Color Vision

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Lecture "Sensory Systems – Basics and Principles II
05.07.2010

Lecture aims: To understand the following

SHOCKING CONFESSION
Daniel B. (24): „I am colorblind!“

Young & Helmholtz state: „Color vision is trichromatic!“

The principle of univariance
Cone mystery resolved

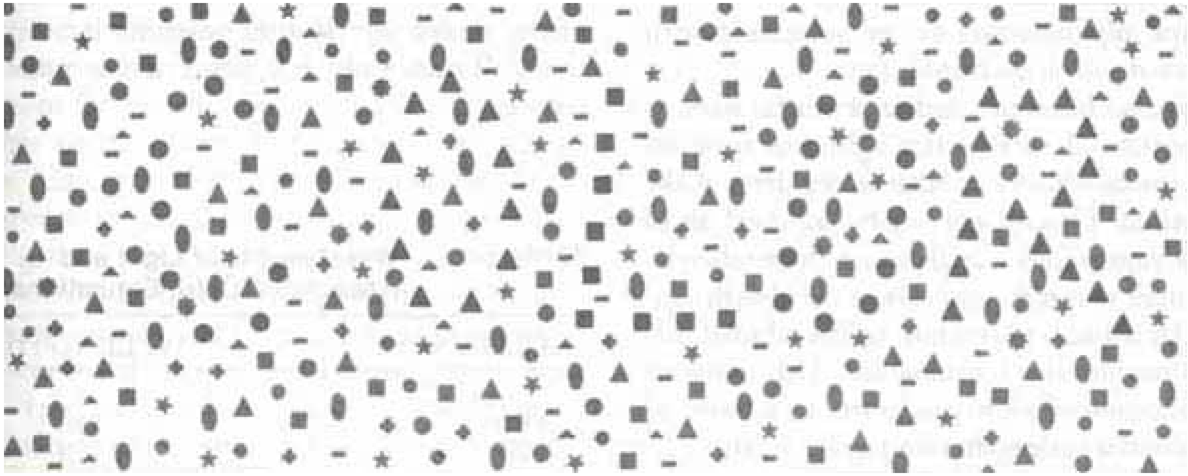
Color opponency: Hering declares his 4 „Urfarben“ to be responsible

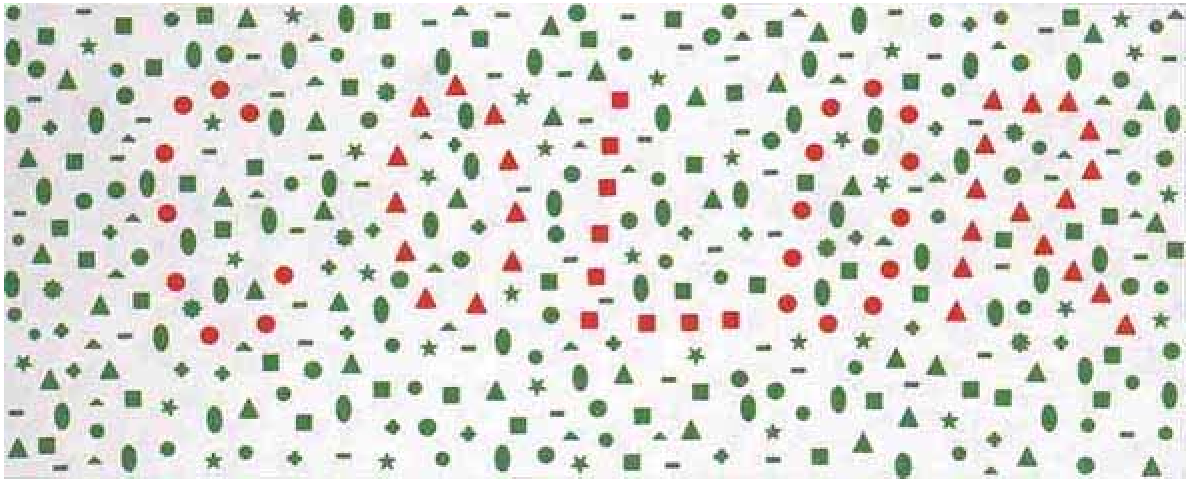
How dependent are we on color vision?

Imagine you are in a hurry...

... or you are hungry

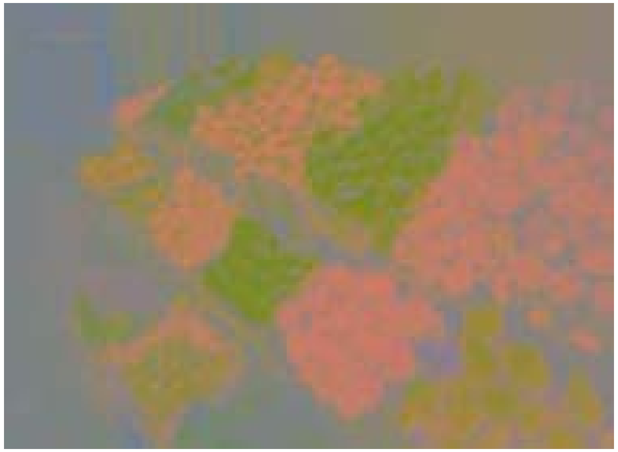
Color helps!



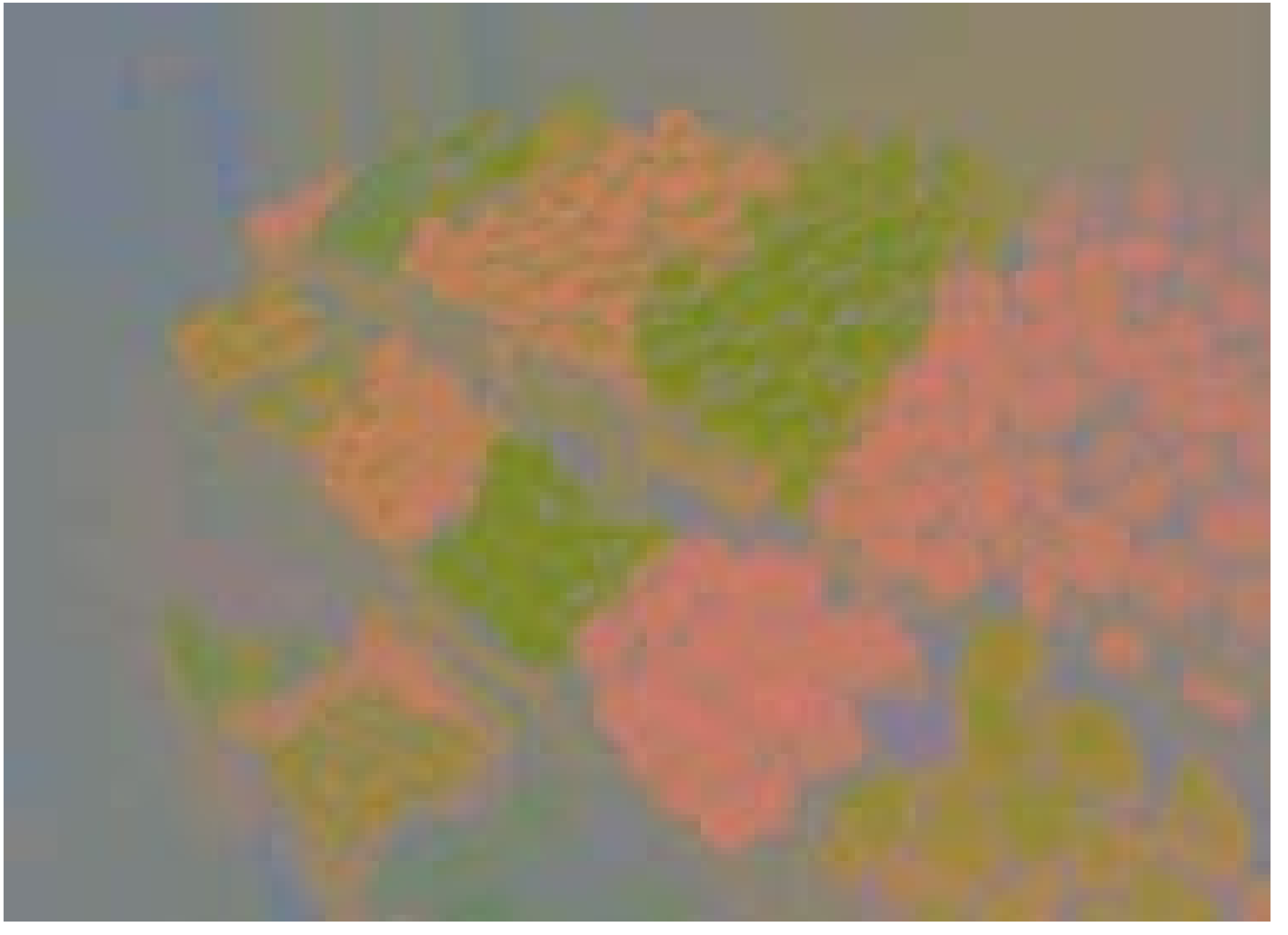


Split the image into...

Chromatic components



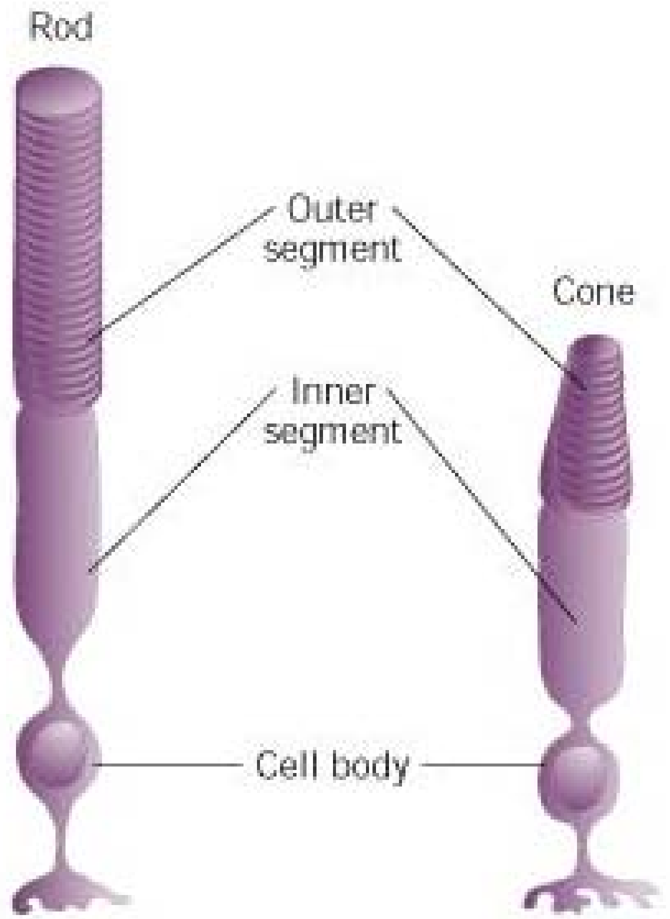
Achromatic components



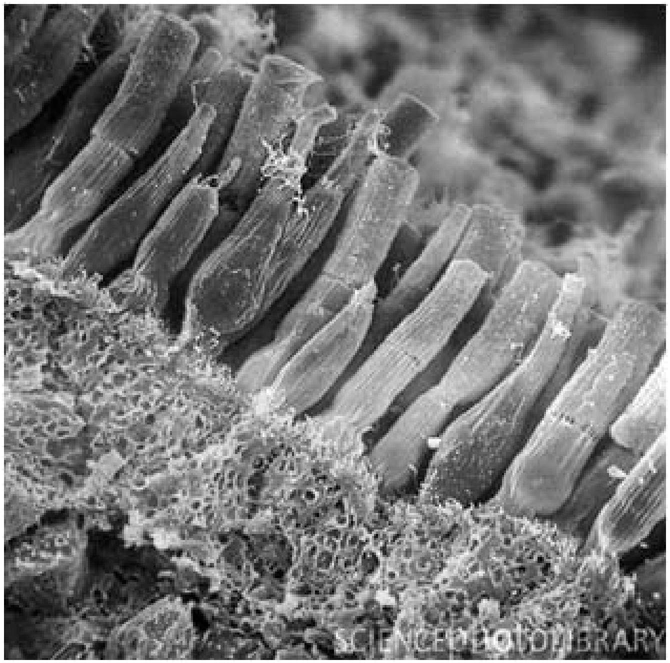
How do we see colors?

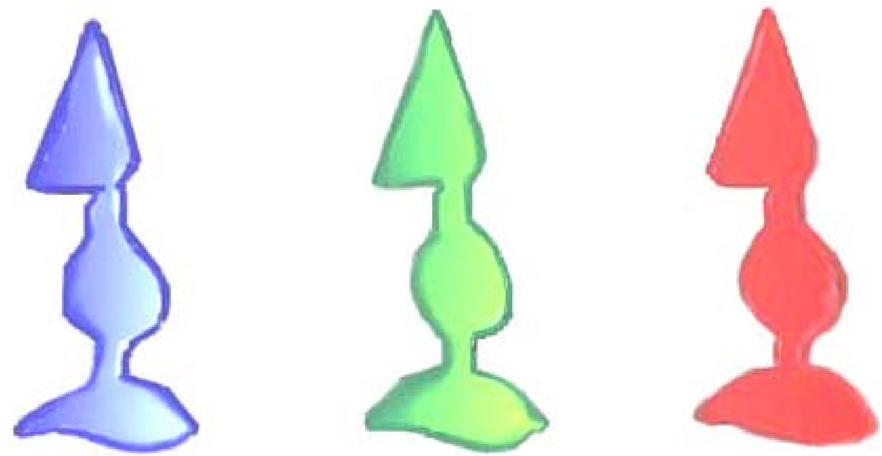
Photoreceptors

There are two types of photoreceptor cells in the human retina, rods and cones.



Color vision is mediated by cones



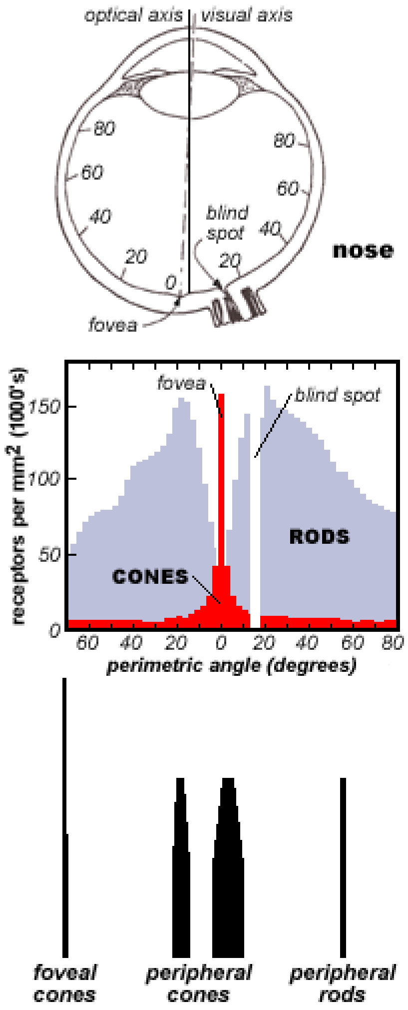


Blue cone „S-cone“

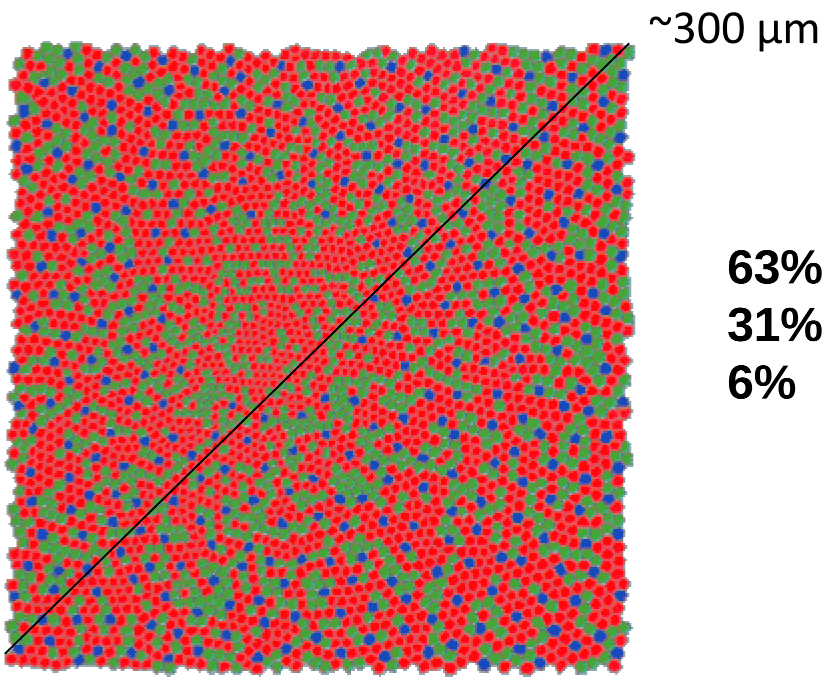
Green cone „M-cone“

Red cone „L-cone“

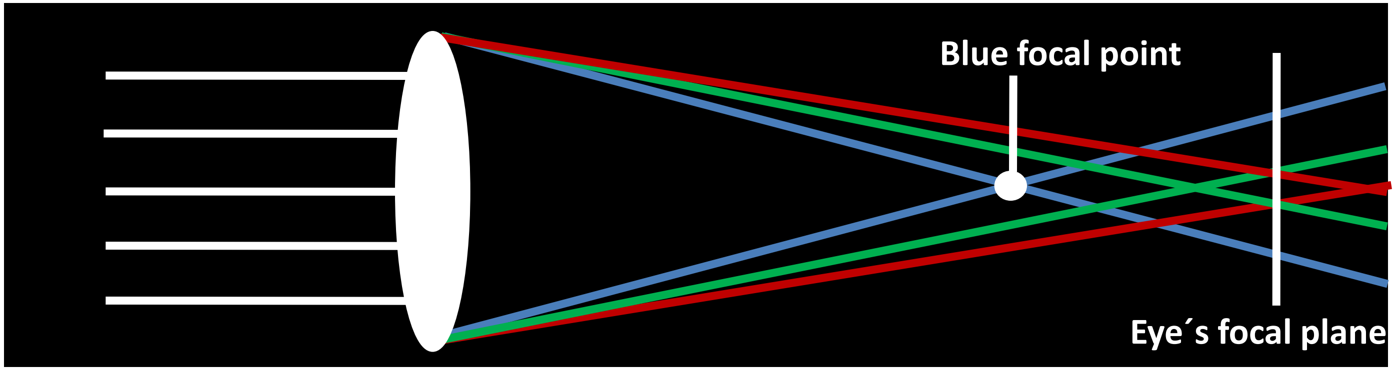
Distribution and size of photoreceptors in the retina



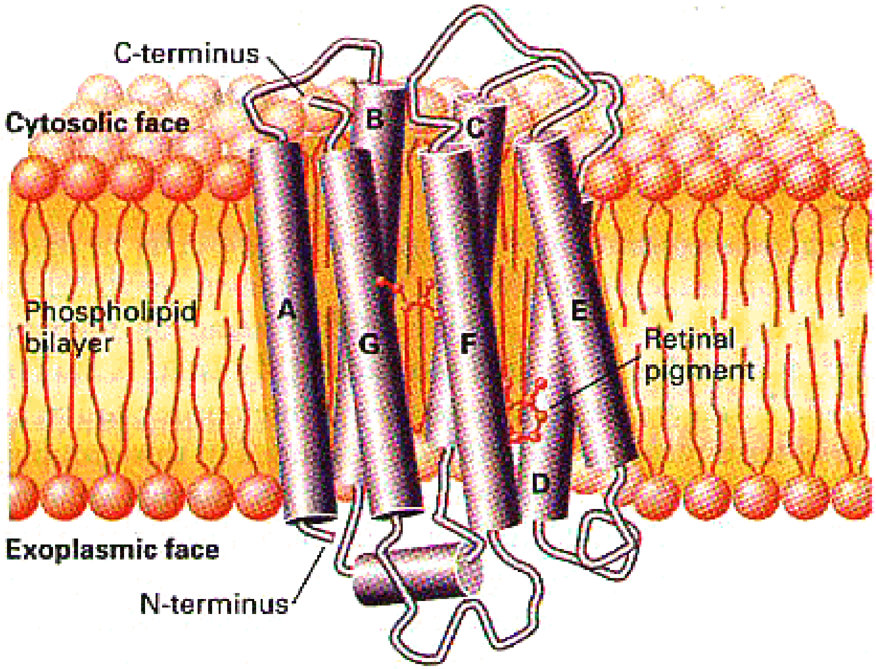
The cone mosaic of the rod-free inner fovea

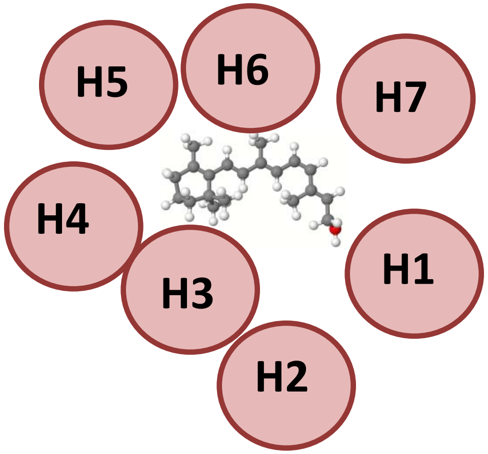


63%	**L-cones**
31%	**M-cones**
6%	**S-cones**



Opsin structure

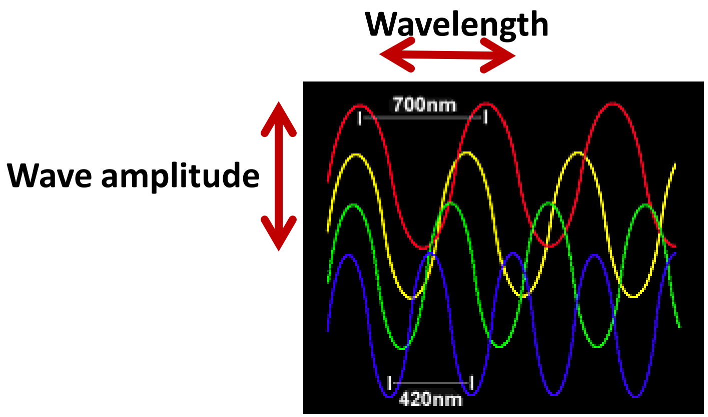




Note: Opsins have a λmax below 300 nm. Retinal has a λmax of ~380 nm. The broad absorbance spectrum of 400-700 nm is created by the binding of both components.
The λmax of the absorbance band depends on the genetically determined aa sequence of the respective opsin and the relationship of the opsin with the chromophore.

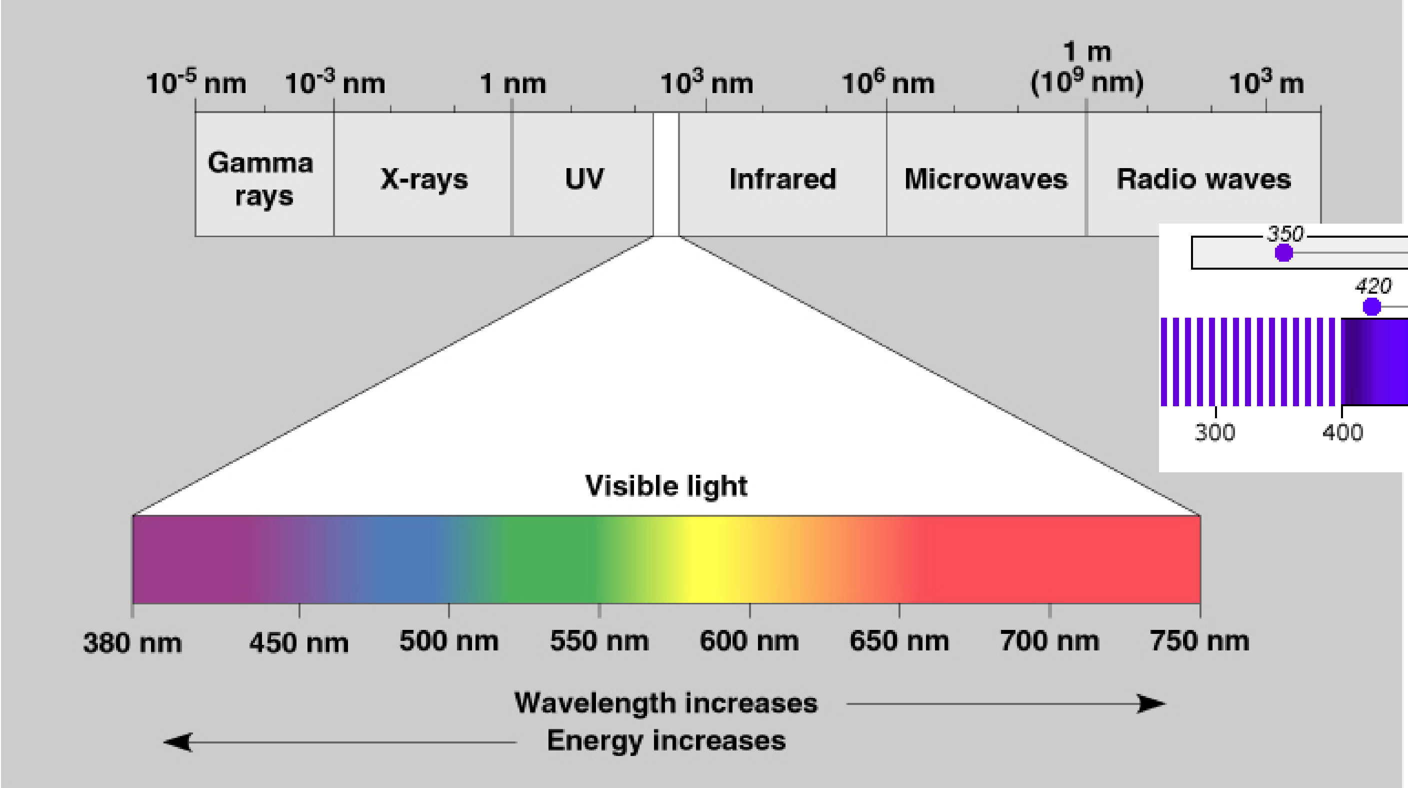
Is colour, as we perceive it, mainly a property of physics or biology?

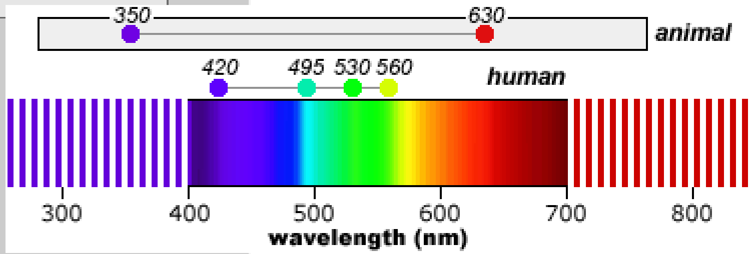
Visible spectrum



Physical properties of light	Related perception
Wavelength	Color
Amplitude	Brightness

Visible light is a small part of the electromagnetic spectrum





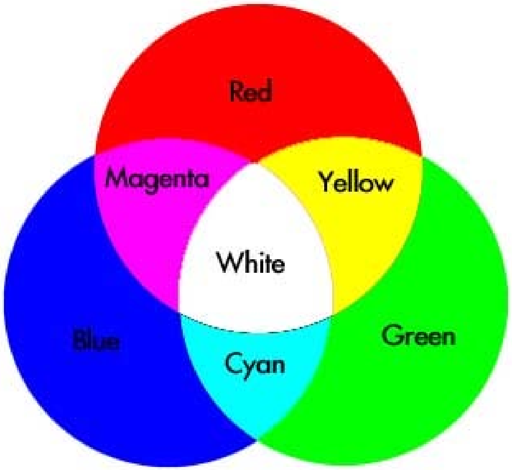
Who knows these gentlemen?

Thomas Young 1773–1829

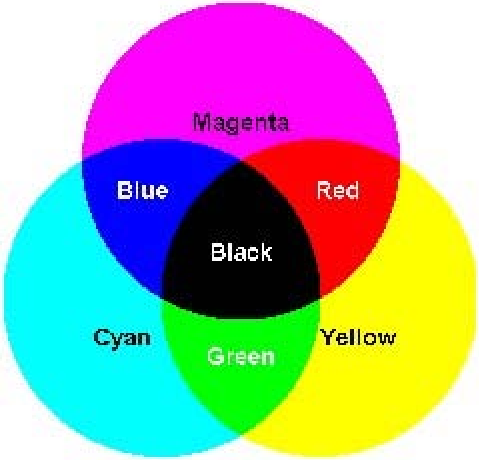
Hermann Ludwig Ferdinand
von Helmholtz 1821-1894

Human vision is trichromatic

Additive color mixing (RGB)

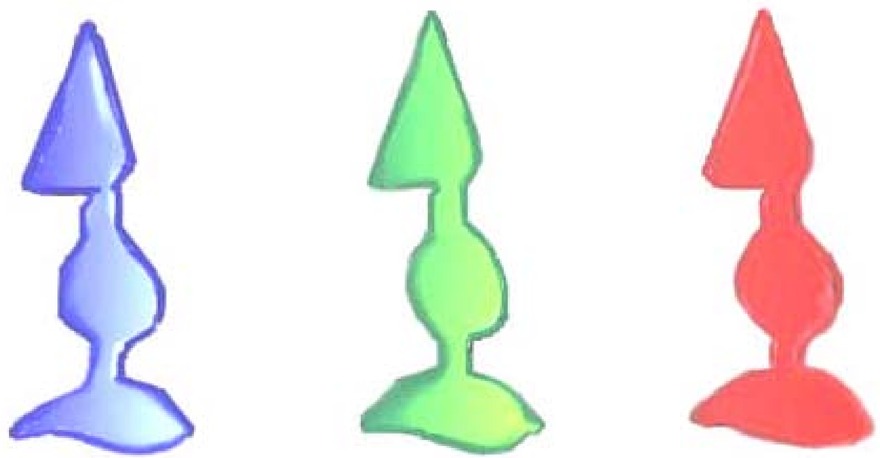


Subtractive color mixing (CYMK)



Why is normal human vision trichromatic?

1. Three types of cones



Blue cone „S-cone“

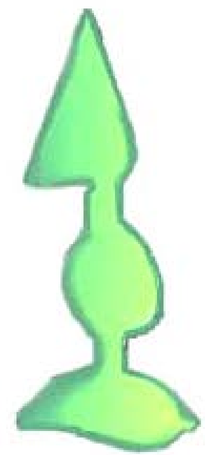
Green cone „M-cone“

Red cone „L-cone“

2. Univariance

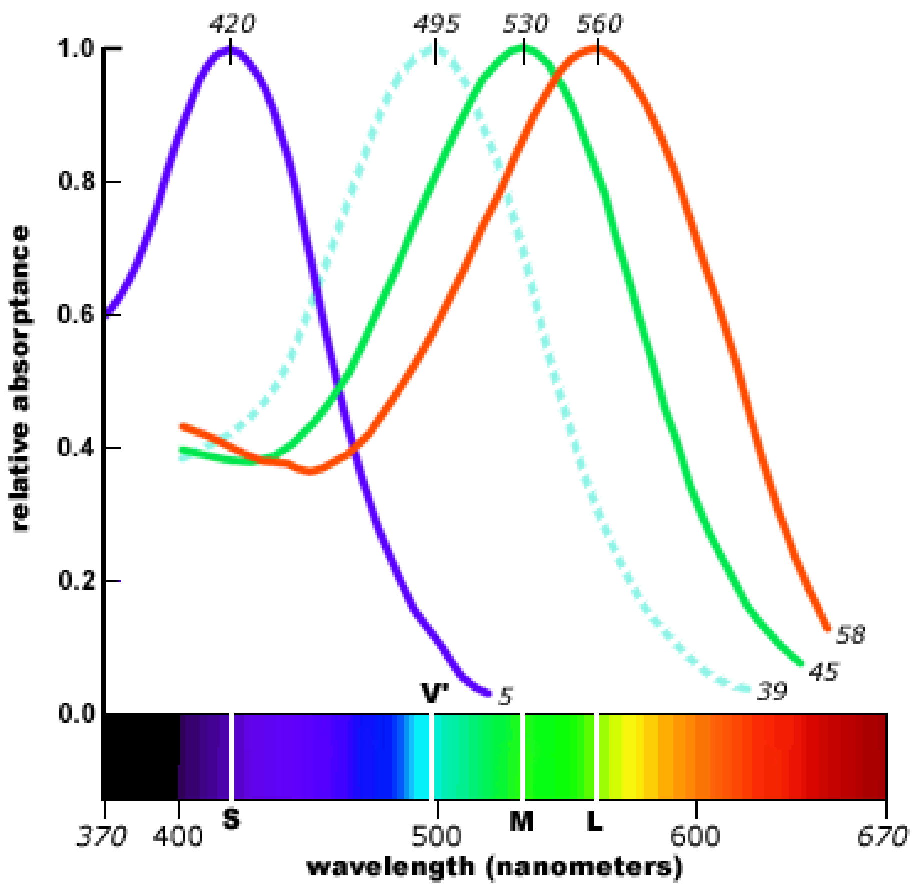
„I just absorbed 1 photon of 450 nm and 1 photon of 600 nm“

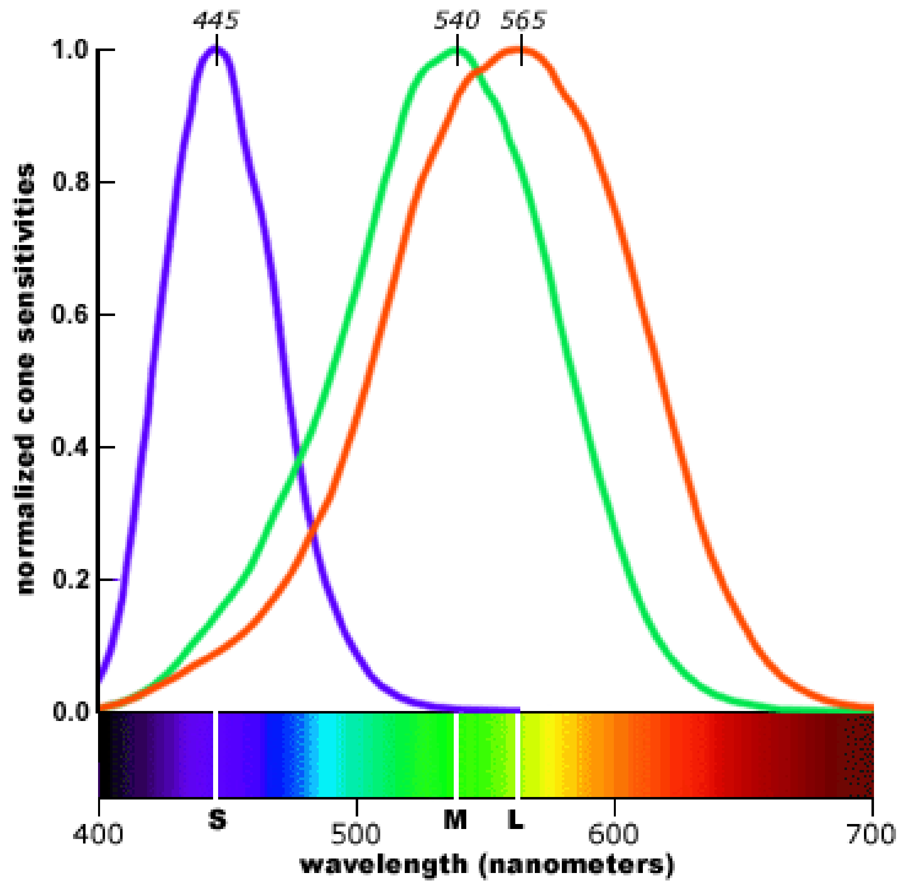
„I just absorbed 2 photons and I have no idea what their wavelengths are“



What do you think is true?

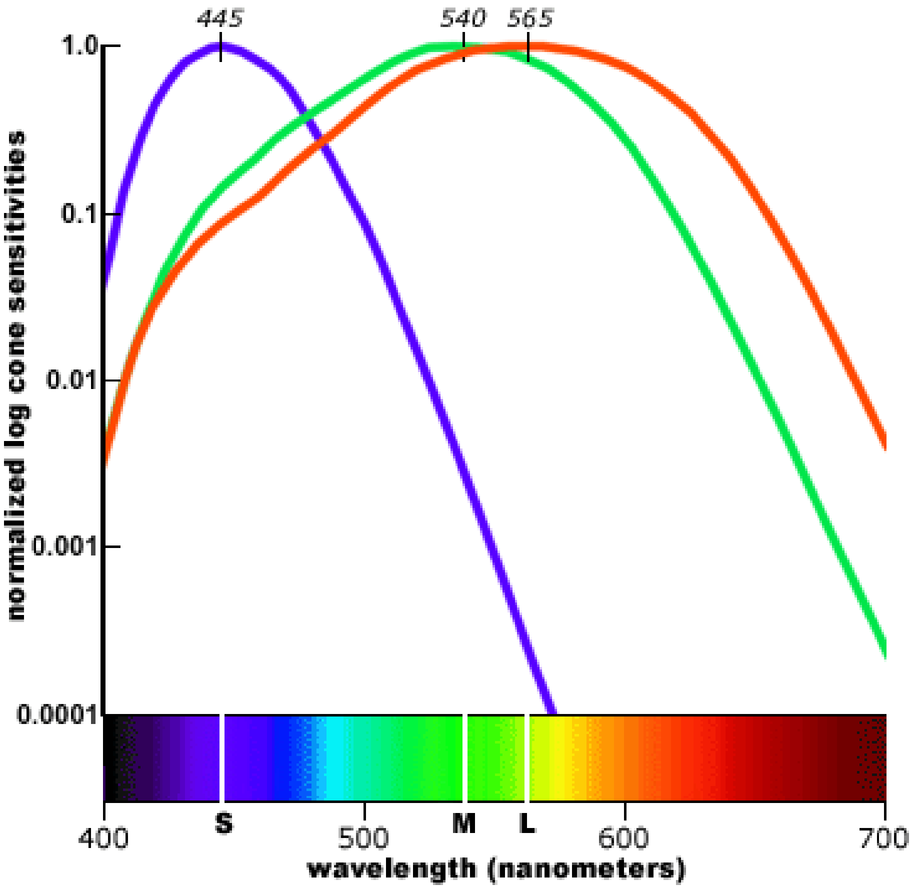
Absorption spectra

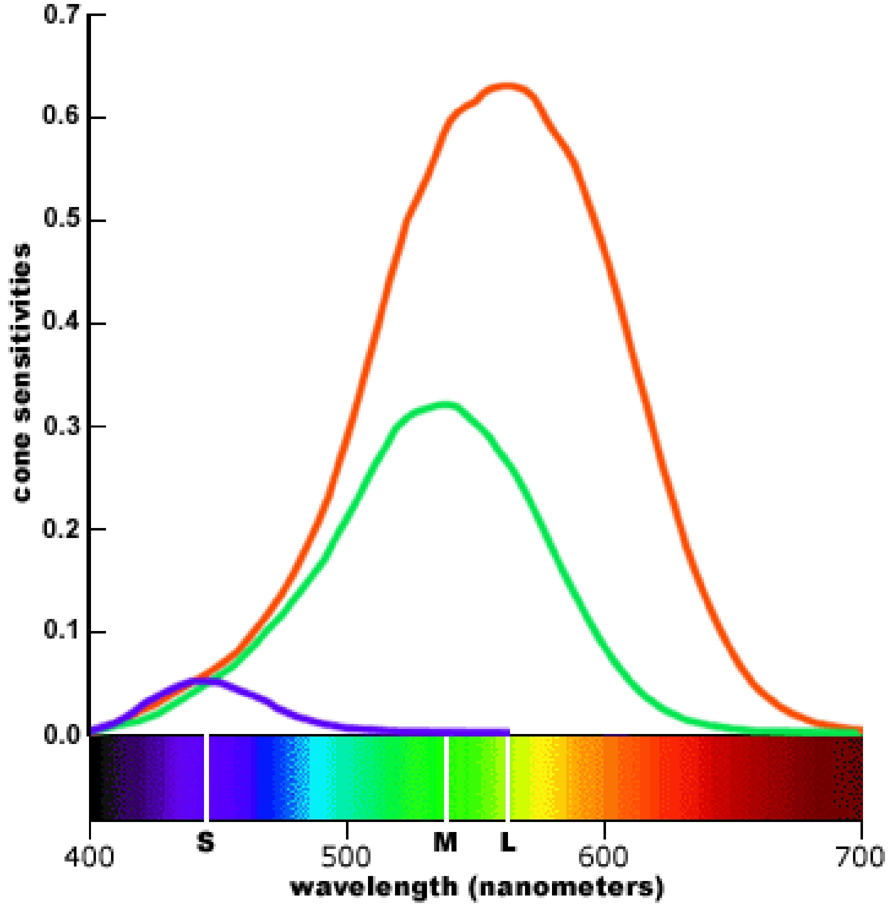




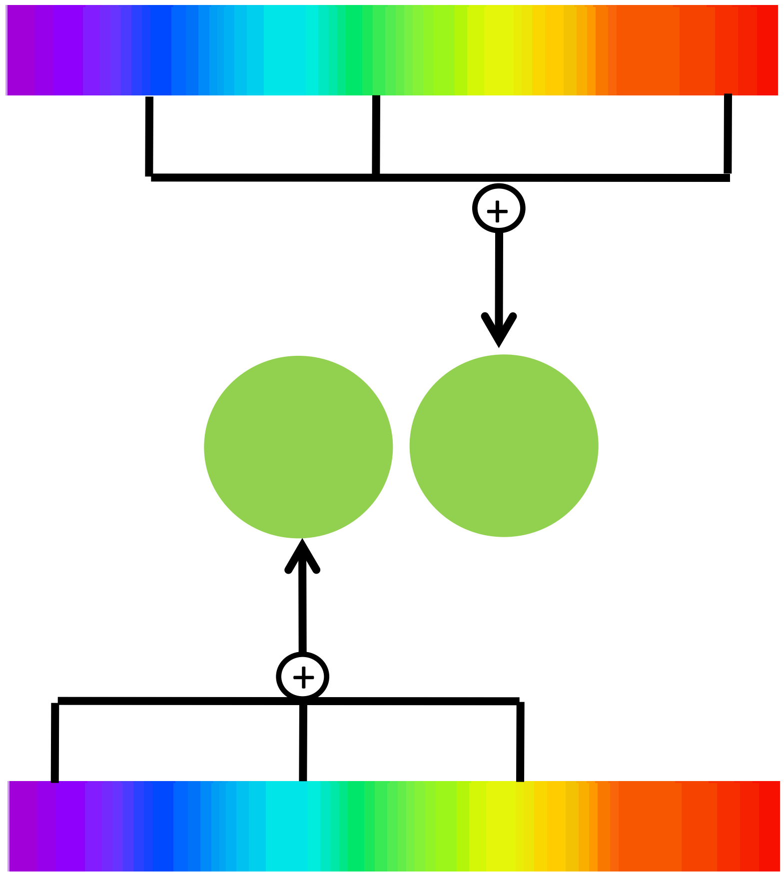
Note: The λ_{max}´s are shifted ***in vivo*** to 445, 540 and 565 nm. This is due to the transmission properties of the intervening ocular media (lens, macular pigment).

Absorption spectra





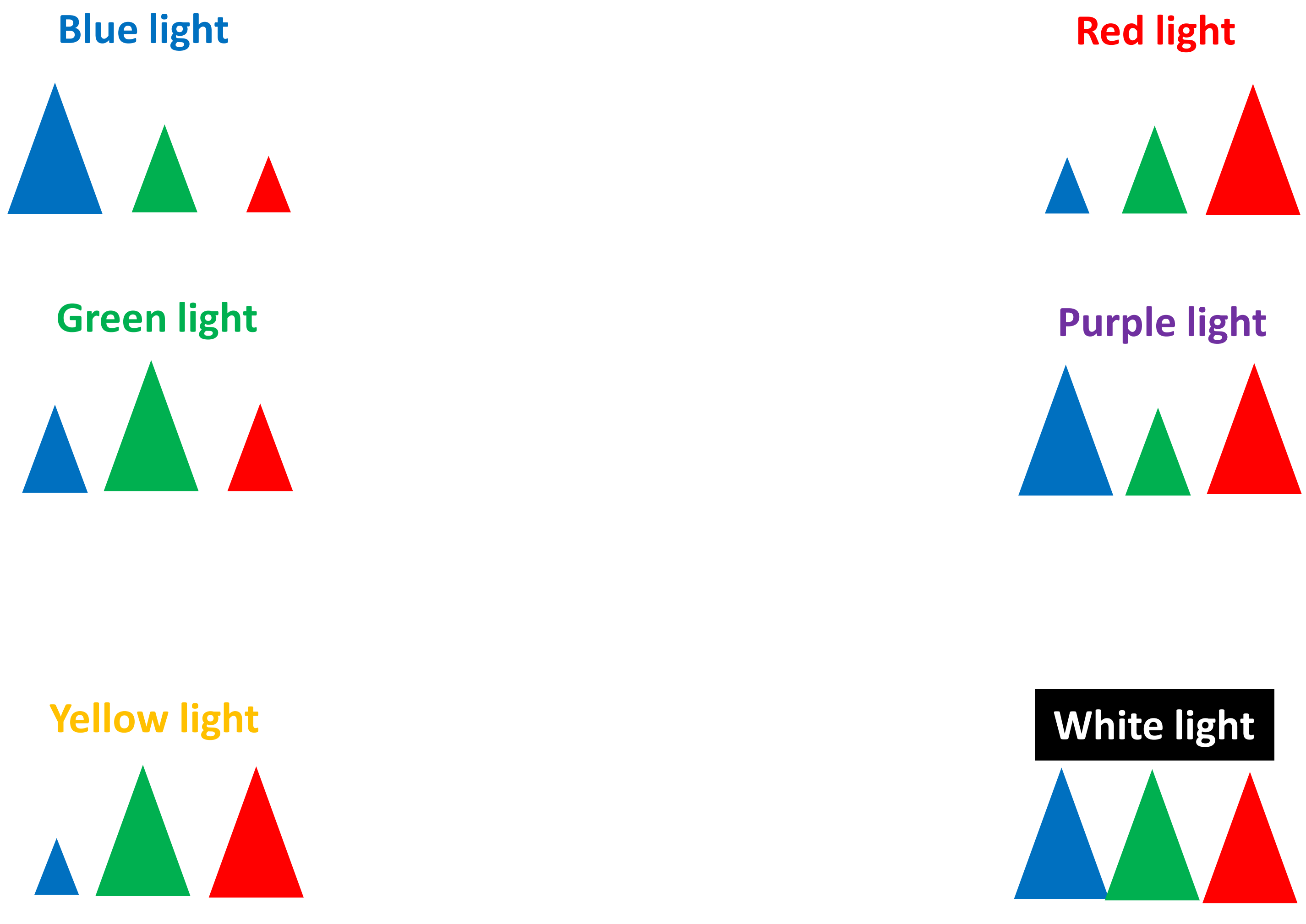
Trichromacy means our color vision is limited



So, if each photoreceptor is color-blind, how do we see color?

The perceiption of color is created by postreceptoral pathways, but we will come to that later...

Colors as relative responses (ratios)



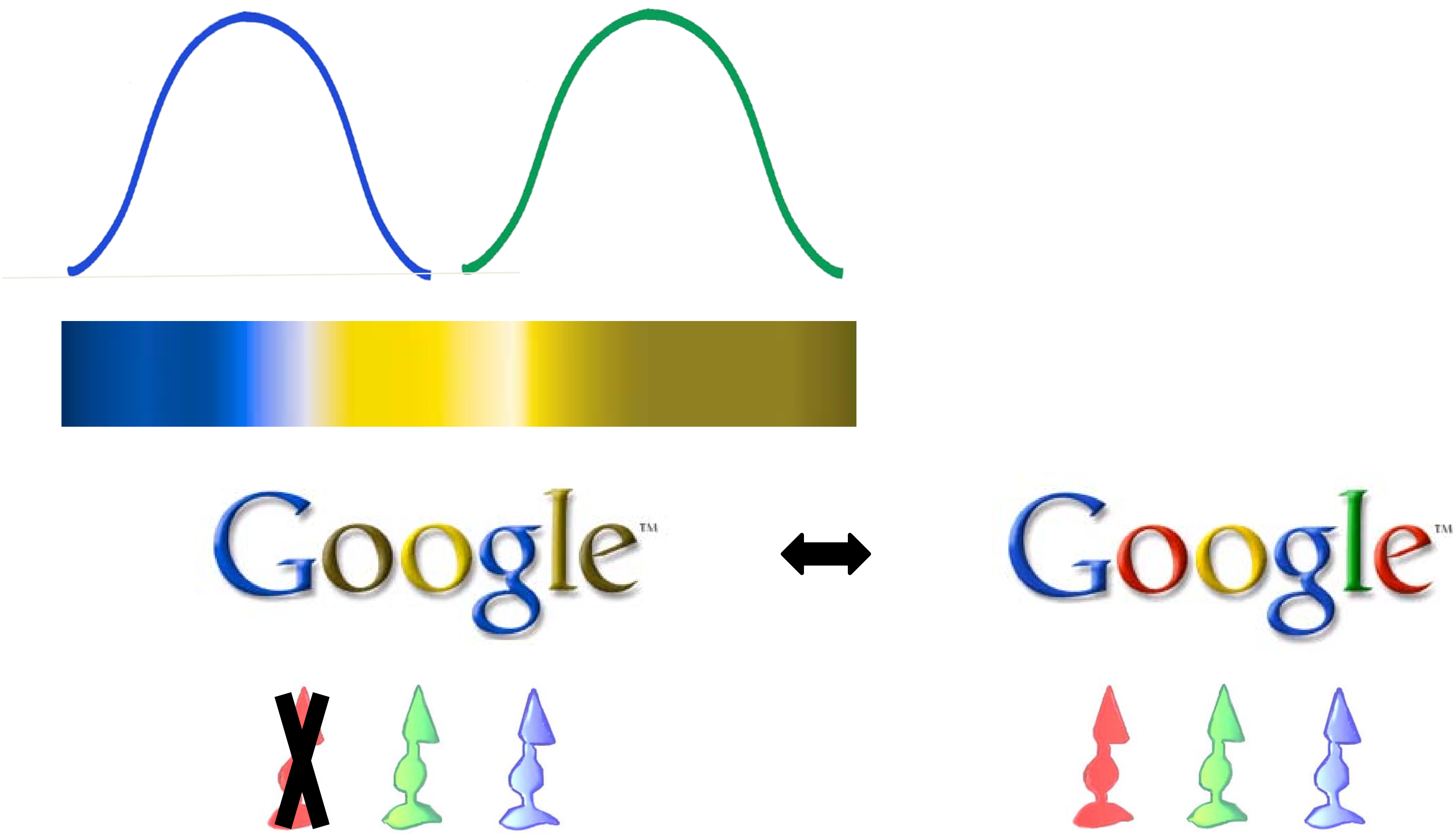
Color vision deficiencies

Protan
- Protanope (missing red cone pigment)
- Protanomalous trichromat (shifted red cone pigment absorption)

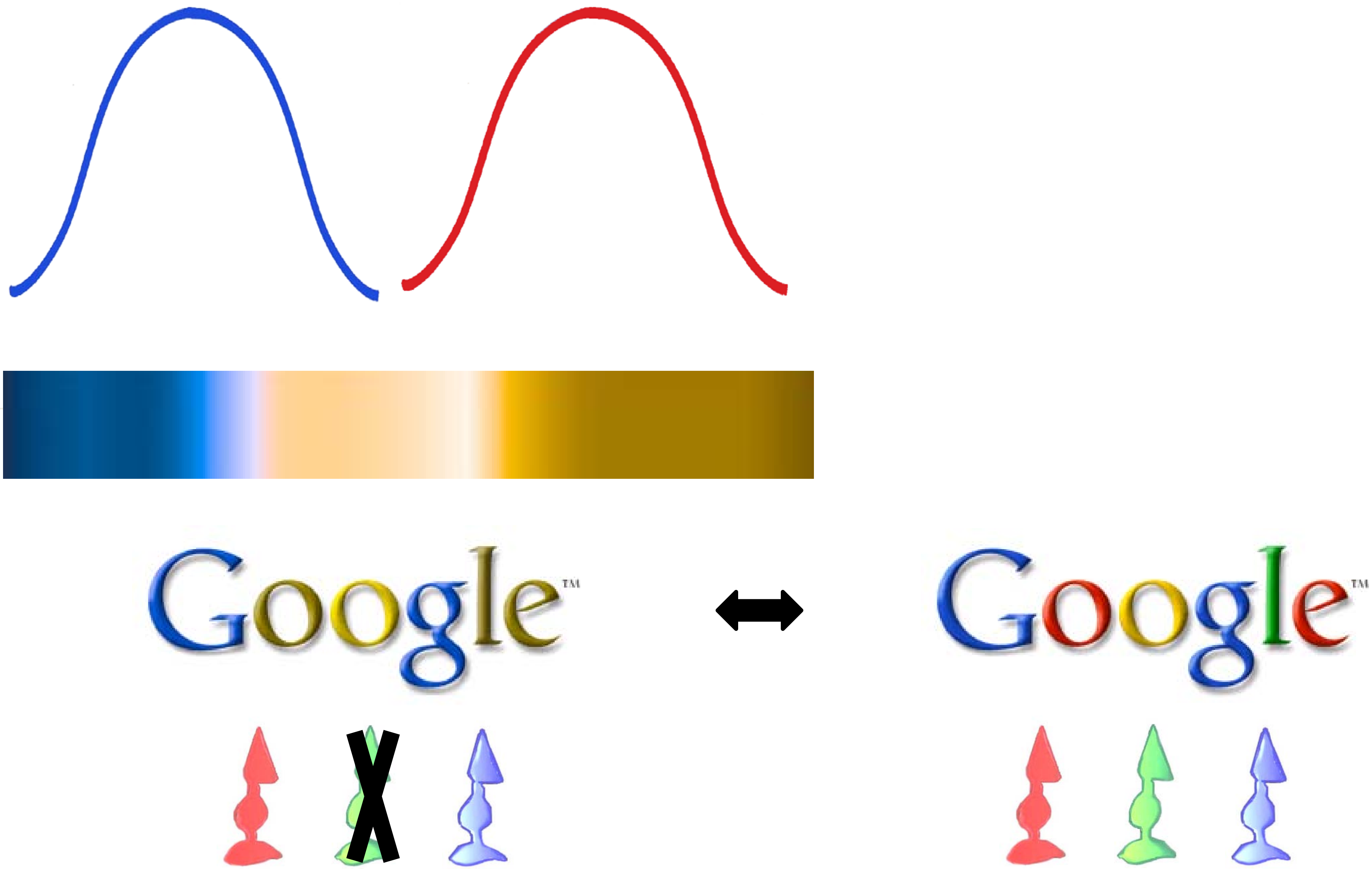
Deutan
- Deuteranope (missing green cone pigment)
- Deuteranomalous trichromat (shifted green cone pigment absorption)

Tritan
- Tritanope (missing blue cone pigment)
- Tritanomalous trichromat(shifted blue cone pigment absorption)

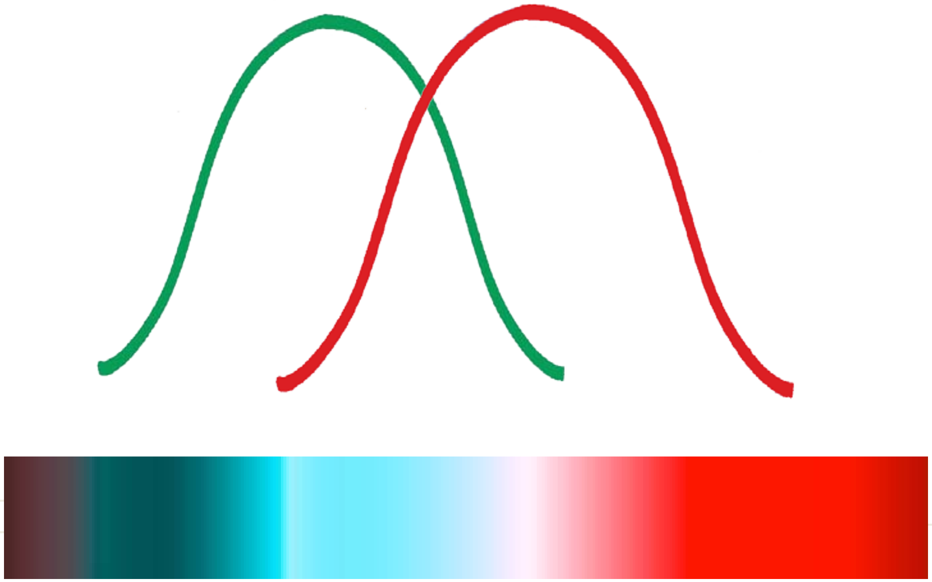
Visualizing Protanopia

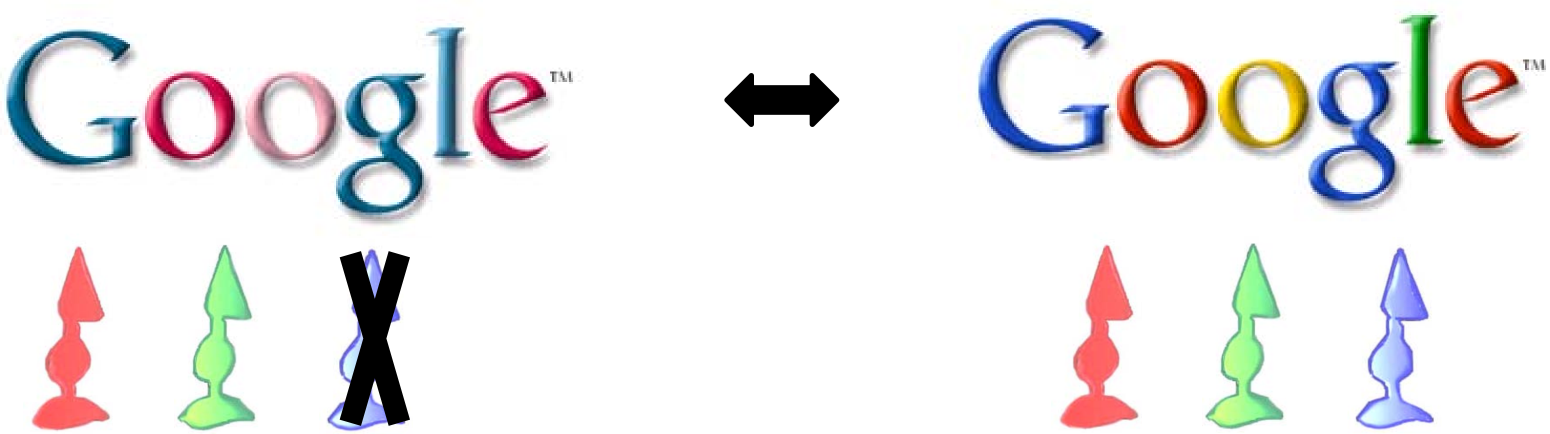


Visualizing Deuteranopia

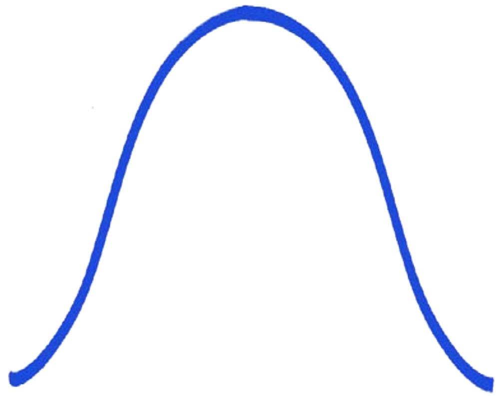


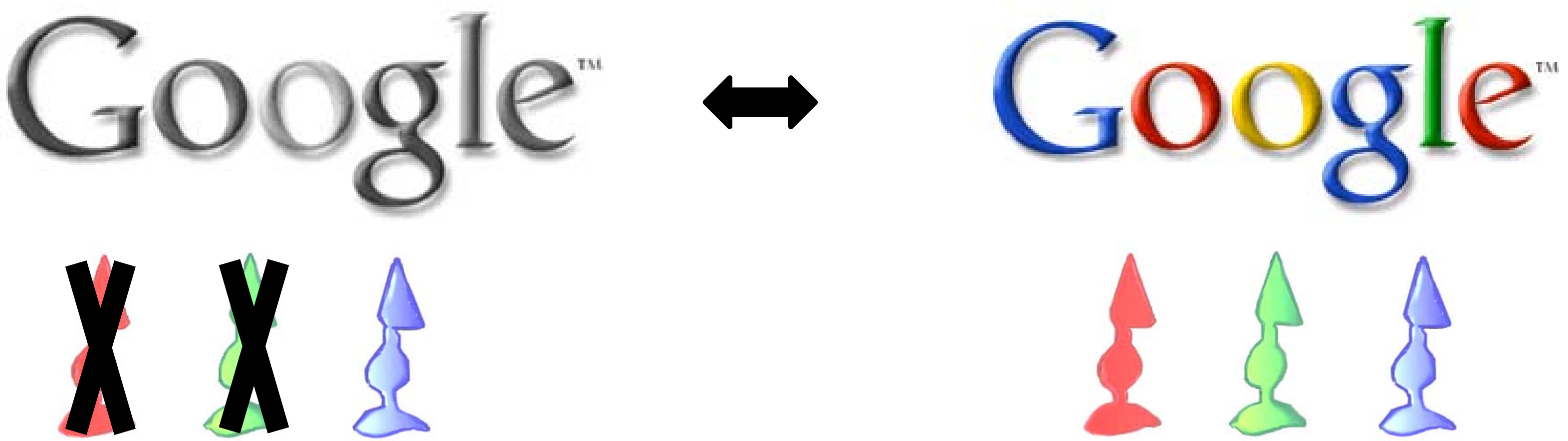
Visualizing Tritanopia





More color vision deficiencies…





Consequences of color vision deficiencies

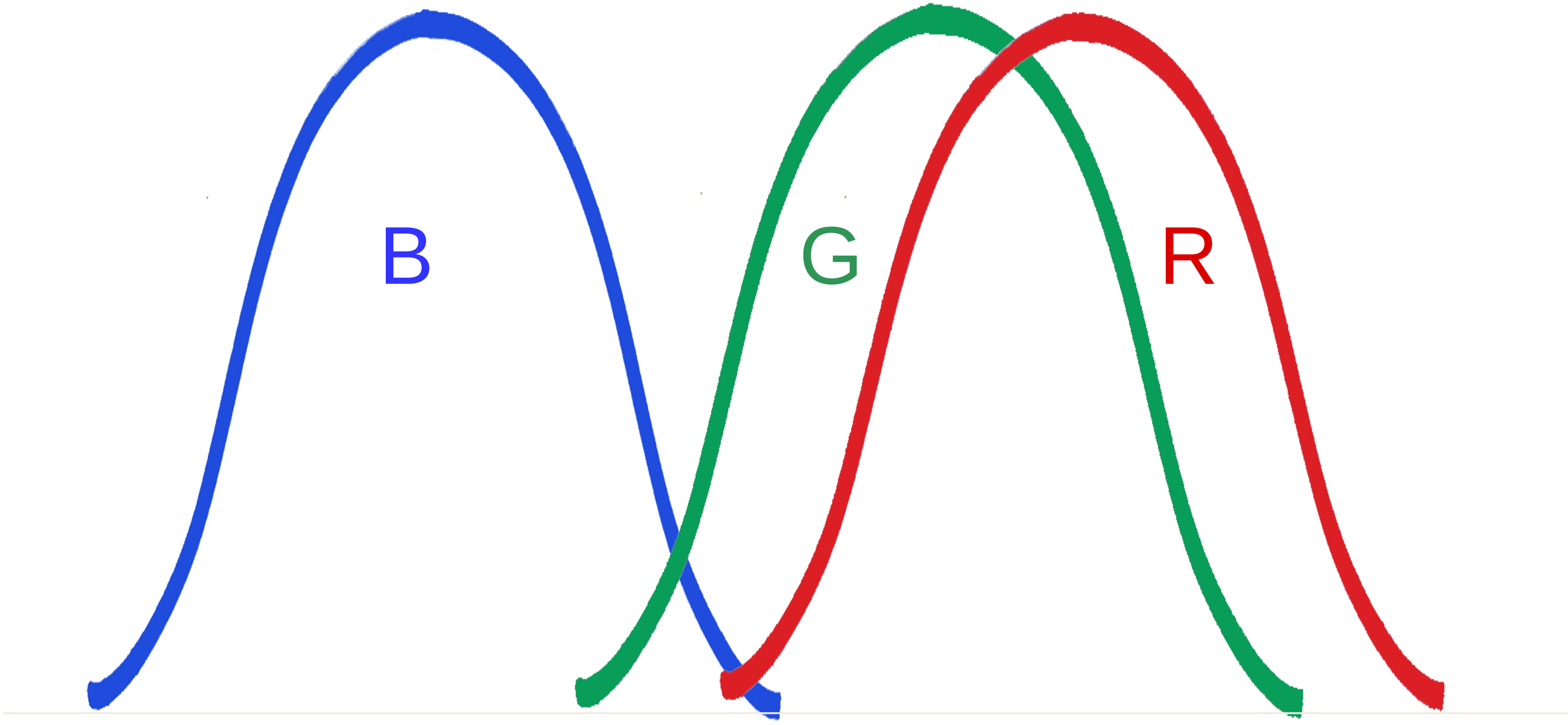
Normal trichromats can distinguish between 150 distinct wavelengths

Protanopes can only distinguish between 21 distinct wavelengths

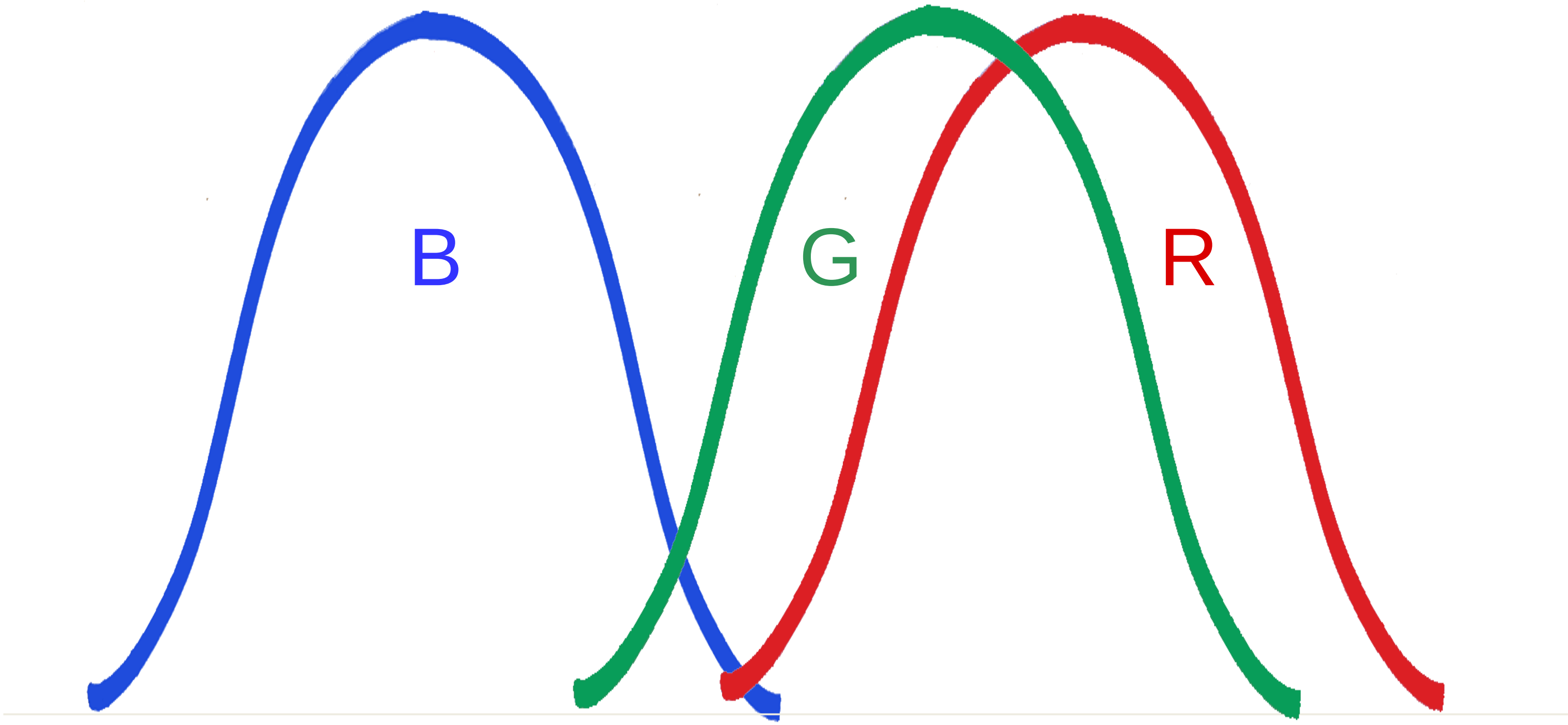
Deuteranopes can only distinguish between 31 distinct wavelengths

Tritanopes can only distinguish between 44 distinct wavelengths

Protanomaly (red shifted towards green)

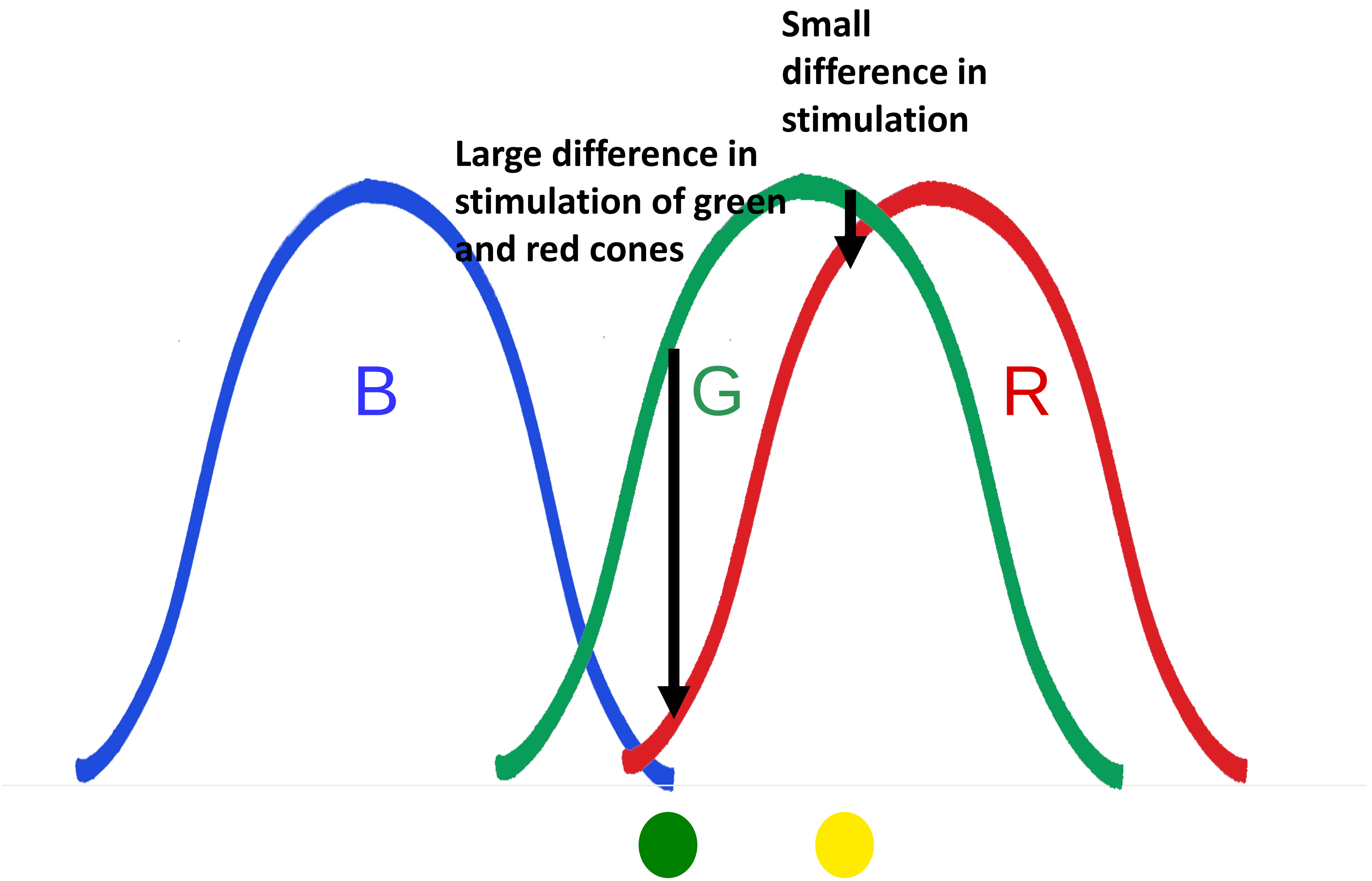


Deuteranomaly (green shifted towards red)

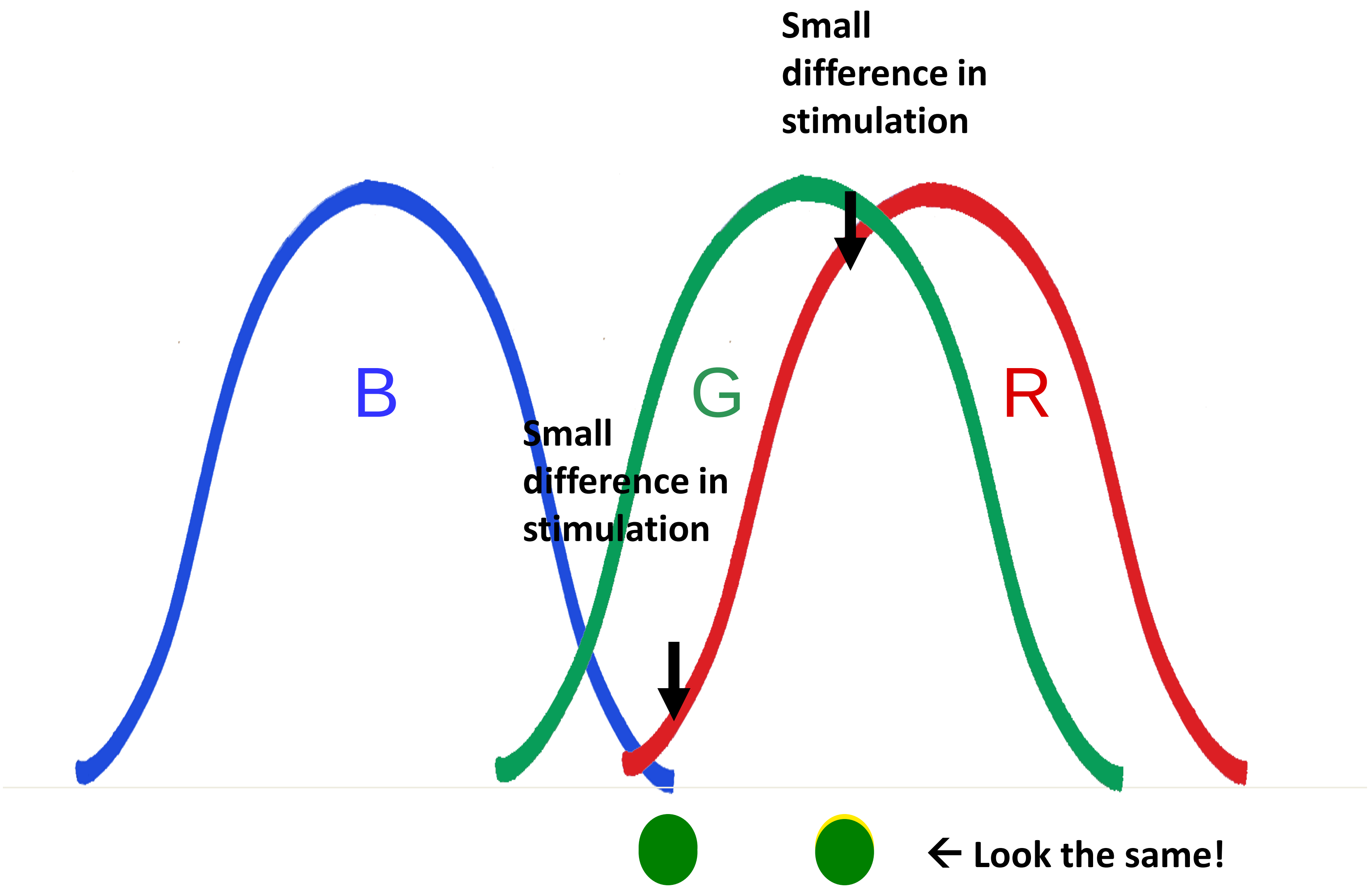


Why do colors that look different to us appear the same to color deficient individuals?

Consider a green versus a yellow light…



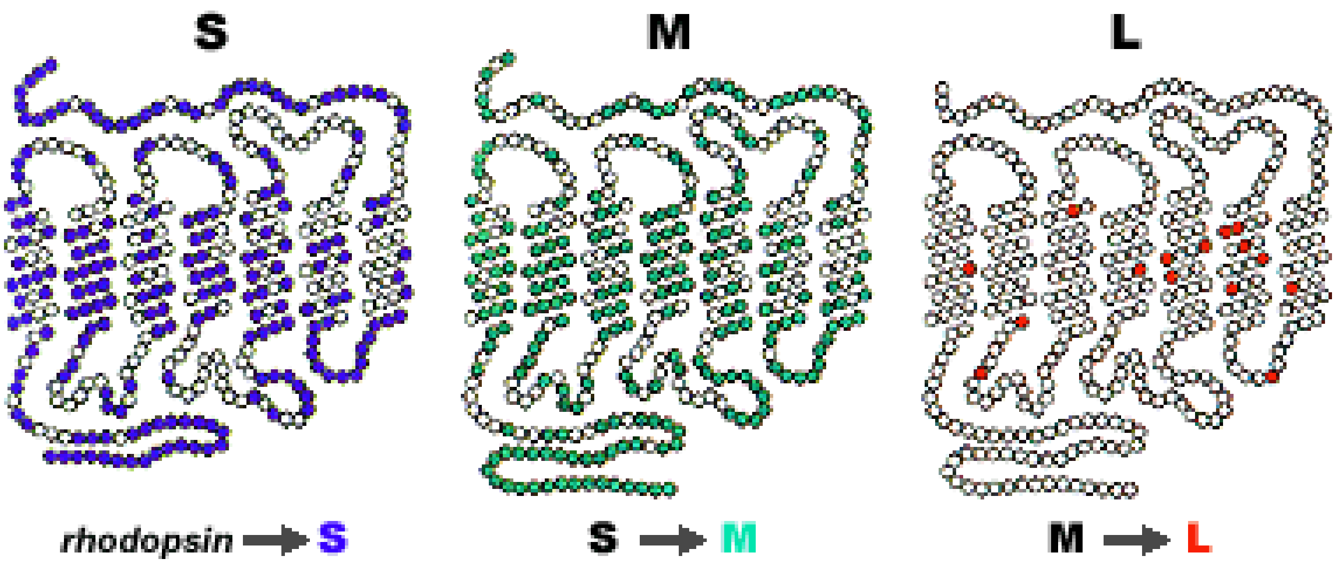
...this is the perception of a deuteranomalous trichromat



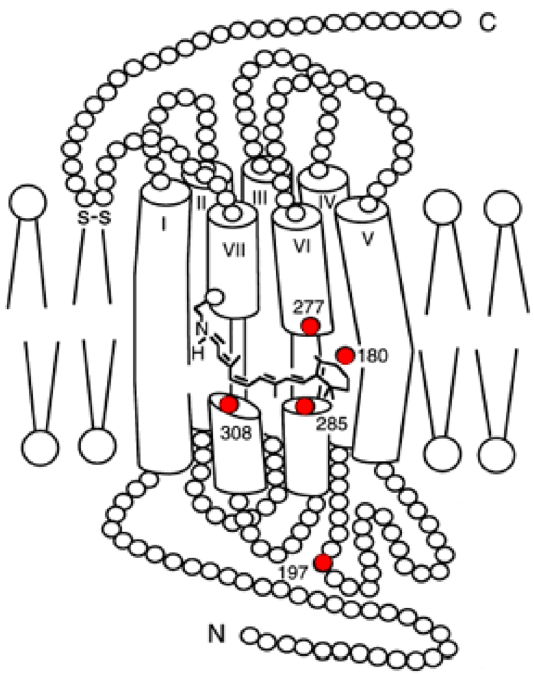
Prevalences of color deficiencies

Color vision deficiency	Males	Females
Protanomaly	1%	0.03%
Protanopia	1%	0.02%
Deuteranomaly	5%	0.4%
Deuteranopia	1%	0.01%
Tritanomaly	Rare (if at all)	Rare (if at all)
Tritanopia	0.008%	0.008%

Genetic background of color vision

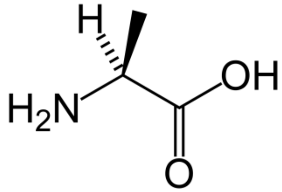


spectral tuning sites: 180, 277, 285

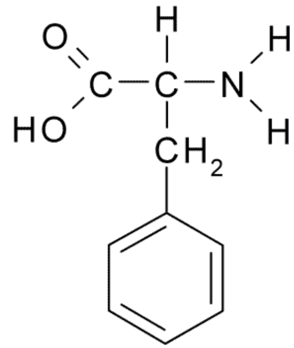


Spectral tuning sites shift the λmax of the respective opsin

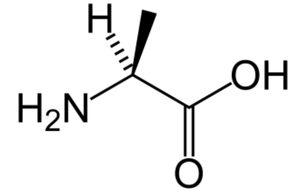
N
O
N
-
P
O
L
A
R



Alanine



Phenylalanine

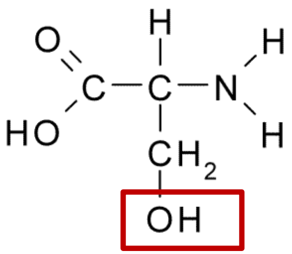


Alanine

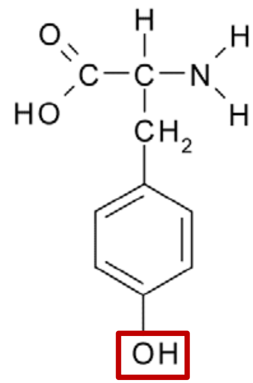
green cone opsin

A180S   F277Y   A285T

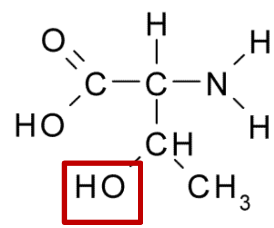
P
O
L
A
R



Serine



Tyrosine

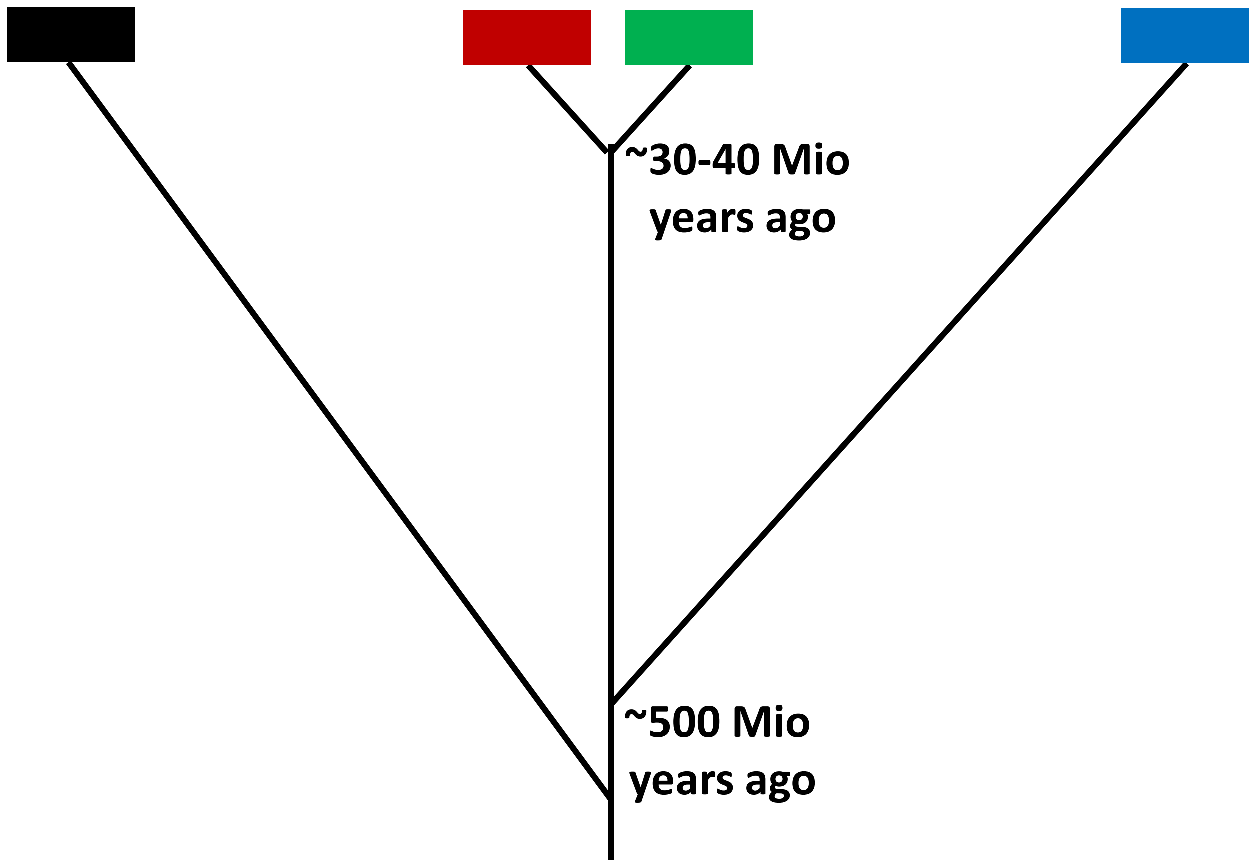


Threonine

red cone opsin
all with OH group

Why are the M- and L-cone opsins so similar?

Evolution of trichromacy

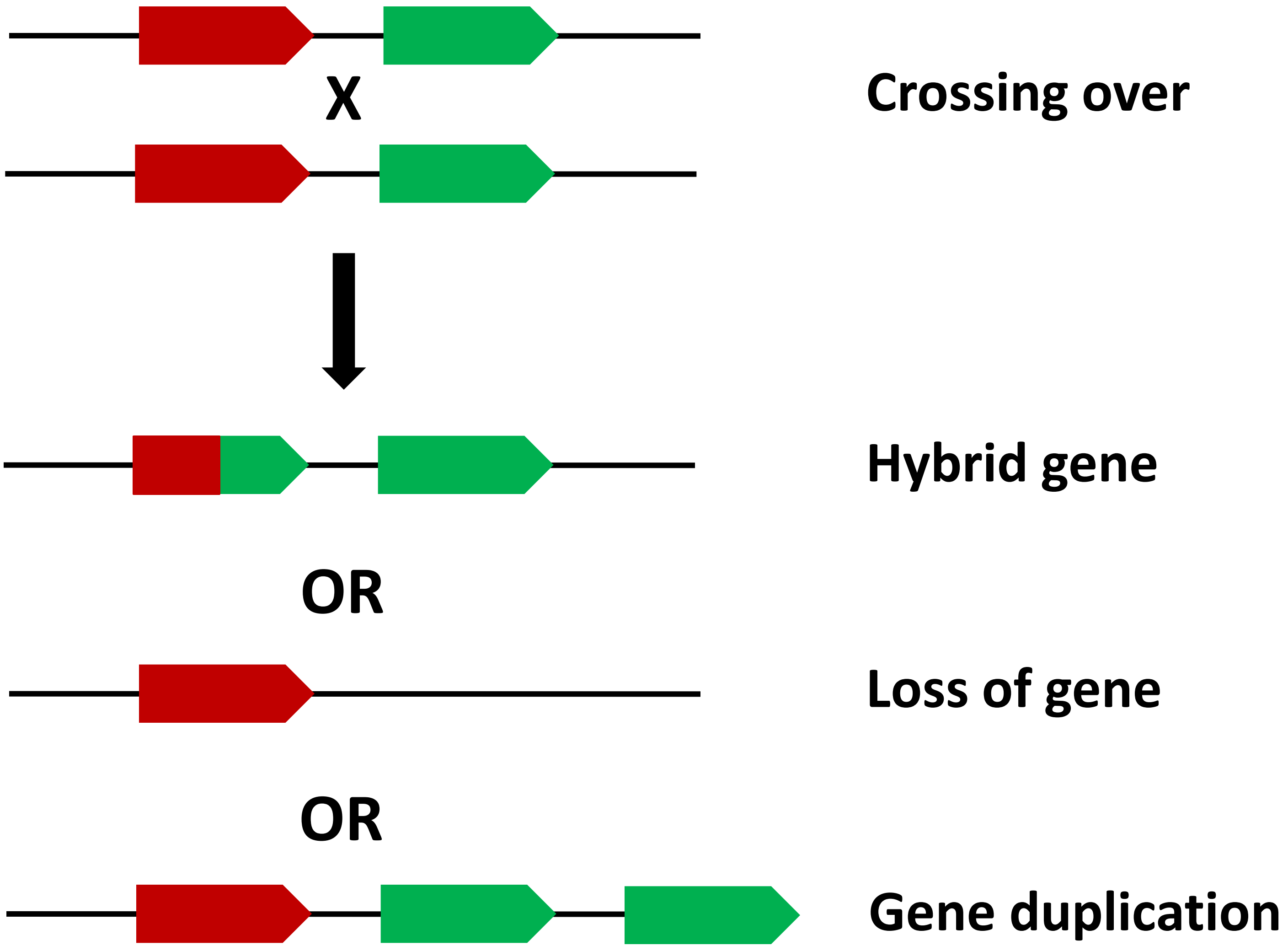


The selective advantage of trichromatic vision is thought to be the ability to detect ripe fruits against a background of dense green foliage.

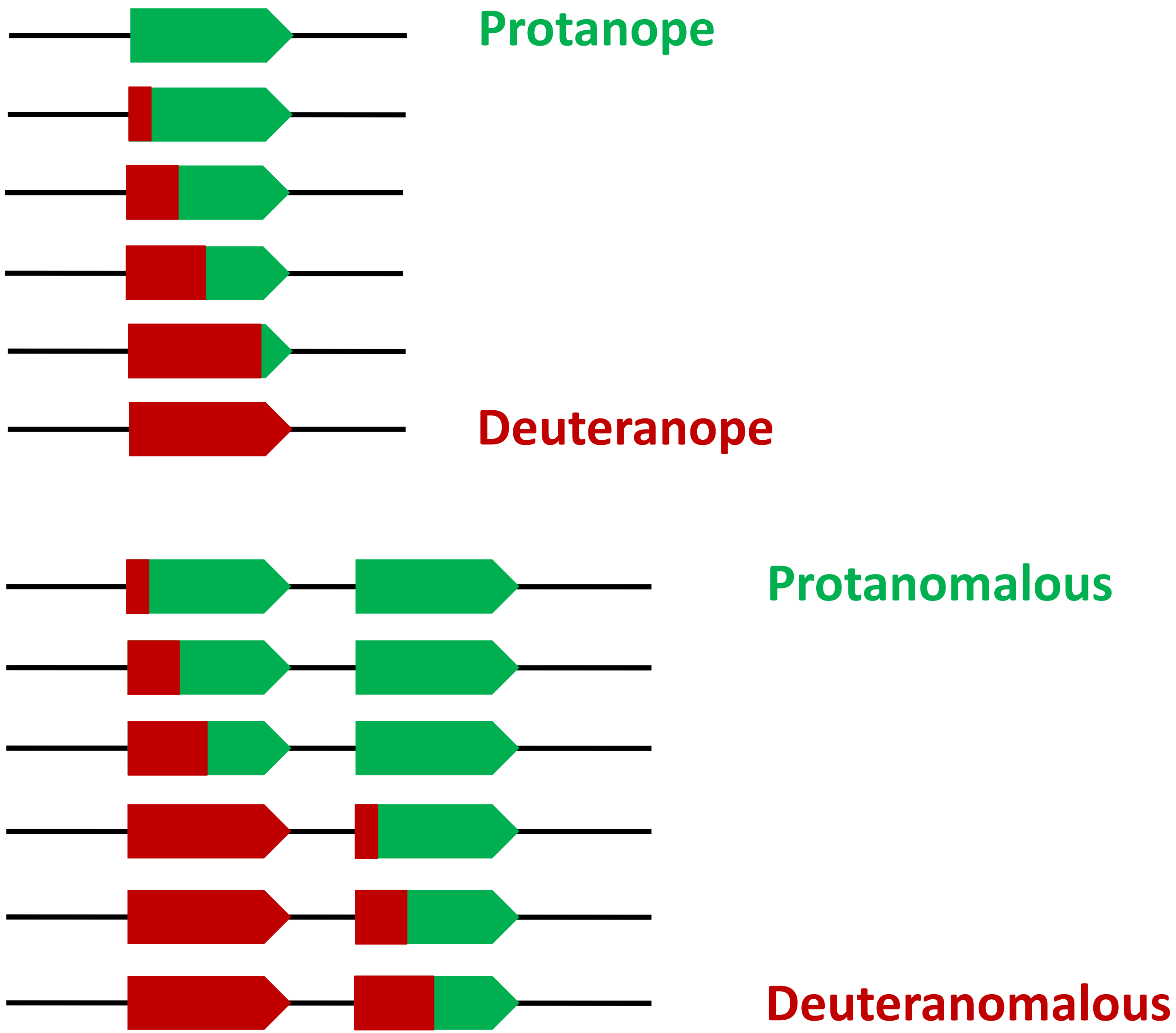
No red-green discrimination

Red-green discrimination

Red and green cone opsin genes

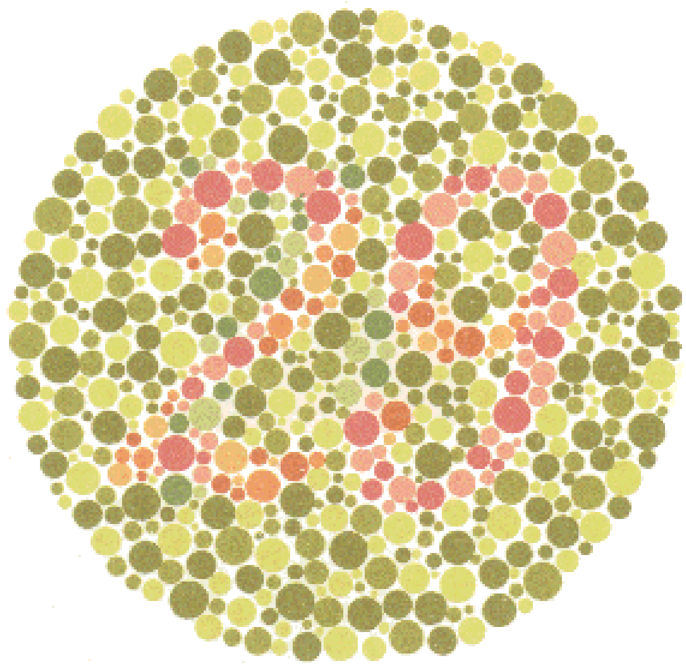


Red and green color deficiencies

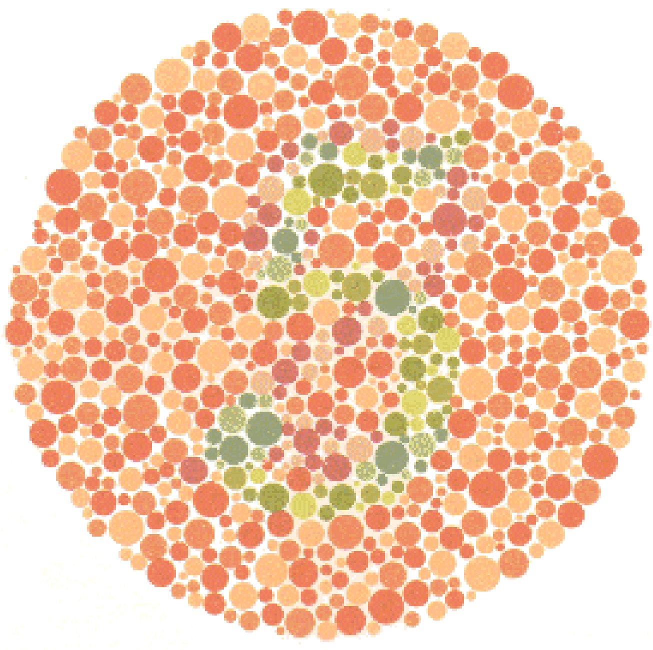


Diagnosing color vision deficiencies

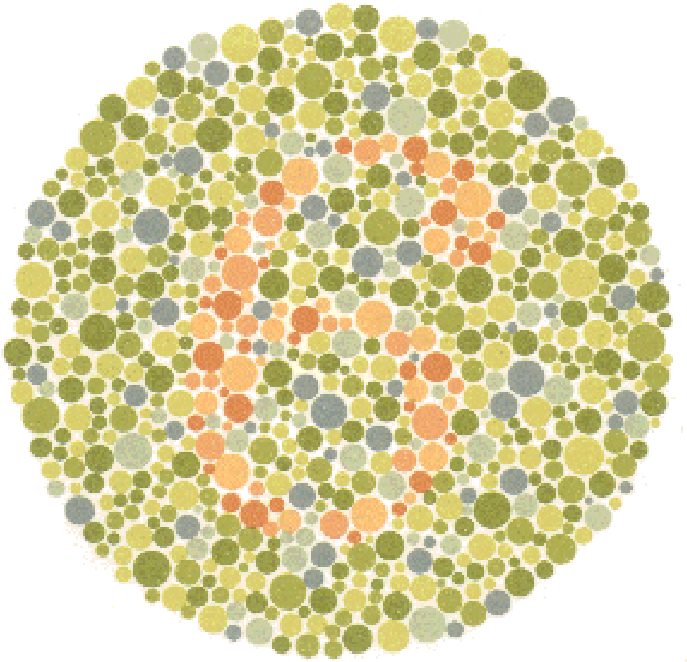
A quick color vision test...



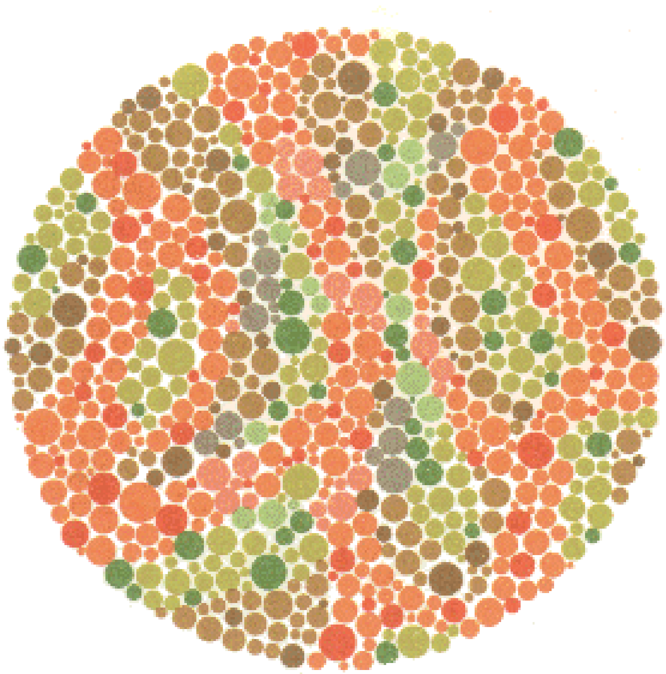
A quick color vision test...



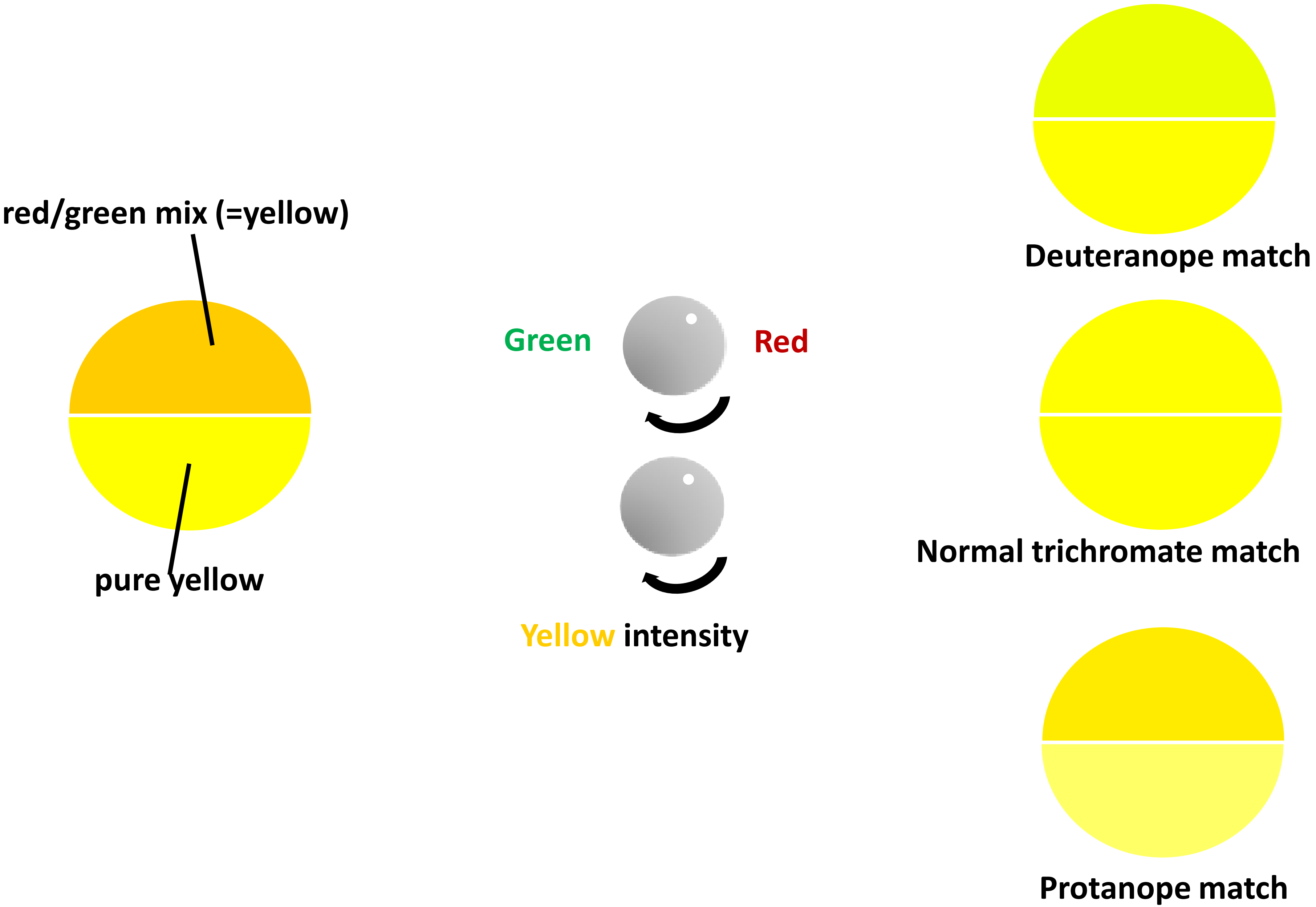
A quick color vision test...



A quick color vision test...



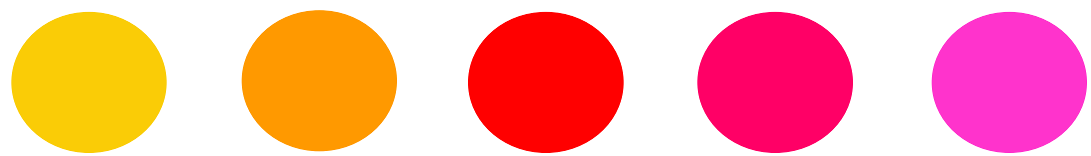
Diagnosis of red-green color deficiencies: Anomaloscope



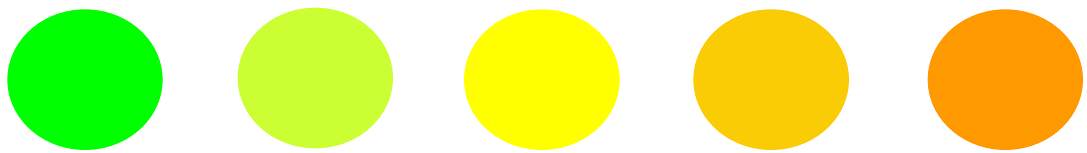
Postreceptoral color vision

Who knows this gentleman?

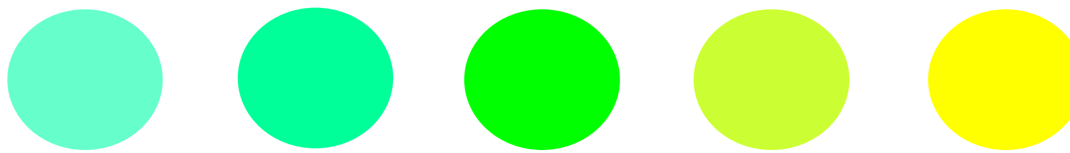
Ewald Hering 1834–1918



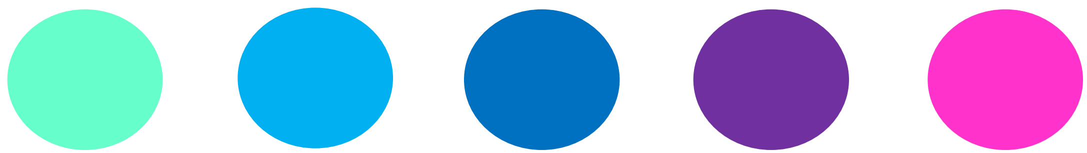
Reds can get bluer or yellower but not greener



Yellows can get greener or redder but not bluer



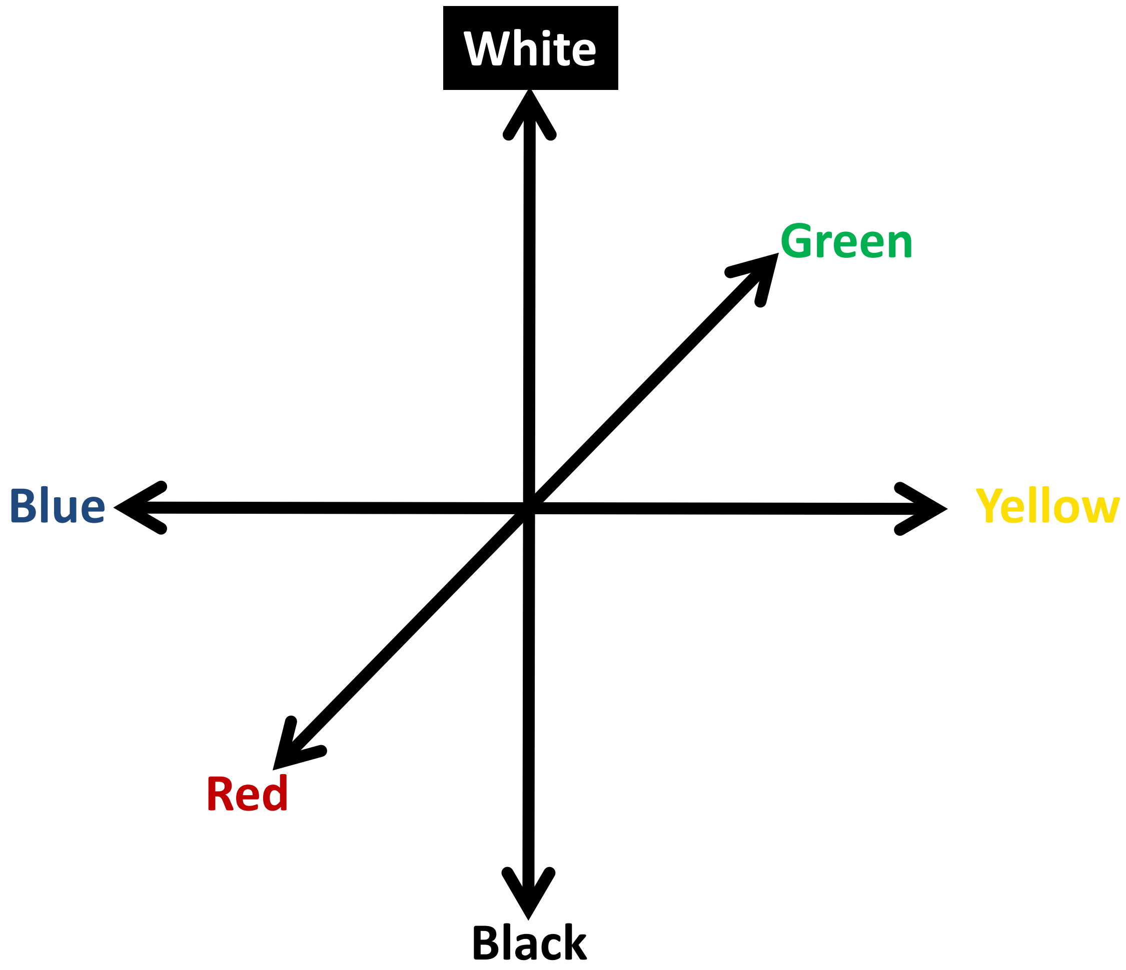
Greens can get bluer or yellower but not redder



Blues can get greener or redder but not yellower

The color opponent theory of Hering

Four „Urfarben“ are arranged in two opponent processes



Opponent channels

B-W channel

R-G channel

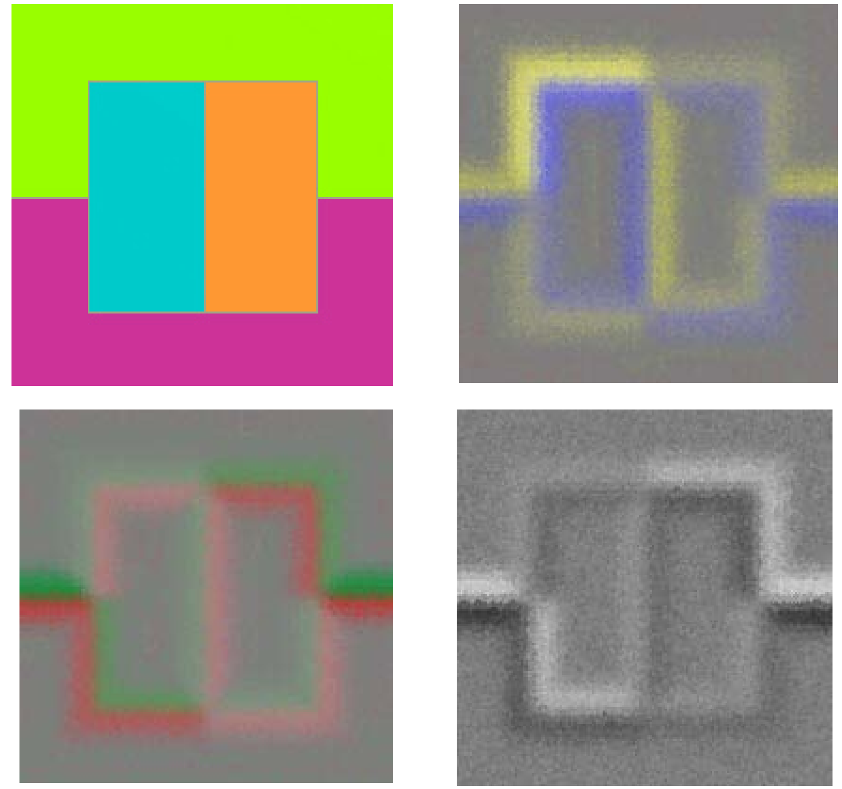
B-Y channel

Illustration of how the opponency channels work in your perception

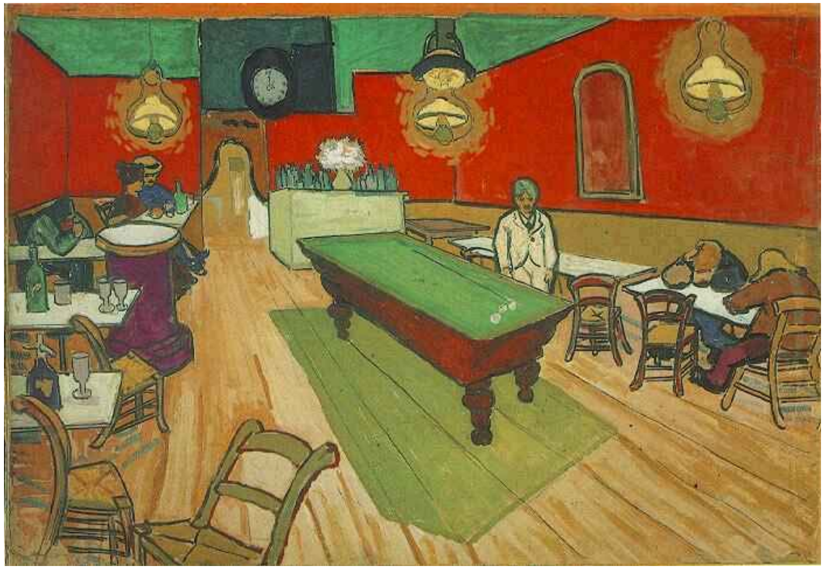
- Here are the *enhanced edges* resulting from your *y-b chromatic channel*

- Here are the *enhanced edges* resulting from your *r-g chromatic channel*

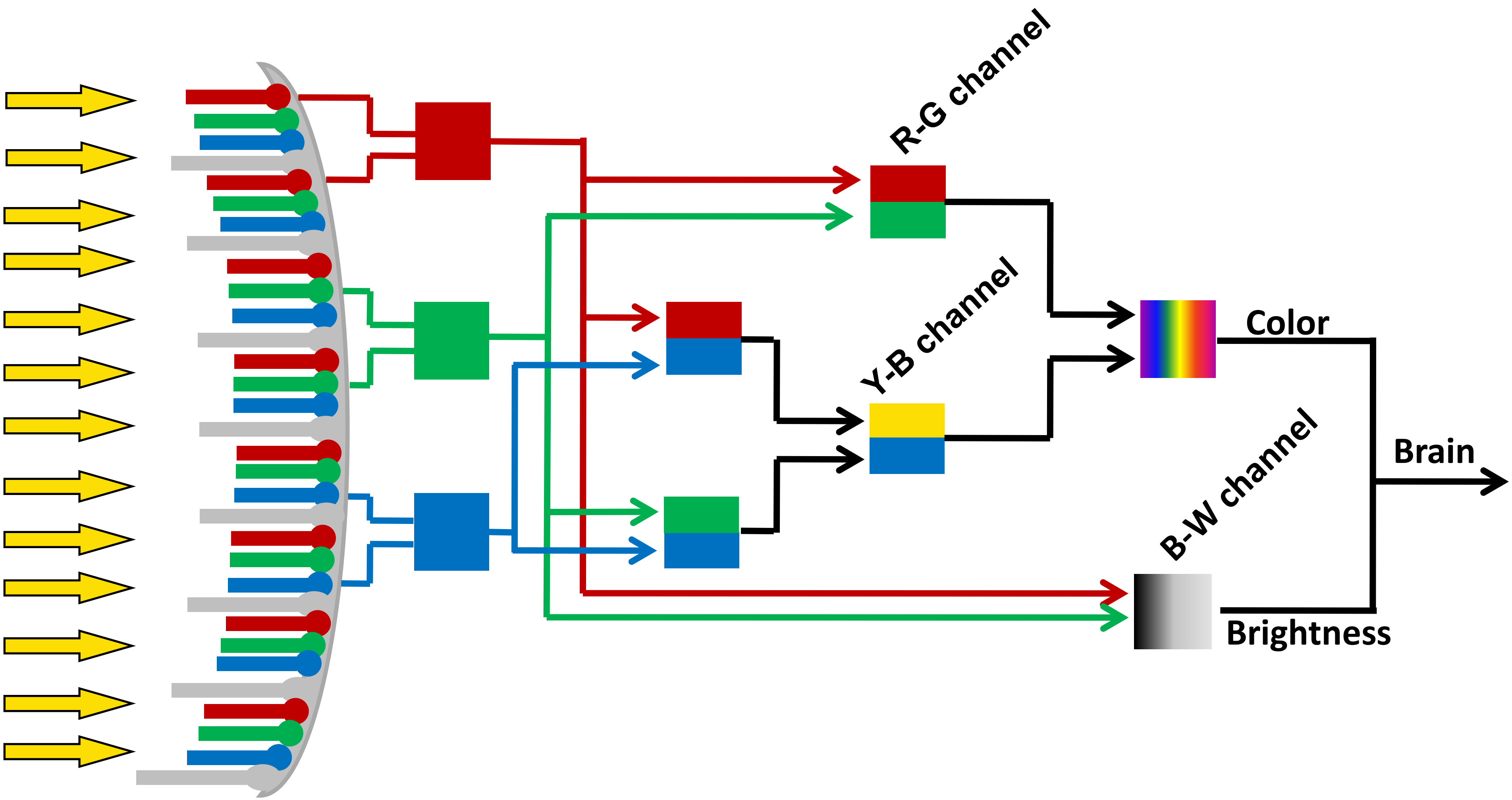
- Here are the *enhanced edges* resulting from your *r-g chromatic channel*



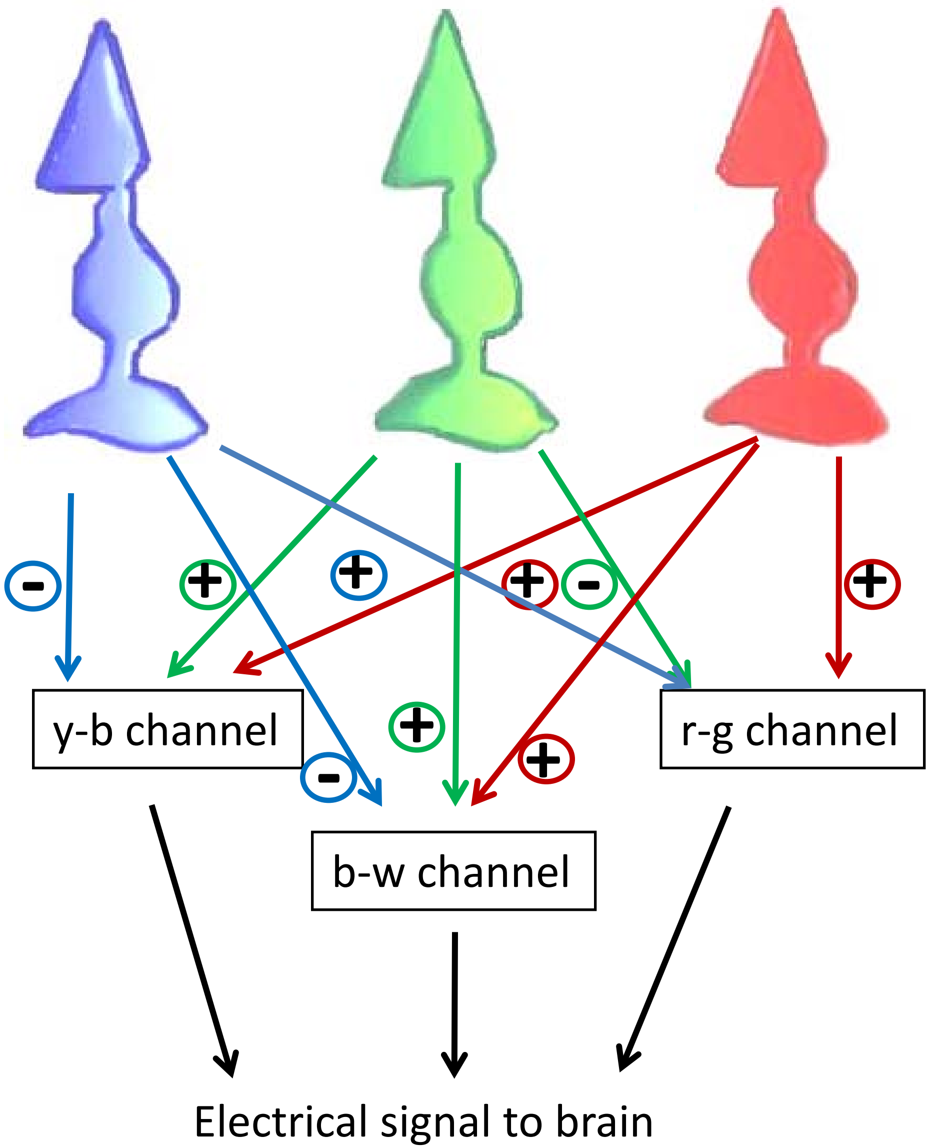
The artist Van Gogh often used opponent colors to enhance them



How are cone outputs organised at subsequent stages of visual processing?



Opponent channels



So far, we've mainly been talking about the colours of isolated patches of light. But the colour of a patch depends also upon:

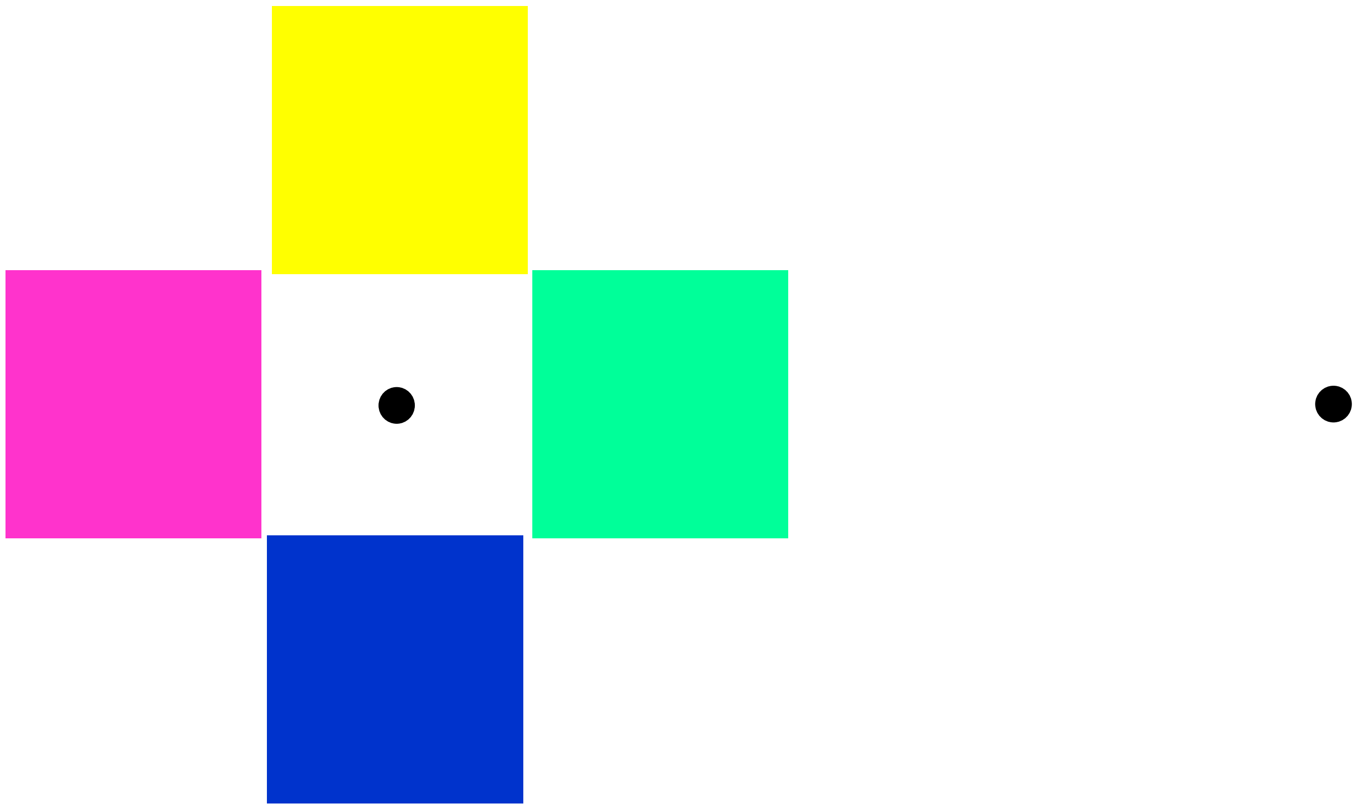
- **What precedes it (in time)**

COLOR AFTER-EFFECTS

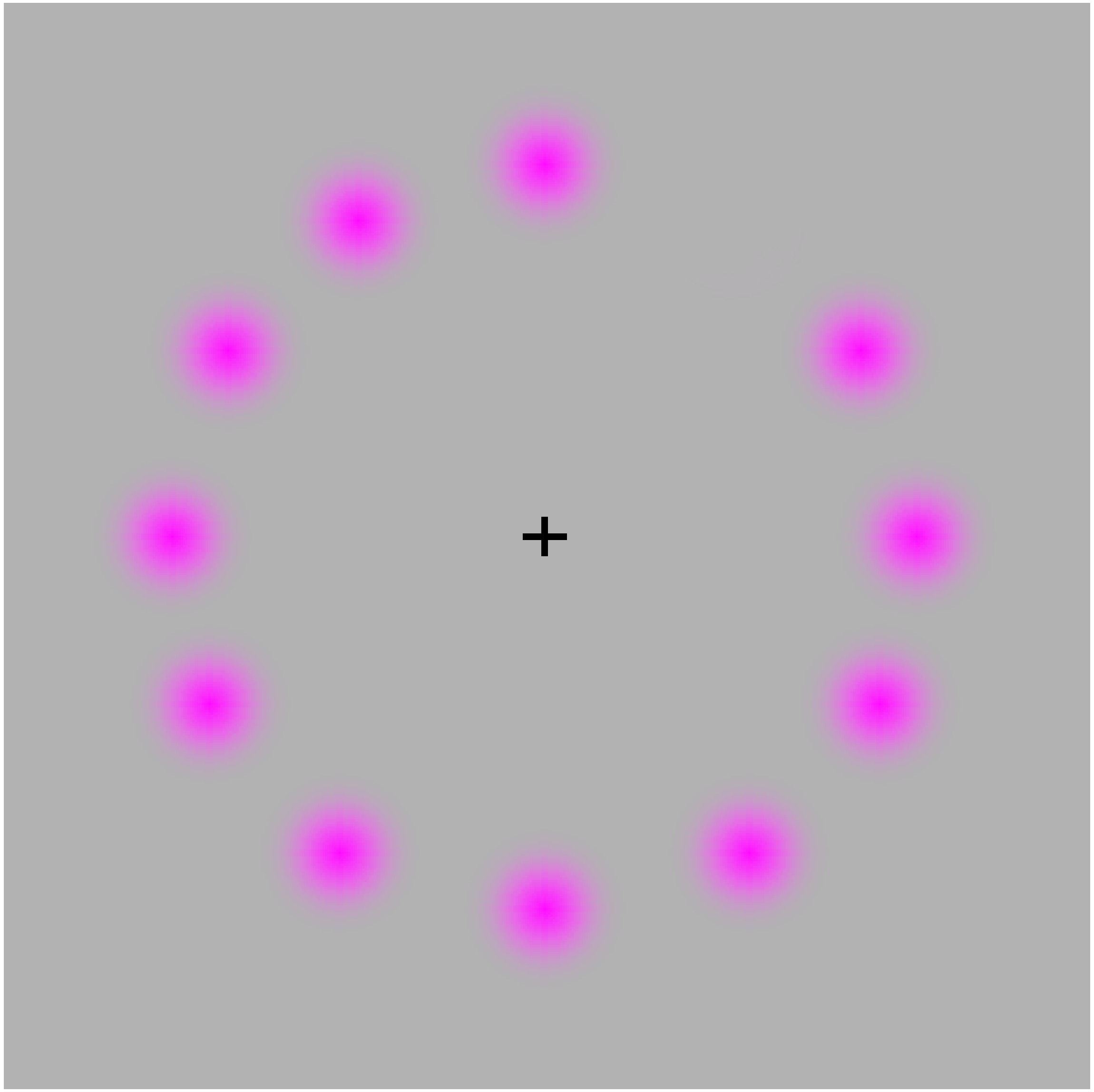
- **What surrounds it (in space)**

COLOR CONSTANCY

Color after-effect: Successive contrast



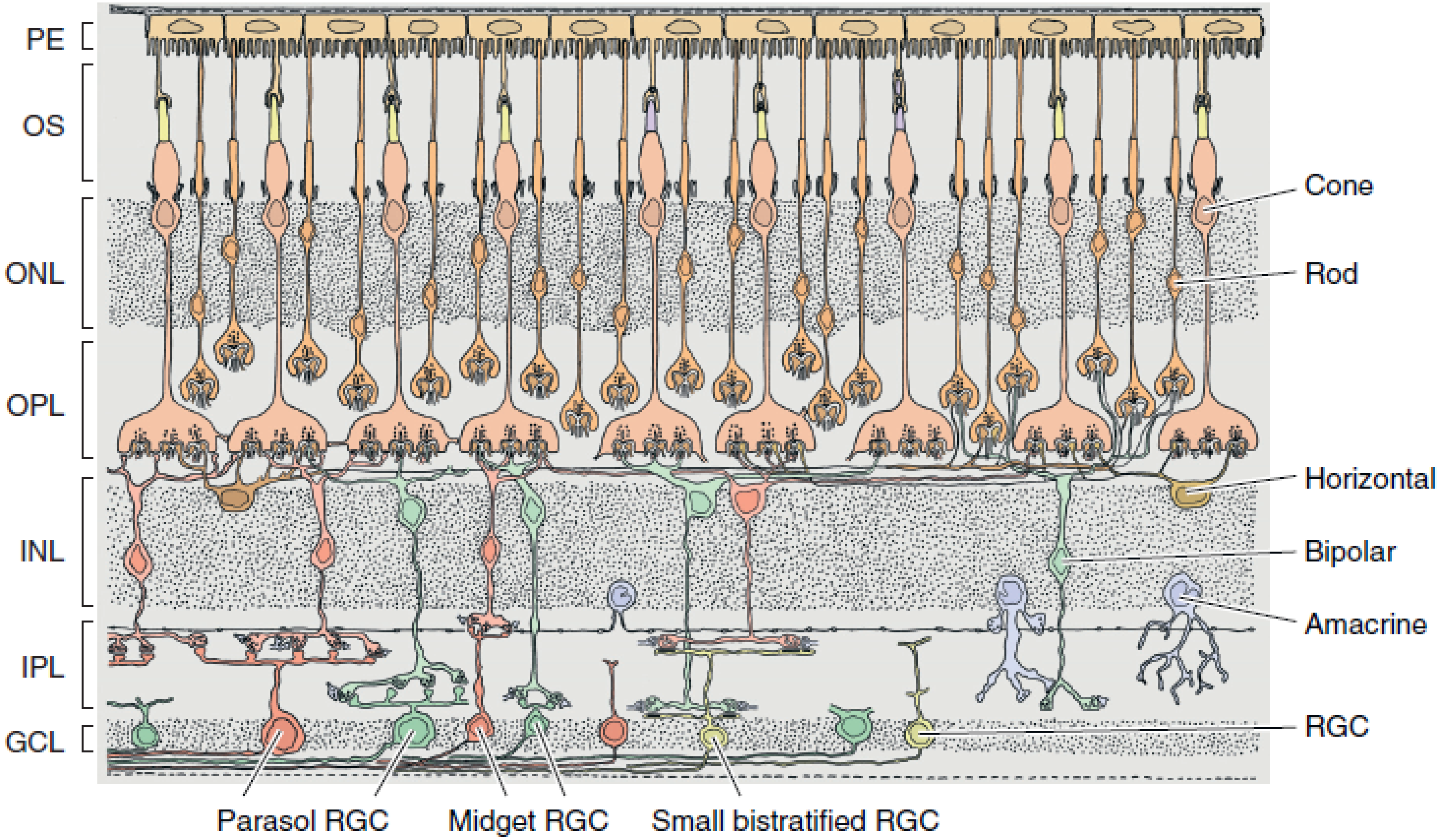
Color after effect: The lilac chaser



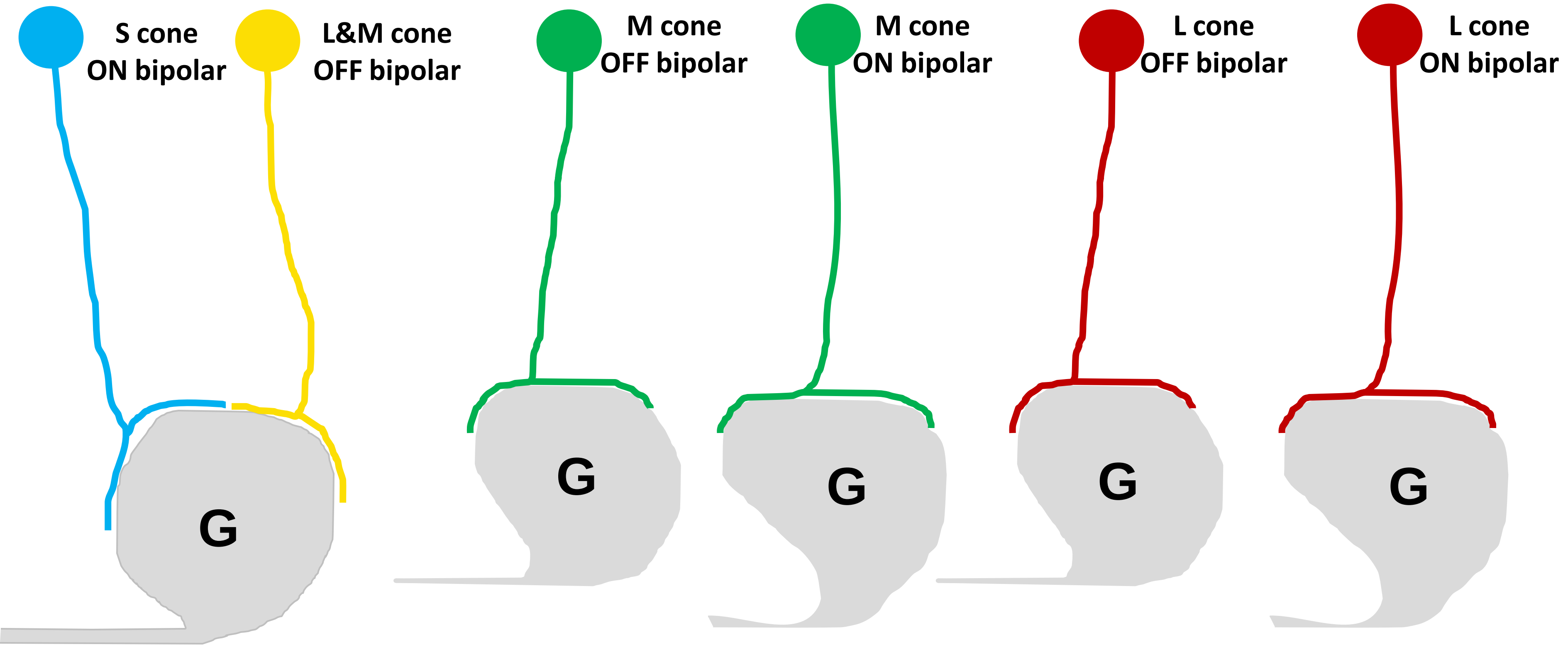
Color vision is a two stage model

- Early processing is trichromatic
- Later on it is opponent processing

The physiological basis of opponency



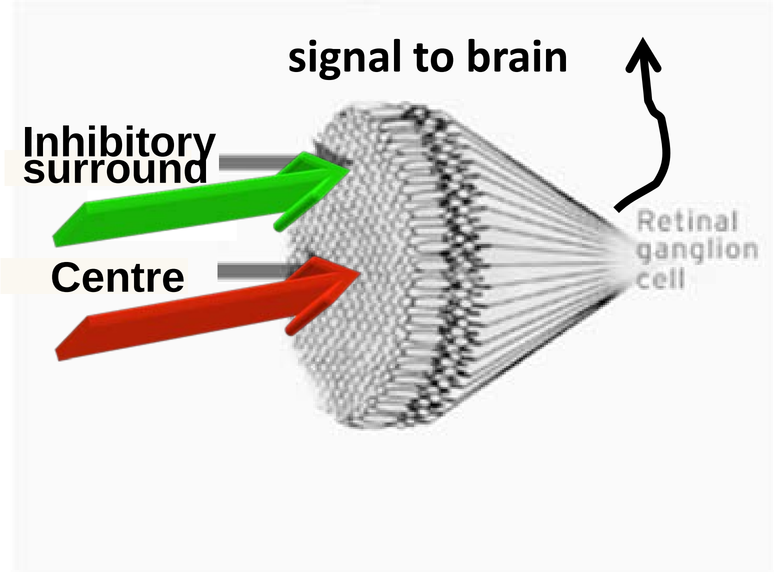
Ganglion and bipolar cells of trivariant color vision



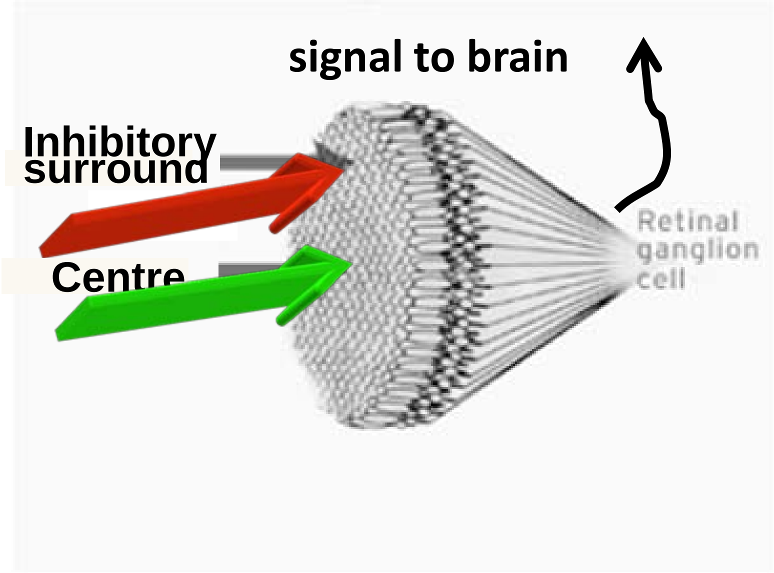
Bistratified S cone ON cell

Midget cell system in the fovea

Opponent receptive fields in our retina

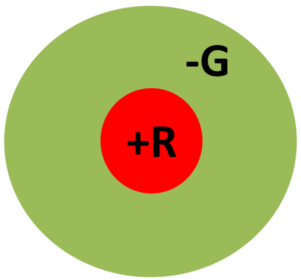


RED



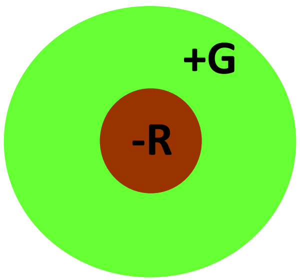
GREEN

The physiological basis of opponency: opponent retinal ganglion cells



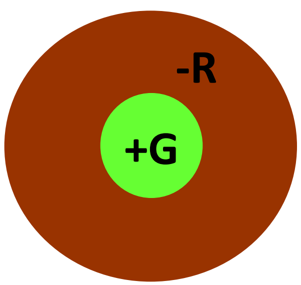
red ON/green OFF

OR



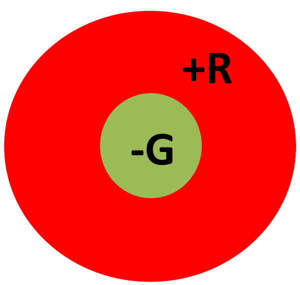
red OFF/green ON

→ signal increase → „red“



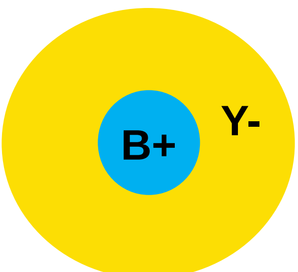
green ON/red OFF

OR



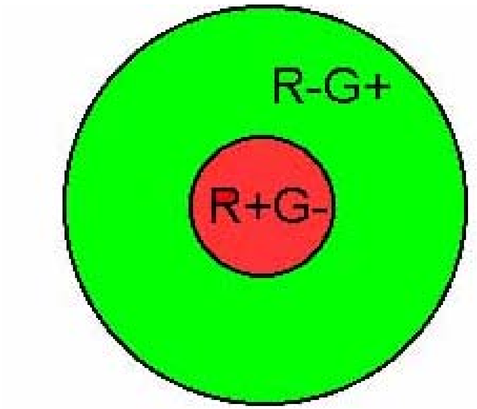
green OFF/red ON

→ signal decrease → „green“



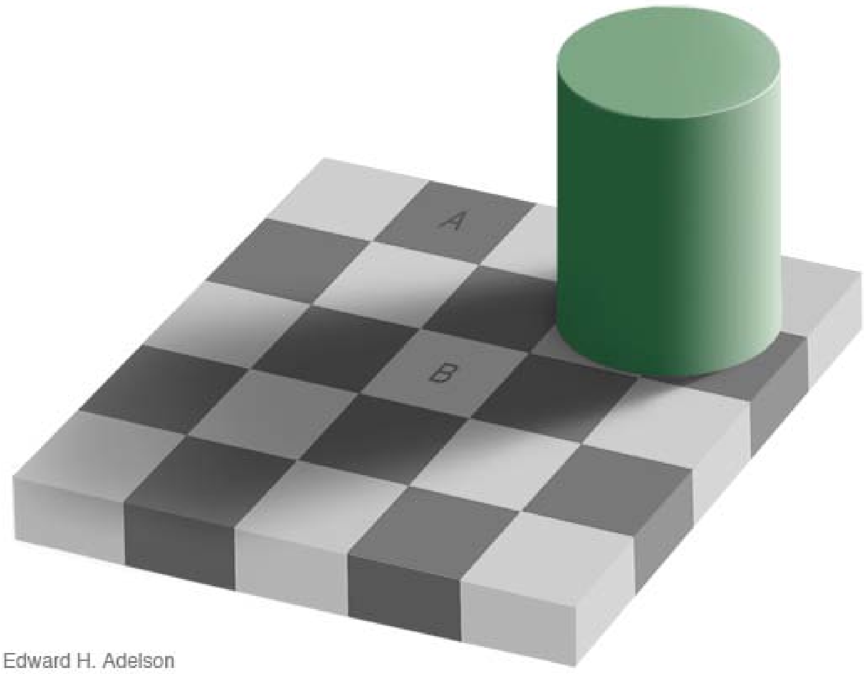
blue ON/yellow OFF

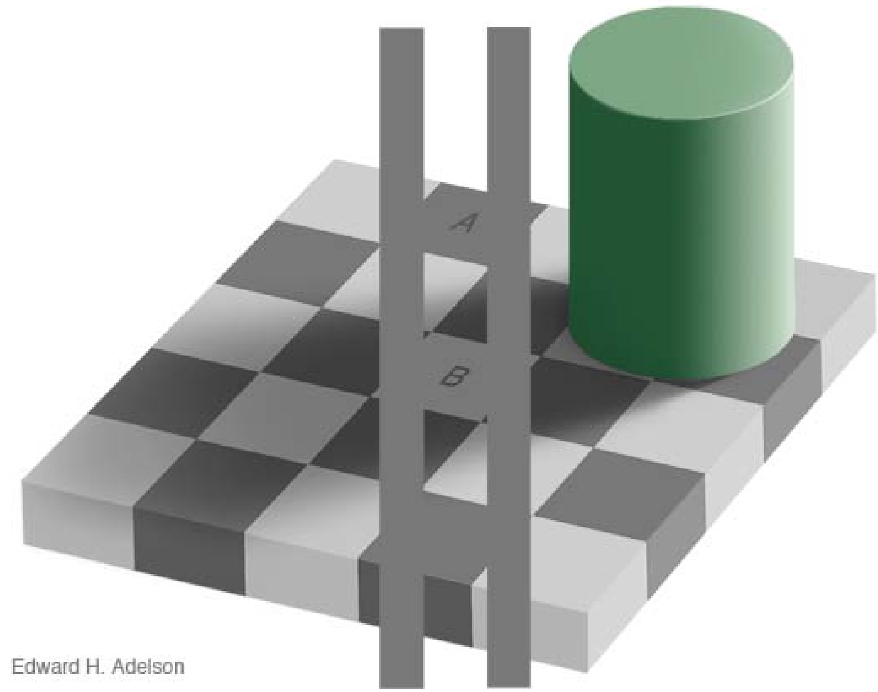
Double opponent cells



Color constancy

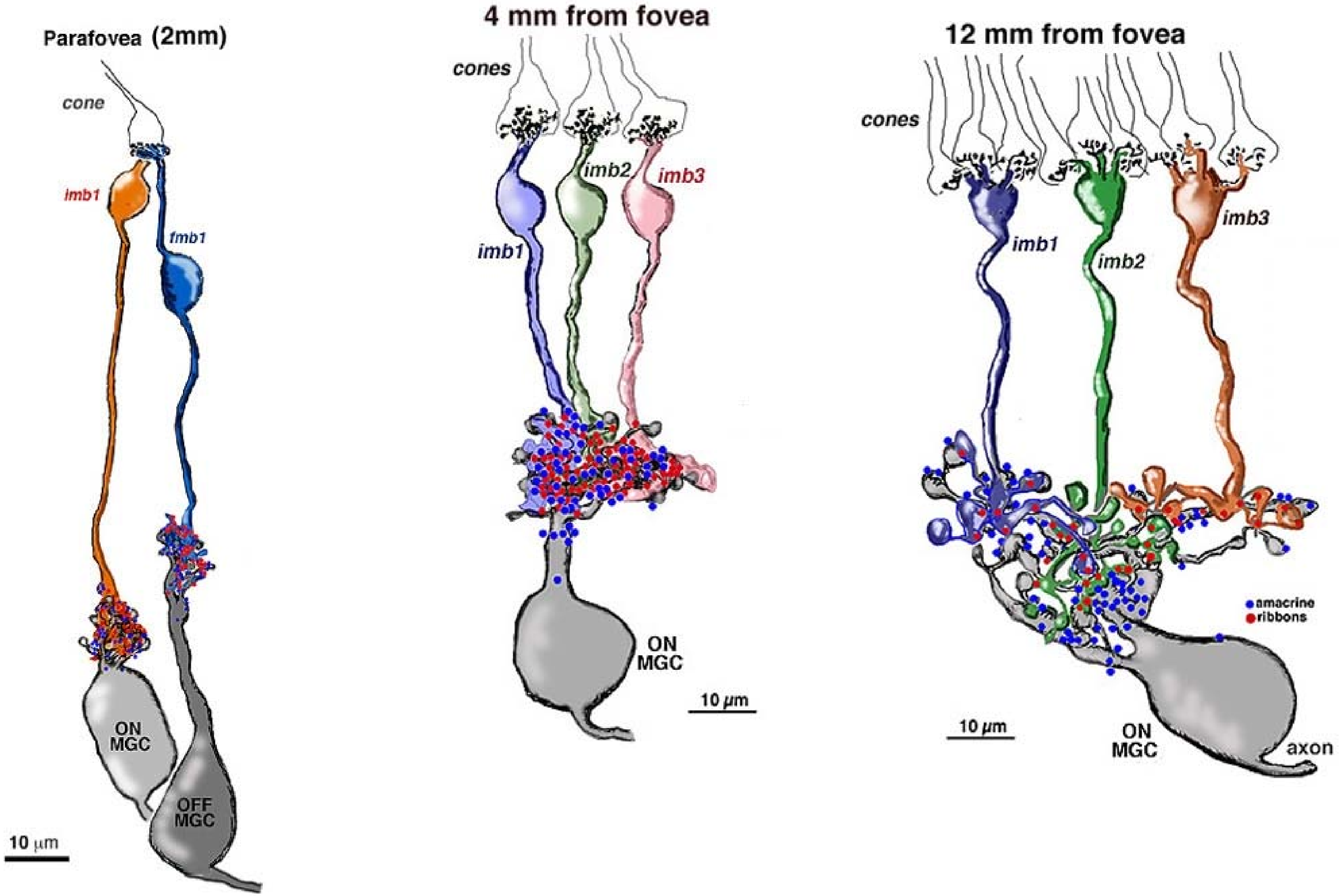
Color constancy





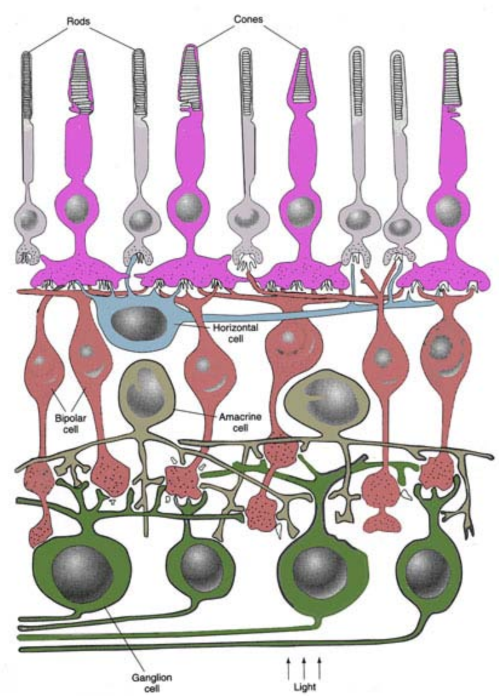
The fovea is optimized for highest spatial resolution

„private line“ between cones, bipolars and ganglion cells



Color perception

The Retina and the Brain: Visual Information Processing



Photons

↓

Photoreceptors

↓ Membrane potential

Bipolars

↓

Ganglion cells

↓ Action potential

Optic nerve

↓

Chiasma

Main pathway:
Lateral geniculate nucleus

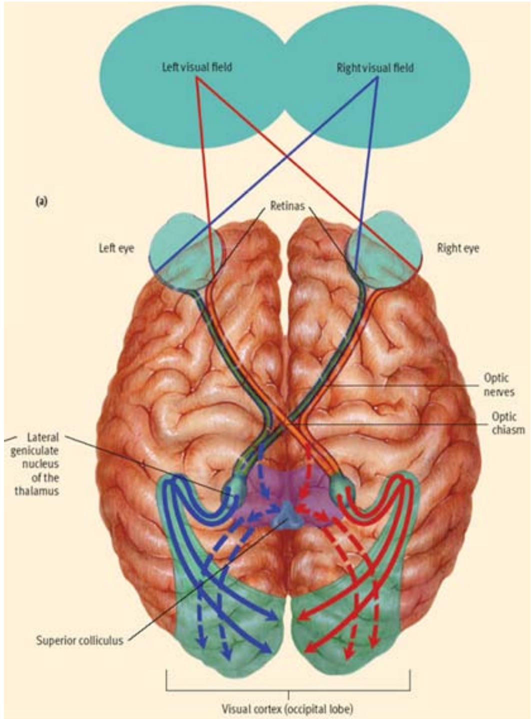
↓

Primary visual cortex

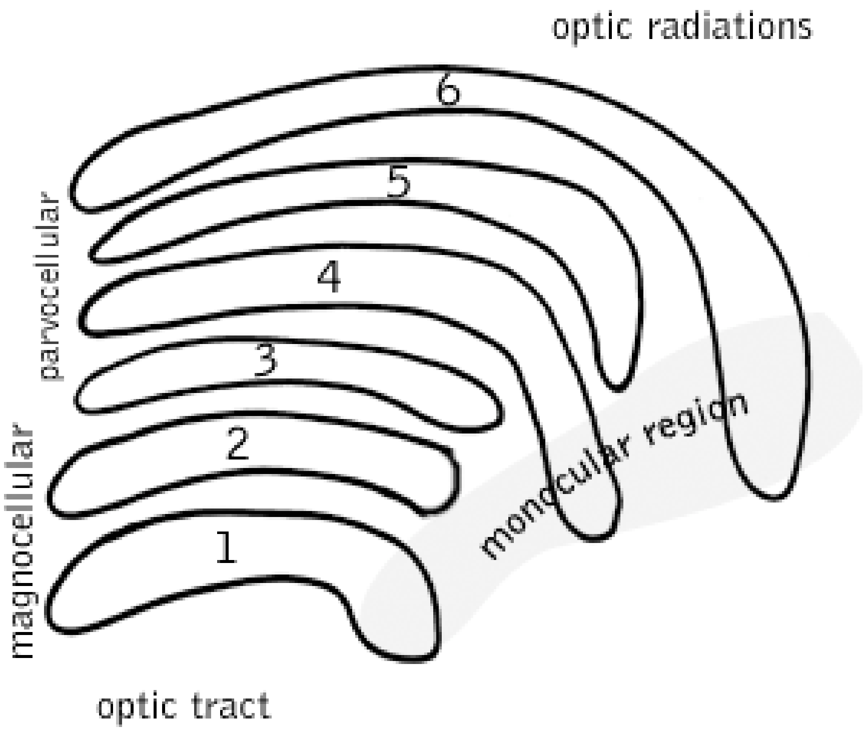
Second pathway:
Superior colliculus

↓

Primary visual cortex



The LGN is a distinctively layered structure



Correspondence between ganglion cells and LGN cells

Retinal ganglion cells	LGN cells	Type of information
Parasol ganglion cells	Layers 1&2: Magnocellular cells	perception of form, **movement**, depth, and brightness
Midget ganglion cells	Layers 3-6: Parvocellular cells	perception of **color**
Small bistratified ganglion cells	In between layers 1-6: Koniocellular cells	perception of **color**

Interactive Stroop Effect Experiment

Red	Green	Blue	Yellow	Pink
Orange	Blue	Green	Brown	Black
Green	Yellow	Pink	Red	Orange
Brown	Red	Black	Blue	Yellow
Black	Orange	Green	Brown	Red

Interactive Stroop Effect Experiment

Blue	Pink	Black	Red	Brown
Brown	Red	Blue	Green	Orange
Yellow	Blue	Red	Orange	Black
Brown	Red	Green	Black	Red
Red	Pink	Blue	Green	Black

So, what does this all mean?

It means that color perception is relative and not absolute. And, since color perception is relative, we are always subject to these effects. In other words, it's in our mind not our eye.