Imperial College London

Lecture 2

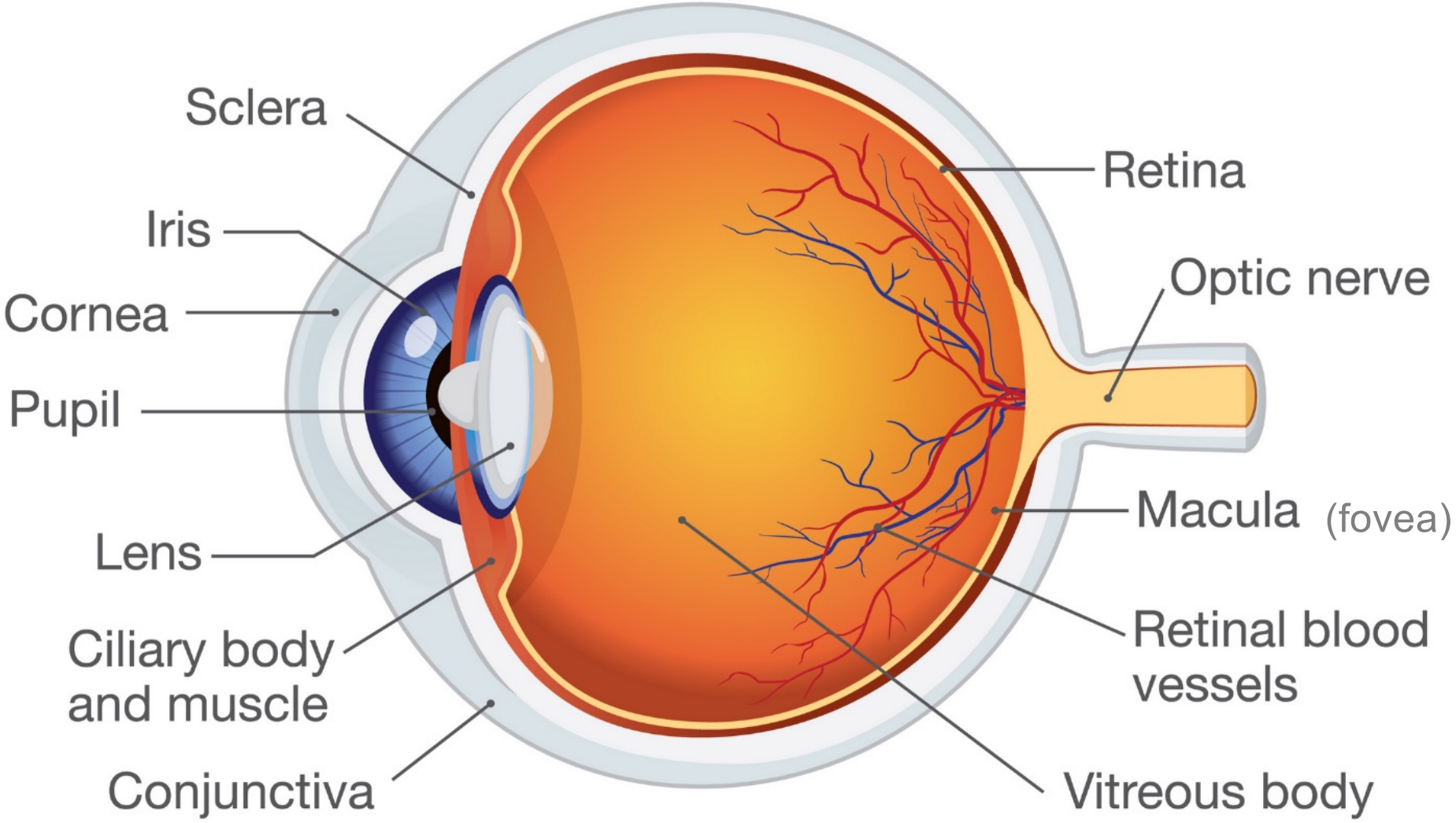
The Anatomy and physiology of Vision

Prof Peter YK Cheung

Dyson School of Design Engineering

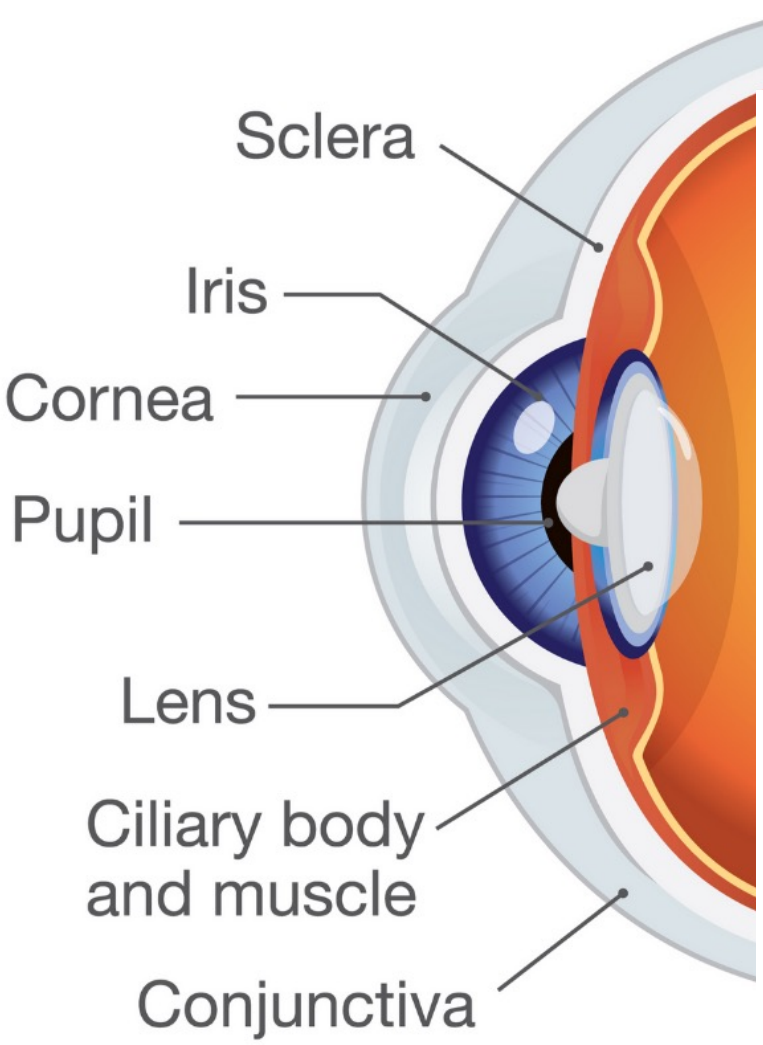
URL: www.ee.ic.ac.uk/pcheung/teaching/DE4_DVS/
E-mail: p.cheung@imperial.ac.uk

Anatomy of the Eye (1)



Source: Sight Research UK

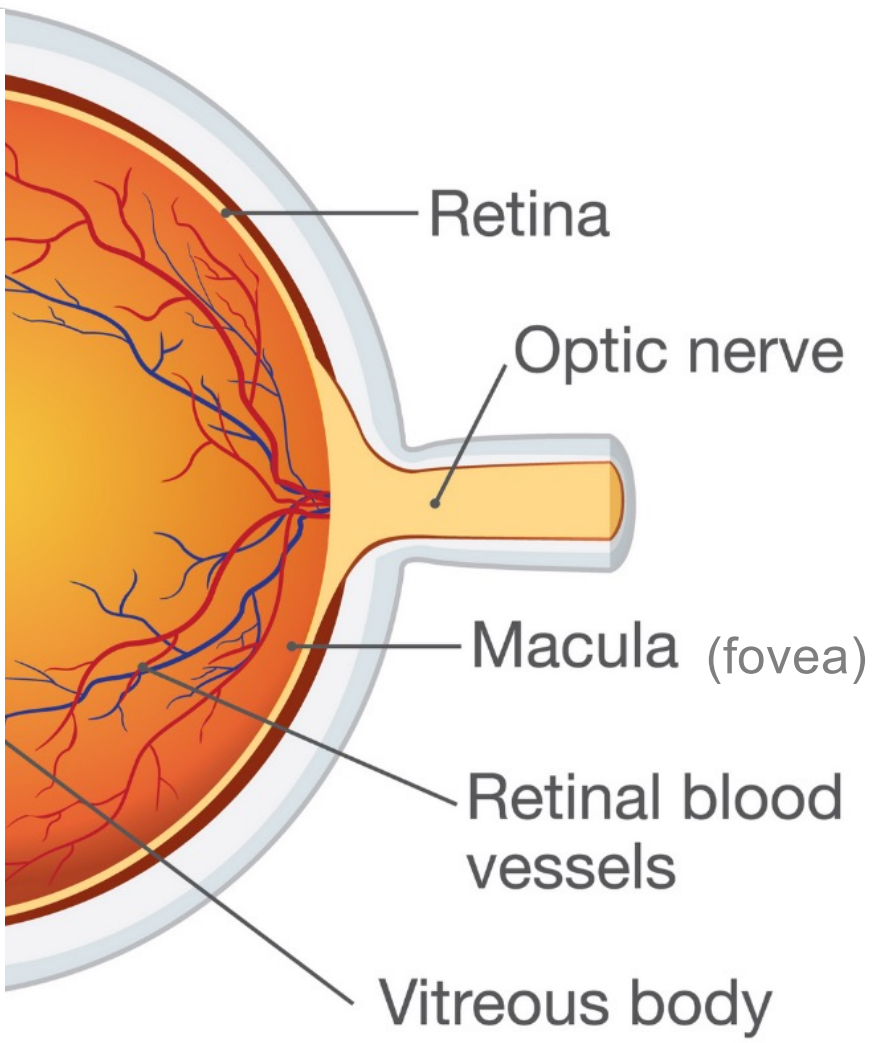
Anatomy of the Eye (2)



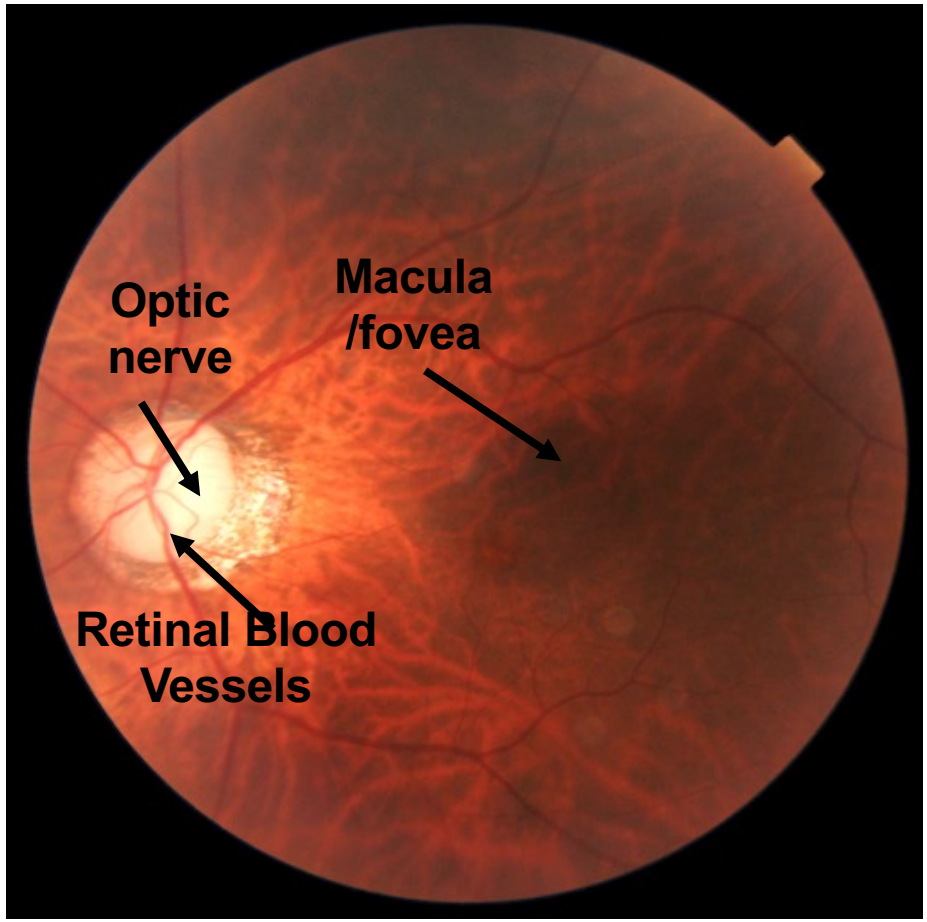
- Cornea – clear outer layer that is transparent and protects the eye
- Sclera – protective layer forming the white of the eye
- Pupil – opening at centre of iris where light passes through
- Iris – coloured part of the eye which dilates or constricts to adjust the amount of light passing through
- Ciliary body – circular structure that produces fluid in the eye and contains muscle to change the shape of the lens
- Lens – transparent structure that refracts and focuses light onto retina

Anatomy of the Eye (3)

- Retina – a layer of photoreceptor cells at the back of the eye that converst photons from light to signals for the brain
- Macular – a 5mm disc around 250 micron thick on the retina for detailed colour vision
- Fovea – a small indentation at the centre of the macula with the highest density of cone photoreceptor cells for colour vision.
- Optic nerve – bundle of over 1 million nerve fibres carrying the visual signals to the brain.
- Vitreous body – transparent gel-like substance under pressure to maintain shape of the eye.

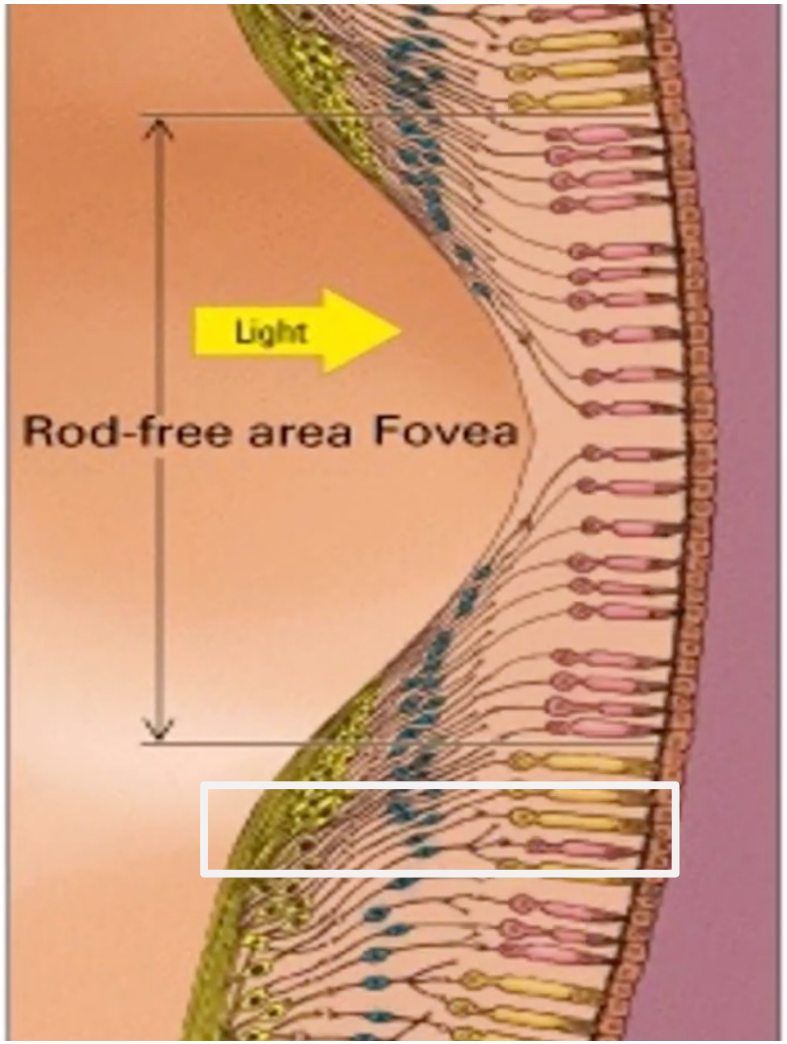


Function of the Retina



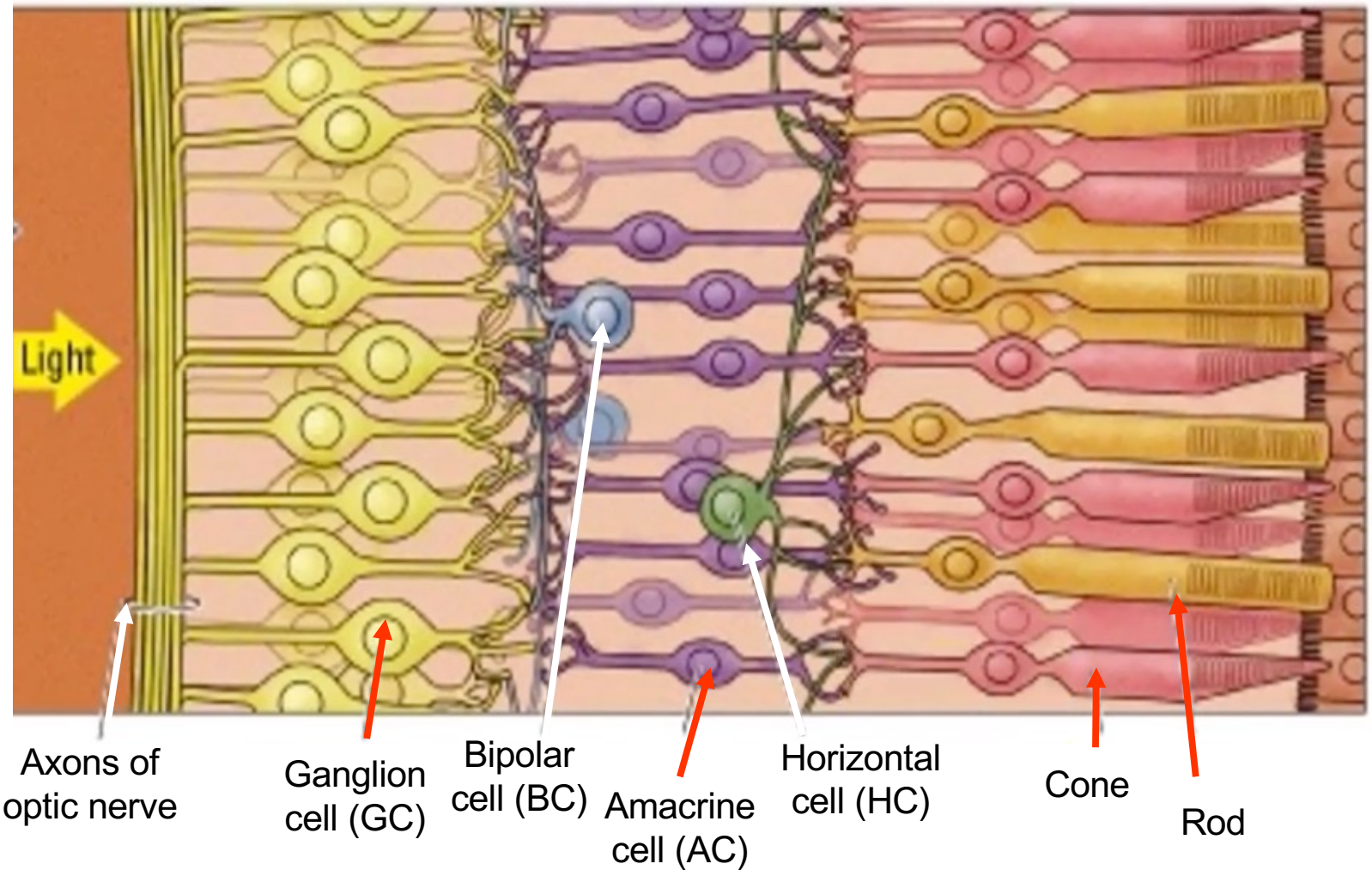
- To accept photons of light
- To translate photos into biochemical messages
- To translate biochemical messages into electrical impulses
- To transmit electrical impulses to the brain via the optic nerve bundle

The Anatomy of the Retina (1)

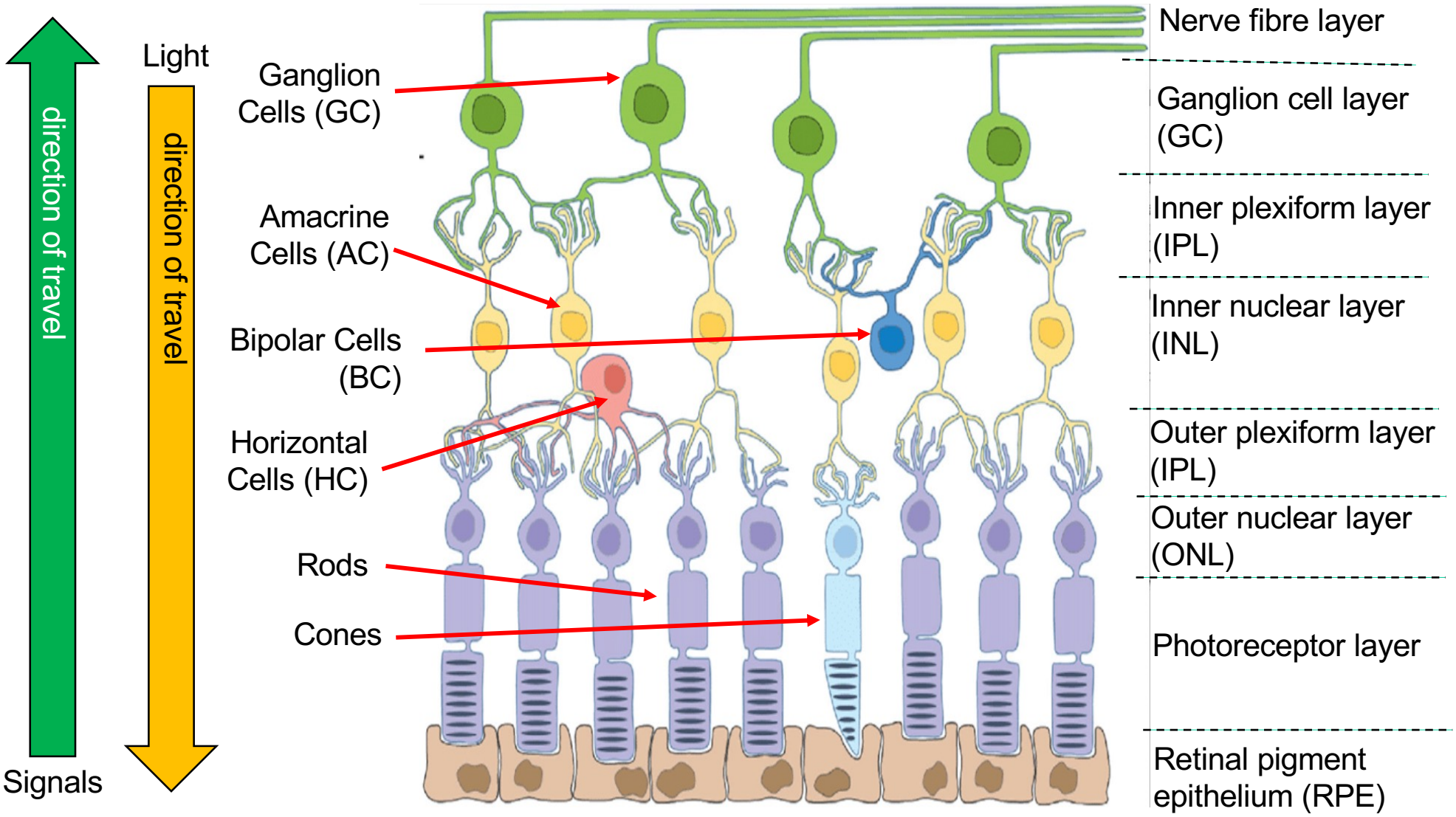


- The retina contains multiple layers of cells, each layer perform different functions.
- At the centre of the of the retina is a pitted region known as the fovea.
- The fovea contains only cones which are photoreceptors sensitive to bright colour lights.
- The density of the cones are very high, thus forming very high-definition image in this region.
- There are no rods in the fovea region.

The Anatomy of the Retina (1)



The Anatomy of the Retina



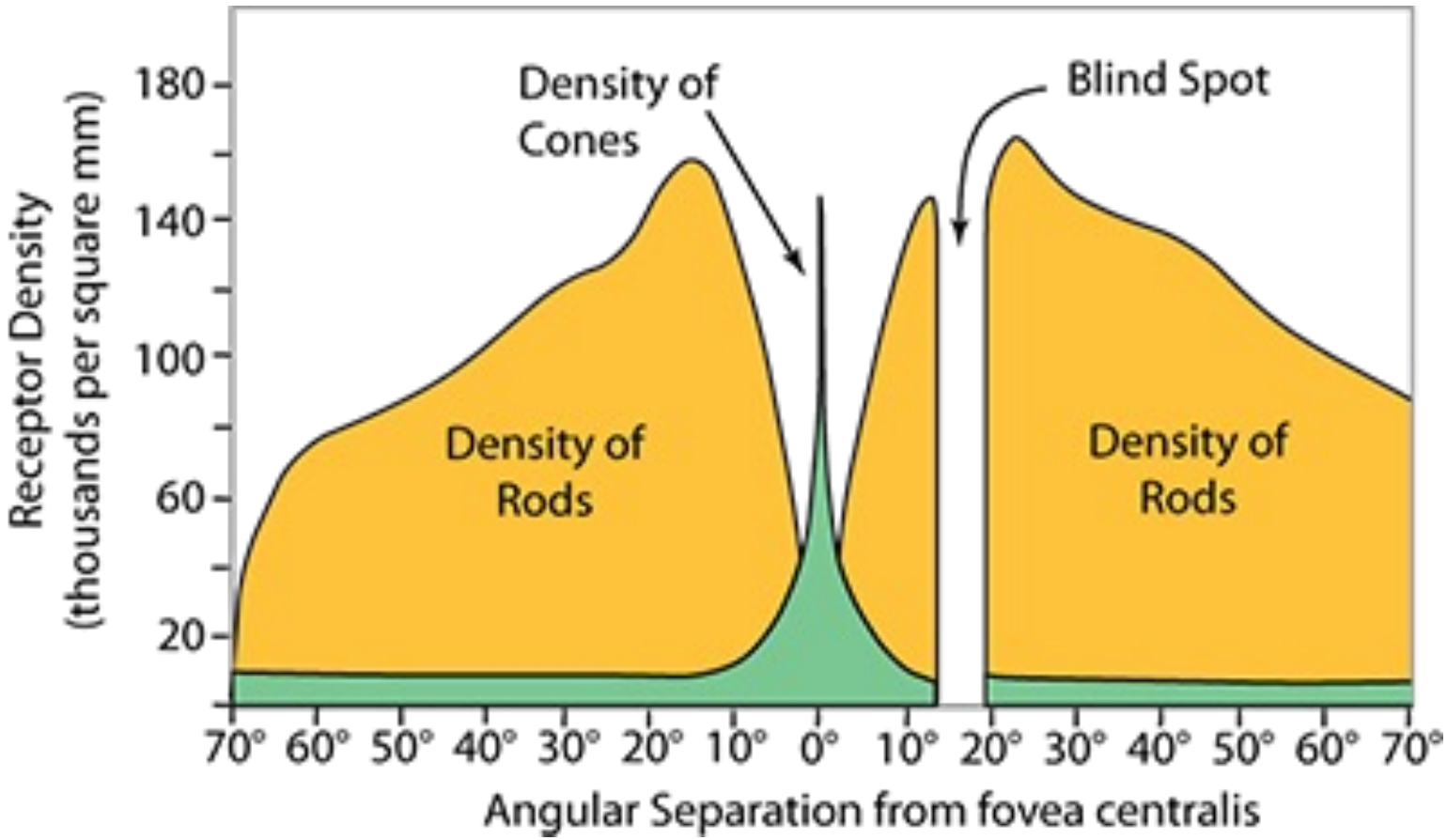
SEM Image of rods and cones

- Rods:
  - Scotopic vision
  - Night vision
  - Achromatic (i.e. BW only)
  - Peripheral vision
  - ~90 million/eye

- Cones:
  - Photopic vision
  - Daytime vision
  - Colour vision
  - Foveal vision
  - ~5 million/eye

Source: Omikron

Densities of rods and cones

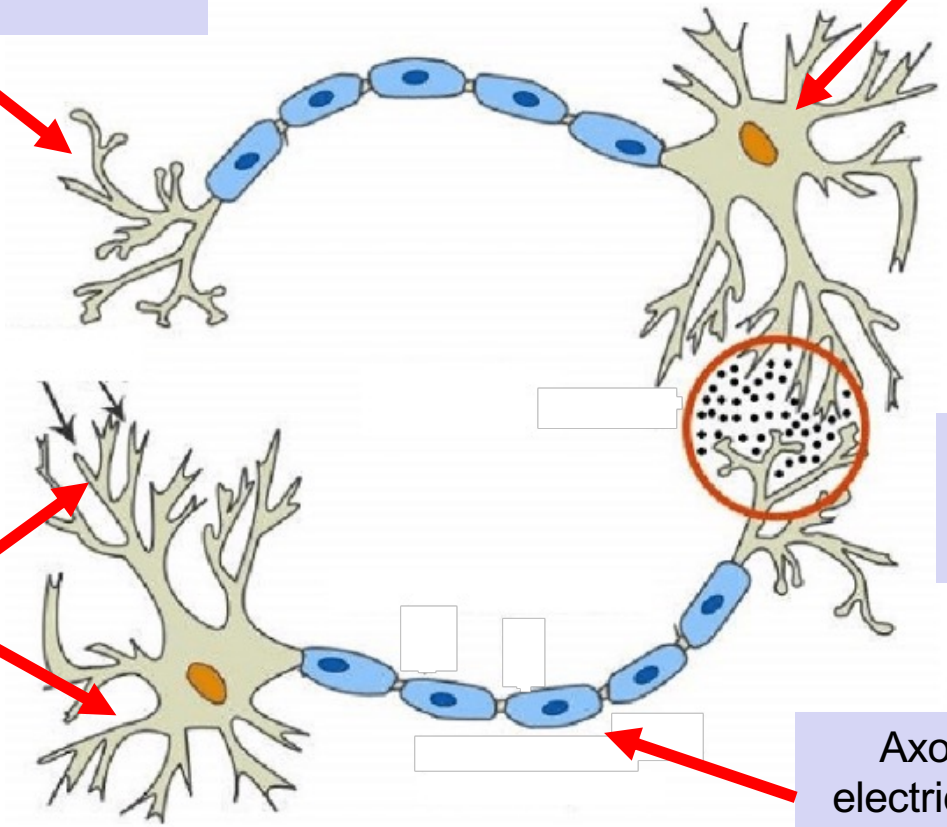


- Concentration of cones at very high density only in the fovea region, around ±6º around the centre of vision.
- Concentration of rod is spread out.

Five Components in a Neuron

Axon terminal: Releases chemical signals to communicate with other neurons

Cell body: contains the nucleus and integrates information from other neurons

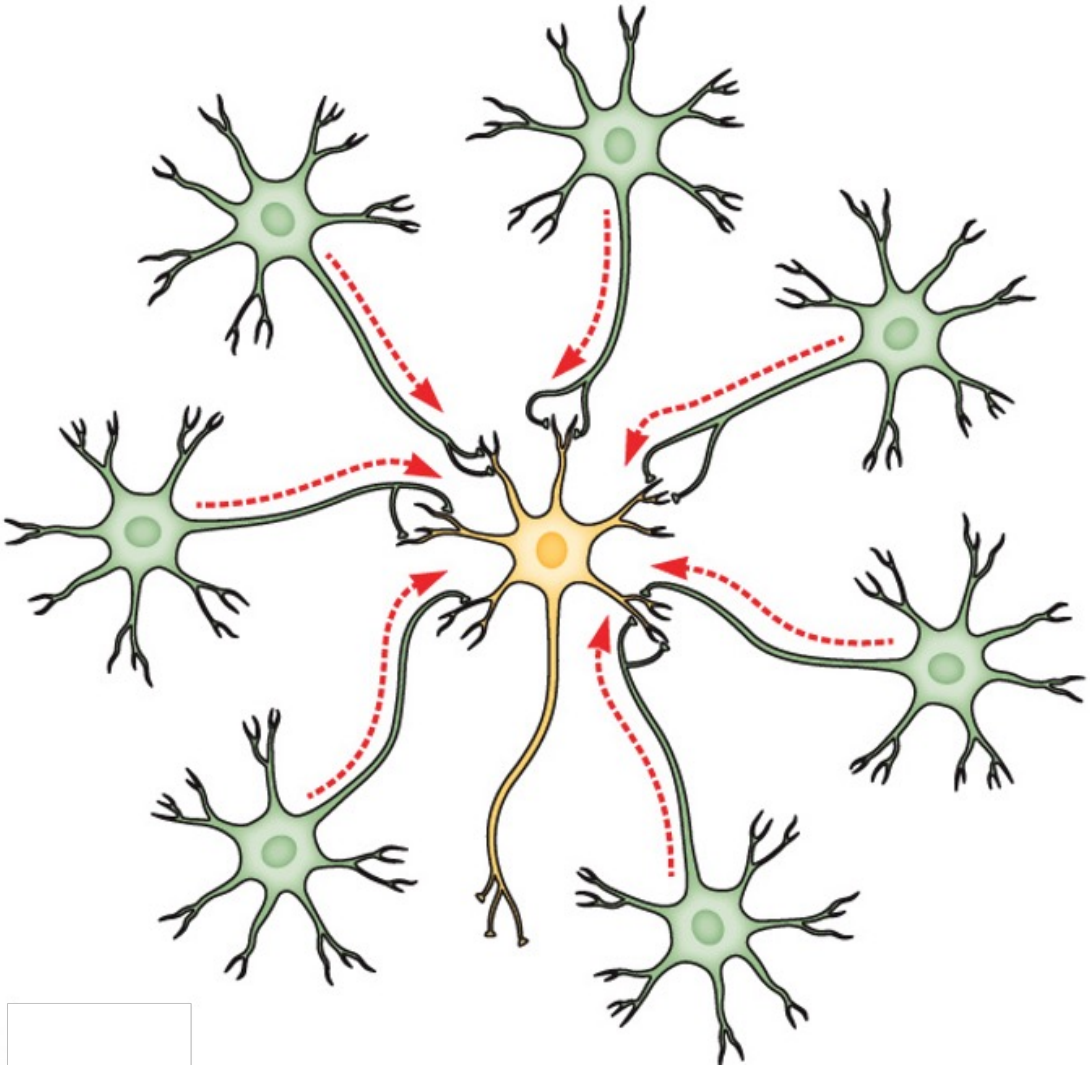


Dendrites: Branches from cell boardy that collects information acting as receiver

Synapse: Small gap across which chemical signals communicates

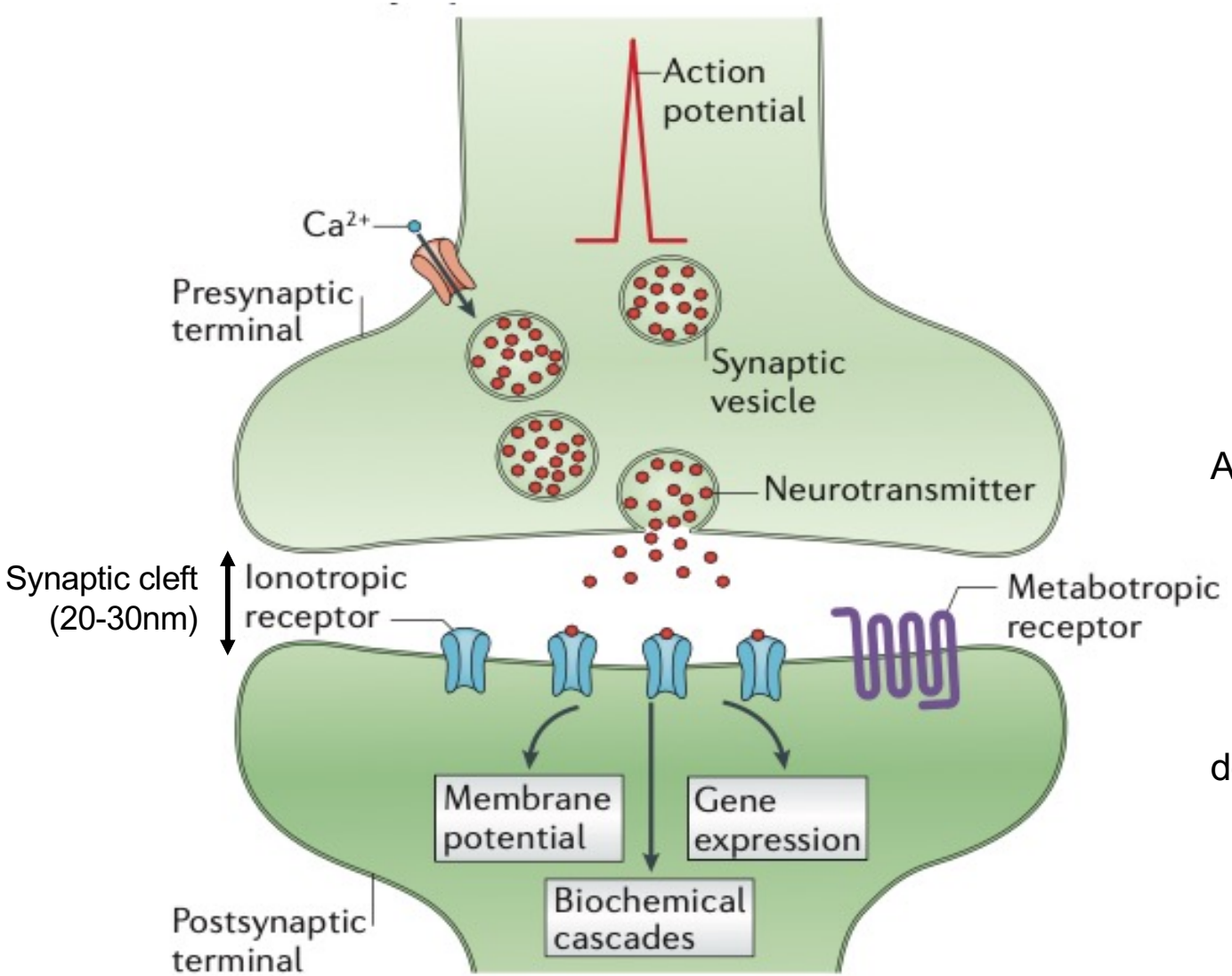
Axon: Conducts the electrical neural signal to other neurons

Neuron connections



There are about 100 billion neurons and over 100 trillion synapses in an adult brain!!

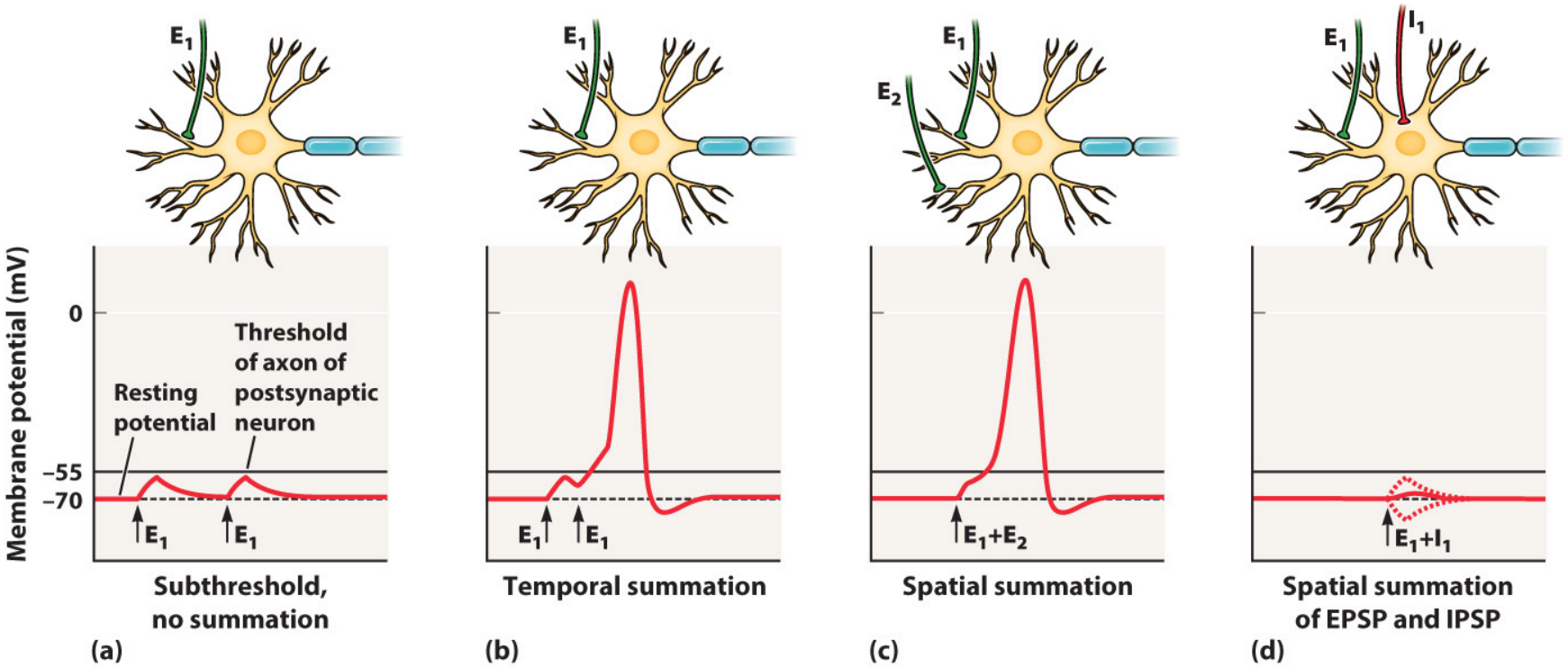
Synapse



Source: Pereda, Nature 2014

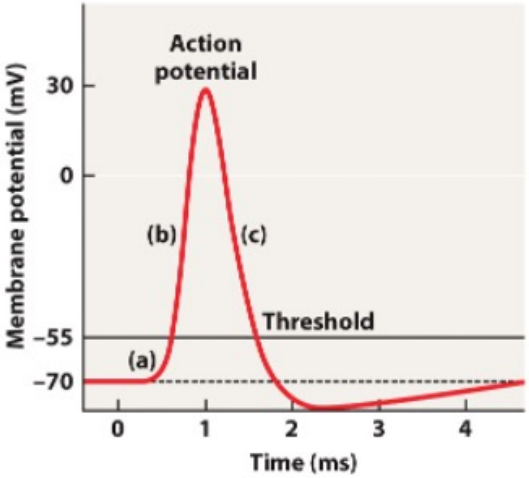
Action Potentials

- Action potentials are all or none.
- EPSPs and IPSPs combine to affect the membrane voltage.
- In temporal summation, PSPs arriving at the cell body at close to the same time are combined.

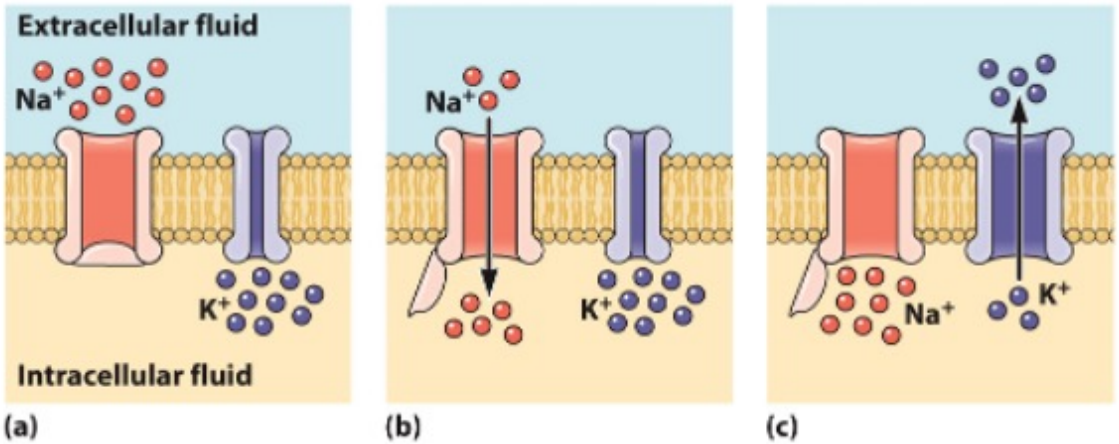


Source: Eagleman

It is all chemistry!



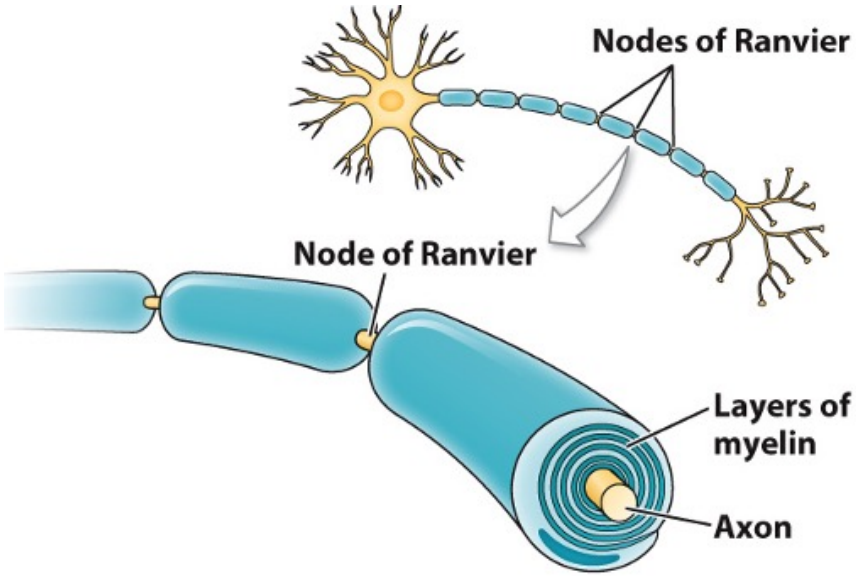
- In neurons at rest, there are more Na+ ions outside the cell and more K+ ions inside the cell.
- At threshold, voltage-gated Na+ channels open, allowing Na+ ions to flow into the cell, down the chemical concentration and electrical gradients.
- Voltage-gated K+ channels open, allowing K+ ions to flow out of the cell.



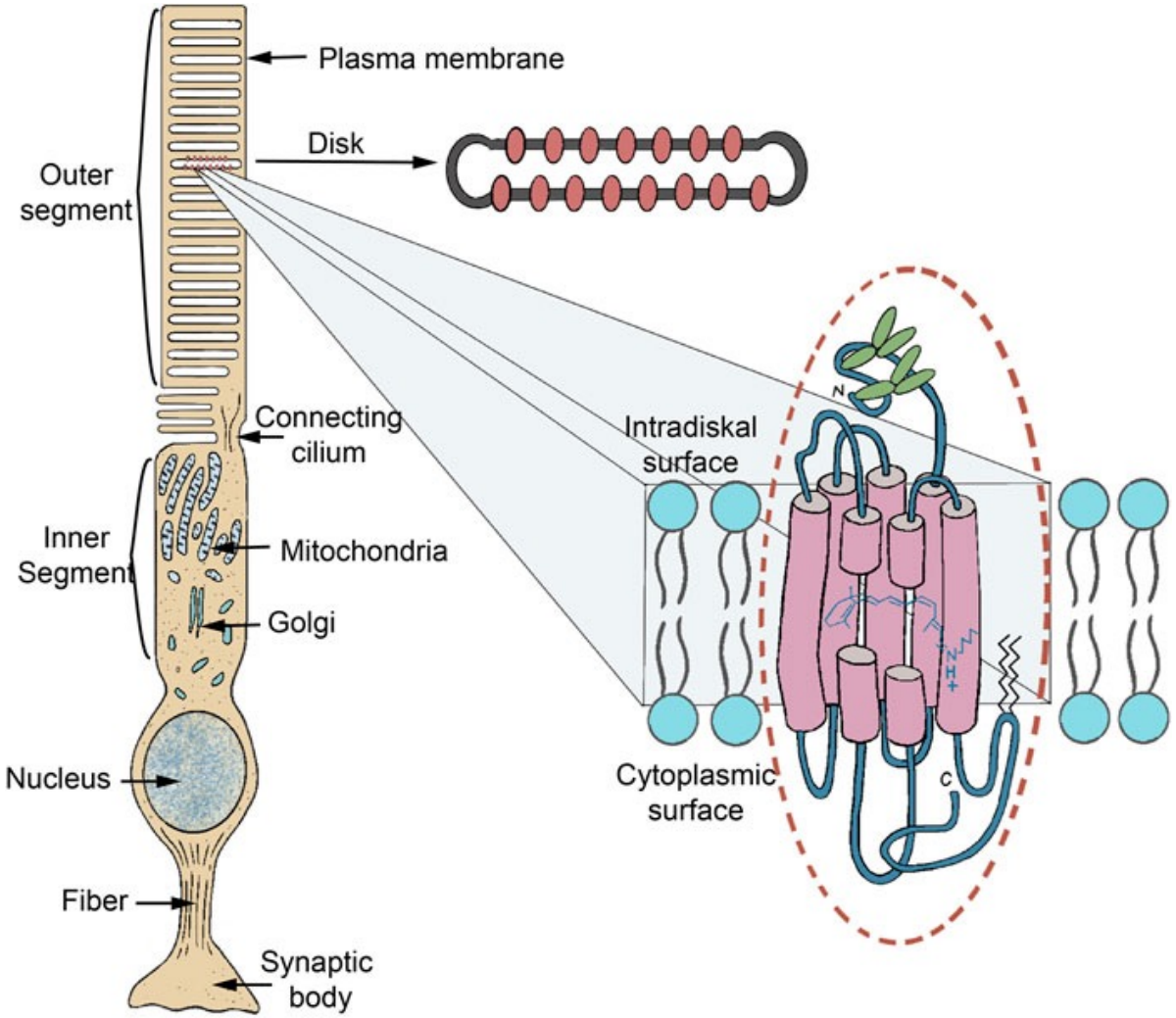
- The current formed by the Na+ ions flows down the neuron, depolarizing the next part of the neuron.
- There is a refractory period after the action potential, when the voltage-gated Na+ ion channels are less likely to open.
- Calcium and chloride ions also contribute to the action potential.

How an Action Potential Travels

- Myelin is interrupted by gaps, known as nodes of Ranvier, where the action potential is regenerated.
- The action potential jumps from node to node, greatly speeding up transmission.
- Myelination decreases the amount of energy used by the neuron.

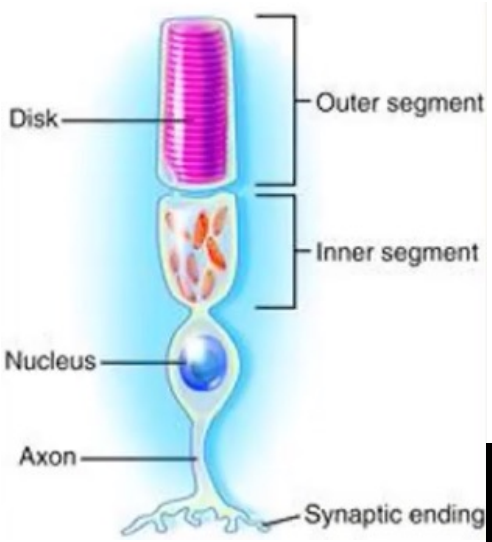


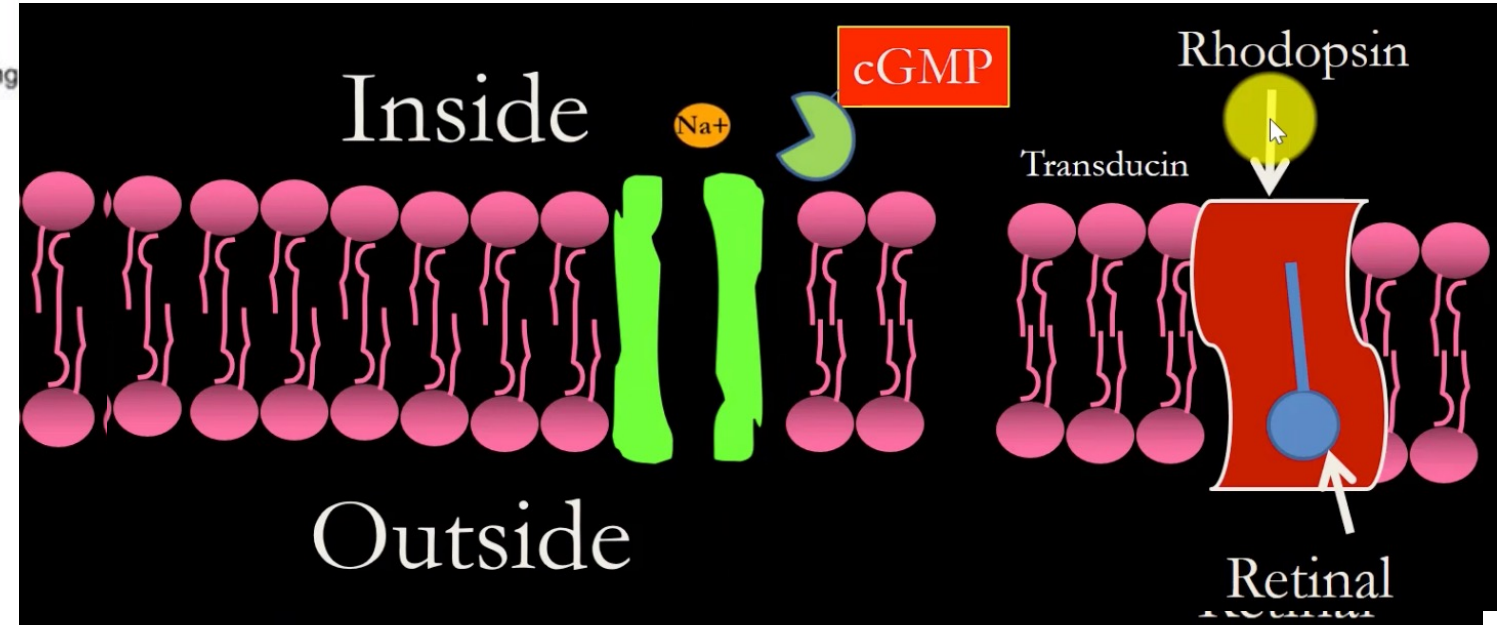
How does a photoreceptor works?



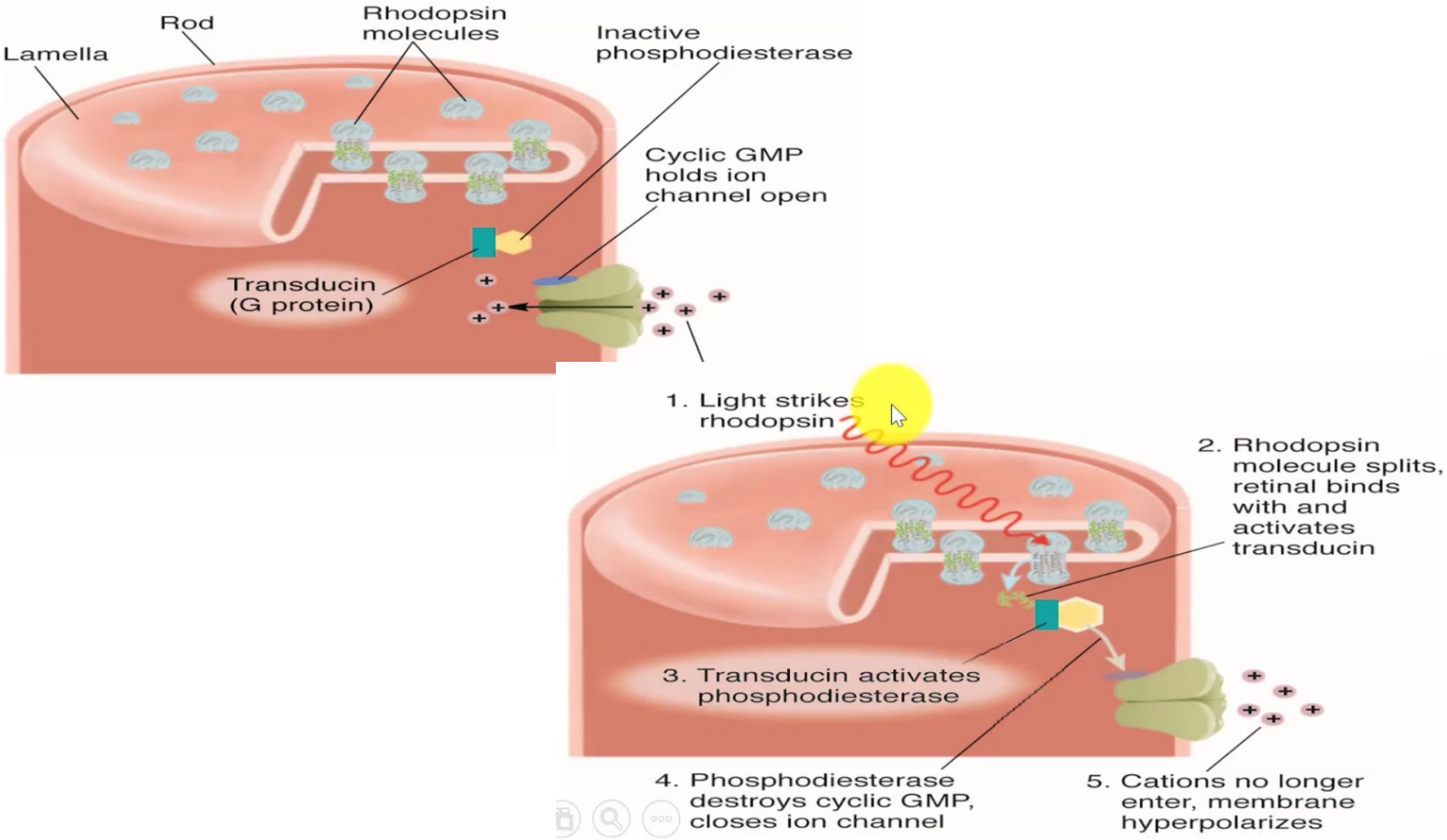
Source: Hargrave 1995

How light is turned into electrical signal (1)

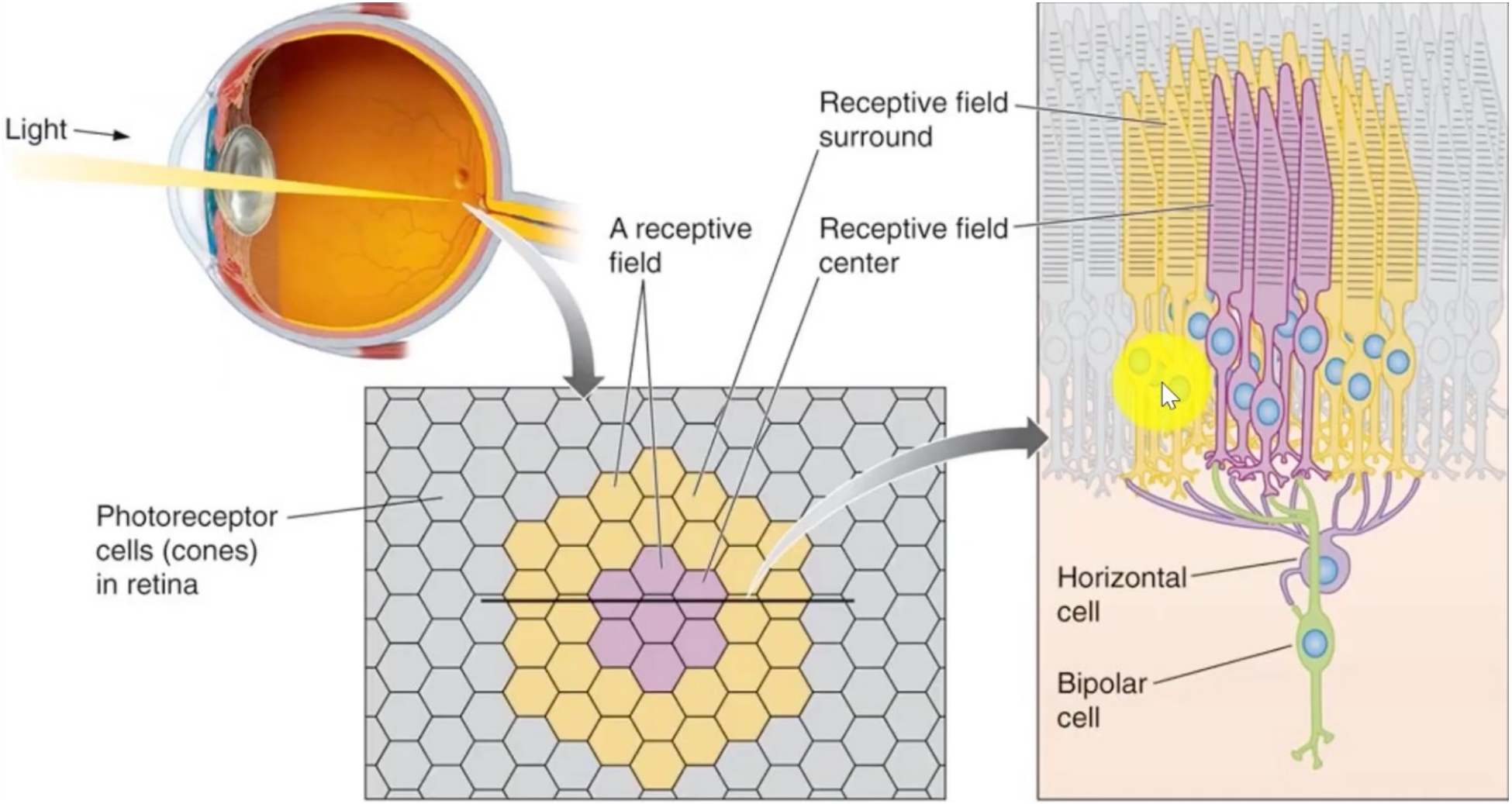




How light is turned into electrical signal (2)

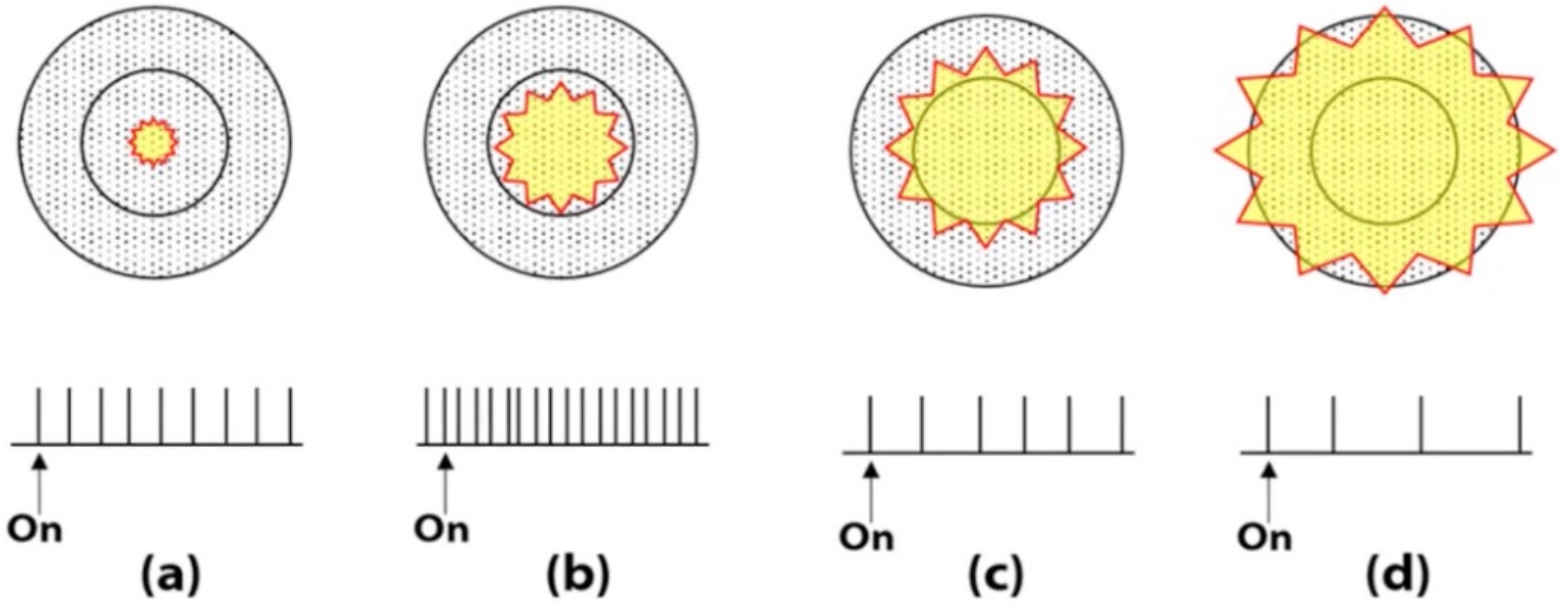


Receptive Field of retinal cells



Receptive Field – Retinal Spatial Processing

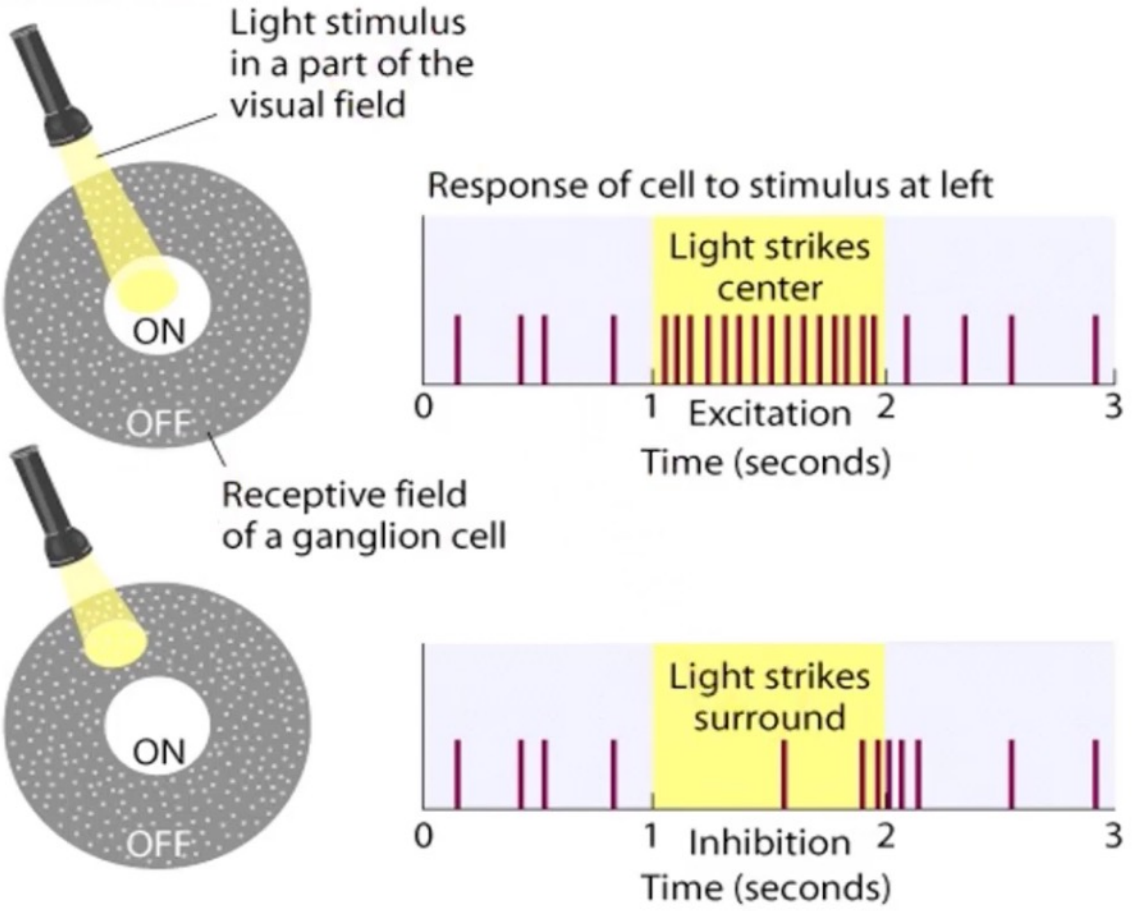
- On-centre receptive field: Fires most when light hits the centre and dark on the periphery



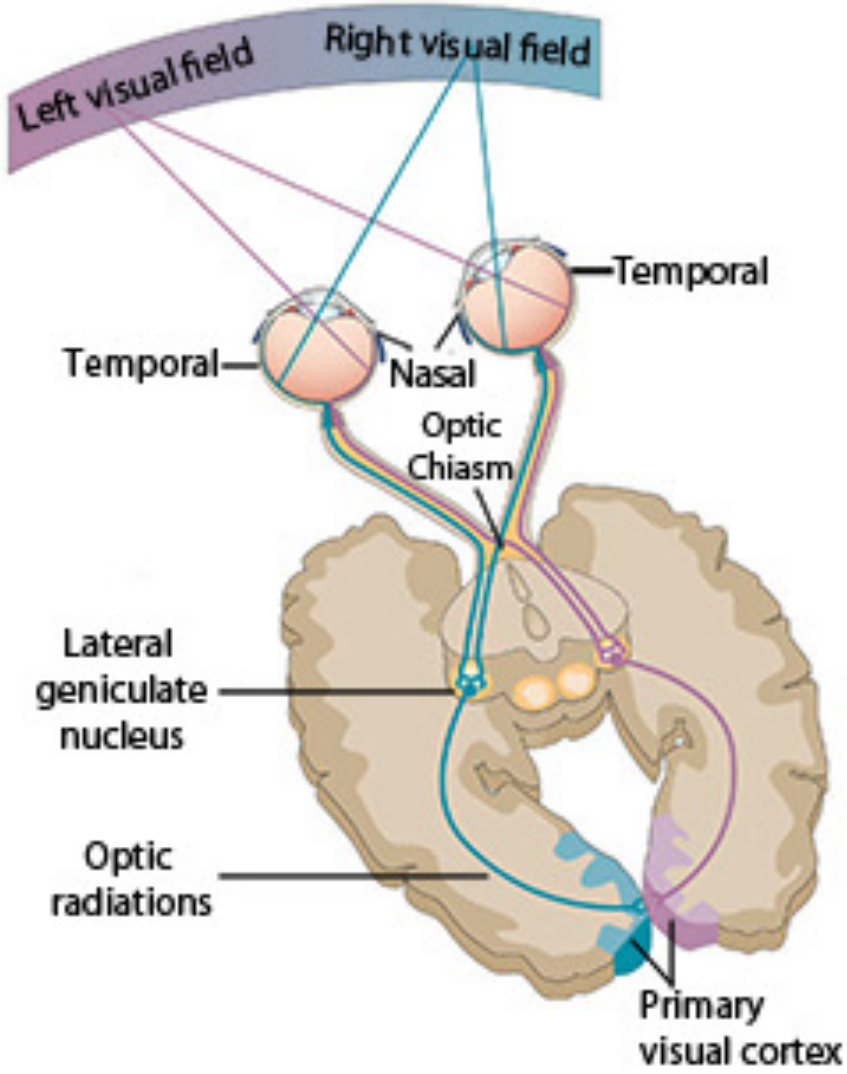
- Off-centre receptive field: Fires most when light hits the periphery of the receptive field and dart on the centre

On-centre Ganglion Cell

- On-centre receptive field: Fires most when light hits the centre and dark on the periphery



Visual Pathway – from eye to brain

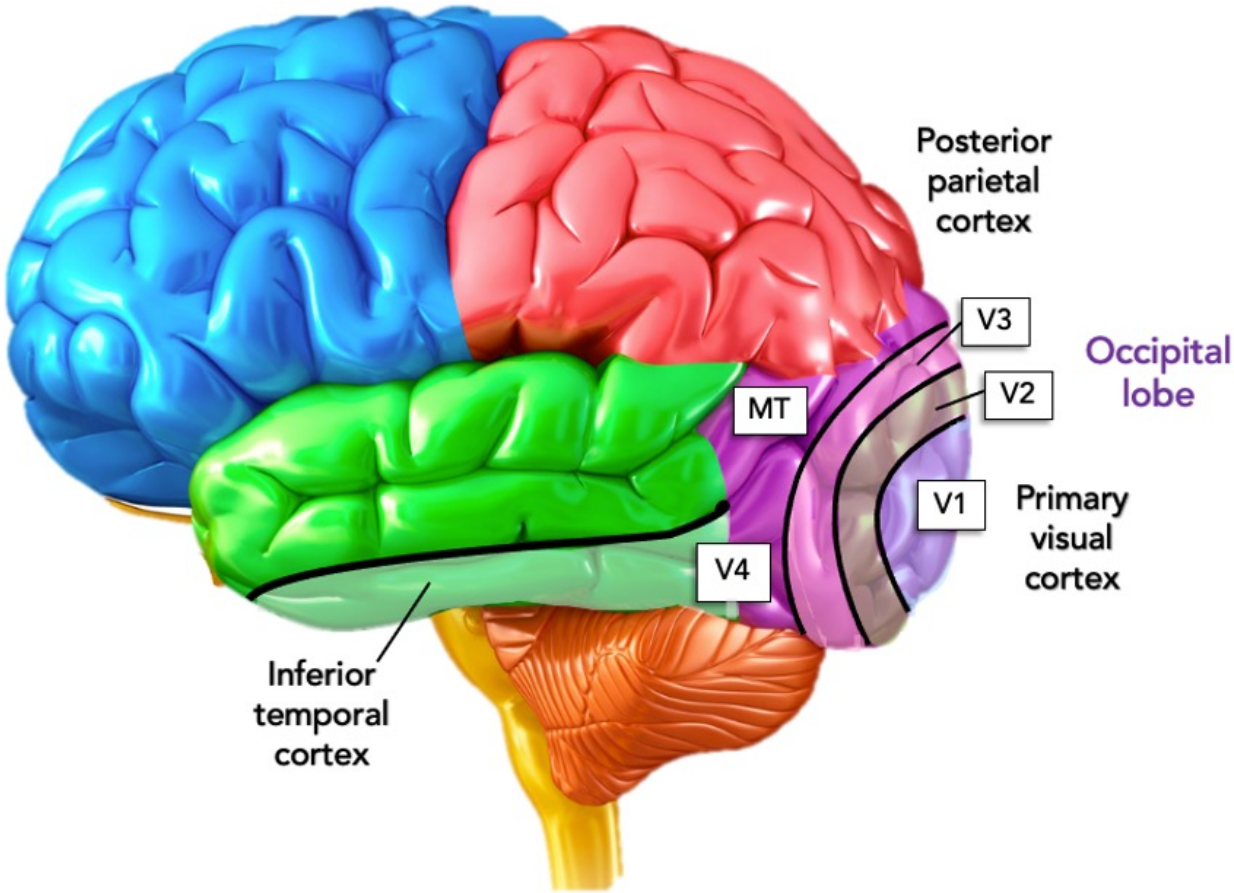


- Right visual field is processed by the left side of the visual cortex, and the left visual field by the right.
- The optic chiasm is the X-like structure in the optic nerves where the cross-over happens.
- The lateral geniculate nucleus (LGN) is the destination of the optic nerve its primary function is to relay and dispatch information to the primary visual cortex. It also perform some pre-processing functions.

Source: Paresh Malhotra, ICL

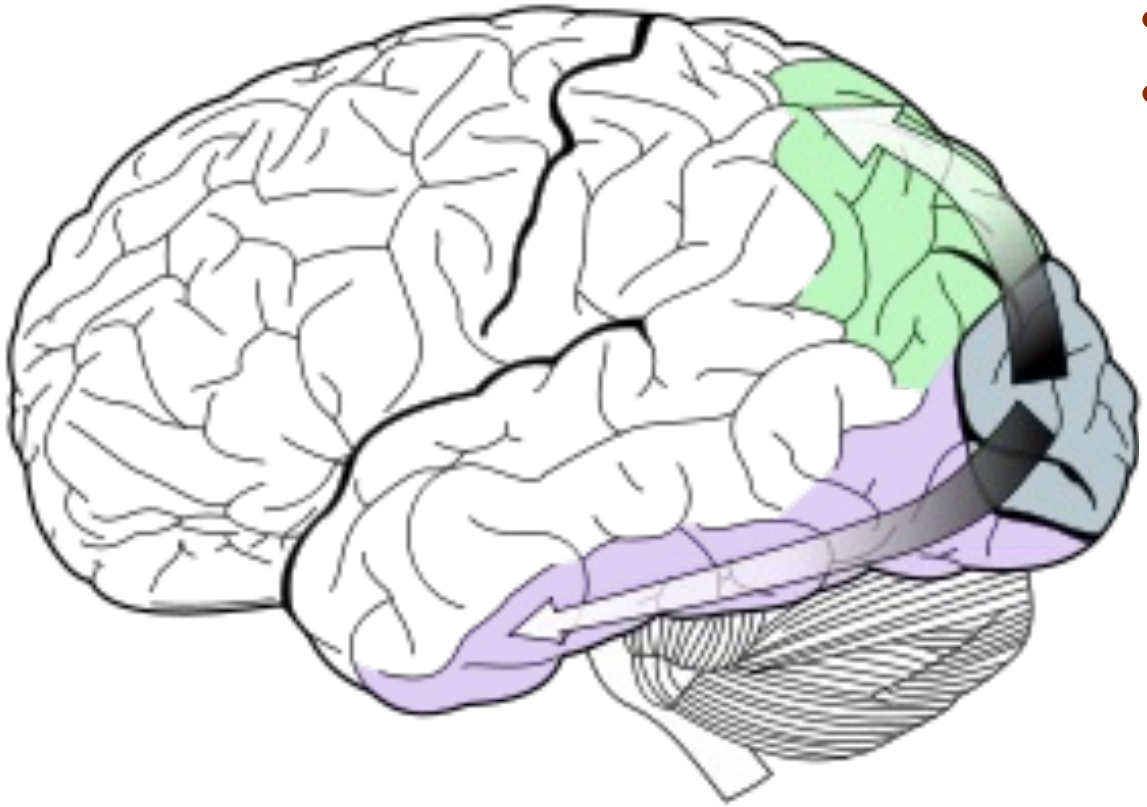
Higher-order Visual Pathway

- Information from the contralateral eye goes to layers 1, 4 and 6
- Information from the ipsilateral eye goes to layers 2, 3 and 5



Source: Banich & Compton, 2018

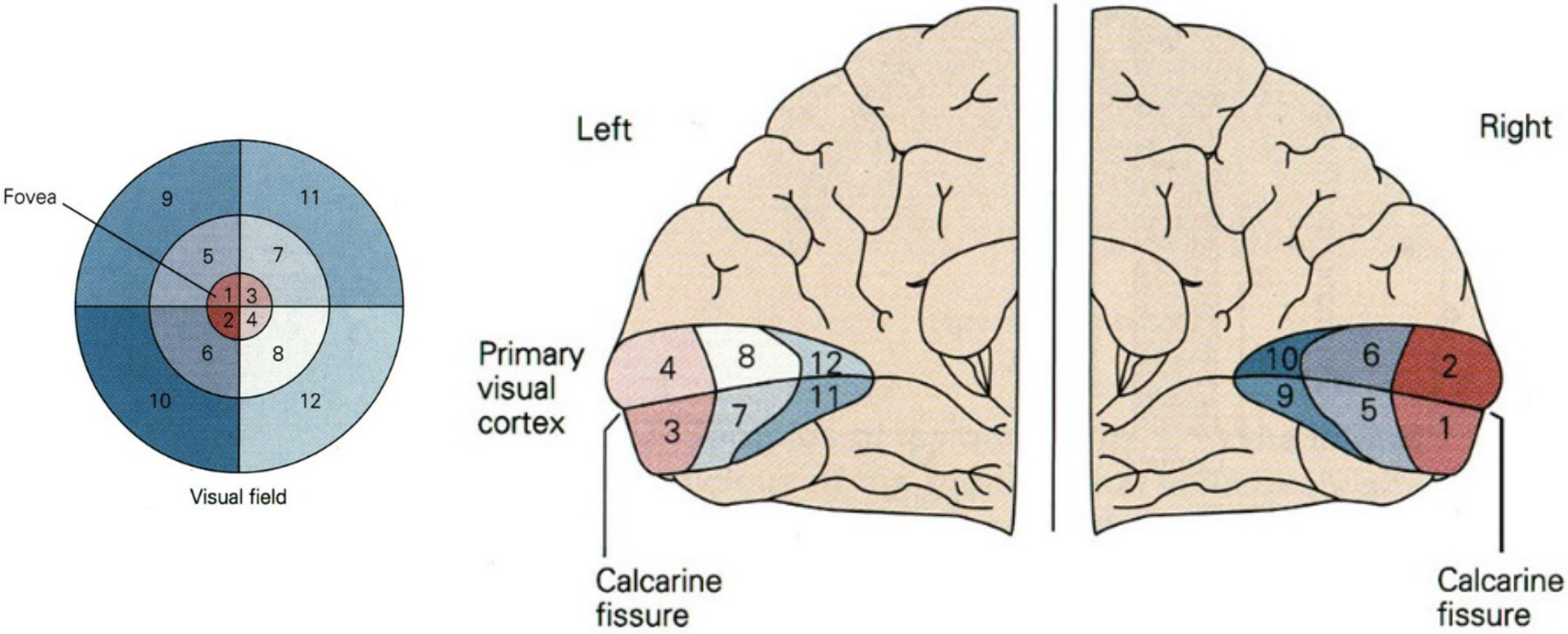
Visual Area



- Dorsal ‘Where’ Stream
  - Spatial awareness
  - Visually-guided behaviour
- Ventral ‘What’ Stream
  - Recognition & discrimination of visual shapes & objects
  - Perception & recognition of faces

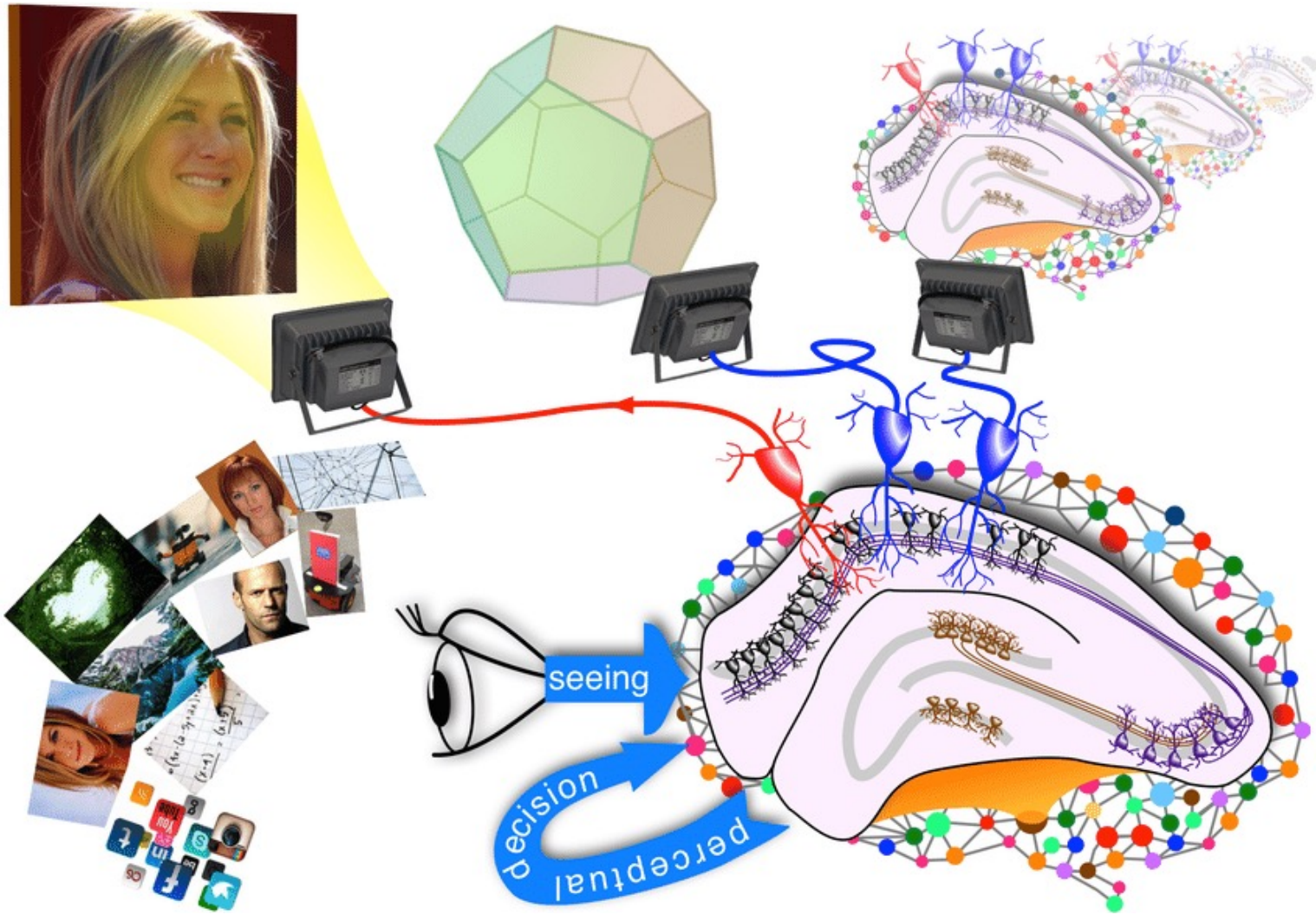
Source: Banich & Compton, 2018

Retinotopic mapping



Source: Paulun et al, 2018.

High dimension perception – Jennifer Aniston Cell



Source: Gorban et al, 2018