The 20 Senses

The Senses: A Comprehensive Reference Elsevier 2008 *6 Volume set*
The Handbook of Sensory Physiology Springer-Verlag 1972 *12 volume set*

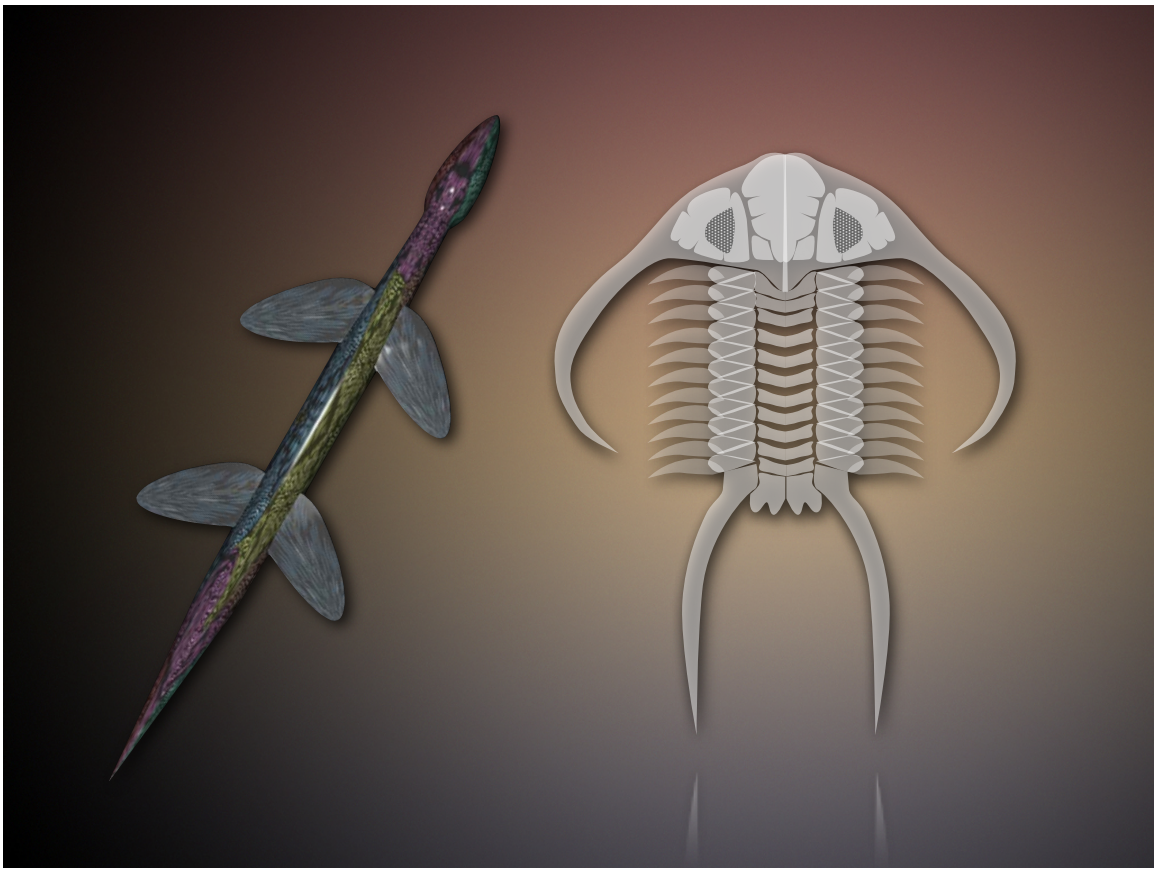
Vertebrates

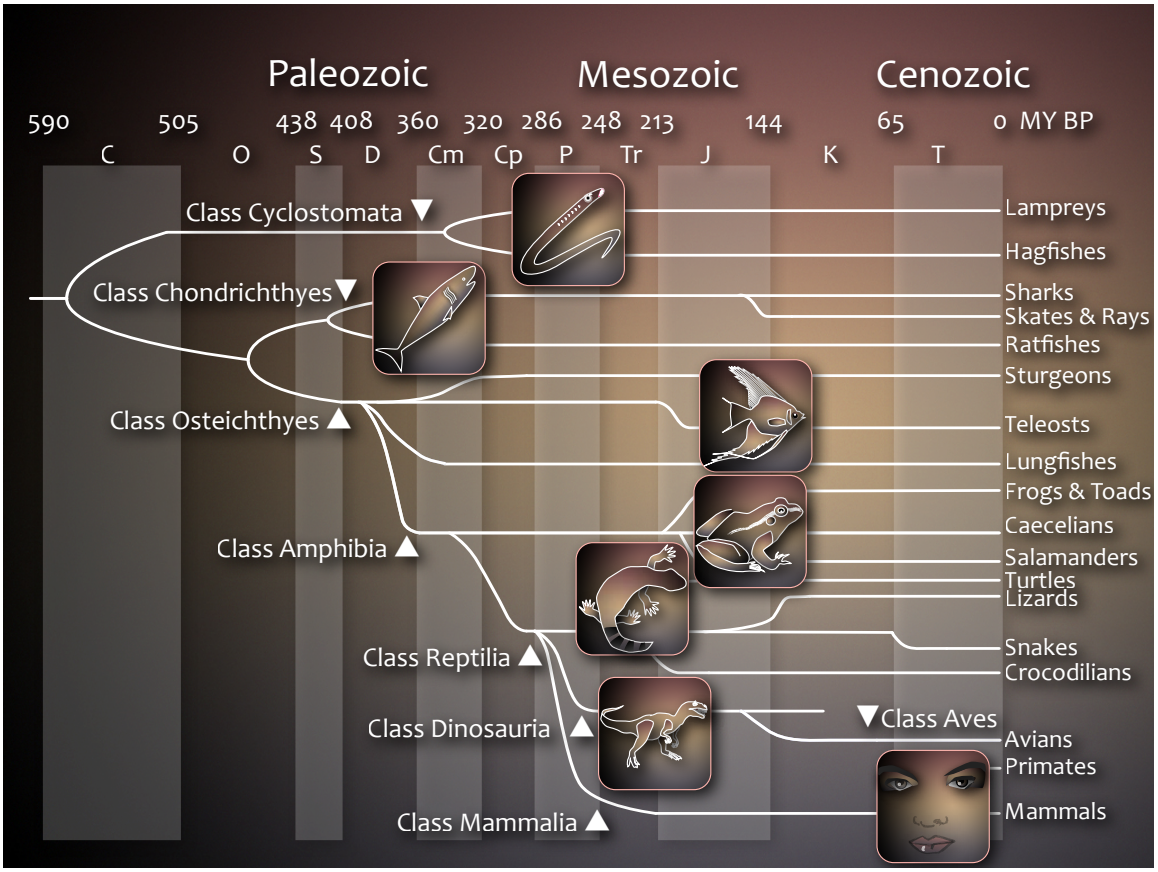
▷·
amplifier

20 primary senses

~
fluidic

dendritic




Paleozoic
Mesozoic
Cenozoic
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408
360
320
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0 MY BP
C
O
S
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Cm
Cp
P
Tr
J
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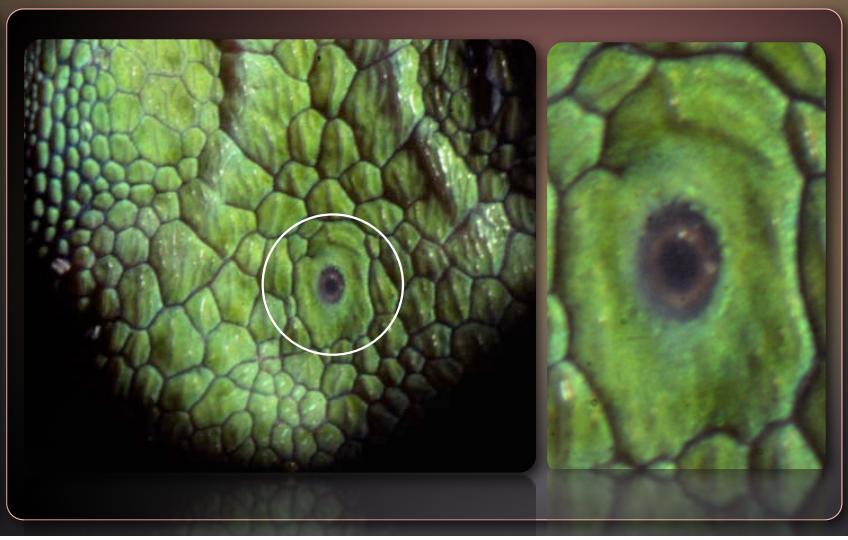
T
Class Cyclostomata
Class Chondrichthyes
Class Osteichthyes
Class Amphibia
Class Reptilia
Class Dinosauria
Class Mammalia
Class Aves
Lampreys
Hagfishes
Sharks
Skates & Rays
Ratfishes
Sturgeons
Teleosts
Lungfishes
Frogs & Toads
Caecelians
Salamanders
Turtles
Lizards
Snakes
Crocodilians
Avians
Primates
Mammals

Photoception

Photoception measures the flow of solar time, the angle of the sun in the sky … binding life to the seasons.

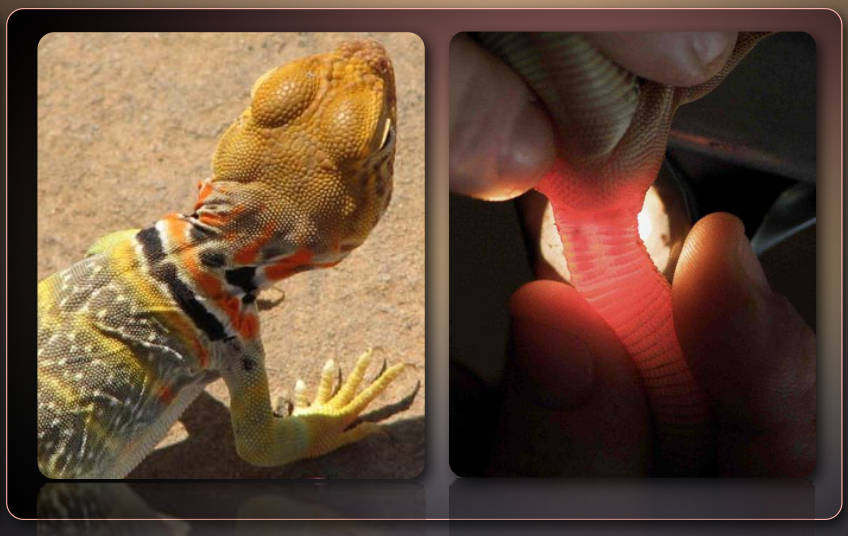
Phyletics



Chronoception

Chronoception measures the flow of daily time, setting body clocks to the pulse of life … sleep … life … sleep ….

Phyletics

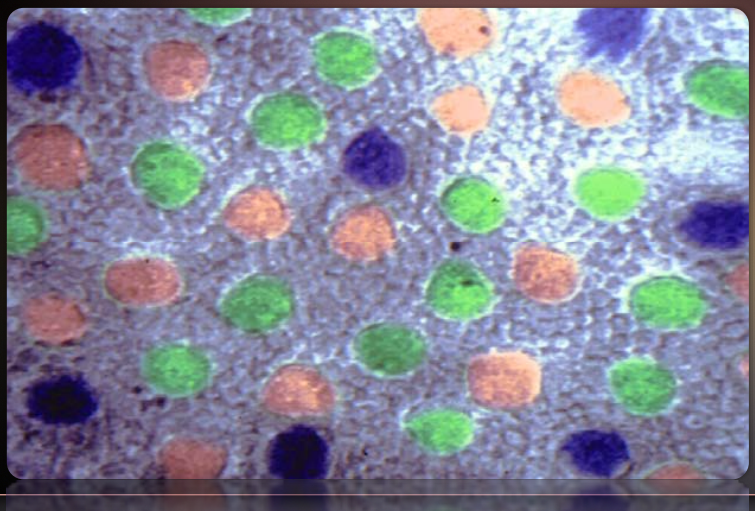


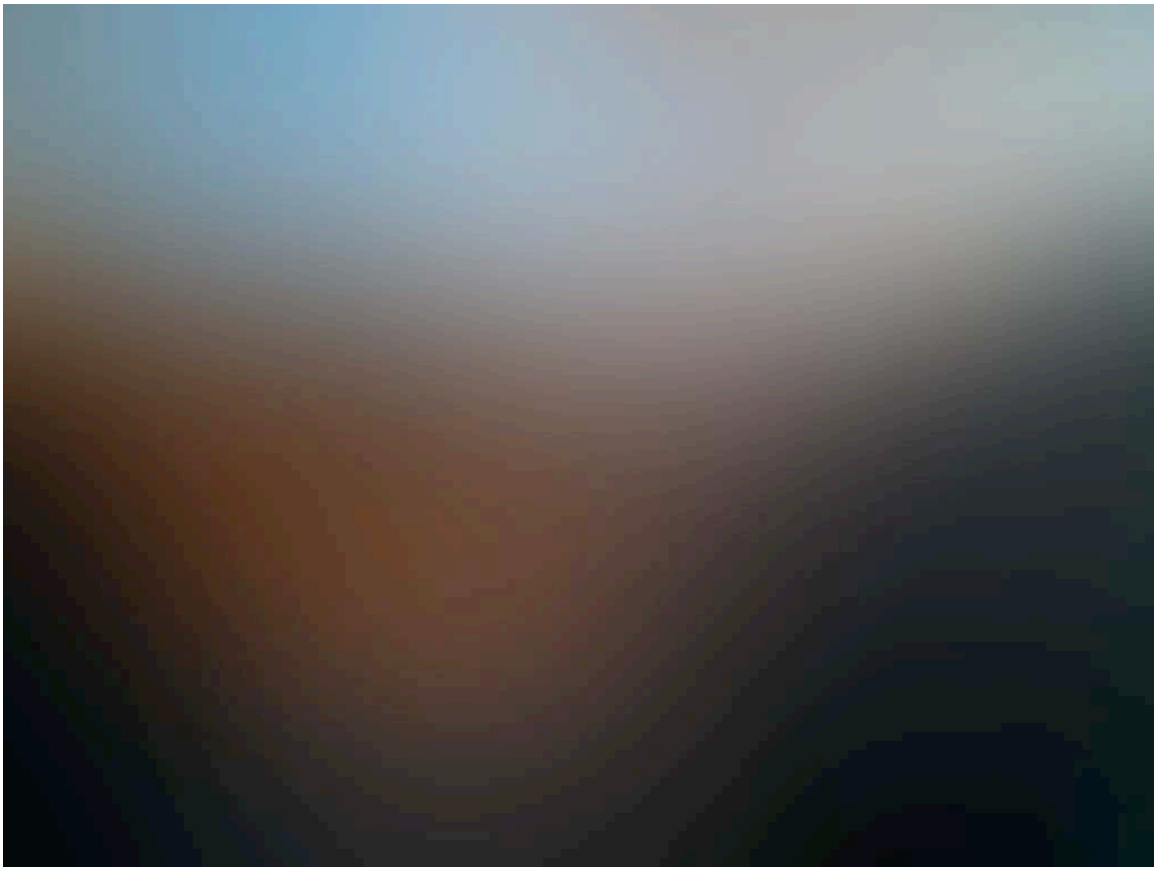
Vision

Vision is sight, encoding the transit of shape across our lives.
It is the sense of images … a dominant arbiter of mobility through landscape & seascape.

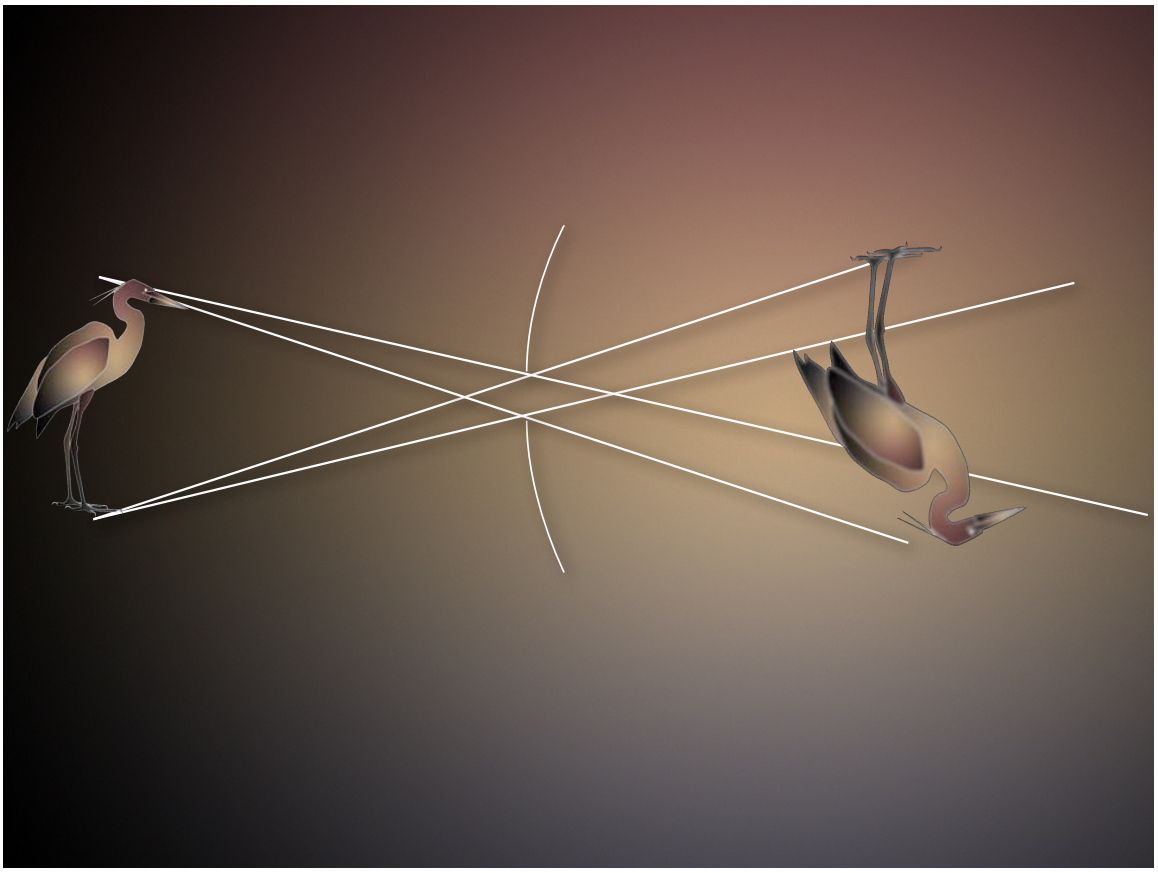
Phyletics

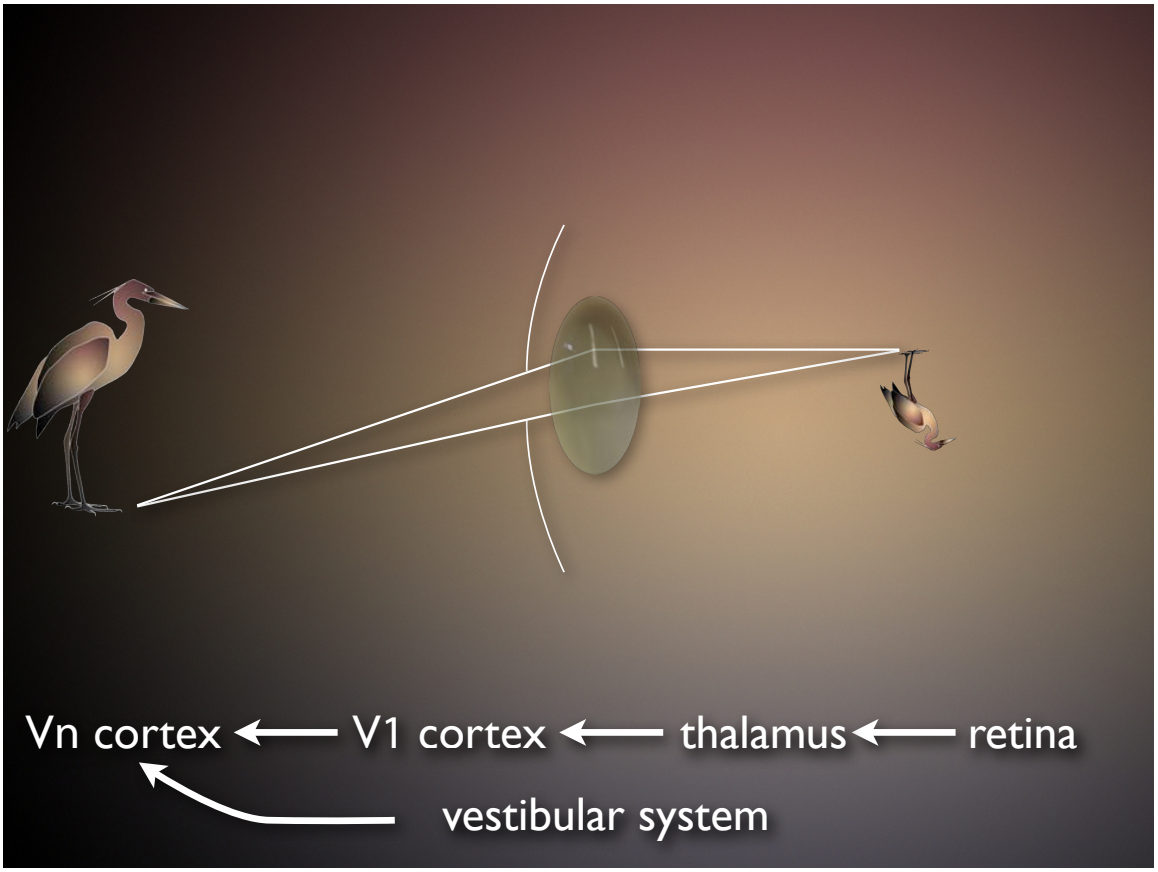
Marc RE, HG Sperling 1977 The chromatic organization of primate cones. Science 196:454-456.



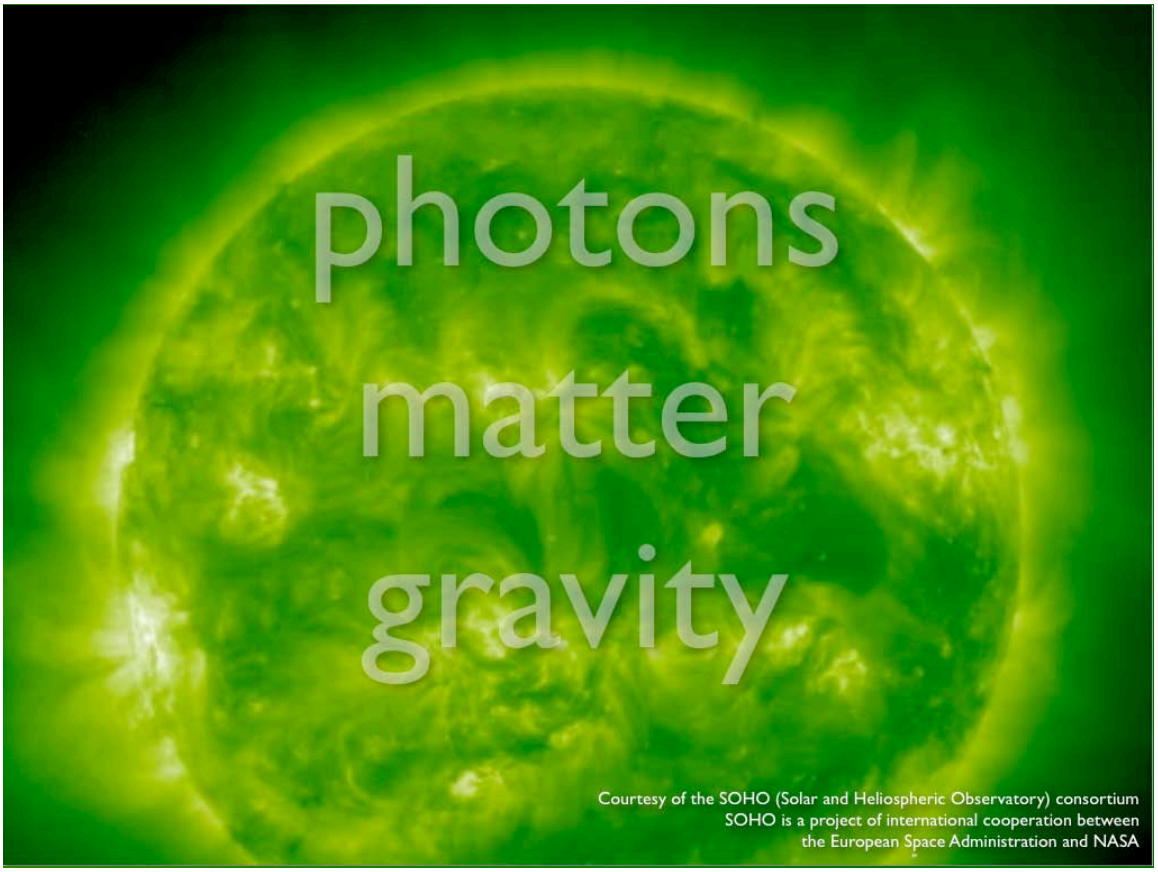



Apertures




Vn cortex
V1 cortex
thalamus
retina
vestibular system

Color


photons
matter
gravity
Courtesy of the SOHO (Solar and Heliospheric Observatory) consortium
SOHO is a project of international cooperation between
the European Space Administration and NASA

DOES THE INERTIA OF A BODY DEPEND UPON ITS ENERGY-CONTENT?

By A. EINSTEIN

September 27, 1905

The results of the previous investigation lead to a very interesting conclusion, which is here to be deduced.

I based that investigation on the Maxwell-Hertz equations for empty space, together with the Maxwellian expression for the electromagnetic energy of space, and in addition the principle that:—

The laws by which the states of physical systems alter are independent of the alternative, to which of two systems of coordinates, in uniform motion of parallel translation relatively to each other, these alterations of state are referred (principle of relativity).

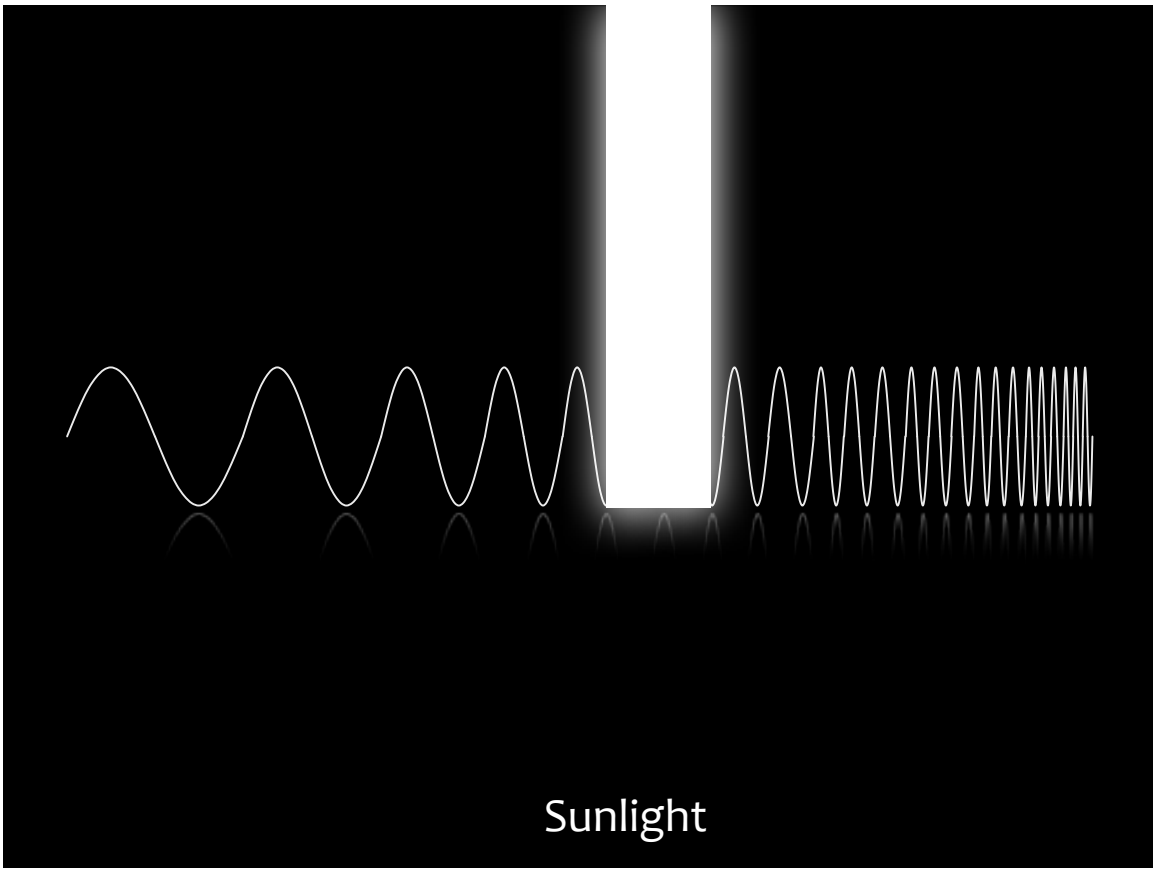
With these principles* as my basis I deduced *inter alia* the following result (§ 8):—

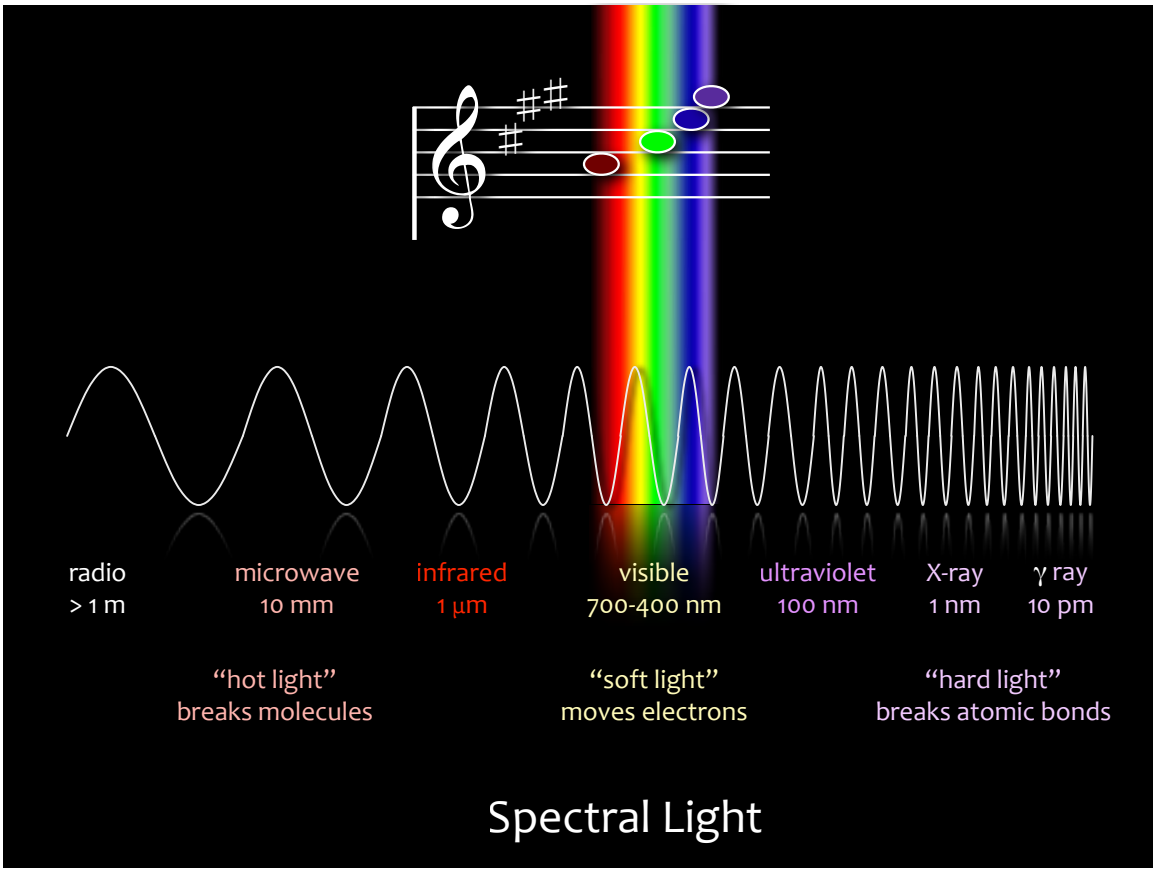
Let a system of plane waves of light, referred to the system of co-ordinates (x, y, z), possess the energy l; let the direction of the ray (the wave-normal) make an angle ϕ with the axis of x of the system. If we introduce a new system of co-ordinates (ξ, η, ζ) moving in uniform parallel translation with respect to the system (x, y, z), and having its origin of co-ordinates in motion along the axis of x with the velocity v, then this quantity of light—measured in the system (ξ, η, ζ)—possesses the energy

$$l^* = l\frac{1 - \frac{v}{c}cos\phi}{\sqrt{1 - v^2/c^2}}$$

where c denotes the velocity of light. We shall make use of this result in what follows.

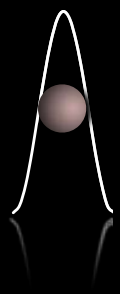
Einstein, Albert. 1905. Ist die Trägheit eines Körpers von seinem Energiegehalt abhängig? Annalen der Physik. 18:639-641.





Spectral Light

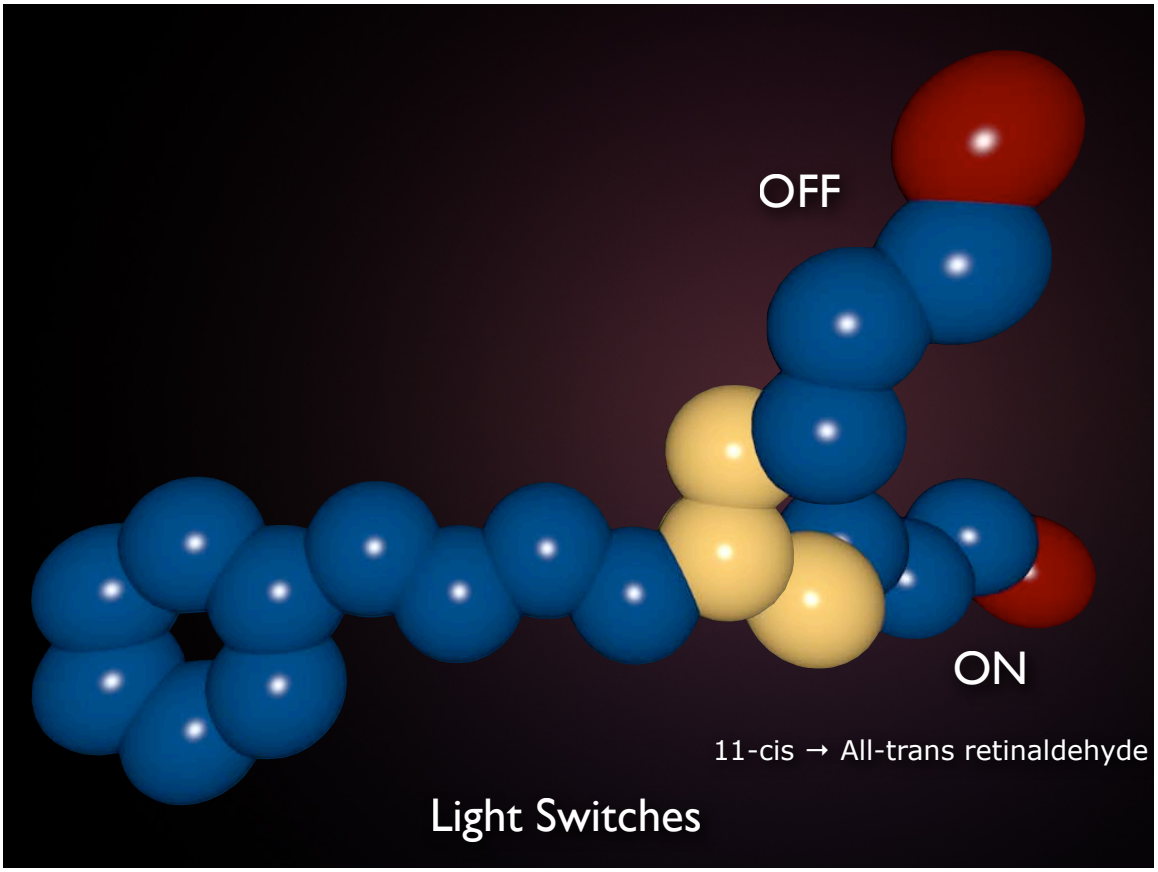
$$\lambda\nu = c$$
$$E = h\nu$$
$$E = mc^2$$
$$\lambda = h/p$$

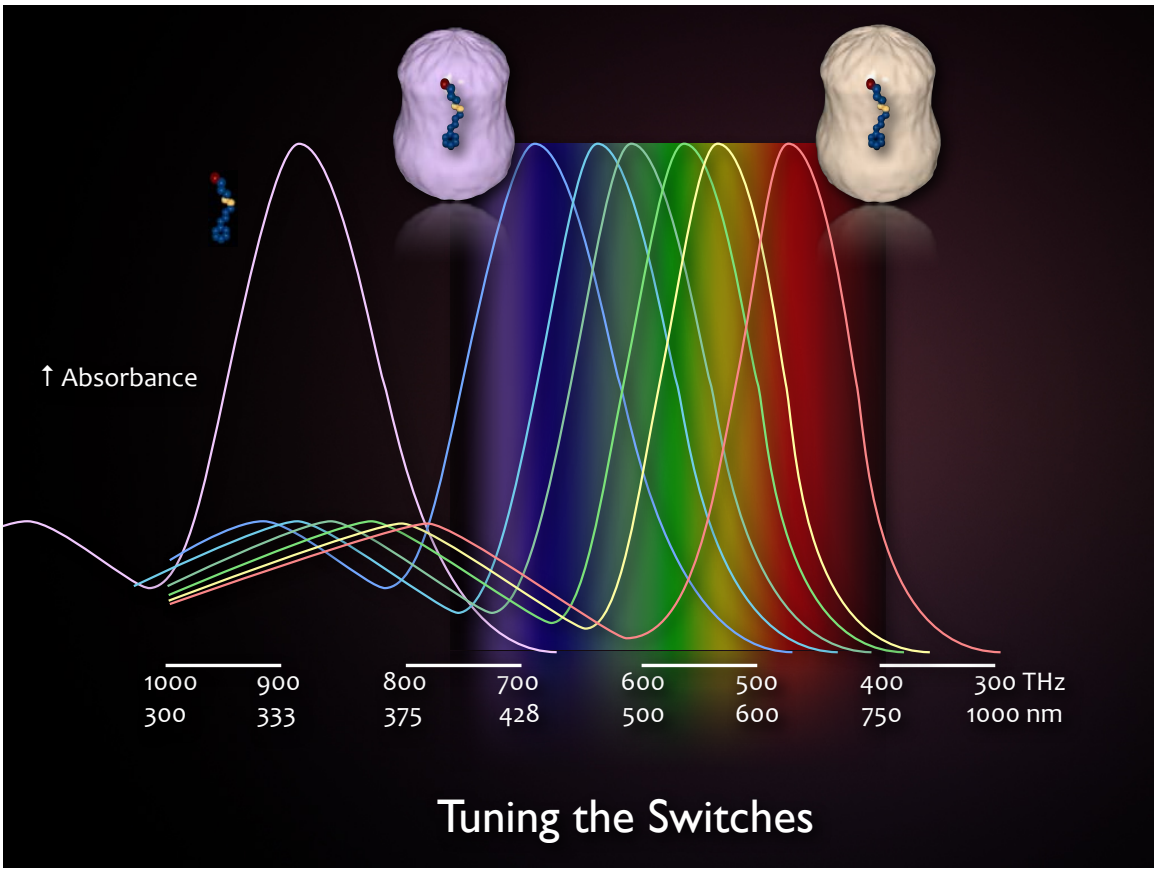


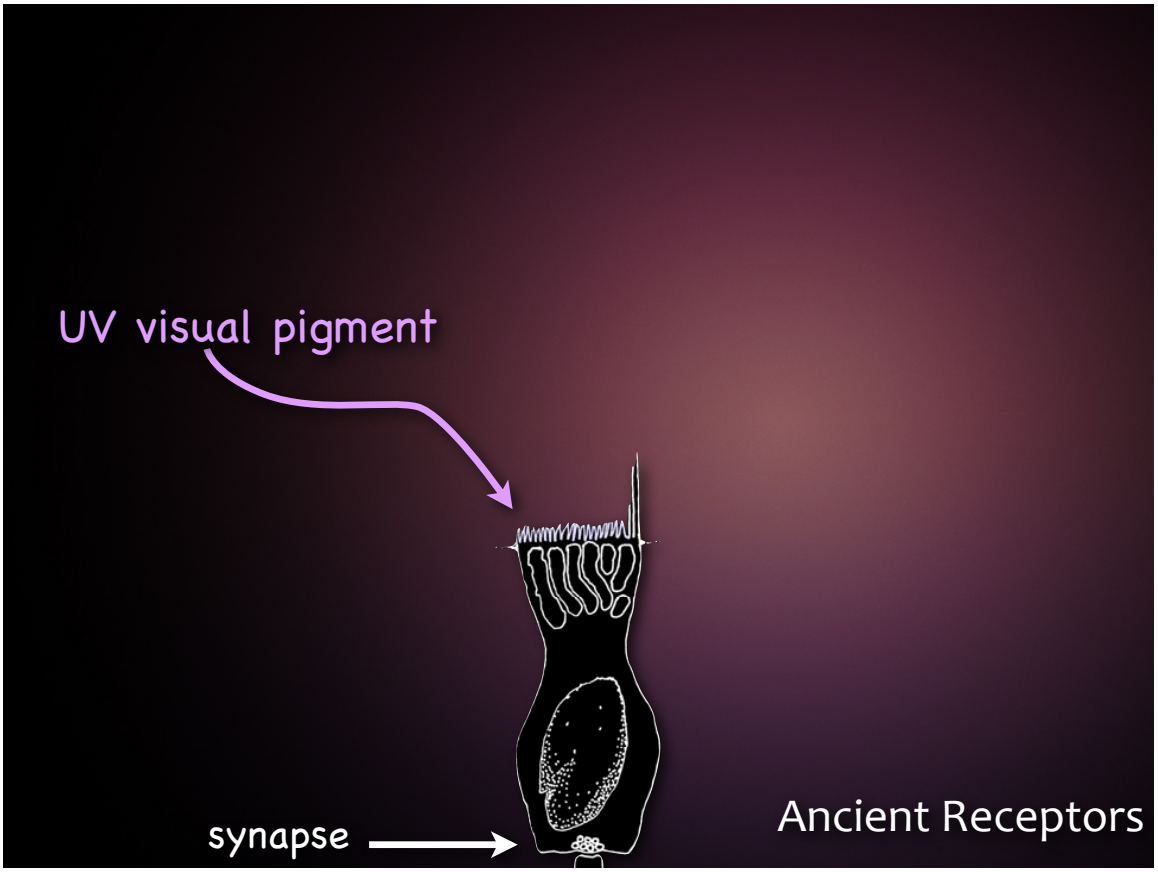
Schrödinger Equation

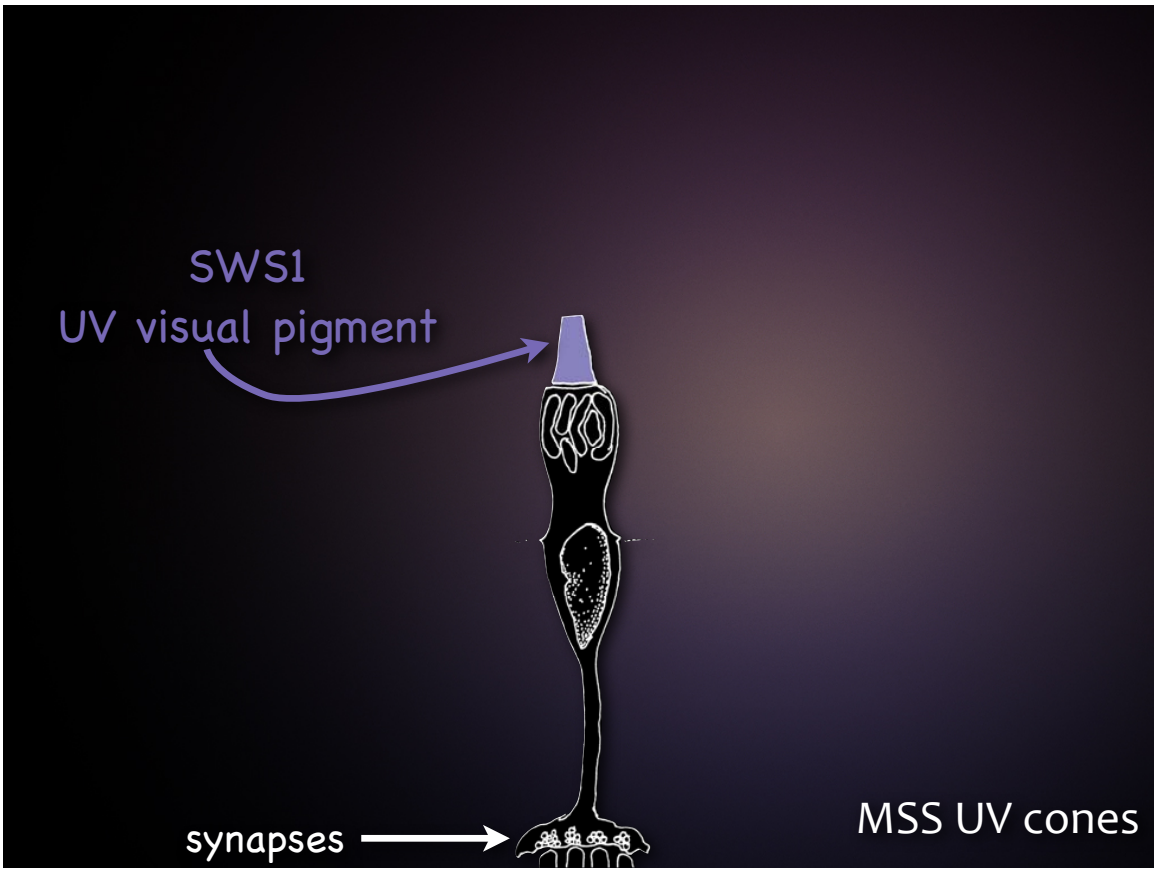
Light , Energy & Matter

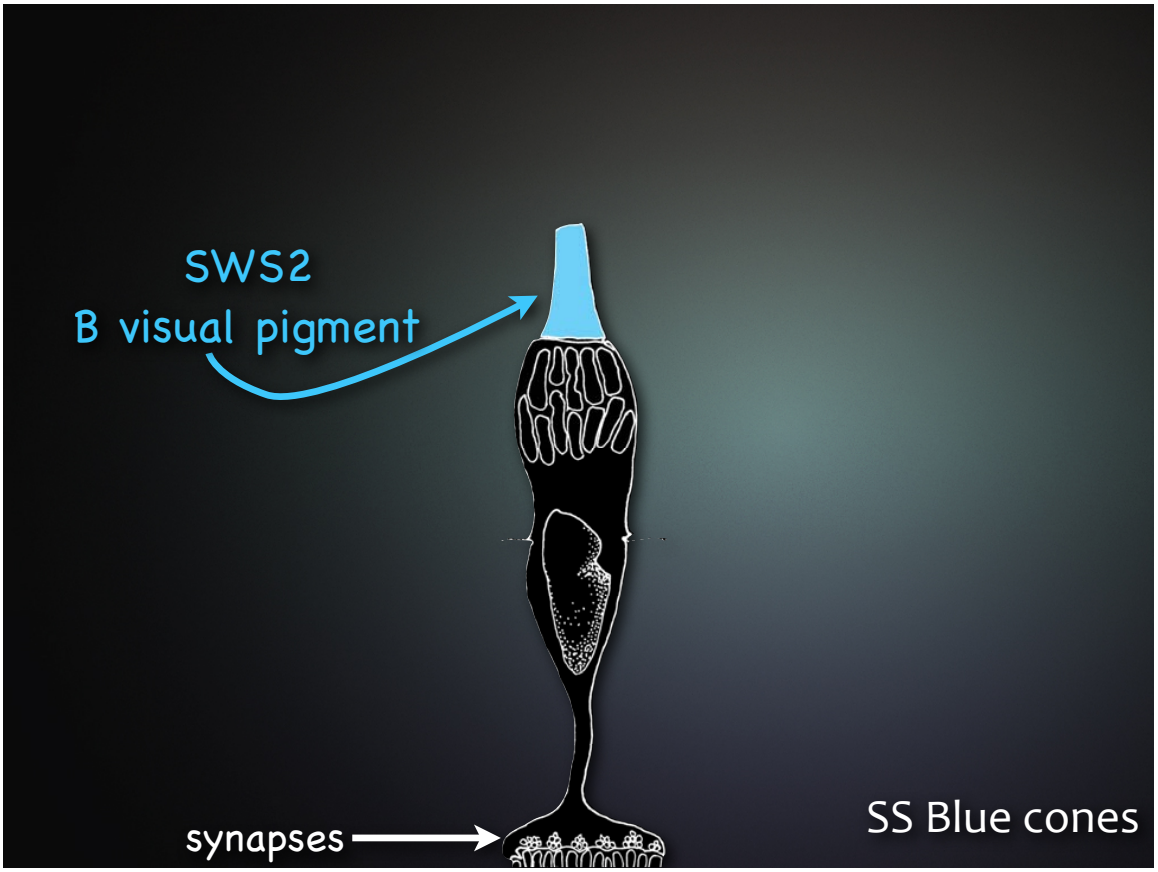
photonic molecular switches

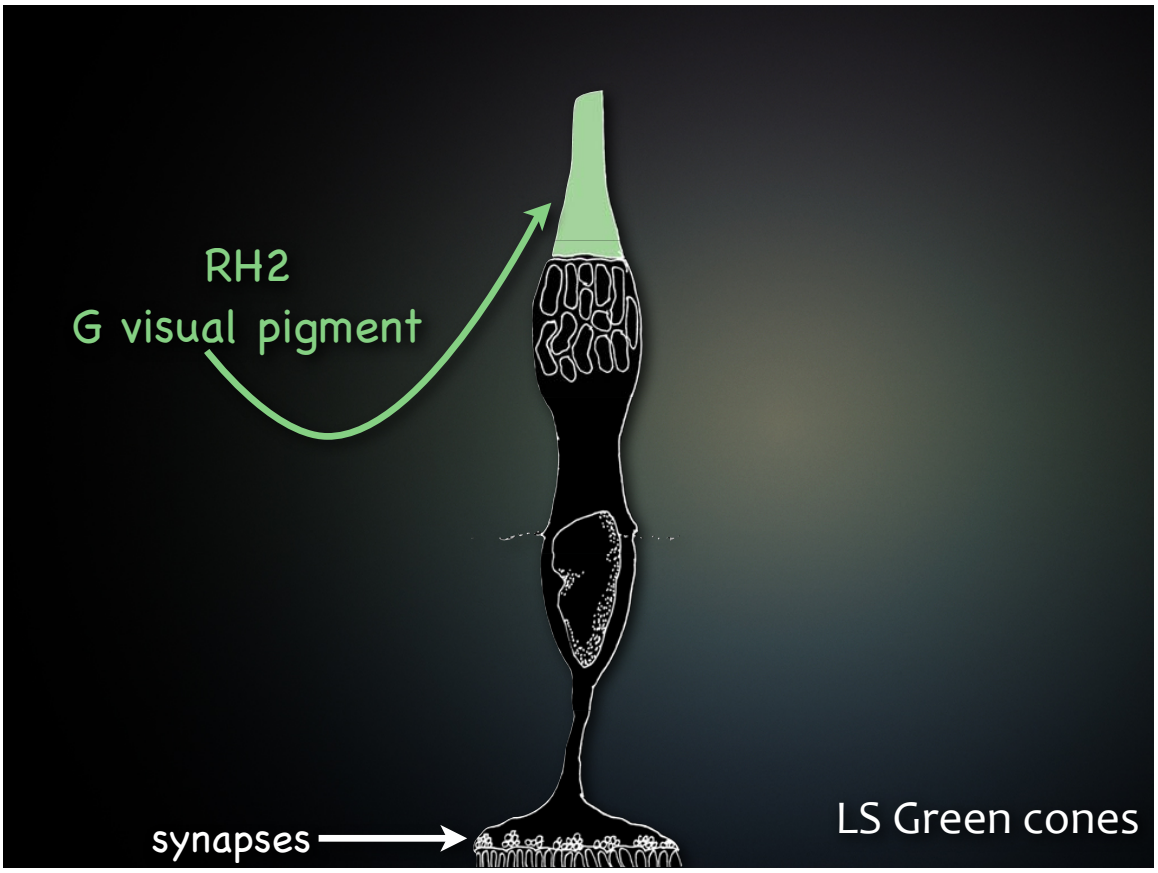


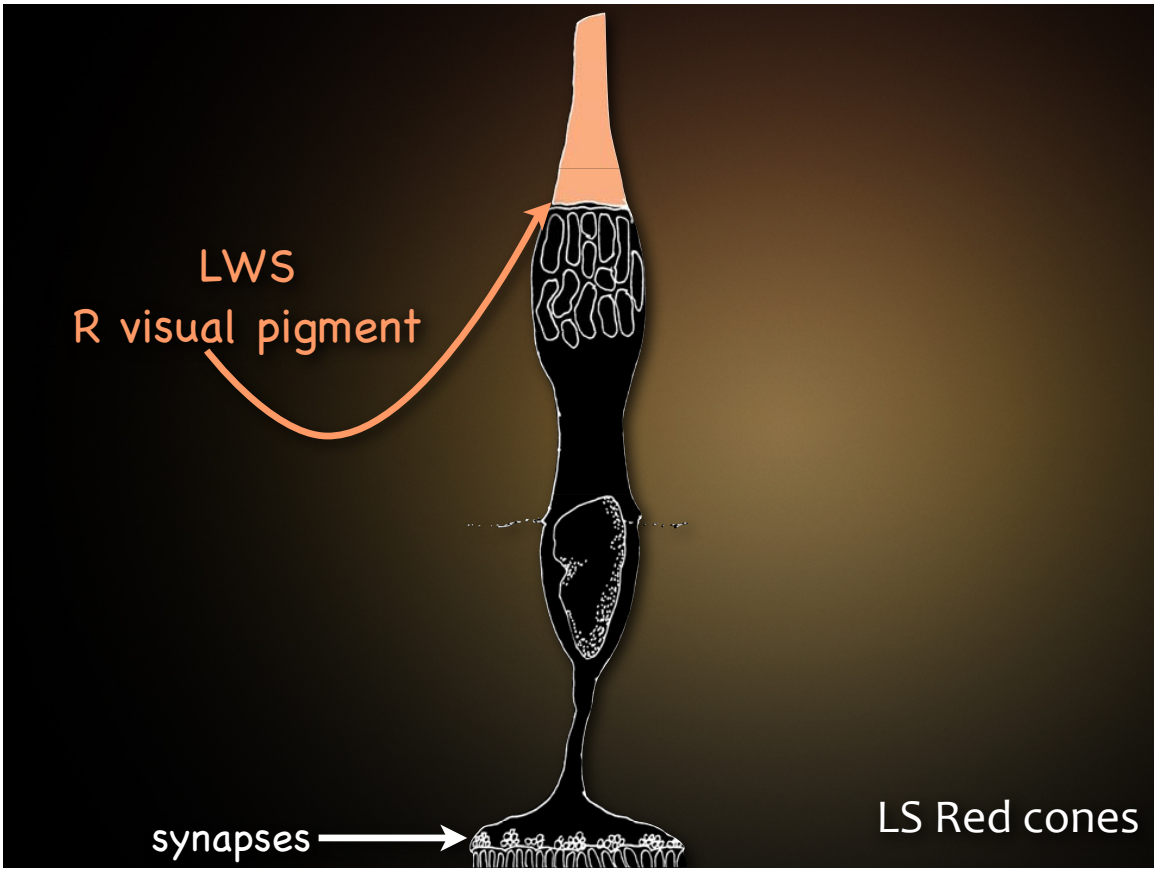

↑ Absorbance
1000 900 800 700 600 500 400 300 THz
300 333 375 428 500 600 750 1000 nm
Tuning the Switches

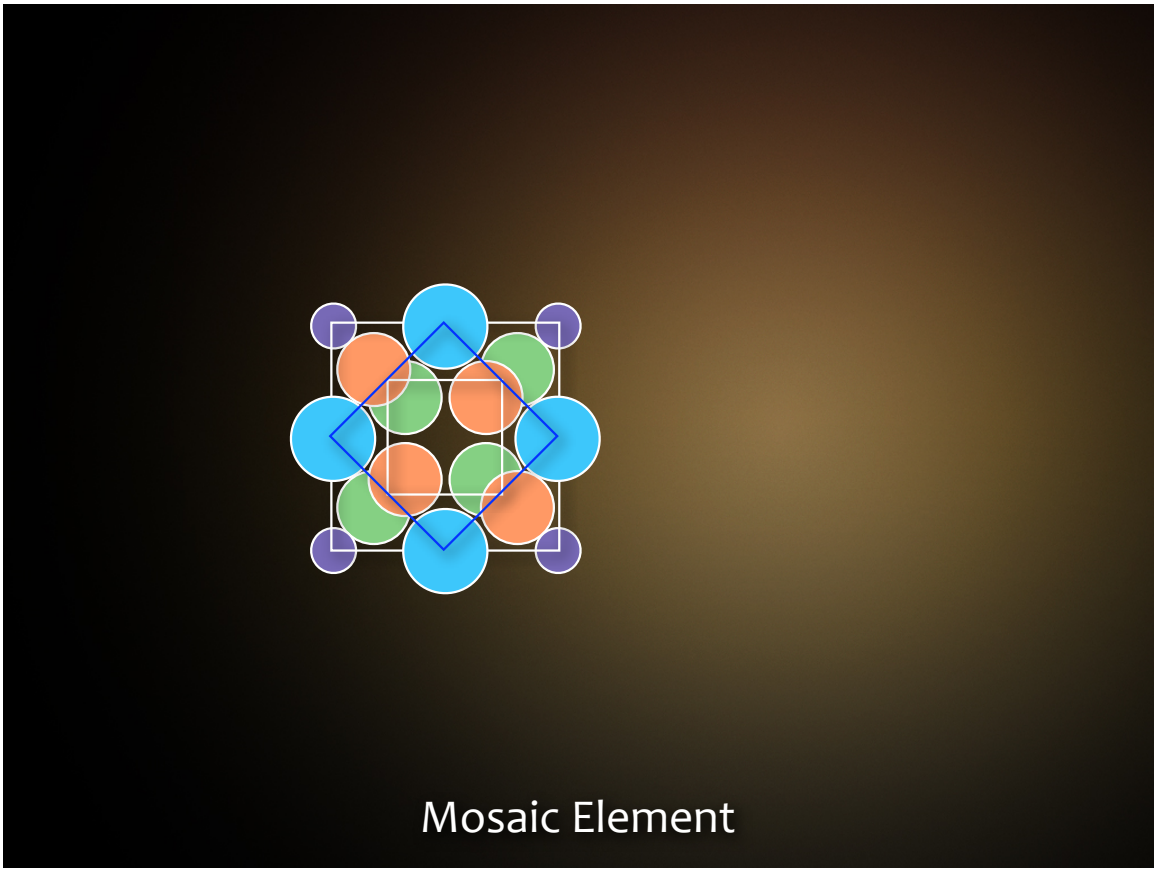

UV visual pigment
synapse
Ancient Receptors

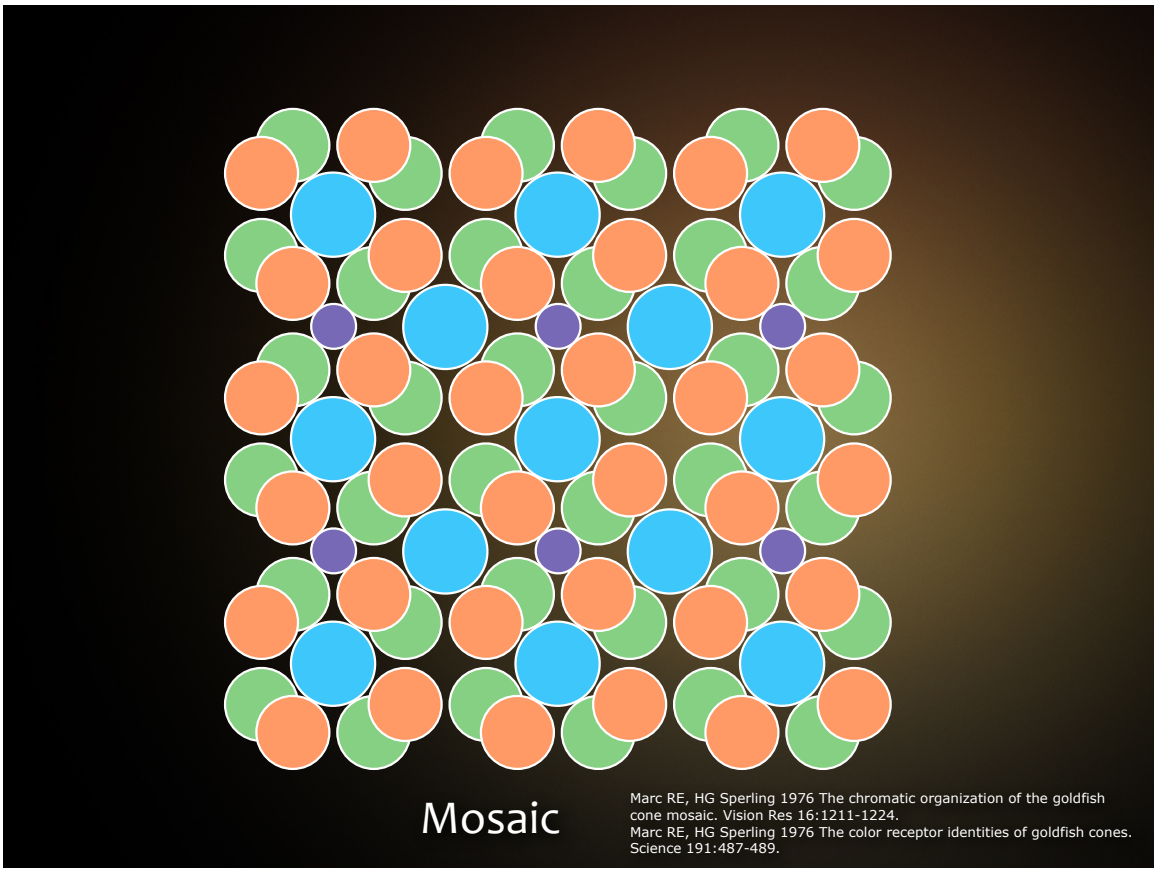

SWS1
UV visual pigment
synapses
MSS UV cones

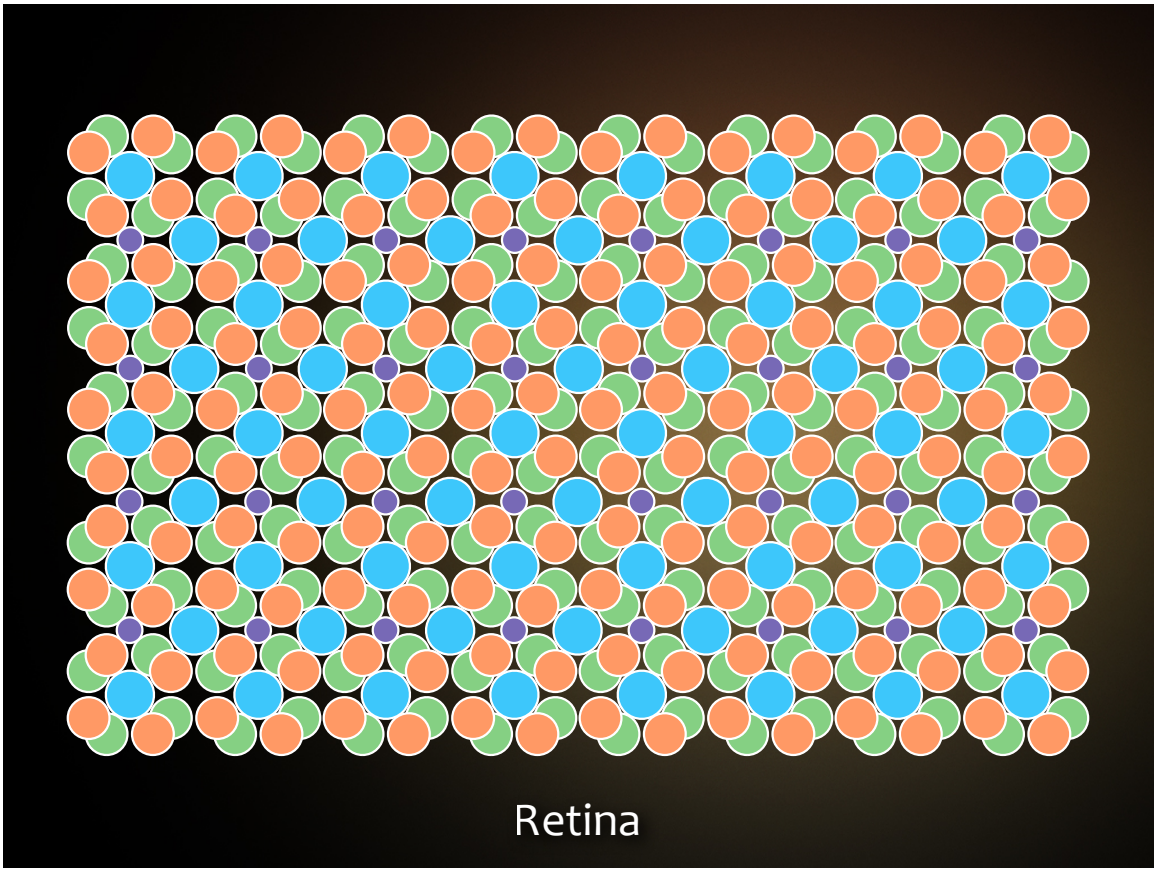

SWS2
B visual pigment
synapses
SS Blue cones

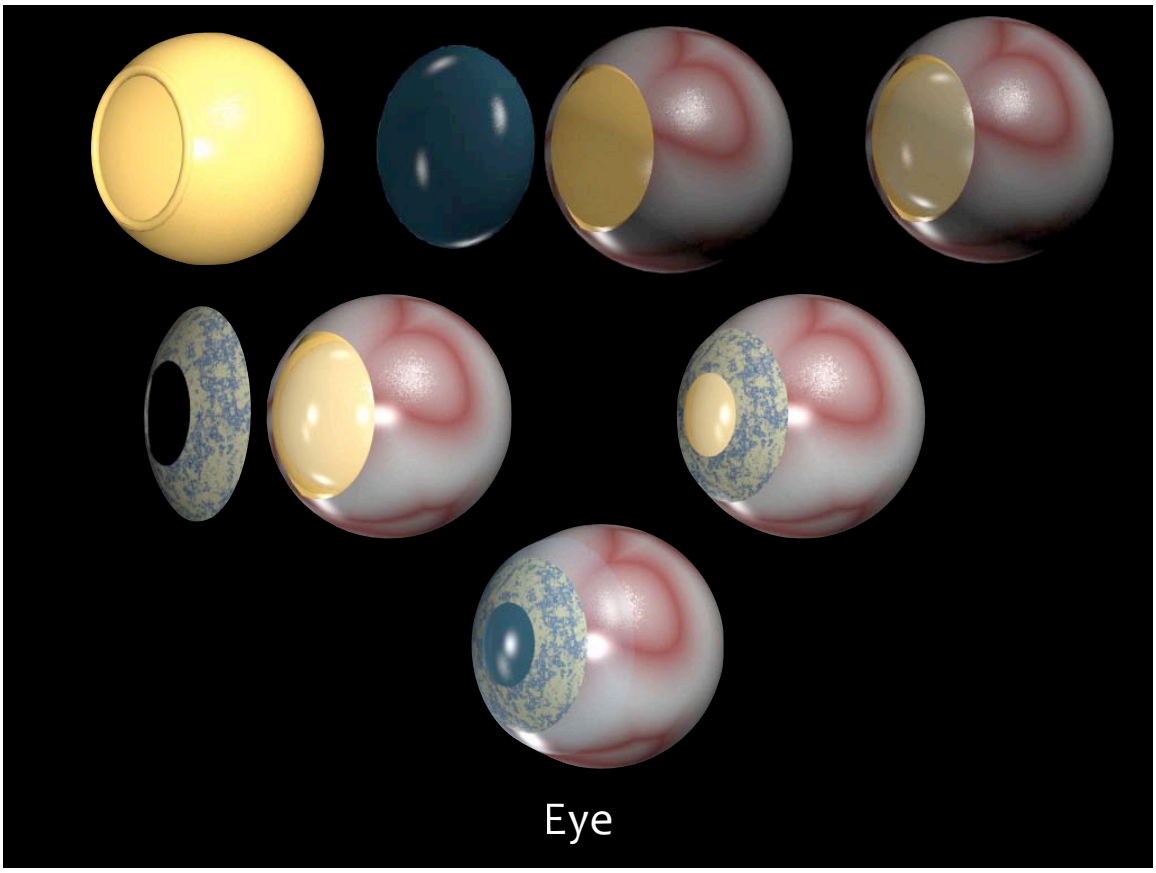

RH2
G visual pigment
synapses
LS Green cones

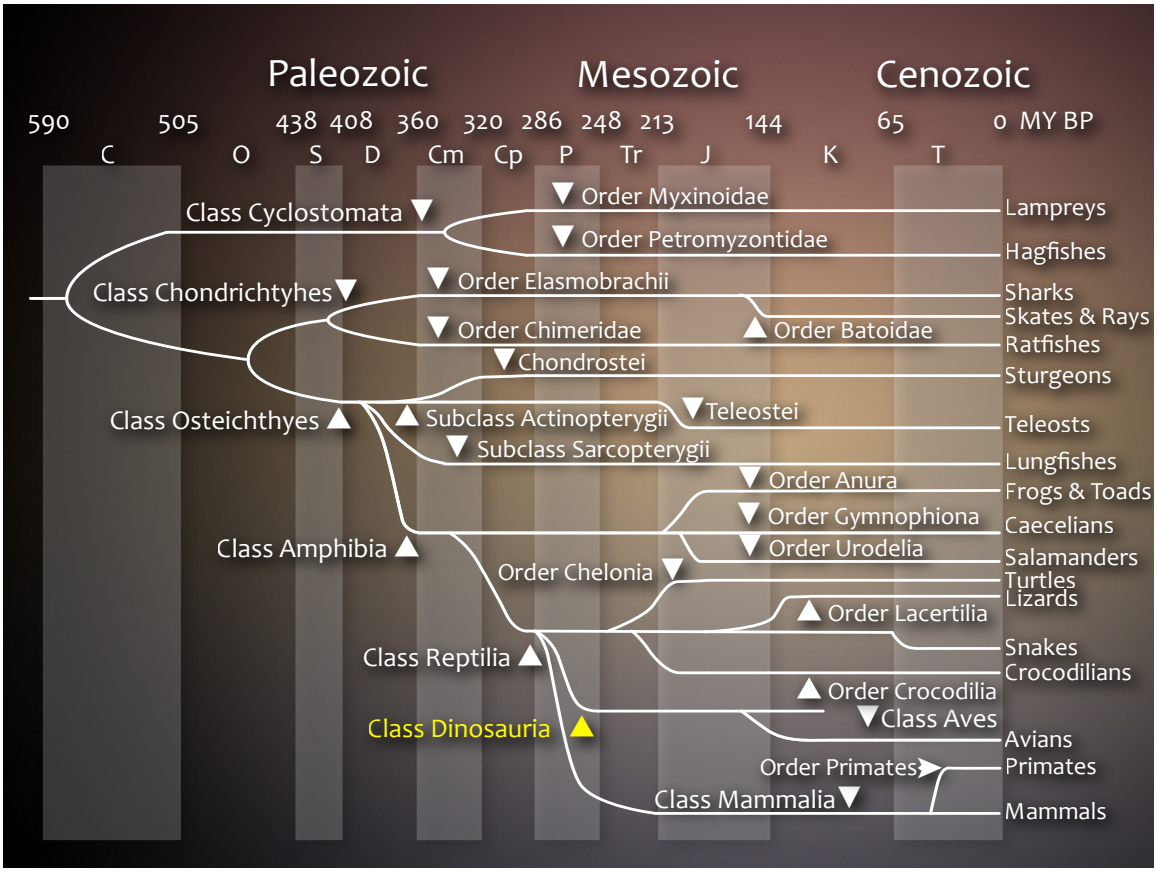

LWS
R visual pigment
synapses
LS Red cones


Mosaic Element


Mosaic
Marc RE, HG Sperling 1976 The chromatic organization of the goldfish cone mosaic. Vision Res 16:1211-1224.
Marc RE, HG Sperling 1976 The color receptor identities of goldfish cones. Science 191:487-489.


Retina


Eye


Paleozoic
Mesozoic
Cenozoic
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0 MY BP
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D
Cm
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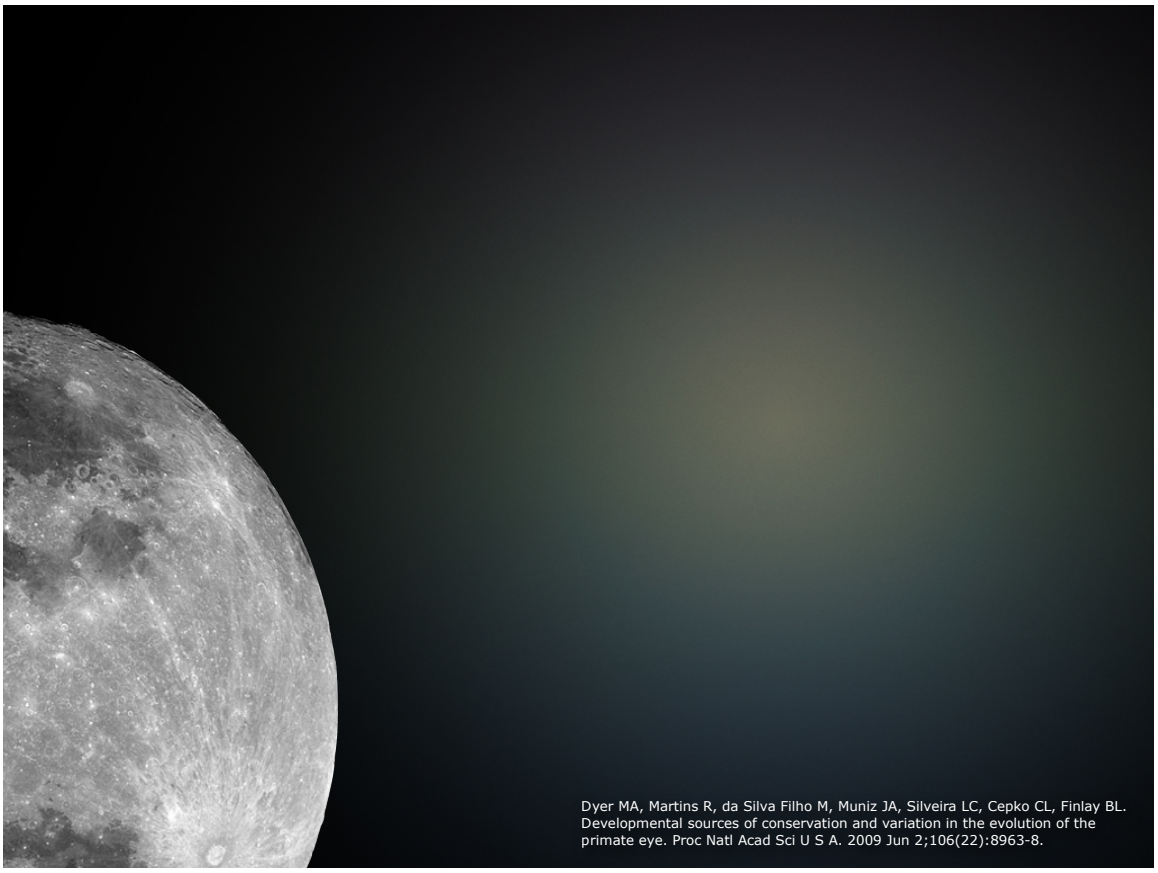
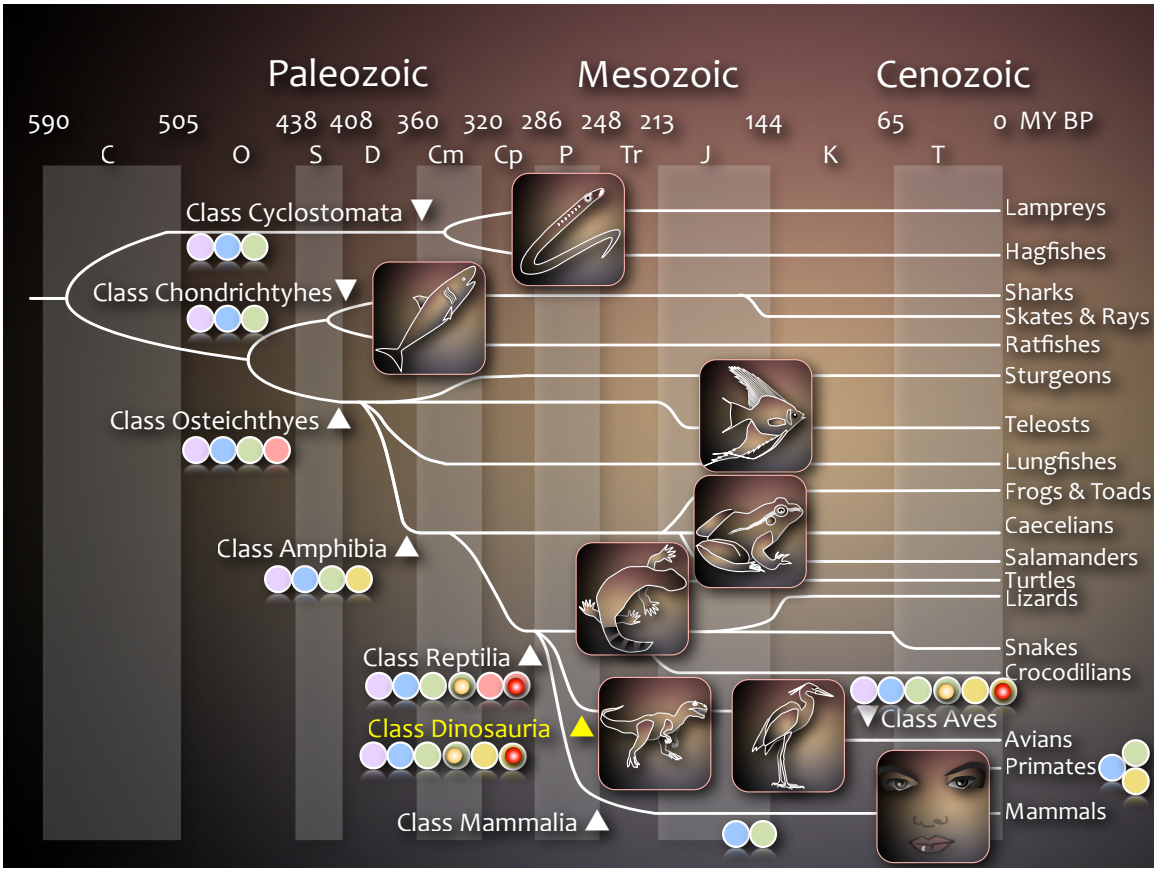
K
T
Class Cyclostomata
Order Myxinoidae
Order Petromyzontidae
Lampreys
Hagfishes
Class Chondrichtyhes
Order Elasmobrachii
Order Chimeridae
Order Batoidae
Chondrostei
Sharks
Skates & Rays
Ratfishes
Sturgeons
Class Osteichthyes
Subclass Actinopterygii
Teleostei
Subclass Sarcopterygii
Teleosts
Lungfishes
Class Amphibia
Order Anura
Order Gymnophiona
Order Urodelia
Frogs & Toads
Caecelians
Salamanders
Order Chelonia
Turtles
Order Lacertilia
Lizards
Snakes
Class Reptilia
Crocodilians
Order Crocodilia
Class Aves
Class Dinosauria
Avians
Order Primates
Primates
Class Mammalia
Mammals


Dyer MA, Martins R, da Silva Filho M, Muniz JA, Silveira LC, Cepko CL, Finlay BL. Developmental sources of conservation and variation in the evolution of the primate eye. Proc Natl Acad Sci U S A. 2009 Jun 2;106(22):8963-8.


Paleozoic
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Class Cyclostomata
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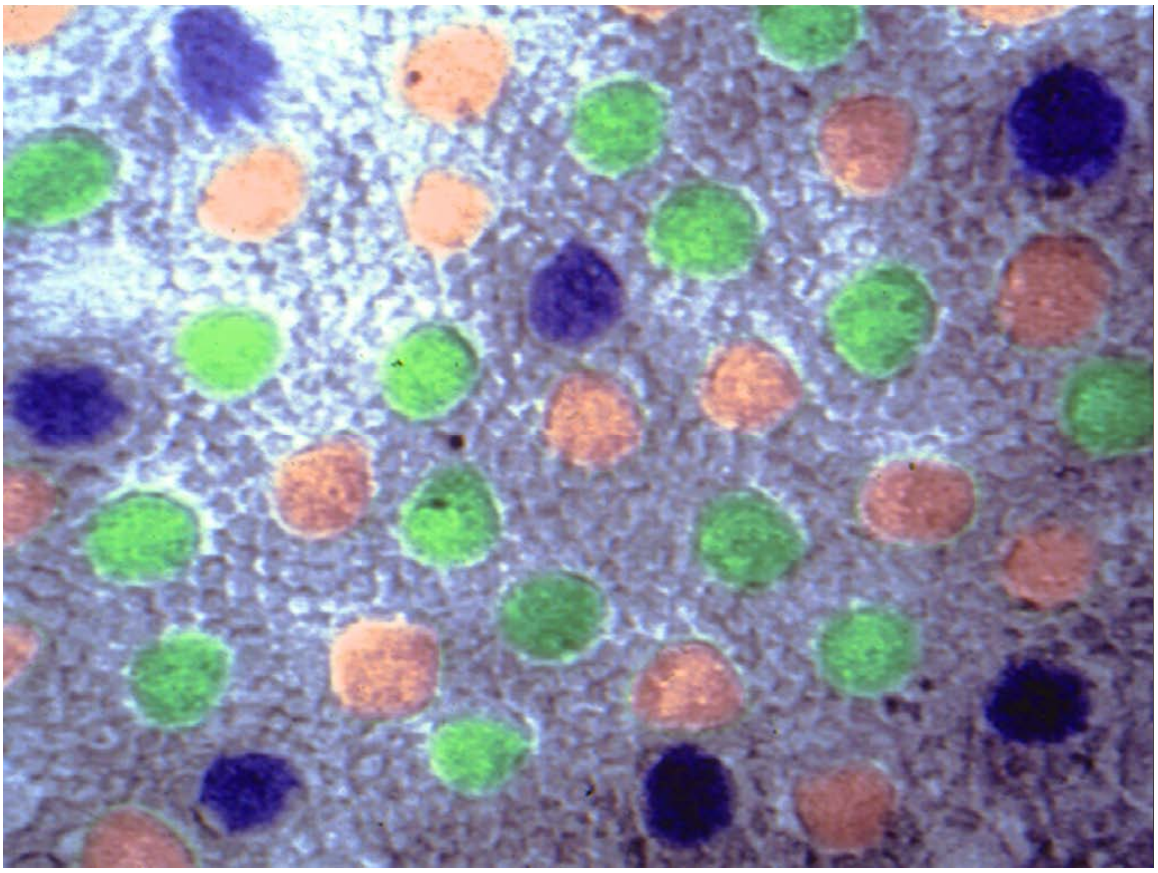
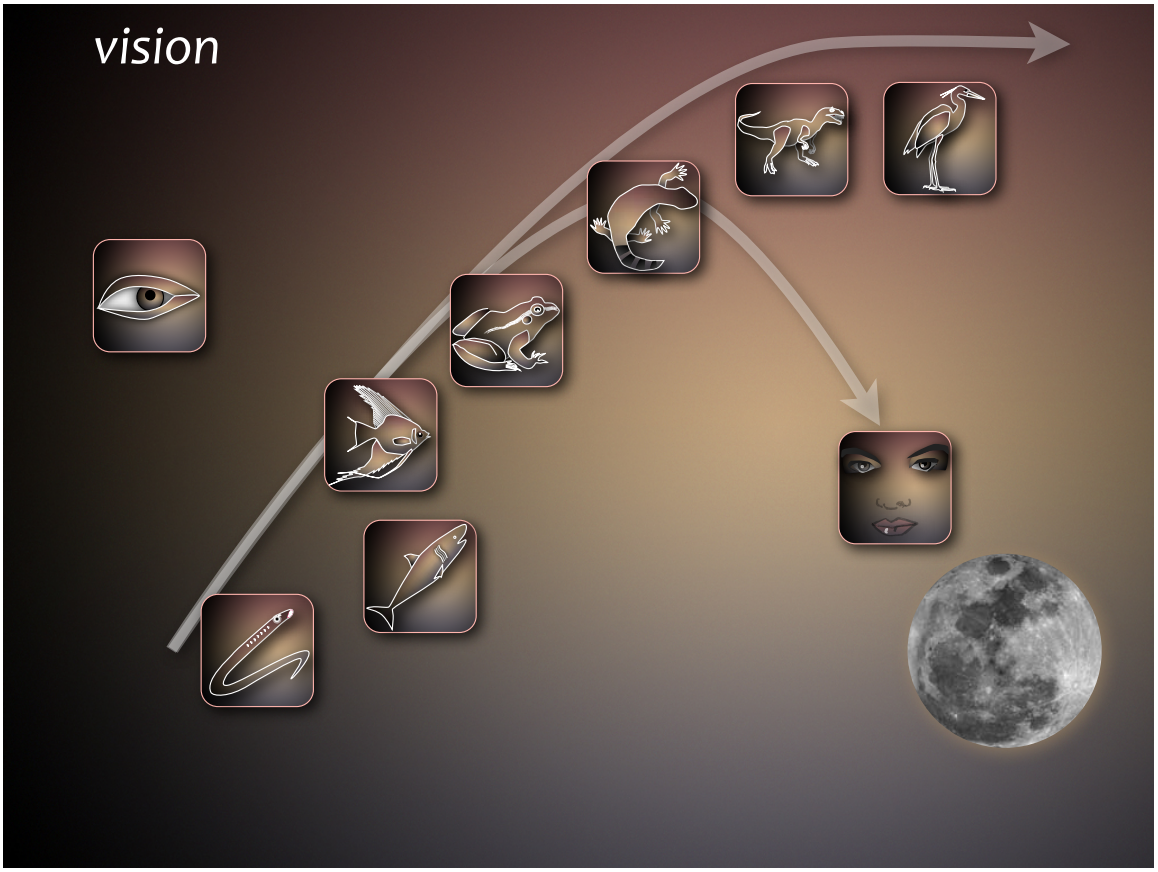
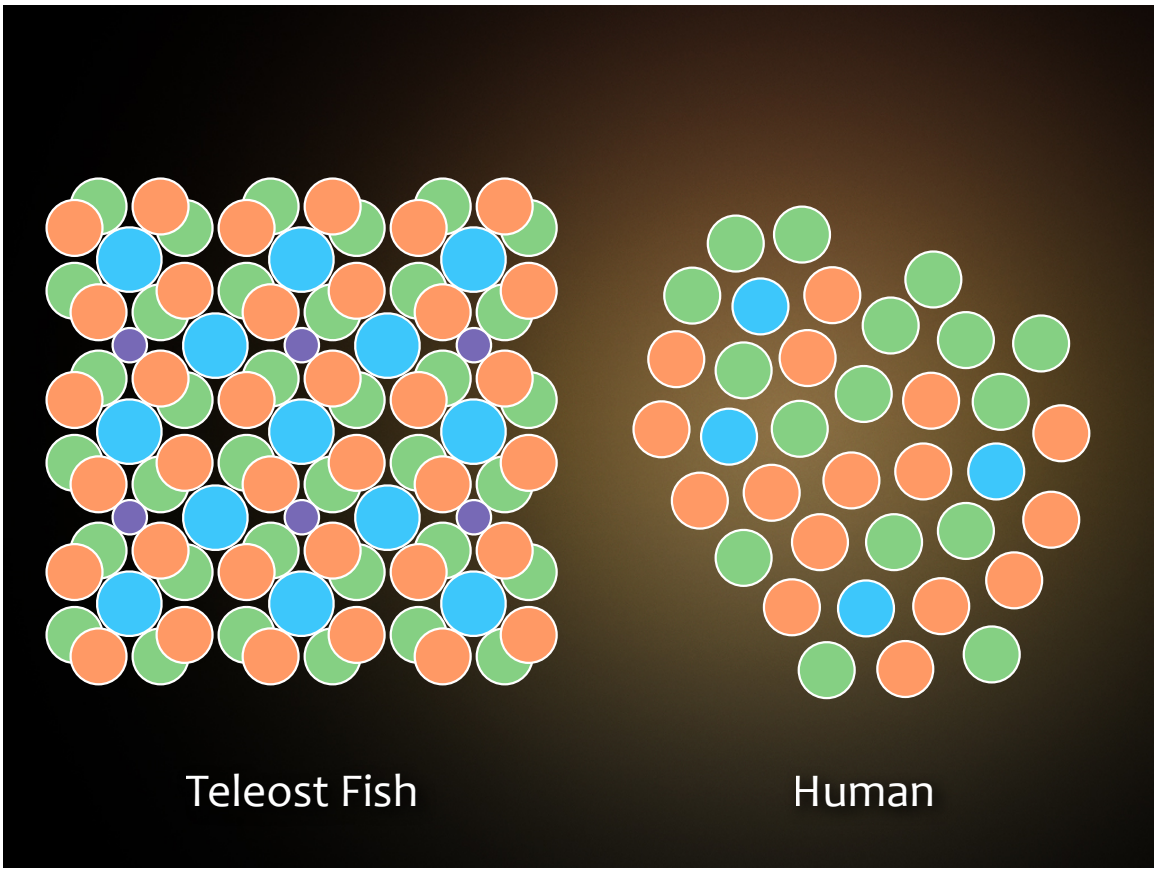
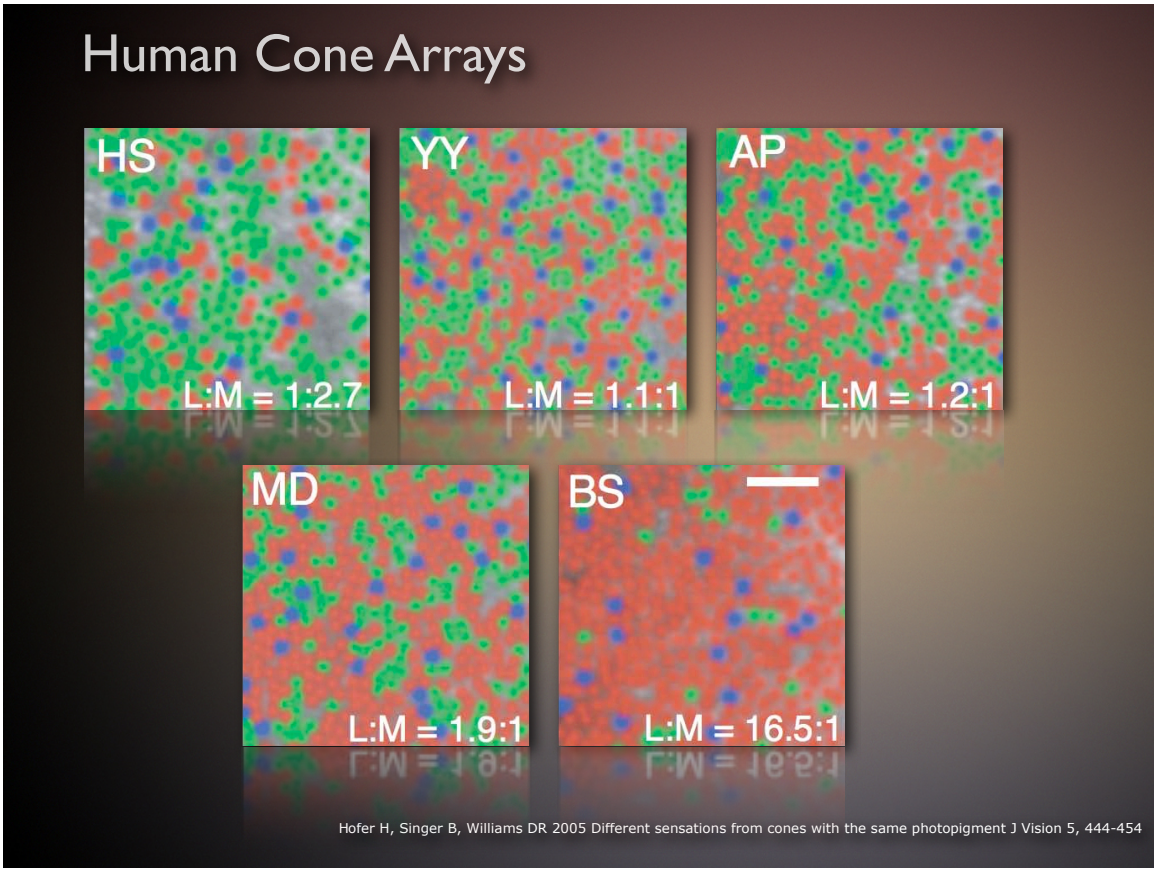
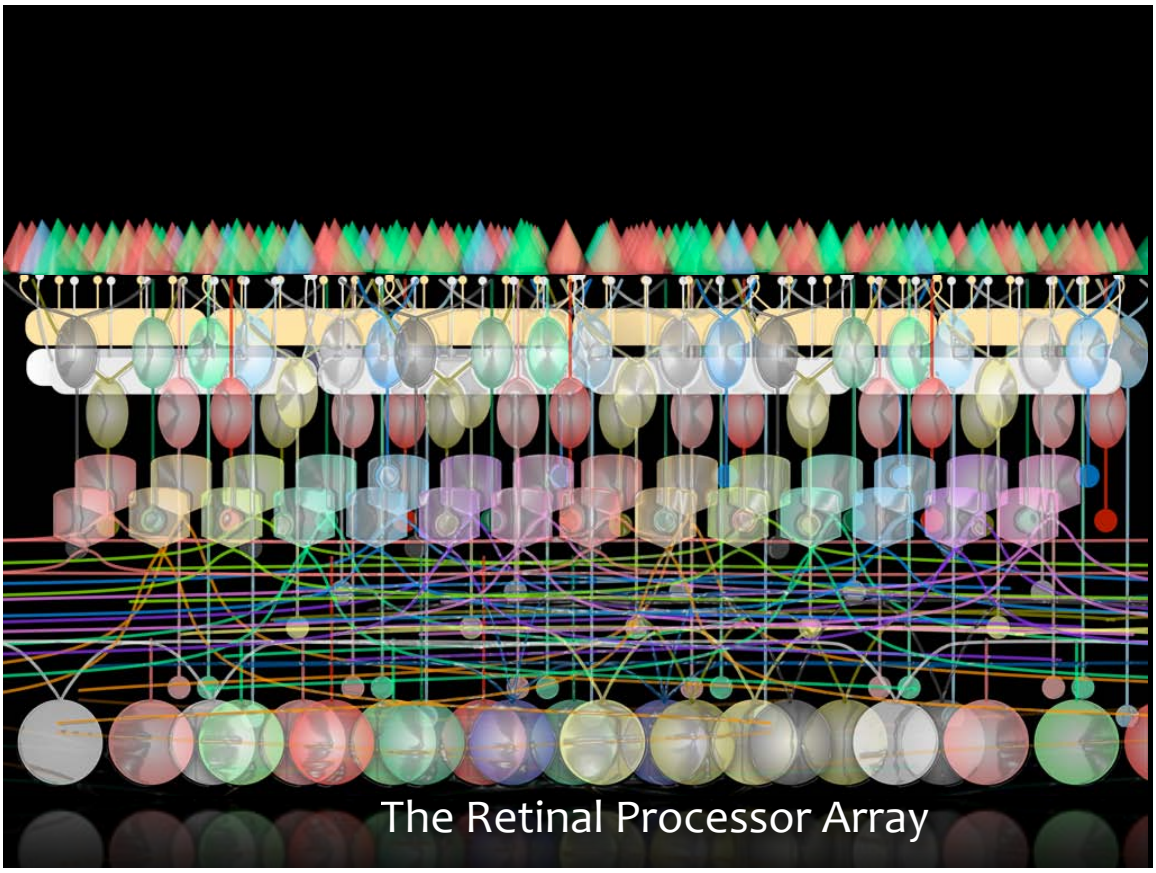
Lampreys
Hagfishes
Sharks
Skates & Rays
Ratfishes
Sturgeons
Teleosts
Lungfishes
Frogs & Toads
Caecelians
Salamanders
Turtles
Lizards
Snakes
Crocodilians
Avians
Primates
Mammals




vision


Teleost Fish
Human

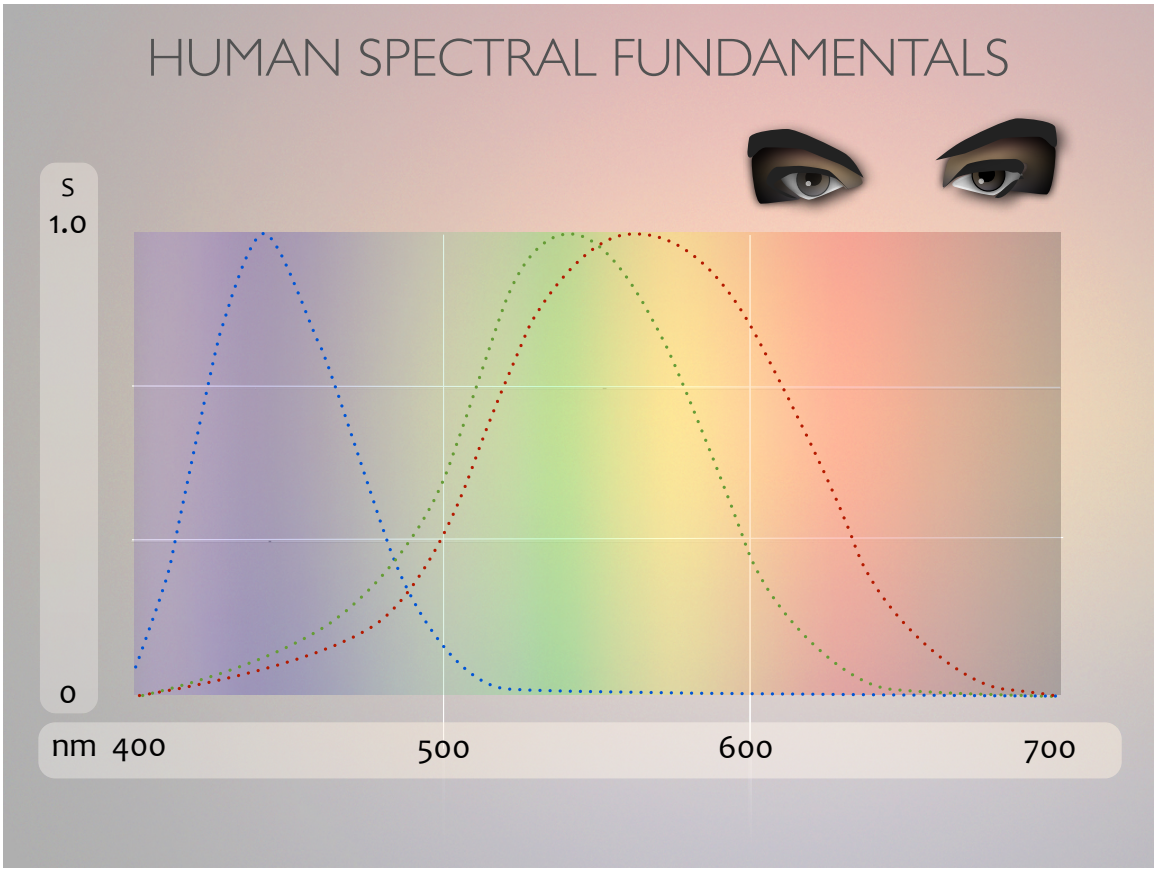

Human Cone Arrays
HS
L:M = 1:2.7
YY
L:M = 1.1:1
AP
L:M = 1.2:1
MD
L:M = 1.9:1
BS
L:M = 16.5:1
Hofer H, Singer B, Williams DR 2005 Different sensations from cones with the same photopigment J Vision 5, 444-454

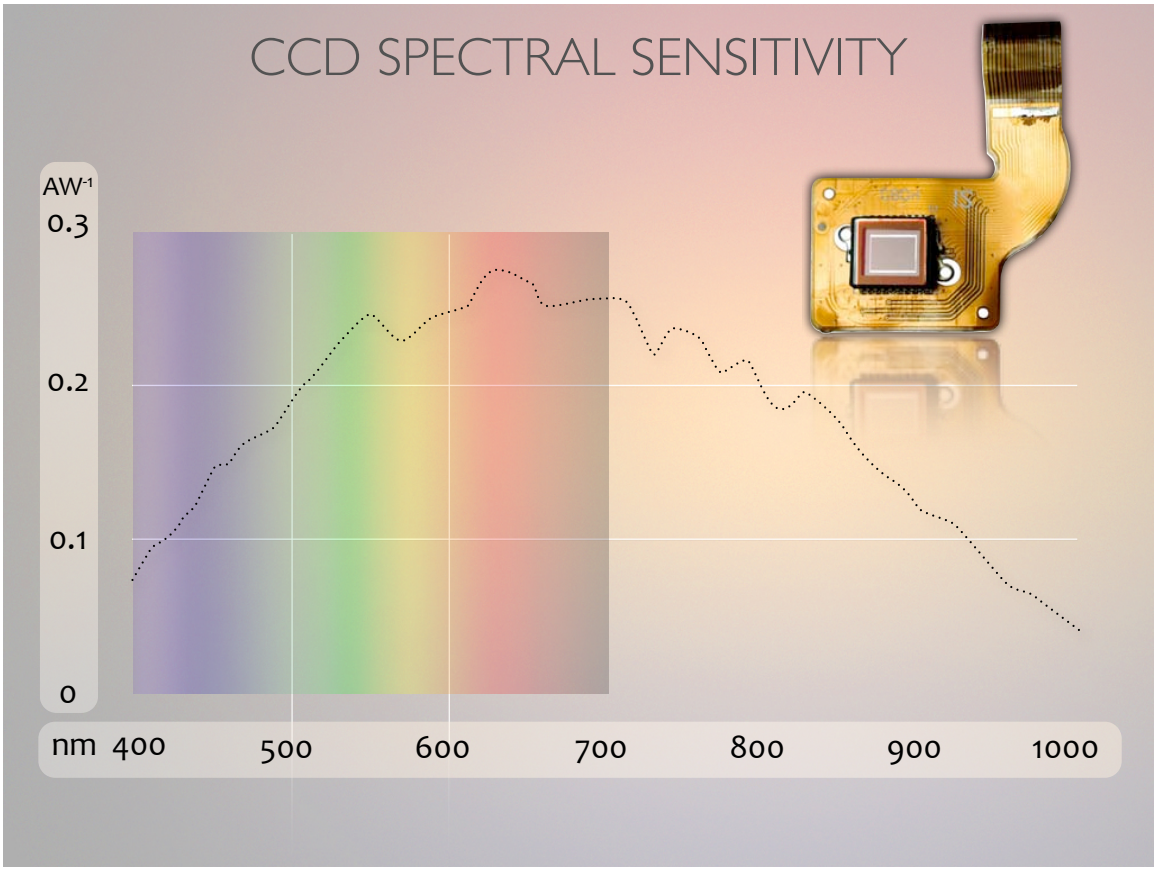


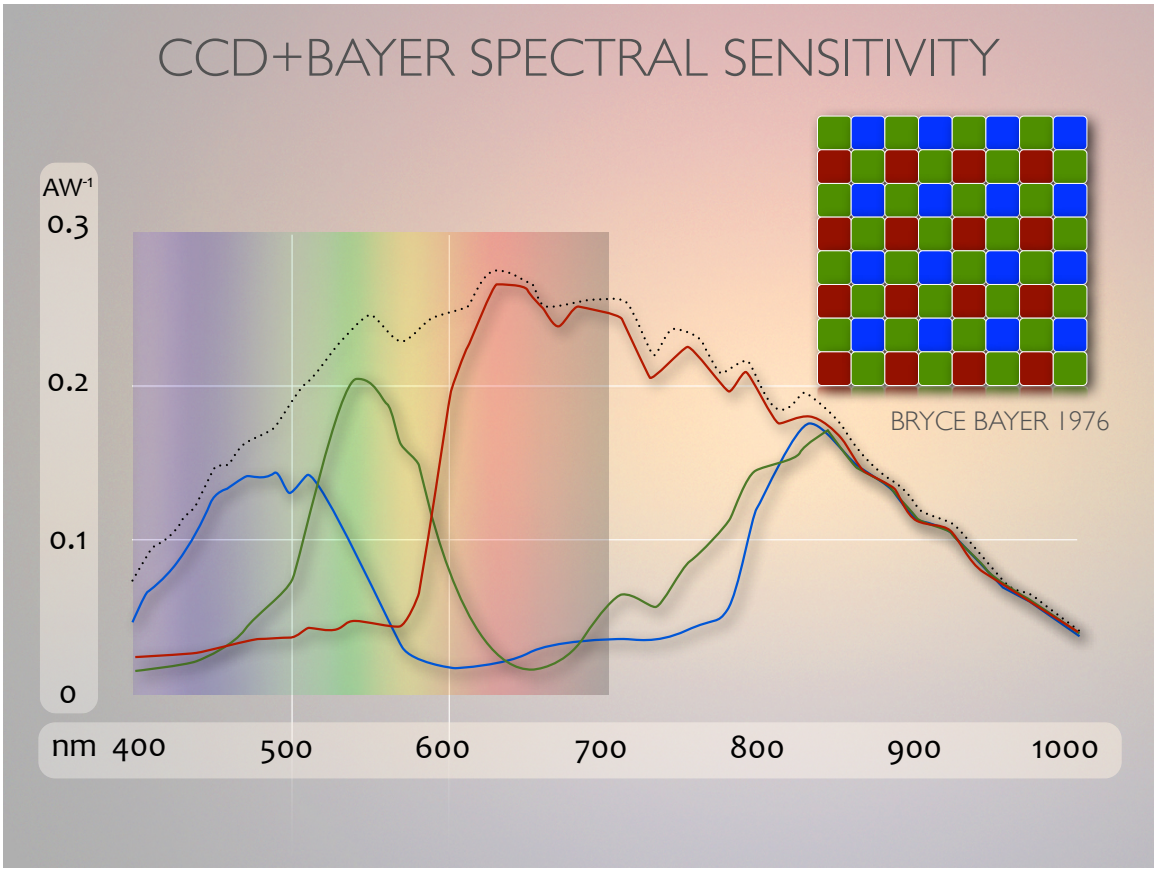
the eye is not a camera
or a 50 mm lens

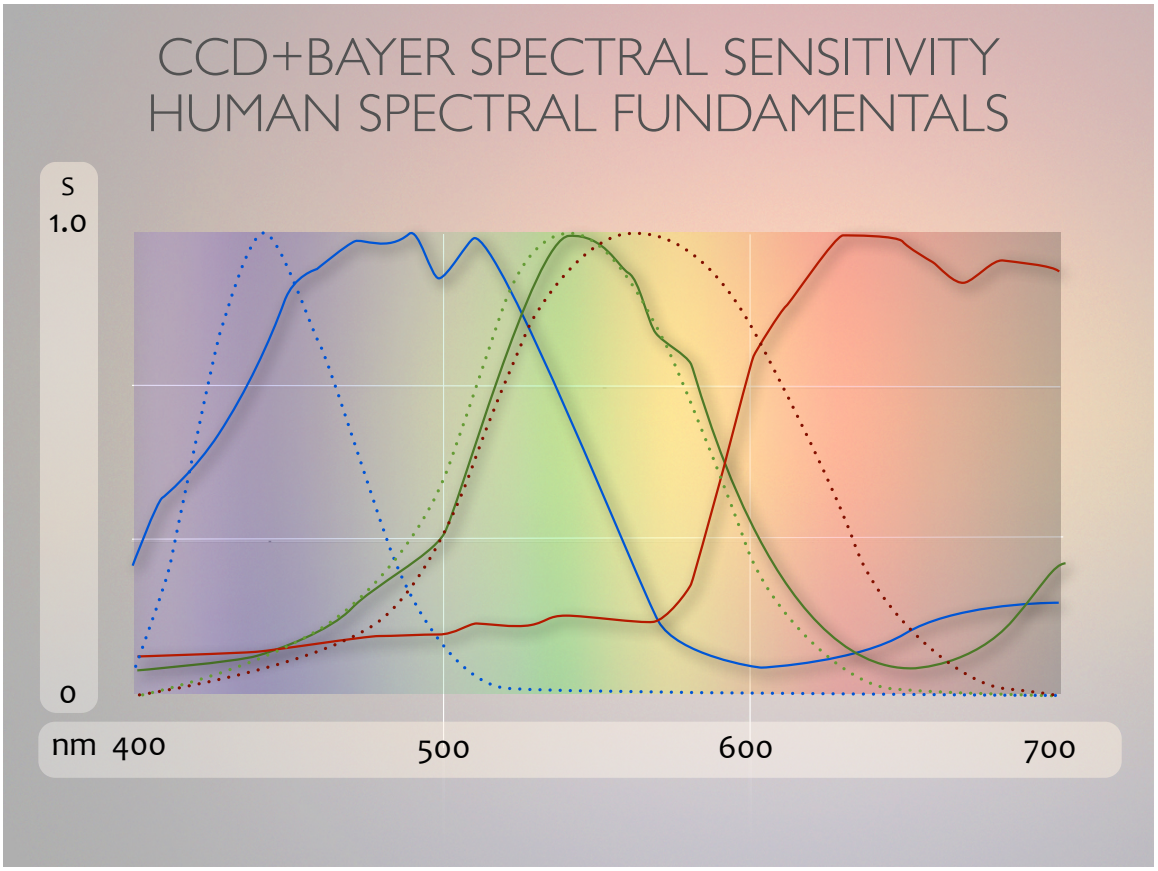
it is an
asynchronous, updating,
multichannel,
streaming,
discrete analogue
sensor and
compute array

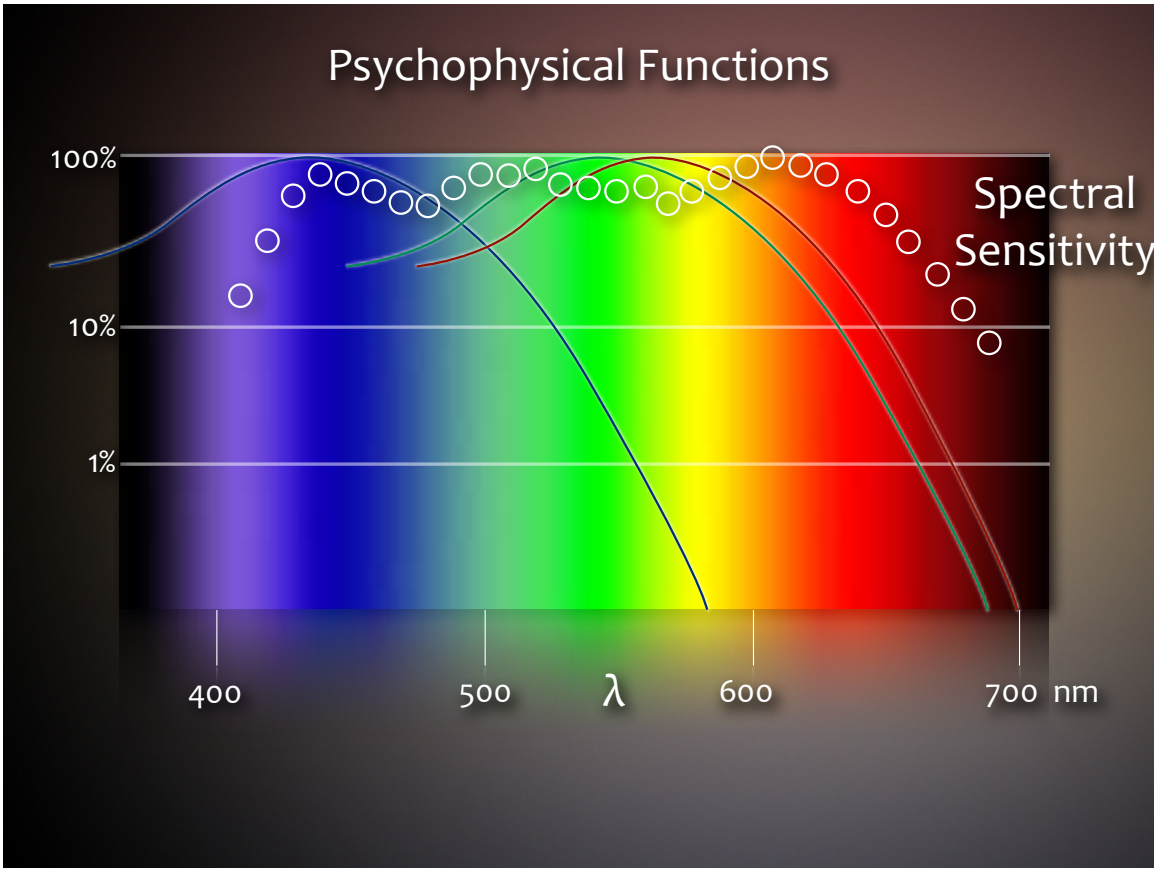
spectral sensor arrays

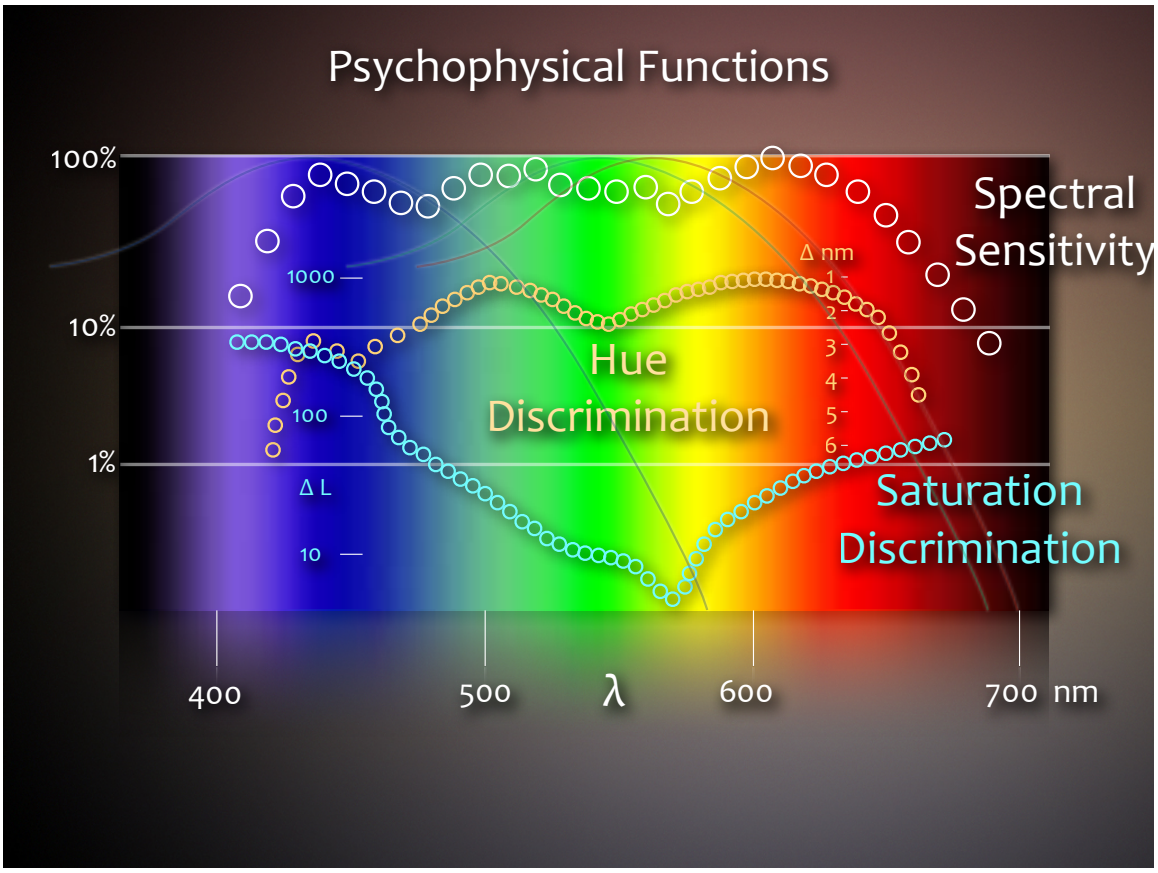


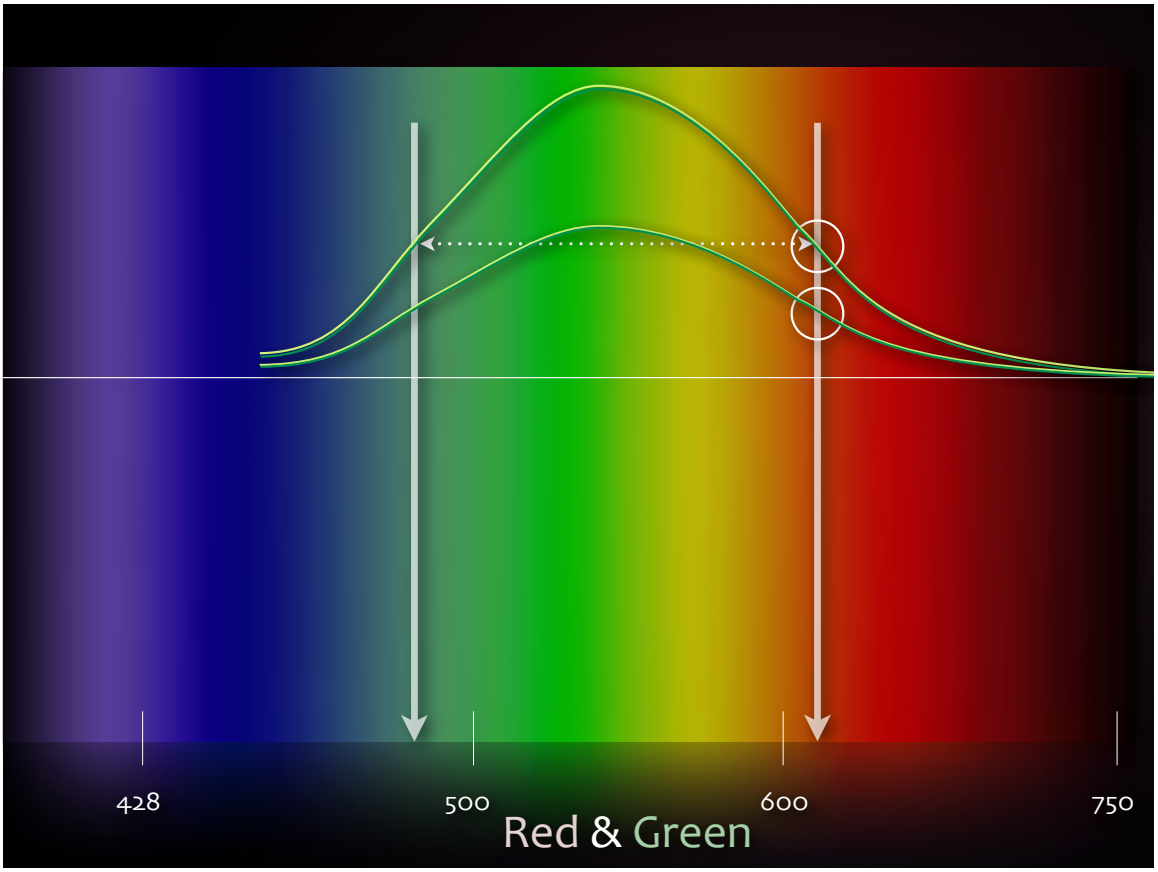

CCD SPECTRAL SENSITIVITY
AW-1
0.3
0.2
0.1
0
nm 400 500 600 700 800 900 1000

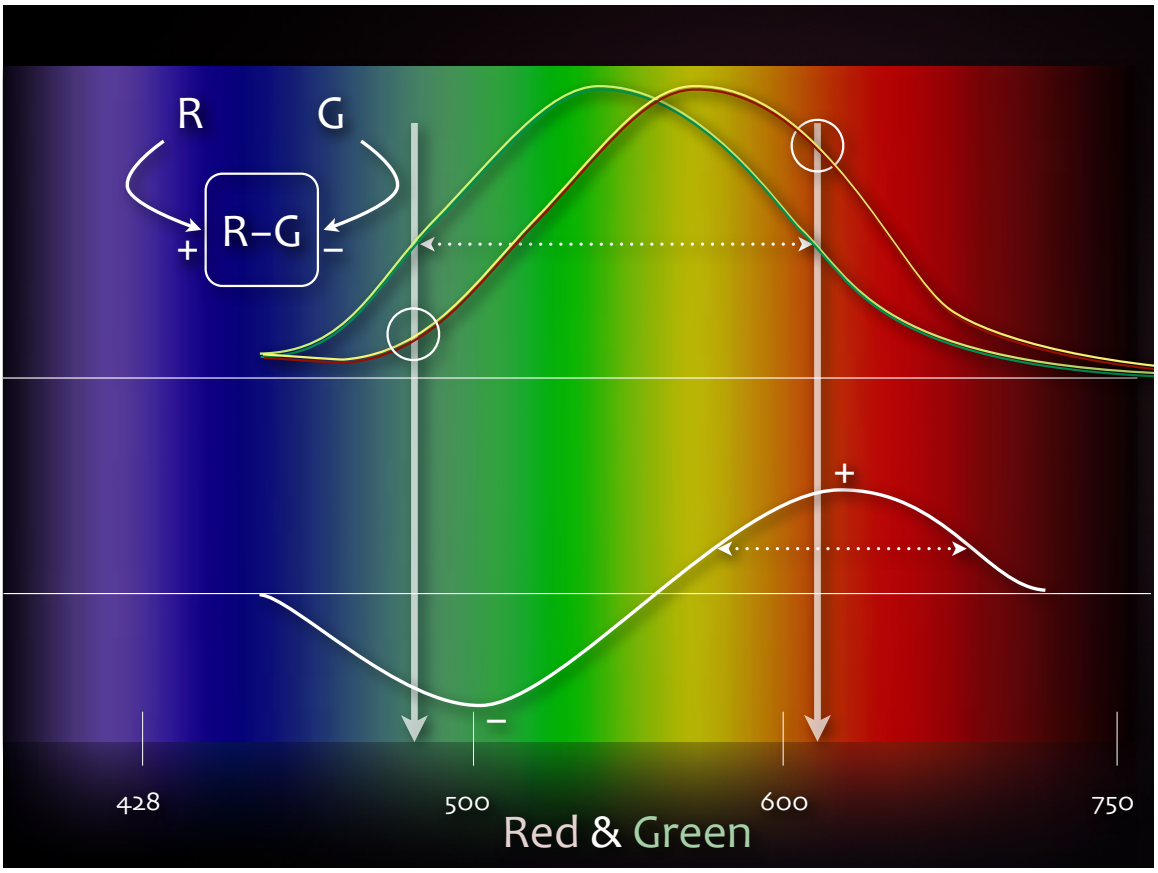

CCD+BAYER SPECTRAL SENSITIVITY
AW-1
0.3
0.2
0.1
0
BRYCE BAYER 1976
nm 400 500 600 700 800 900 1000


CCD+BAYER SPECTRAL SENSITIVITY
HUMAN SPECTRAL FUNDAMENTALS
S
1.0
0
nm 400
500
600
700

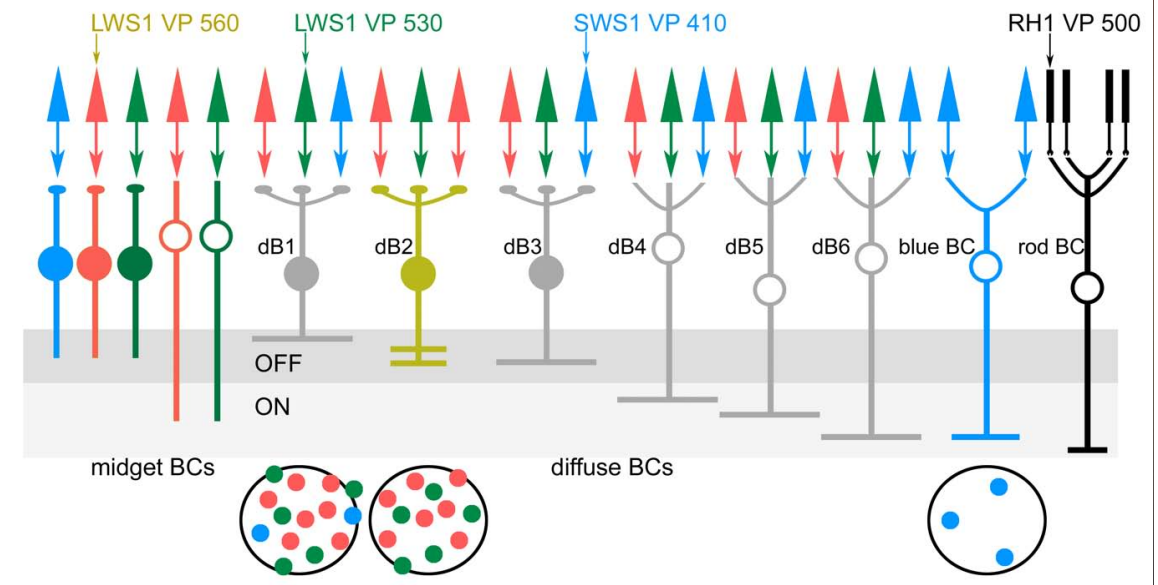

Psychophysical Functions
100%
10%
1%
Spectral
Sensitivity
400
500
λ
600
700 nm

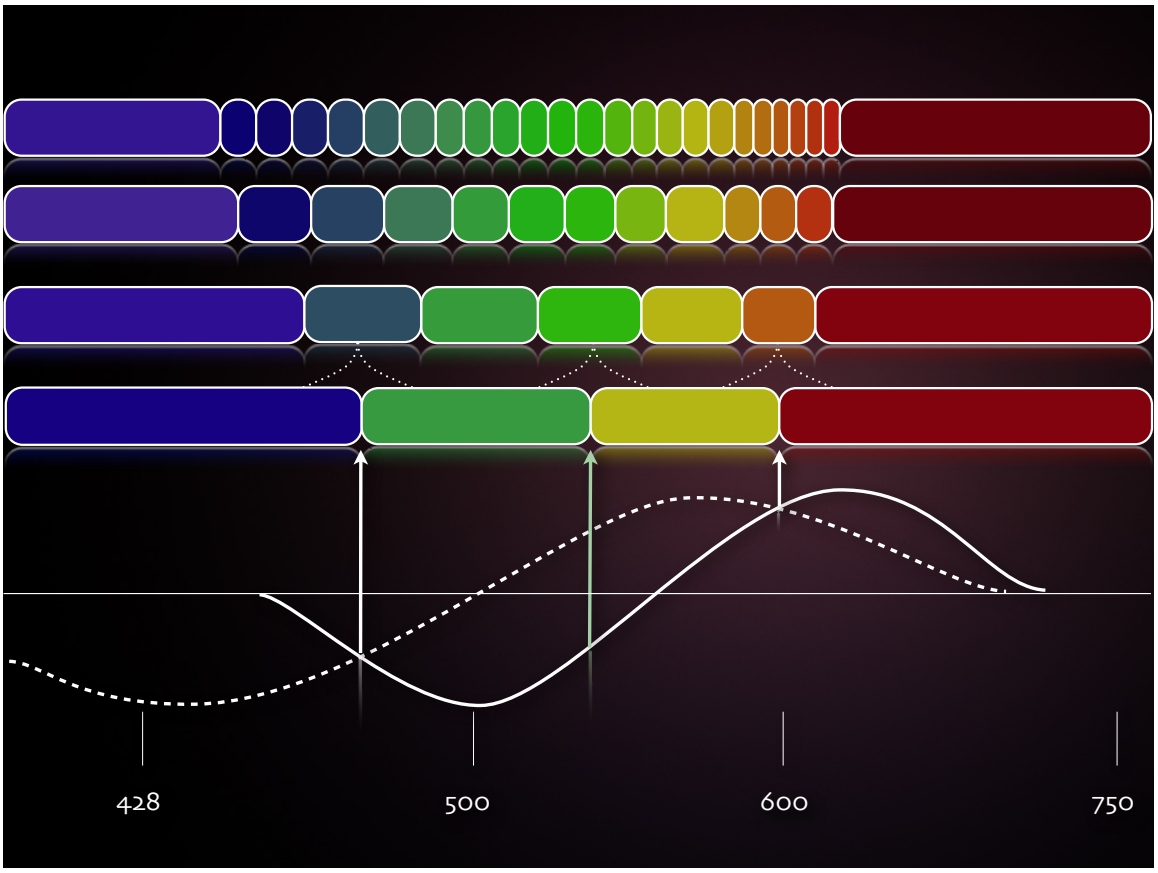

Psychophysical Functions
100%
10%
1%
Spectral
Sensitivity
1000
100
ΔL
10
Δ nm
1
2
3
4
5
6
Hue
Discrimination
Saturation
Discrimination
400
500
λ
600
700 nm


428
500
600
750
Red & Green



Primate Color Networks

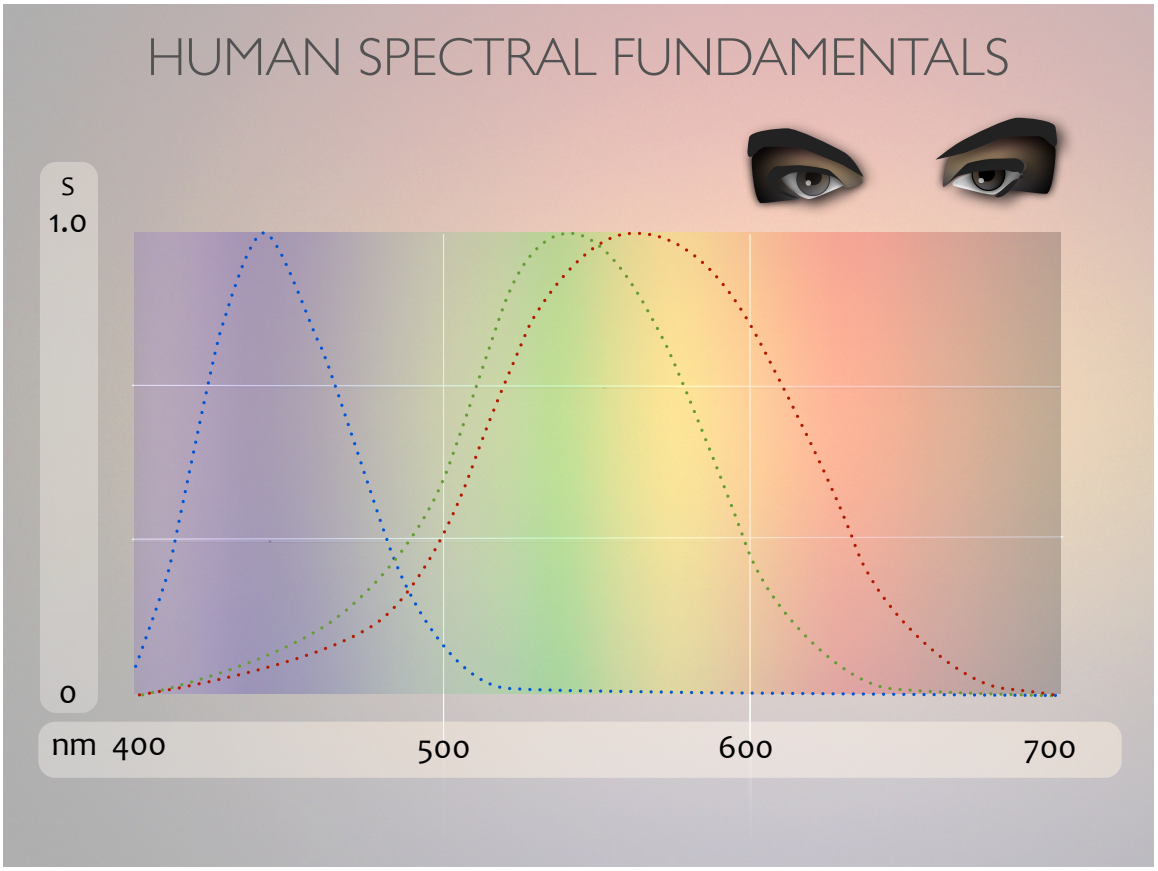


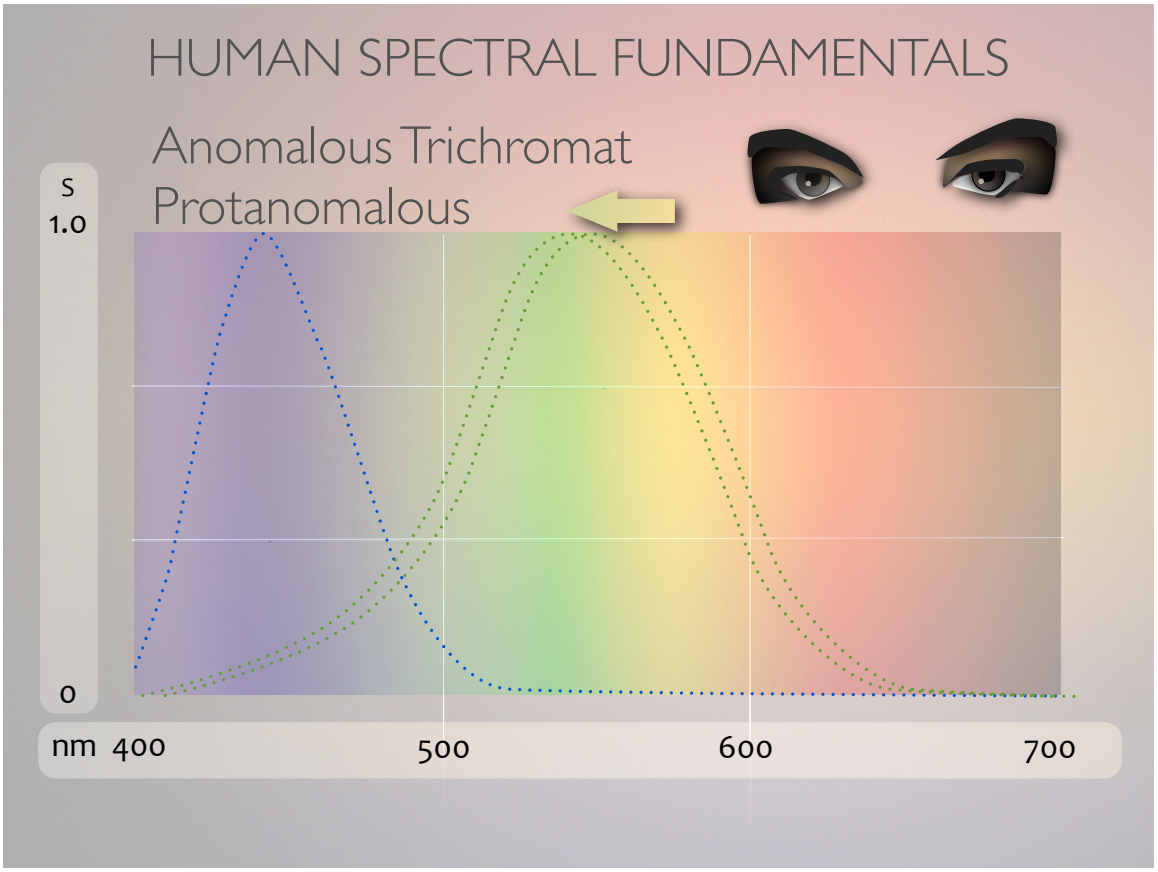

428
500
600
750

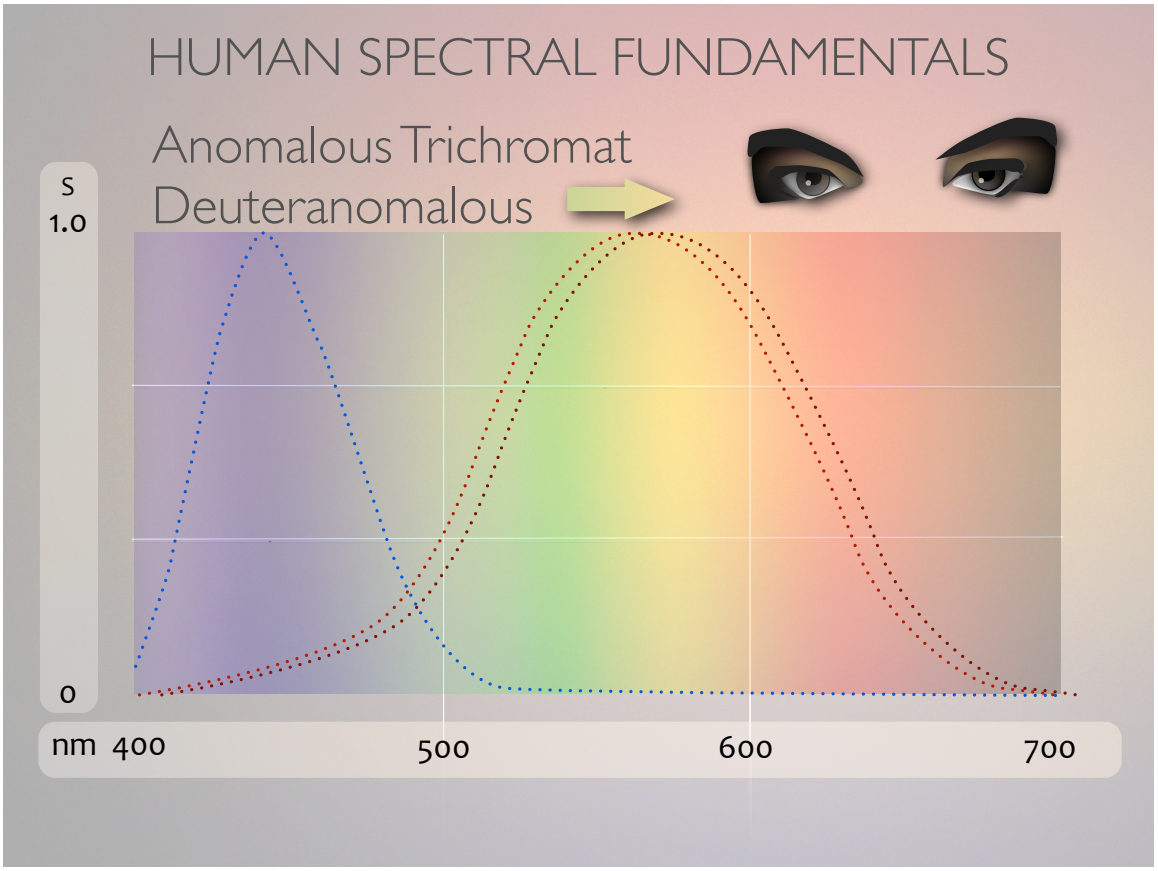

Trichromat
© Ann Torrence 2009 By permission

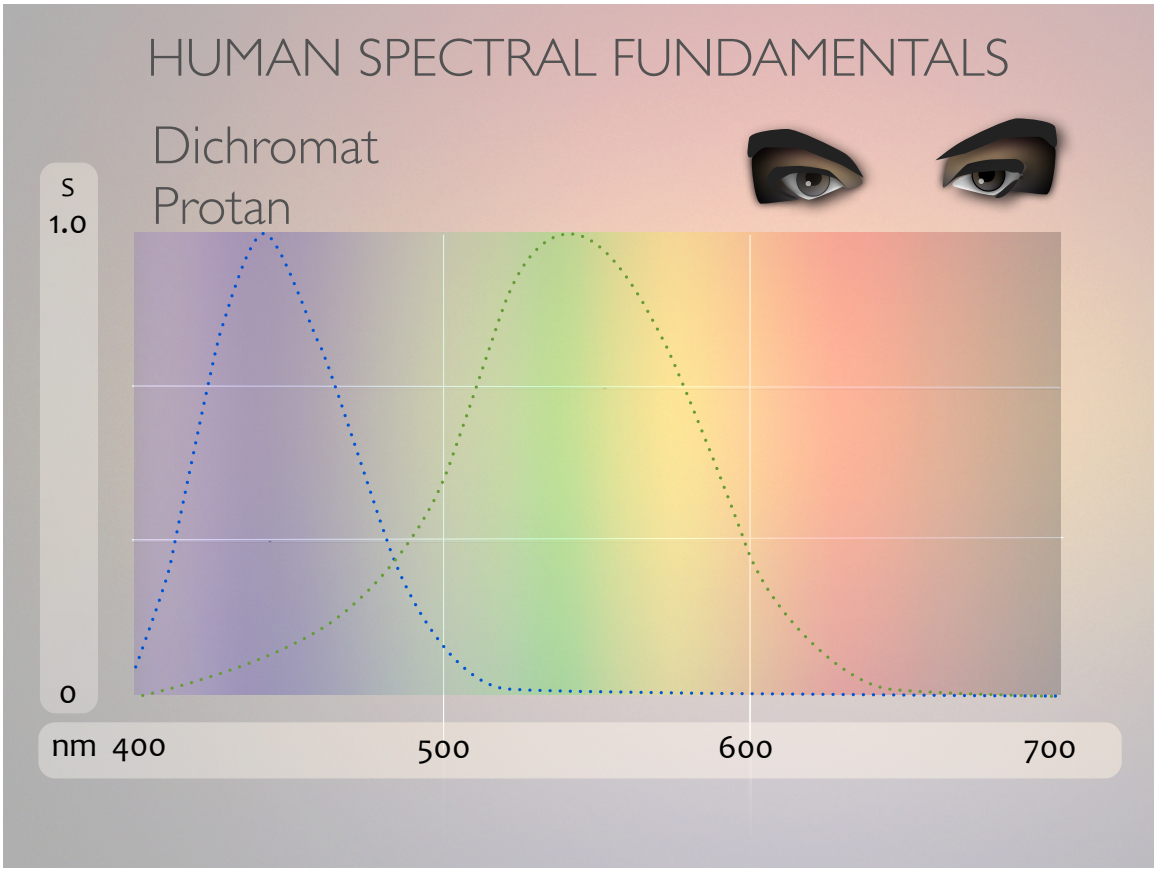
Dichromat :: Protan

Dichromat :: Deutan


HUMAN SPECTRAL FUNDAMENTALS
S
1.0
0
nm 400
500
600
700


HUMAN SPECTRAL FUNDAMENTALS
Anomalous Trichromat
Protanomalous
S
1.0
0
nm 400
500
600
700


HUMAN SPECTRAL FUNDAMENTALS
Anomalous Trichromat
Deuteranomalous
S
1.0
0
nm 400
500
600
700


HUMAN SPECTRAL FUNDAMENTALS
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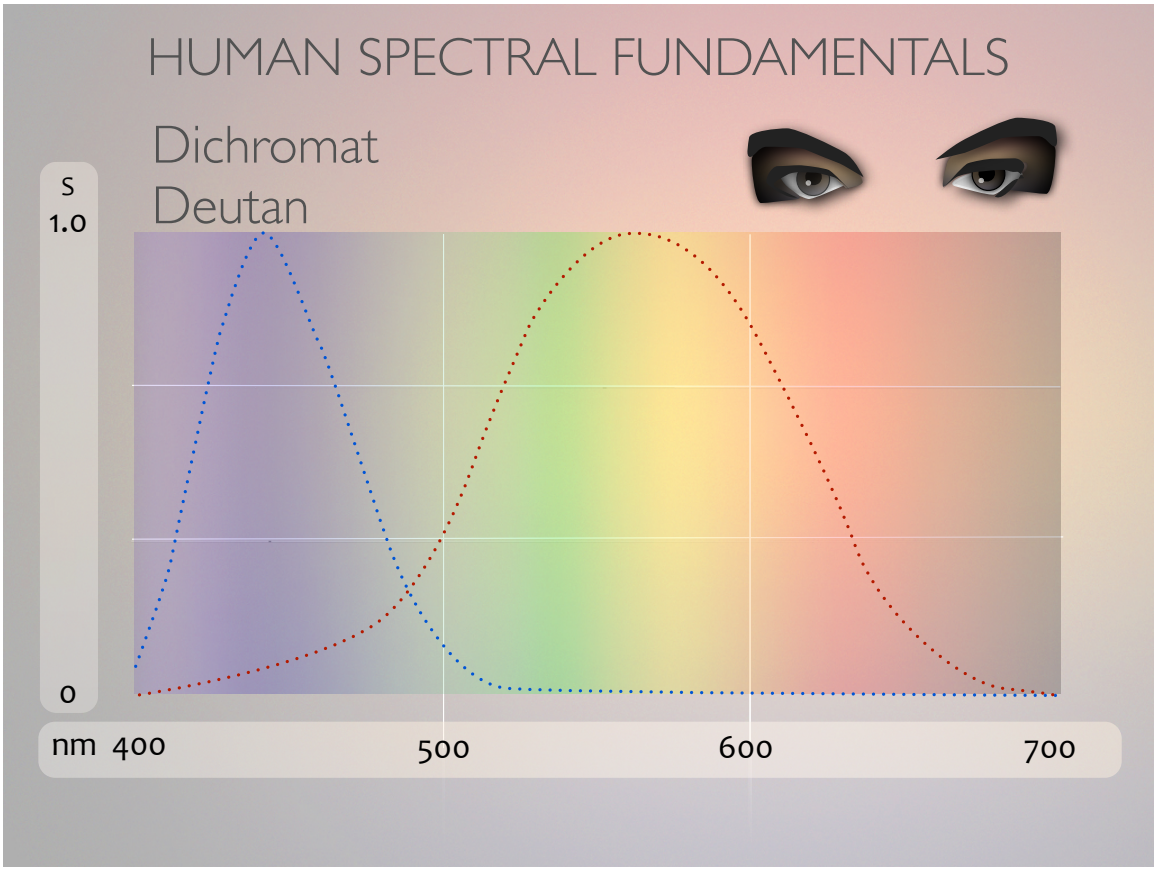
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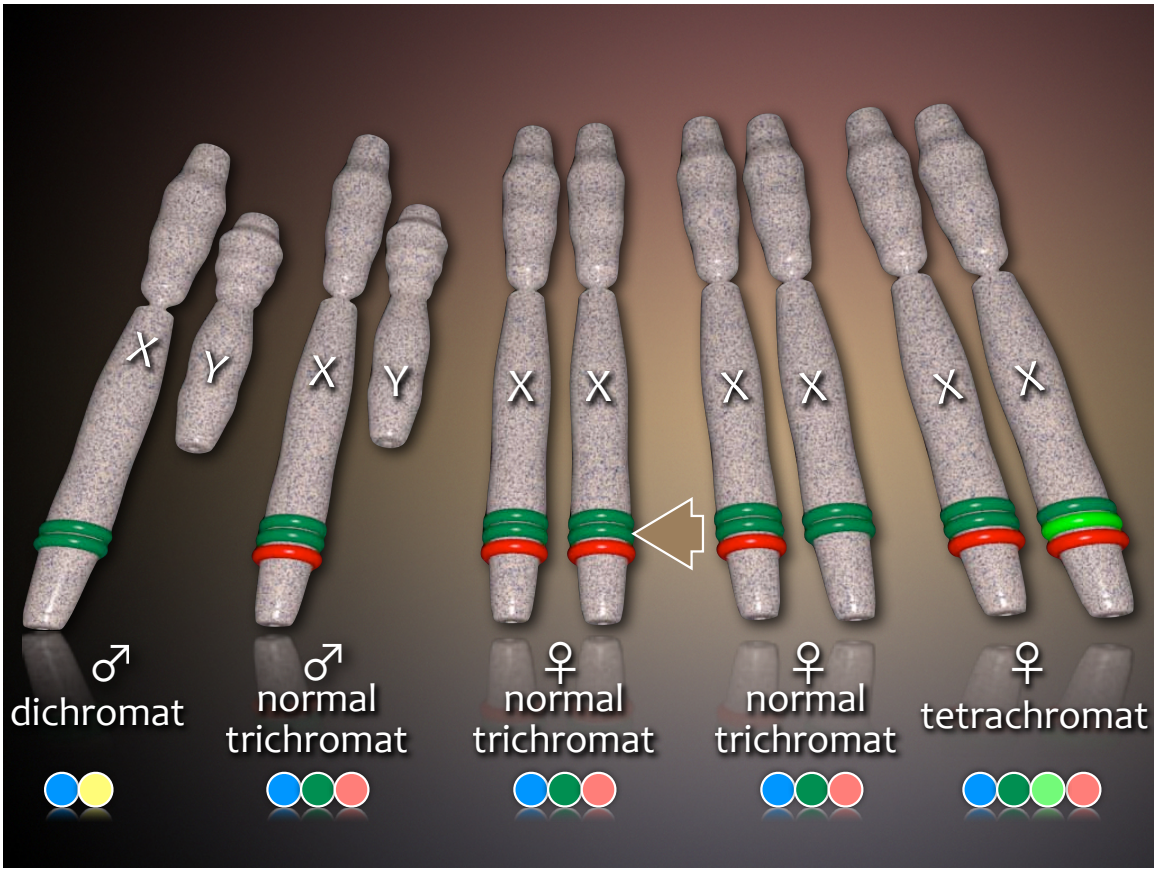
X
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tetrachromat

Trichromat

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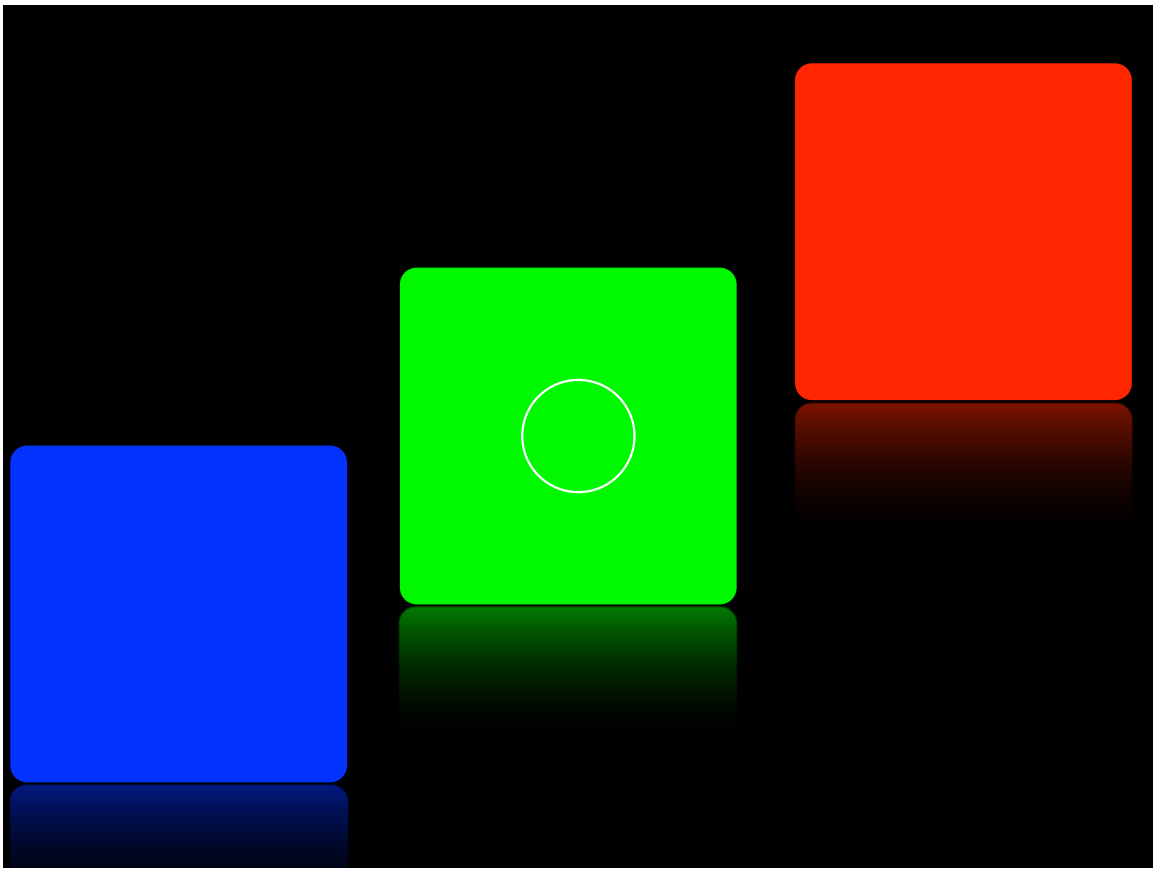
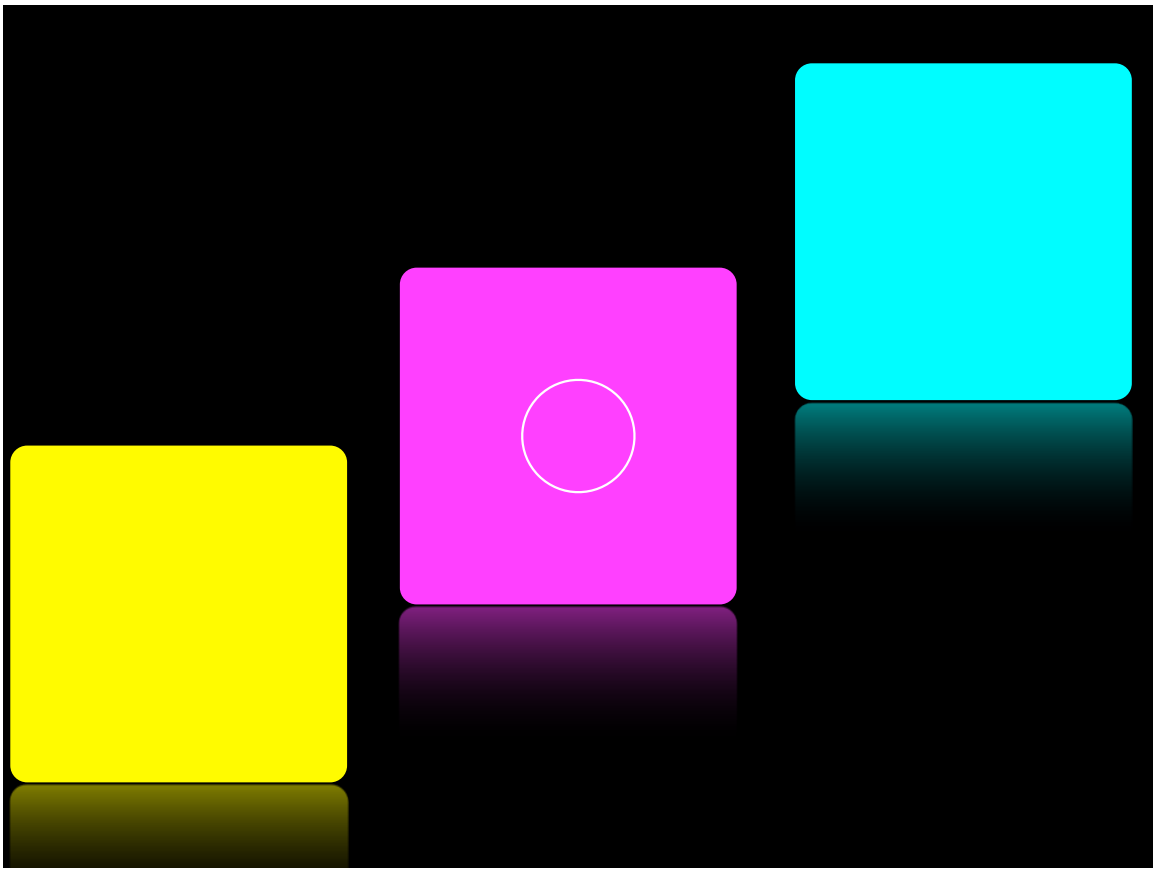
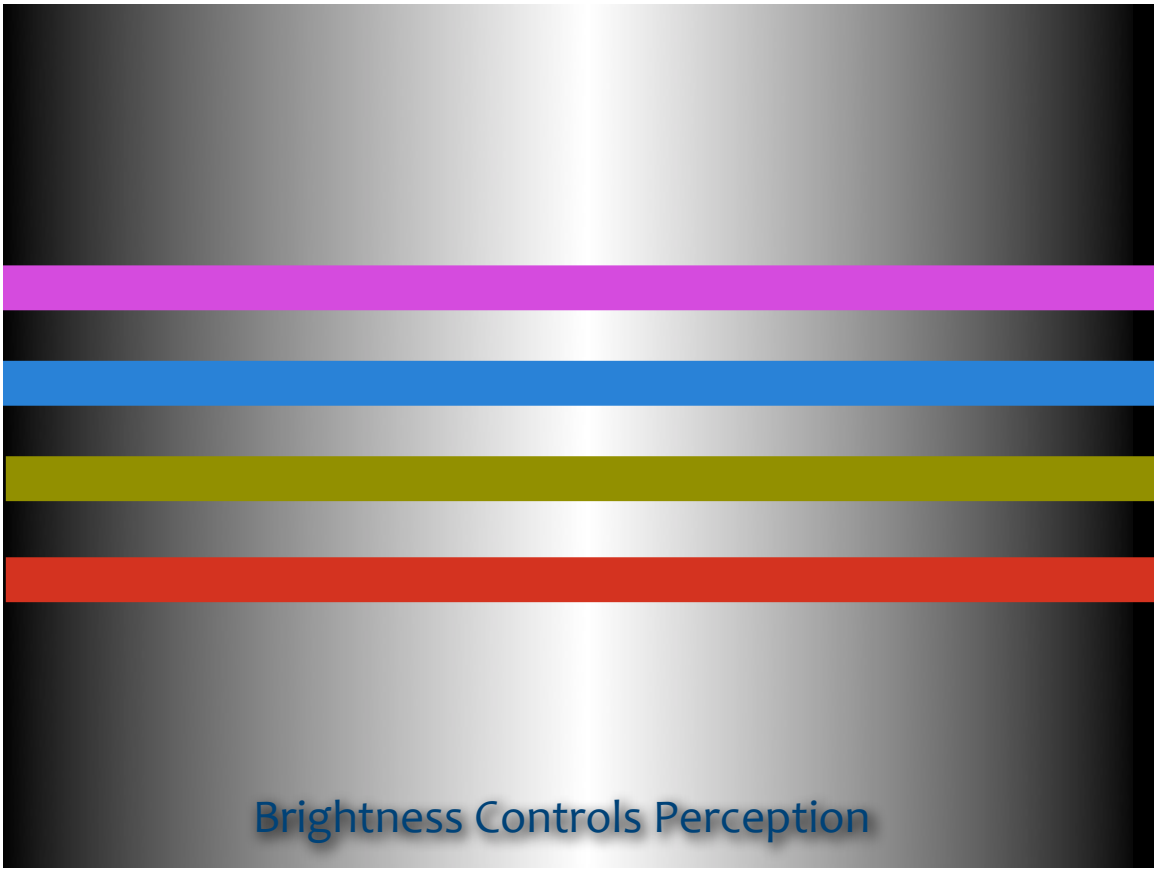
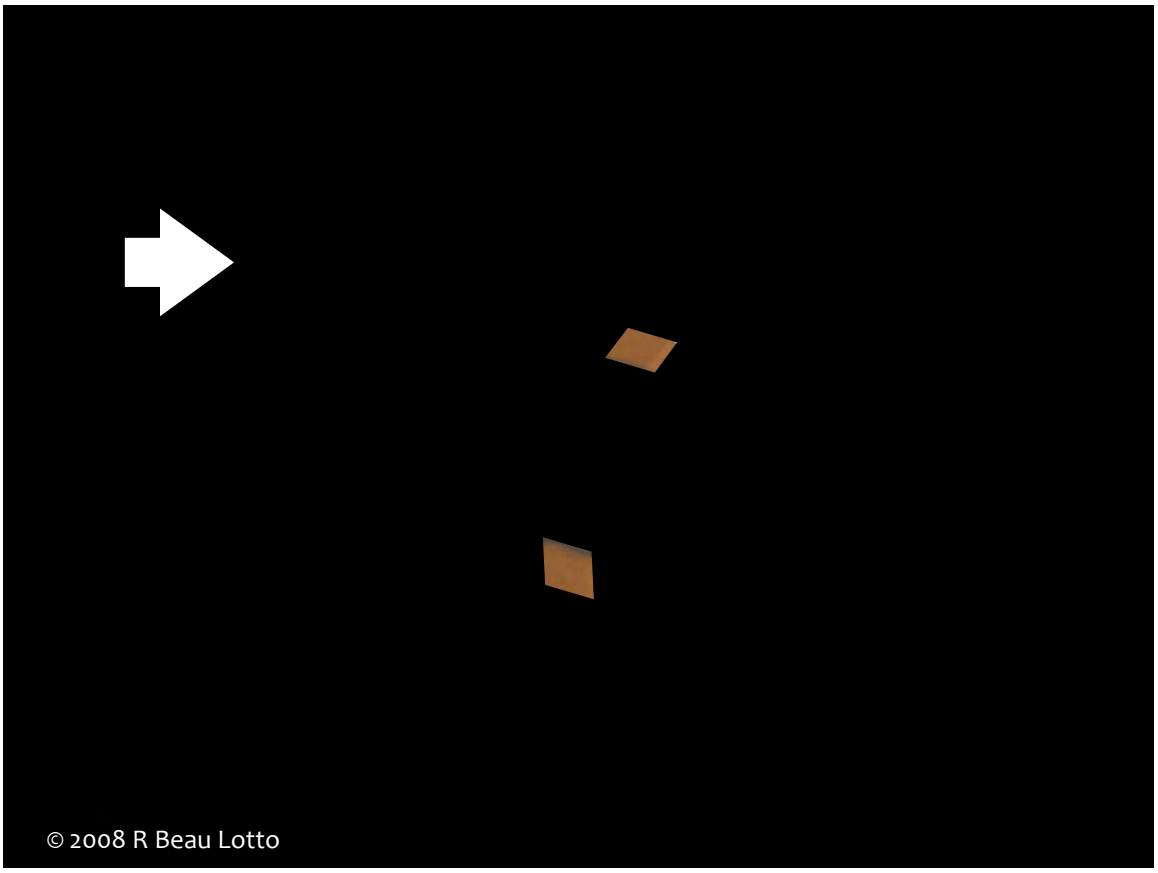
Dichromat :: Protan


Dichromat :: Deutan






Brightness Controls Perception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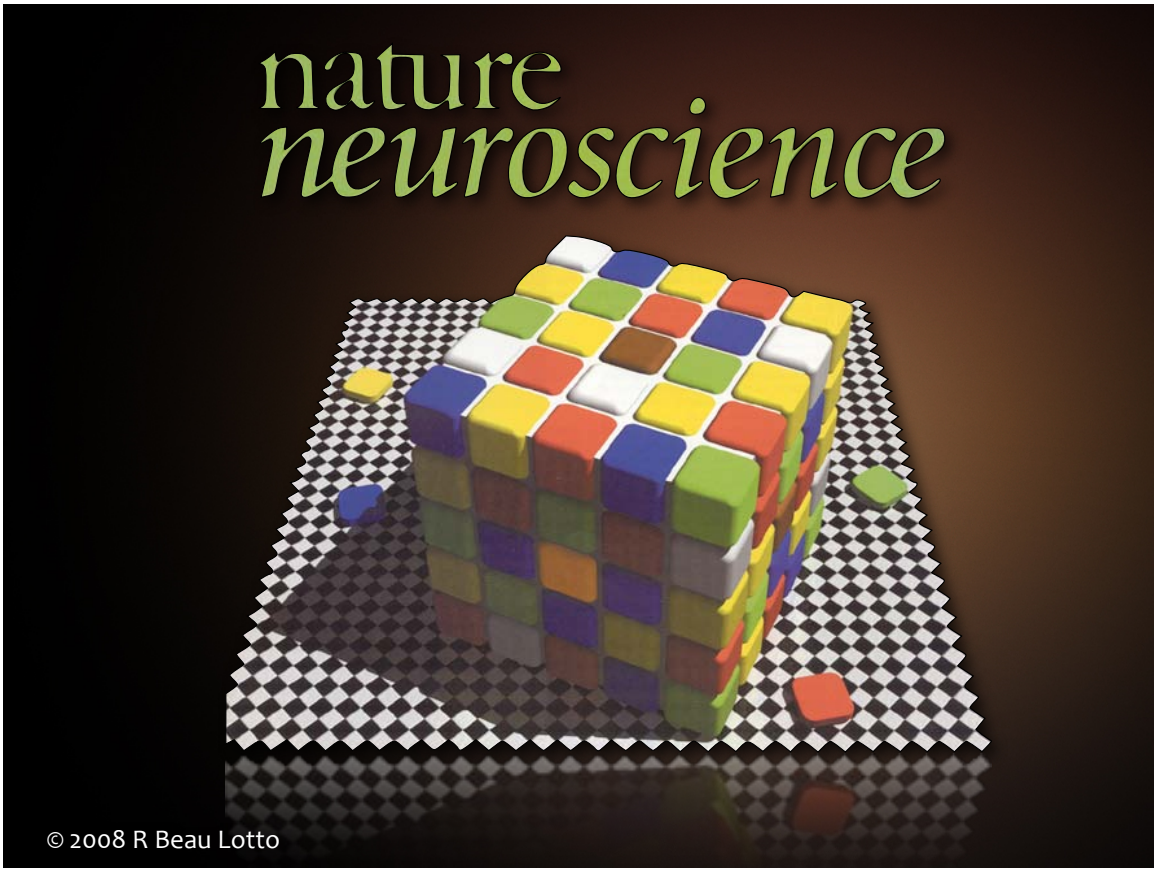
nature
neuroscience
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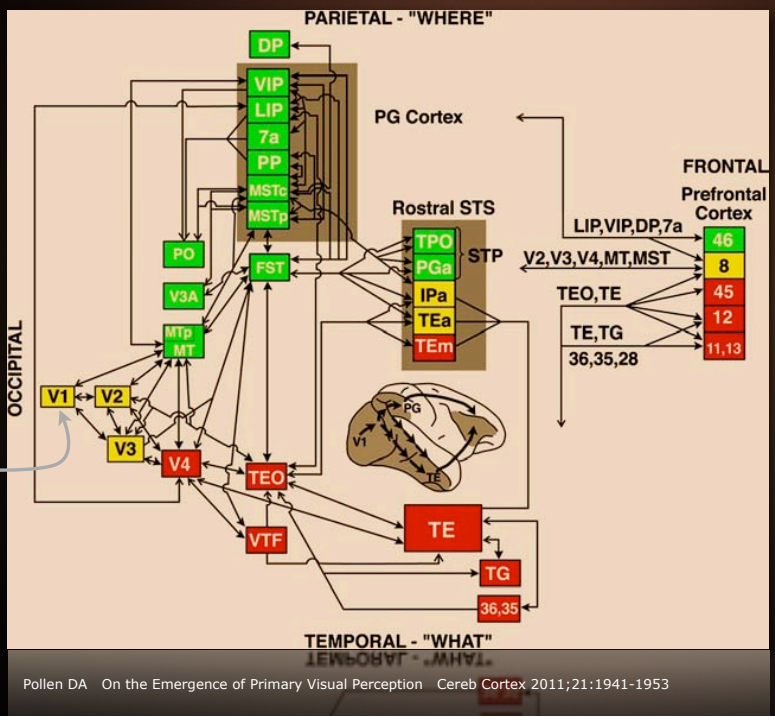
Central visual processing pathways

"There is currently an insurmountable gap between identifying the neural representations that correlate with perceptual experience and for accounting for such experience itself."

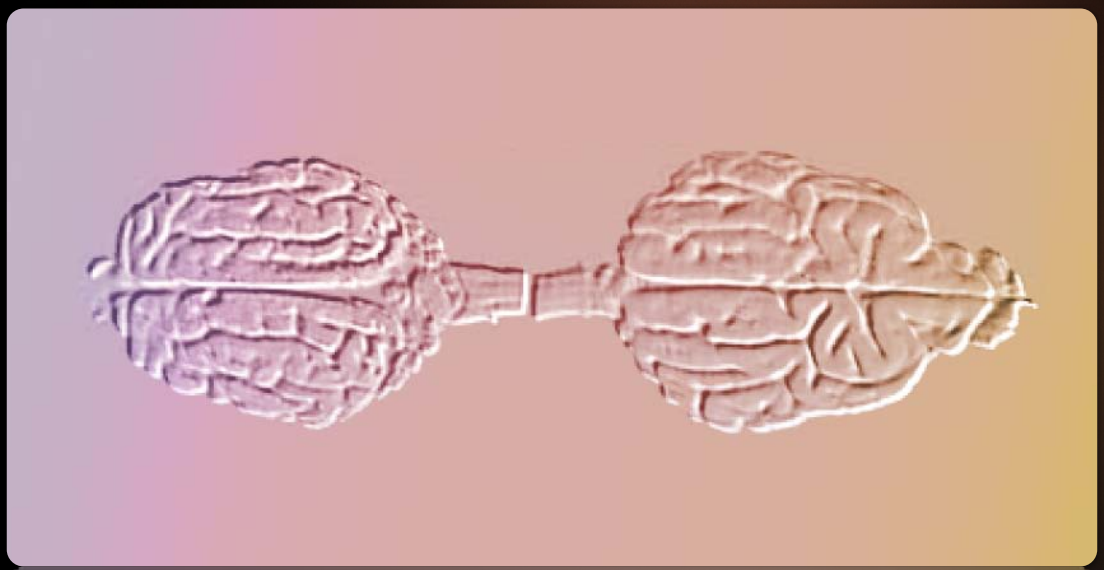
retina

LGN



Pollen DA On the Emergence of Primary Visual Perception Cereb Cortex 2011;21:1941-1953

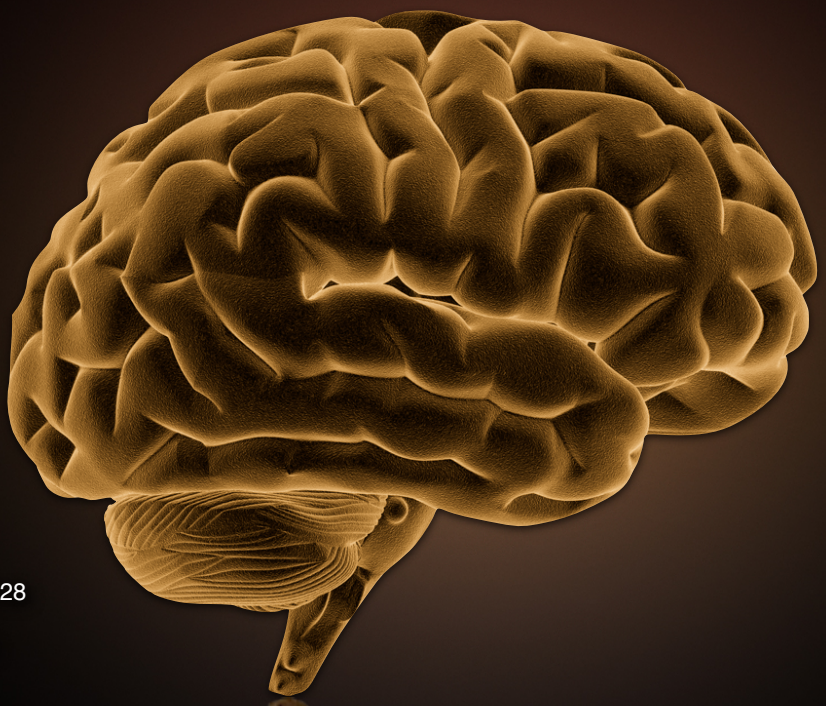
Brain shape & connectomics



Brain shape & connectomics

labeled *n*-vertex directed graphs

$\mathcal{D}_n = 2^{n(n-1)}$



$\mathcal{D}_{1000} = 9 \cdot 10^{300728}$

$atoms = 1 \cdot 10^{80}$

Marc et al., *Current Opinion in Neurobiology*, 2012