Behavioral Neuroscience A
8: Vision

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https://youtu.be/PuDejwM1JUQ

Lecture Video at above link.

Vision!

Vision

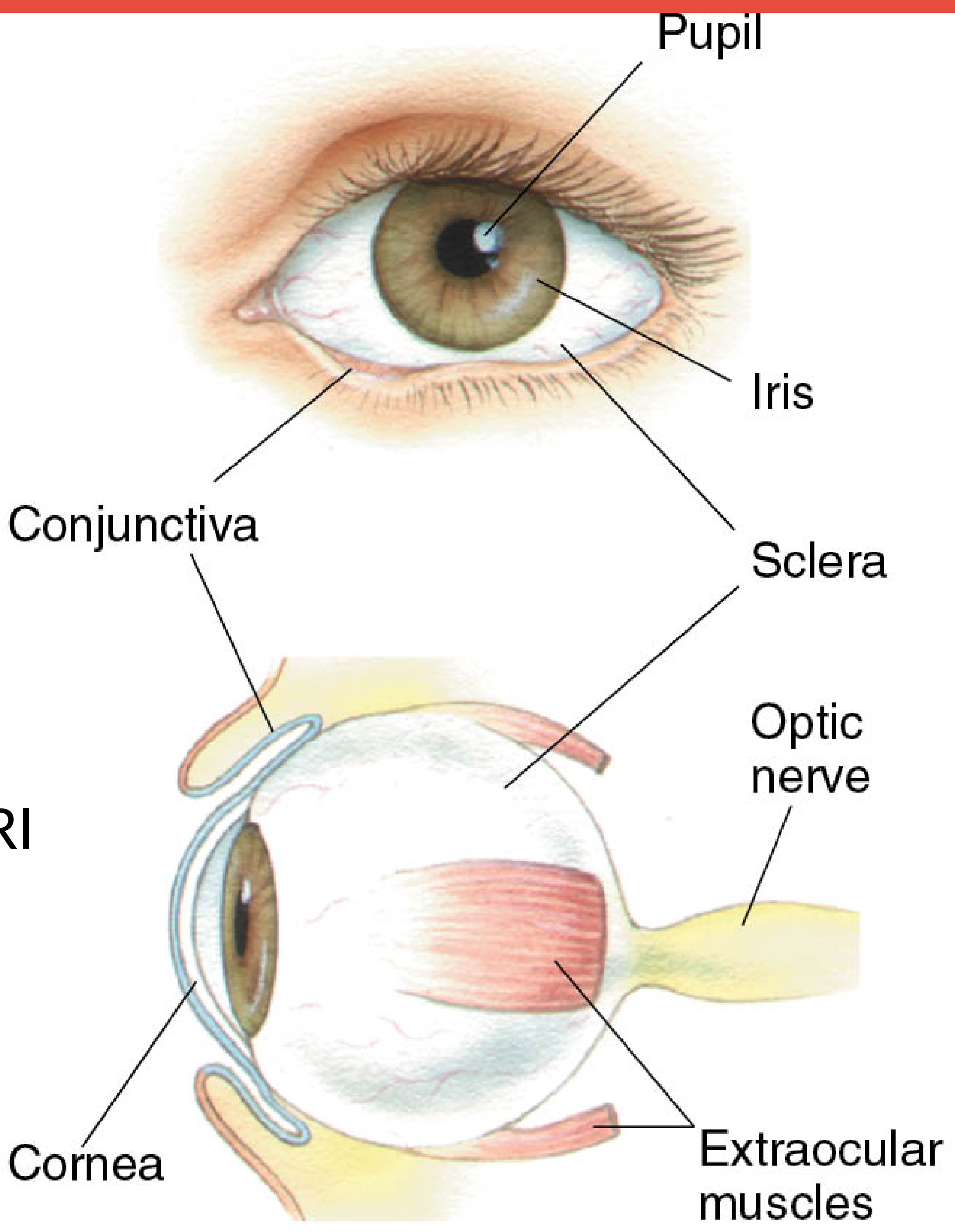
- To understand how light impinging on our eyes is converted into nerve excitation.

- To understand how our visual environment is interpreted by the brain.

Topics

Vision – or how we see…

1) Eye and retina
2) Visual pathway
3) Primary Visual Cortex
4) Mapping of visual cortex with fMRI
5) Higher visual functions
   (Motion, Objects, and Faces)



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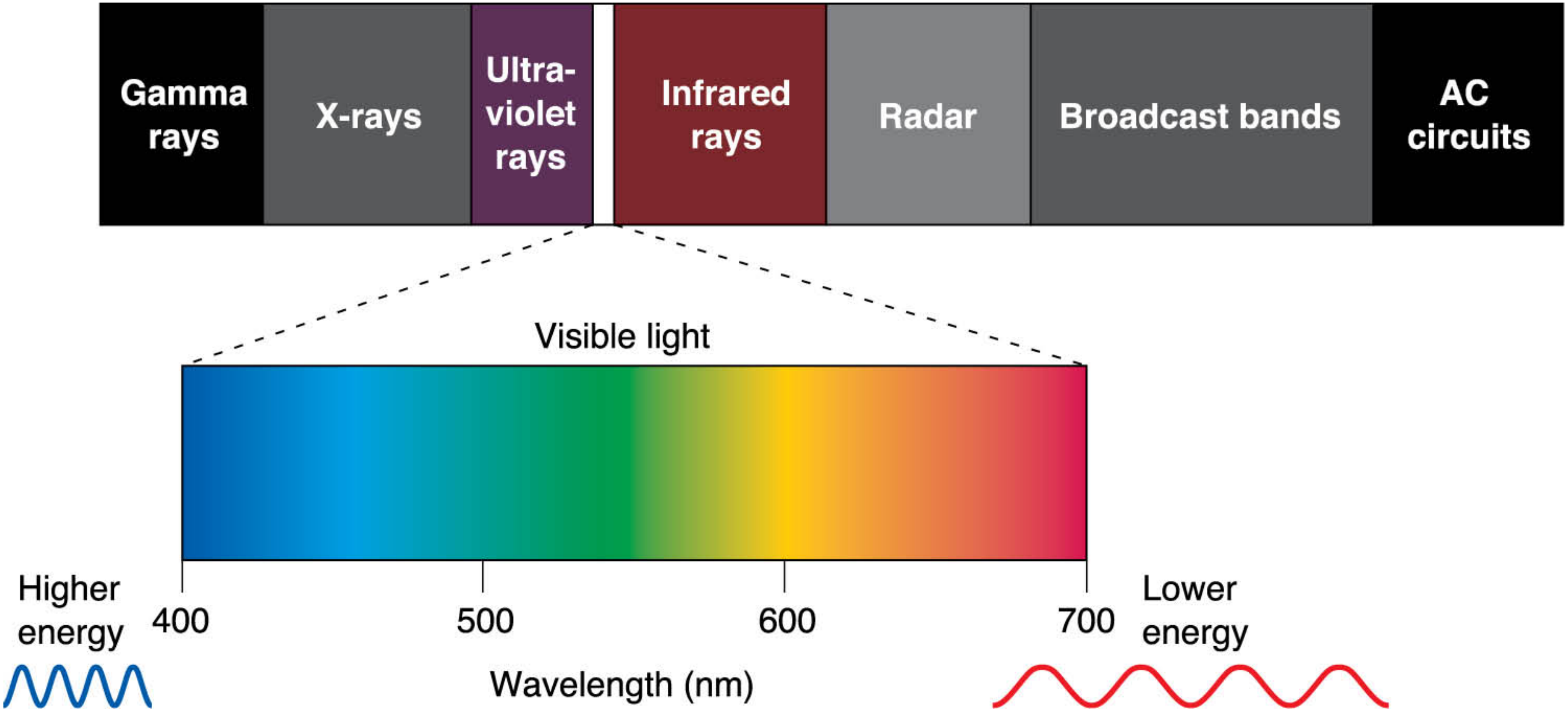
Vision is *hard*

From Daimler Pedestrian Dataset (www.gavrila.net)

Vision is not trivial, object segmentation (what is part of an object and what is not), object recognition, or motion trajectory prediction are hard problems for computer vision.

It starts off with light…

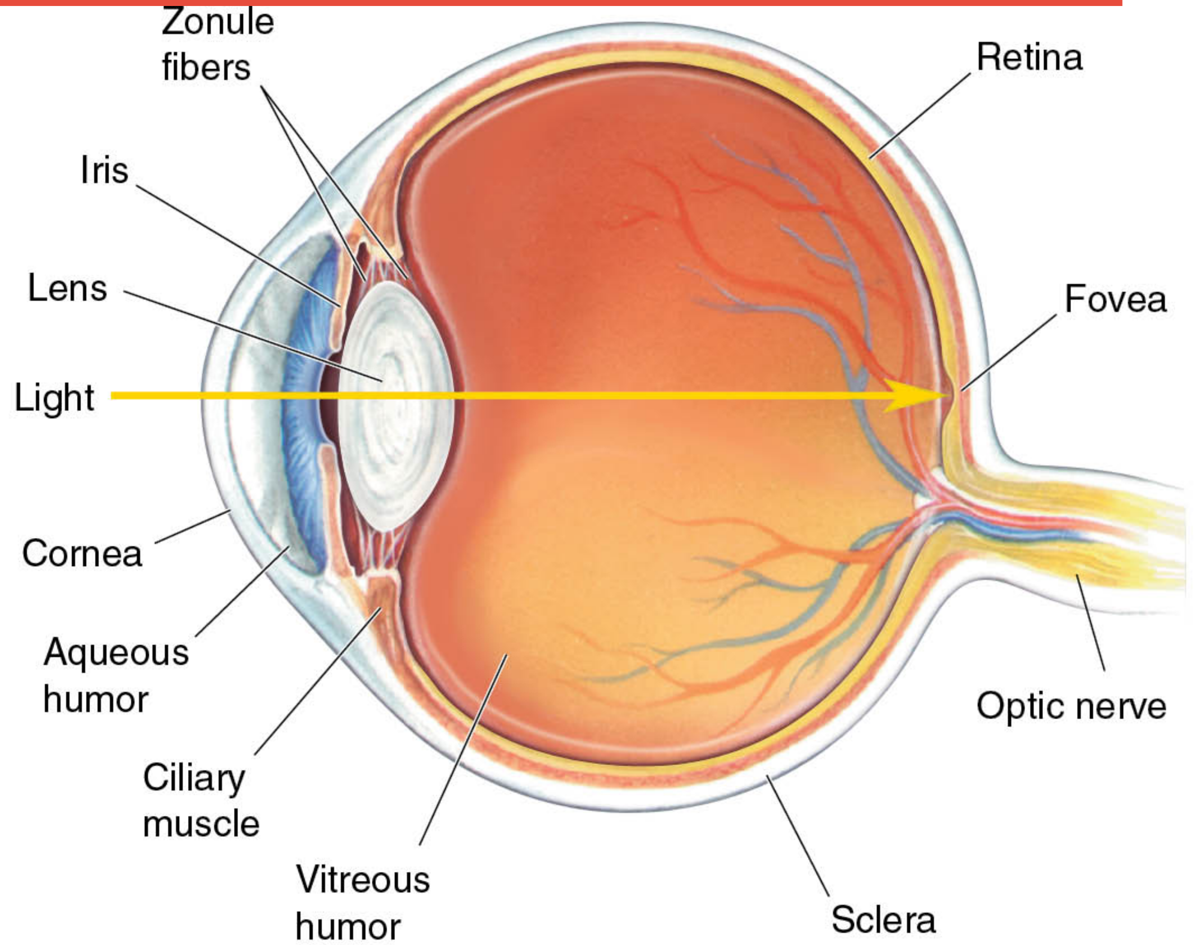
Visible light has a wavelength of 400-700 nm.



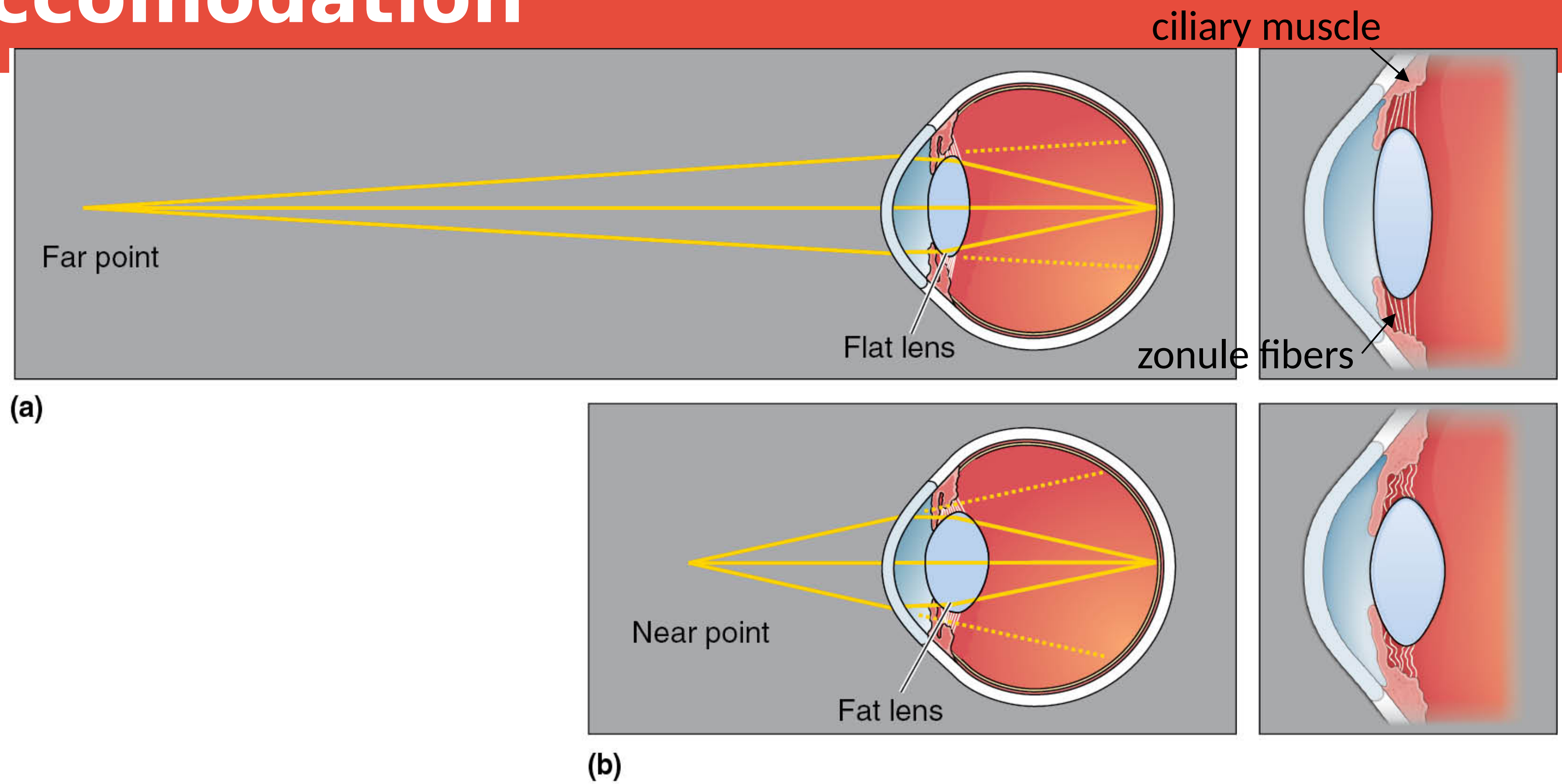
The Eye

Focus is controlled by the lens which changes shape when the ciliary muscle is contracted.

Pupil width is controlled by iris sphincter/dilator muscles (wide pupils in poor light conditions).



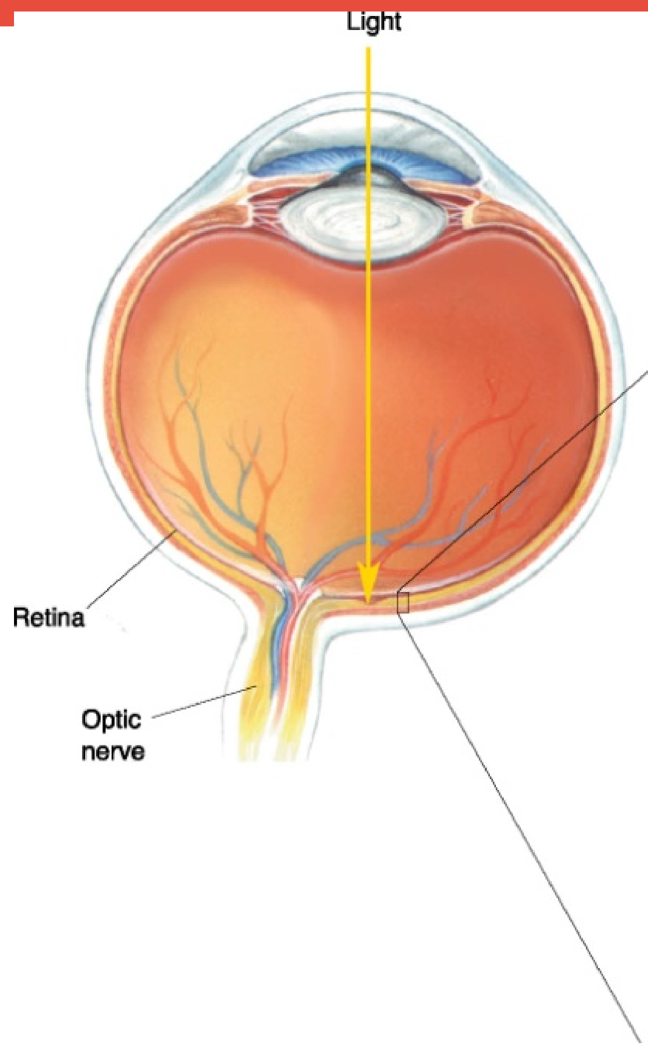
Accomodation

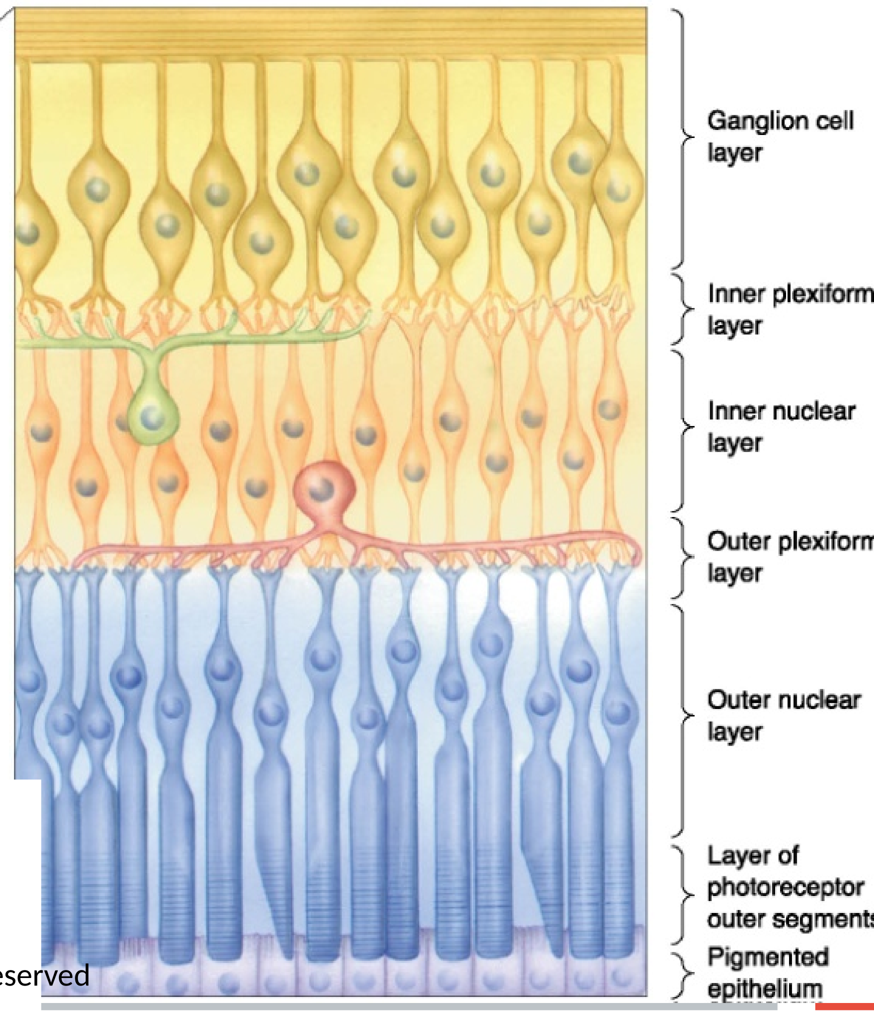


For a far point (a), the lens has to be flatter (less refraction), so the ciliary muscle relaxes, stretching the zonule fibers.
For a near point (b), the lens has to be rounder (more refraction), so the ciliary muscle contracts, resulting in less tension in the zonule fibers and the lens becomes rounder because of its elasticity.

Retina (light-detecting part of the eye)

Light passes the retina first through layers of neurons (ganglion cells, etc.) before it hits the photoreceptors, where phototransduction (light is converted into neural activity) occurs.





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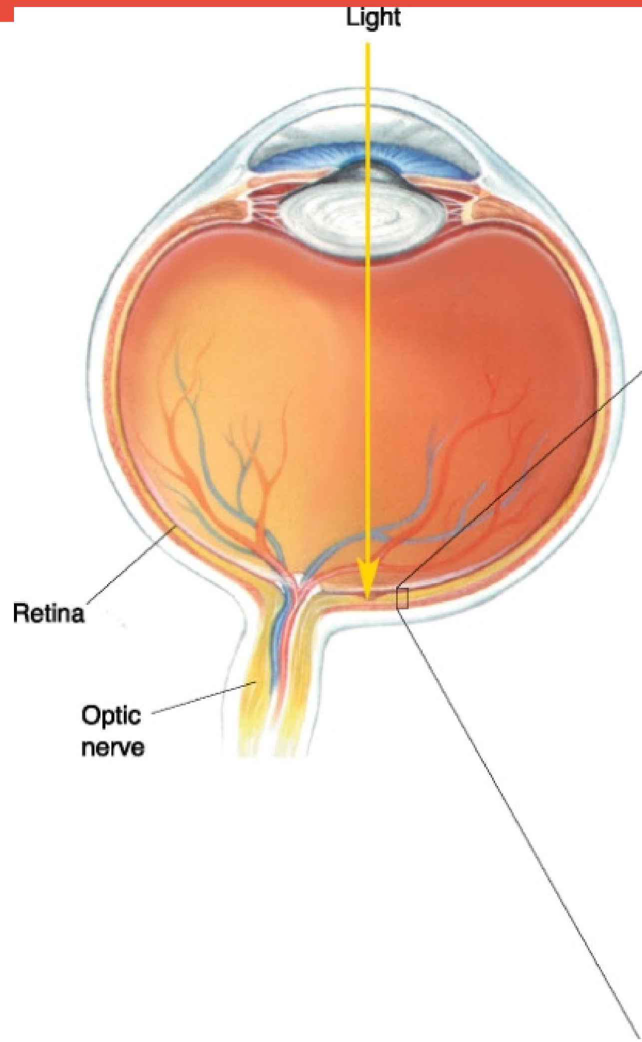
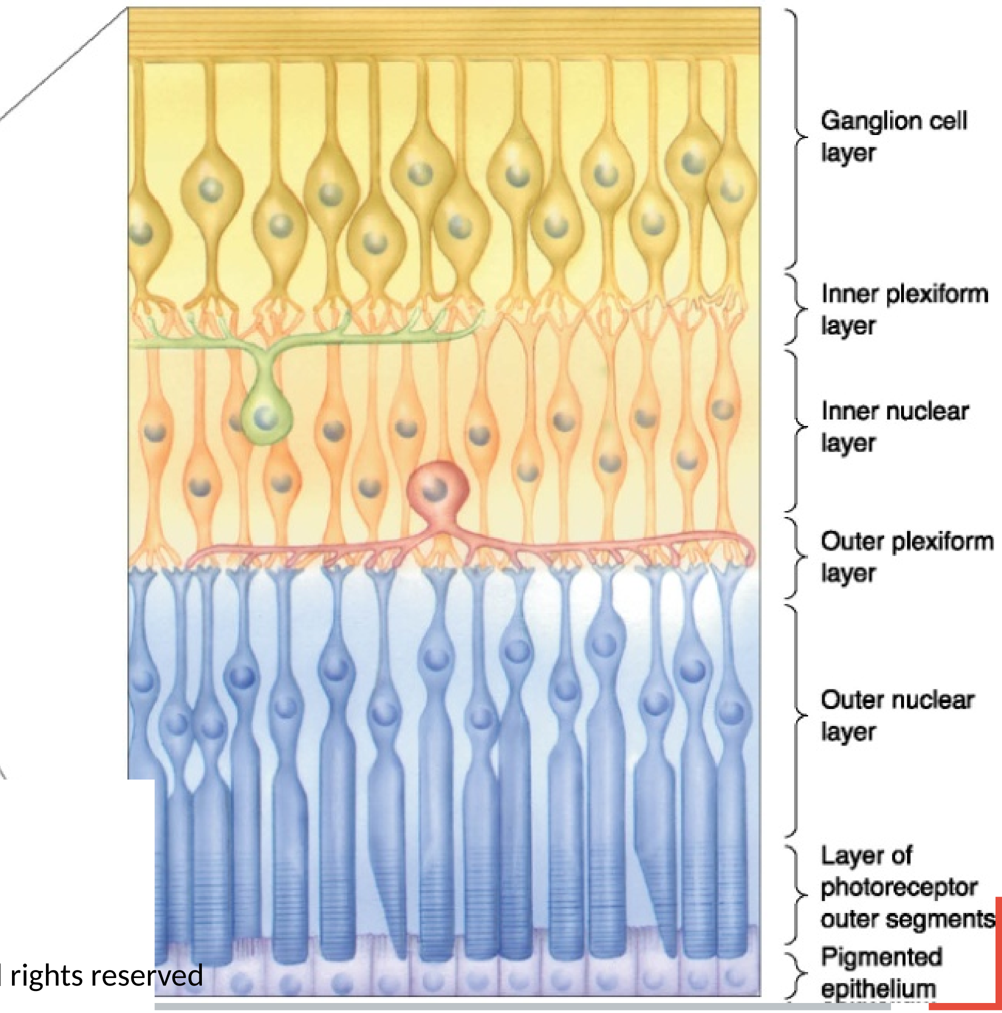
Retina (light-detecting part of the eye)

Where optic nerve enters there are no photoreceptors → blind spot





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Fovea
(most accurate part at center of retina)

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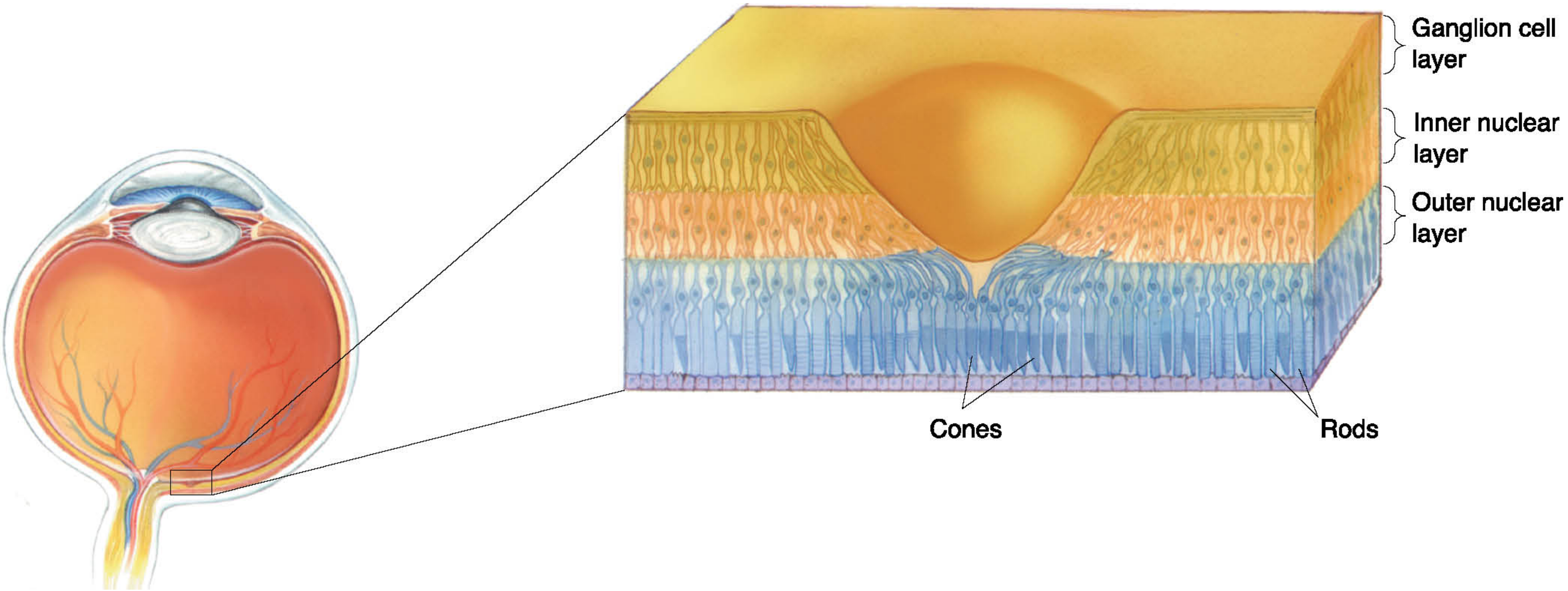
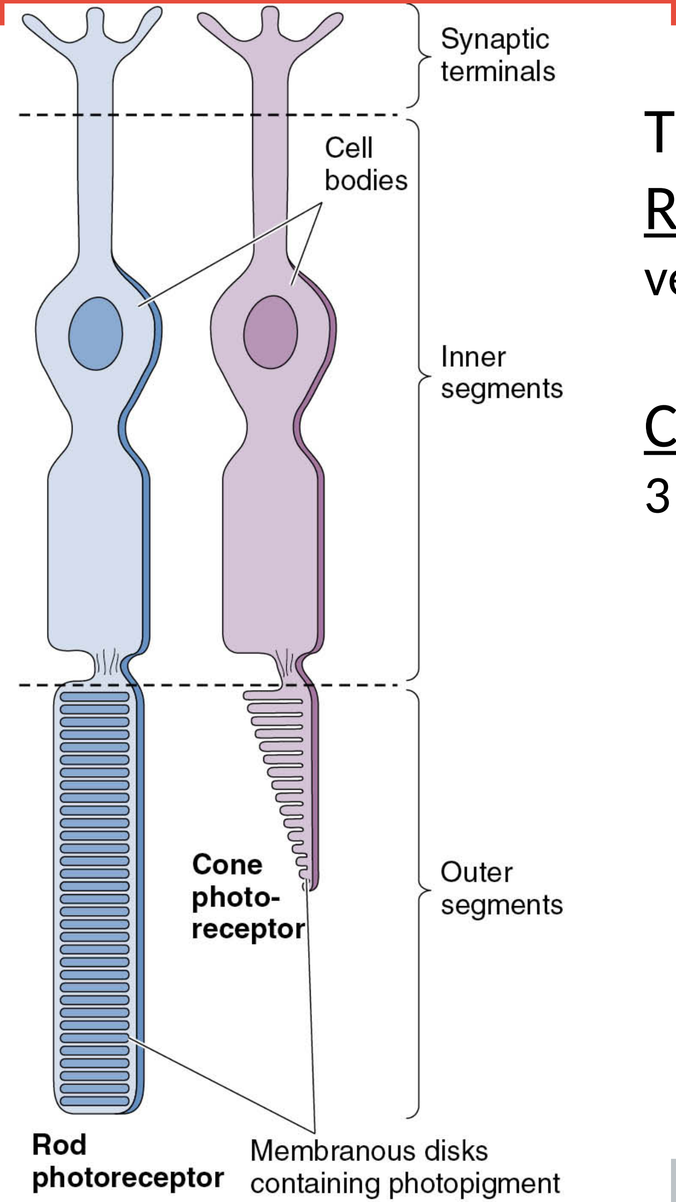


The fovea is a pit in the retina, in which the cells above the photoreceptors are displaced to the side. In terms of photoreceptors it consists of cones rather than rods. The fovea has highest visual acuity and color sensitivity in the retina.

Photoreceptors: Rods and Cones



There are two main types of photoreceptors:

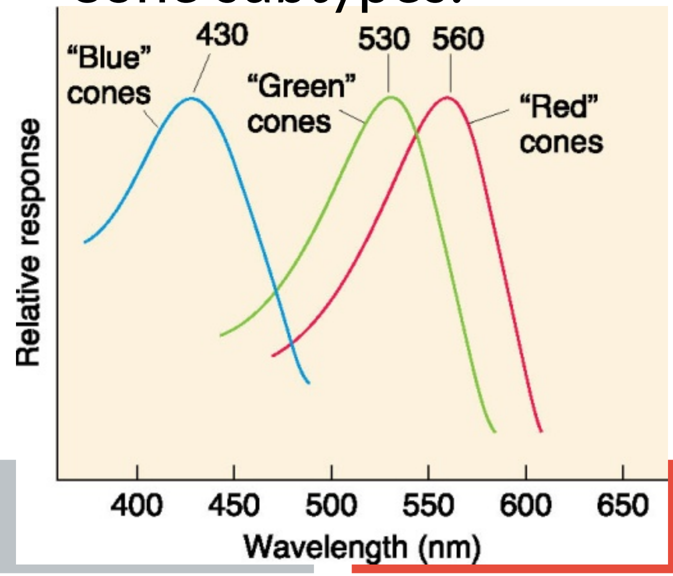
Rods:

very photosensitive, important for night vision.

Cones:

3 types of cone photoreceptors, allow for color vision.

Cone subtypes:



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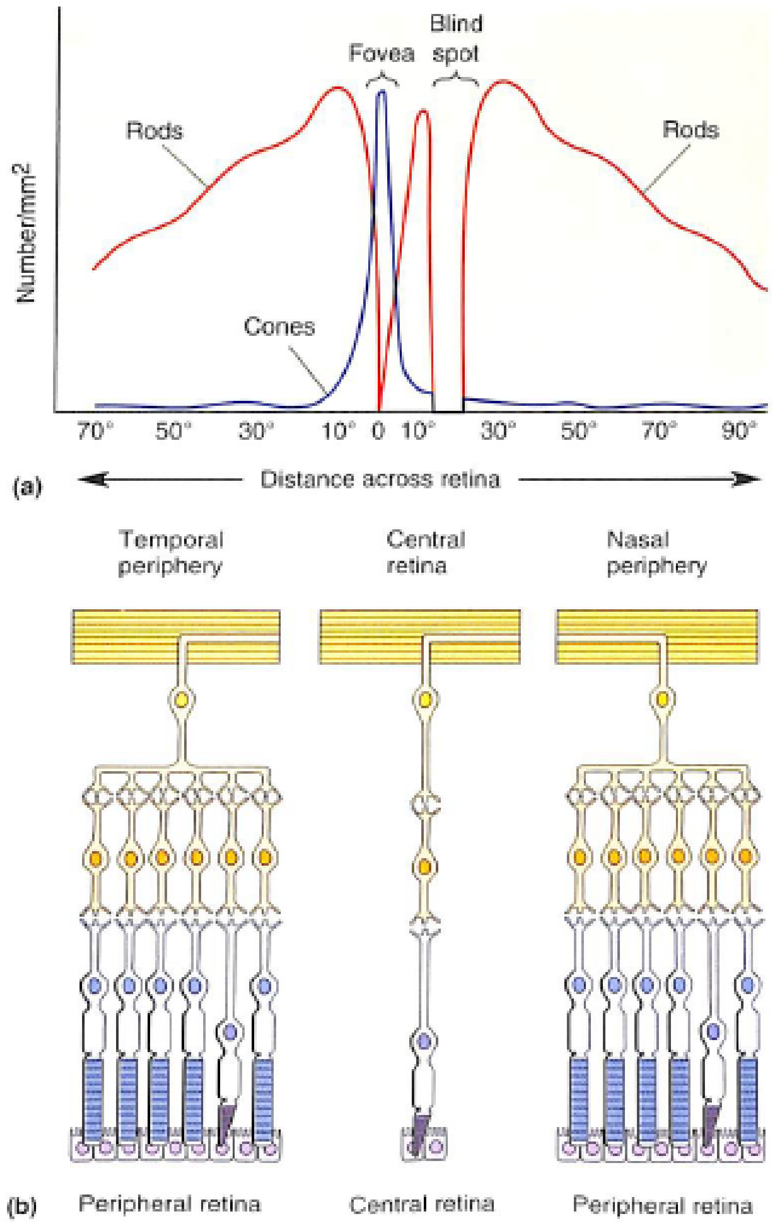
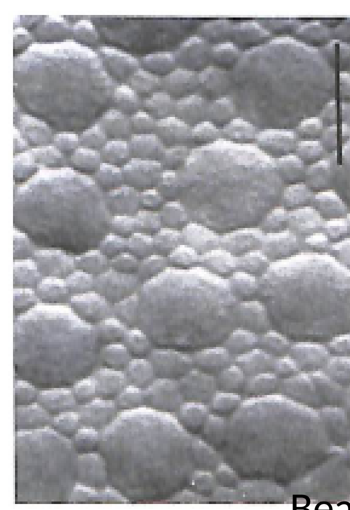
Rod and Cone distribution




(c)

<u>Fovea</u>:
- High concentration of cones
- One cone may activate one ganglion cell


(d)

<u>Periphery</u>:
- Many rods (small hexagons), few cones (larger hexagons)
- Many photoreceptors may activate one ganglion cell

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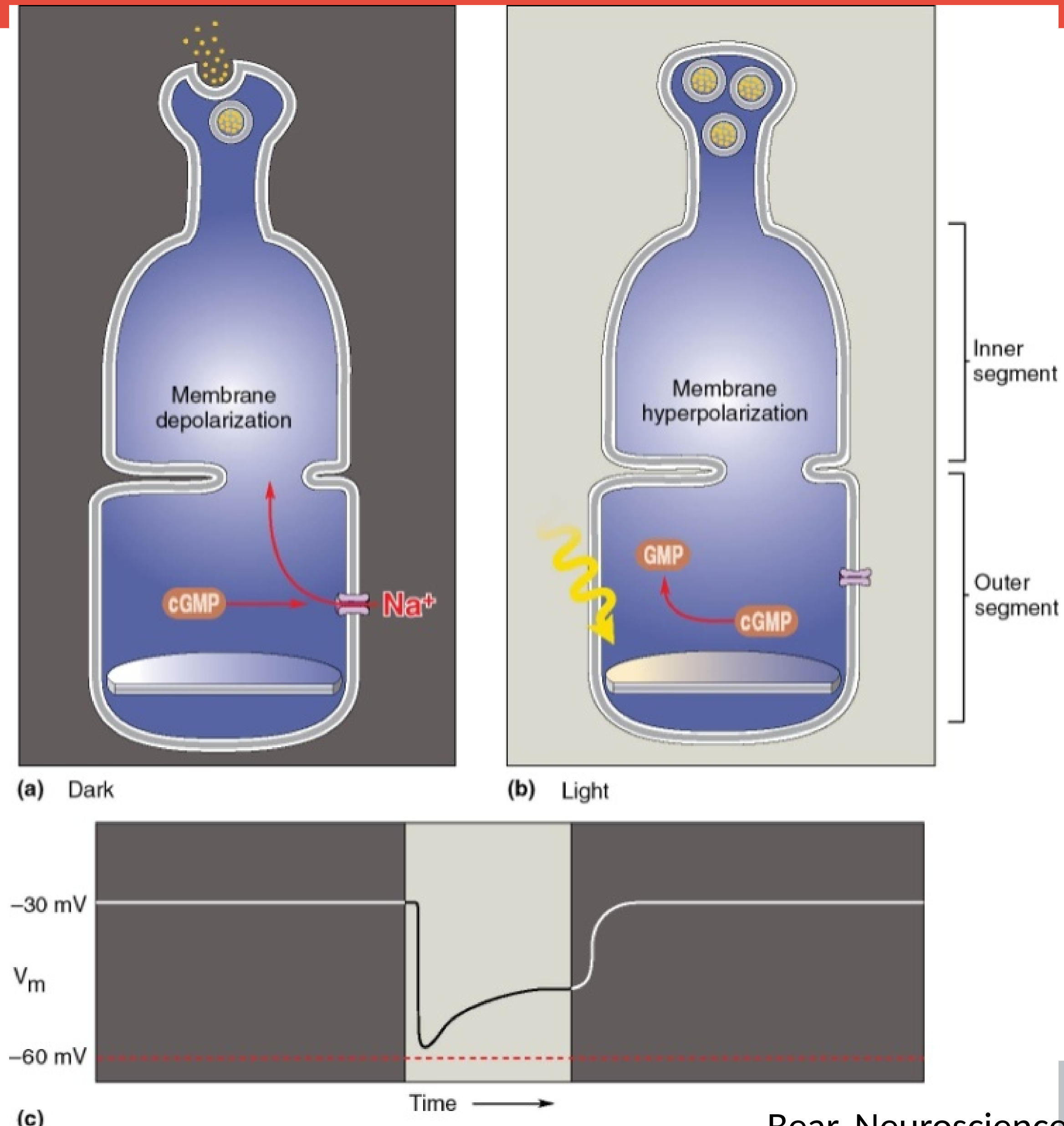
Phototransduction: mechanism



Rod in dark (a):
Membrane potential: -30 mV
Na^+ channels are open, because they are gated by cGMP (cyclic guanosine mono-phosphate)
-> constant release of glutamate

Rod in light (b):
cGMP concentration is reduced->
Na^+ channels close->
Membrane potential gets more negative -> hyperpolarization
-> release of less glutamate

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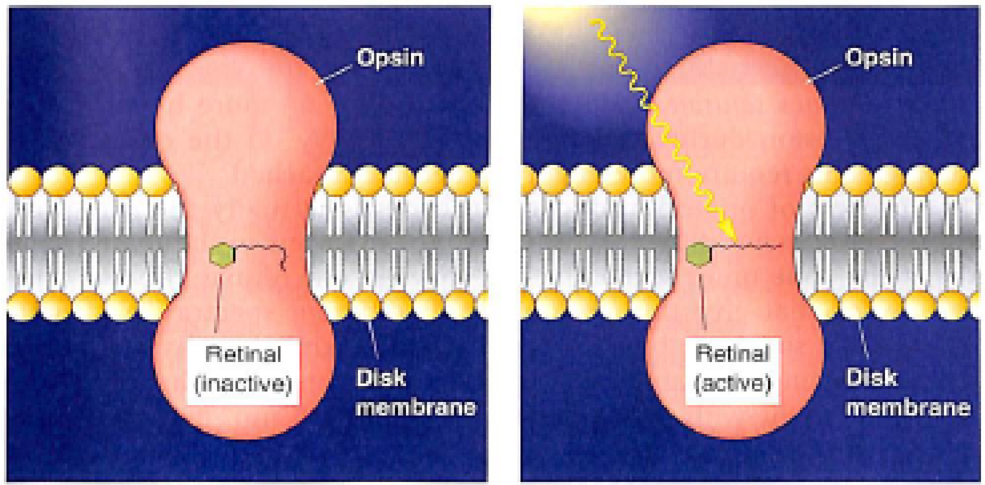
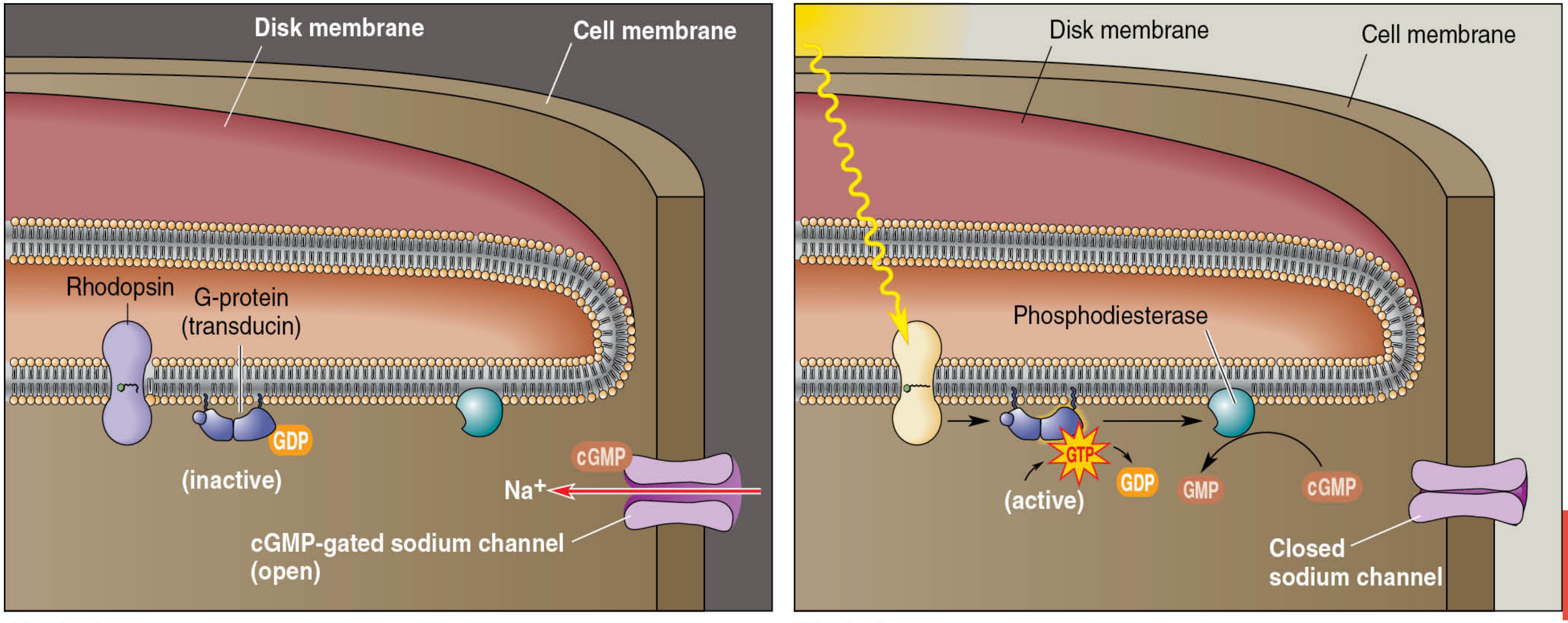
Phototransduction: mechanism



Opsin in the disk membranes contains retinal.

Retinal changes its conformation in response to light (bleaching)
-> G-protein transducin is activated and activates enzyme (Phosphodiesterase) which reduces cGMP to GMP
-> Na^+ channels close



(a) Dark (b) Light

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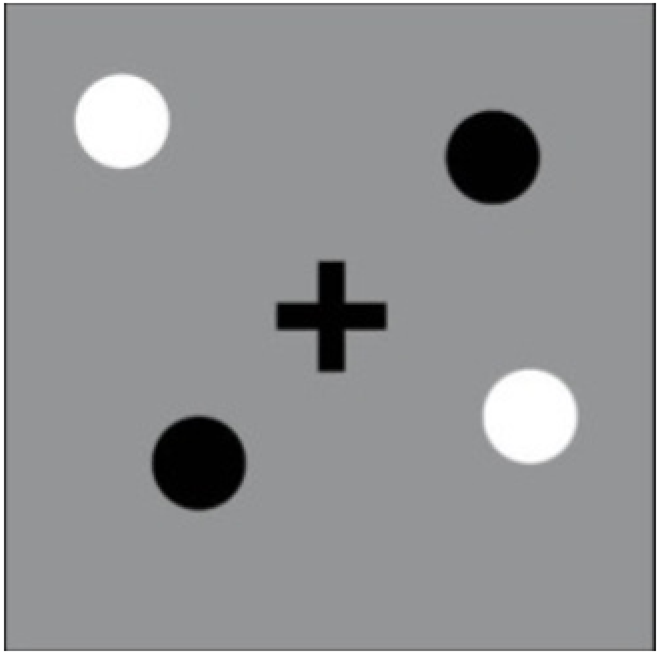
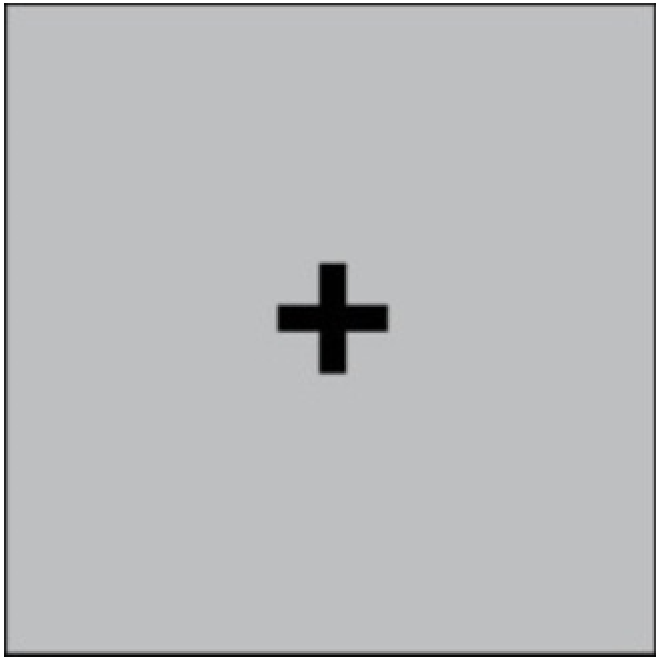
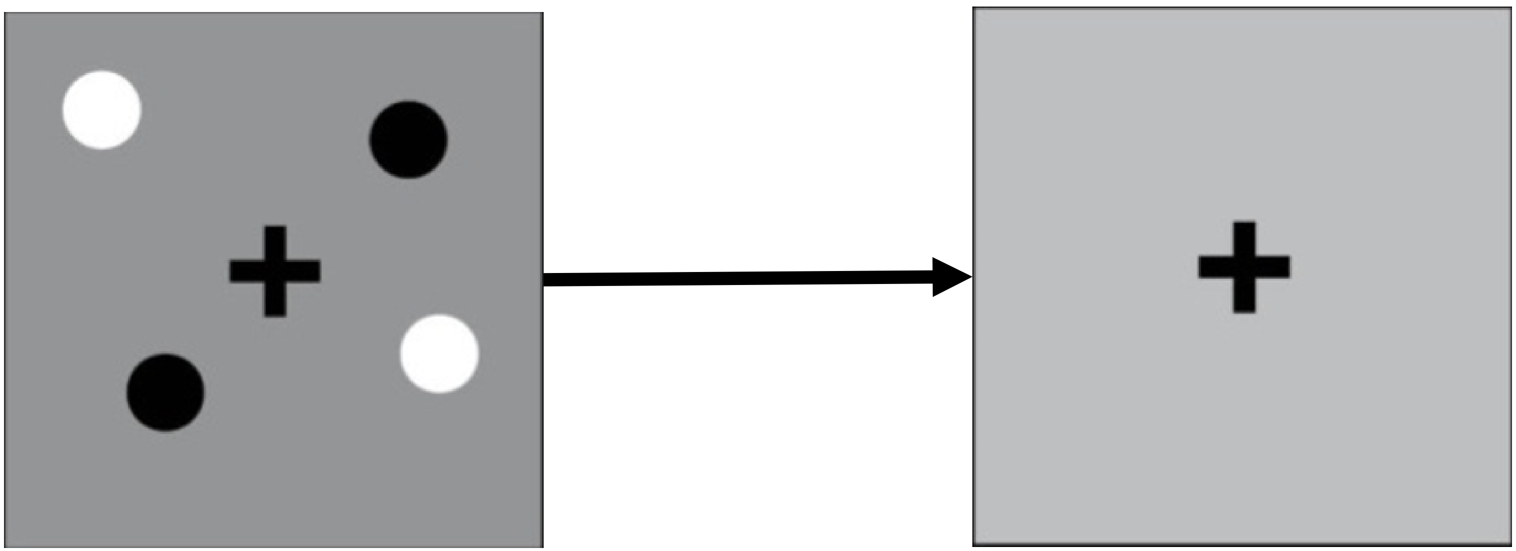
Dark/Light adaptation



Dark/Light adaptation



Dark/Light adaptation



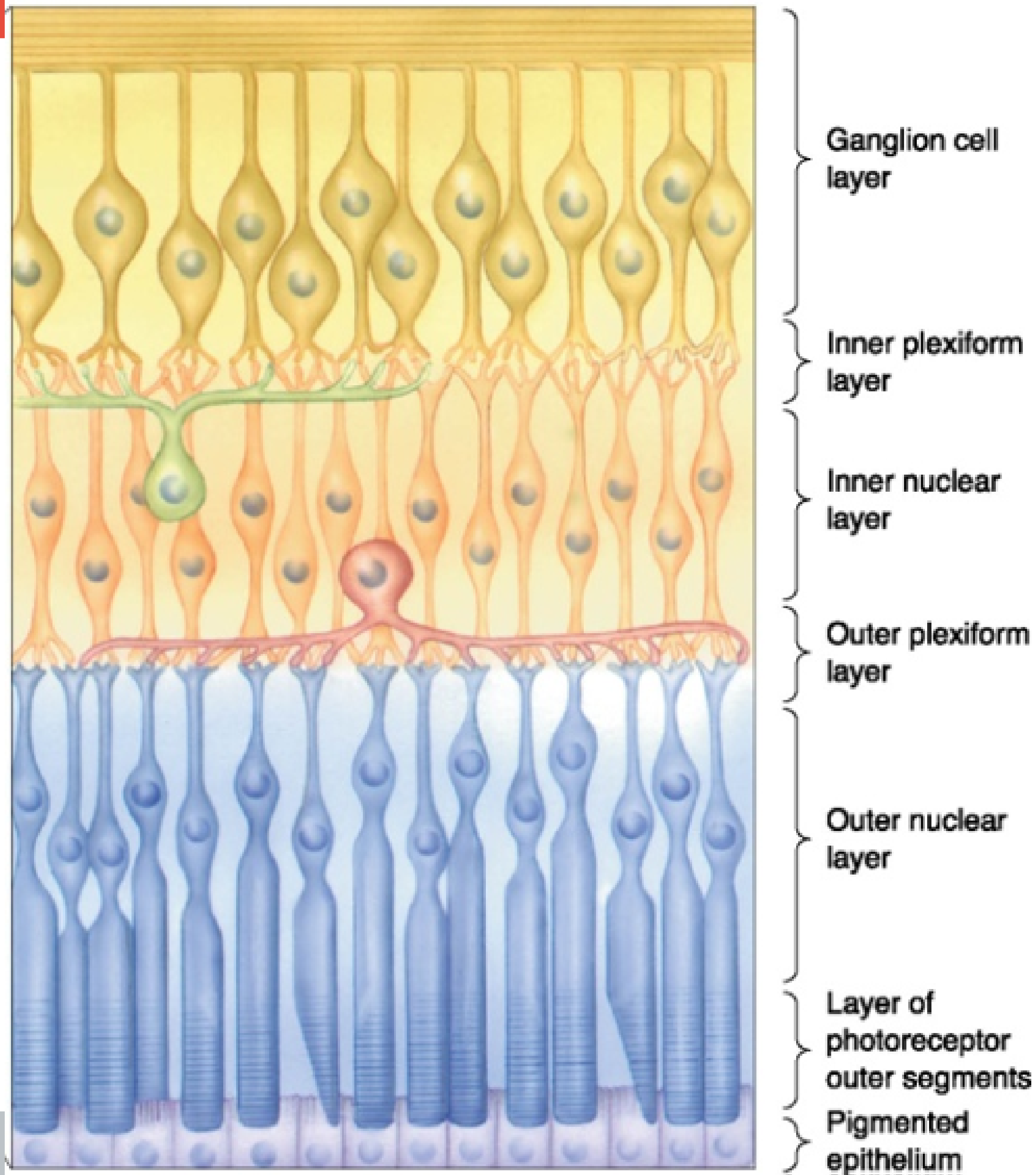
Looking at this image for about 1 minute will locally adapt the photoreceptors mainly by bleaching (retinal transformed due to more light from the white circles).

If, after adaptation, you look at this image, you will see dark spots where light spots have been and vice versa.

Retinal Ganglion Cells (RGC)

The ganglion cells are the only retinal cells to generate action potentials (retinal output) and are innervated by the optic nerve.

Between the photoreceptors and ganglion cells is a layer of bipolar cells, connecting the two. Horizontal cells (in red) contribute to the integration of information from several photoreceptors.



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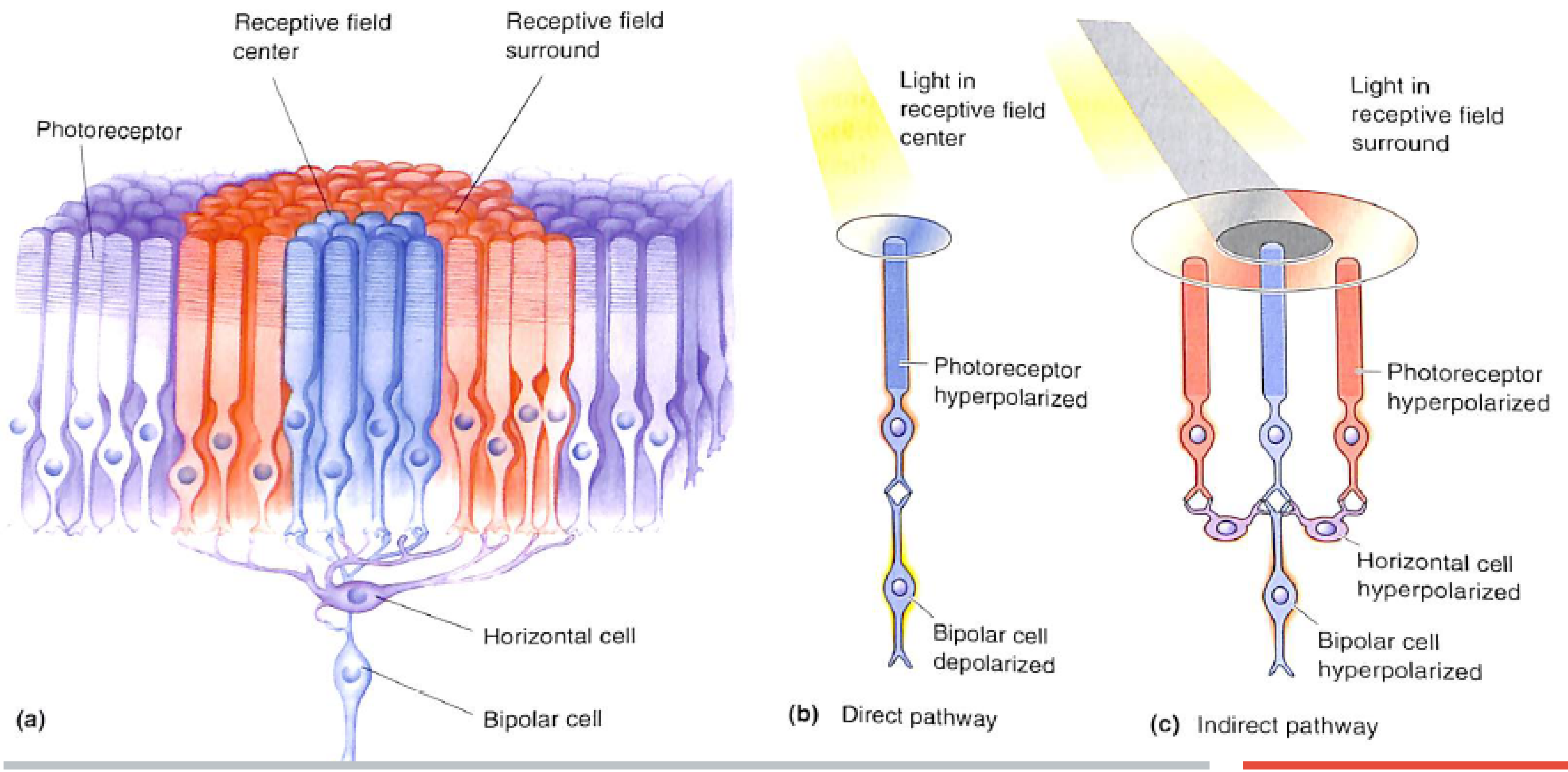
Retinal Processing

There are different types of bipolar cells:
ON bipolar cell: will respond to glutamate (no light) with hyperpolarizing (more negative)
OFF bipolar cell: will respond to glutamate (no light) with depolarizing (more positive)

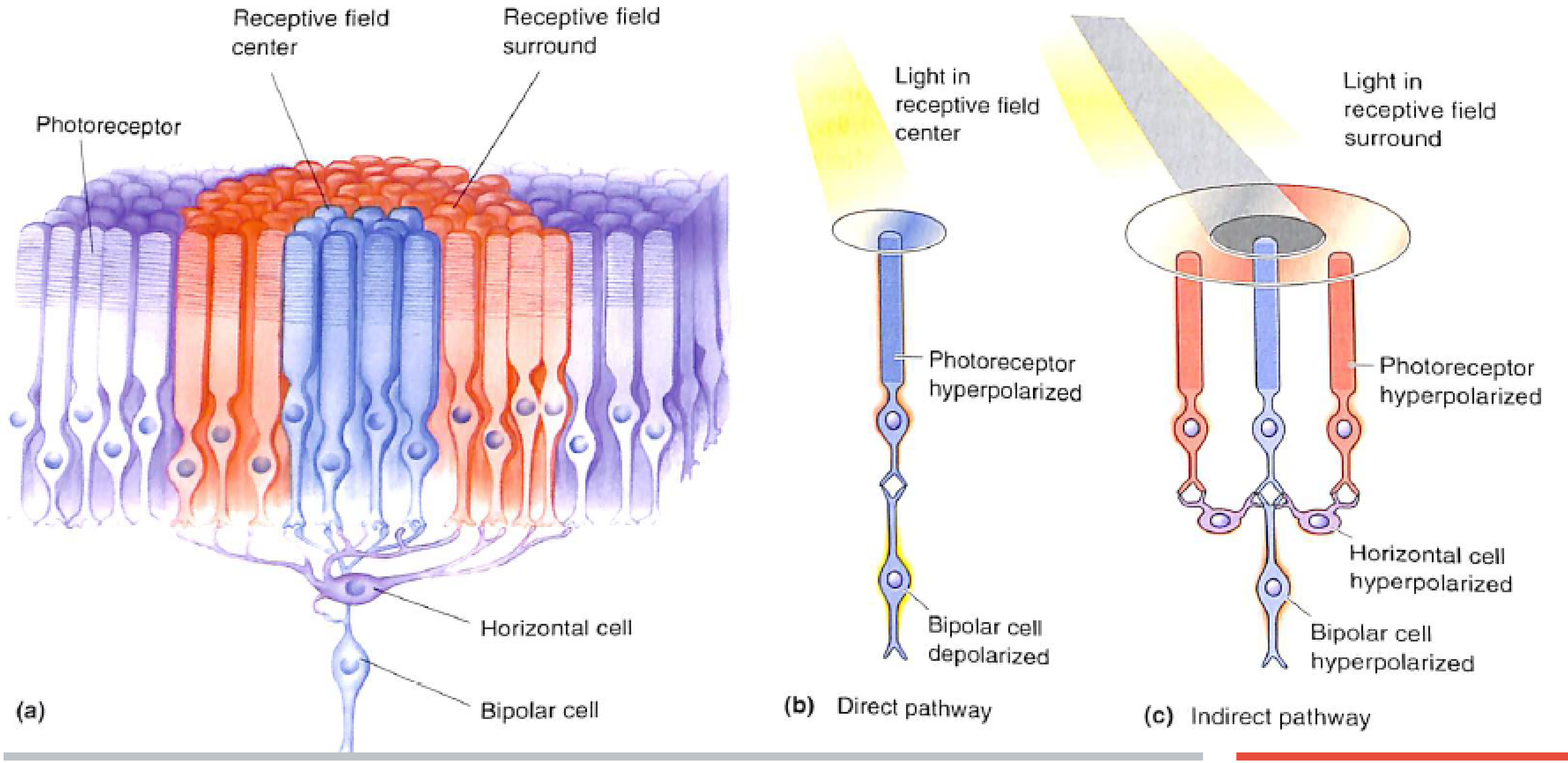
Receptive field of a cell: retinal area that when stimulated with light will result in a change of the cell's membrane potential



Retinal Processing

In b), light in the center will hyperpolarize the photoreceptor, and depolarize the ON bipolar cell.

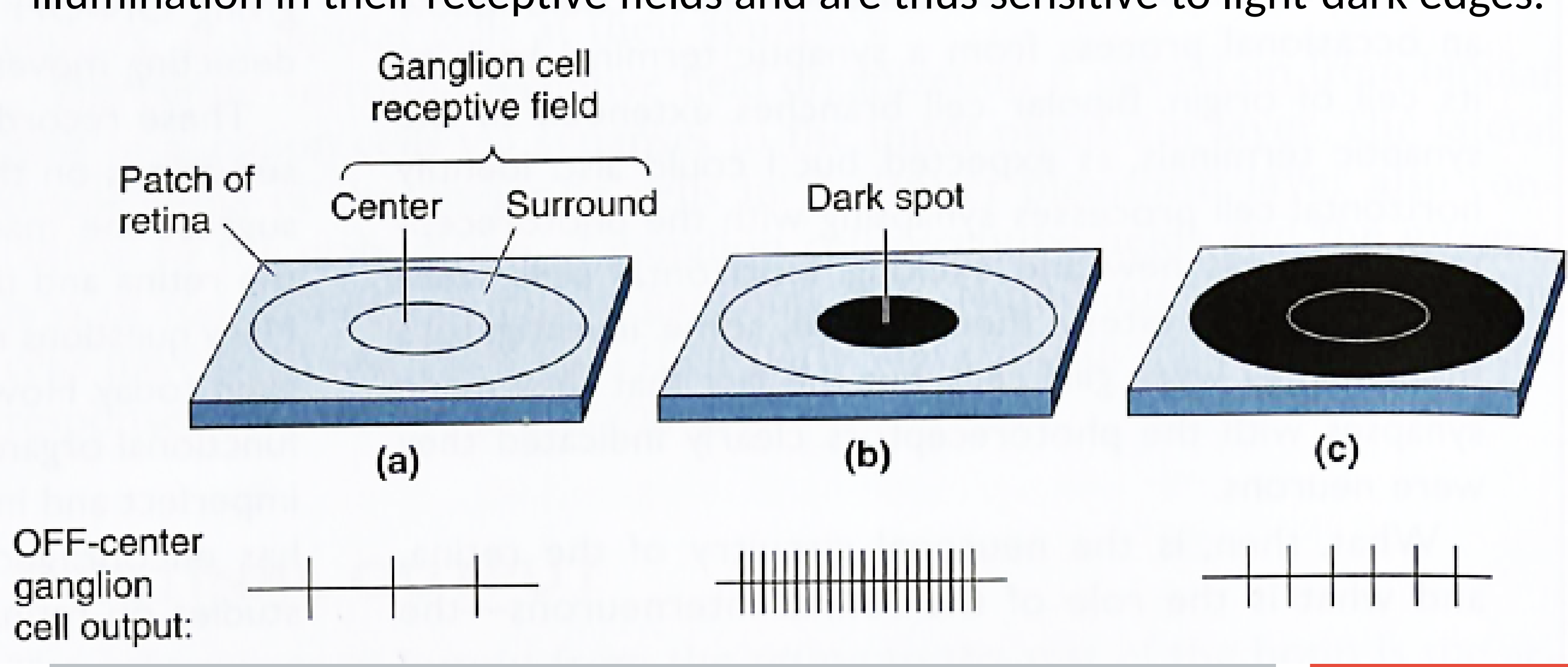
The bipolar cell in c) has a center-surround receptive field: light in the receptive field surround will hyperpolarize the photoreceptors in the surround, the horizontal cells, and thus the bipolar cell, preventing depolarization by light in the center.



Retinal Ganglion Cell Processing

Similar to bipolar cells, ganglion cells have a center-surround receptive field. In this case, an OFF-center ganglion cell will fire most with a dark spot in the center, surrounded by light. In contrast, an ON-center ganglion cell will fire most with light in the center, surrounded by darkness.

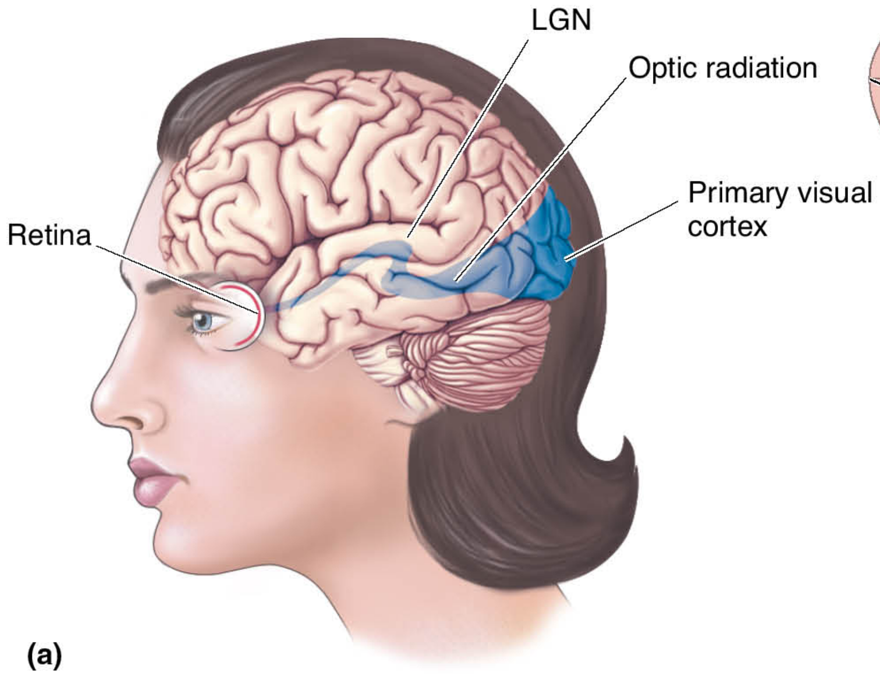
This means that the retinal ganglion cells are most sensitive to changes of illumination in their receptive fields and are thus sensitive to light-dark edges.

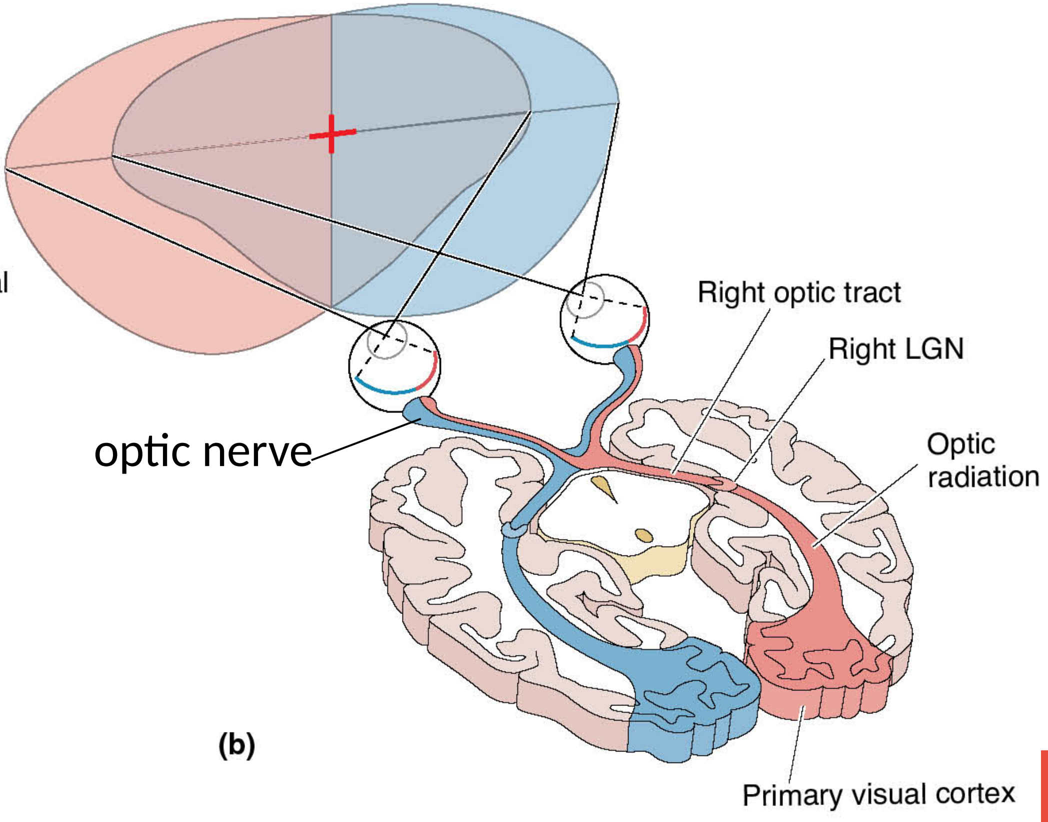


Primary visual pathway (thalamocortical)

Retinal ganglion cells have axons (via optic nerve, optic chiasm, and optic tract) reaching the lateral geniculate nucleus (LGN) of the thalamus. At the optic chiasm (crossing) the nerve crosses such that visual input from the right hemifield (blue) goes to the left brain hemisphere and visual input from the left hemifield (red) crosses to the right brain hemisphere.

From LGN, visual input is transmitted via the optic radiation to primary visual cortex.



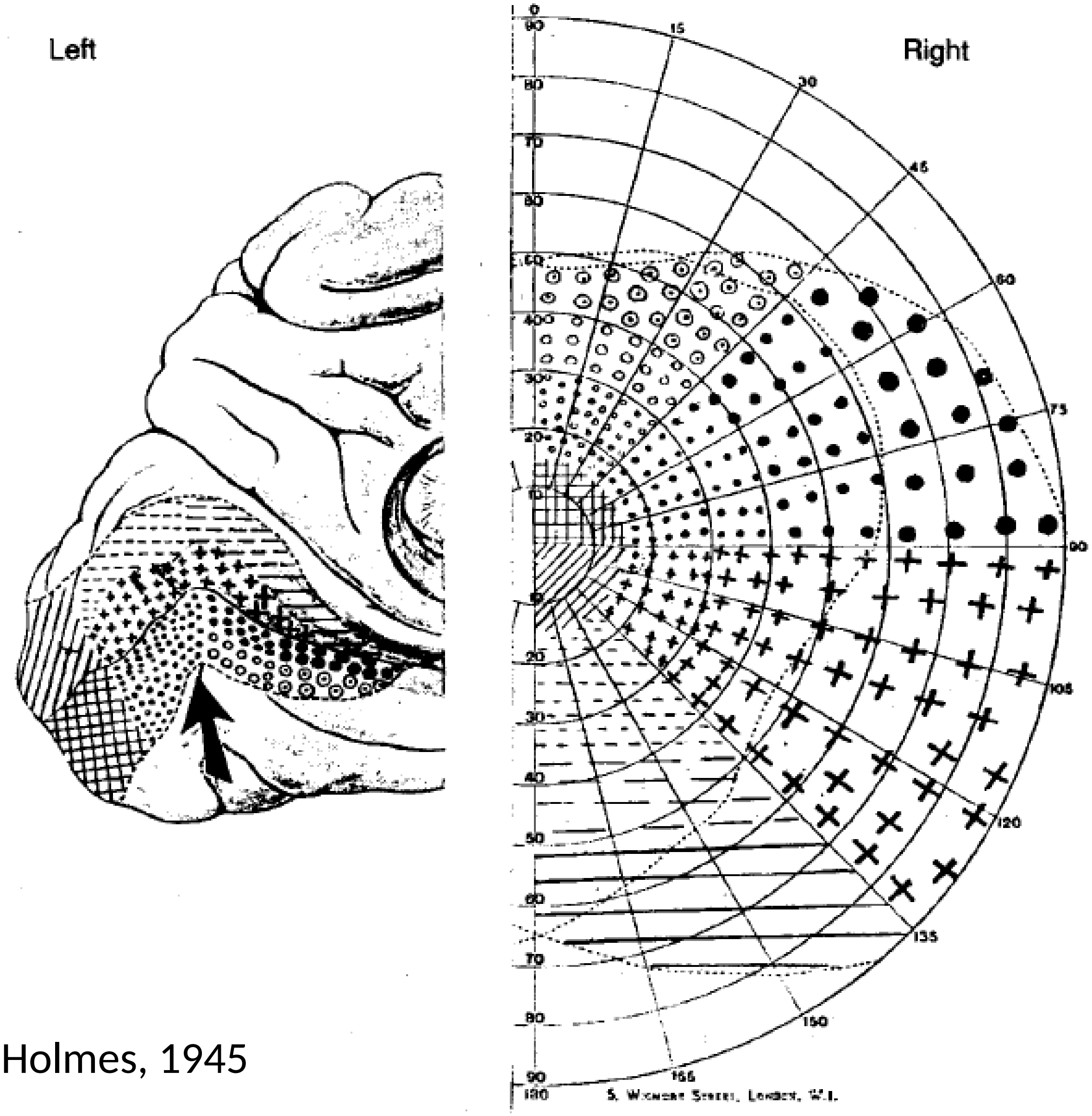


Primary Visual Cortex (V1)

British Expeditionary Force WWI

Tatsuji Inouye (Japanese ophthalmologist) investigated the effect of lesions (soldiers in the Russo-Japanese War) to the occipital cortex on the loss of vision in parts of the visual field. Gordon Holmes (British neurologist) later confirmed these results with data from WWI soldiers.

Primary Visual Cortex (V1)



Holmes, 1945

The upper right visual field is represented by the inferior part of primary visual cortex (arrow).

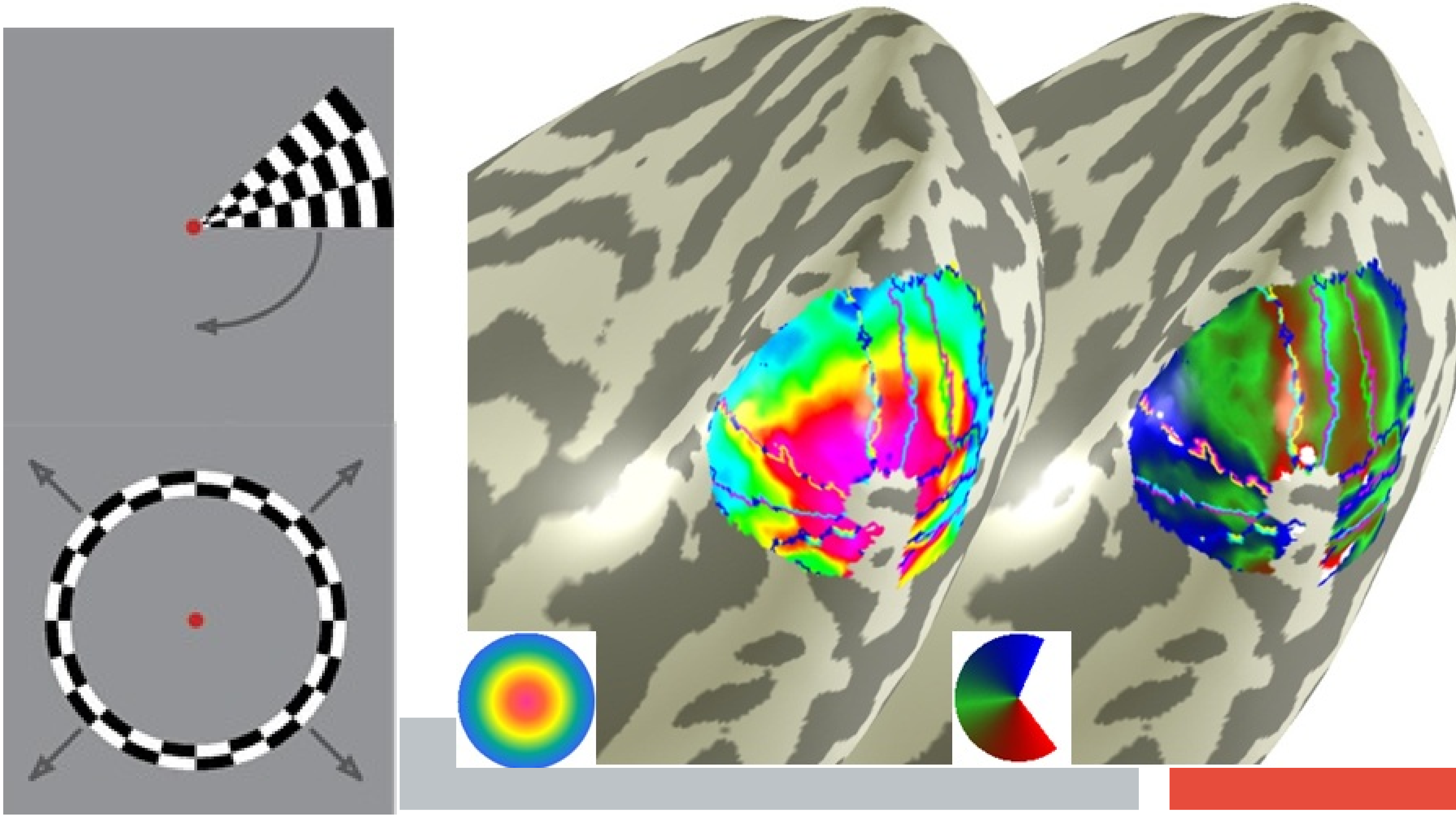
The foveal visual field is represented by the posterior part of primary visual cortex (occipital pole).

The cortex surface dedicated to the foveal visual field is comparatively larger than the peripheral visual field.

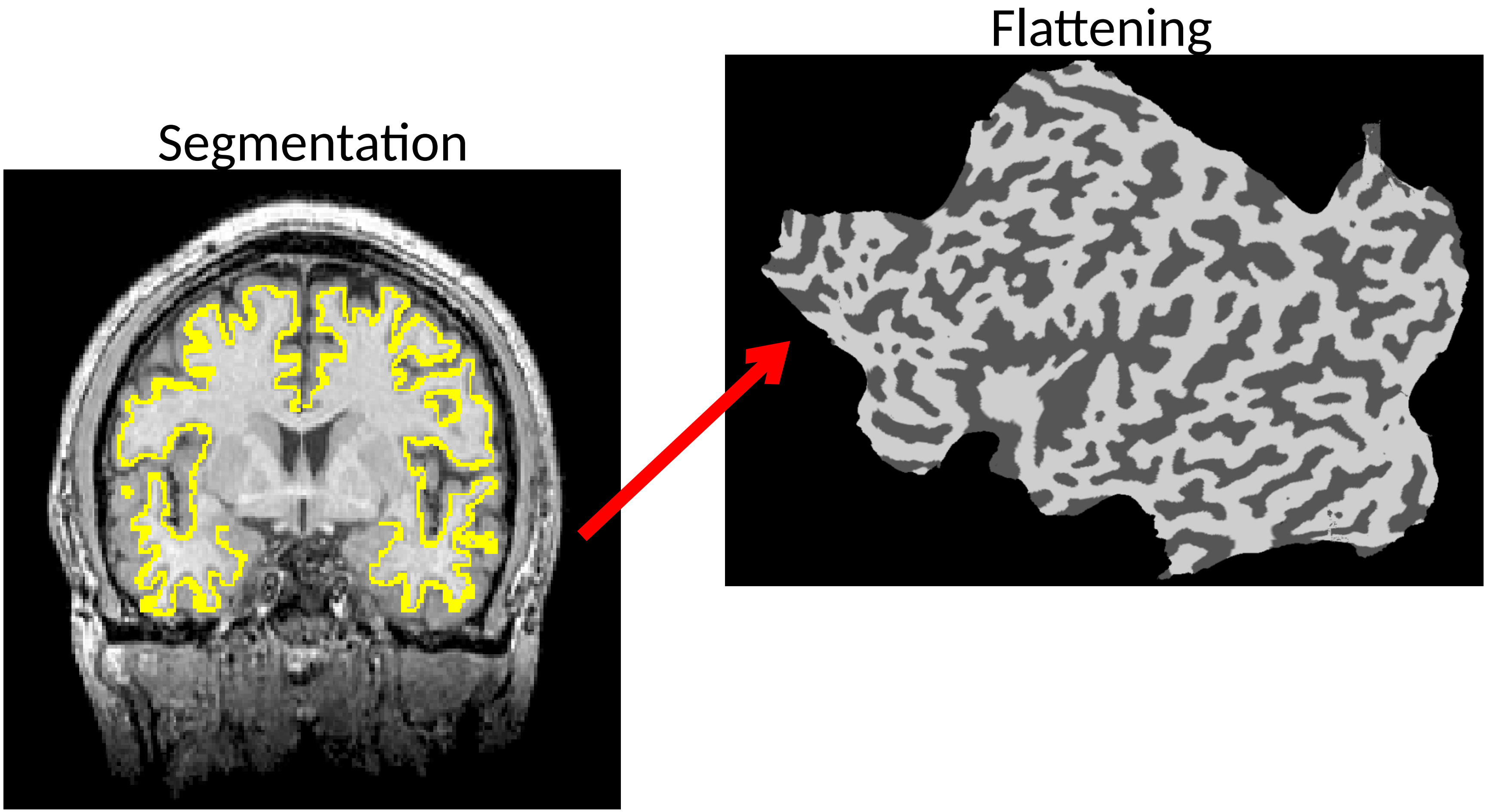
This mapping of the visual field on visual cortex is called retinotopy.

Visual cortex is “retinotopic”: fMRI

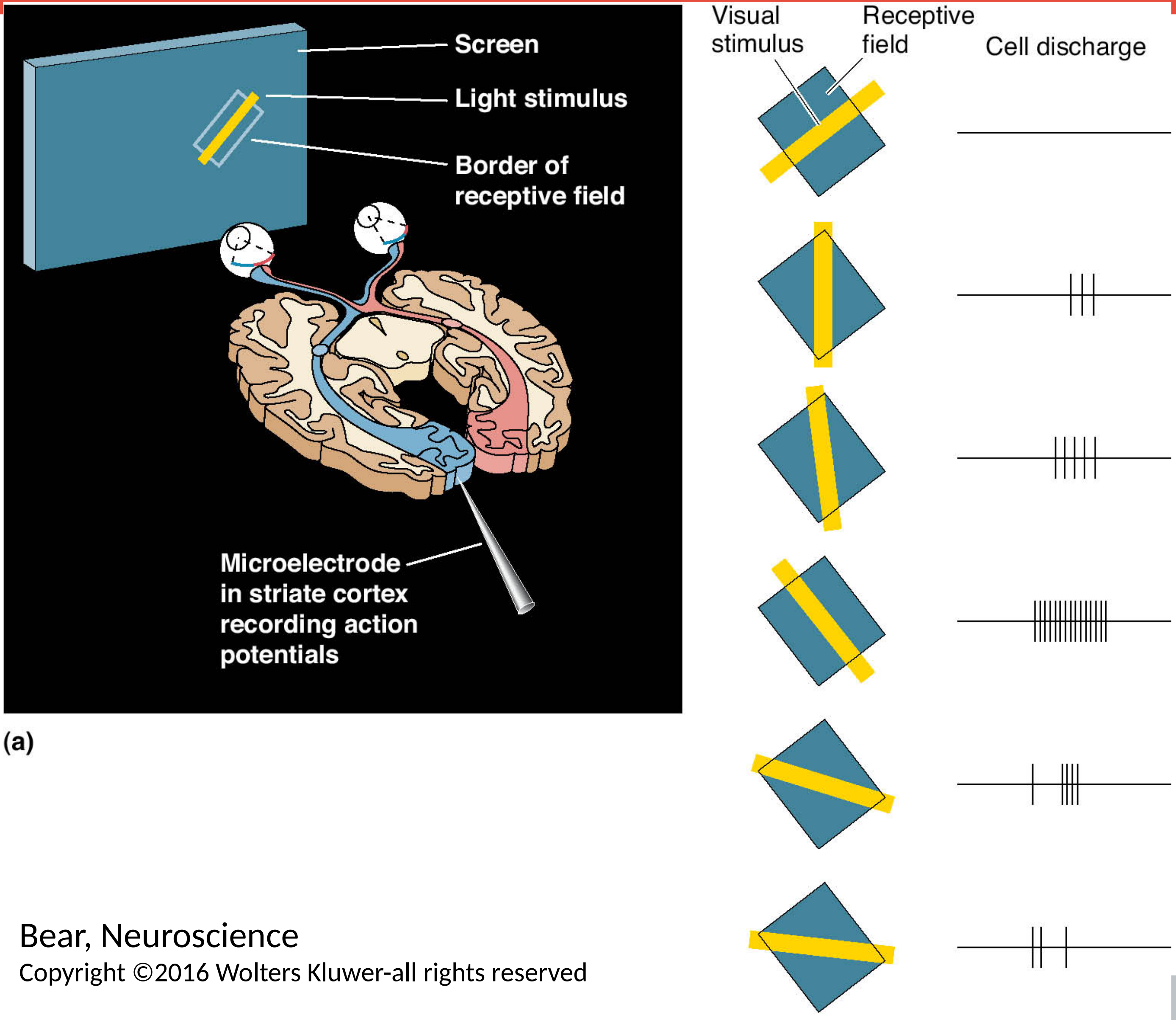
Retinotopy can be visualized with fMRI by presenting checkerboard visual stimuli. On the right image, we see that there are turning-points (green-red-green) that demarcate borders between visual areas (e.g., primary visual cortex = V1 and secondary visual cortex = V2).



MRI: “Flattening”



Orientation selectivity in V1



(a)

(b)

In the 1950s, Torsten Wiesel and David Hubel have found that many cells in V1 are orientation-selective, i.e., they respond strongest to one particular direction of a line.

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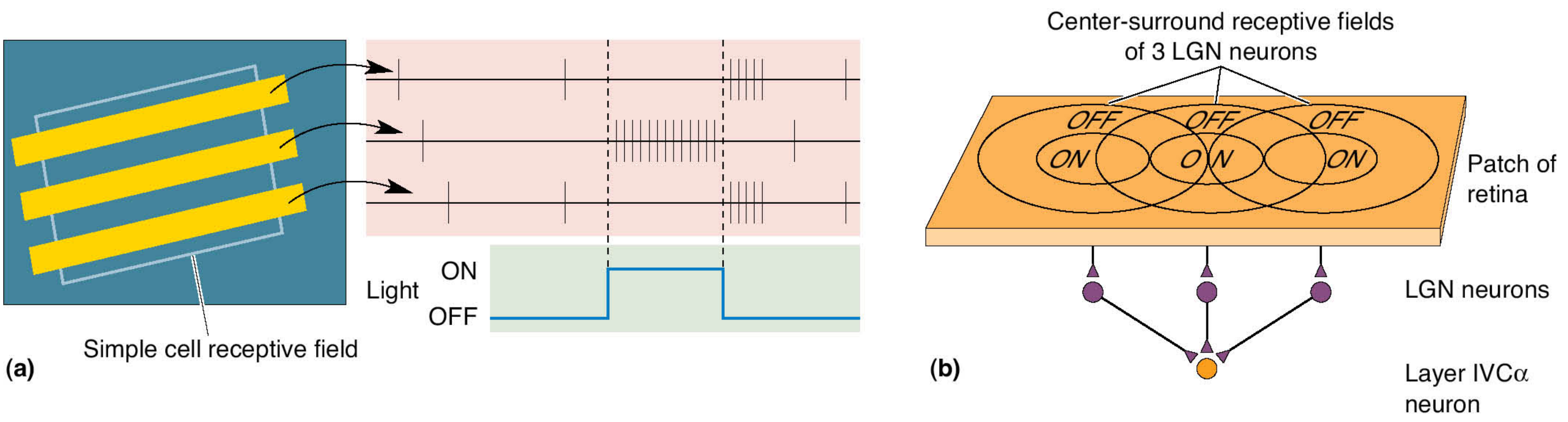
“Simple cells” in V1

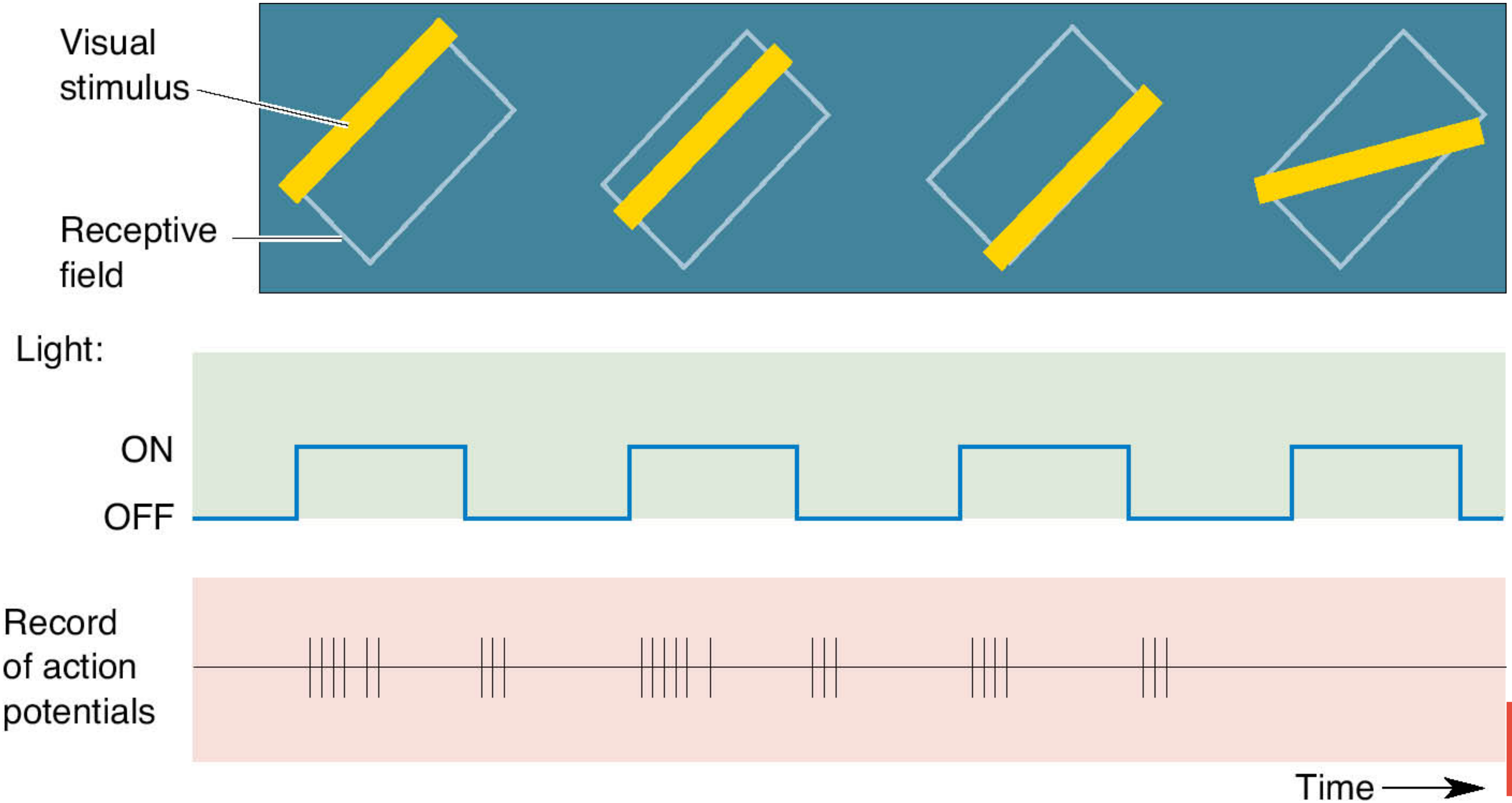


Orientation selectivity can be built by combining the input of several neurons with a center-surround receptive field (b).

For “simple cells”, the response is strongest for some specific location in their receptive field (a).

“Complex cells” in V1

In contrast to simple cells, complex cells respond to lines of a specific orientation throughout their receptive field. They are to some degree “translation-invariant”.



Other V1 cells

V1 also has:

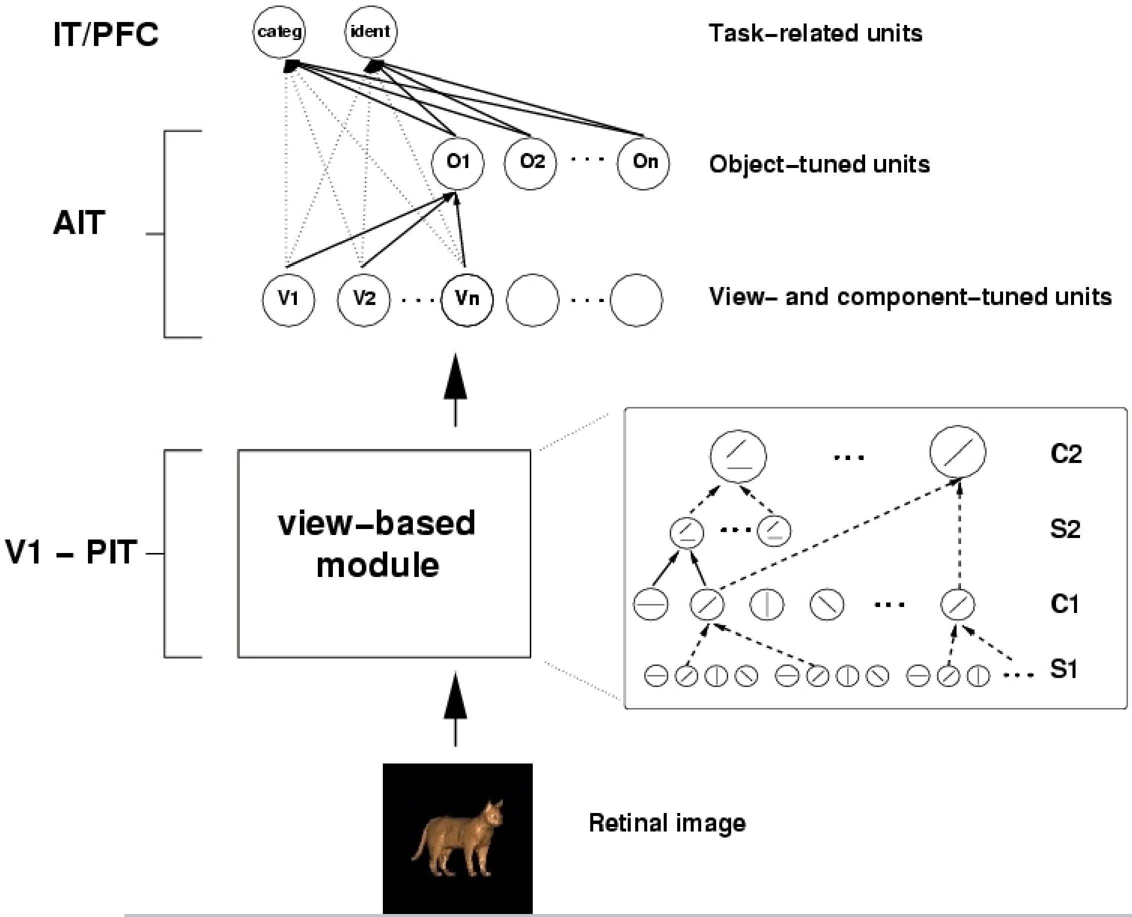
→ Motion sensitive cells

→ Color sensitive cells

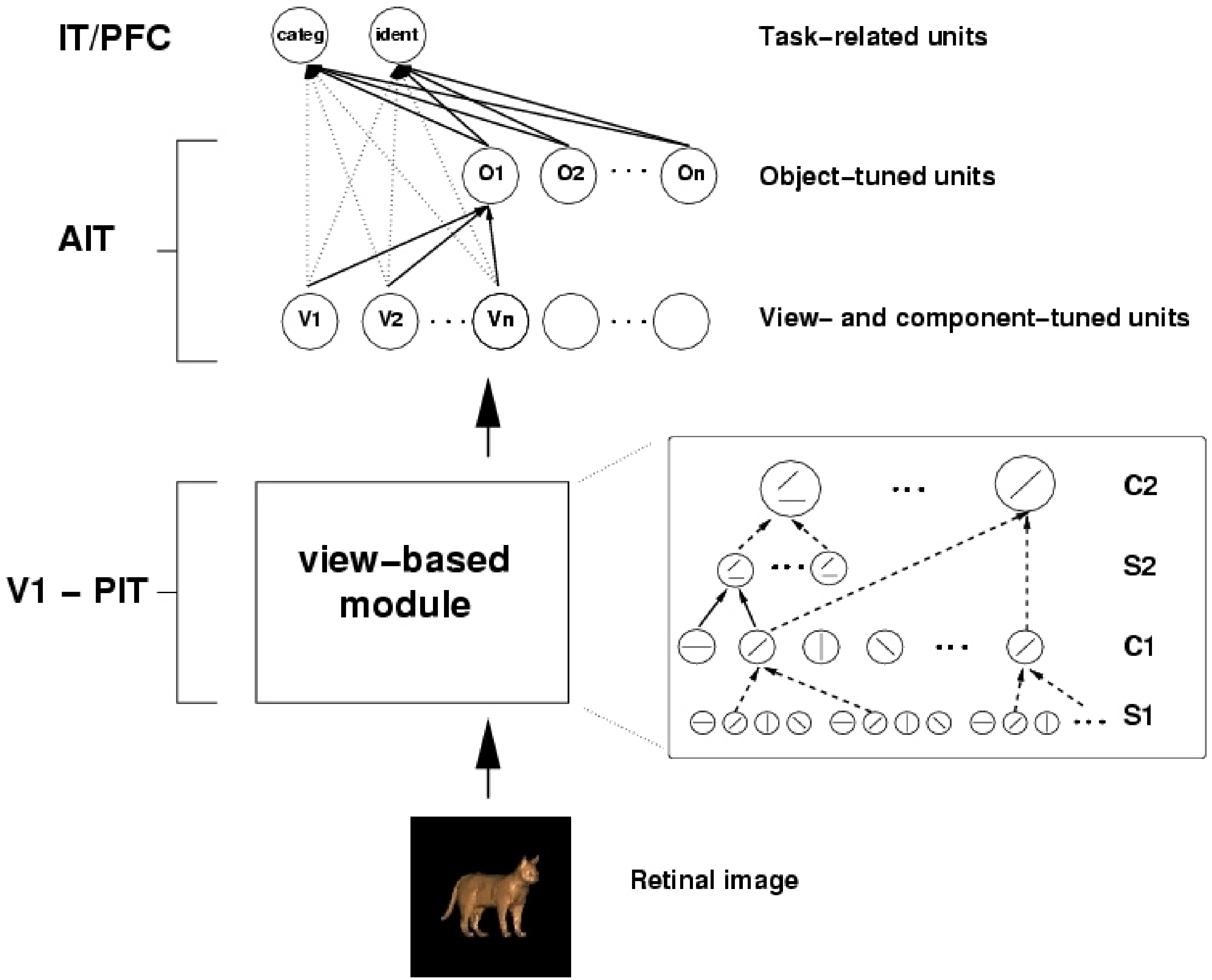
V1 is the “first step” in a *hierarchy* of brain areas that do additional processing on the visual stimulation

Hierarchical Visual Processing

Combination of simple features (orientation) to more complex features (corners, complex shapes) is called hierarchical processing and possibly underlies object perception. The hierarchy is reflected anatomically such that from occipital cortex (V1) to inferotemporal cortex (PIT, AIT, IT) the complexity of represented shapes increases.



Max Riesenhuber, Georgetown University



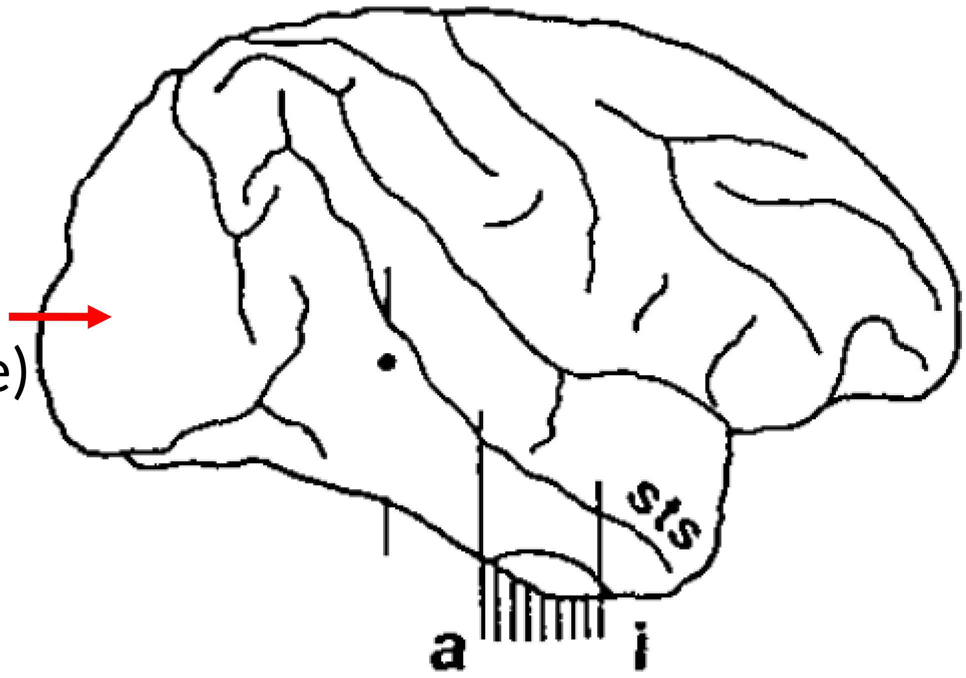
C2, S2: detect combinations of edges

C1: complex cells

S1: simple cells

What about recognizing “things” (“objects”)

Primary visual cortex (macaque)

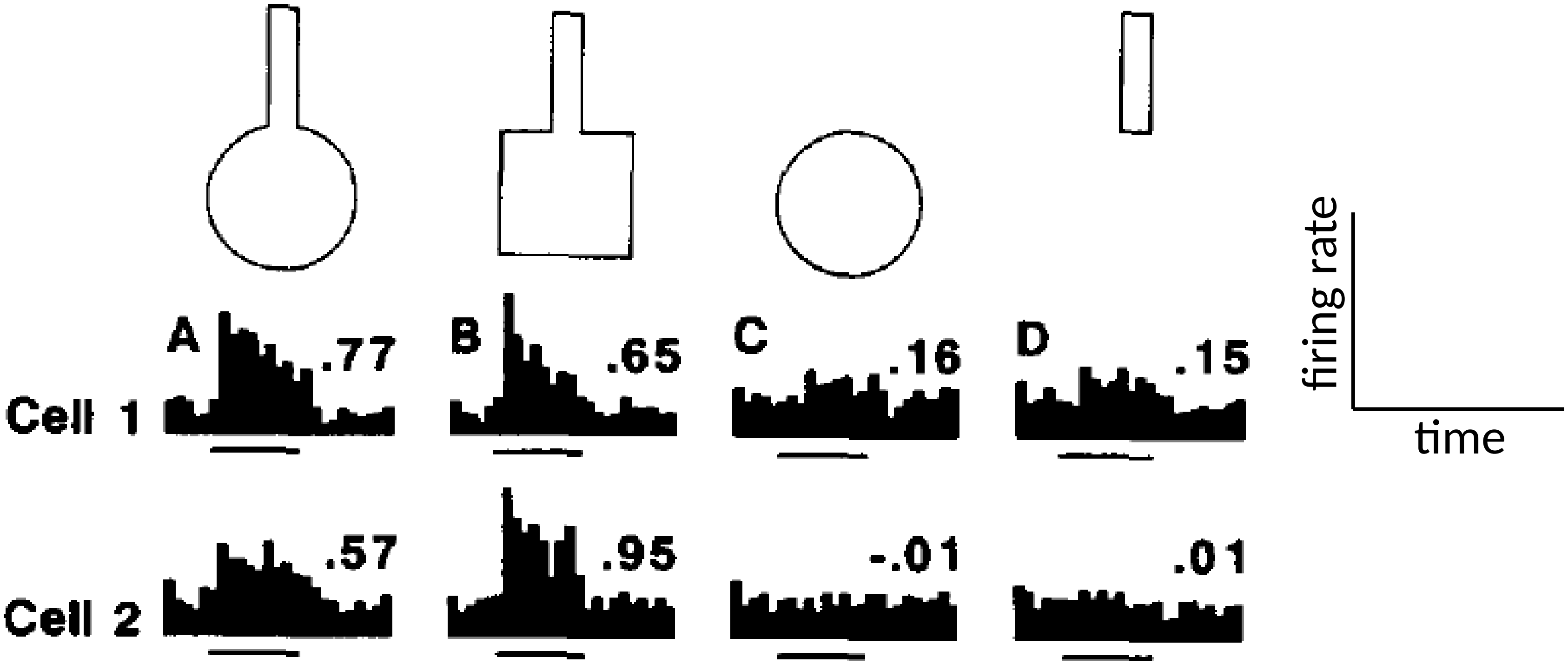


Inferotemporal cortex

Neurons in the inferotemporal cortex respond to rather complex shapes.

Tanaka, Annual Reviews in Neuroscience, 1996

Object processing

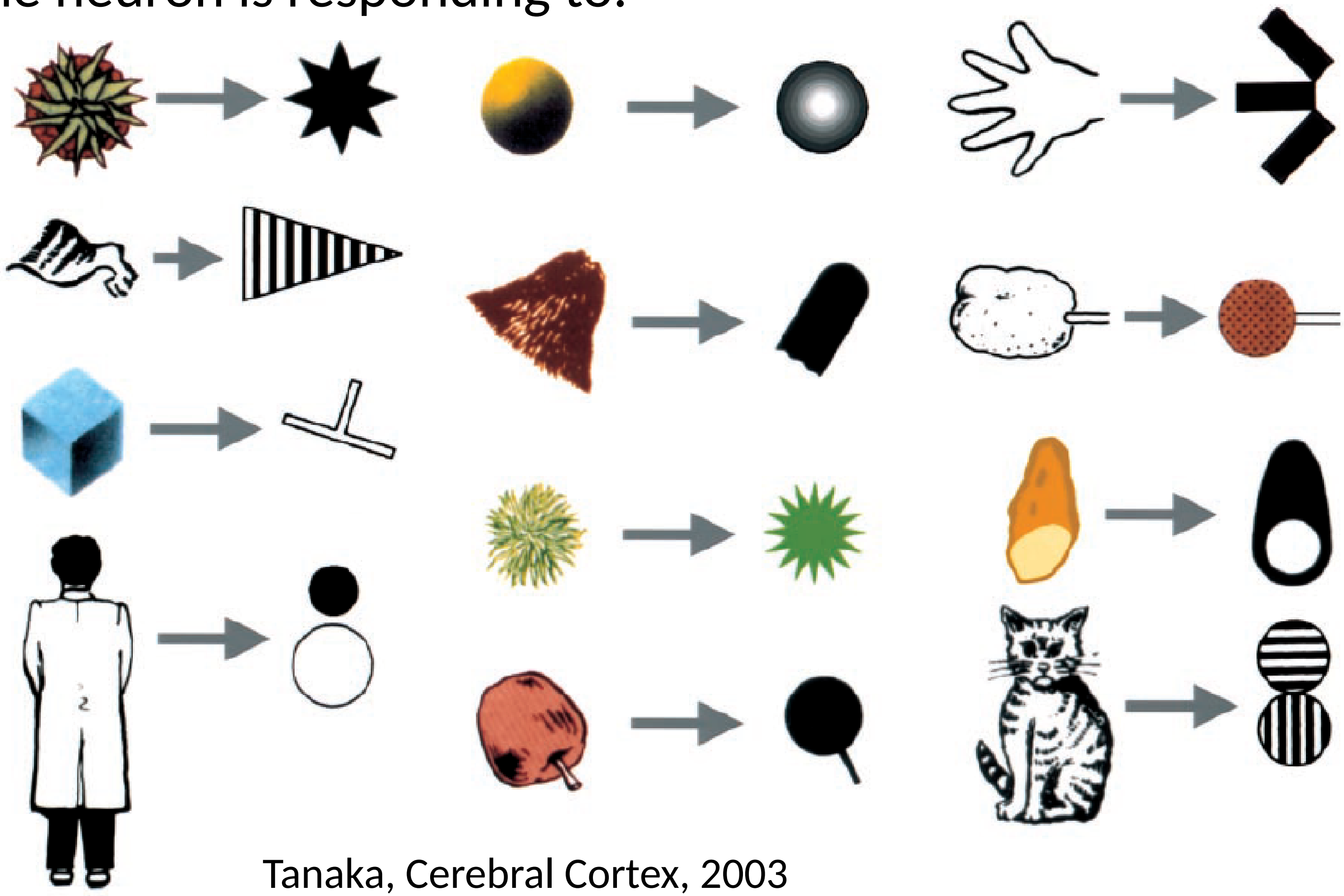


Here are two exemplary cells (inferotemporal cortex): cell 1 responds with a higher firing rate to shape A; cell 2 responds strongest to shape B. Object parts are not sufficient to lead to strong responses.

Tanaka, Annual Reviews in Neuroscience, 1996

Object processing

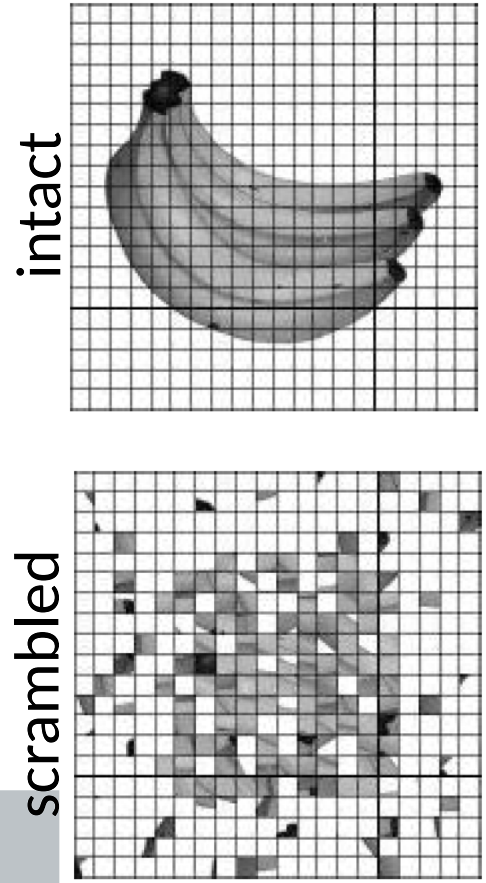
Reduction method: first complex, natural stimuli are presented. Once a neuron responds to one stimulus, the stimulus is simplified to find what the neuron is responding to.

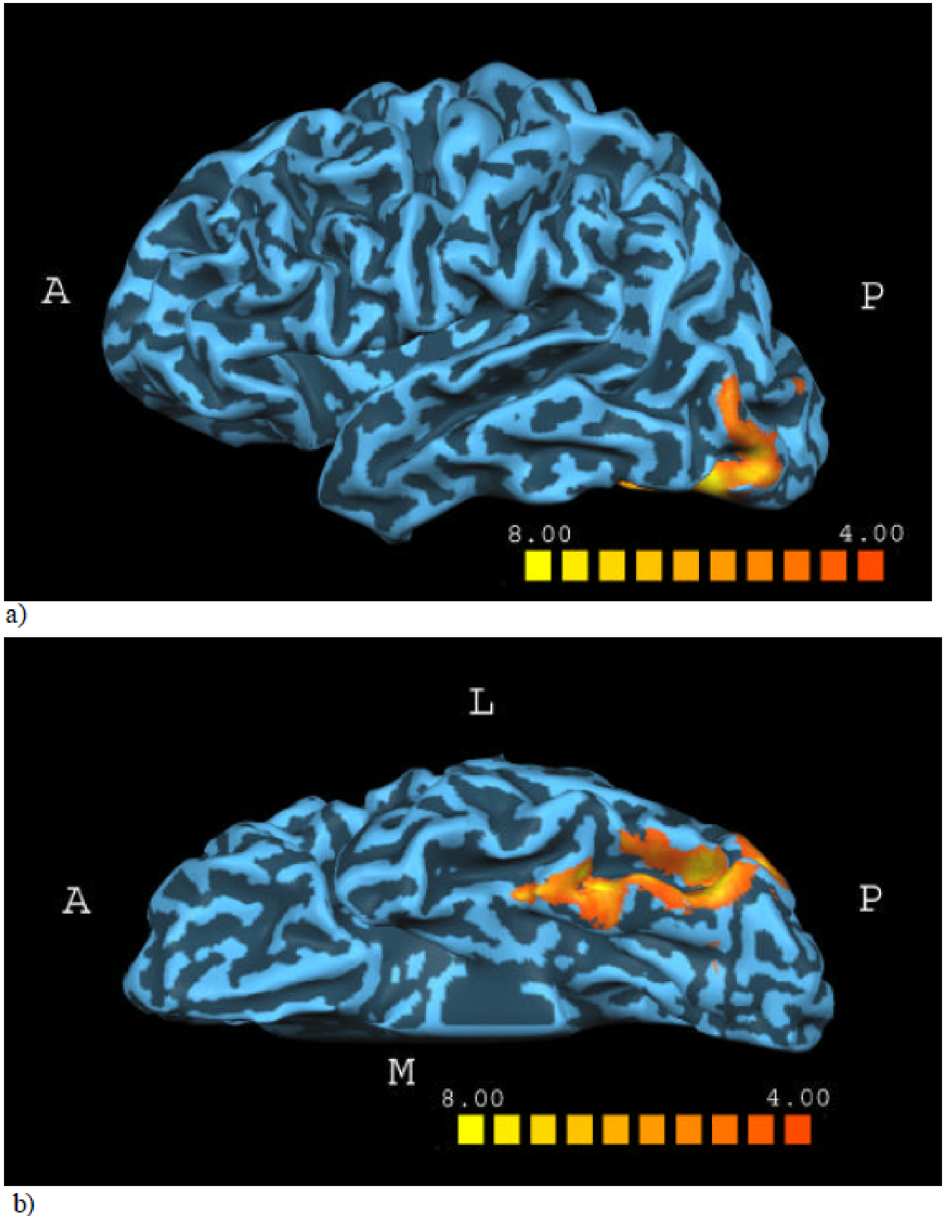


Tanaka, Cerebral Cortex, 2003

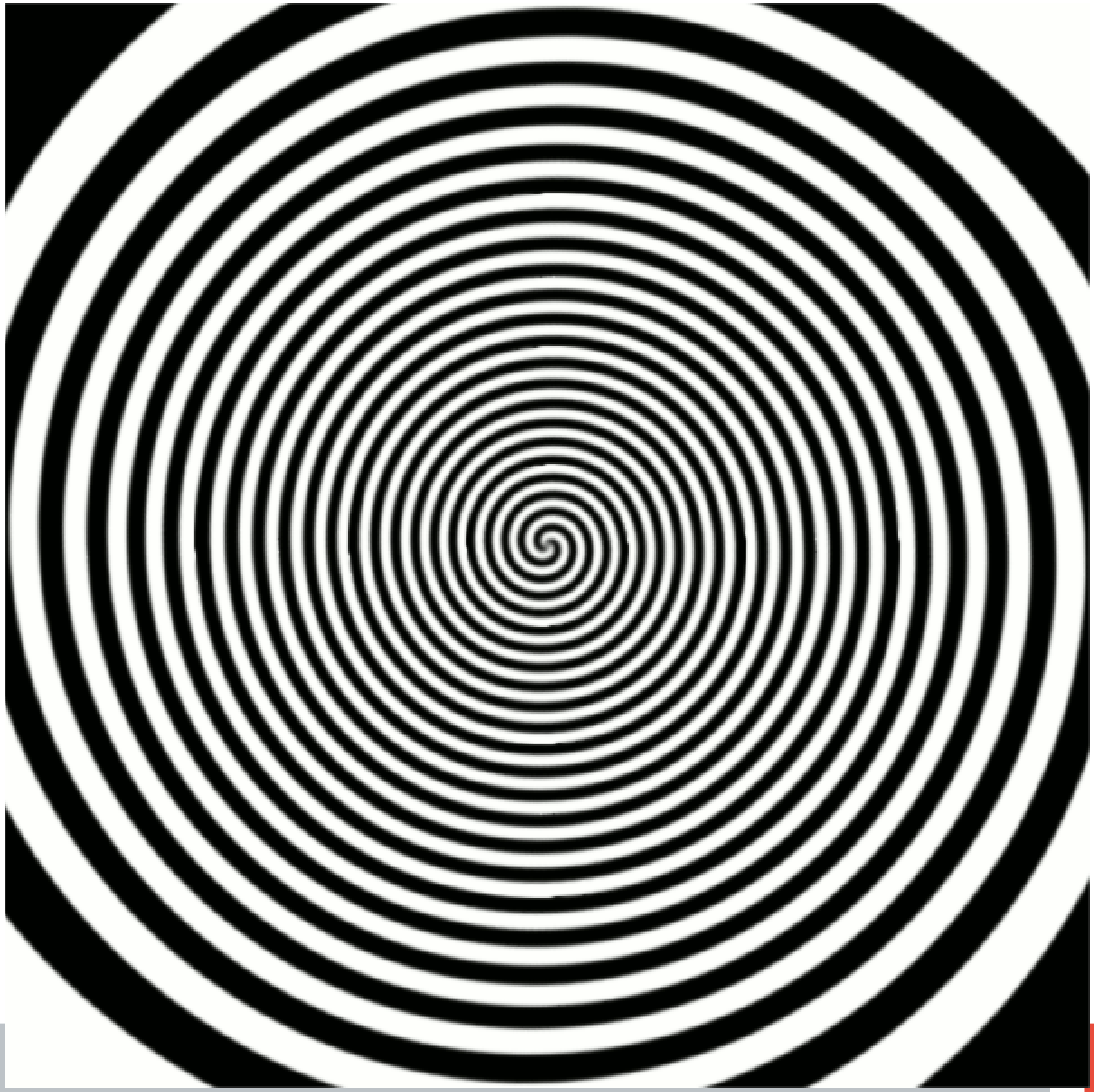
Object processing

In the human brain, the so-called lateral occipital complex (right: red/yellow areas in occipital and inferior temporal lobe) responds stronger to intact than scrambled objects.



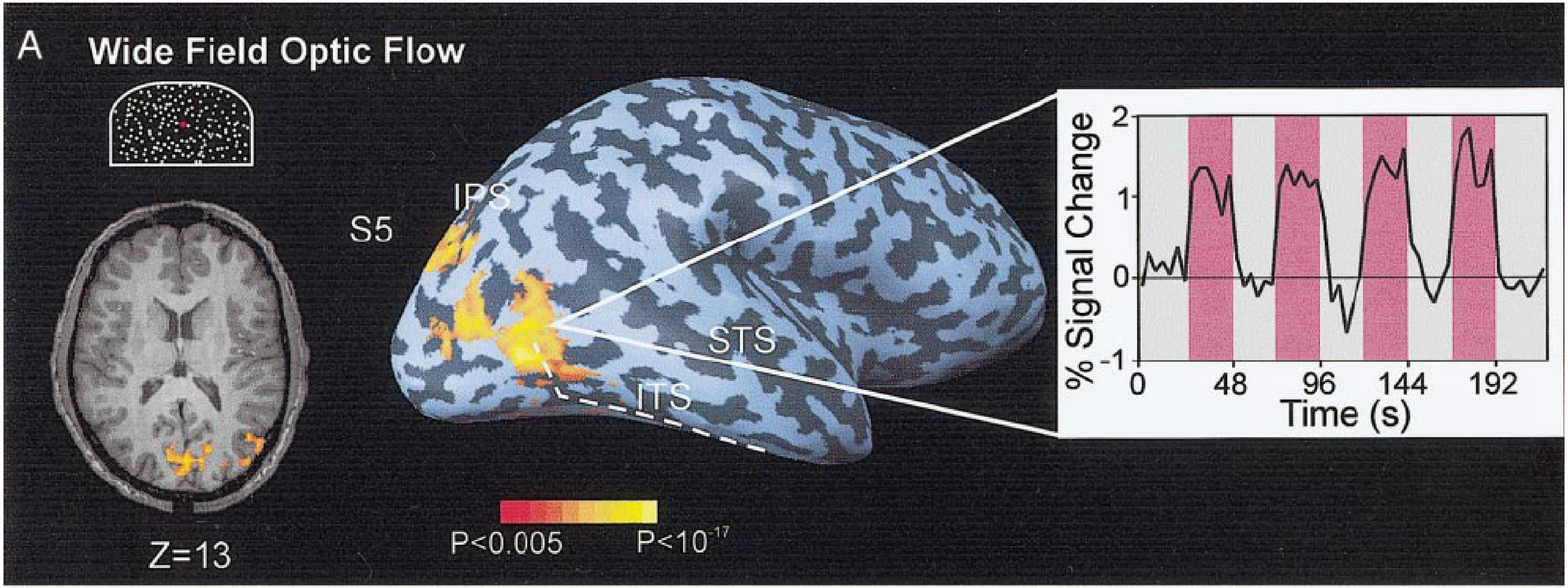


Motion aftereffect



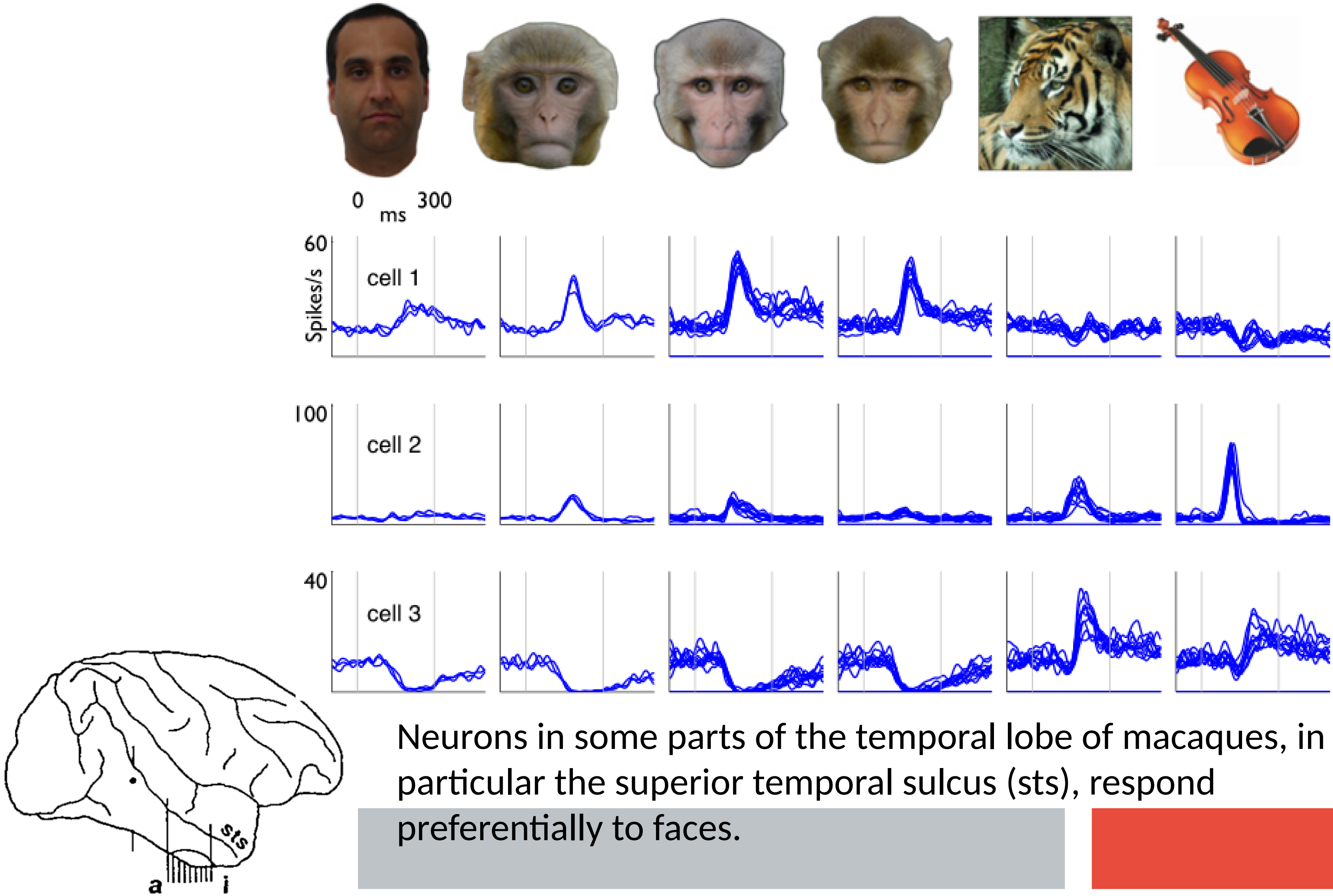
Visual Motion

As the motion aftereffects suggest, some visual neurons are selective for motion direction. One motion-sensitive cortical area in humans is MT/V5. It can be mapped with fMRI: activation contrast between moving versus static dots.



Dukelow et al., Journal of Neurophysiology, 2001

Face-selective neurons



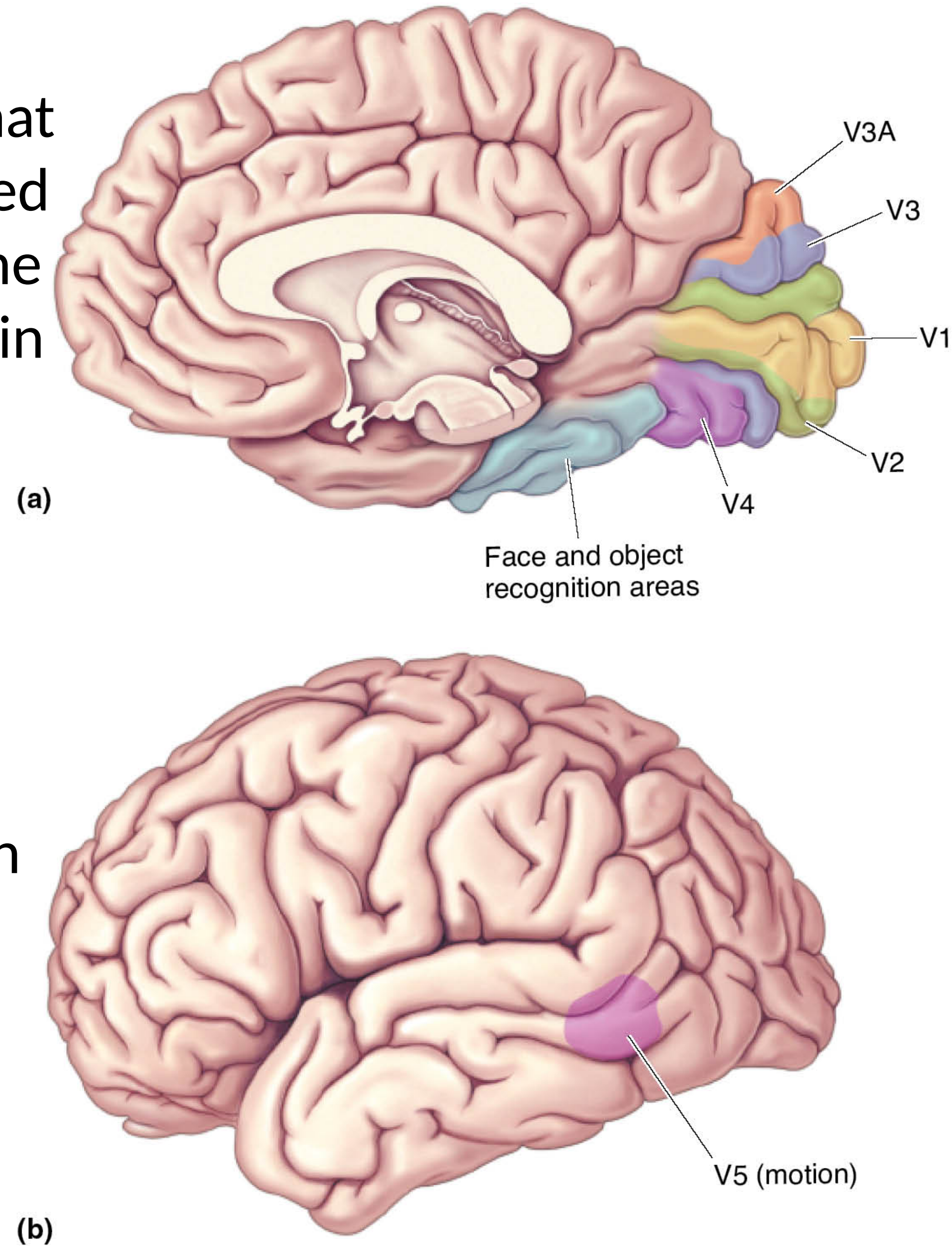
Neurons in some parts of the temporal lobe of macaques, in particular the superior temporal sulcus (sts), respond preferentially to faces.

Fusiform face area

In humans, there are also areas that respond strongly to faces compared with other objects, in particular the so-called fusiform face area (FFA) in the inferior temporal lobe.

Lesions in this area can lead to prosopagnosia, a deficit in recognizing faces.

Lesions to object-related areas can lead to visual object agnosia (a deficit in recognizing objects).



Summary

- The eye and retina convert light into neural excitation.

- The circuit properties of the retina result in an enhanced sensitivity to differences in illumination.

- In the visual system, many visual features are processed in parallel, such as orientation, motion, color, etc.

- The complexity of represented features increases along the visual pathway -> hierarchical processing.