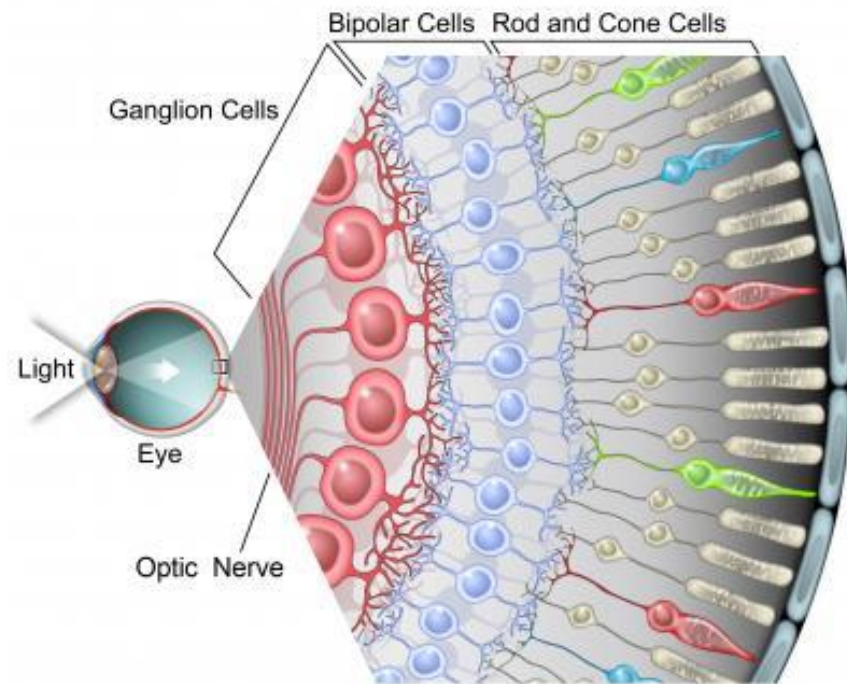
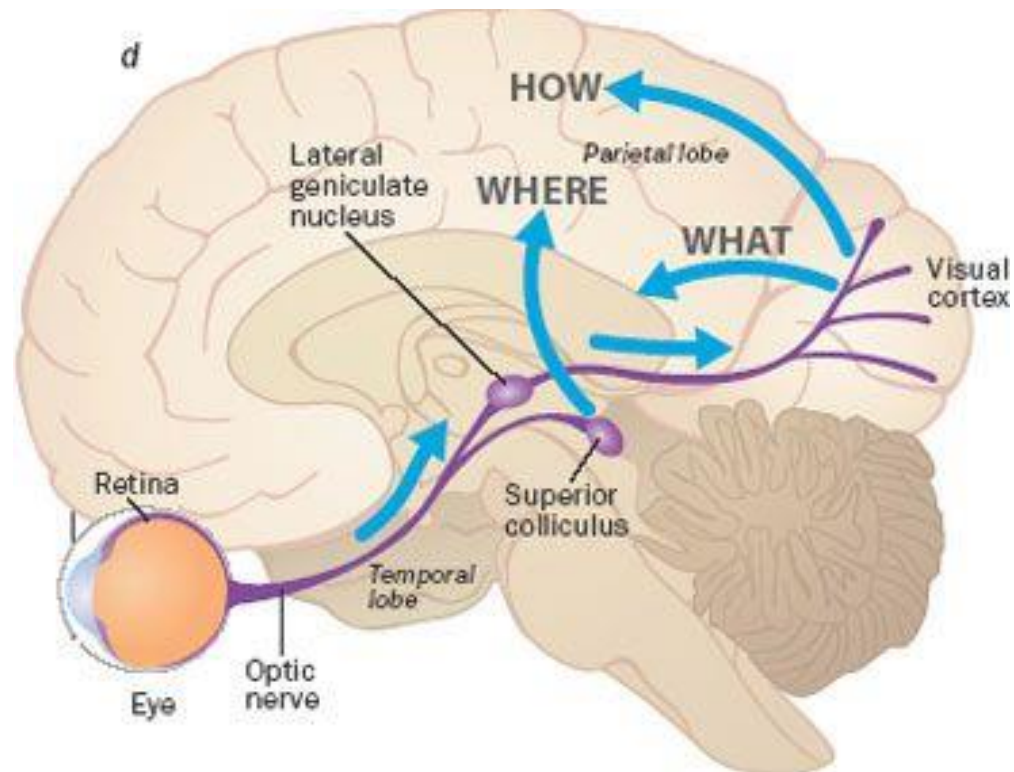


Principles of Visual Processing

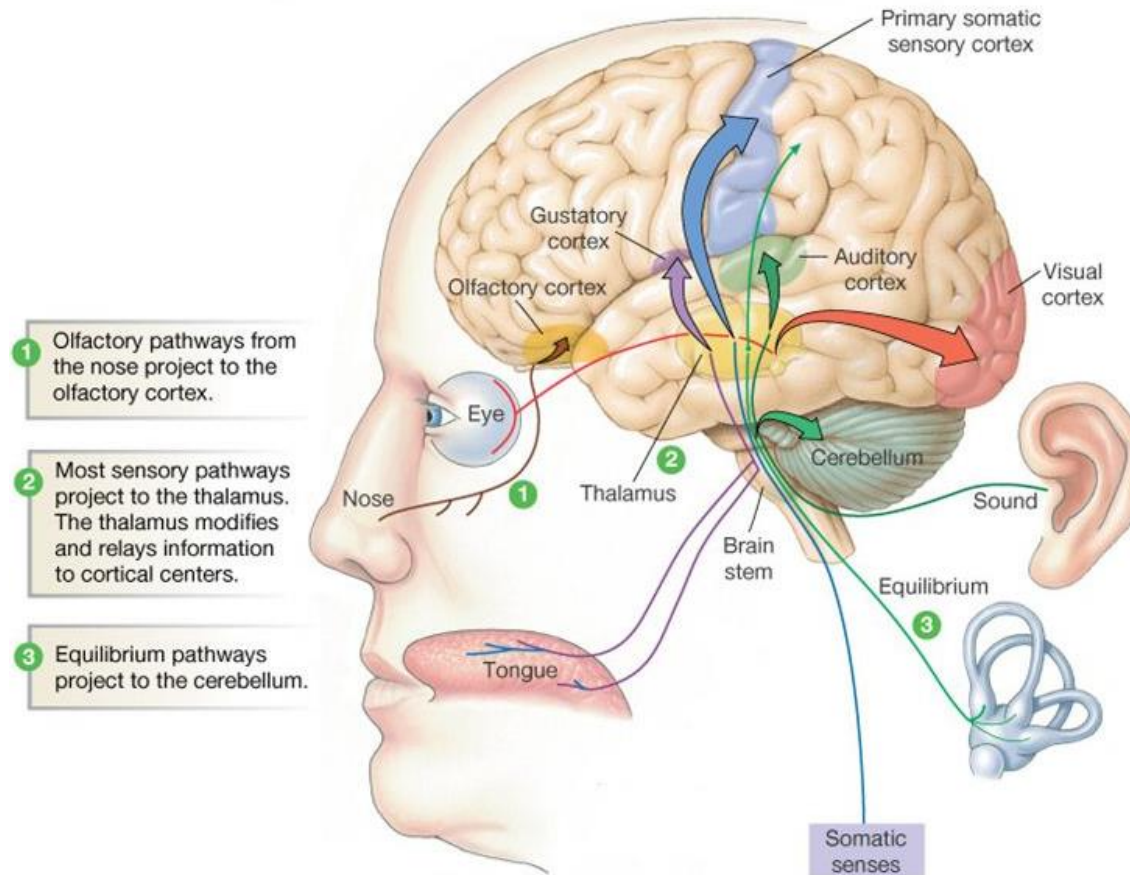
Retinal processing



Visual brain areas



Sensory Transduction



Sensory Transduction = conversion of a sensory stimulus to format neurons can understand.

Visual system; converts photons to action potentials

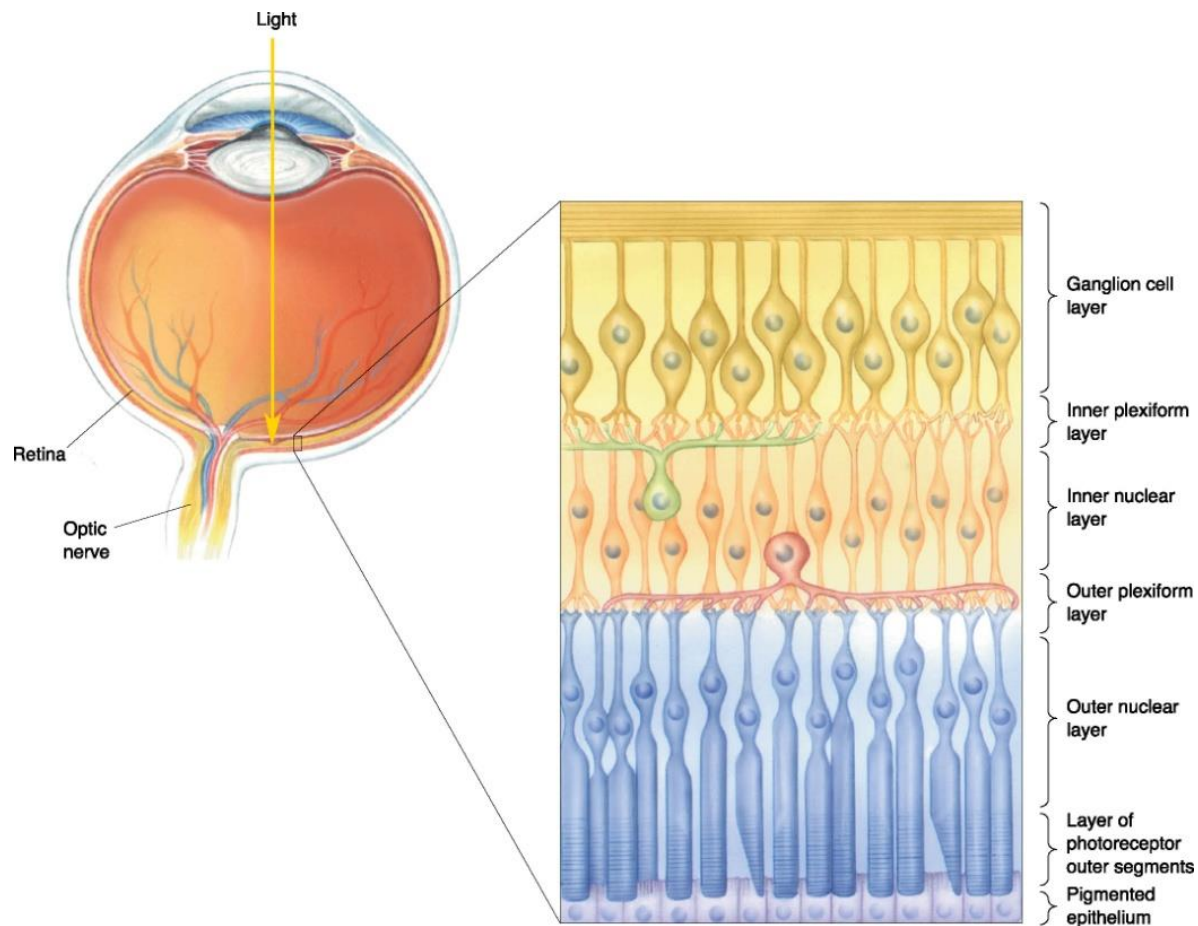
Why do animals need vision?



- Most basic function; to go towards the light (Phototaxis).
- Circadian rhythm
- More sophisticated visual systems can be used to hunt prey or avoid predators

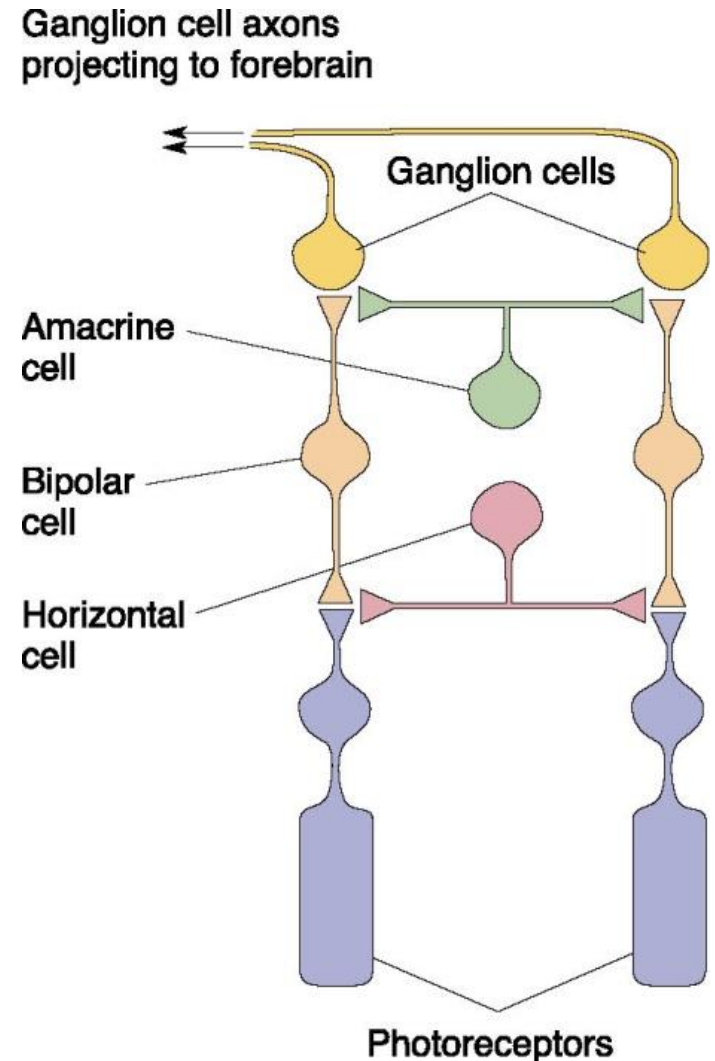
Laminar Organization of the Retina

- Seemingly inside-out layers
- Light passes through ganglion cells and bipolar cells before reaching photoreceptors.



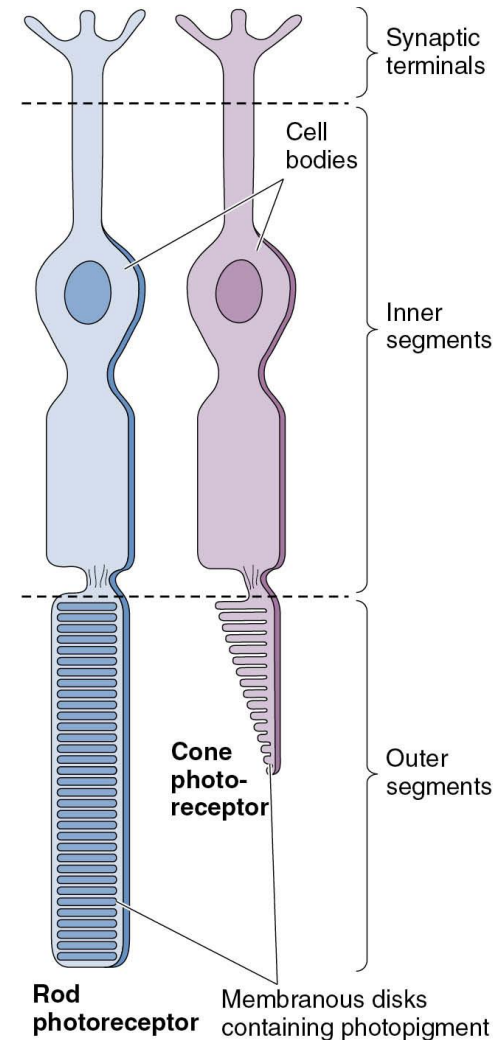
Microscopic Anatomy of the Retina

- Direct (vertical) pathway
 - Ganglion cells
 - Bipolar cells
 - Photoreceptors

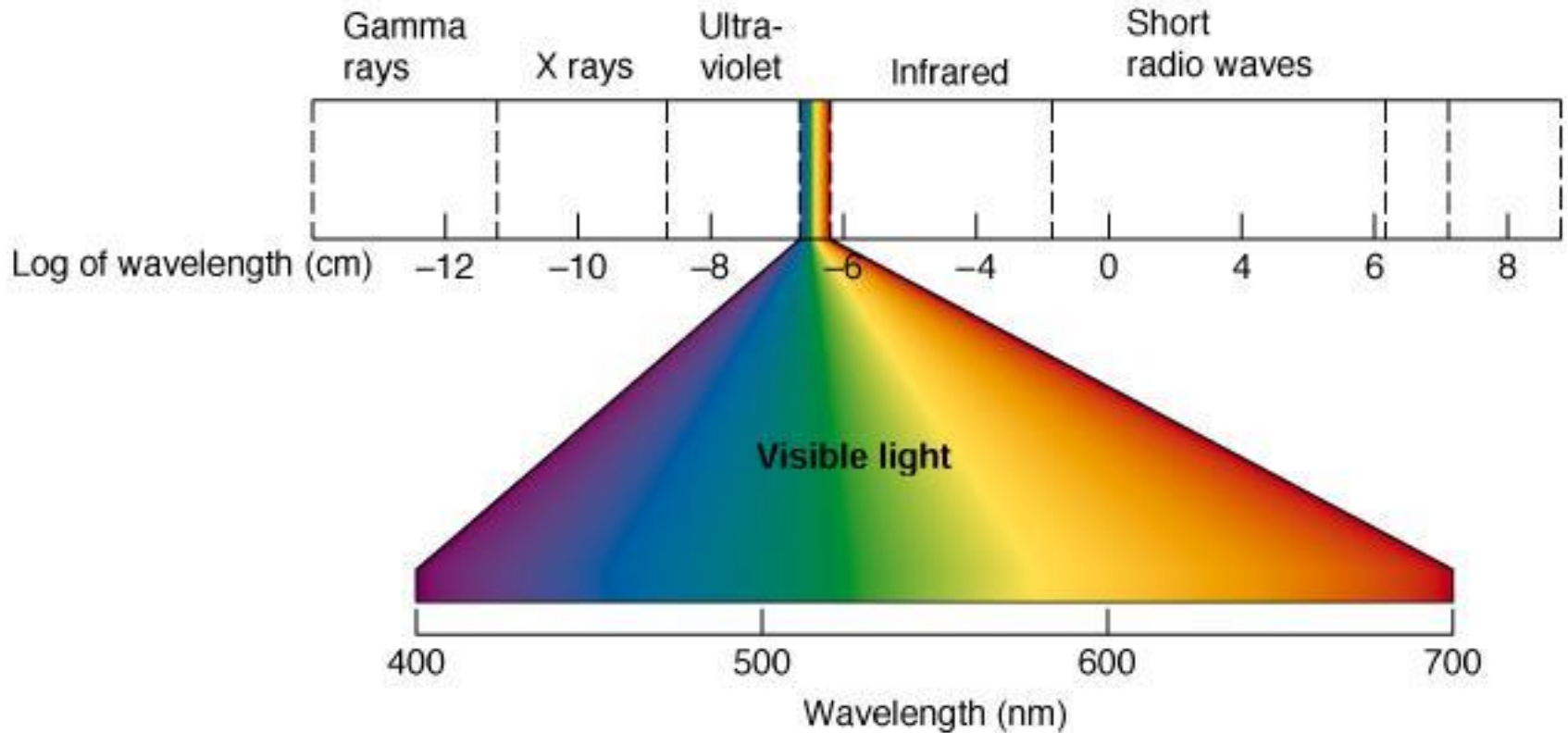


Photoreceptors

- Receptor neurons with structural and functional adaptations to detect the stimulus
- Four main regions
 - Outer segment
 - Inner segment
 - Cell body
 - Synaptic terminal
- Types of photoreceptors
 - Rods and cones

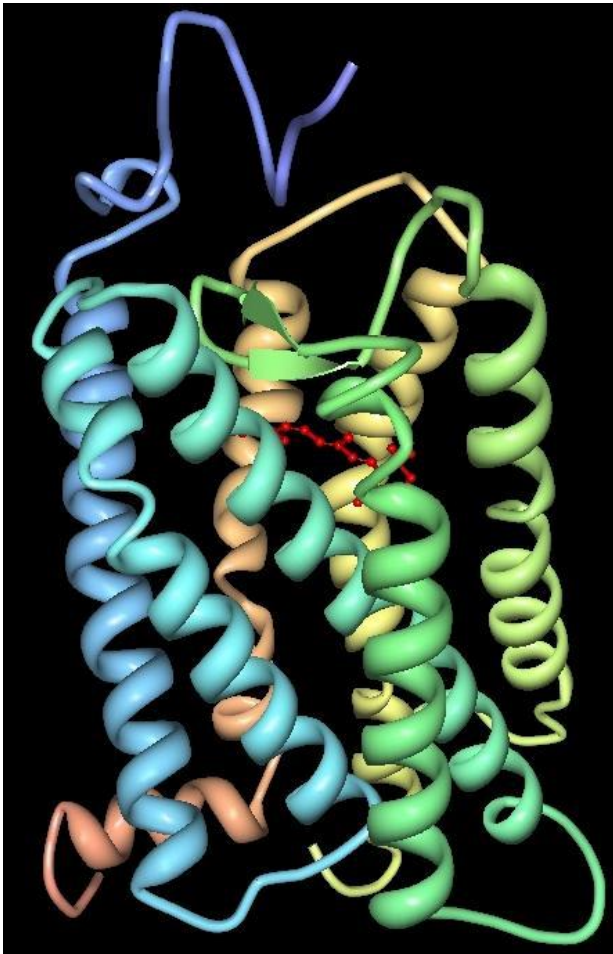


Electromagnetic spectrum

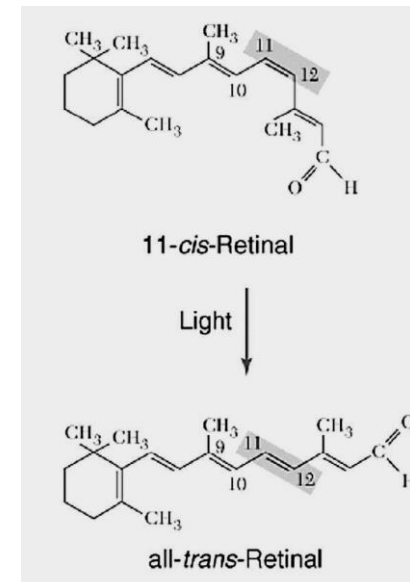


Problem; amino acids don't absorb much visible light; peak is in the UV

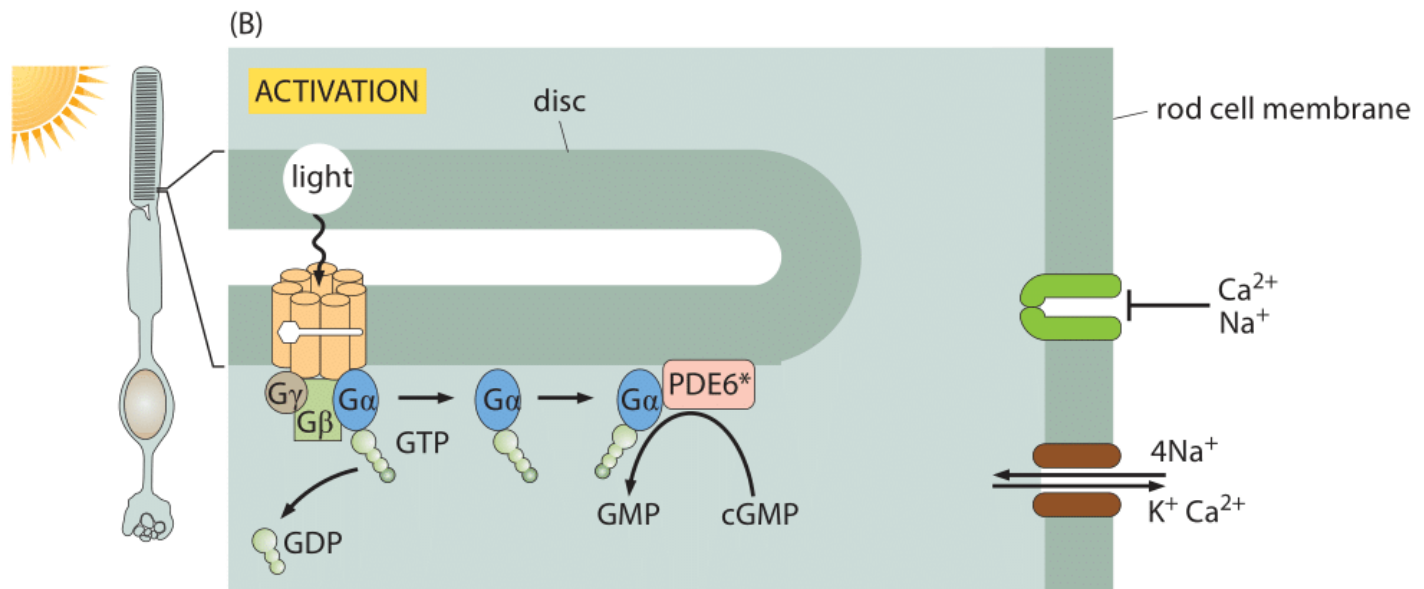
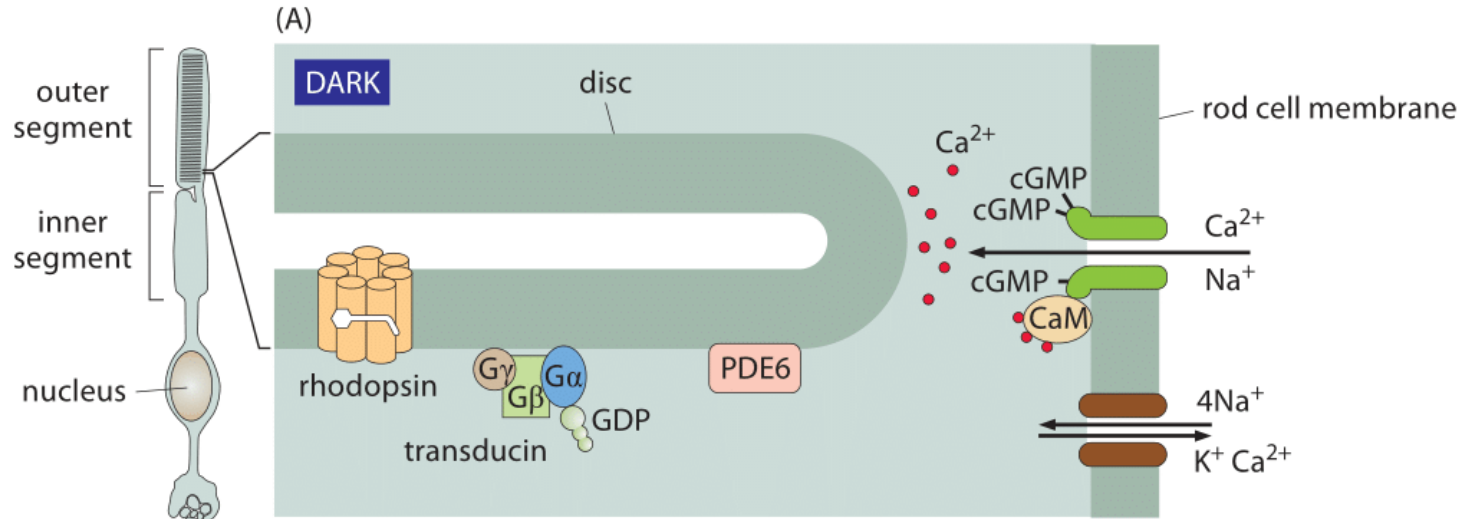
To absorb light, protein molecule is joined to prosthetic group



- Prosthetic group = Chromophore
- Able to absorb longer wavelengths
- Proteins that use Chromophore = opsins
- Opsin + Chromophore =
Rhodopsin

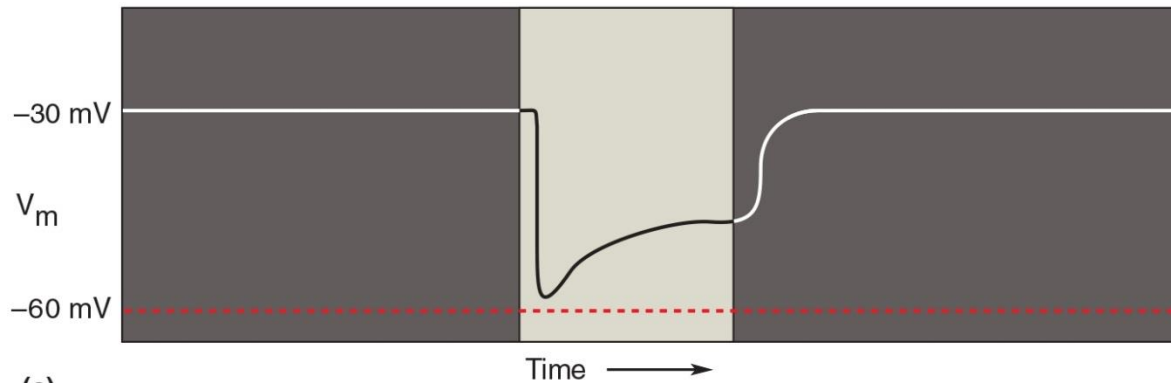


Dark and light states



- Phosphodiesterase 6 converts cGMP to GMP in light

Photoreceptor hyperpolarizes in response to light on

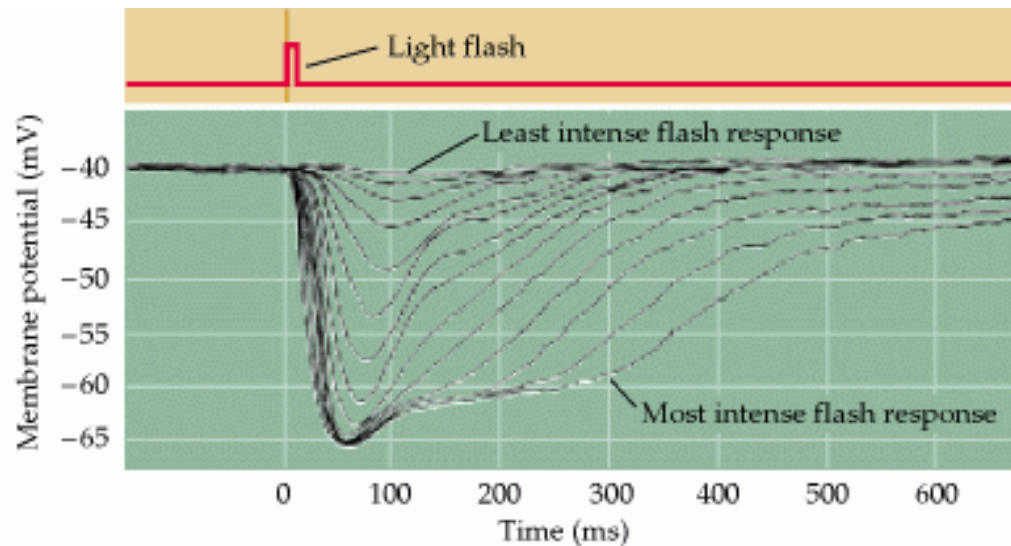


(c)

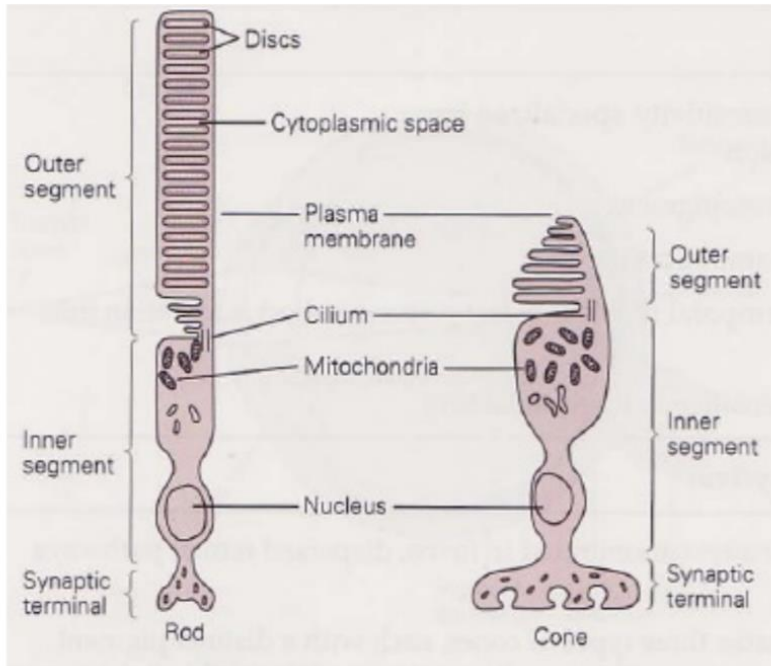
Copyright © 2016 Wolters Kluwer - All Rights Reserved

- Phosphodiesterase 6 converts cGMP to GMP in light

Graded response to light; more photons = more hyperpolarization

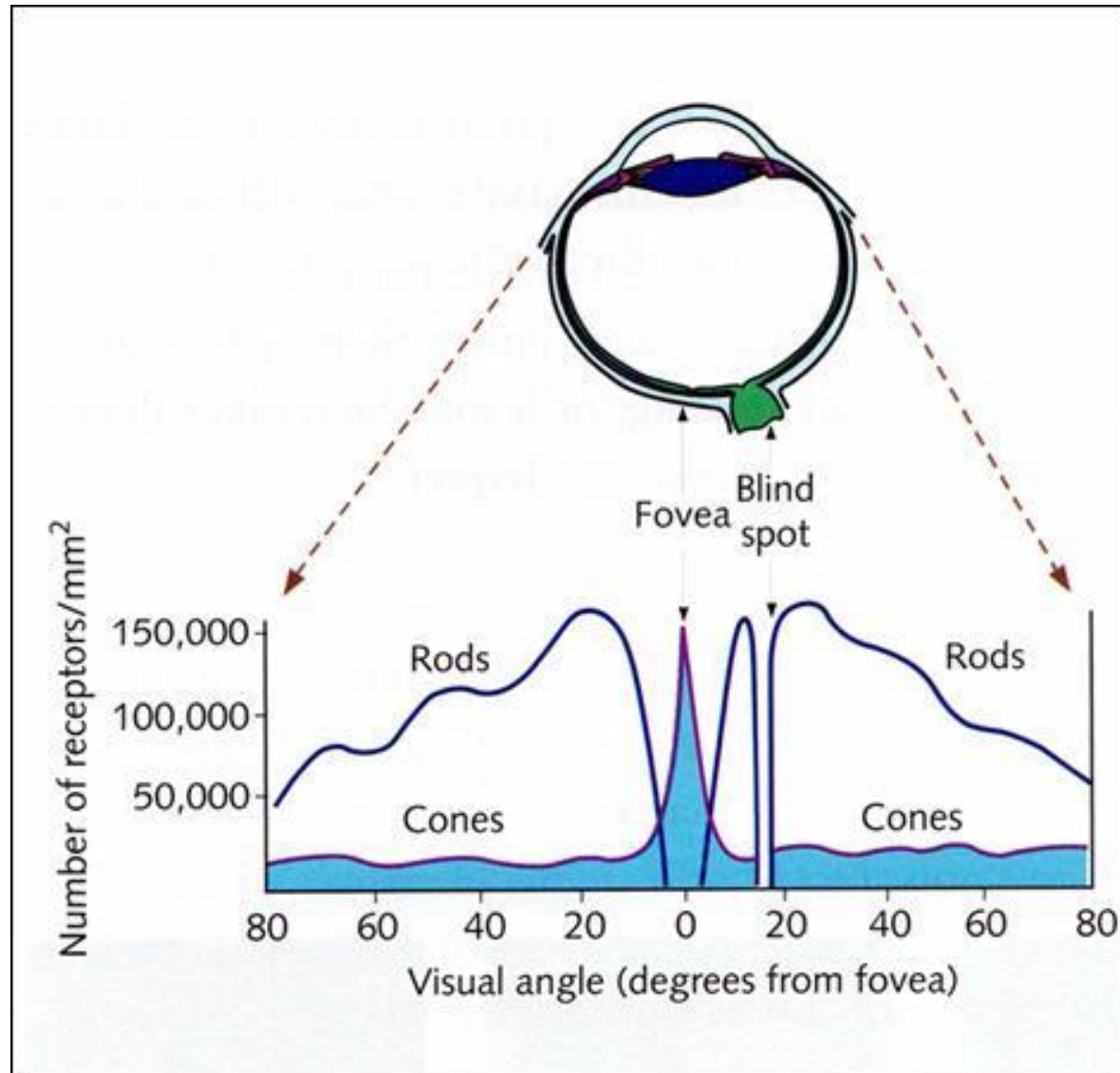


Rods and Cones

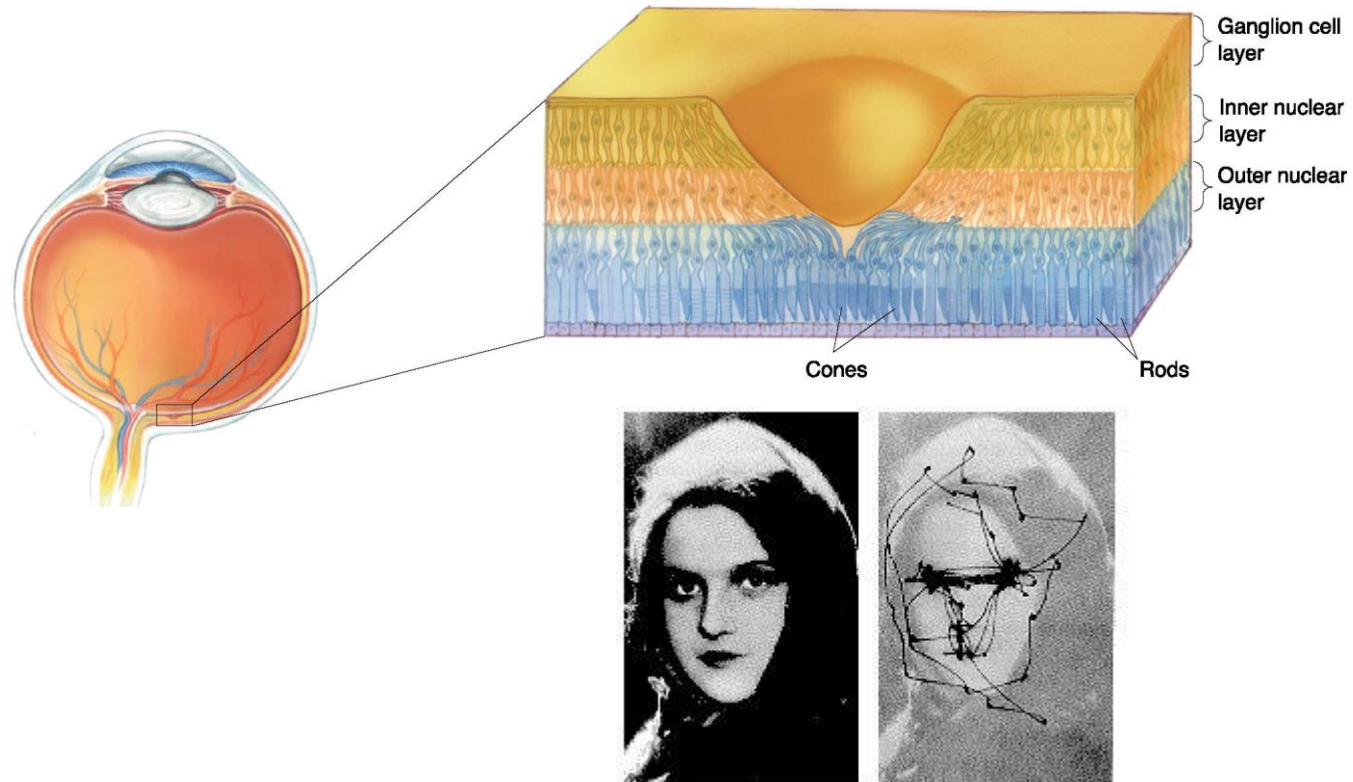


- Rods are more reliable in transmitting signals (which is why they are useful in the dark)
- Rods saturate at bright lights and cones do not
- Cones are faster and responses are more transient (high rate of opsin regeneration)

Distribution of rods and cones



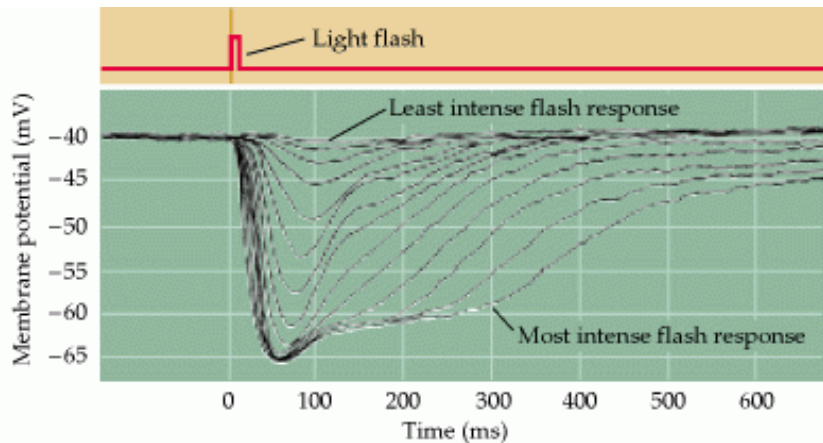
The fovea



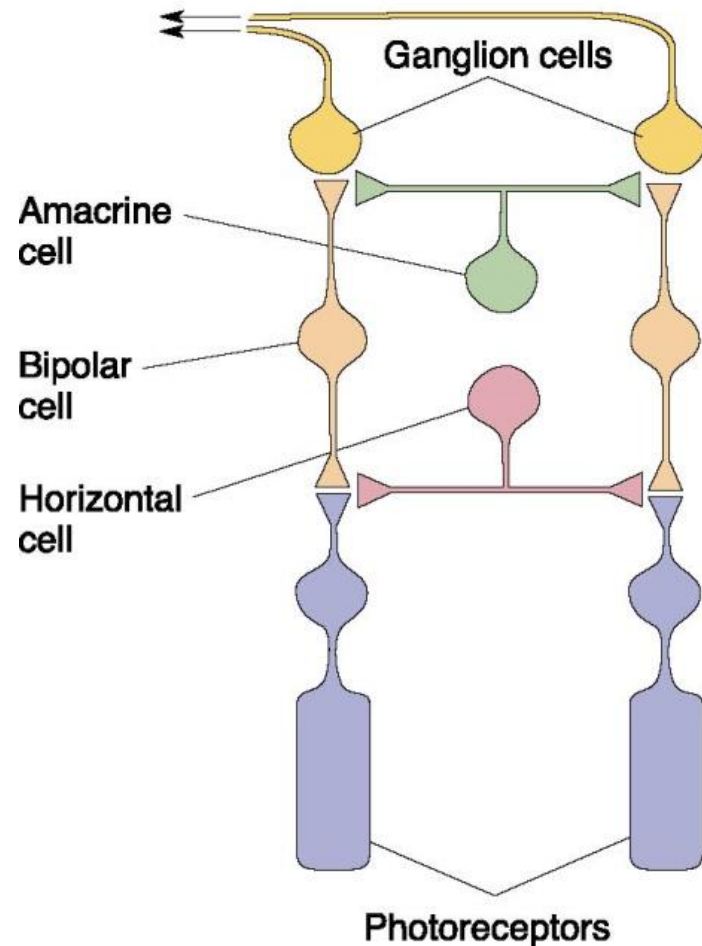
- Cross section of fovea: pit in retina where outer layers are pushed aside
 - Maximizes visual acuity
- Central fovea: all cones (no rods)
 - Area of highest visual acuity

Microscopic Anatomy of the Retina

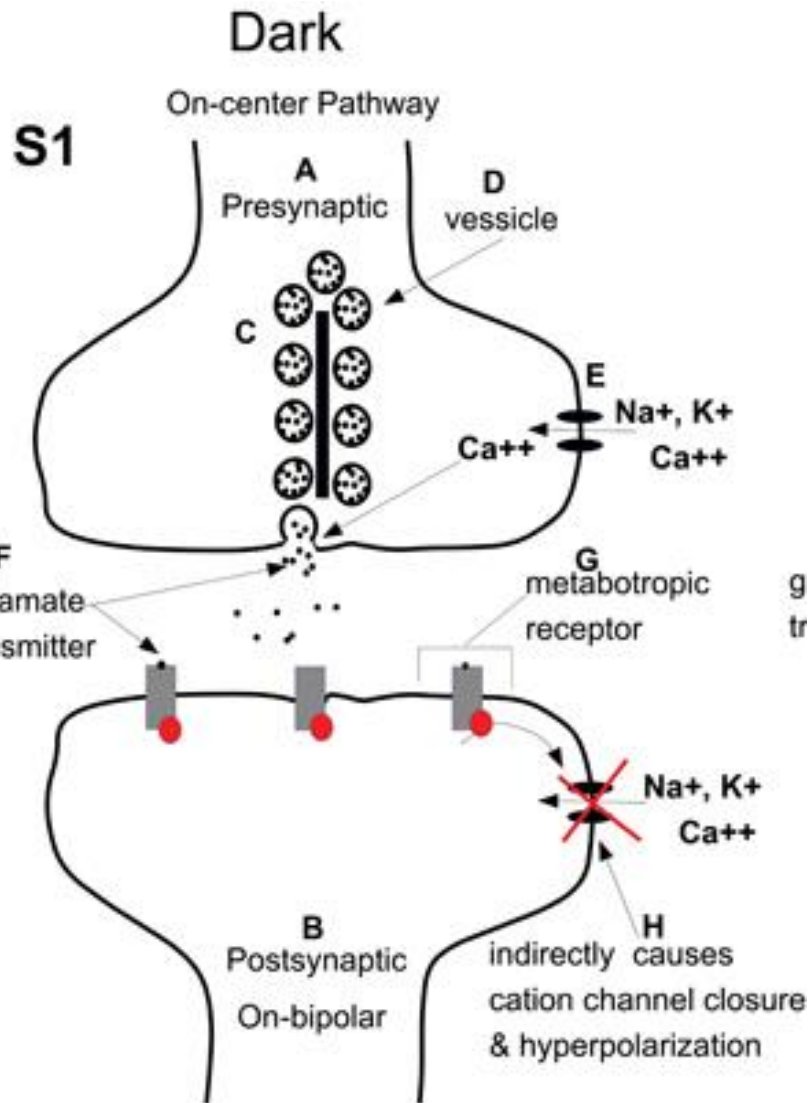
- Direct (vertical) pathway
 - Ganglion cells
 - Bipolar cells
 - Photoreceptors



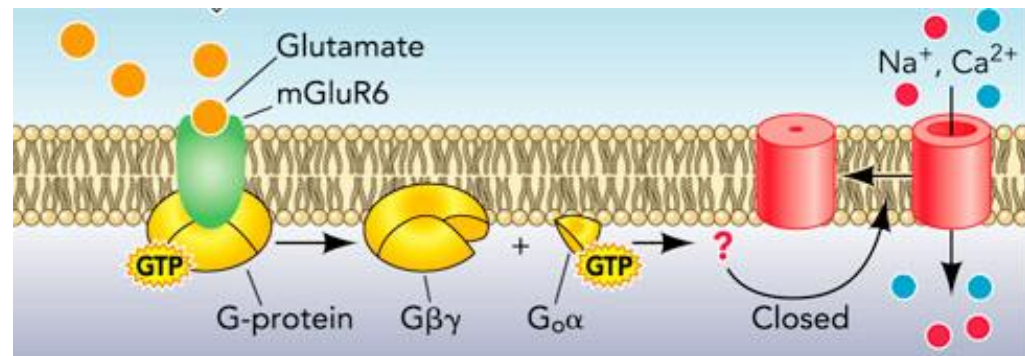
Ganglion cell axons
projecting to forebrain



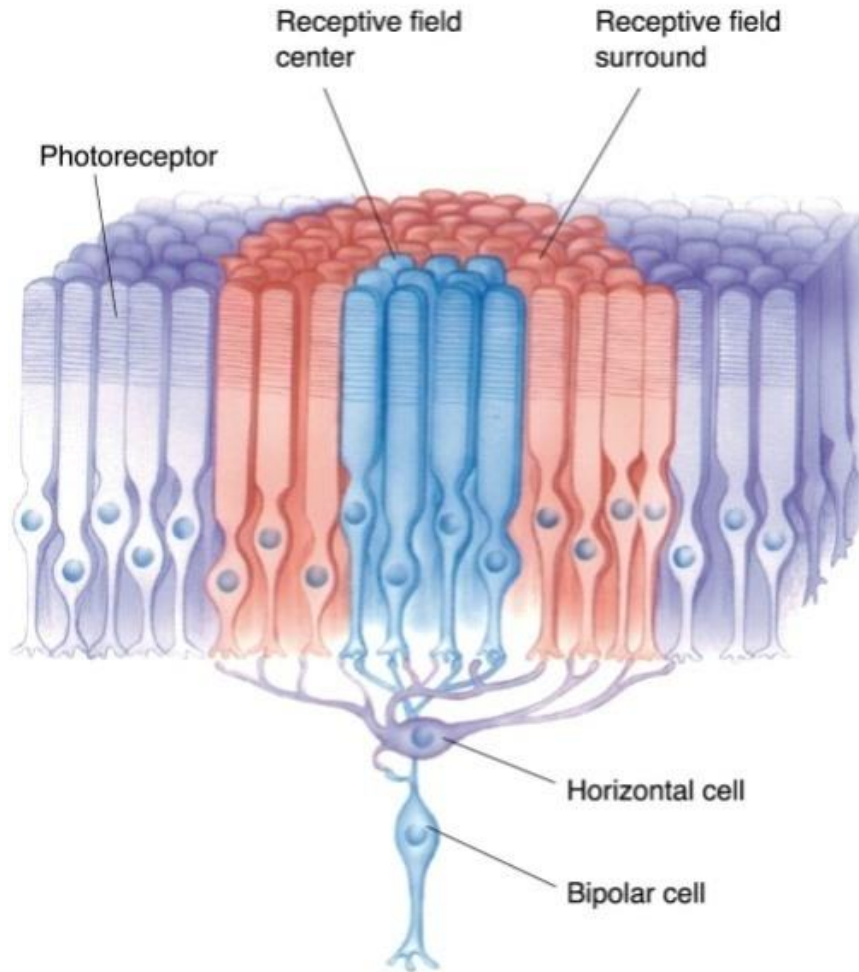
ON bipolar cells



- ON bipolars have metabotropic glutamate Rs
- Glutamate causes G protein activation.
- Therefore OFF bipolars are depolarized in the dark, hyperpolarized in light.



Bipolar cells also get input from horizontal cells



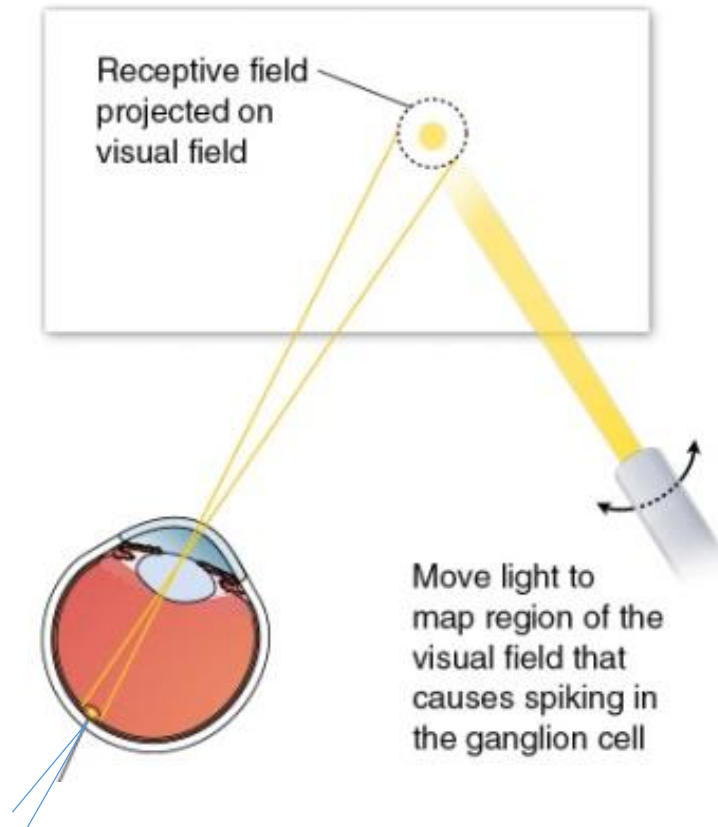
- Horizontal cells are gabaergic
- Provide inhibitory input to bipolar cells.

The Receptive Field

A neuron's receptive field is the **area of sensory space** in which a stimulus will **modify** the response of that neuron.

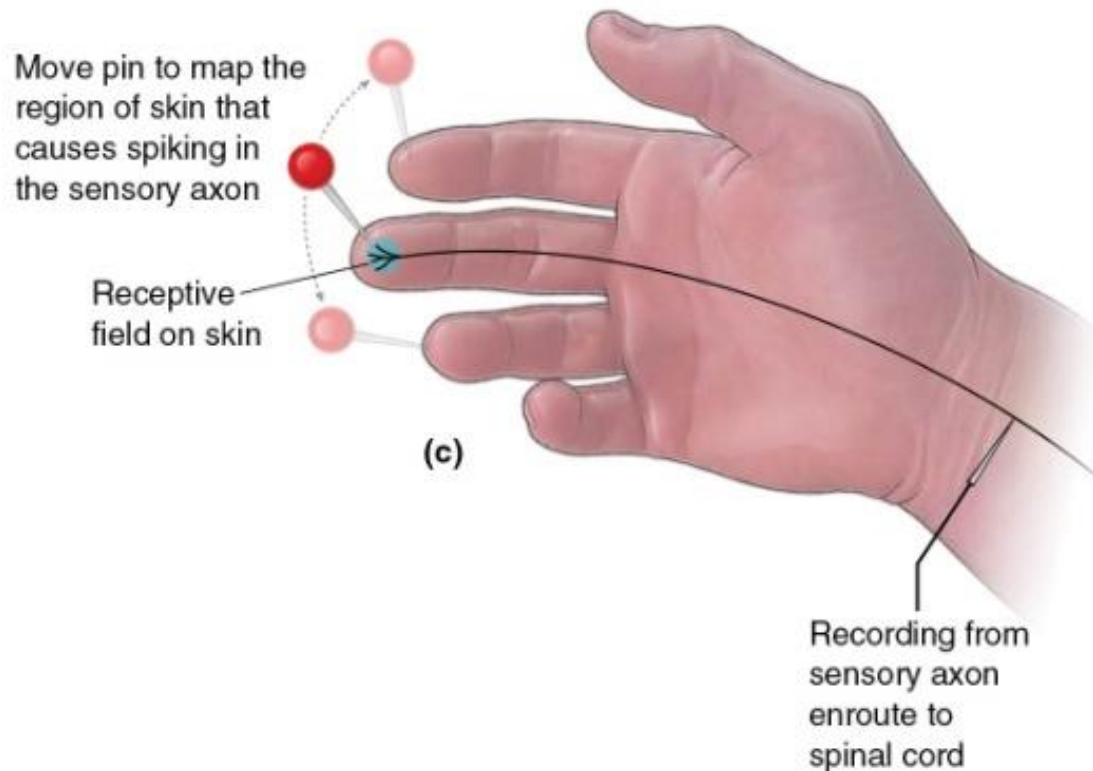
ON Bipolar cell
recording:

ON center cell

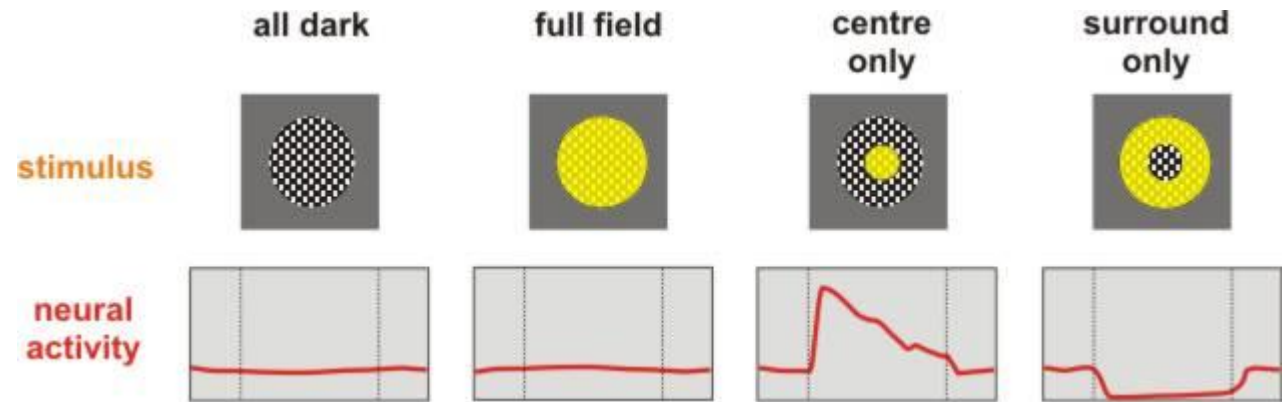
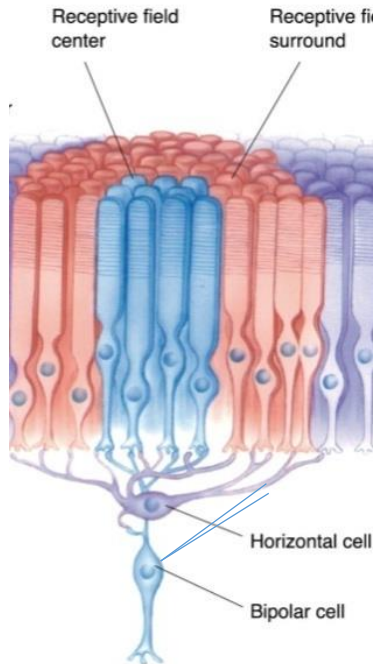


The Receptive Field

RF for touch: this neuron's RF is the tip of the middle finger.

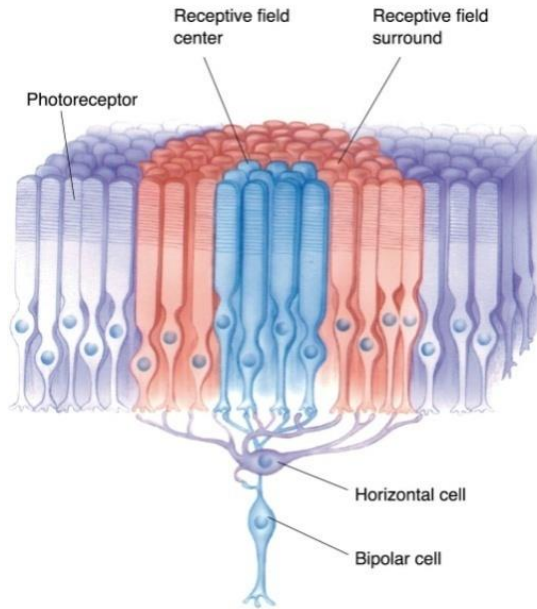


Many bipolar cells have center-surround receptive fields



- Their preferred stimulus is a small spot with a contrasting ring
- In this case, light ON in the center depolarizes the BC
- Effect is mediated by horizontal cells

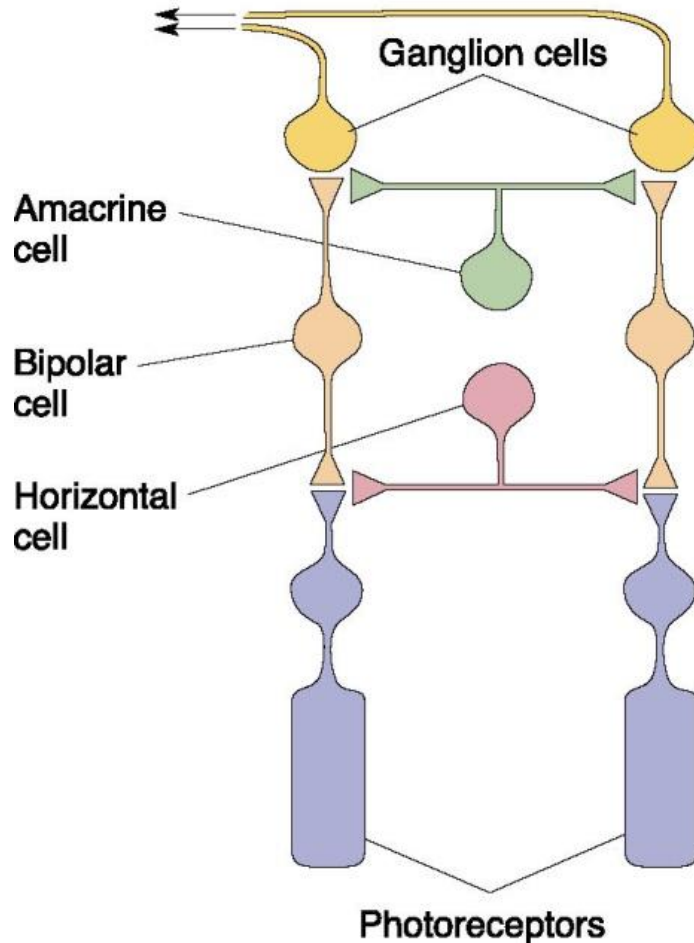
Function of center surround circuits; they emphasize edges



- Cells are optimally activated by center plus contrast in surround
- Has the effect of sharpening the image and defining the borders of an object

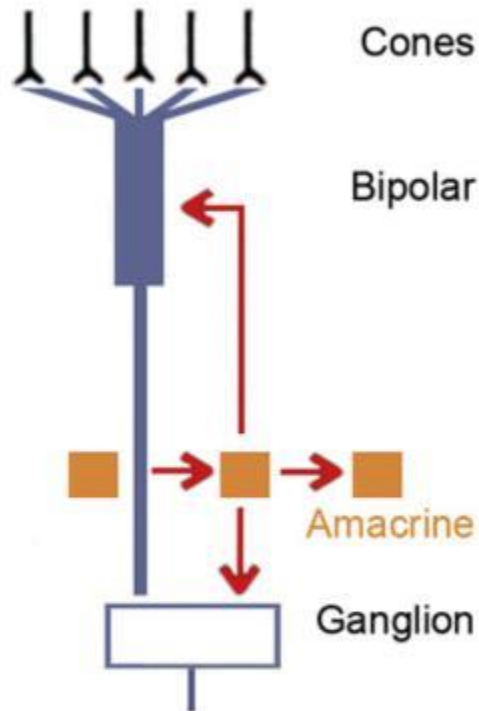
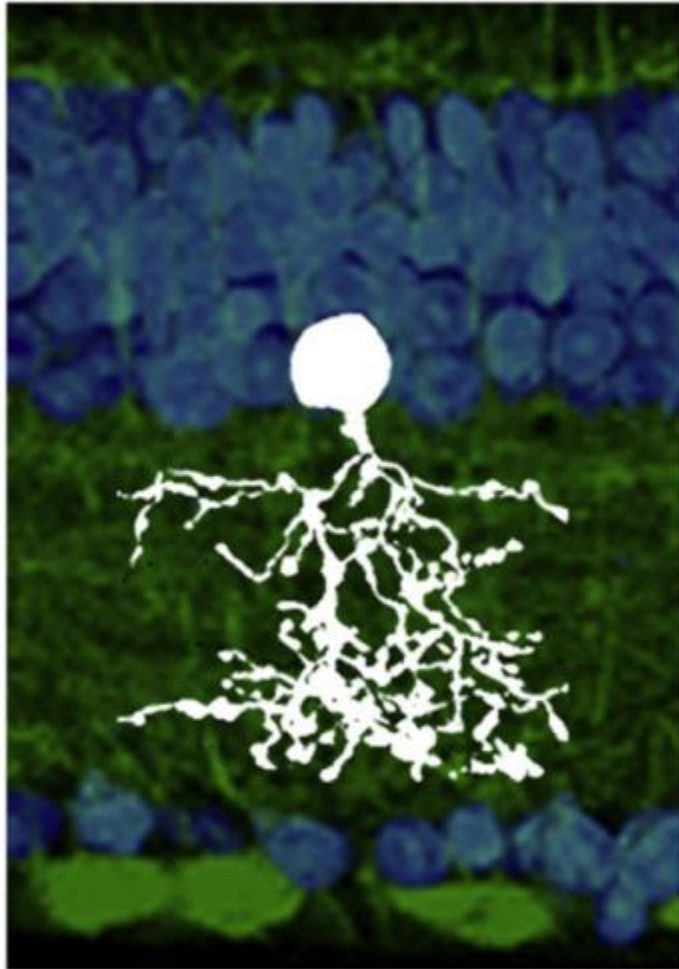
Retinal Ganglion Cells and Amacrine cells

Ganglion cell axons
projecting to forebrain



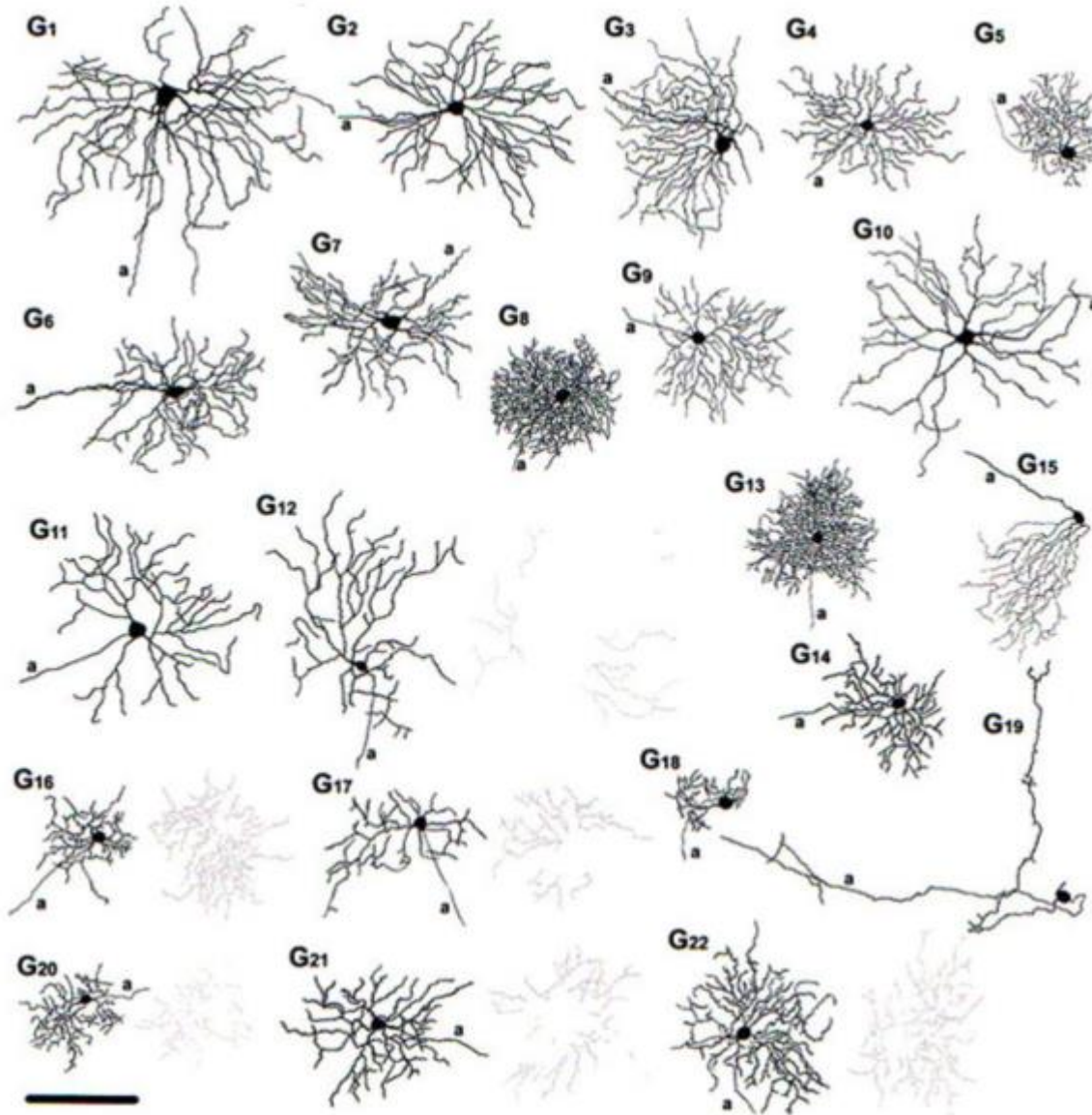
- RGCs get input from bipolar cells and Amacrine cells

Amacrine cells



- Amacrine cells are axonless so input/output can be difficult to determine.
- Connect to bipolar and retinal ganglion cells

Retinal Ganglion Cell (RGC) Types



- There are at least 30 types of RGCs
- Can be distinguished by morphology and/or function

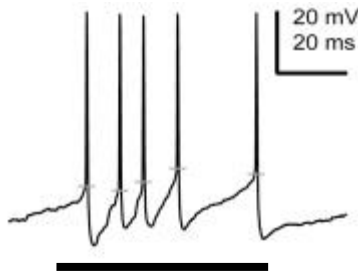
ON center RGCs

ON Bipolar cell recording:

ON center cell

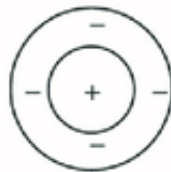


ON RGC recording:

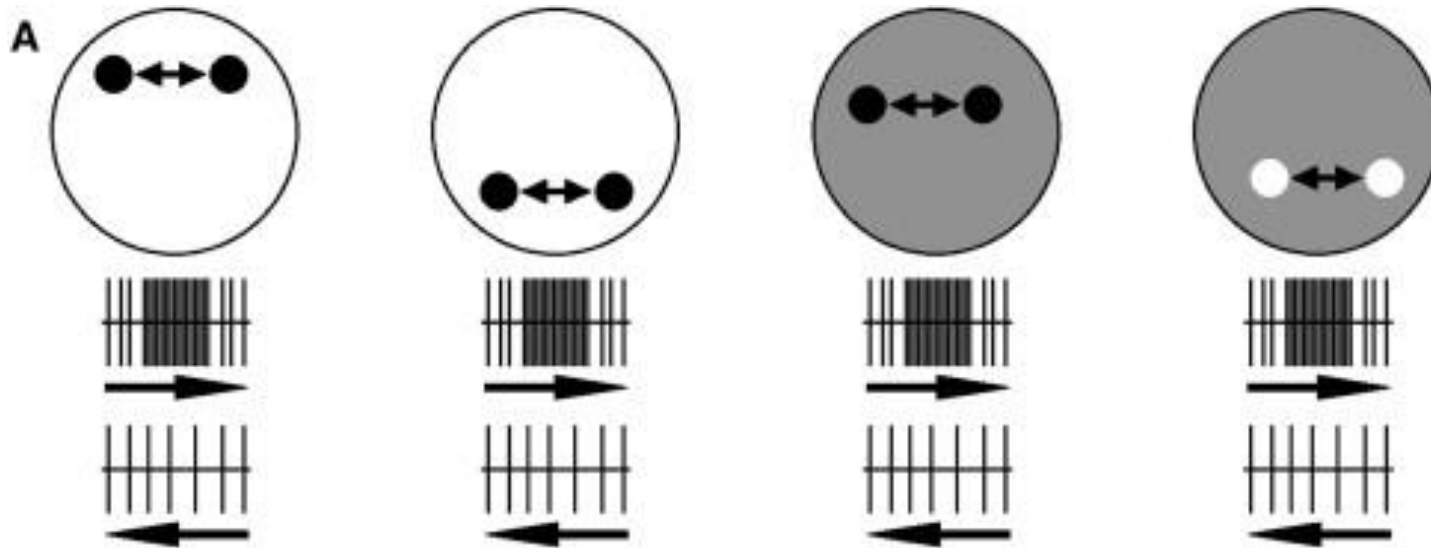


- Similar to ON BCs
- Key difference; they fire action potentials.
- Q; why do RGCs need to fire APs while BCs don't?

ON centre

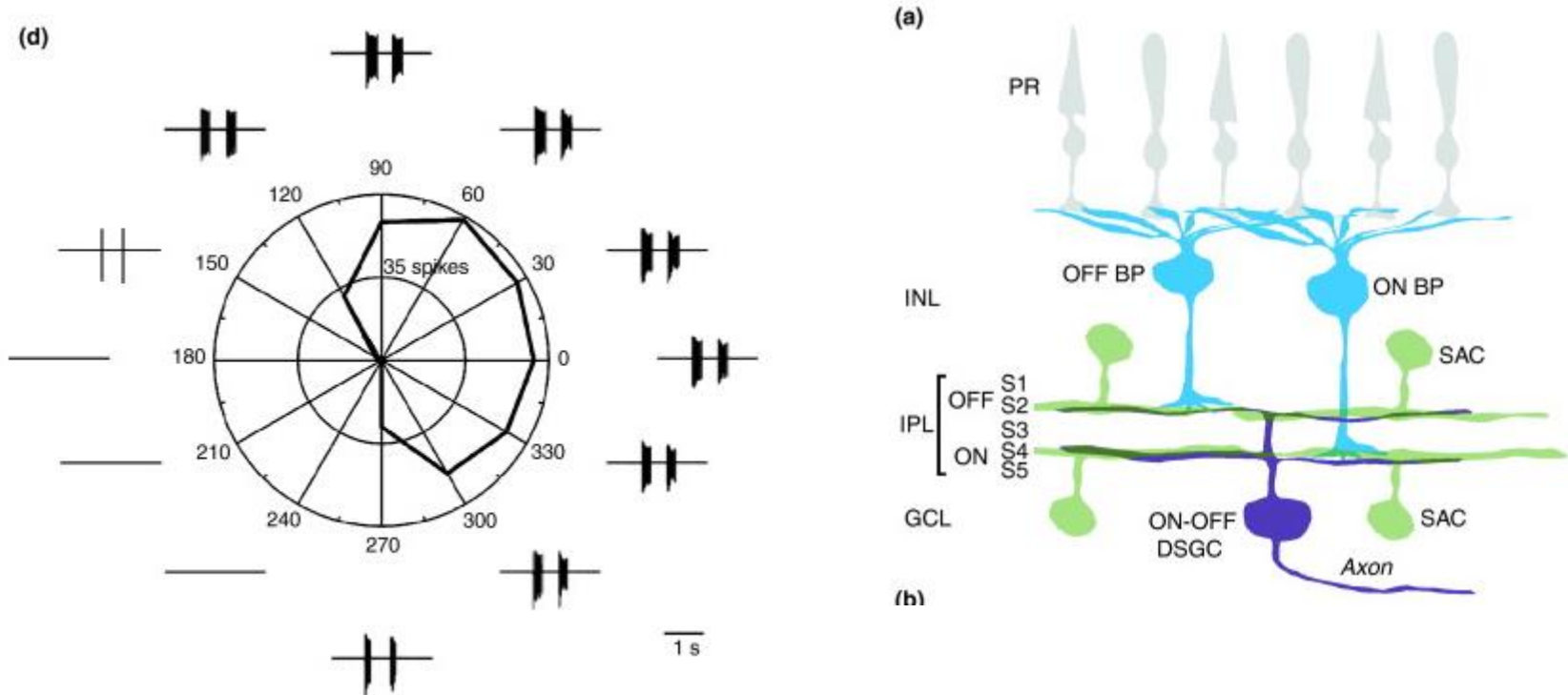


Direction Selective Retinal Ganglion Cells (dsRGCs)



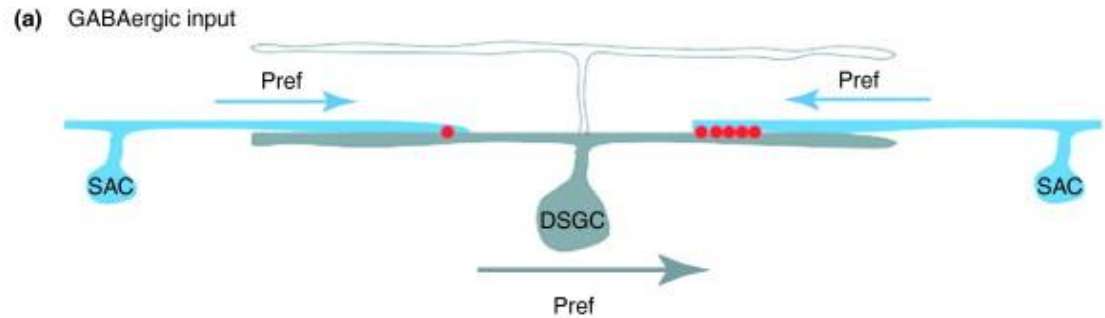
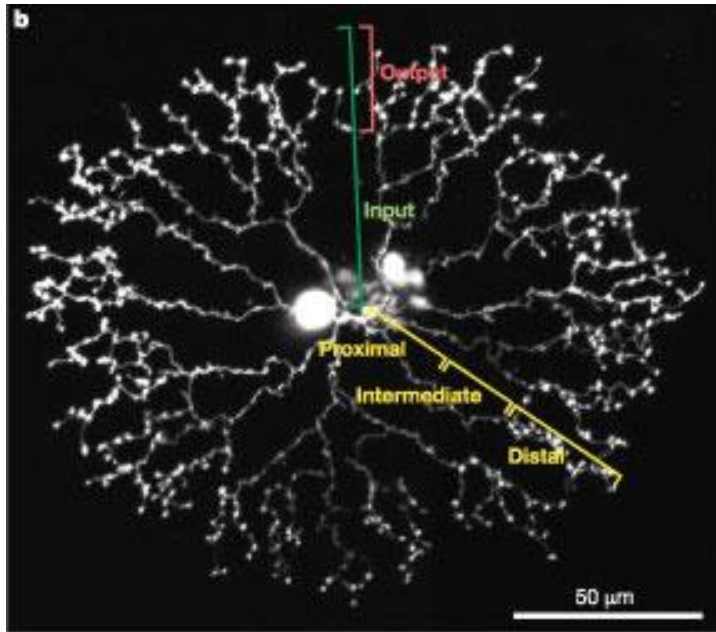
- RGCs that spike in response to motion in one direction
- They don't care about the exact location of the stimulus within their RF (receptive field).
- They don't care whether it's a light or dark stimulus

Direction Selective Retinal Ganglion Cells



- dsRGCs spike in response to motion in one general direction
- These RGCs get input from Starburst Amacrine Cells

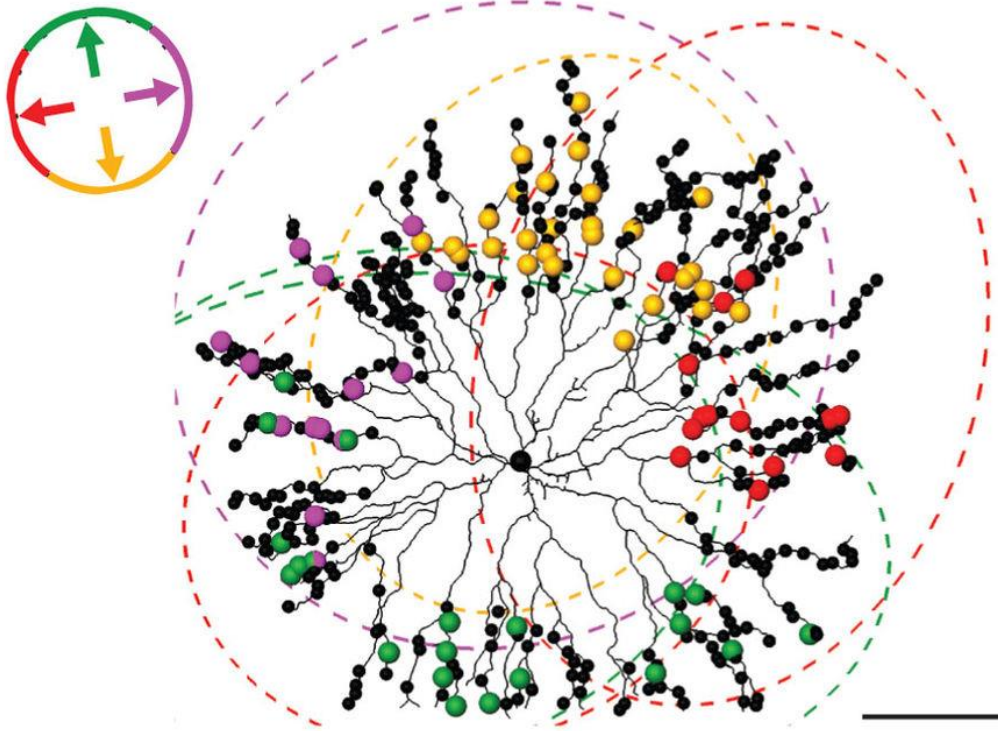
dsRGC and SAC relationship



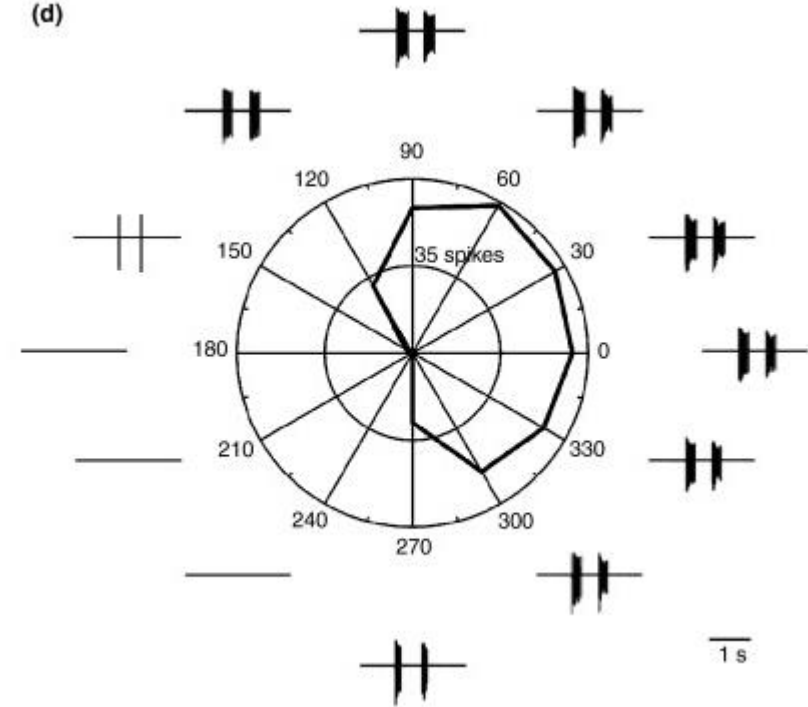
- Starburst amacrine cell dendrites respond to centrifugal motion (fleeing the center)
- dsRGCs tend to get GABAergic input from SAC dendrites with the opposite preference

dsRGC and SAC relationship

a

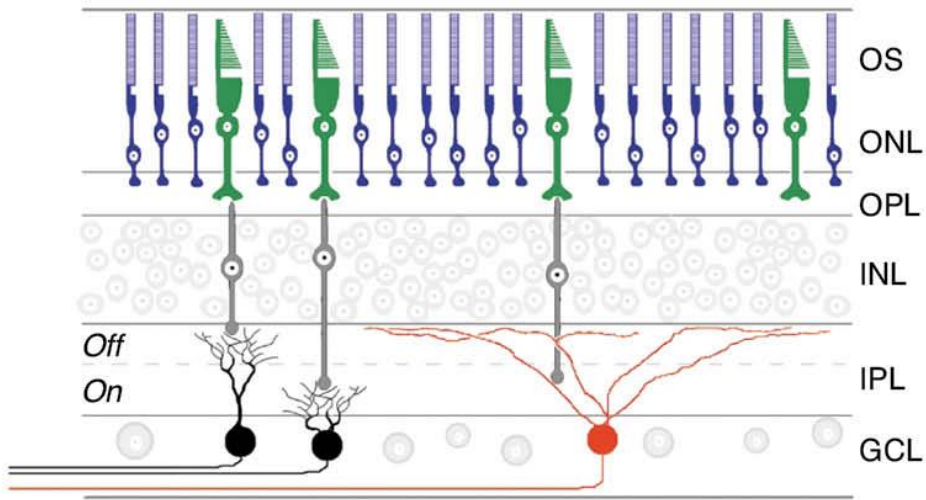


(d)

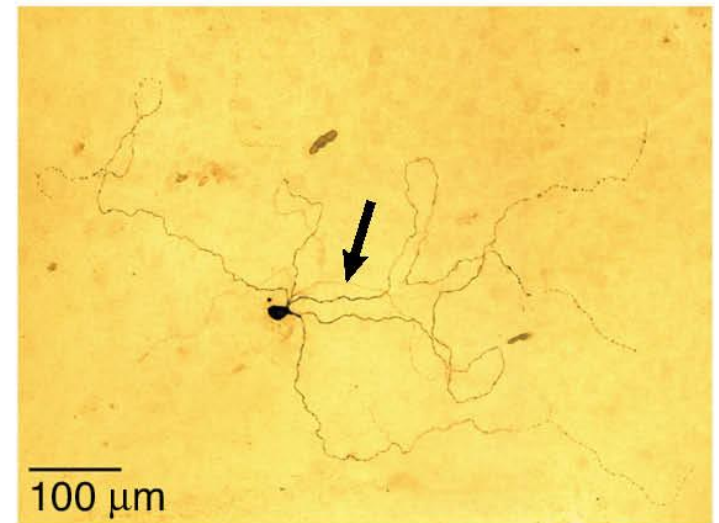


- This SAC's synapses are color coded by the directional preference of that dsRGC
- dsRGCs with downward preference (yellow) tend to synapse with upper part of SAC. Thus they get inhibited by upward motion

Retinal Ganglion Cells that detect light directly



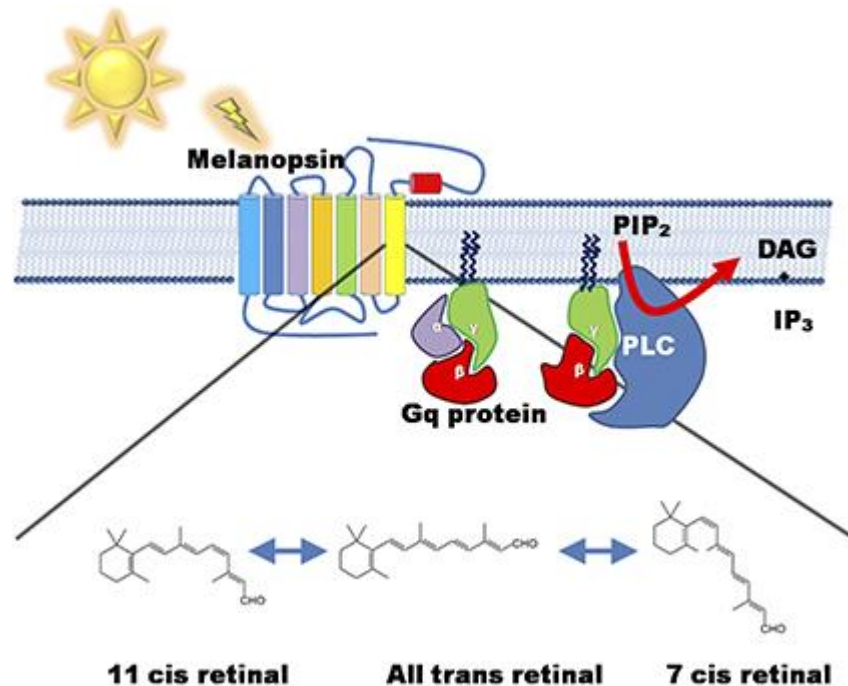
(a)



(b)

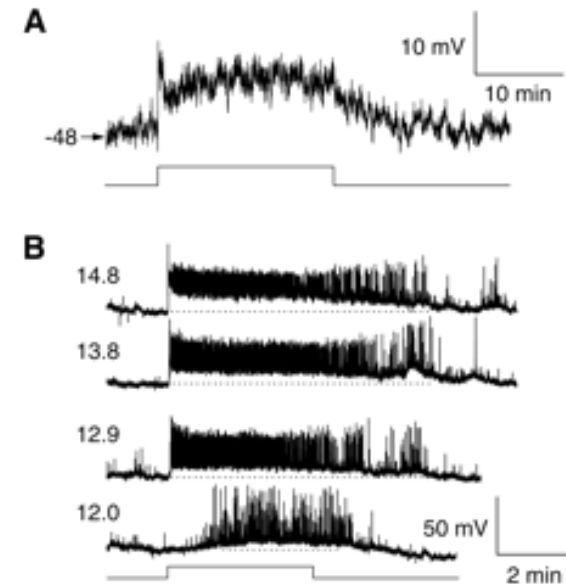
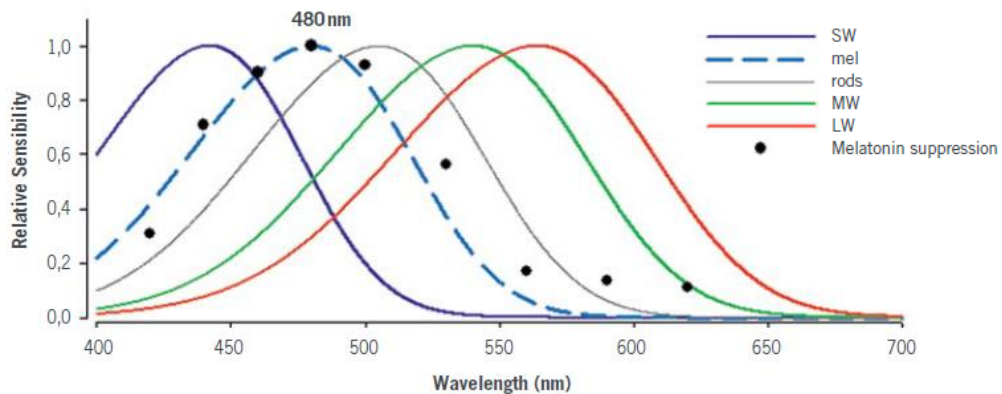
- Intrinsically photosensitive RGCs = ipRGCs
- Have large dendritic arbor

ipRGCs use Melanopsin to detect photons



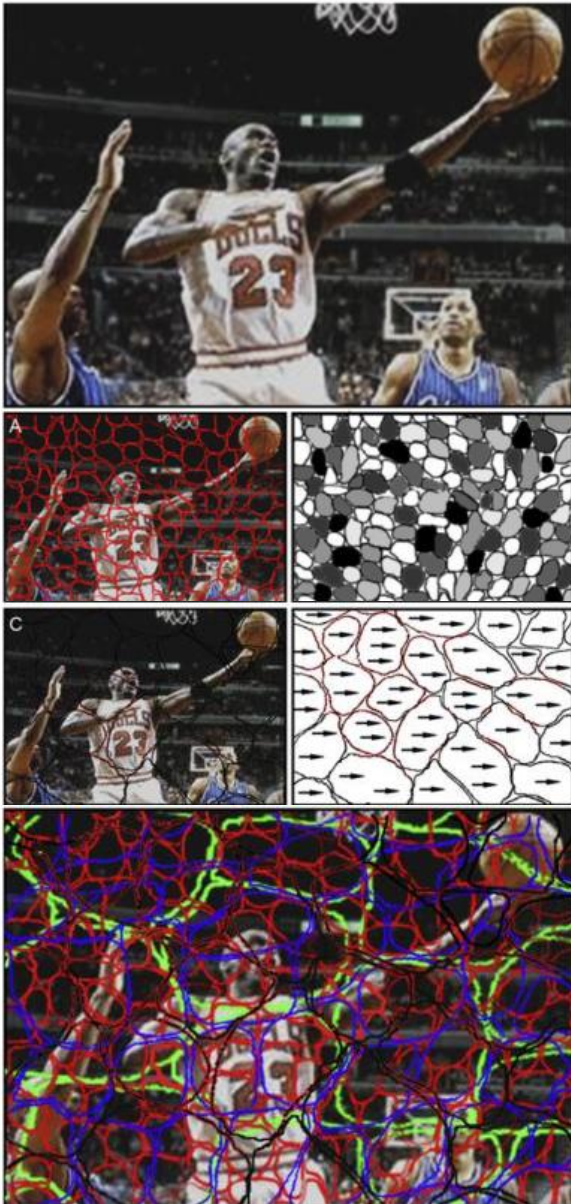
- Signal transduction pathway; compare to Rods and Cones
- What pathway is this more similar to?

ipRGCs use Melanopsin to detect photons



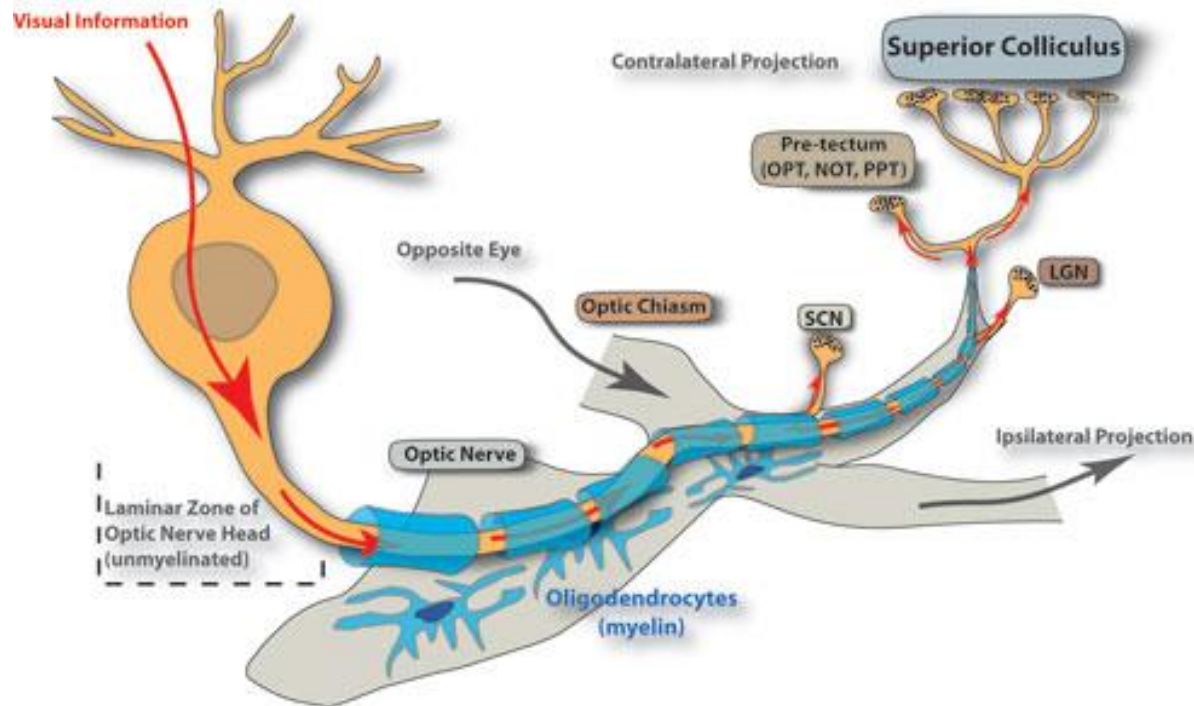
- Melanopsin responds to blue/green light
- ipRGC voltage response to light on
- How is it different from rod and cone response?

RGC Types are channels for one type of info



- Different RGCs detect different aspects of the moving image of basketball players.
- One cell type may detect illumination intensity
- Another may detect motion direction
- Other channels for color
- Somehow your brain puts these back together for visual percept formation
- Some channels may have distinct behavioural roles.

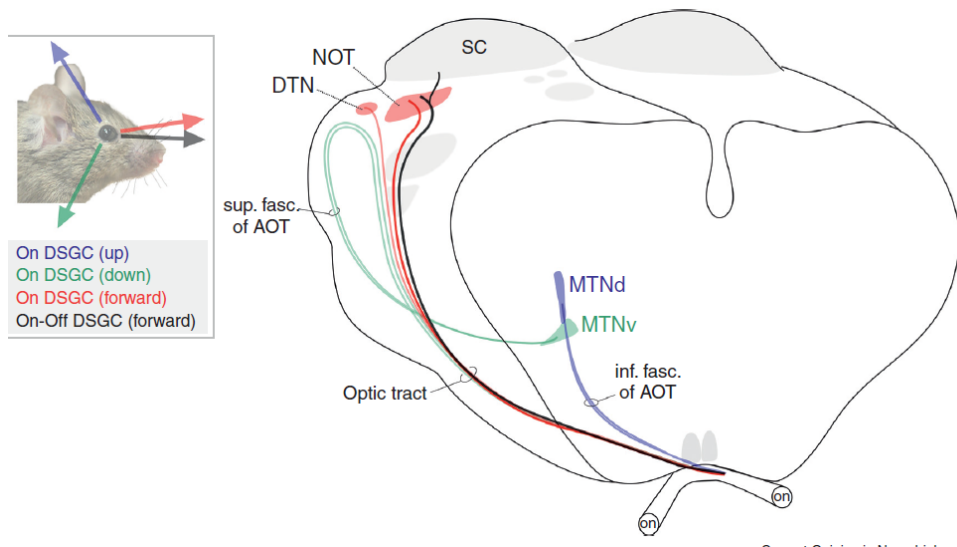
Retinal Ganglion Cells send axons to the brain



- RGCs project to multiple visual areas
- LGN = region of thalamus
- Superior Colliculus = part of midbrain

dsRGCs projections and function

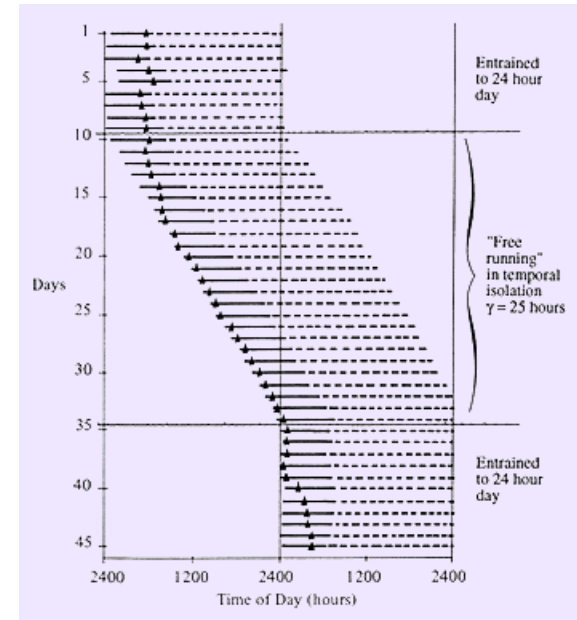
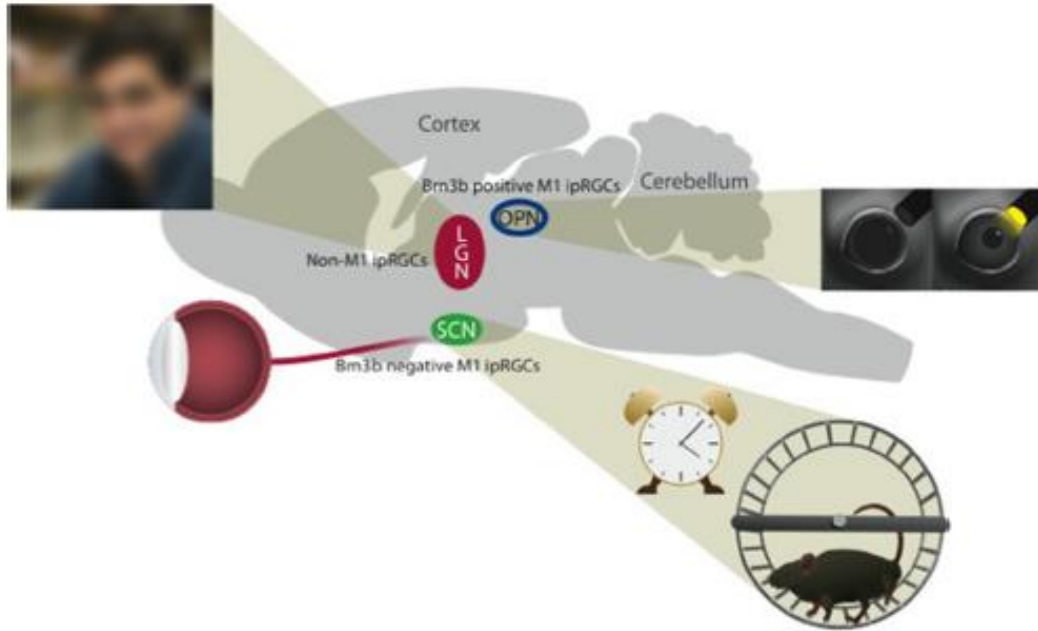
Whole field motion



Dhande and Huberman, 2014

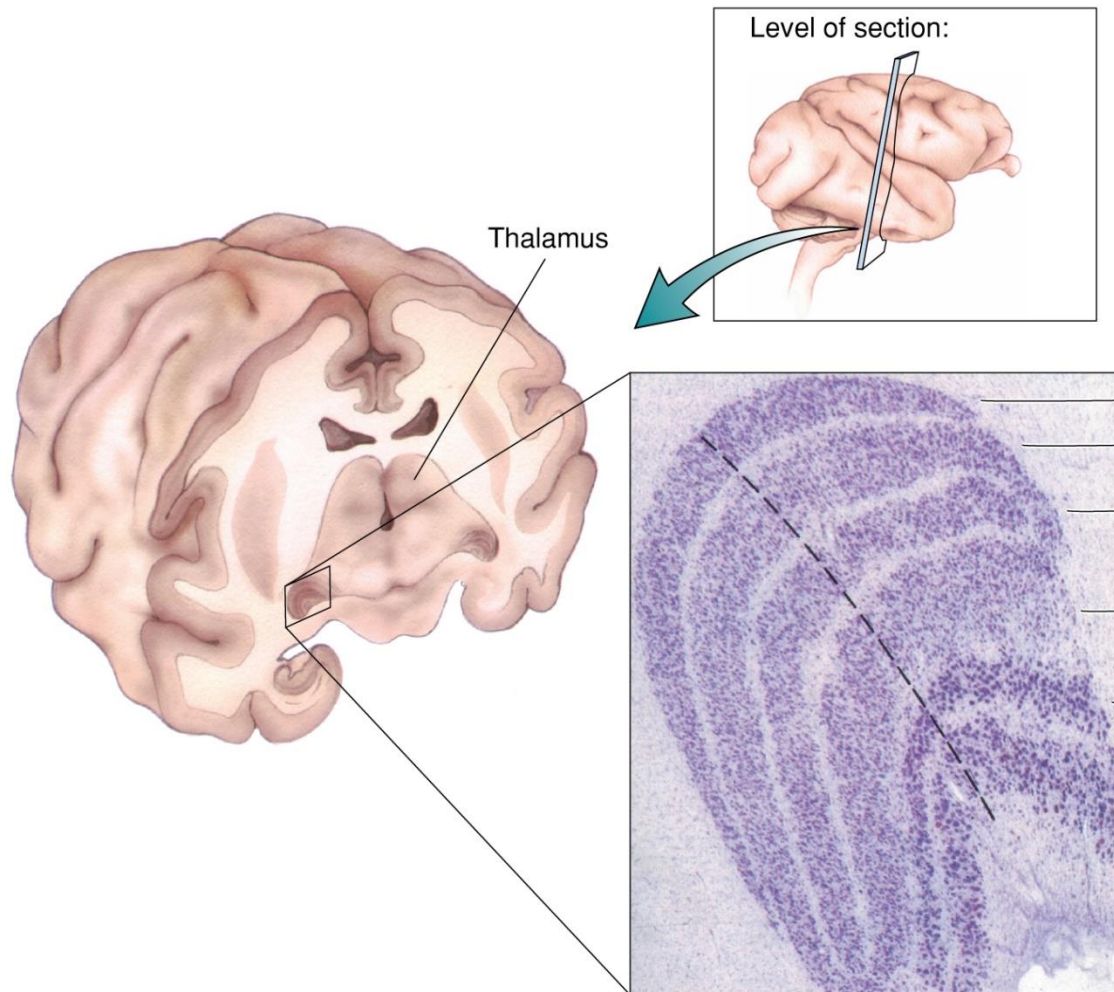
- dsRGCs project to areas that move eyes to compensate for self motion

ipRGCs project to areas that use information about overall light level

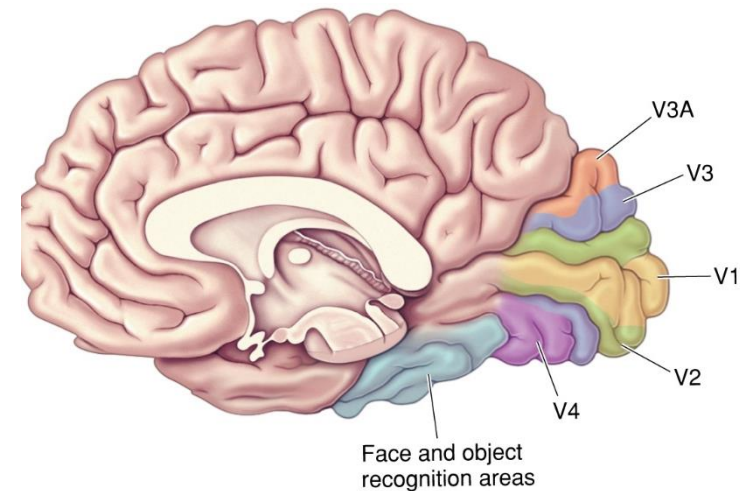


- ipRGCs project to the Suprachiasmatic Nucleus (SCN); important for setting circadian rhythm
- This is why your phone has a setting to give off less blue light at night
- ipRGCs also project to the Olivary pretectal nucleus (OPN) which mediates the pupillary light reflex

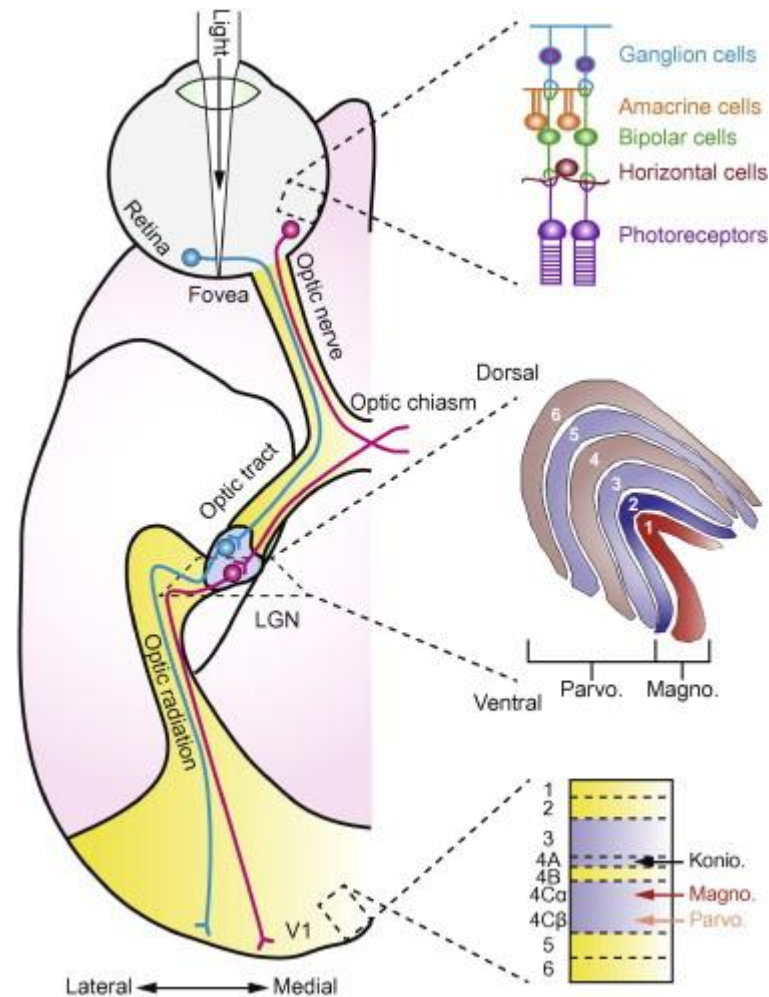
Retinal Ganglion Cell Projections; Thalamus



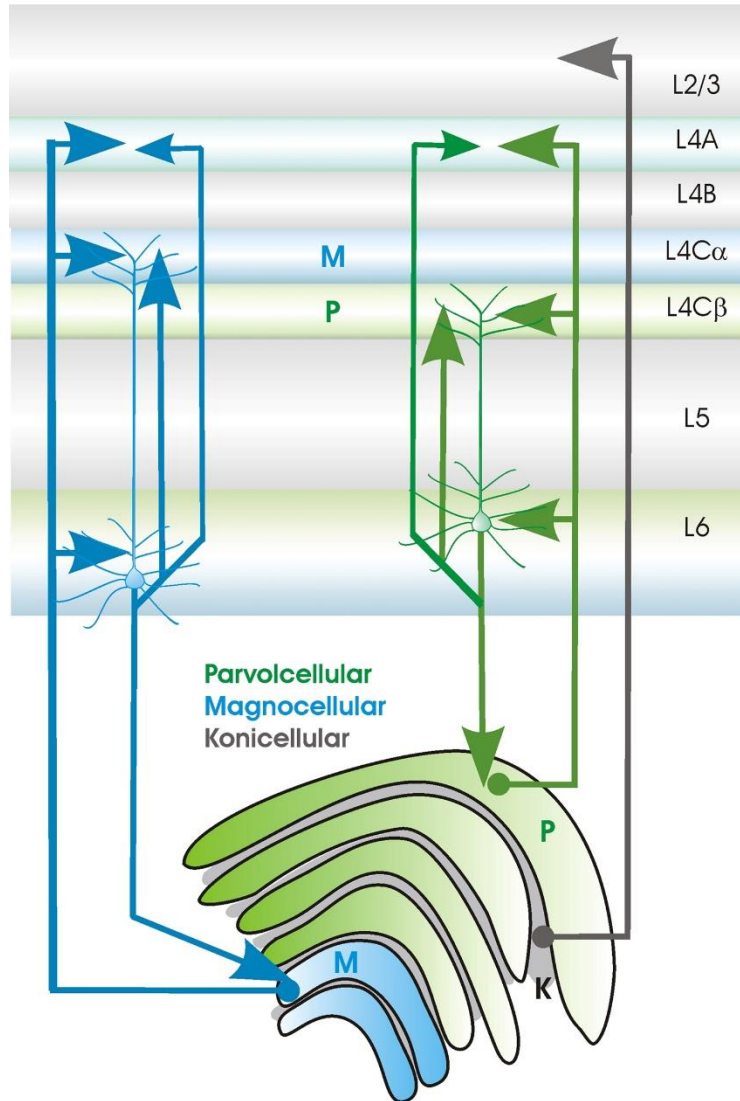
- Some RGCs project to the thalamus, gateway to the cortex.
- This pathway is thought to mediate conscious vision.



RGC projections to the LGN (region of the thalamus)

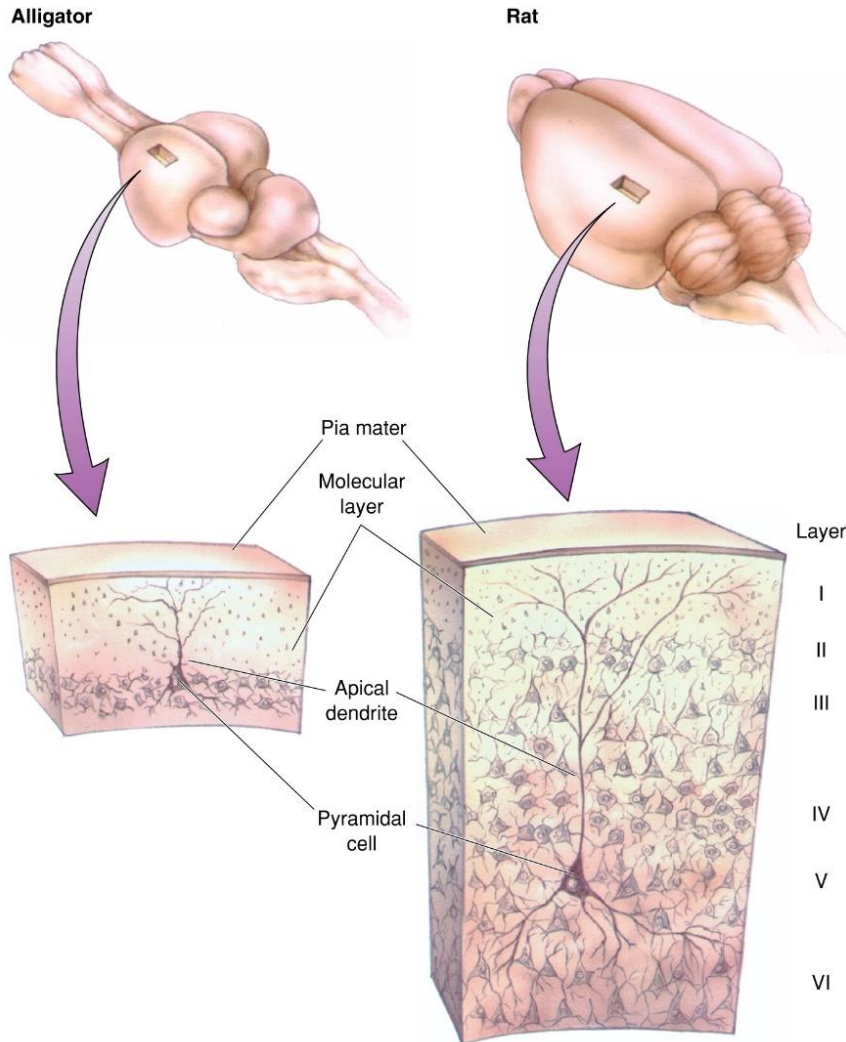


LGN function



- 80% of the LGN's excitatory synapses are from V1
- Function of feedback not fully understood
- Why?
- It's difficult to access in mammals (compared to retina and cortex)
- Inputs are difficult to know
- Early work suggested it was just a relay station

Review of Cortex



- Cortex = outer layer of brain (latin; bark of a tree)
- Two types; allocortex and neocortex
- Neocortex= only in mammals

Architecture of neocortex

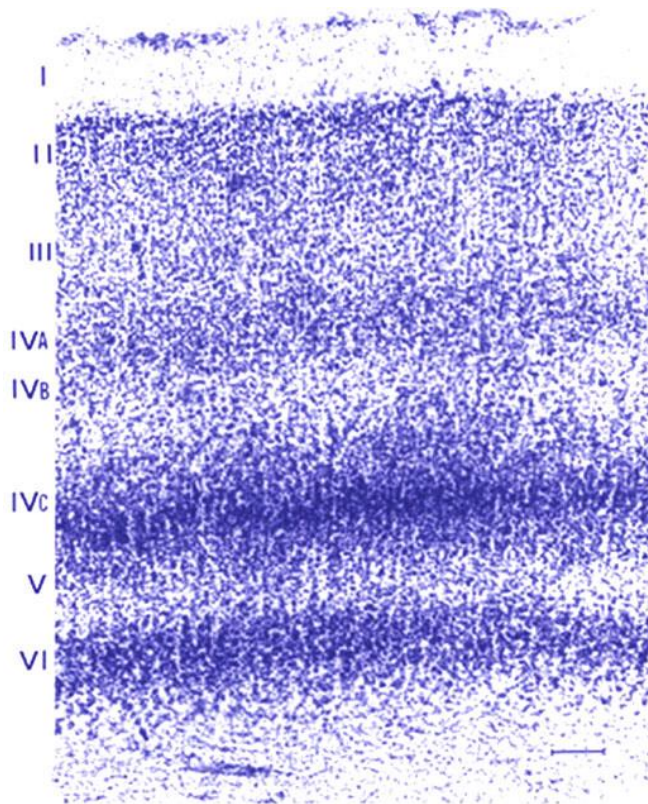
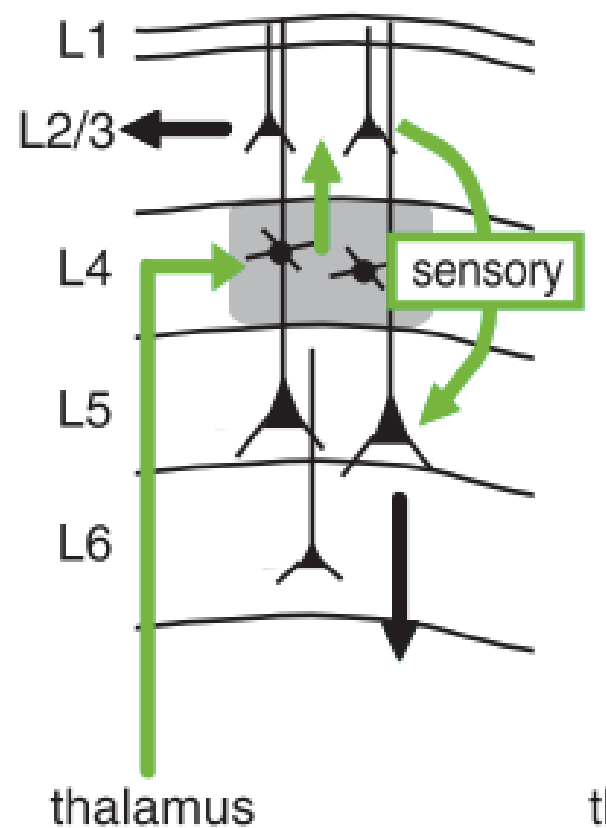
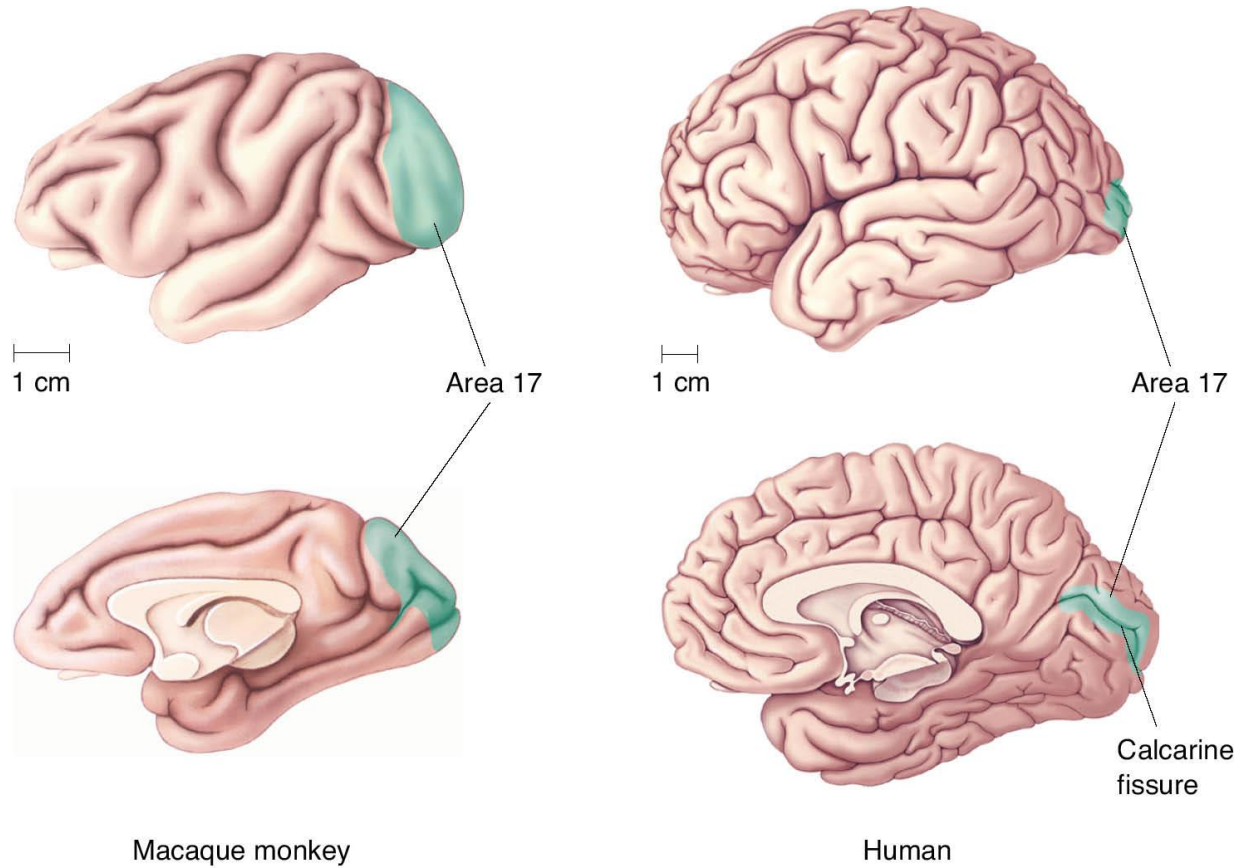


Figure 13. Nissl stain of the visual cortex reveals the different layers I through VI quite clearly.

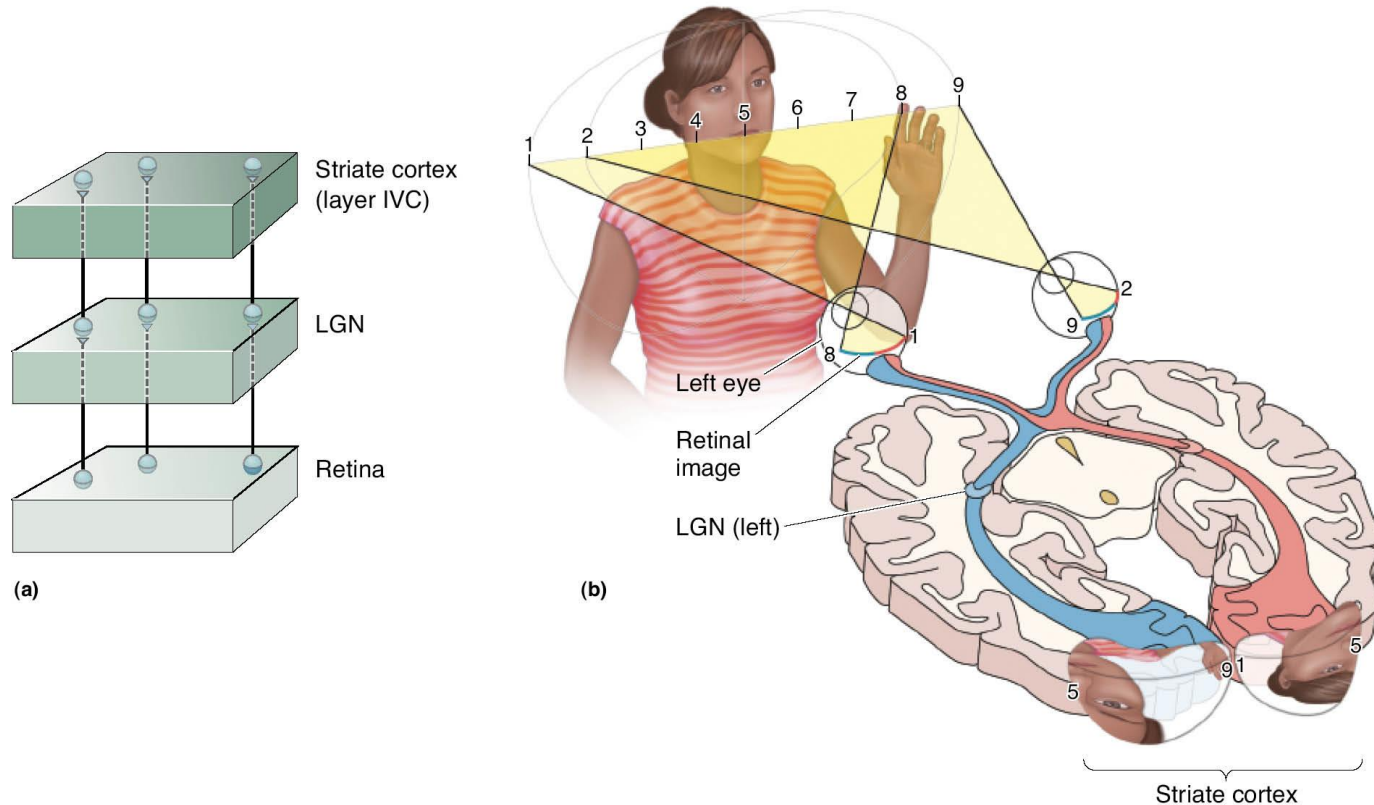


Open questions; how are cortical neurons connected? What kind of processing do they do?

V1, aka primary visual cortex

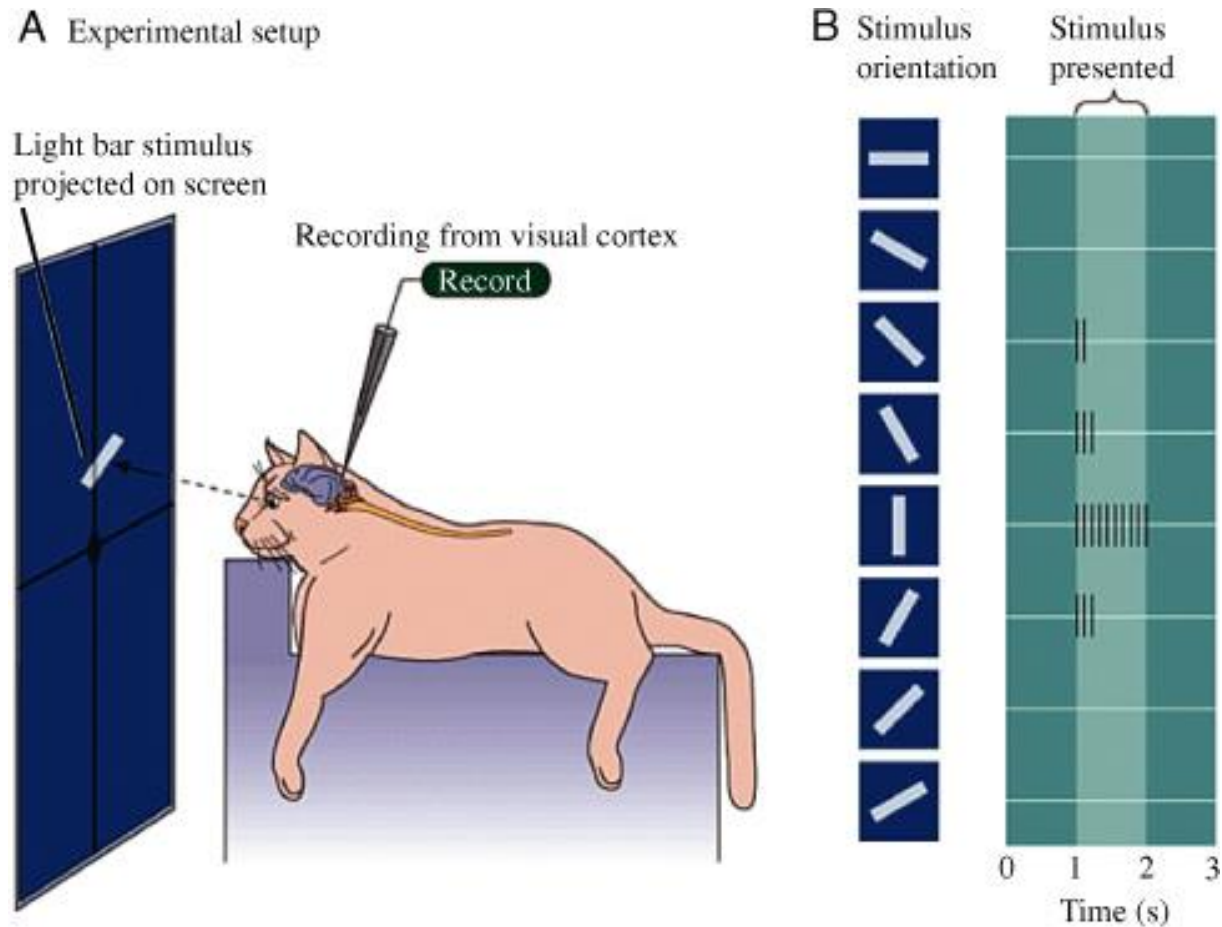


V1 retinotopy



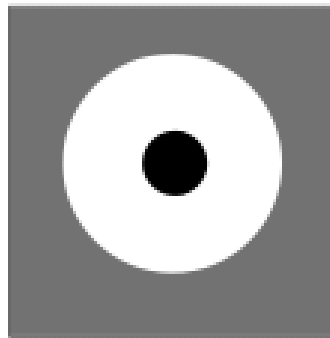
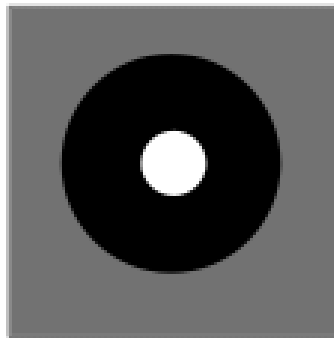
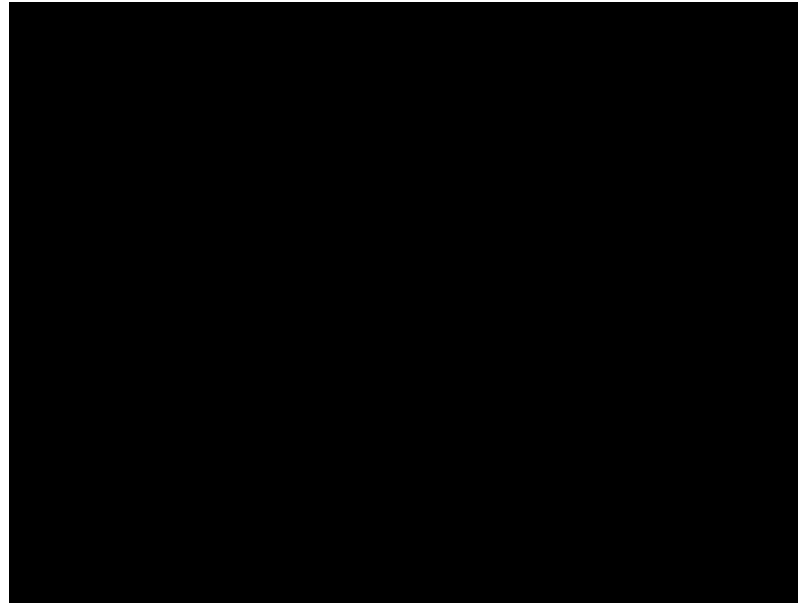
There's no actual picture in the visual cortex, just patterns of active neurons. But, an external observer can read these out...

What are the response properties of neurons in LGN and V1?

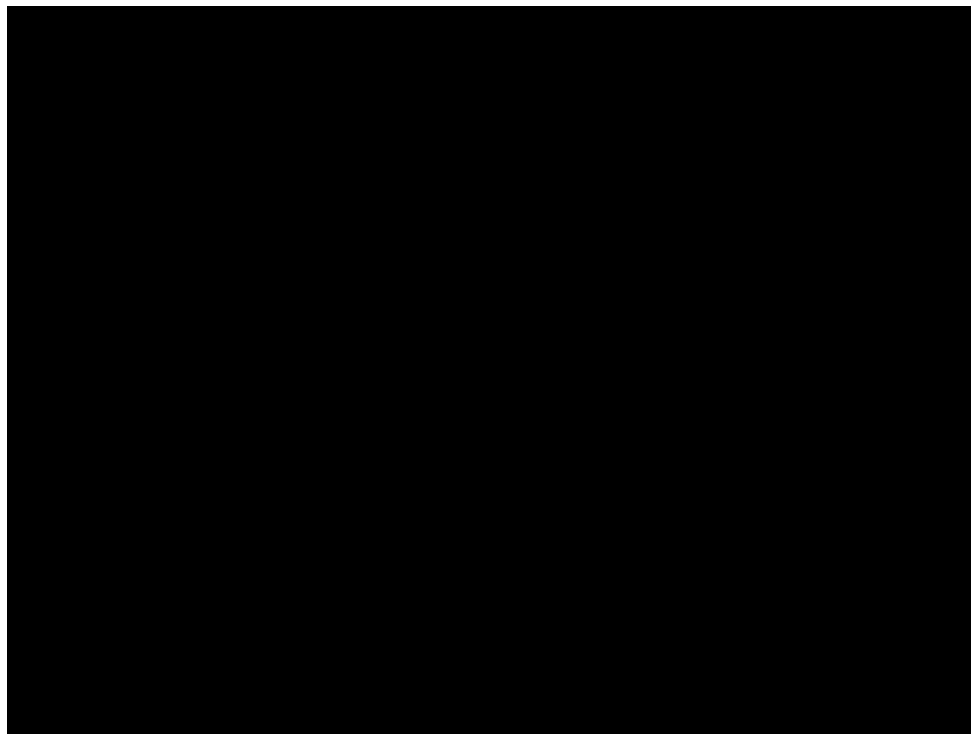


Late 1950's; Hubel and Weisel's experiments on cats. Later switched to nonhuman primates.

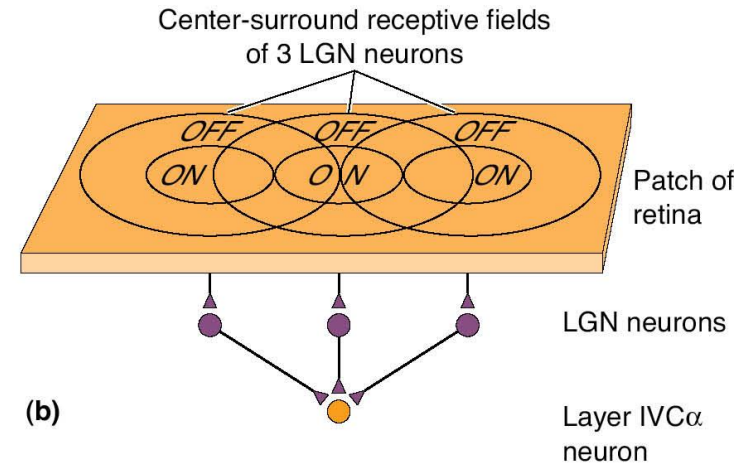
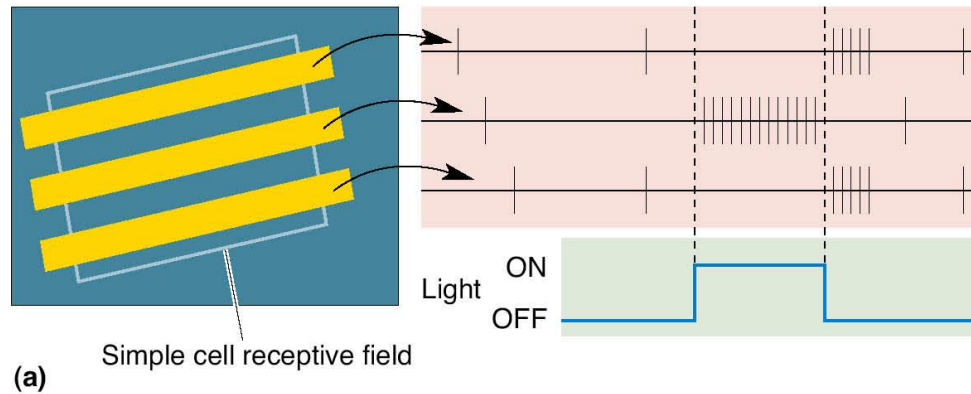
Recording from an LGN neuron



Recording from a V1 neuron



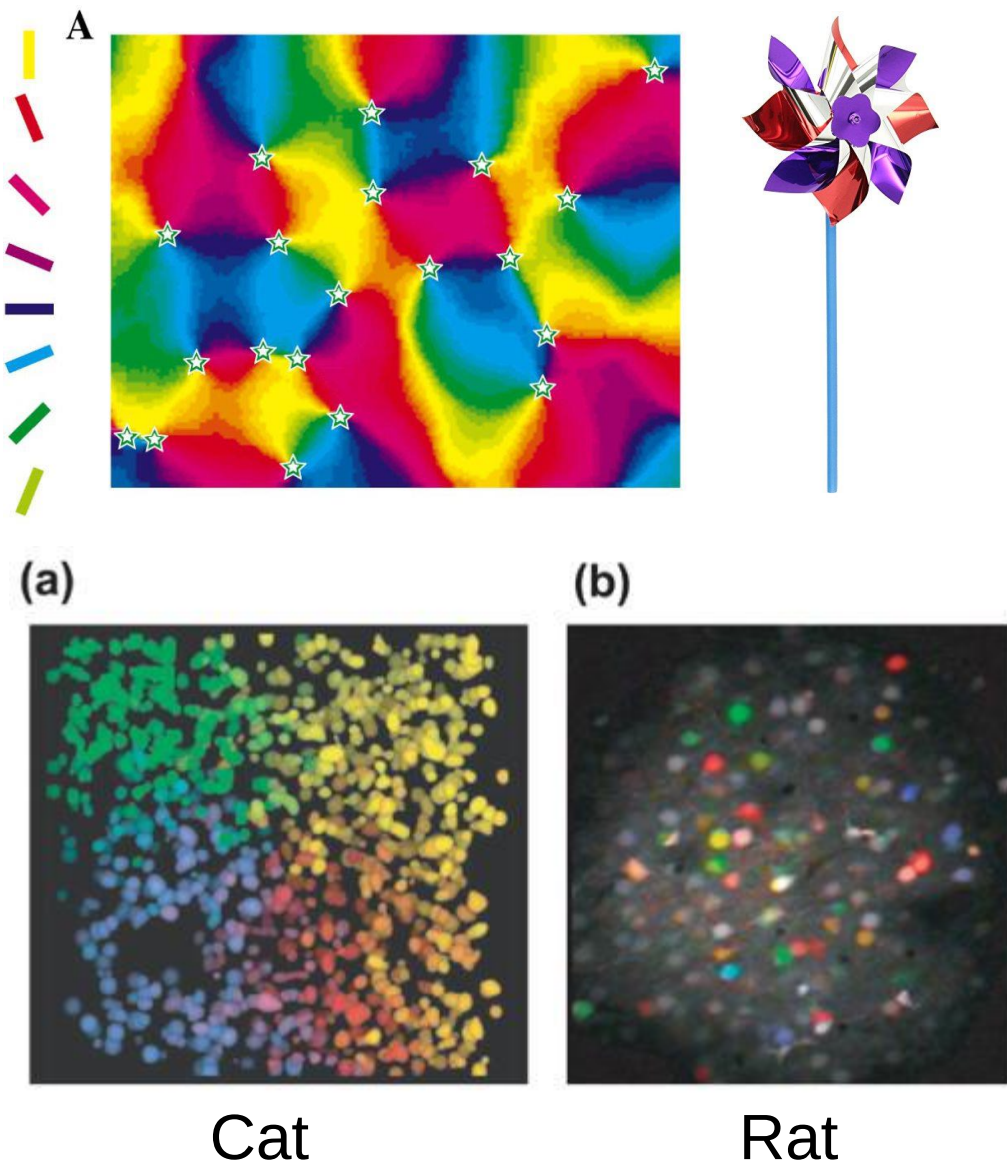
A Simple Cell Receptive Field



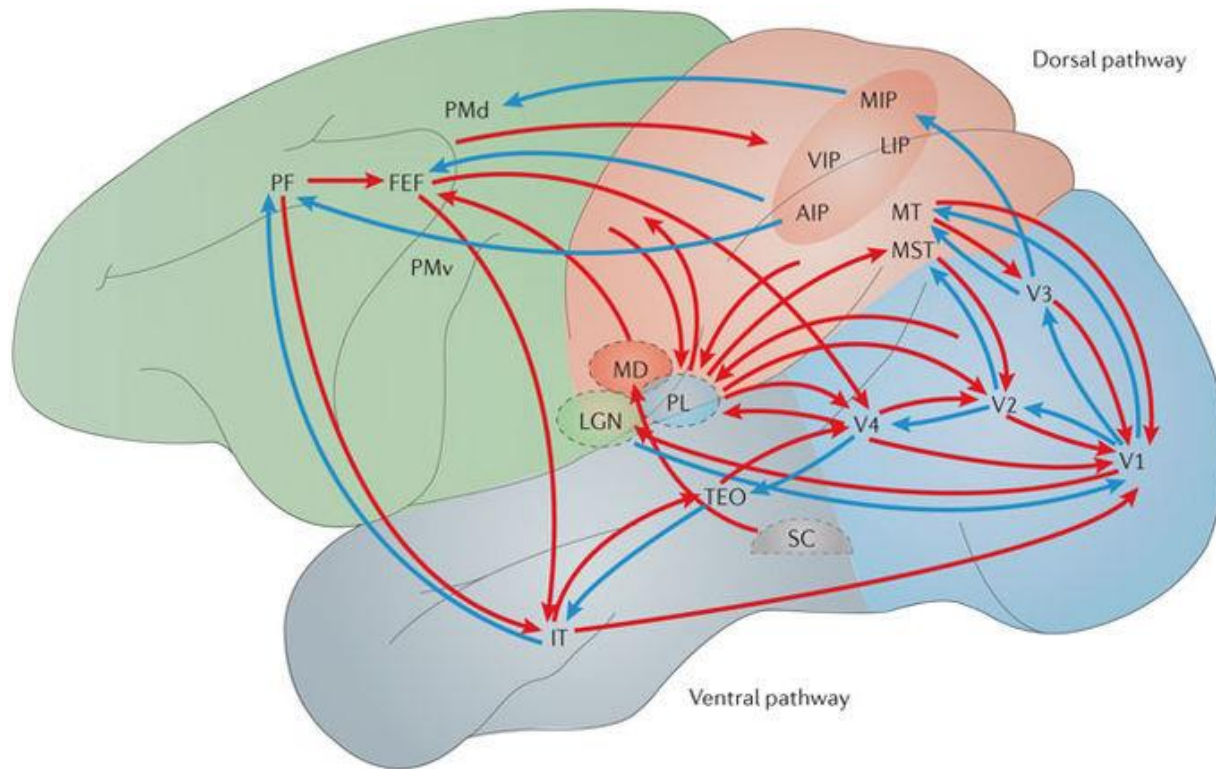
- Simple cells: binocular, orientation-selective, elongated ON or OFF area flanked with antagonistic surround
- Receptive field may be composed of three LGN inputs from cells with aligned center-surround receptive fields.
- Difficult to record from both LGN and V1

Cortical Structure: orientation pinwheels

- Present in monkey and cat V1
- However, rodent visual system lacks this organization
- Could be because rats have less orientation discrimination ability
- Or, could be that pinwheels have no function and are just the byproduct of having a larger V1

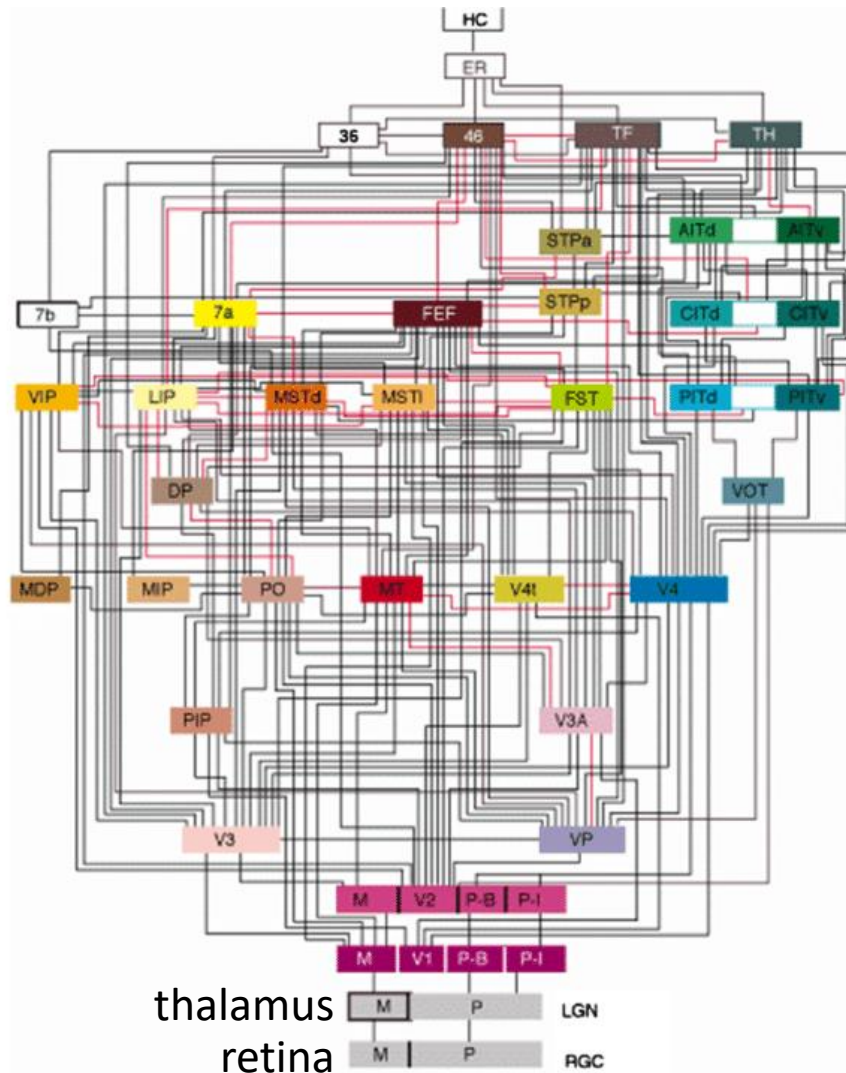


What happens after V1? Visual areas in primates



- V1 projects to a few other visual cortical areas, and gets feedback
- Those areas project to other areas
- Some areas are thought to be specialized for certain visual features, e.g. motion

What are all these areas actually doing?



- A partial map of connections between visual cortical areas
- Function of most areas is not settled
- These are mostly studied in primates
- Difficult to map function and connectivity, manipulate areas of the primate brain

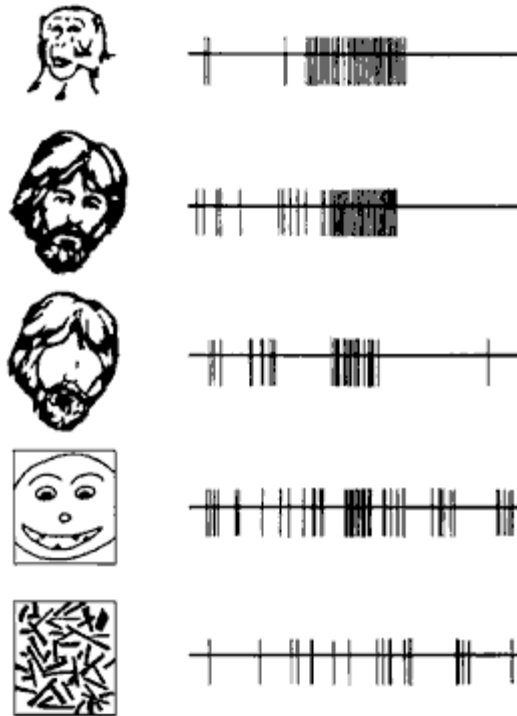
Face recognition



Our brains perform this task seemingly effortlessly. Steps within the task:

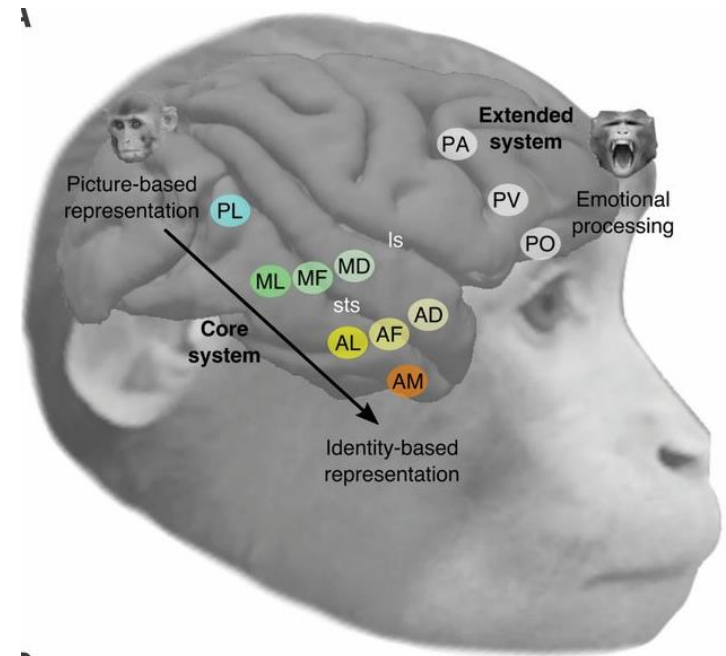
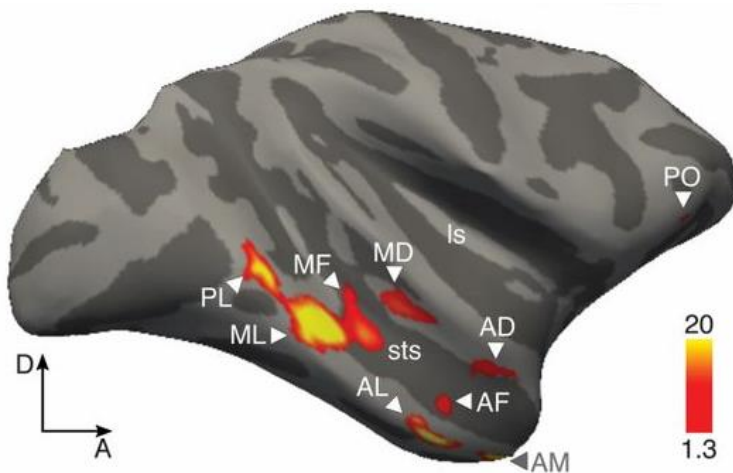
1. Is this object a face?
2. Do I recognize this person?
3. Other characteristics; gender, age, expression/emotion

Face neurons in primates



- Recording of IT neuron in monkey
- Neuron responds to human and primate faces
- Responds less if eyes are removed, face is a cartoon
- Does not respond to line stimulus

Face neurons are located in face patches



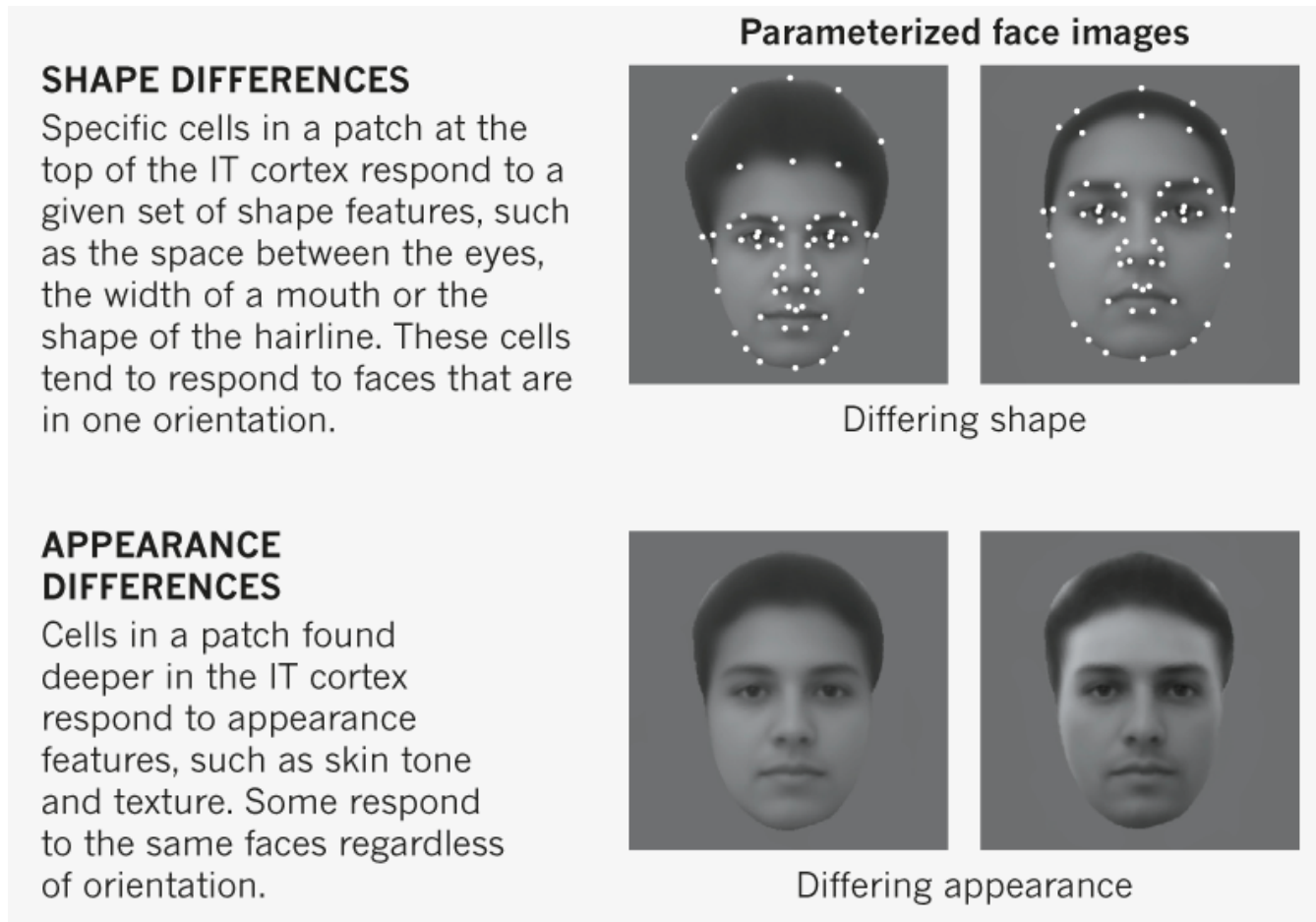
- Face patches = cortical regions in the temporal lobe
- Identified by fMRI
- Located in Inferotemporal (IT) cortex
- Electrodes can be used to record responses of individual neurons

How is face identity encoded?



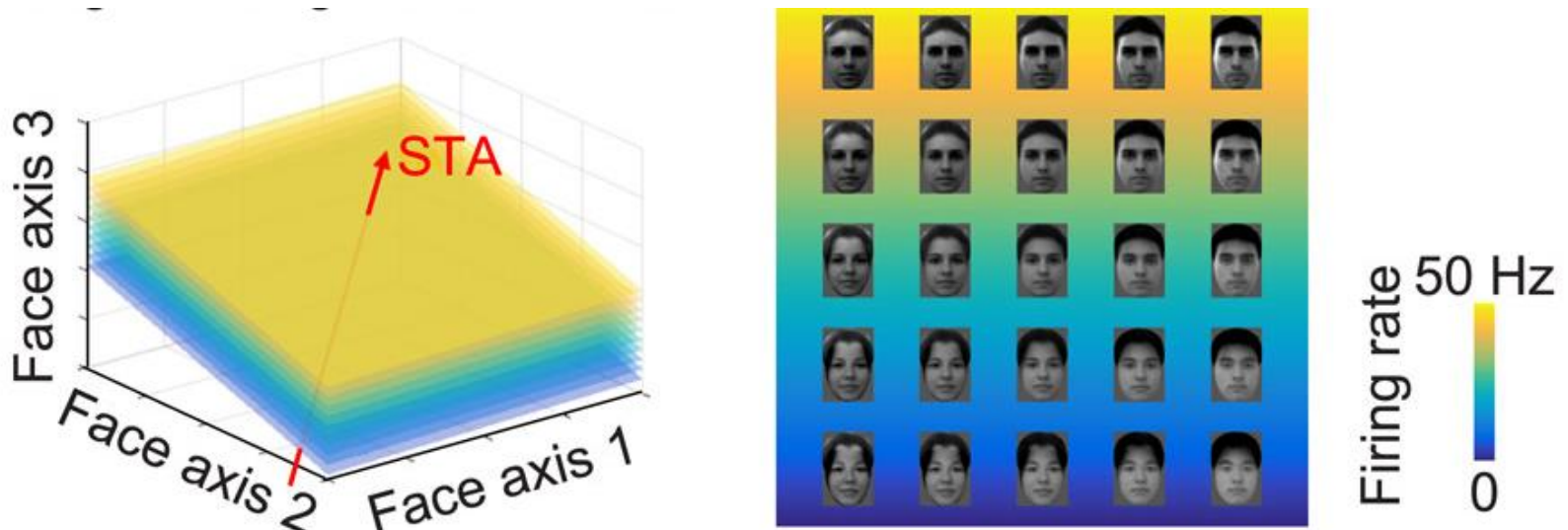
- Face neurons respond to some extent to **all faces**, but fire more in response to **some** faces
- How to we recognize a particular face?
- Population code?
- Response to particular features?

The Code for Facial Identity in the Primate Brain, Chang & Tsao, 2017, Cell



- Analysed 200 real faces, generated 50 dimensional “face space”
- first shape dimension involved changes in hairline, face width, and height of eyes

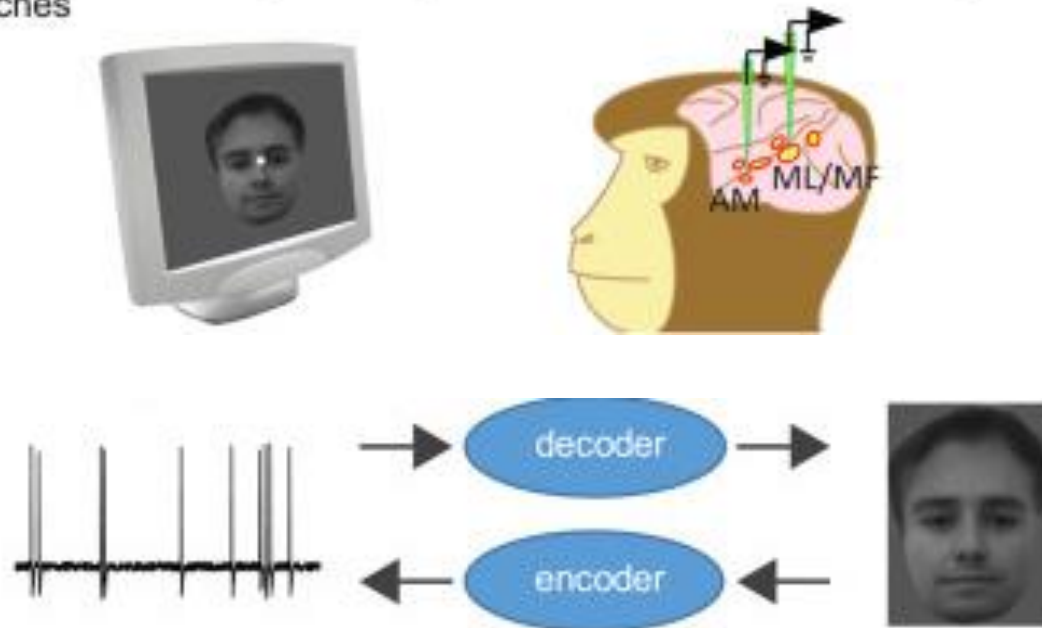
Face cells are tuned to single axes in face space



- Face cell firing encodes position of face along one axis, e.g. Face axis 2

Face decoding experiment

1. We recorded responses to parameterized faces from macaque face patches



- Recorded responses in face patches to 2000 artificial faces pulled from face space
- Population response can predict face identity!

System to quantitatively describe faces

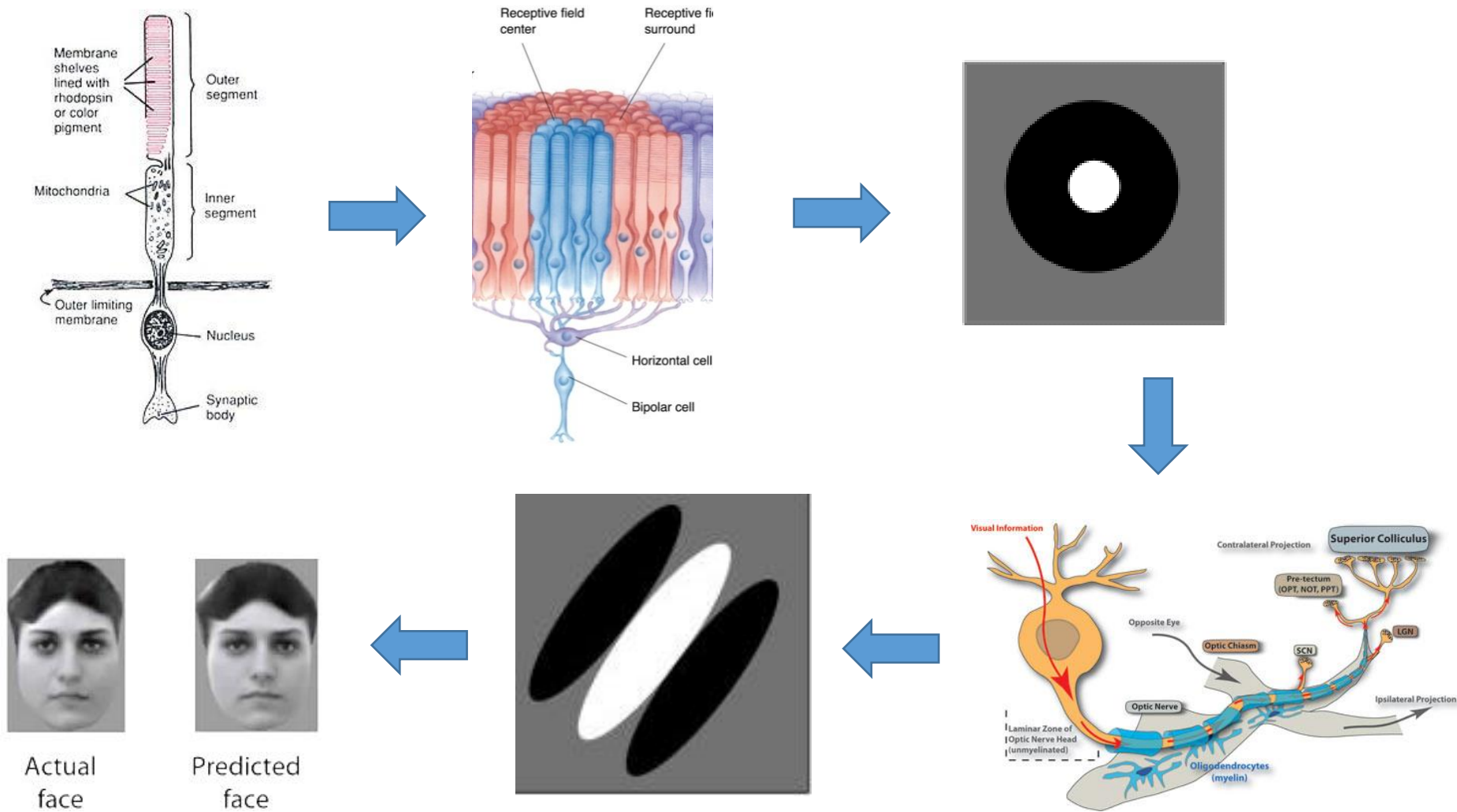


Actual
face

Predicted
face

- Without knowing which face stimulus was used, predict appearance based on 200 cells' response and the 50 dimensional face space
- Suggests that neurons are not encoding specific people or facial features, but axes in multidimensional space
- Still unknown; how are these responses built up from previous levels? How is this population response read out by other areas, e.g. involved in memory?

Visual System Summary



Questions?