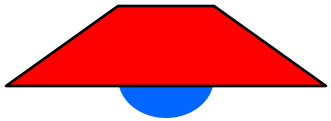
Complementary afterimage

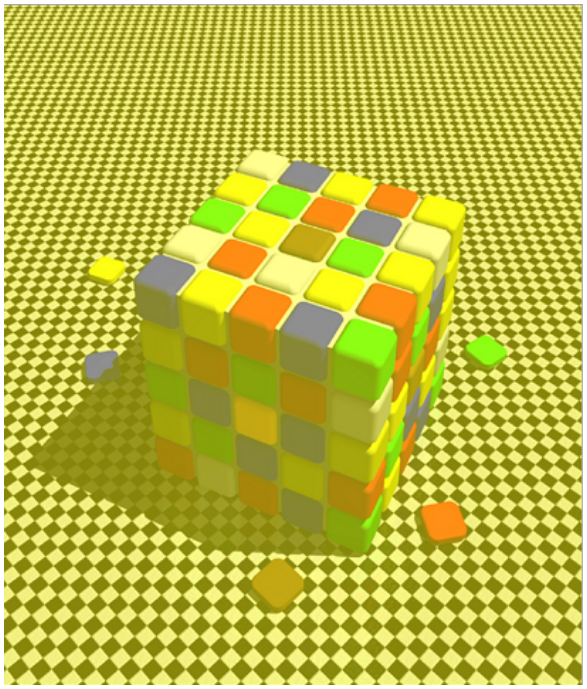
Piero della Francesca
Madonna di Monterchi

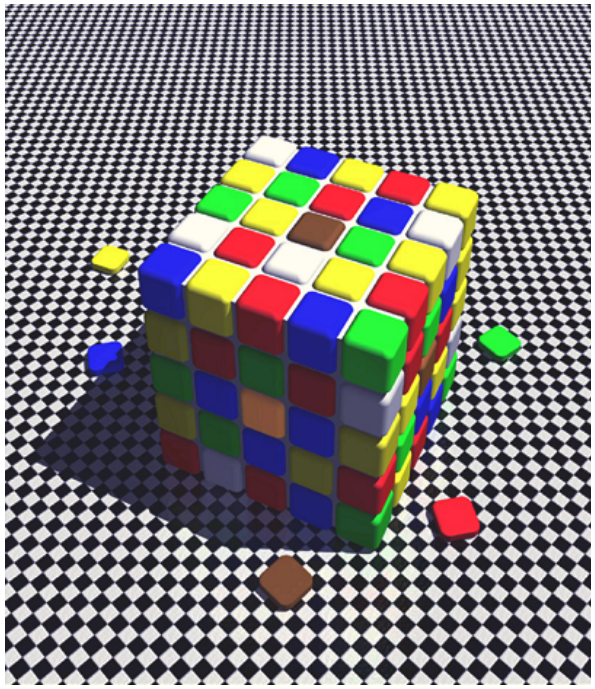
Color constancy

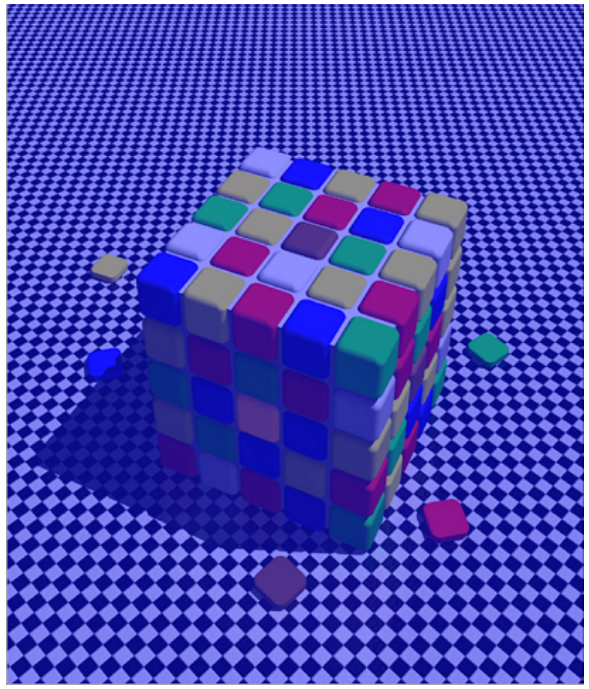












Depending on the incident light spectrum, the wavelengths reflected by objects do change, but the attribued color is maintained

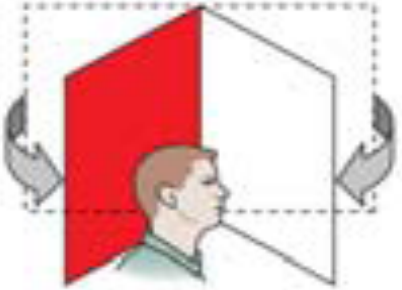
E. Land

Does color appearance correlate with reflectance?

Always Mostly Seldom

Visual perception is an adaptive process

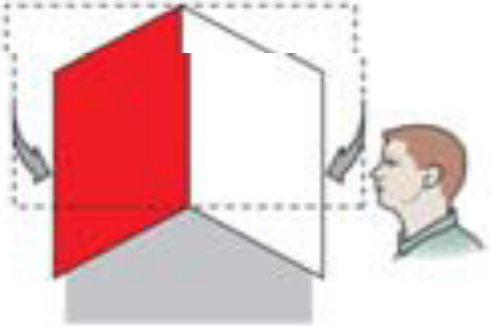
1. Start with a card half red, half white.



2. Fold it so that red faces white.

3. Light reflects from red onto white.

4. The visual system "knows" about the reflection and knows to discount it.



5. Now, fool the visual system into thinking the card is folded like a roof.

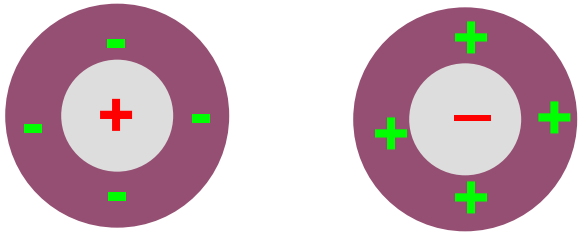
6. Without the reflection explanation, the white side now looks quite pink.

RETINA e LGN :

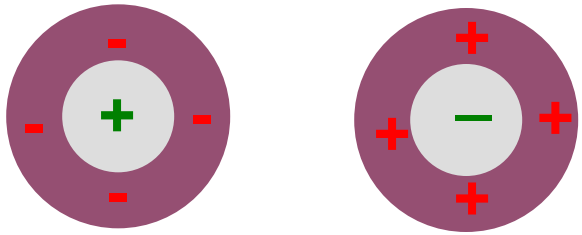
- **Cells with simple chromatic opponence**
- **Concentric cells broad spectrum**
- **Coextensive cells simple opponents**

Cells with simple chromatic opponence

Center surround antagonism based on afferences from M and L cones.
Transmit **color information** + **achromaric luminance constrast**.

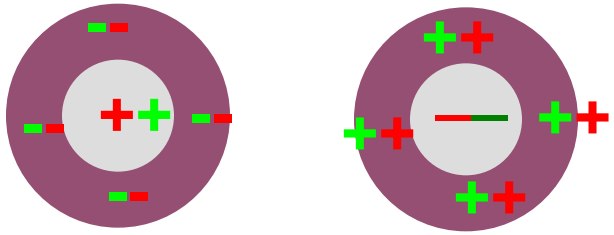


Only P cells in the retina



Concentric cells broad spectrum

Center surround receptive fields.
Afferents from M and L cones (no S)
Respond to luminance.



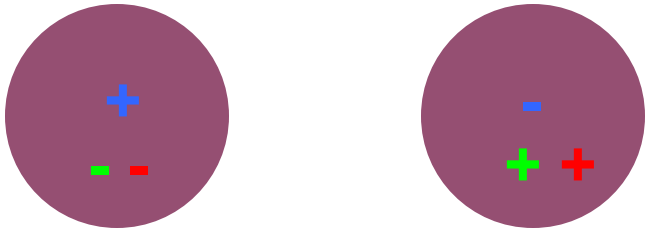
S cones do not project to these cells: do not contribute to shape perception but to color vision (chromatic aberrations often alter the S part of the spectrum).

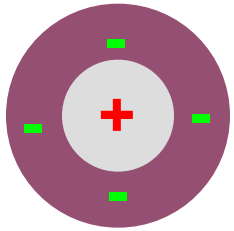
Diffuse light is a very weak stimulus for these cells.

Both M and P cells in the retina

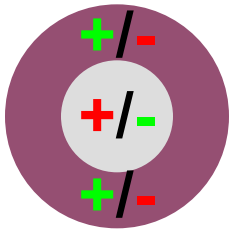
Coextensive cells simple opponents

Afferences from S Cones: uniform receptive field
S cones antagonise M and L Cones

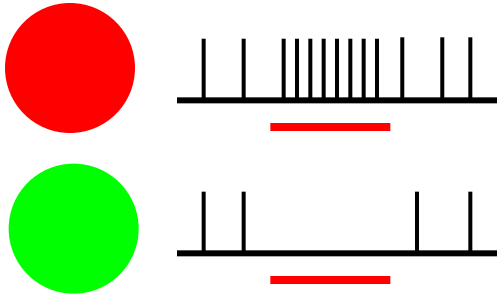


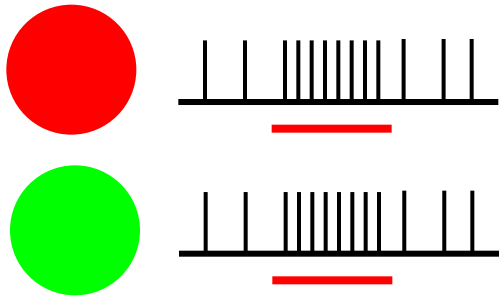


Cells with simple chromatic opponence
V1
Wavelength sensitive



Concentric cells broad spectrum
V4
Color sensitive





Sensitive to chromatic contrast (hues)

P system blobs: **colors**

P system interblob: **shapes**

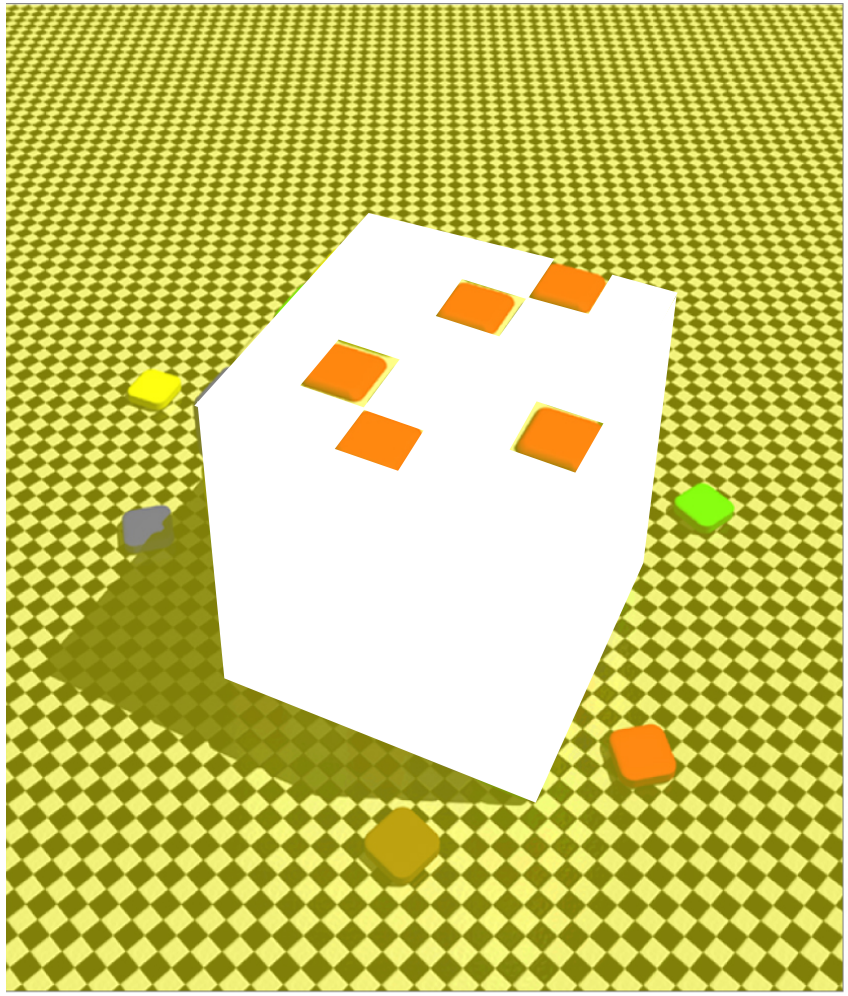
M system: **movement and depth of the field of view**

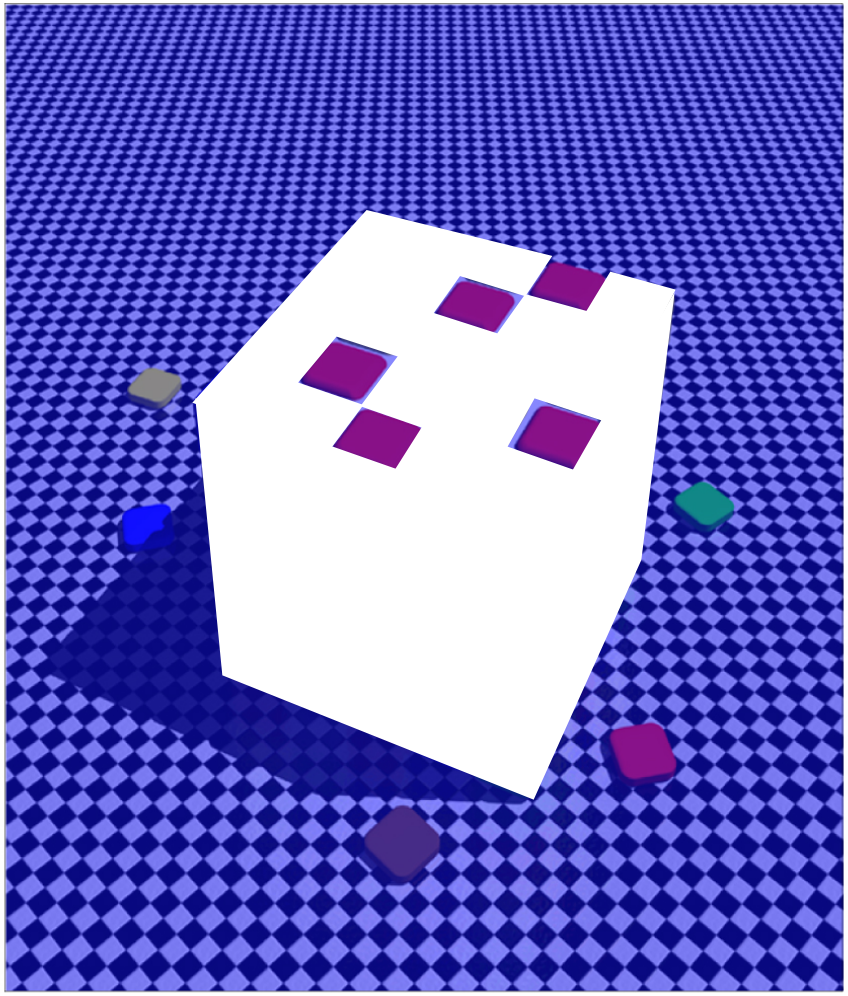
The visual cortex relies on contextual details to infer information on the source of light and therefore determine the perception of specific colors.

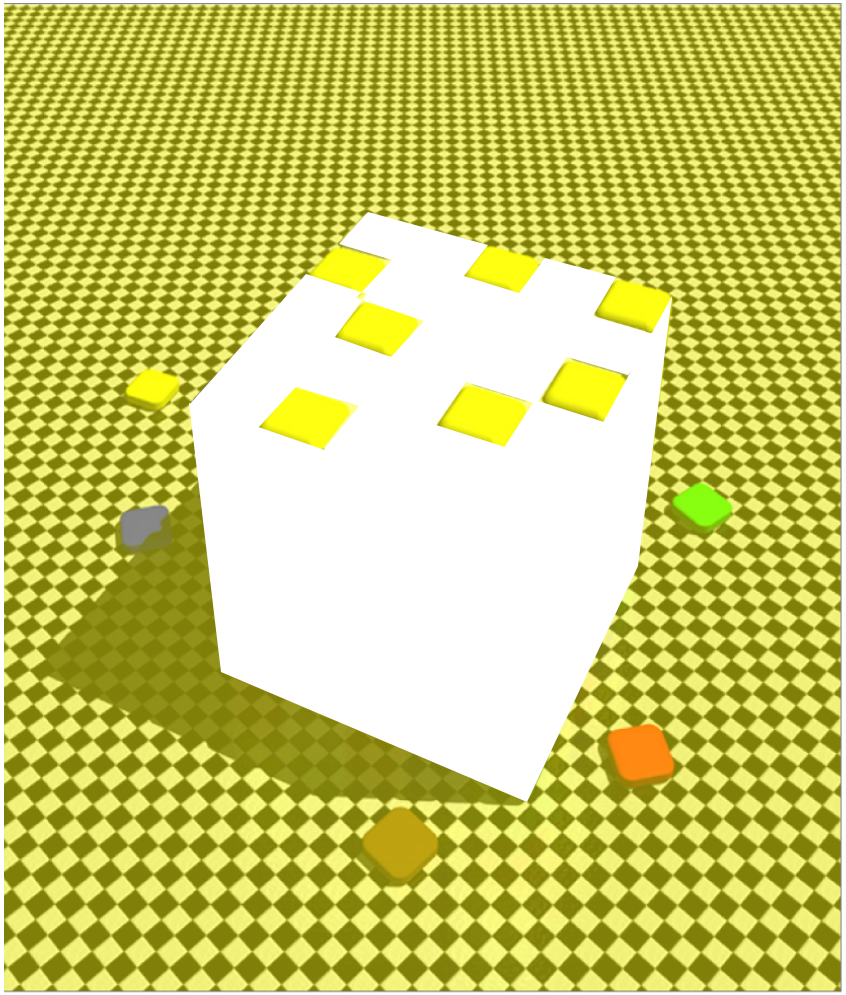
Vision is an active, cognitive process

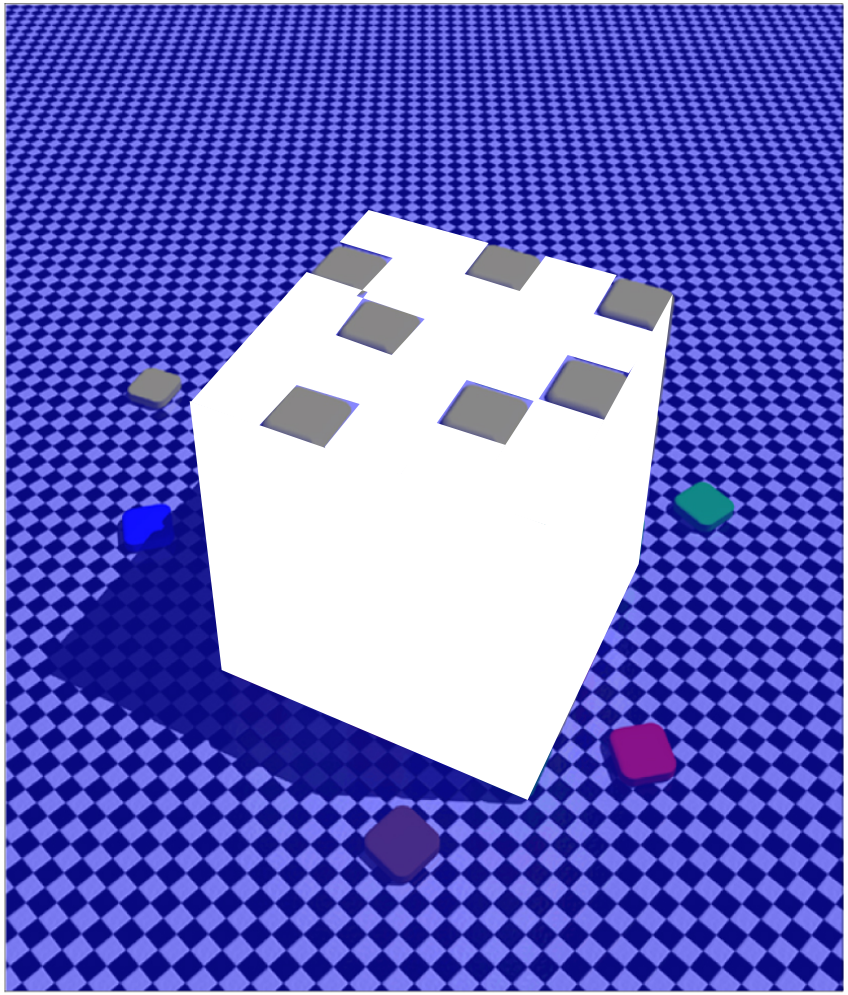
Color constancy:
adaptive/experience-based attribution of features to objects

Color constancy

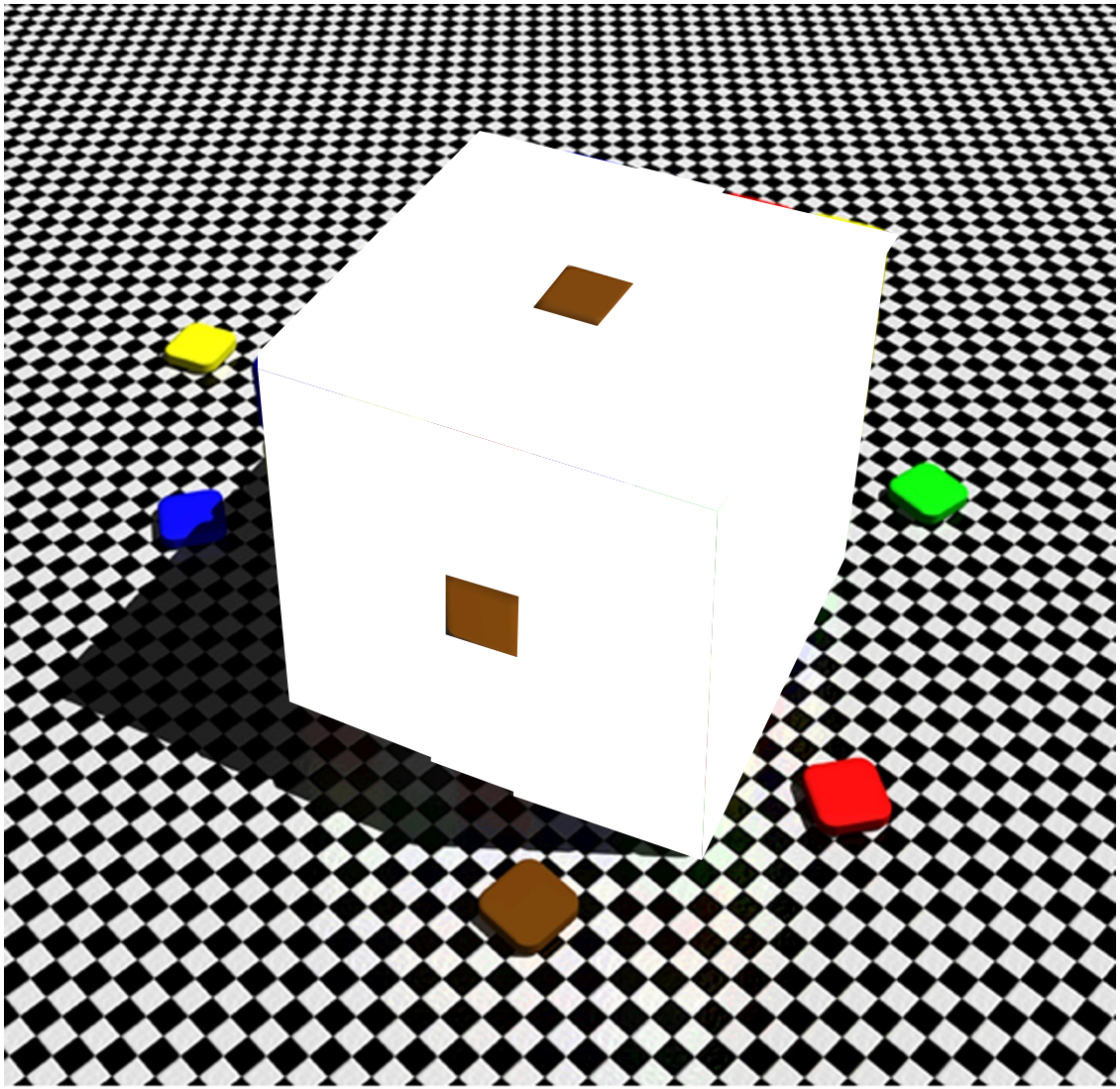




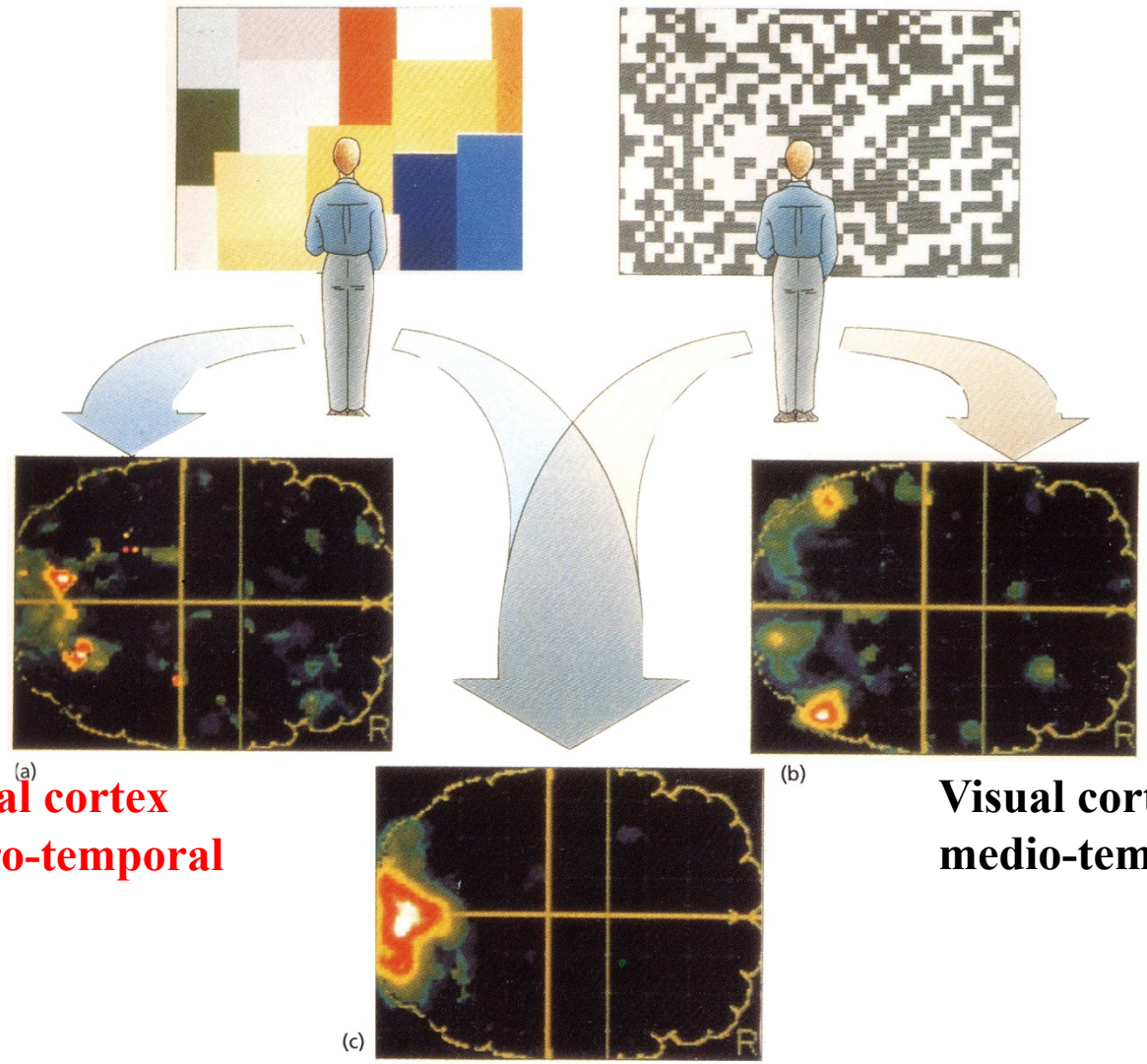




Color contrast



Physically identical patches can be made different depending on background contrast

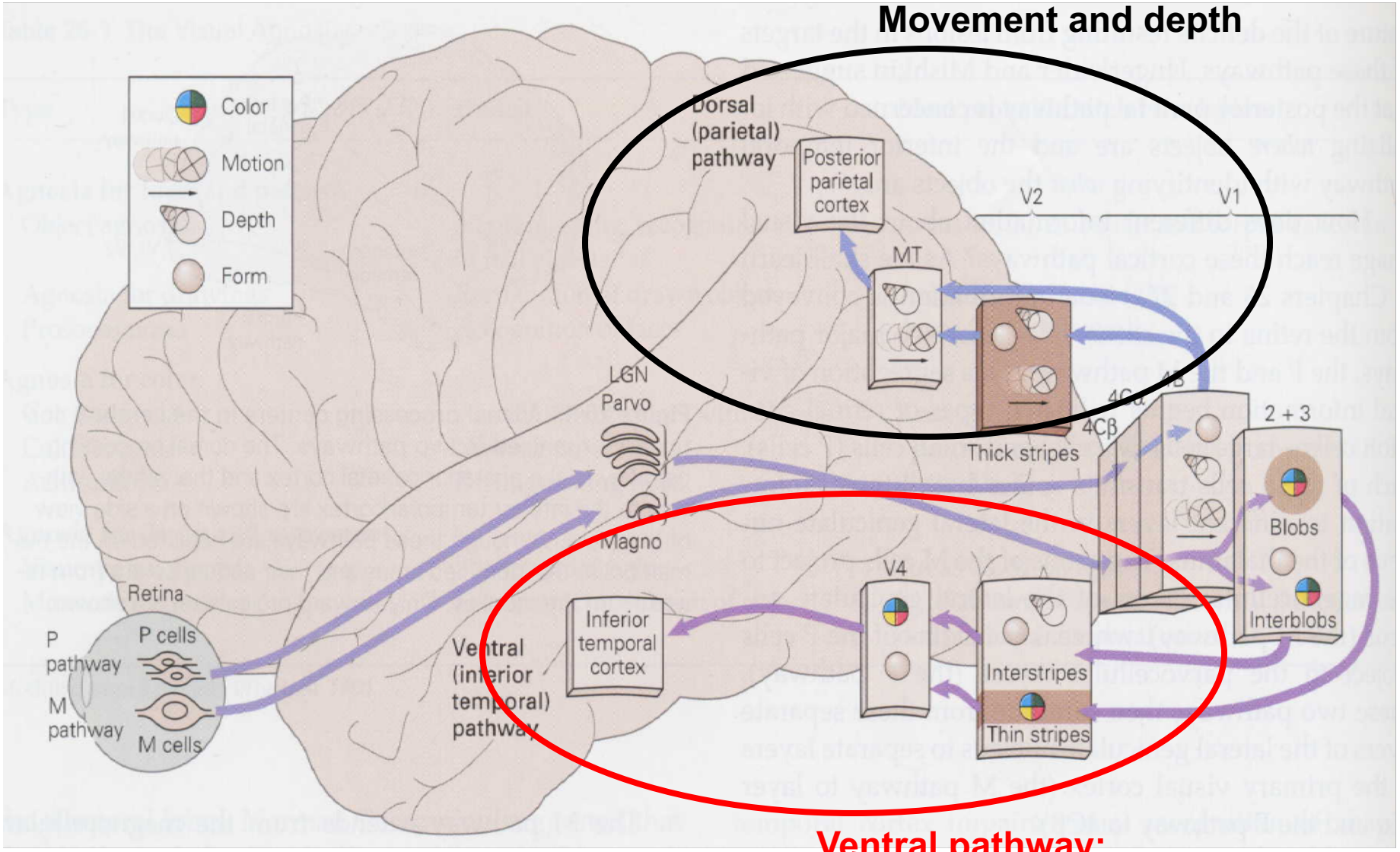


Visual cortex infero-temporal (V4)

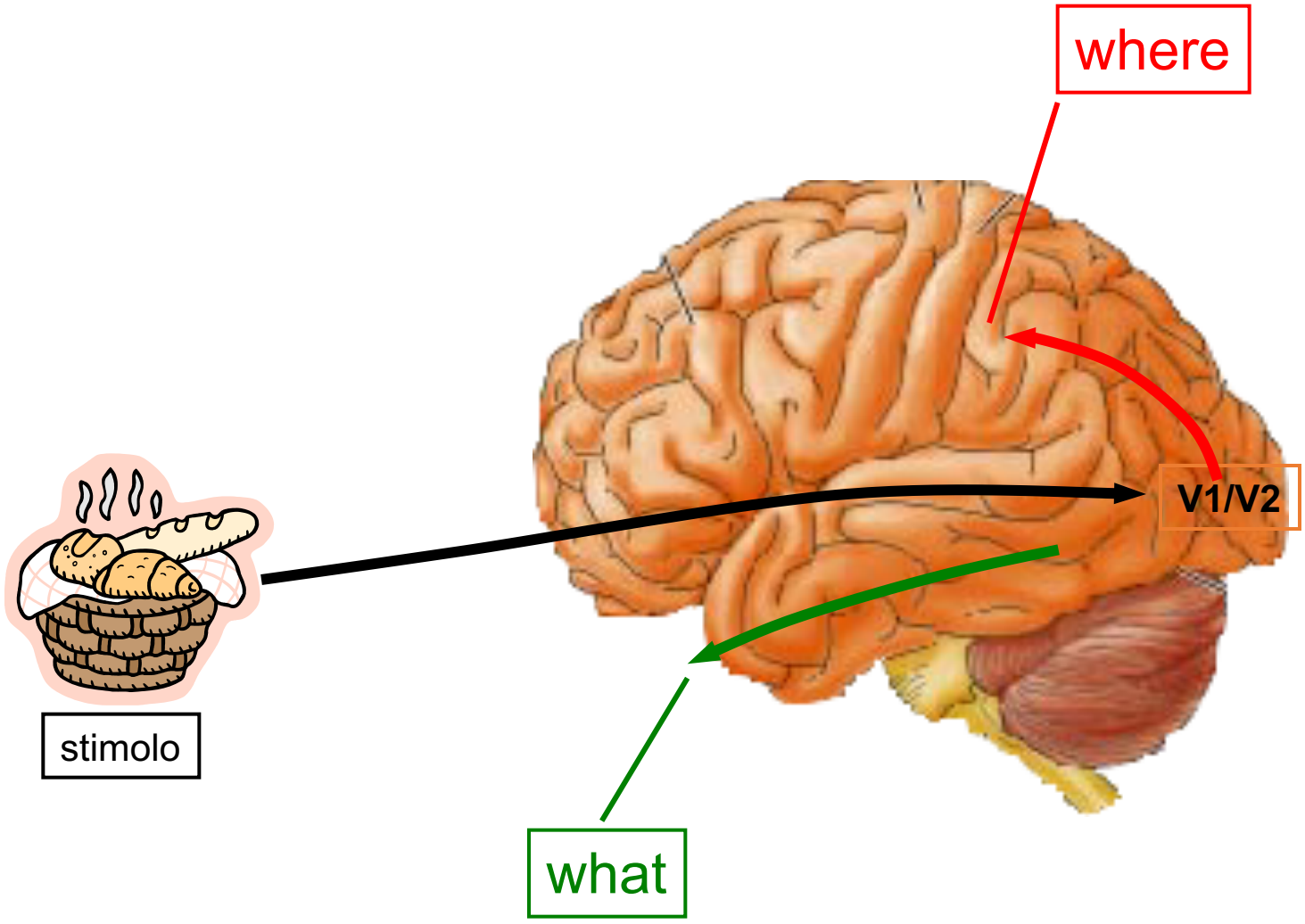
Visual cortex medio-temporal

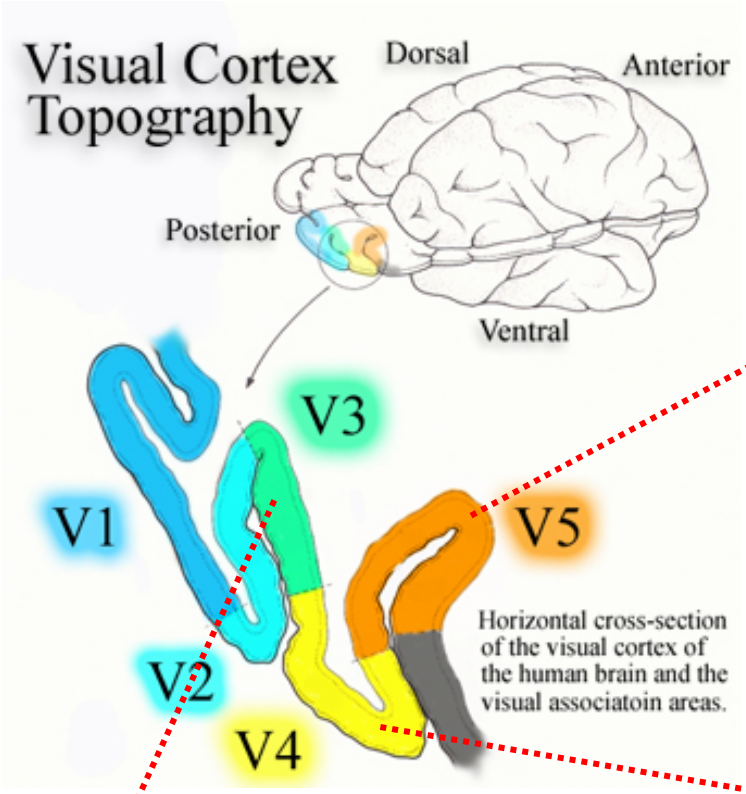
Primary visual cortex (V1)

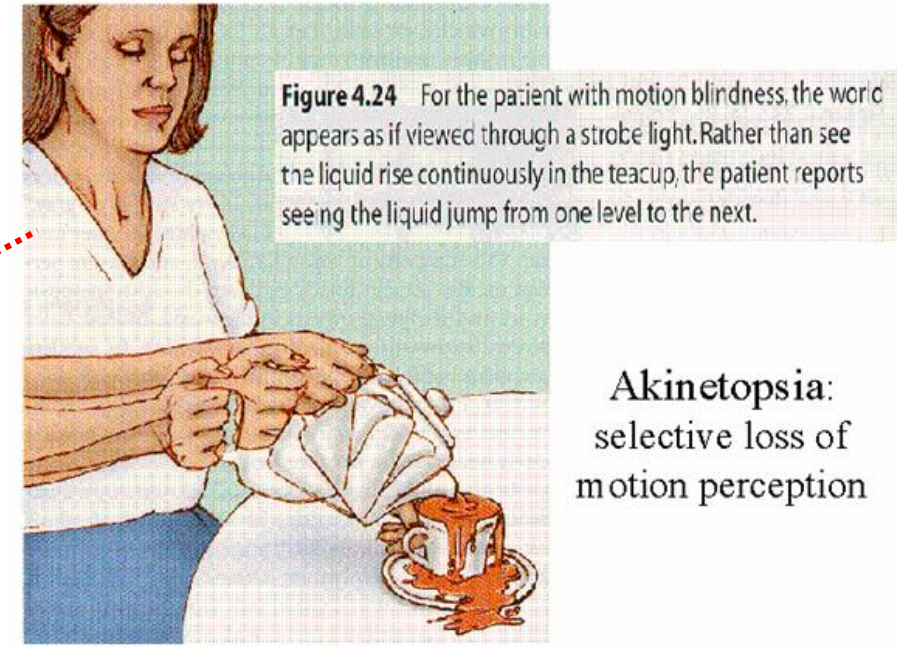
Dorsal path:
To the posterior parietal cortex
Movement and depth



Ventral pathway:
To the temporal cortex
Analysis of colors and shapes

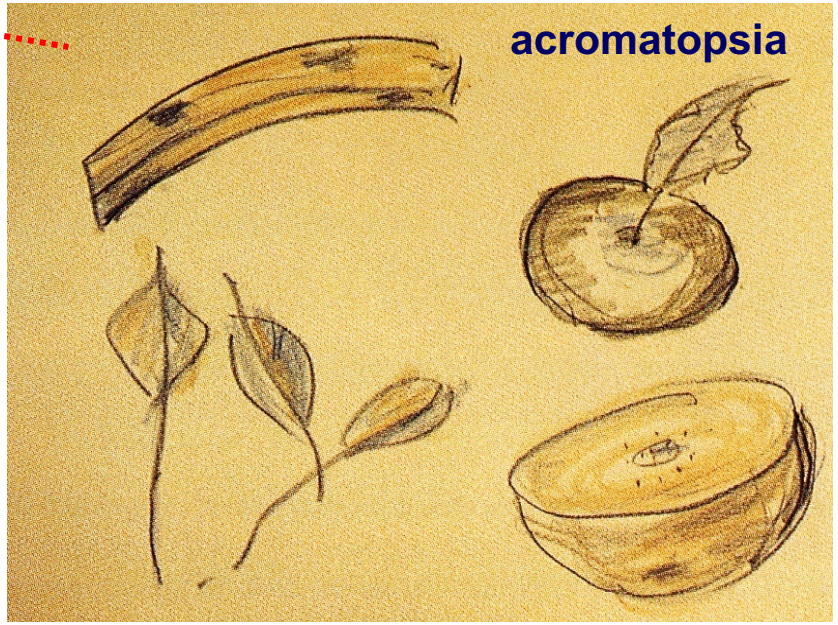

where
V1/V2
stimolo
what





Akinetopsia: selective loss of motion perception

Forma e colore



Stereopsis and perception of depth

Intrinsic physiological cues

- Convergence/Divergence
  - Convergence – Eyes converge to focus a near object
  - Divergence – Eyes diverge to focus a far object

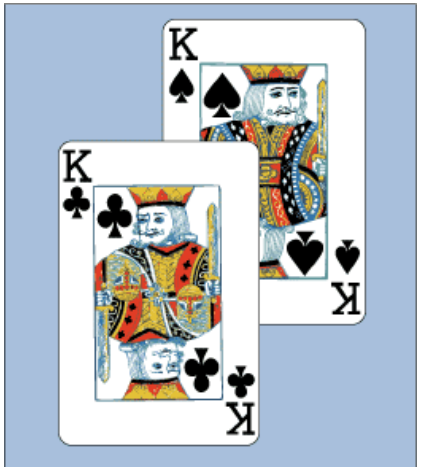
Oculomotor cues

Accomodation – lens changes shape to focus

Monocular cues

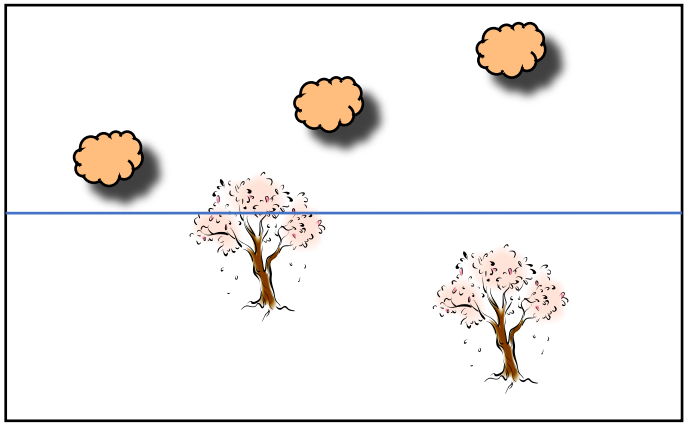
Up to 3 months of life: identical retinal images

- Occlusion



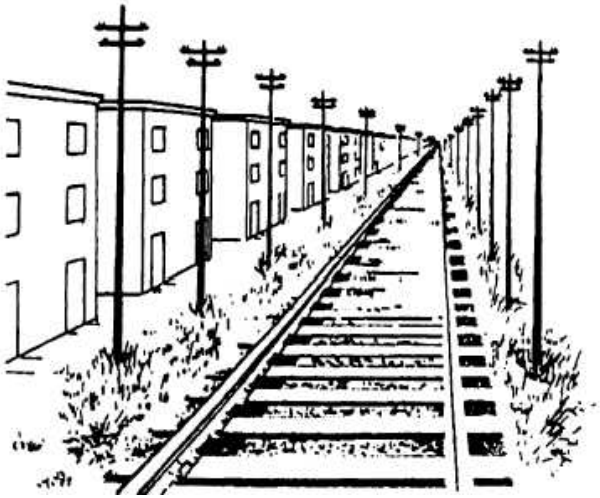
- Relative heights

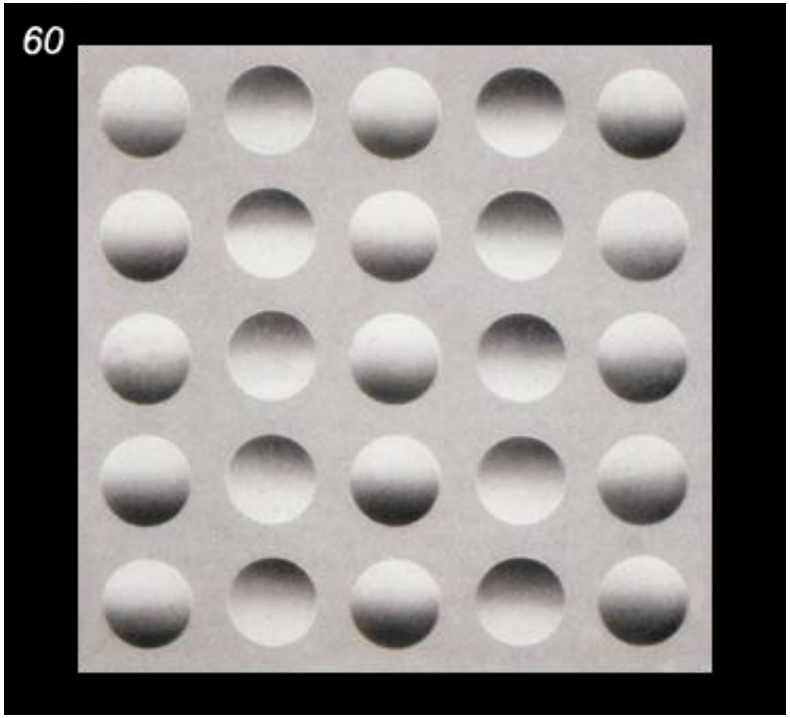
Objects nearer the horizon line are perceived as farther

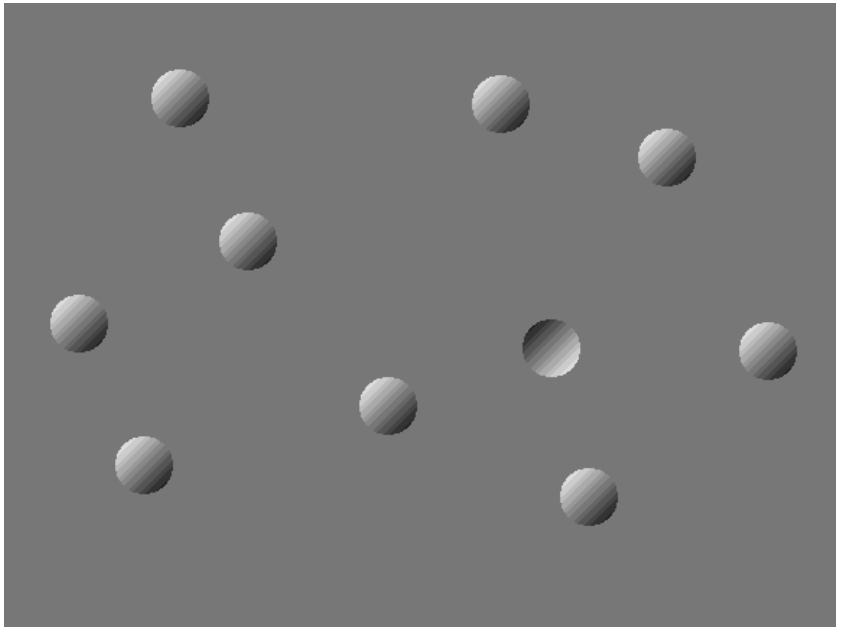


- Relative size
- *Chiaroscuro*
- Linear perspective
- Movement related cues

Linear Perspective: Depth Cues

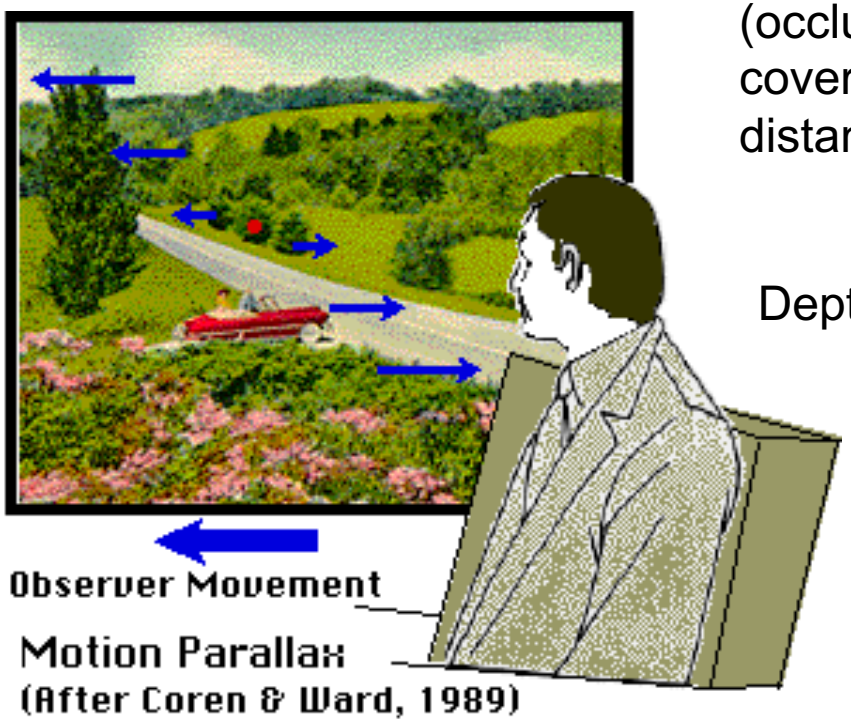






Parallass movements

- Direction and speed of movement differ for objects near or far from fixation point



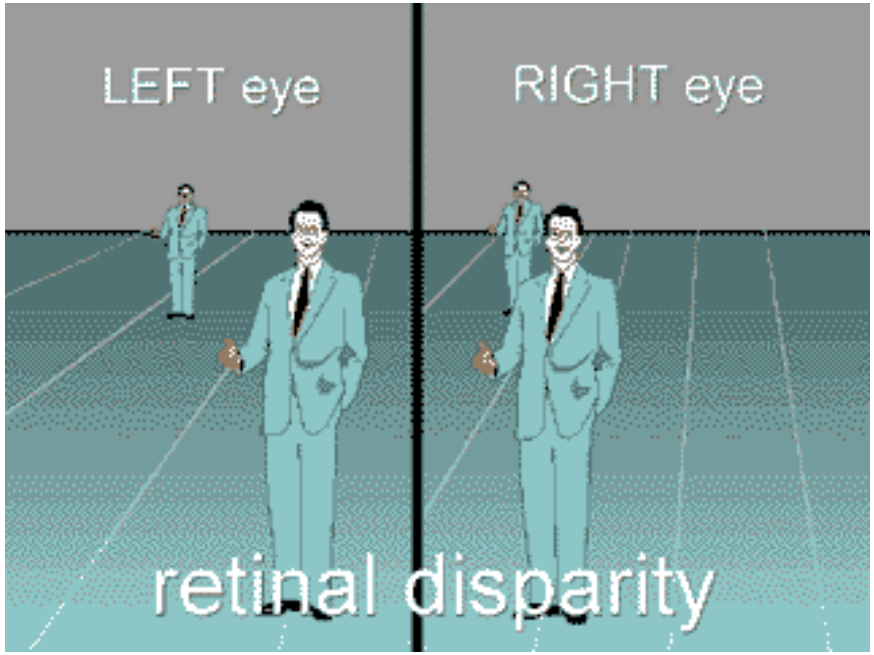
(occlusion): near objects cover those at longer distances

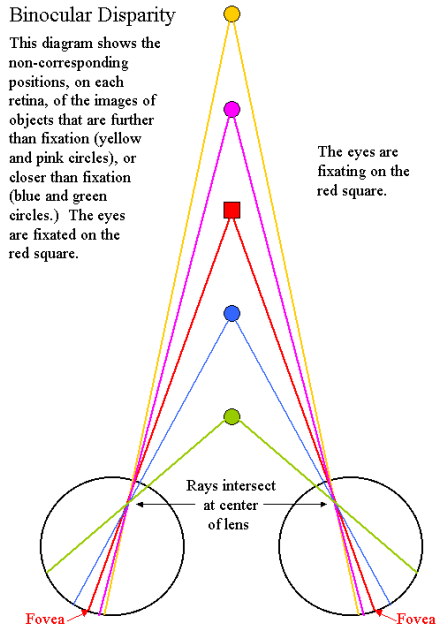
Depth kinetic effect

Binocular disparity

> 3m

Our eyes observe the world from slightly different positions



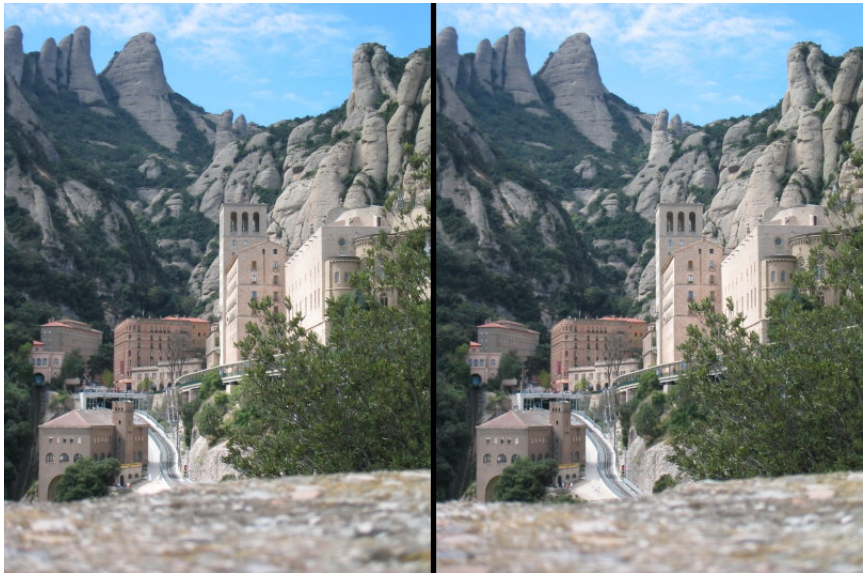


Stereoscope

Stereopsis understood only in 1838 (Wheatstone)

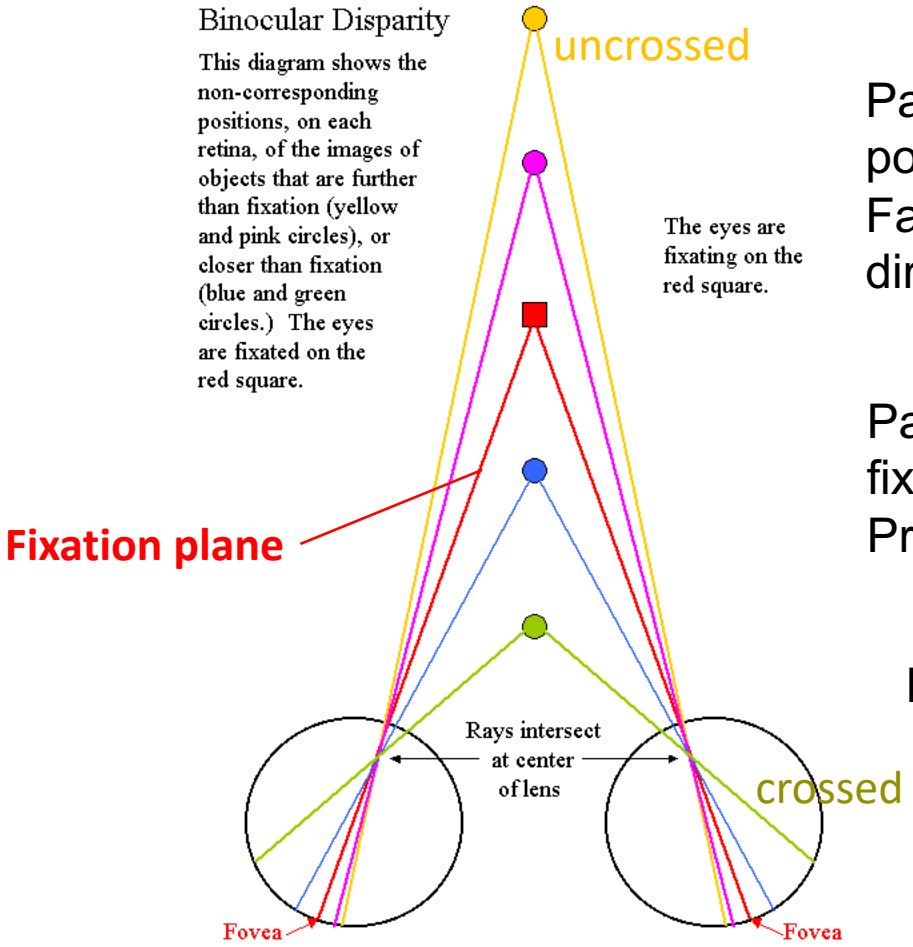
Stereoscope

Slightly different immages to create 3D illusion



2 photographs taken from the point of view of each eye

Objects on planes distinct from that of the fixation point project on slightly different positions on the two retinas



Parts of objects closer to us than the fixation point:
Farther apart on the retinas in a horizontal direction

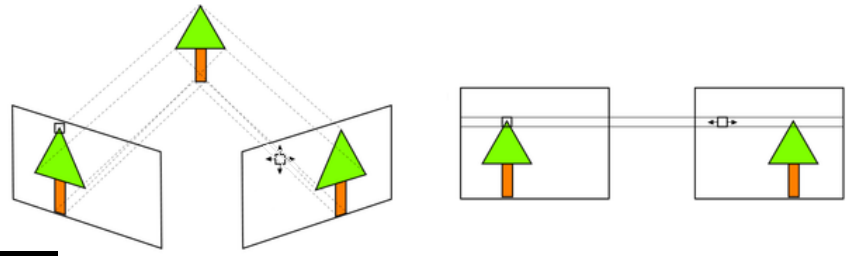
Parts of objects farther from us than the fixation point:
Project closer together on the two retinas

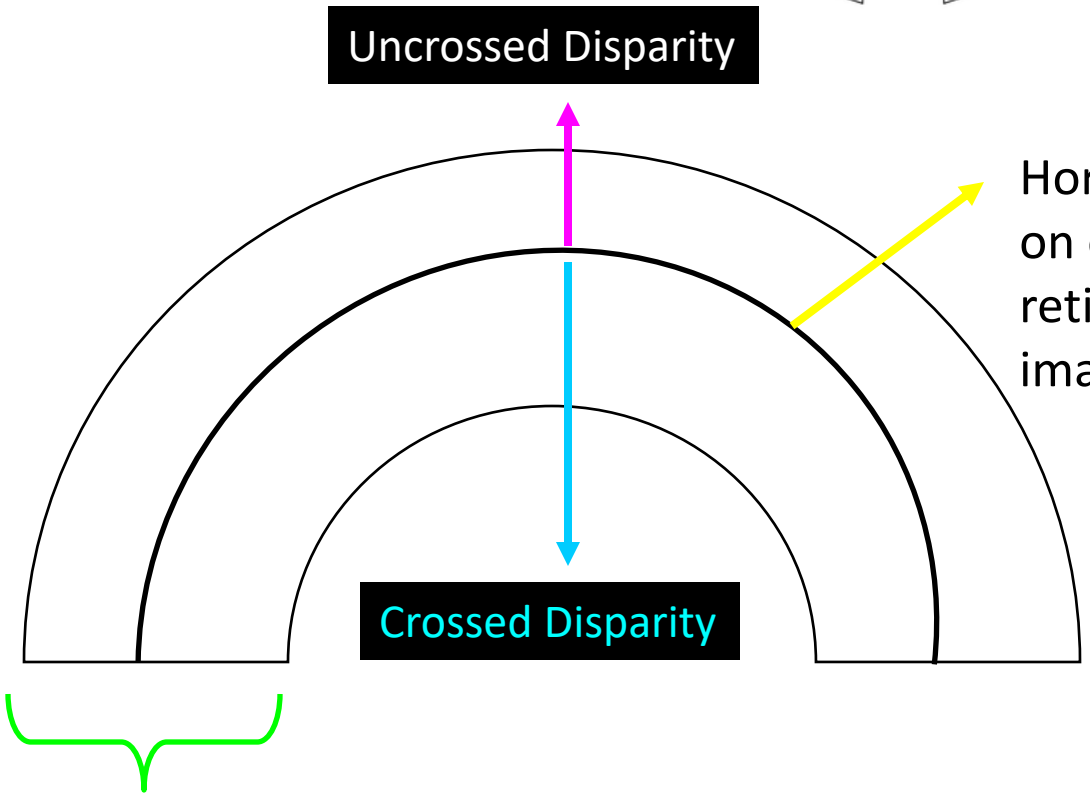
Difference in position (retinal disparity)

↓

Binocular disparity

Retinal Disparity





Horopter – images fall on corresponding retinal points and the image is fused.

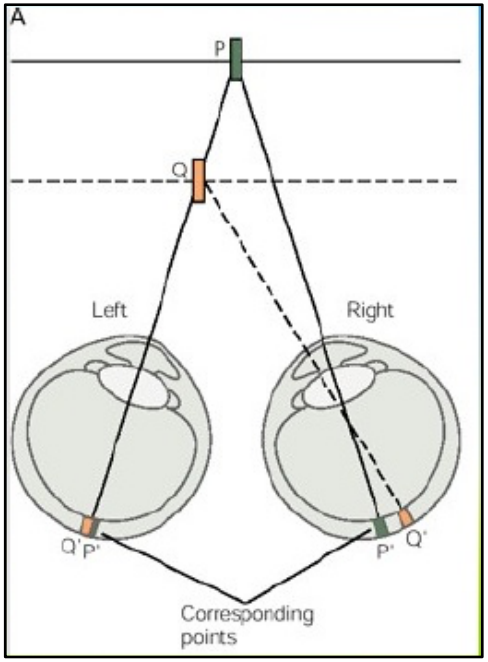
Panum's Area – noncorresponding retinal images with low retinal disparity. Observer can still fuse images.

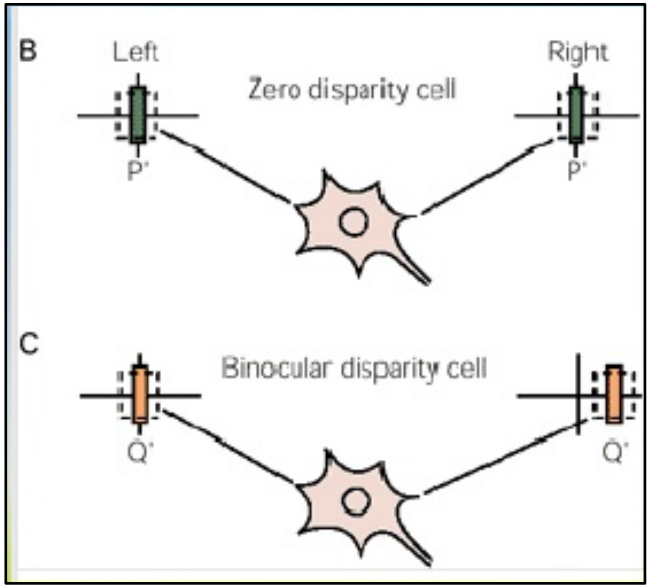
Outside of Panum's area images cannot be fused. We have diplopia – double vision.

Neuronal basis of stereoscopic vision

Computation of horizonal disparity

V1- Binocular neurons selective for horizontal disparity:
neurons for specific disparity /far –near cells
Also in extrastriate areas





Disparity information : development for convergence and divergence movements

Auto-stereogram