Visual pathway

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U2IS - ENSTA - IPParis

ecampus moodle: MI210 - Modèles neuro-computationnels de la vision (P4 - 2020-21)

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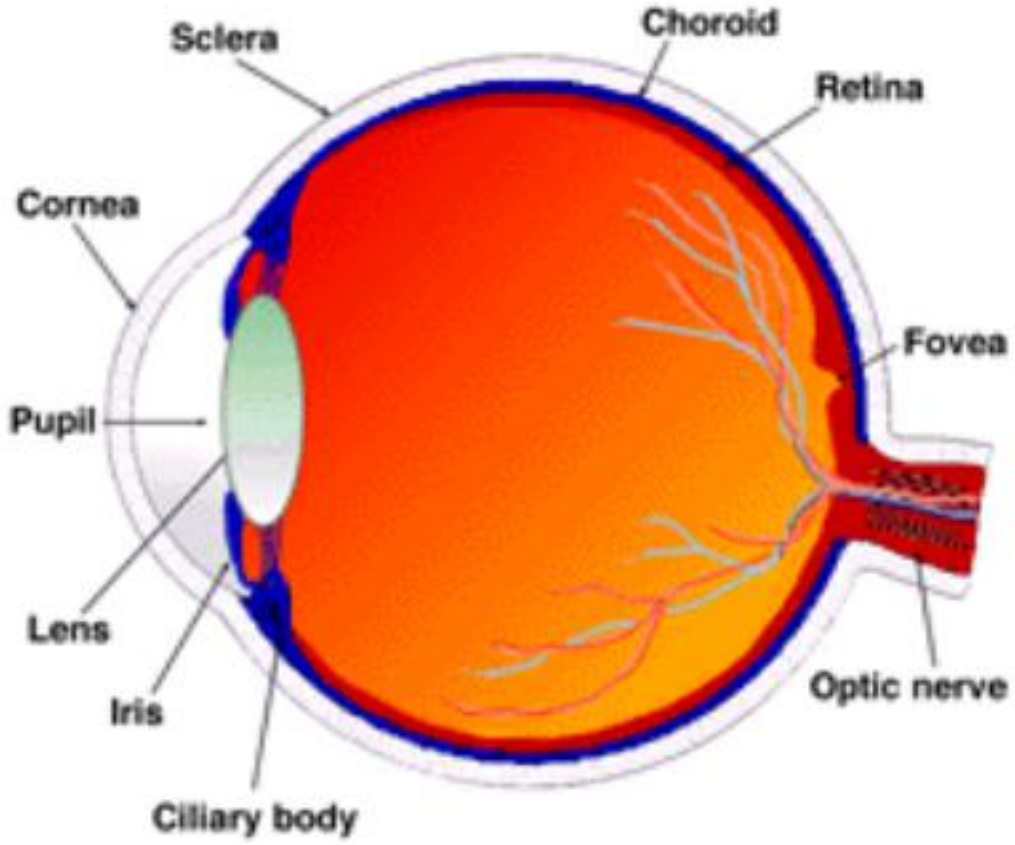
Contents

Contents

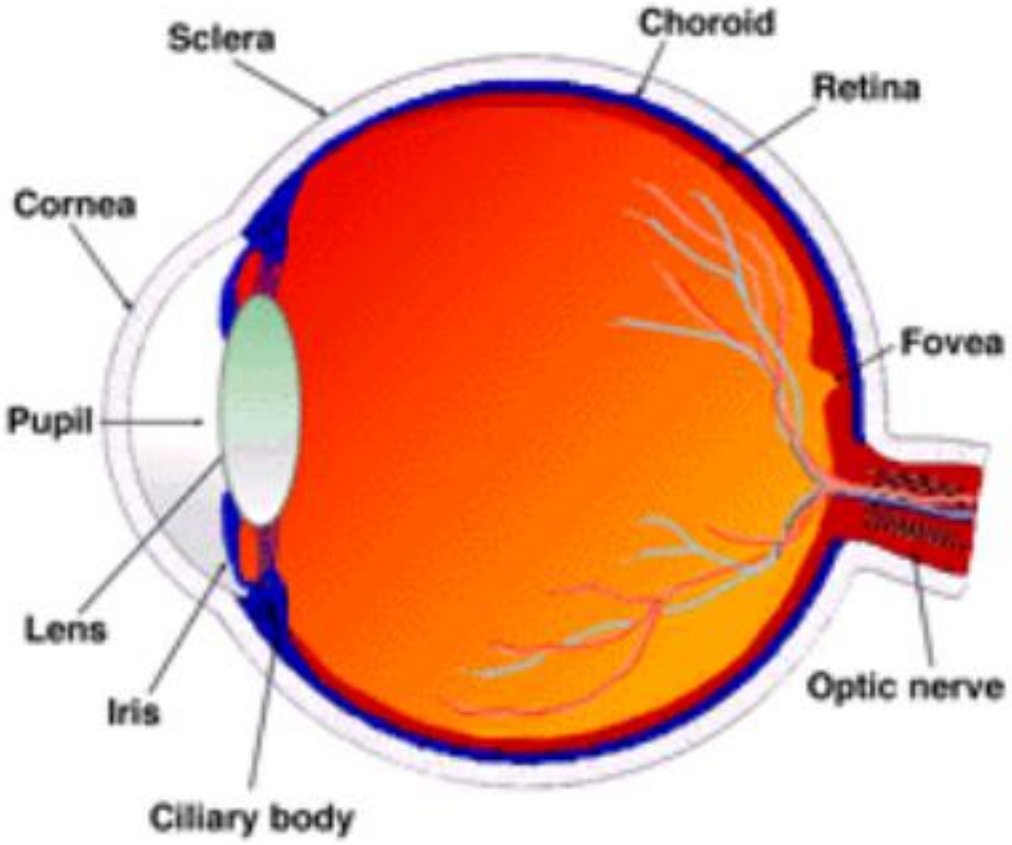
Sensing: the eye (outside)

Pupil: black-looking aperture,that allows light to enter the eye
Iris: colored circular muscle, which is pigmented giving us our eye's color. It controls the size of the pupil so that more or less light
Cornea: transparent external surface that covers both the pupil and the iris. This is the first and most powerful lens of the optical system of the eye
Crystaline Lens: secondary lens
Sclera: The "white of the eye", which forms part of the supporting wall of the eyeball.



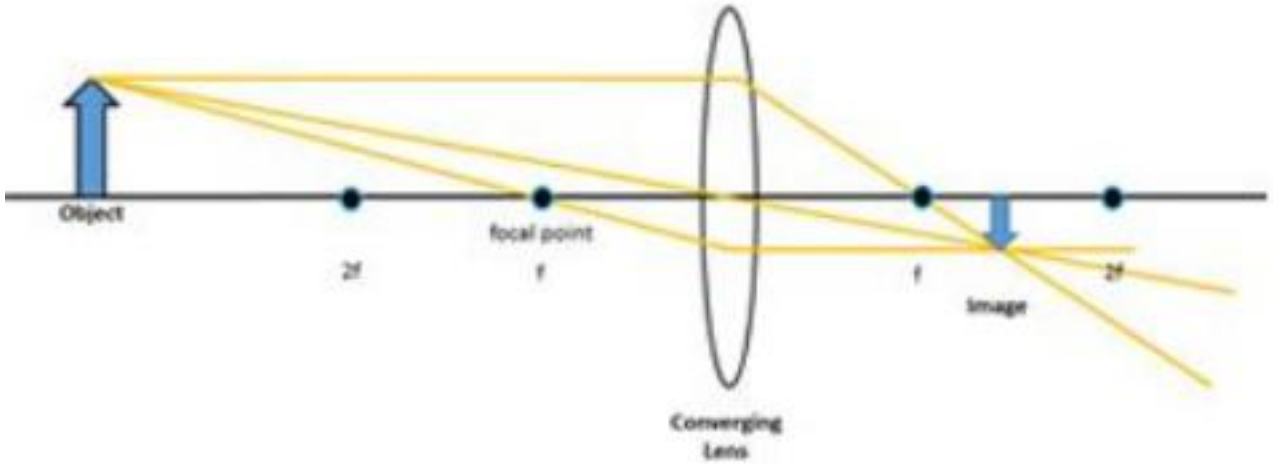
Sensing: the eye (inside)

Cilliary body: accommodation, aqueous humor production and resorption (providing oxygen, nutrients, and metabolic waste removal), and maintenance of the lens
Choroid: the vascular layer
Retina: light-sensitive layer of tissue of the eye, where the neurons are
Fovea: central pit composed of closely packed cones (one type of photoreceptors)

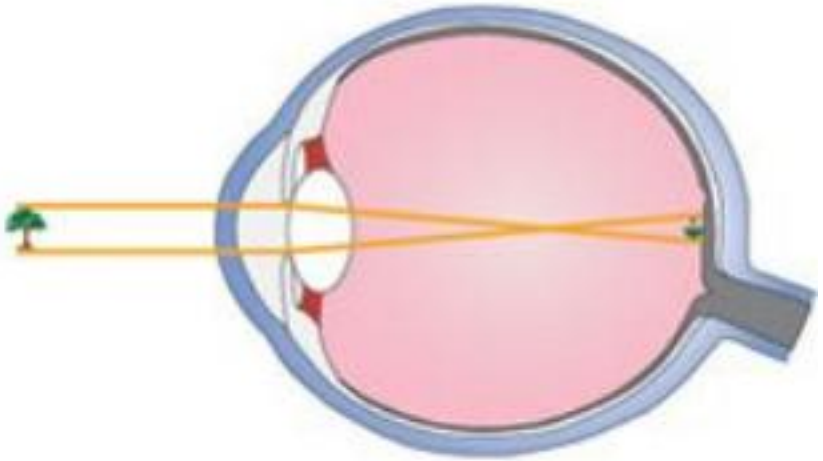


https://webvision.med.utah.edu

Sensing : the eye (optics)



Ray diagram for a converging lens.

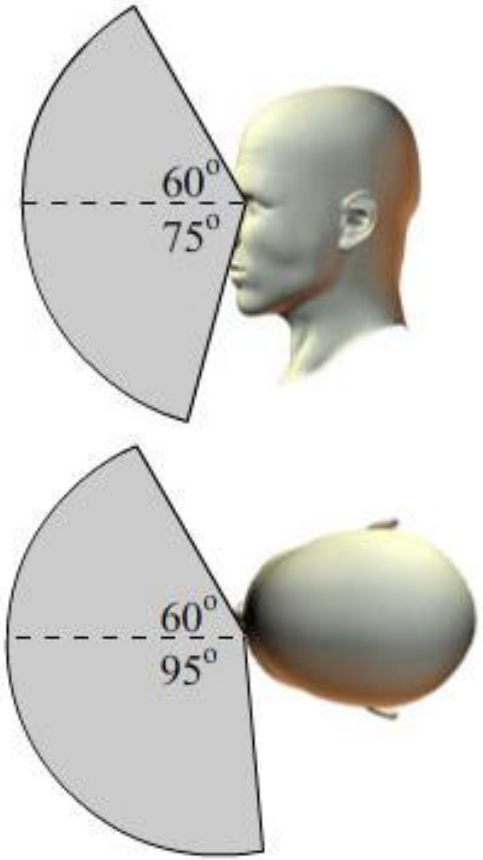


Ray diagram for the human eye.

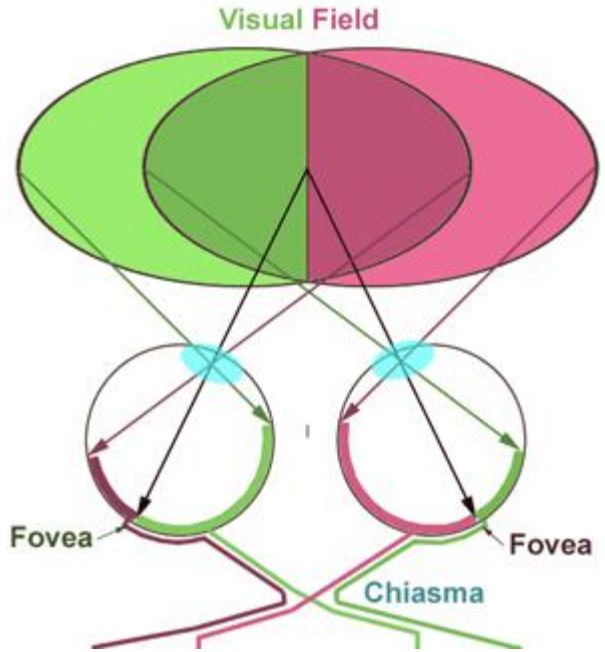
https://www.carolina.com/teacher-resources/Interactive/optics-of-the-human-eye/tr39501.tr

Sensing: the eye (visual field)

Monocular



Binocular



Retina: structure

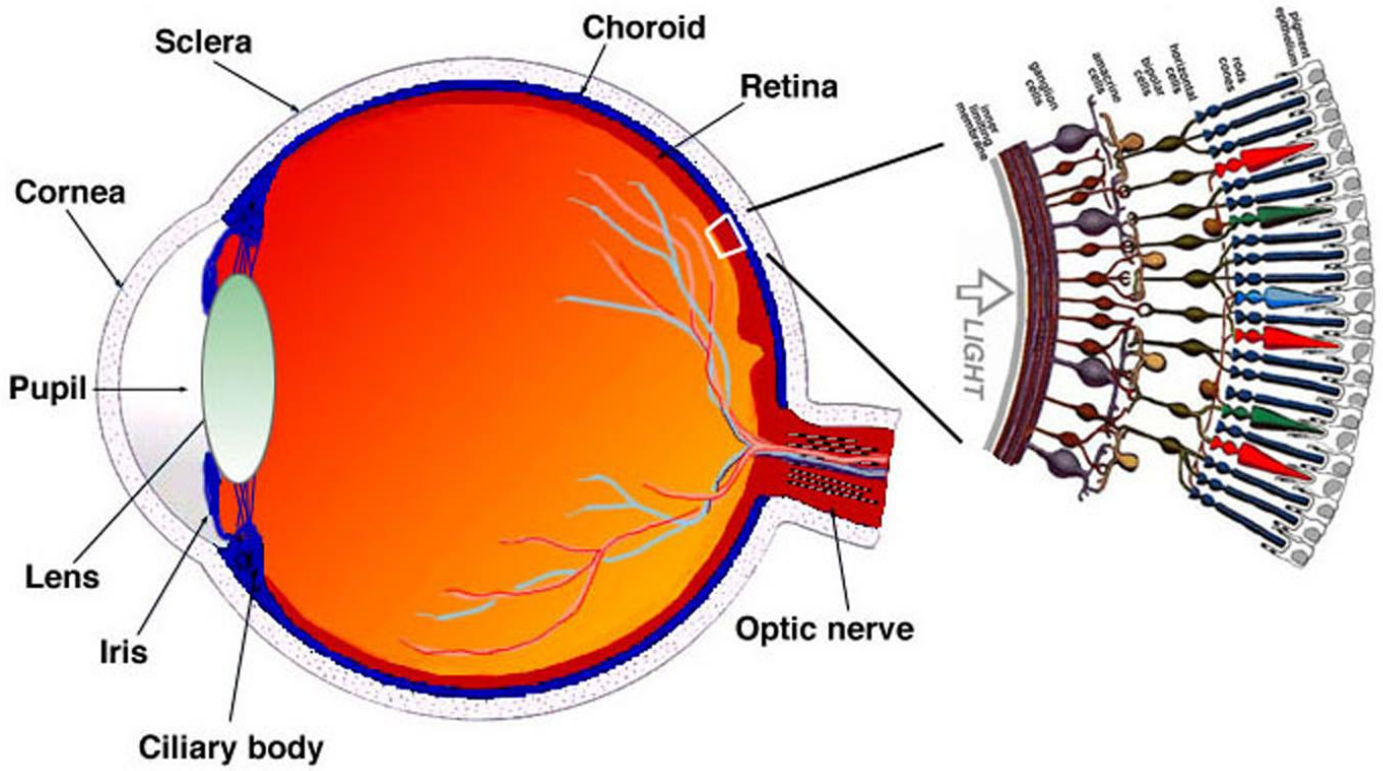
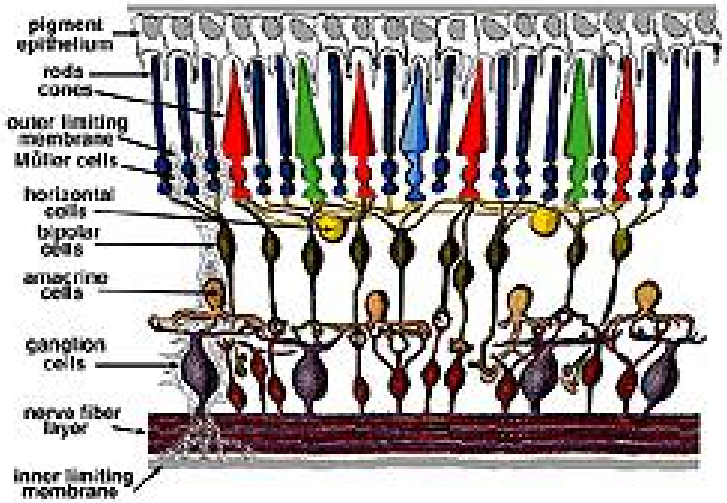
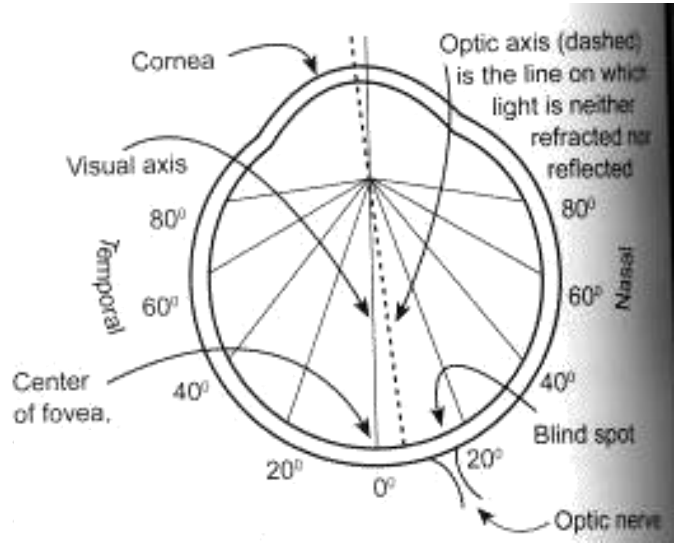


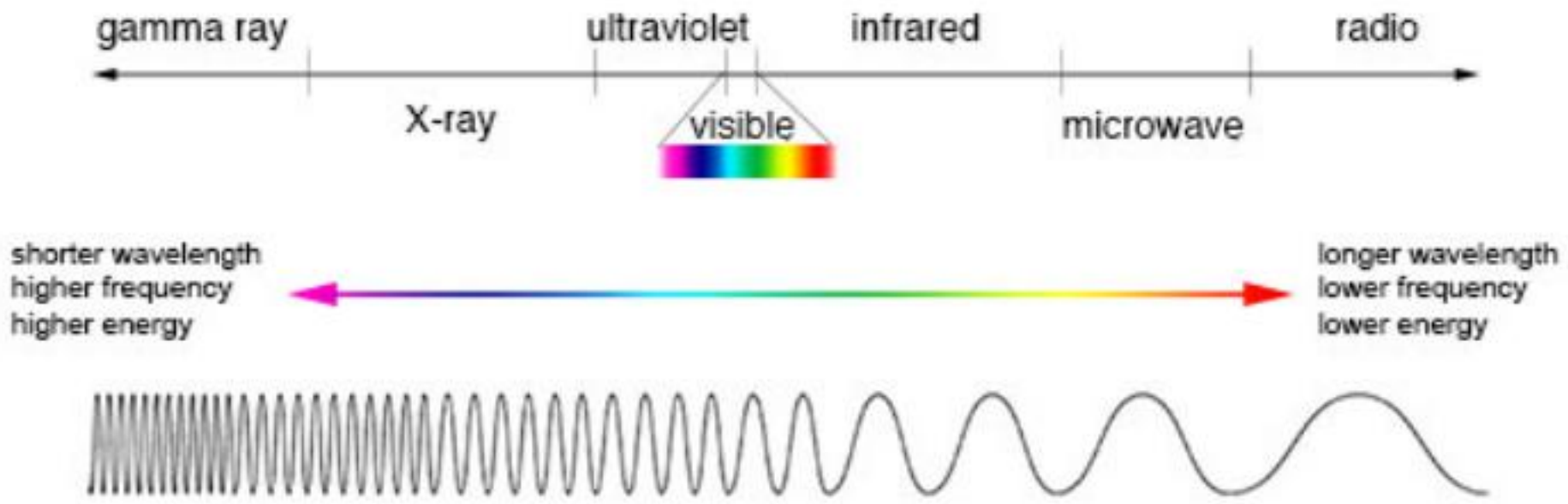
Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.





https://webvision.med.utah.edu

Retina: Visual Spectrum



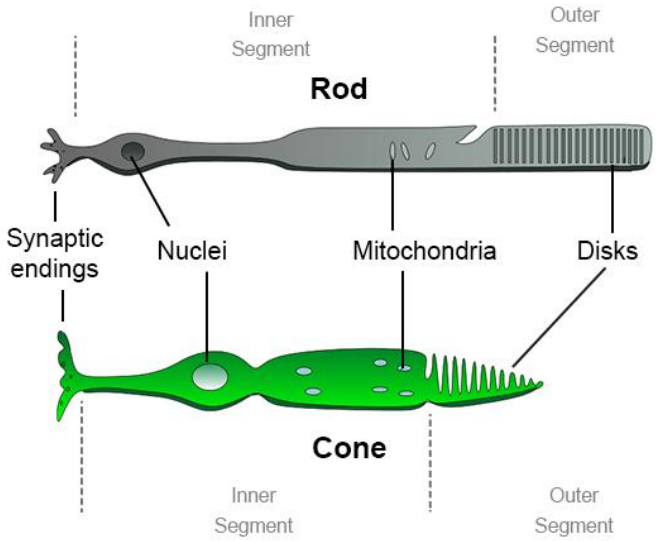
Comparison of wavelength, frequency and energy for the electromagnetic spectrum. (Credit: NASA's Imagine the Universe)

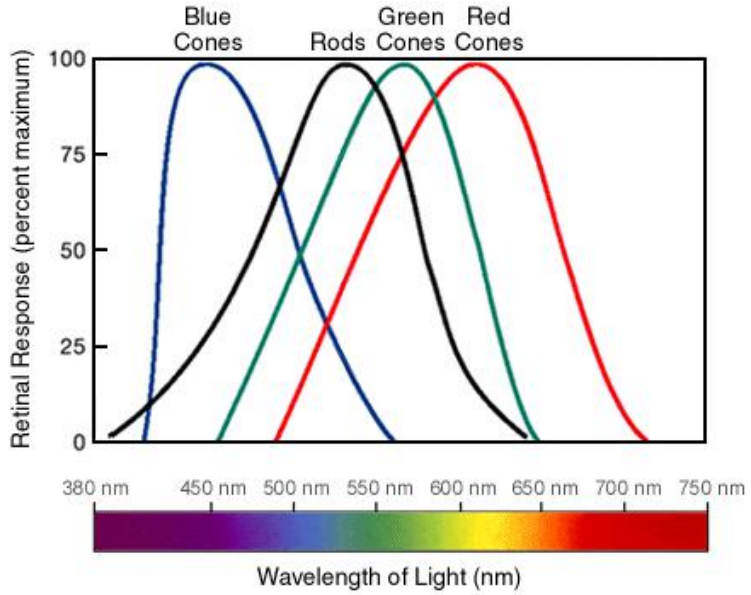
https://askabiologist.asu.edu/rods-and-cones

Retina: Photoreceptors

Cones: cone-shaped, operate in high light, color vision: Red, Green and Blue
Rods: rod-shaped, operate at night gray-scale vision

- Rods are 100 times more sensitive to a single photon than cones, but they respond slower





https://askabiologist.asu.edu/rods-and-cones

Retina: Photoreceptors

- 20 times more rods than cones in the retina
- The cones density decreases exponentially with the eccentricity
- The rods density decreases “linearly” from the peak

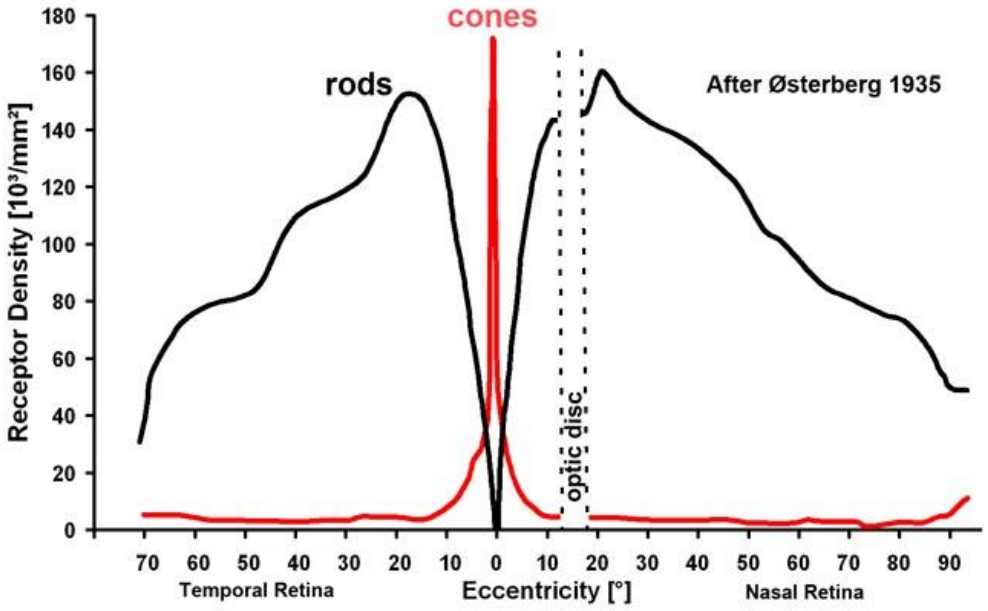
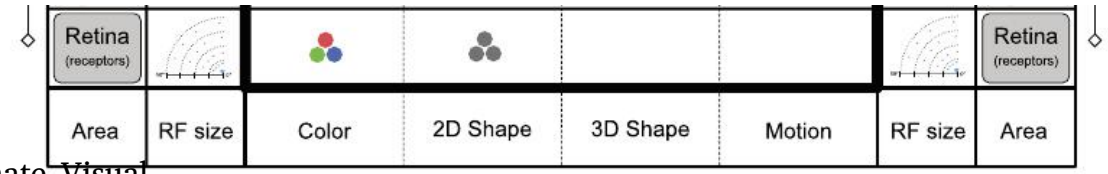


Fig. 20. Graph to show rod and cone densities along the horizontal meridian.

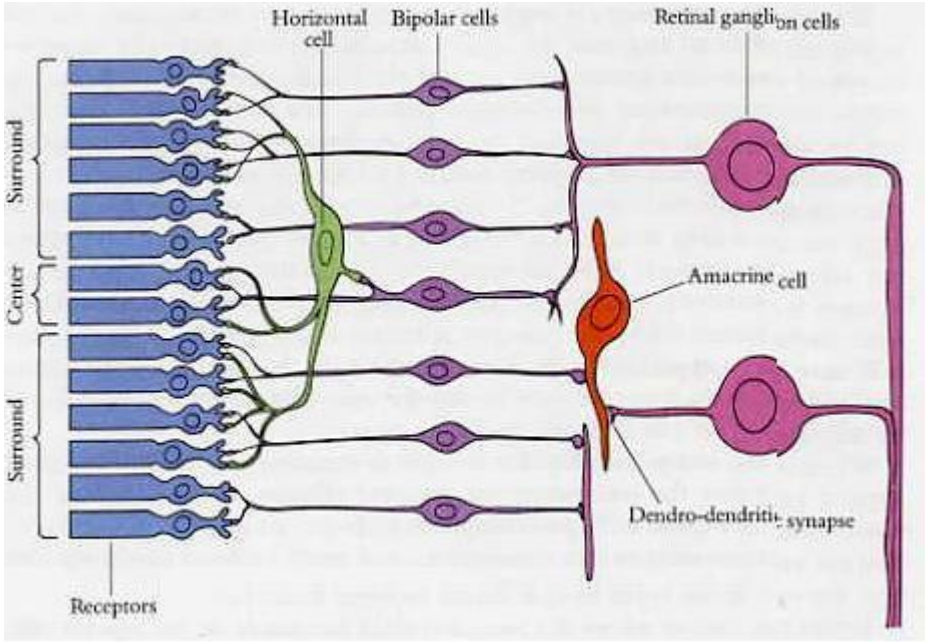
Summary



Krüger et al., Deep Hierarchies in the Primate Visual Cortex What Can We Learn for Computer Vision

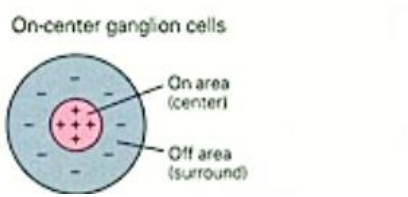
Retina: Interneurons

- **Bipolar Cells:** send information directly to Ganglion Cells or to Amacrine. Gates for cirtuitry in the retina. Contrast sensitivity
- **Horizontal Cells:** illumination adaptation, large range connectivity, contribute to the Ganglion Cells (surrond Receptive Field)
- **Amacrine Cells:** detection of directional motion, modulate light adaption and circadian rhythm, and control high sensitivity in scotopic (low light) vision

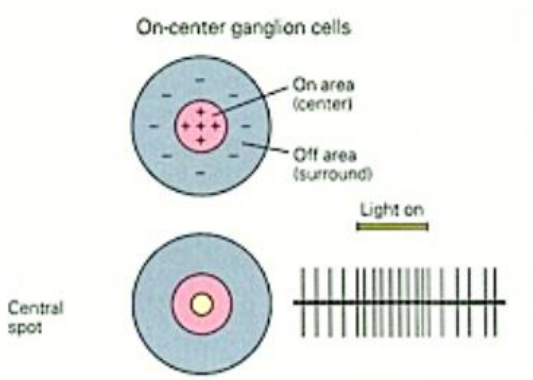


http://neuronbank.org/wiki/index.php/Horizontal_cells

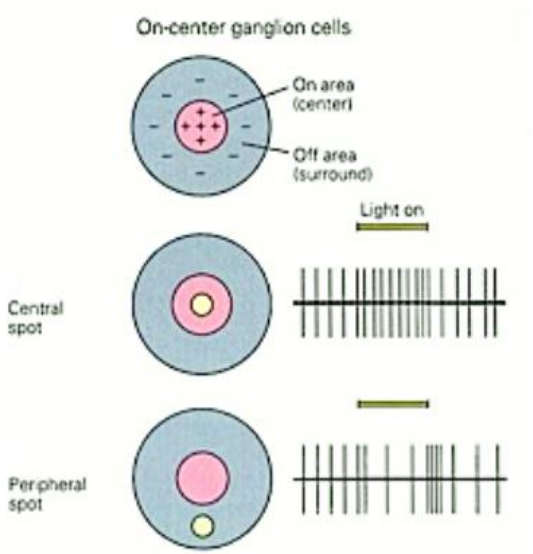
Retina: Ganglion Cells Receptive Fields Spatial Shape



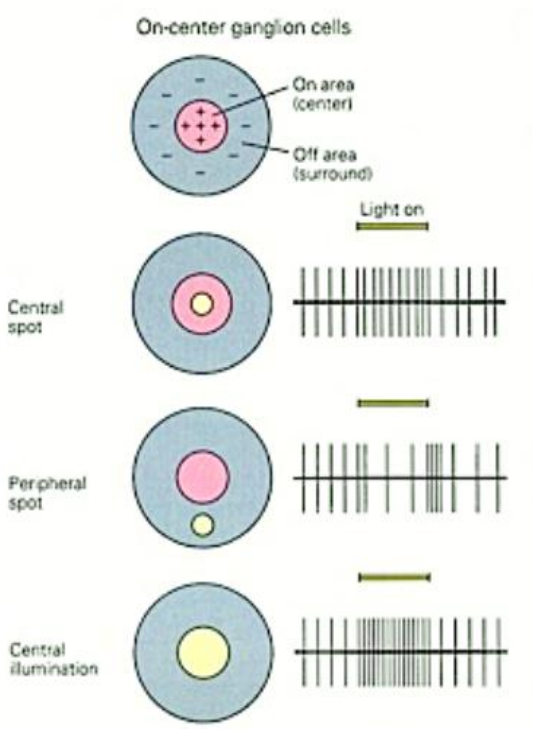
Retina: Ganglion Cells Receptive Fields Spatial Shape



Retina: Ganglion Cells Receptive Fields Spatial Shape



Retina: Ganglion Cells Receptive Fields Spatial Shape



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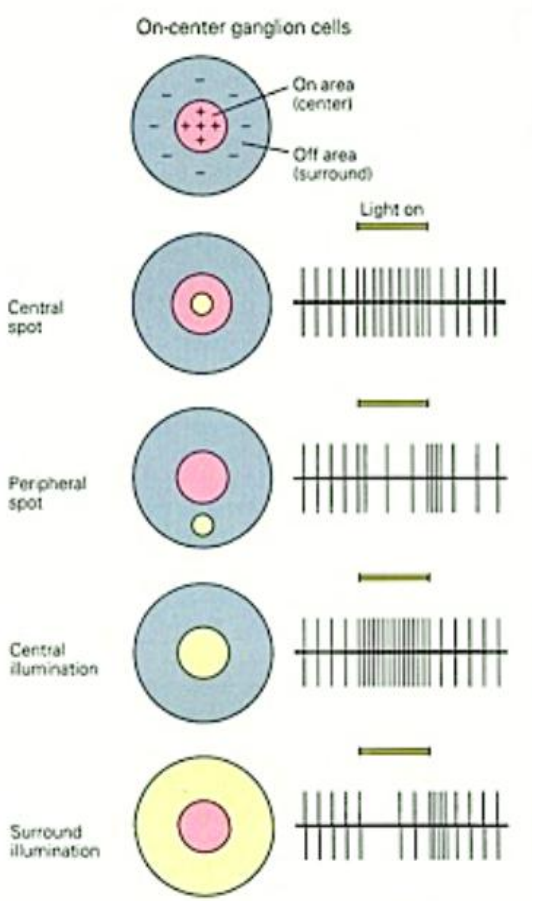
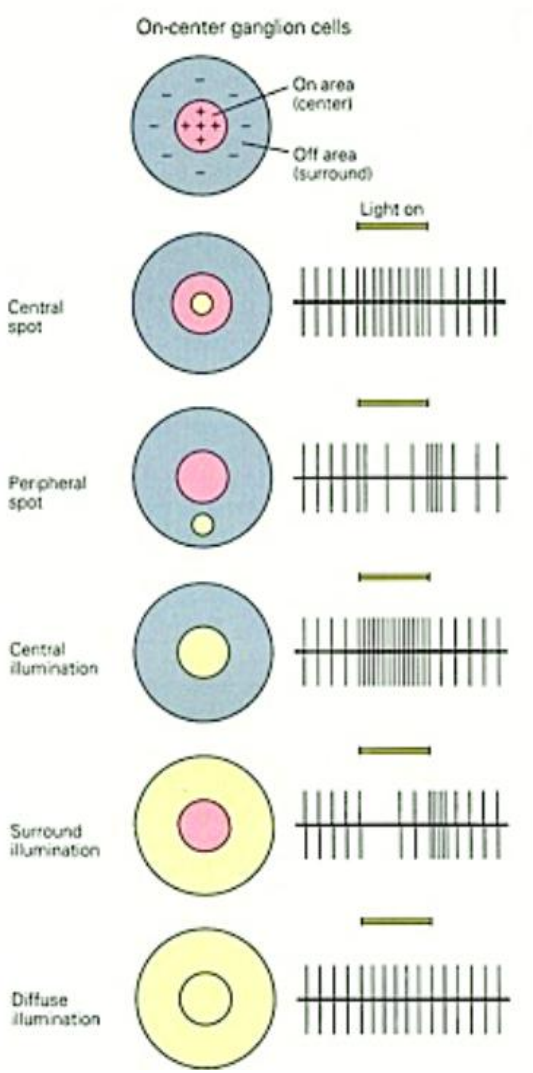
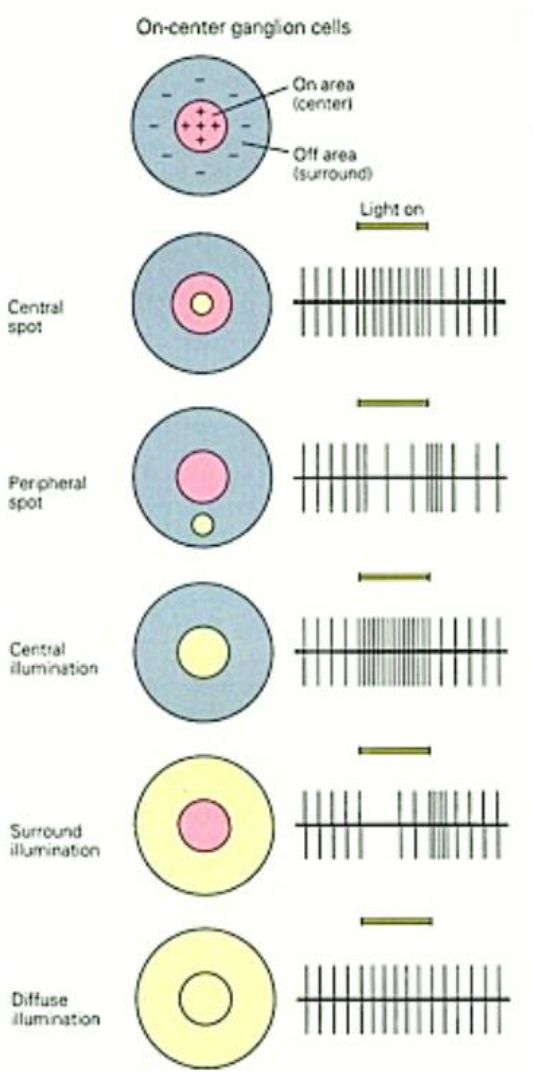


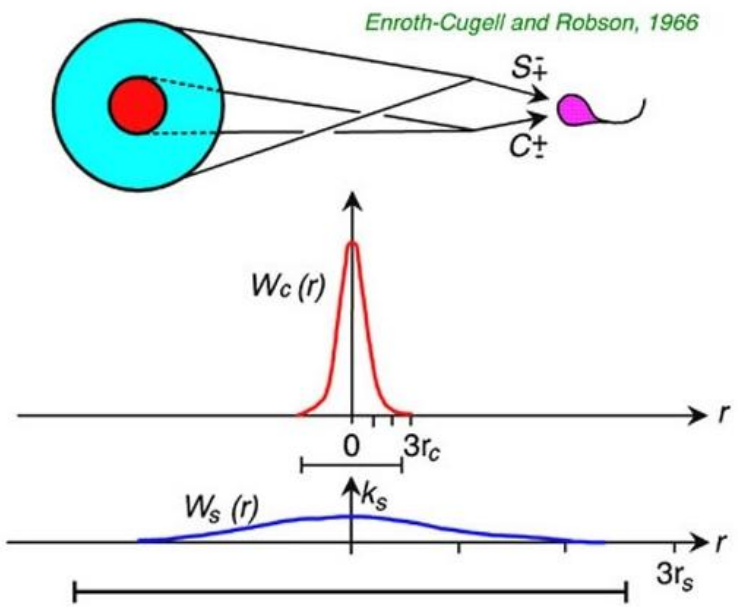
Retina: Ganglion Cells Receptive Fields Spatial Shape



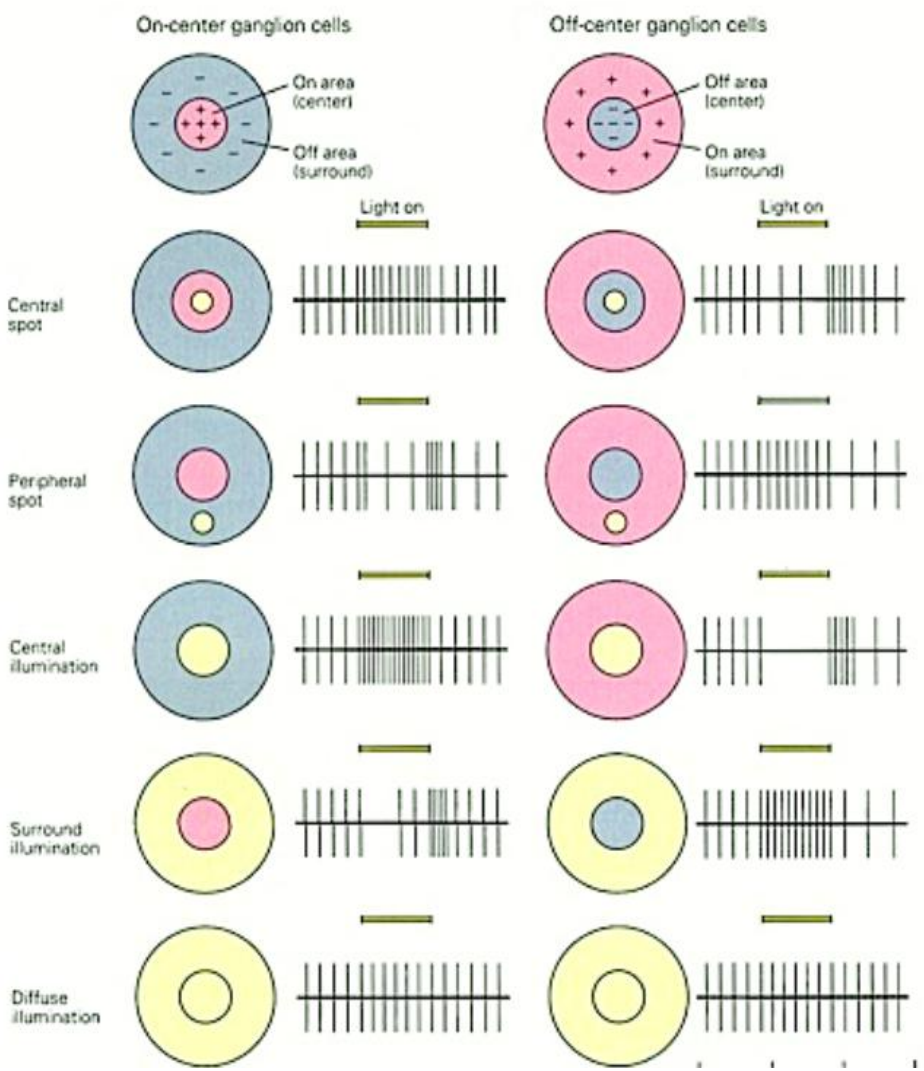
Retina: Ganglion Cells Receptive Fields Spatial Shape



On-center RF



Retina: Ganglion Cells Receptive Fields Spatial Shape



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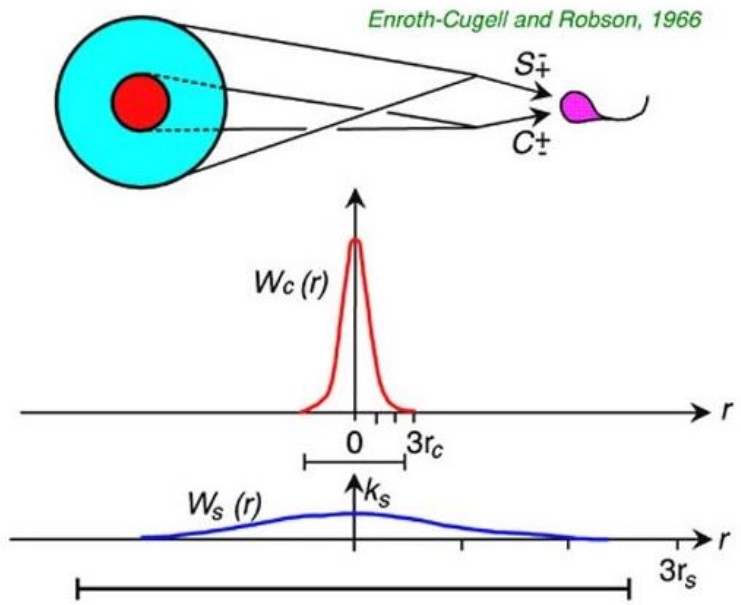


Retina: Ganglion Cells Receptive Fields Spatial Shape Across the Visual Field

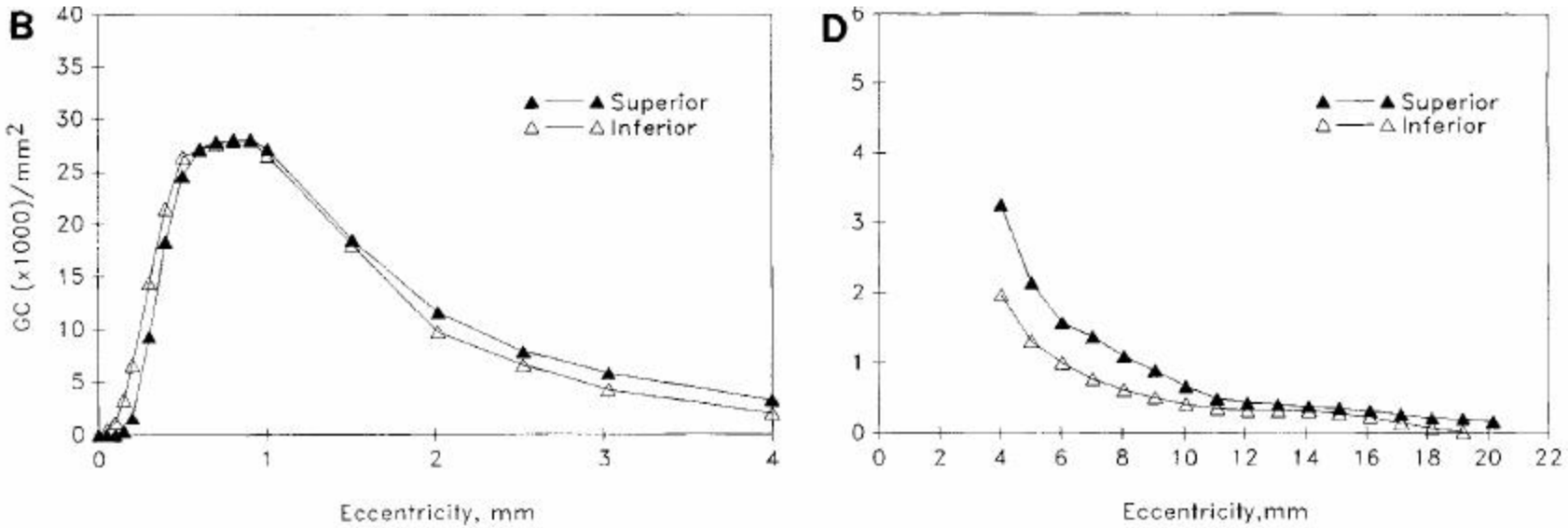
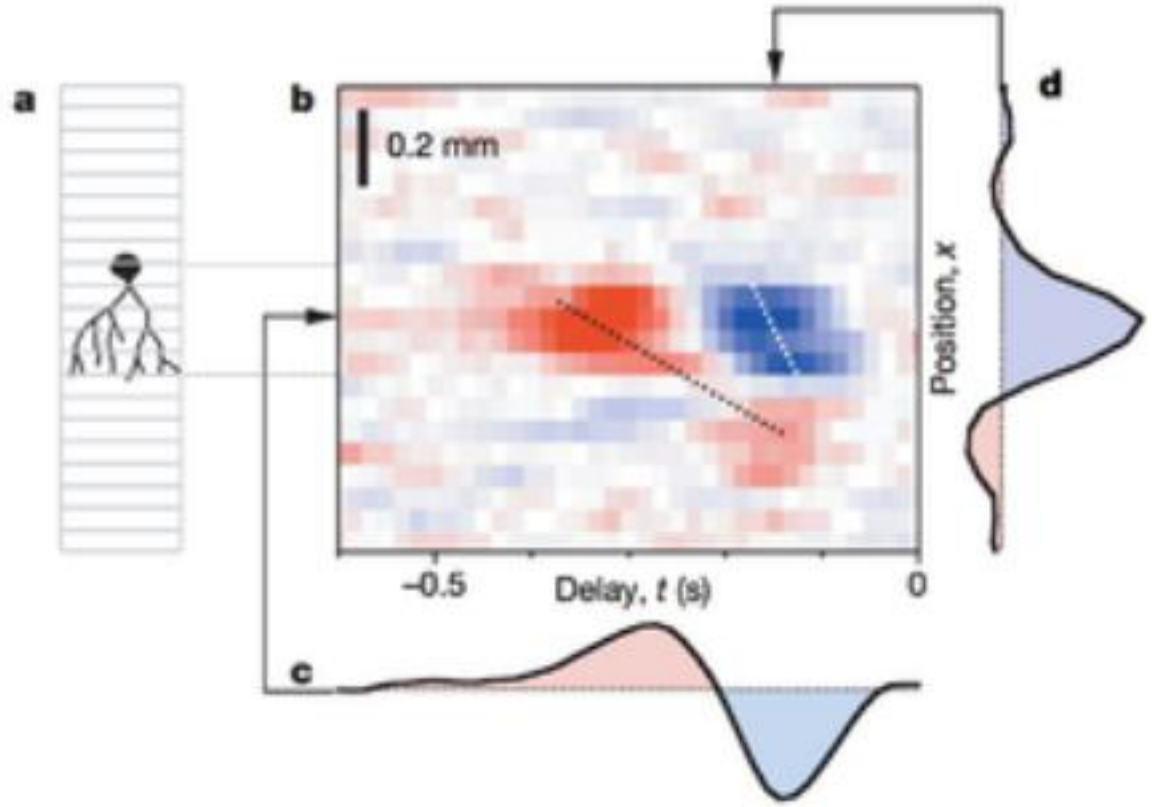


Fig. 6. Ganglion cell (GC) density as a function of eccentricity along the horizontal (**A, C**) and vertical (**B, D**) meridians of the composite retina. A, B show foveal and C, D show peripheral ganglion cell density at appropriate scales. The gap in the nasal curve at 4 mm represents the site of the optic disk.

Topographyof Ganglion Cells in Human Retina, Curcio and Allen

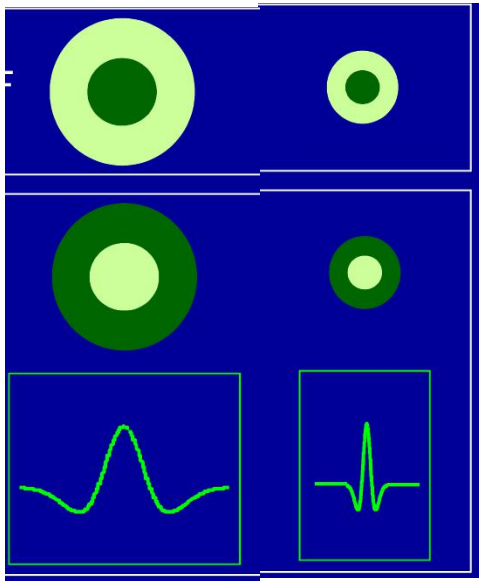
Retina: Ganglion Cells Receptive Fields Temporal Shape



http://wiki.eyewire.org/index.php?title=J-RGC

Retina: Ganglion Cells types

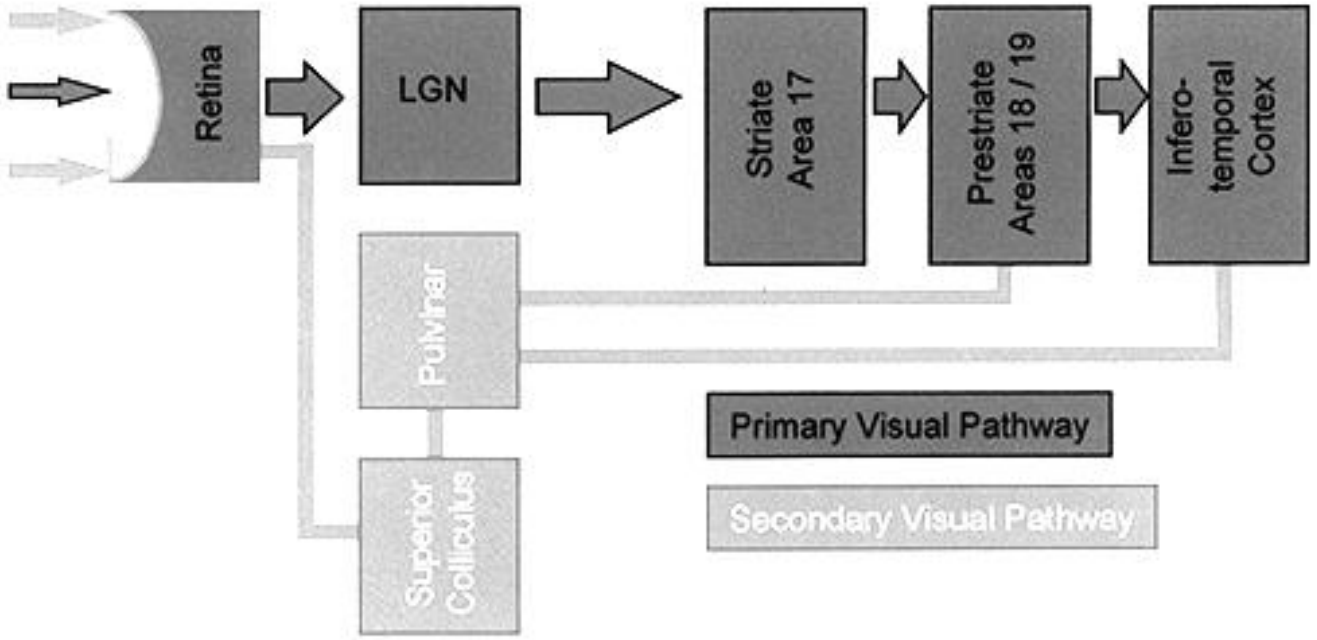
Parasol Midget



Name	Prop	Dendritic Size	Conduction	Receptive Field Size	Receptive Field Shape	Color Sensitivity	Contrast Sensitivity
Midget	80%	Small	Slow	Small	Center-Surround	Strong	Weak
Parasol	10%	Large	Fast	Large	Center-Surround	Weak	Strong
Bistratified	5%	Very Small	Moderate	Very Large	Center	?	Medium

Gollish, eye's smarter than scientists believe

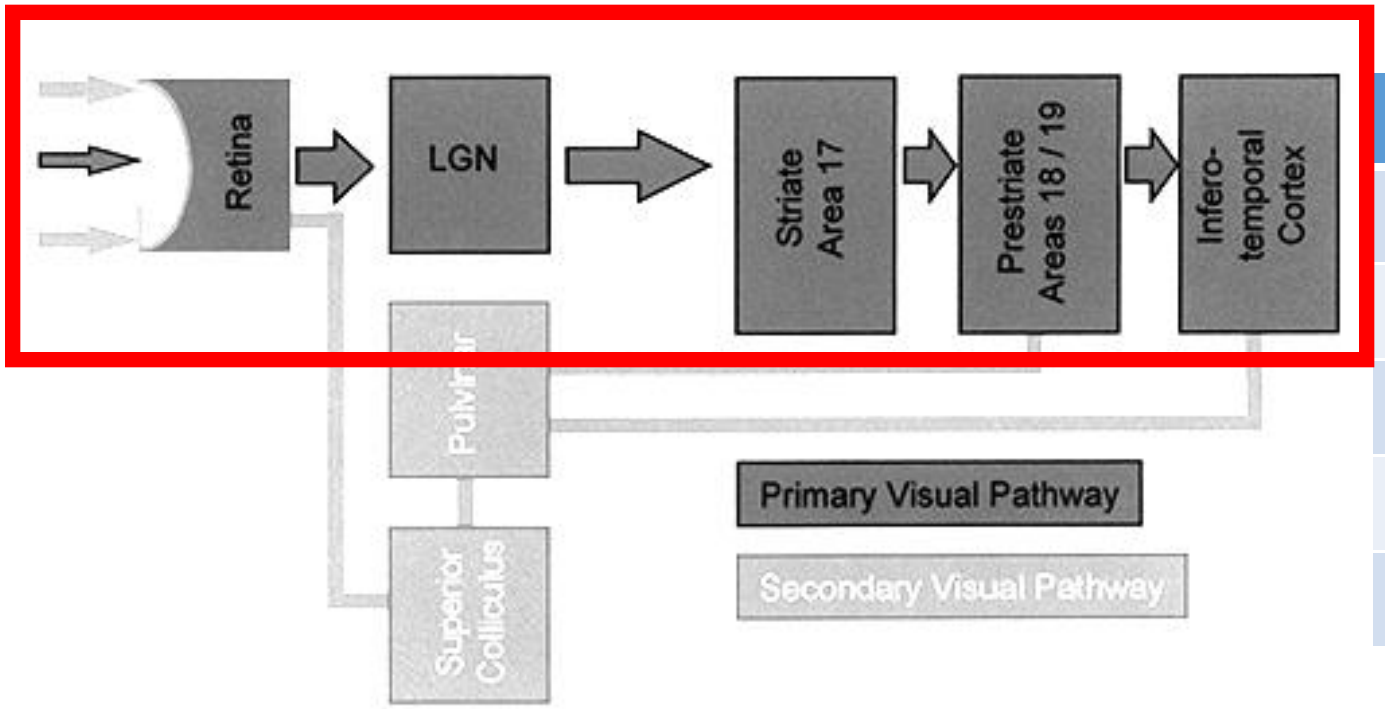
Primary and Secondary Pathways



Primary	Seconday
focal	global
attentive	pre-attentive
what	where
scrutinizing	early warning
internal	external

http://www.mrineonatalbrain.com/ch04-18.php

Primary and Secondary Pathways

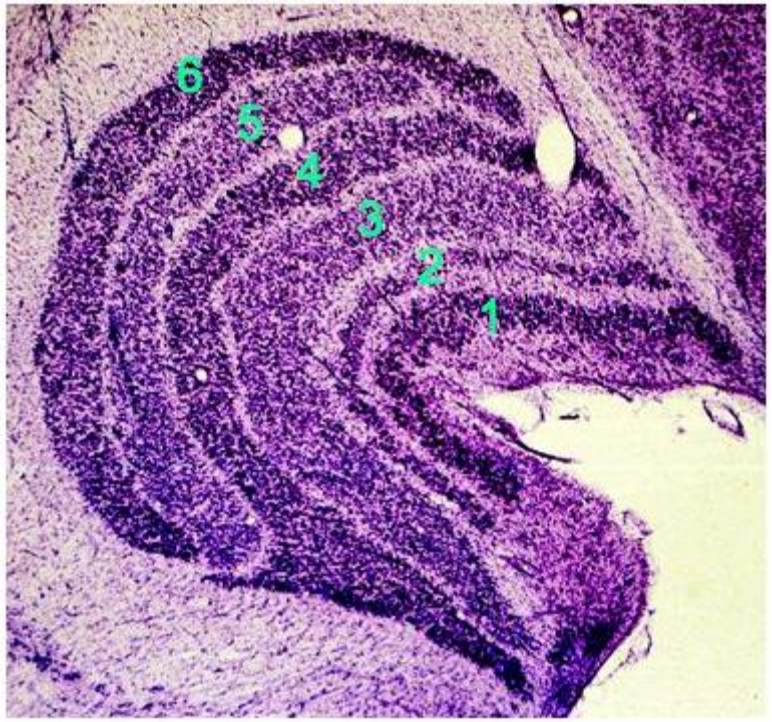


Primary	Seconday
focal	global
attentive	pre-attentive
what	where
scrutinizing	early warning
internal	external

http://www.mrineonatalbrain.com/ch04-18.php

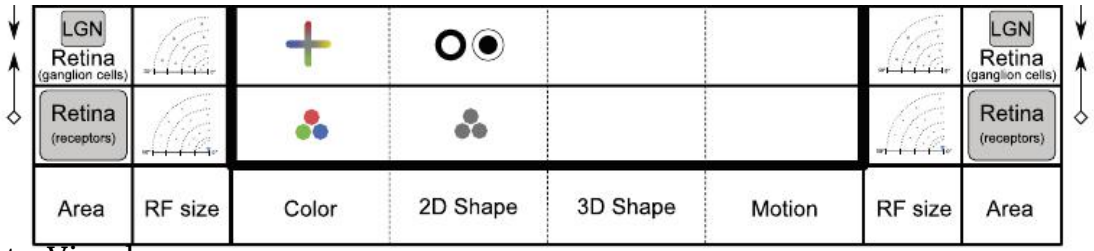
Lateral Geniculate Nucleus

- Function and RFs associated with RGC
- Clear pathway division
- Strong feedback connections from V1
- 6 celullar layers organised as a stack of pancakes bent around the optic trackow
- Layers 1, 4 and 6 are related to the opposite eye (contralateral) whereas 2,3 and 5 relate the the eye on the same side (ipsilateral)



https://medical-dictionary.thefreedictionary.com/lateral+geniculate+body

Summary



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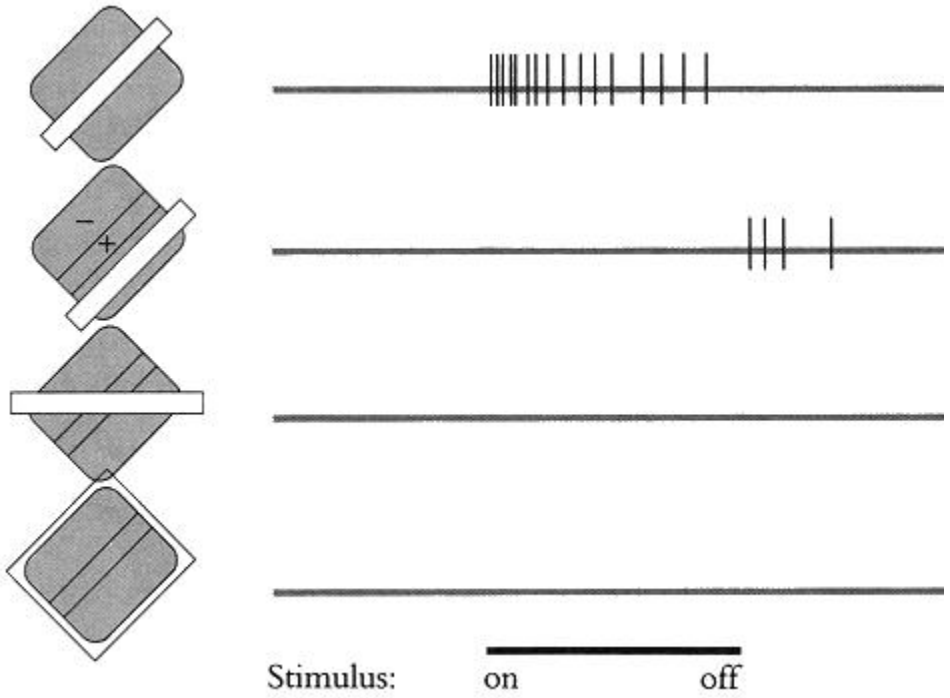
Simple cells and complex cells in V1

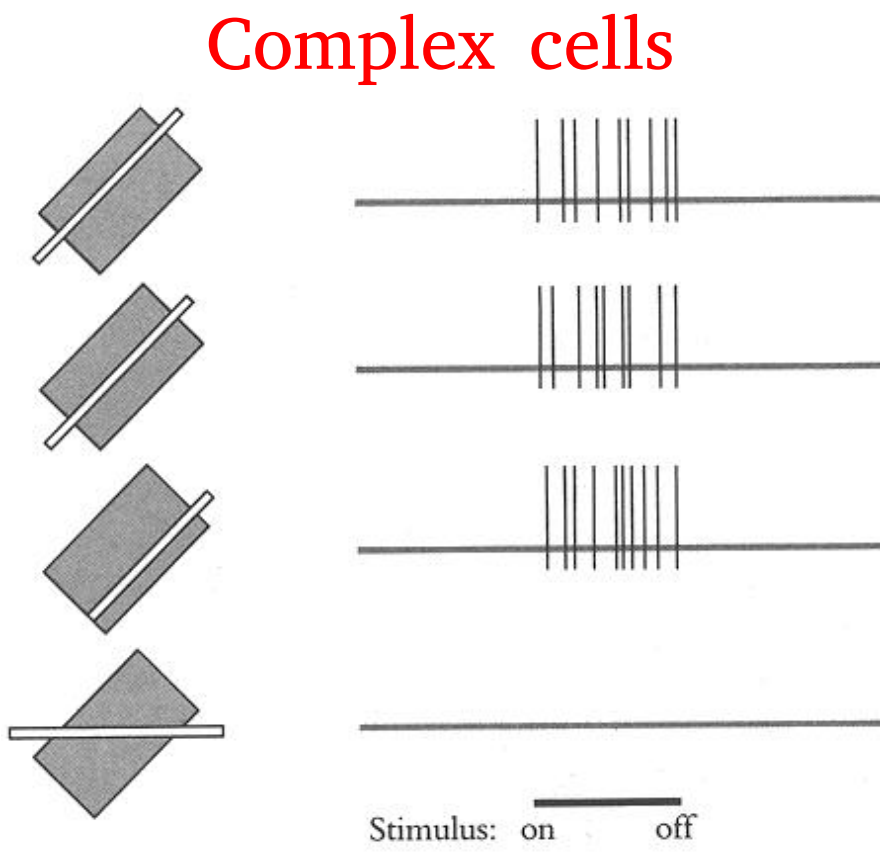
Simple Cells



- 10% of V1 cells
- Probably the most studied cells in vision
- Shape like Gabors varying orientation, phase and frequency

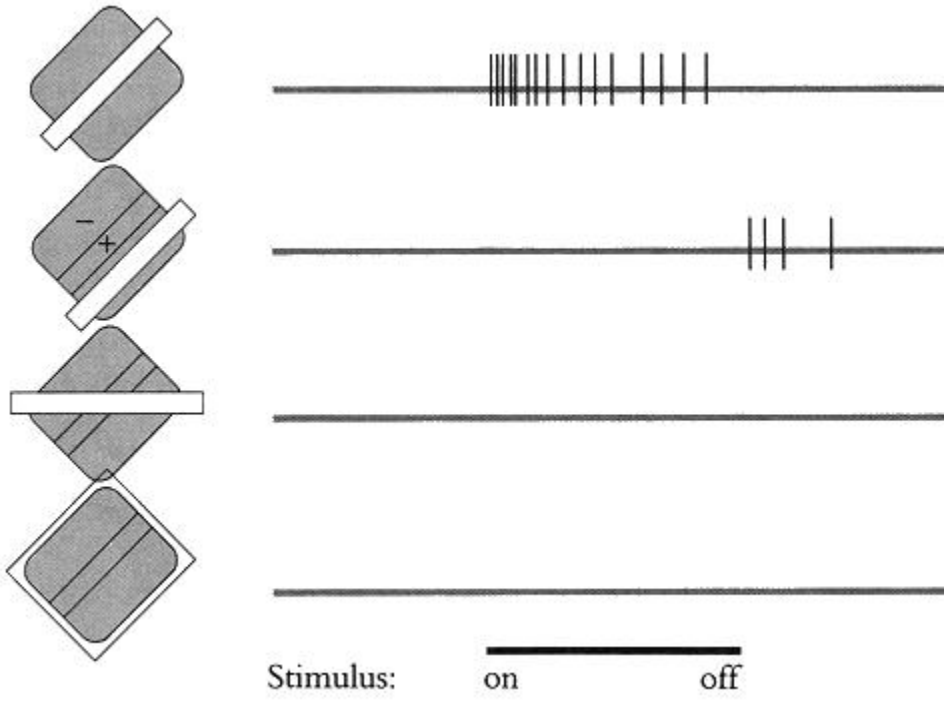
Simple cells and complex cells in V1

- Nonlinear summation
- Spatial invariance
- Some direction selectivity

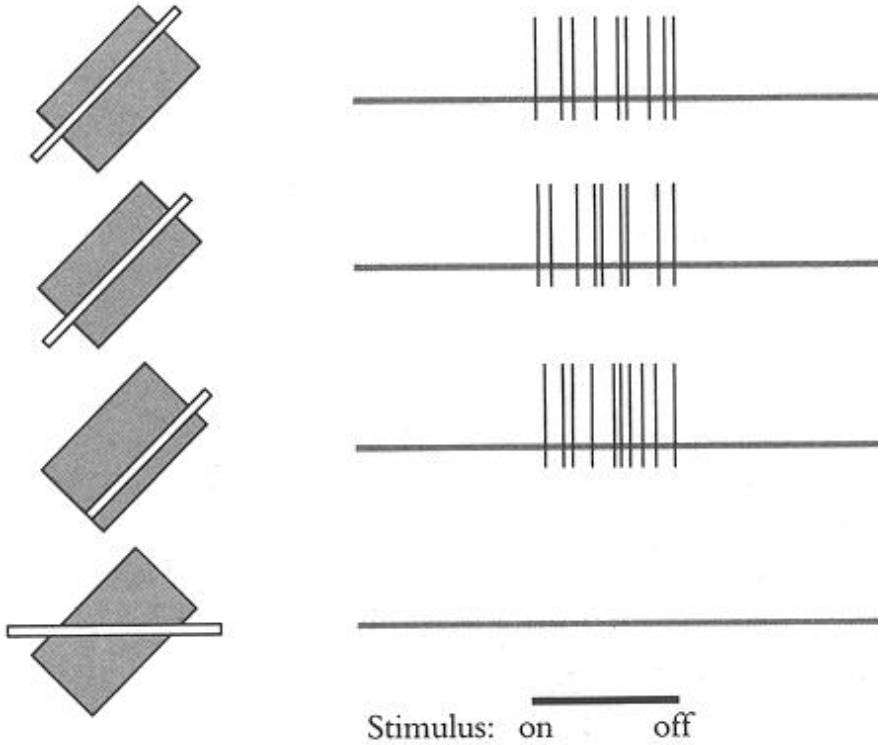


Simple cells and complex cells in V1

Simple Cells



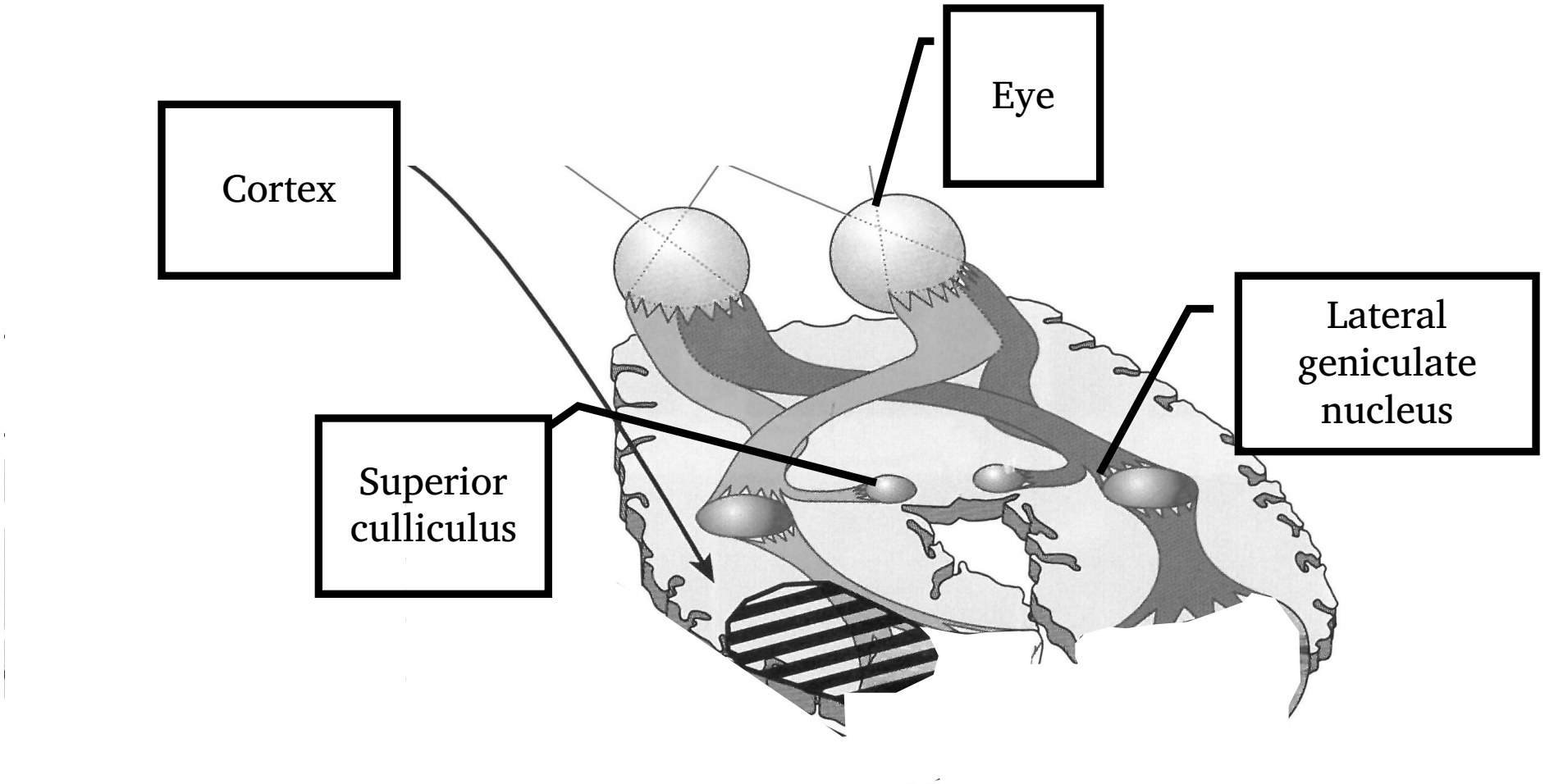
Complex cells



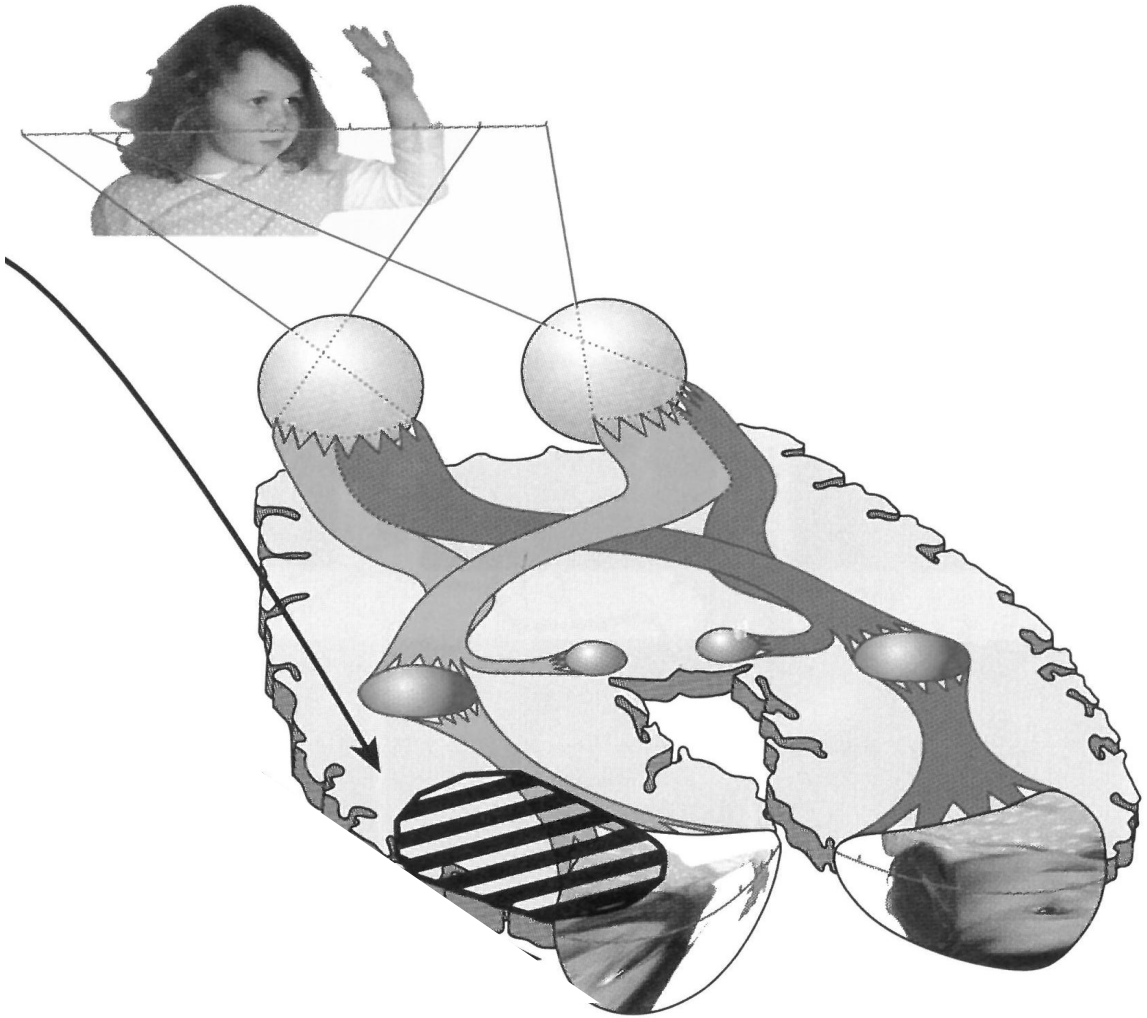
V1: other properties

- Binocular neurons
- local motion detectors
- Center surround (similar to retinal ganglion cells)

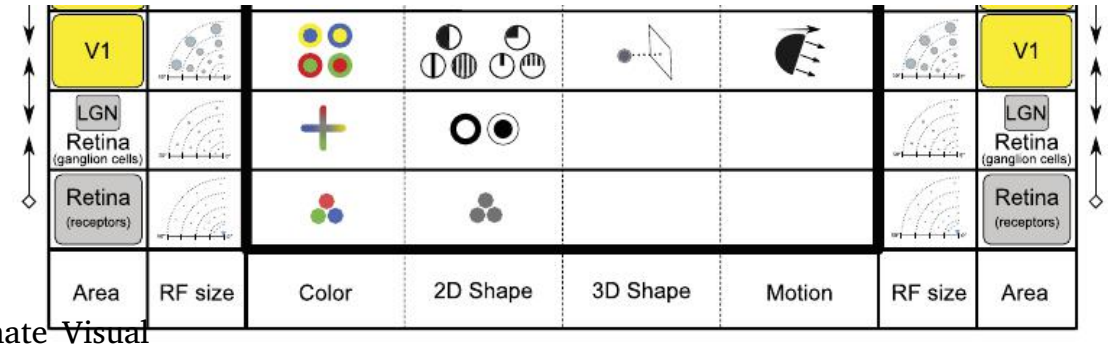
V1: retino-cortical map



V1: retino-cortical map



Summary



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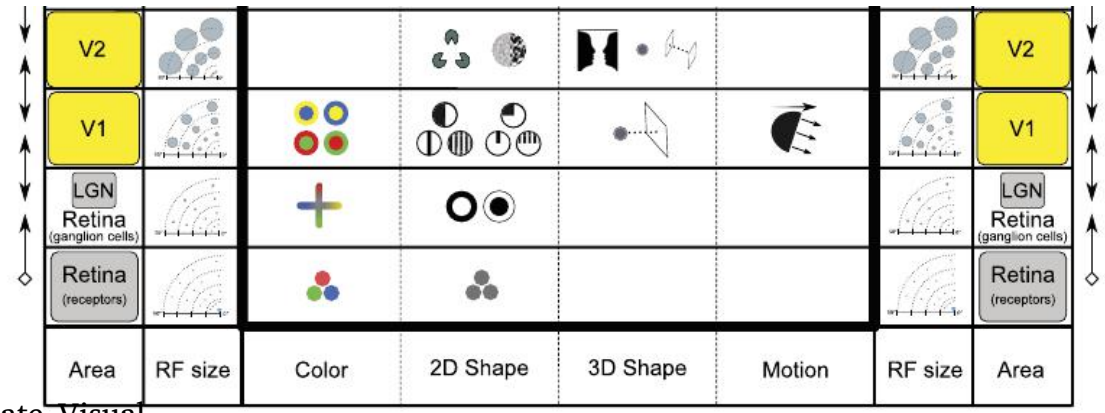
V2

- Receptive fields similar to V1
- Detect texture-defined contours
- Relactive disparity (in V1 is absolute)
- Border ownership
- Many illusions can be explained in function of the cells of this area

Summary



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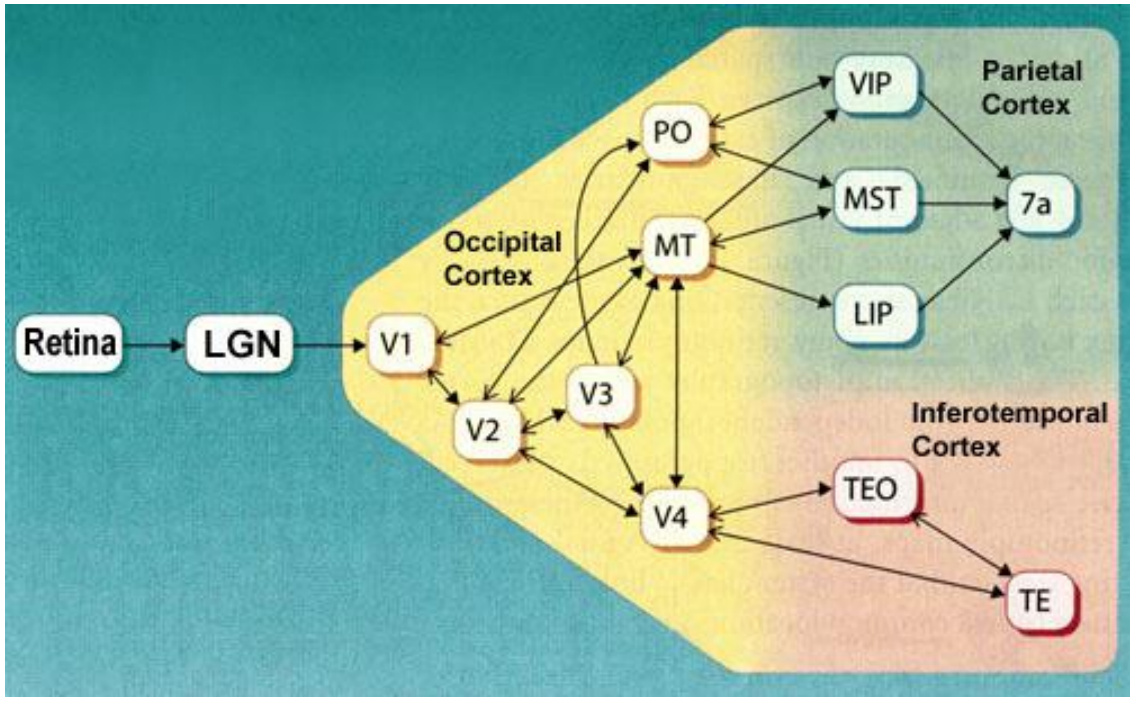
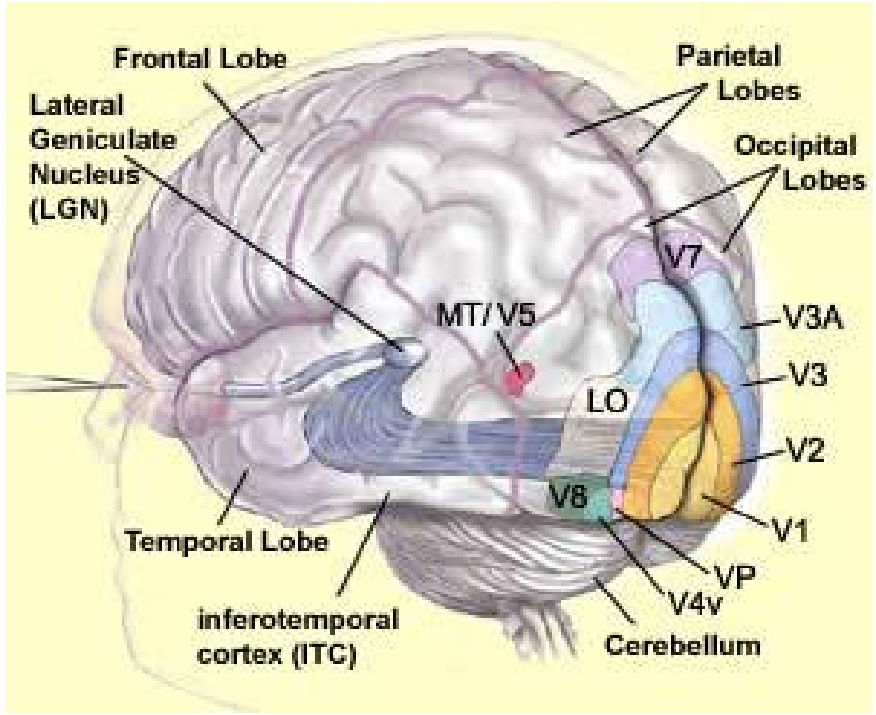
More pathways





http://thebrain.mcgill.ca/flash/a/a_02/a_02_cr/a_02_cr_vis/a_02_cr_vis.html

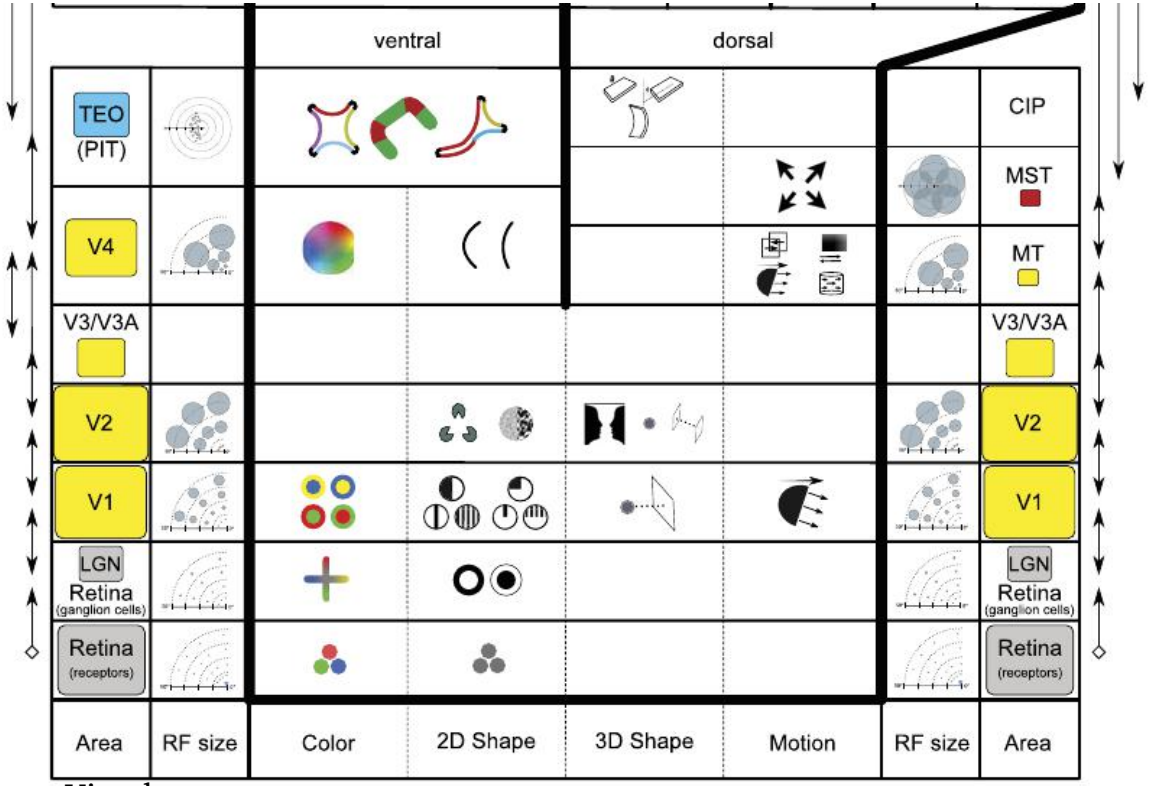
V4

- Shape detection
- Curvature selectivity
- Luminance invariance/ color consistency by coding the hue (instead of RGB opponency)

V5 (Middle Temporal visual)

- Motion in 2D (direction and speed)
- Binocular depth

Summary



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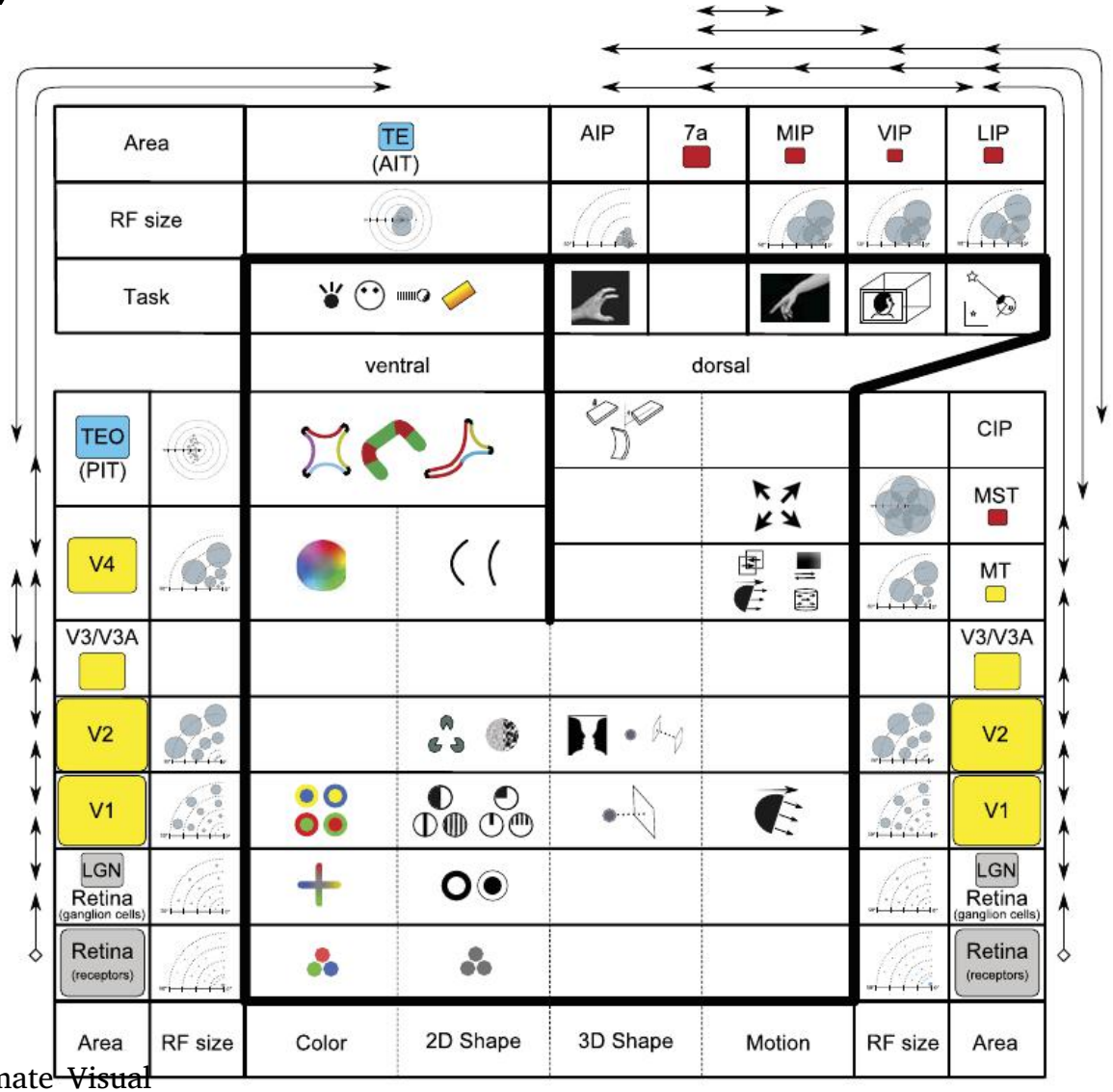

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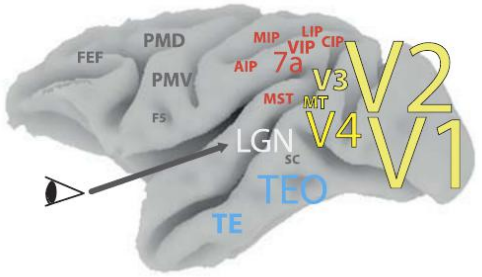
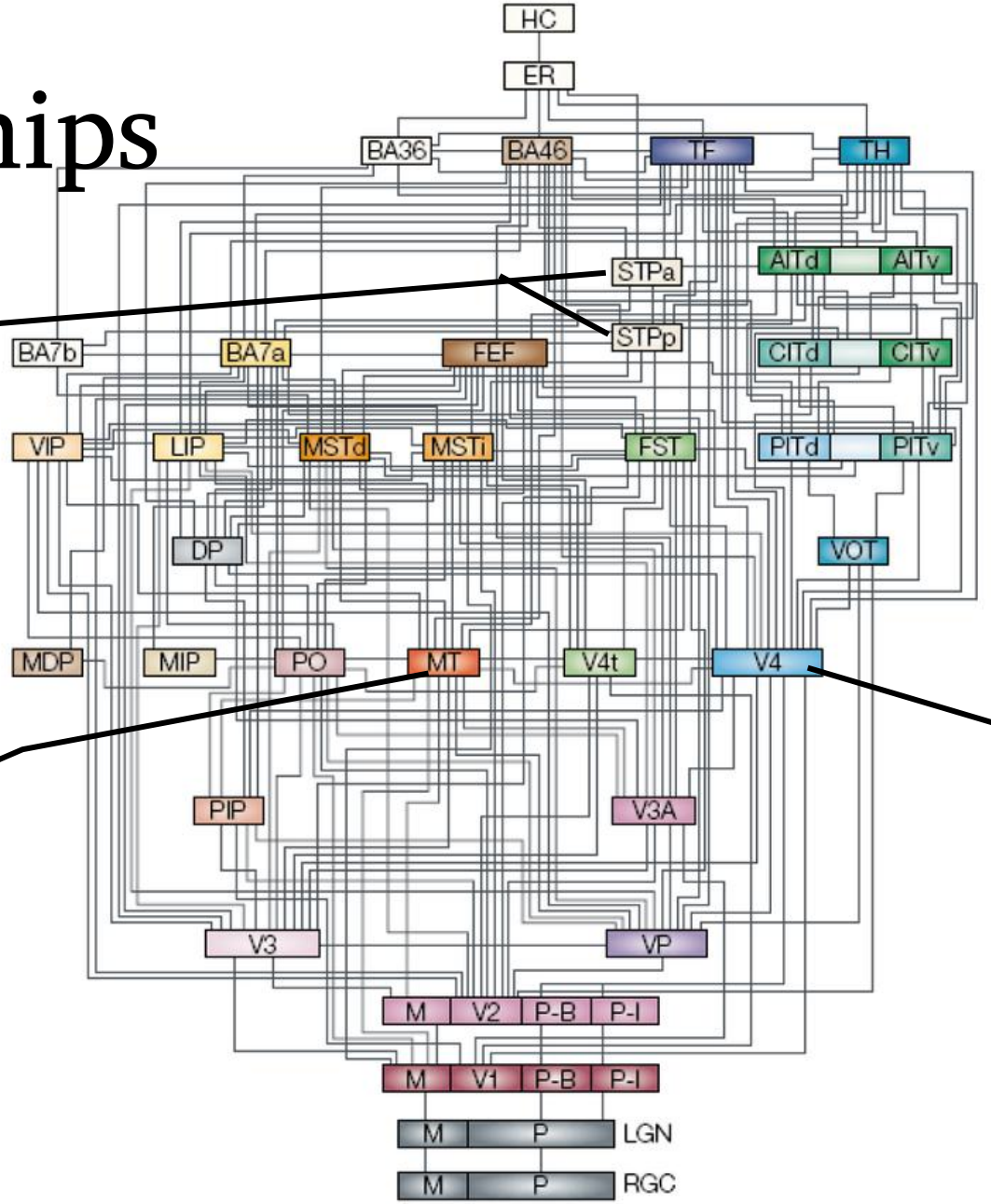
Relationships



human face recognition

motion

color



Felleman, Van Essen, Distributed hierarchical processing in the primate cerebral cortex

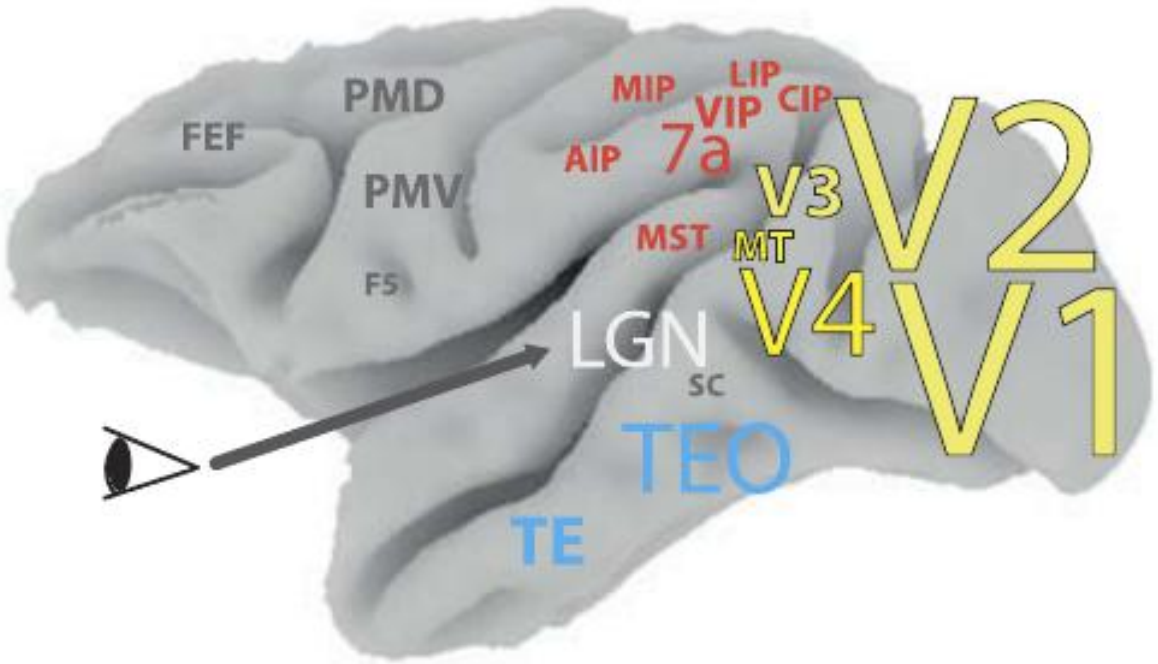
Contents

Systems Architecture

Architecture of a system is a global model of the system consisting of:

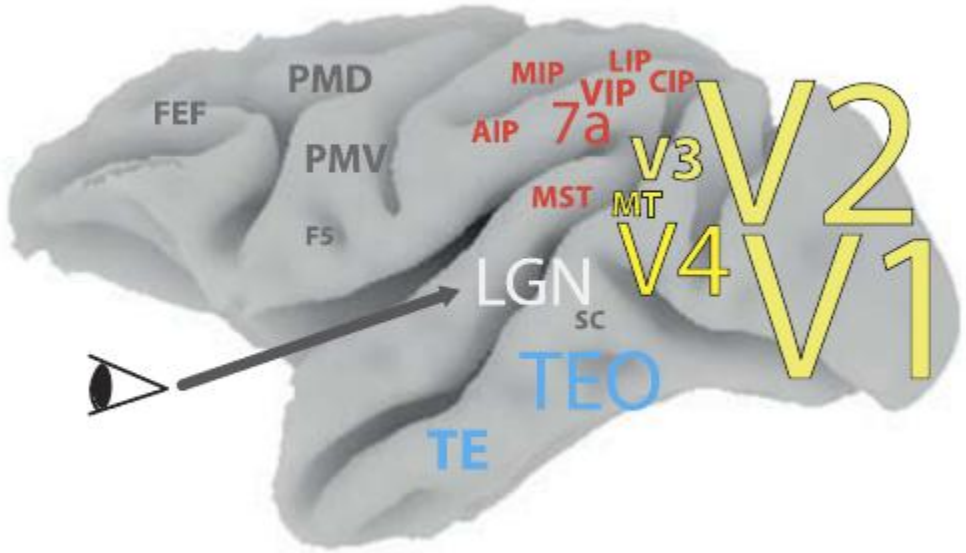
- structure
- properties of various elements involved
- relationships between various elements
- behaviors & dynamics
- multiple views of the system: complementary and consistent

Structure: What are the areas responsible for visual processing



Krüger et al., Deep Hierarchies in the Primate Visual Cortex What Can We Learn for Computer Vision

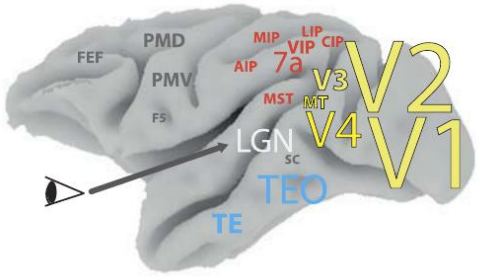
Properties: What are their physiological properties?



Area	Size (mm^2)	RFS
Sub–cortical		
Retina	1018	0.01
LGN		0.1
Occipital		
V1	1120	3
V2	1190	4
V3/V3A/VP	325	6
V4/VOT/V4t	650	8
MT	55	7
Sum	3340	
Ventral Pathway		
TEO	590	3-5
TE	180	10-20
Sum	770	
Dorsal Pathway		
MST	60	>30
CIP	?	?
VIP	40	10-30
7a	115	>30
LIP	55	12-20
AIP	35	5-7
MIP	55	10-20
Sum	585	

Krüger et al., Deep Hierarchies in the Primate Visual Cortex What Can We Learn for Computer Vision

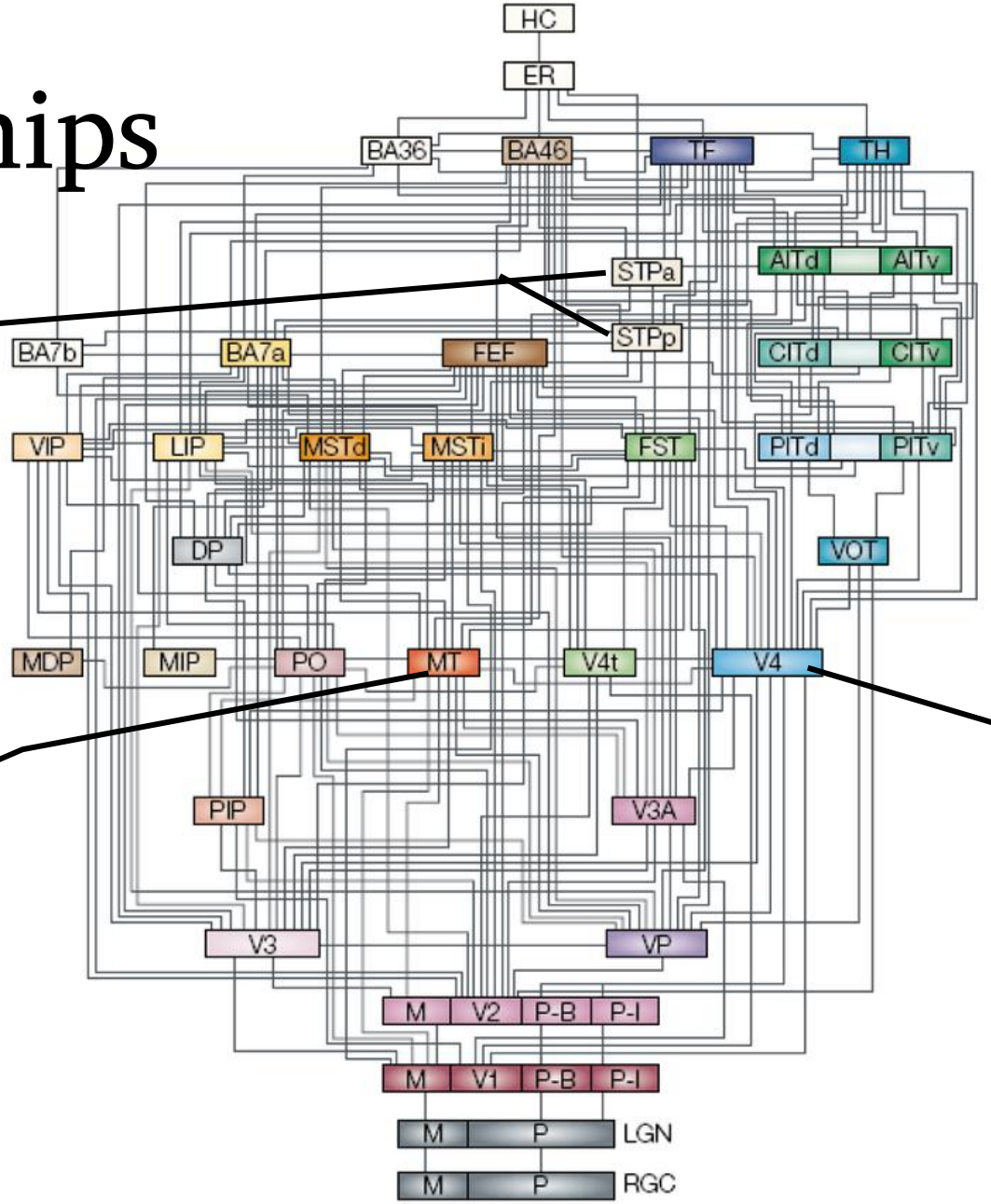
Relationships



human face recognition

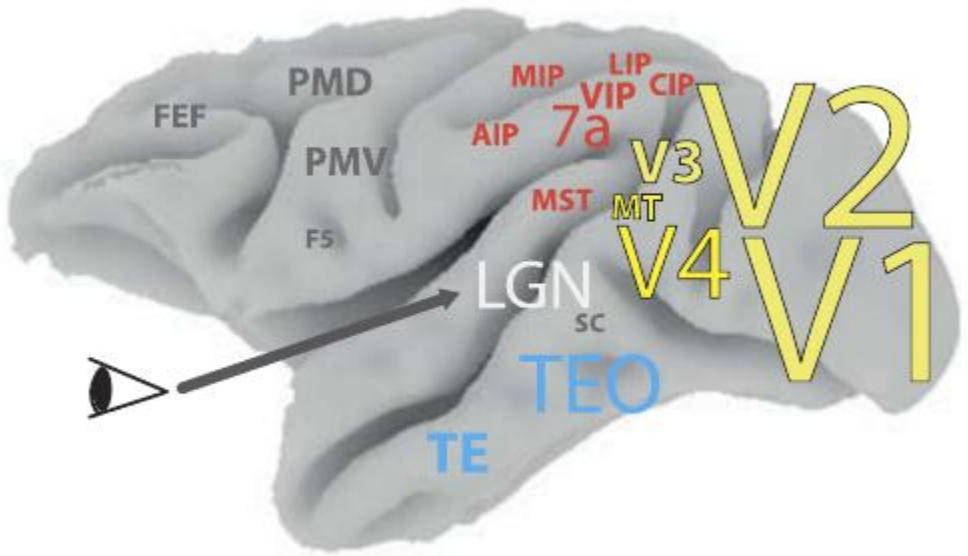
motion

color



Felleman, Van Essen, Distributed hierarchical processing in the primate cerebral cortex

Dynamics



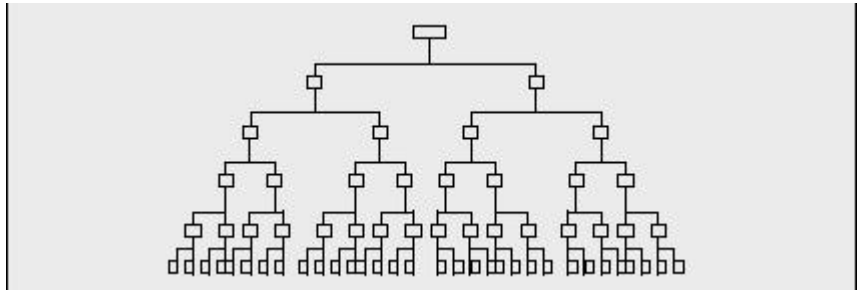
Area	Size (mm^2)	RFS	Latency (ms)
	Sub–cortical		
Retina	1018	0.01	20-40
LGN		0.1	30-40
	Occipital		
V1	1120	3	30-40
V2	1190	4	40
V3/V3A/VP	325	6	50
V4/VOT/V4t	650	8	70
MT	55	7	50
Sum	3340		
	Ventral Pathway		
TEO	590	3-5	70
TE	180	10-20	80-90
Sum	770		
	Dorsal Pathway		
MST	60	>30	60-70
CIP	?	?	?
VIP	40	10-30	50-60
7a	115	>30	90
LIP	55	12-20	50
AIP	35	5-7	60
MIP	55	10-20	100
Sum	585		

Krüger et al., Deep Hierarchies in the Primate Visual Cortex What Can We Learn for Computer Vision

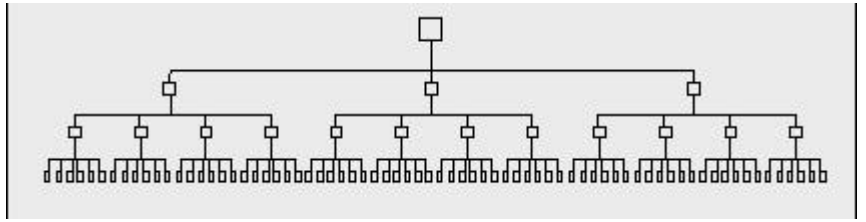
Contents

Hierarchical vs Flat Organizations

Hierarchical Organization



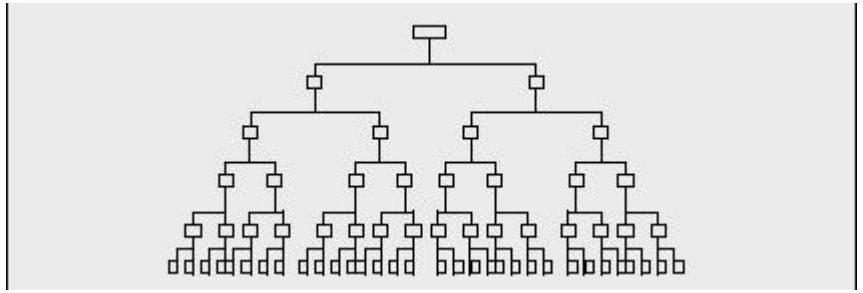
Flat Organization



Griffin, D. Pros & cons of a flat organizational structure.

Hierarchical vs Flat Organizations

Hierarchical Organization



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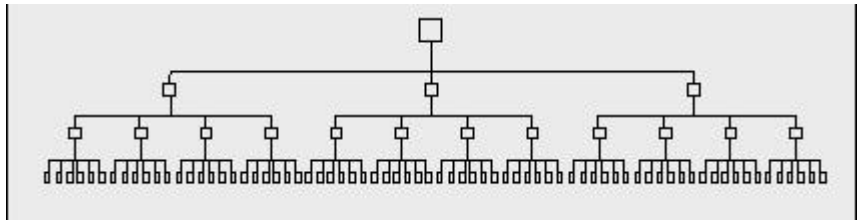


Pros:

- clarity and managerial control;
- close supervision of employees;
- clear, distinct layers with obvious lines of responsibility and control; ...

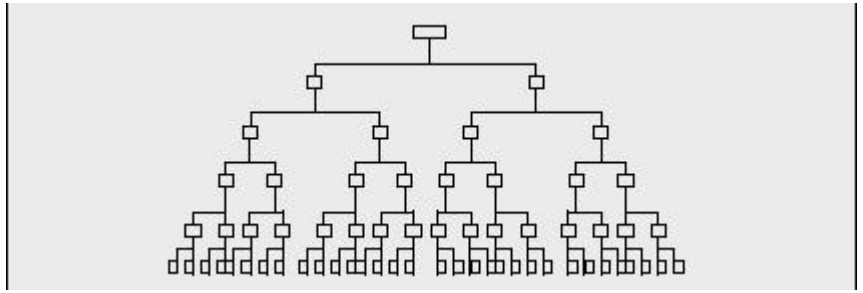
Cons:

- communication take too long;
- slow decision-making;
- obstruct progress; ...

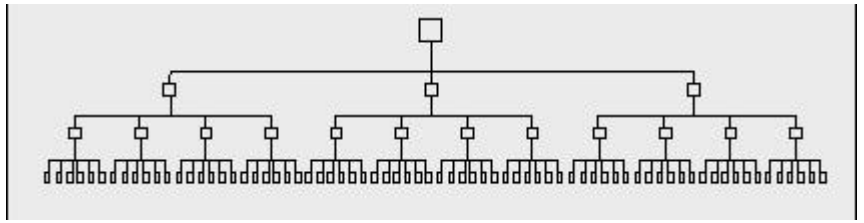
Griffin, D. Pros & cons of a flat organizational structure.

Hierarchical vs Flat Organizations

Hierarchical Organization



Flat Organization



Pros:
- clarity and managerial control;
- close supervision of employees;
- clear, distinct layers with obvious lines of responsibility and control; ...

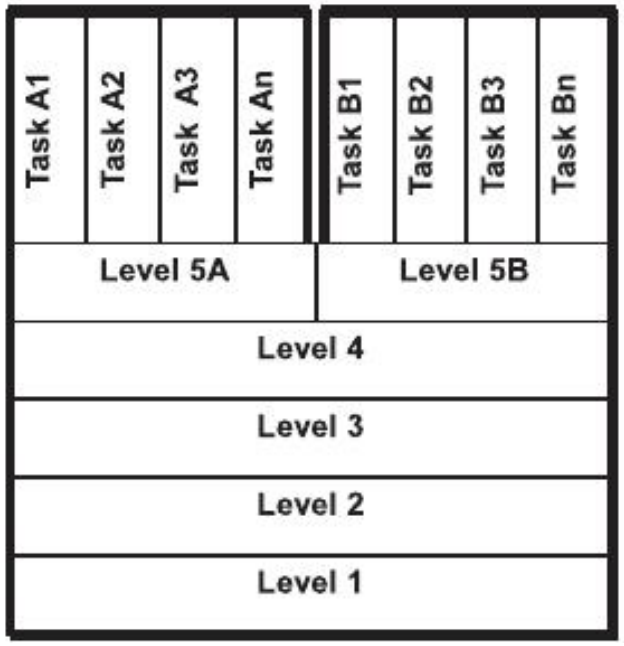
Cons:
- communication take too long;
- slow decision-making;
- obstruct progress; ...

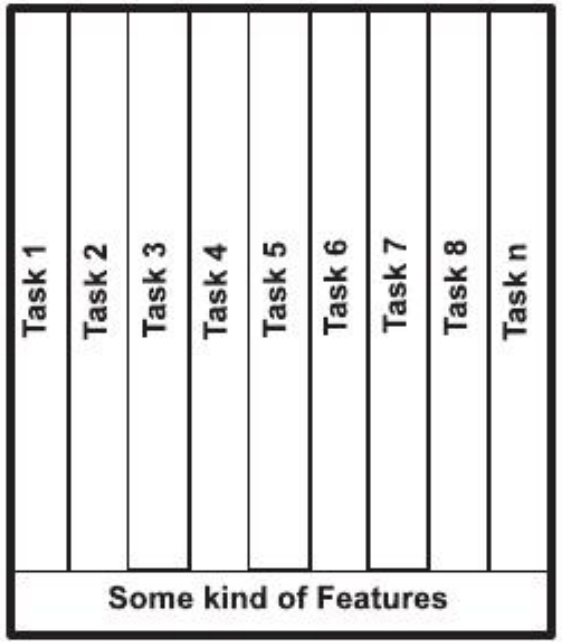
Pros:
- flexible and better able to adapt to changes;
- faster communication;
- quicker decisions;
- more democratic style; ...

Cons:
- confusion over roles;
- managers with a heavier workload; ...

Griffin, D. Pros & cons of a flat organizational structure.

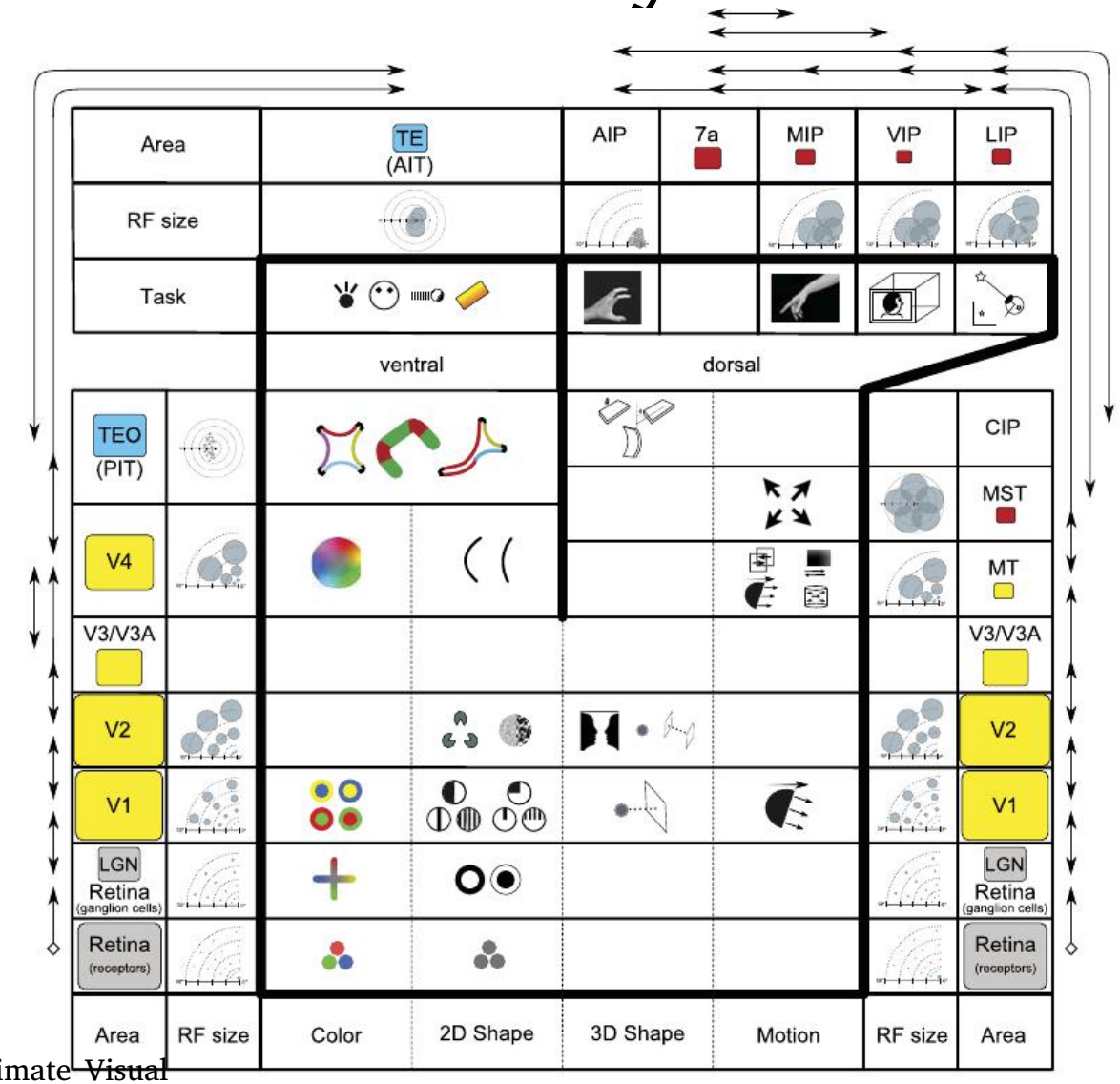
Hierarchical vs flat hierarchies





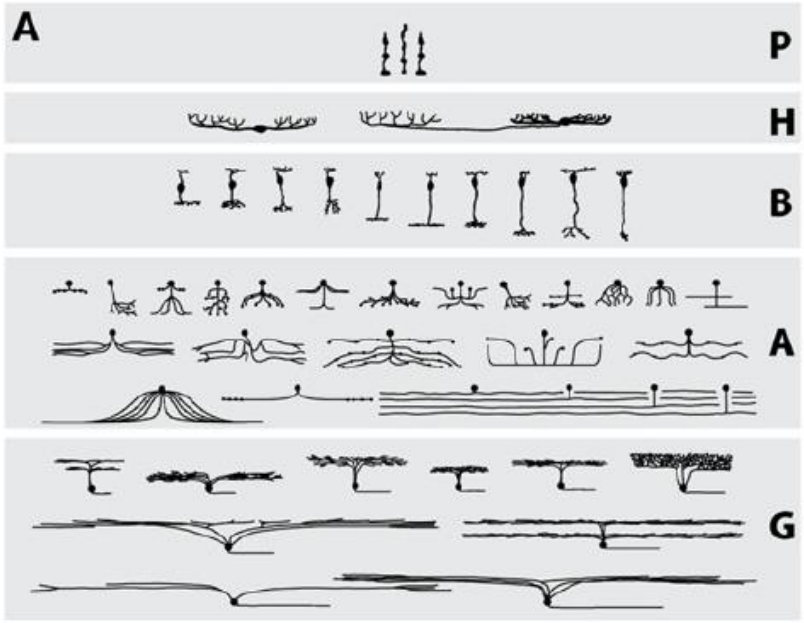
Krüger et al., Deep Hierarchies in the Primate Visual Cortex What Can We Learn for Computer Vision

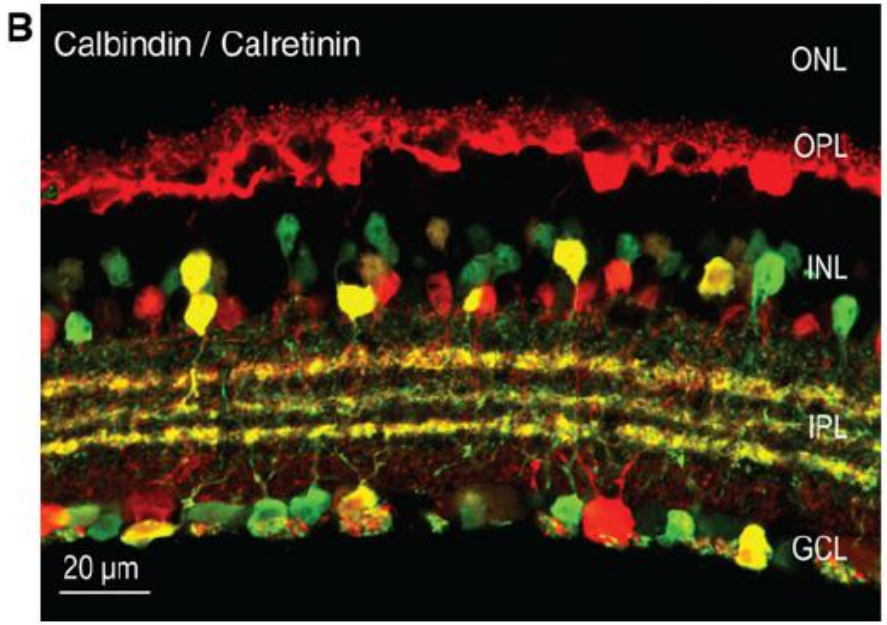
Hierarchical visual system



Krüger et al., Deep Hierarchies in the Primate Visual Cortex What Can We Learn for Computer Vision

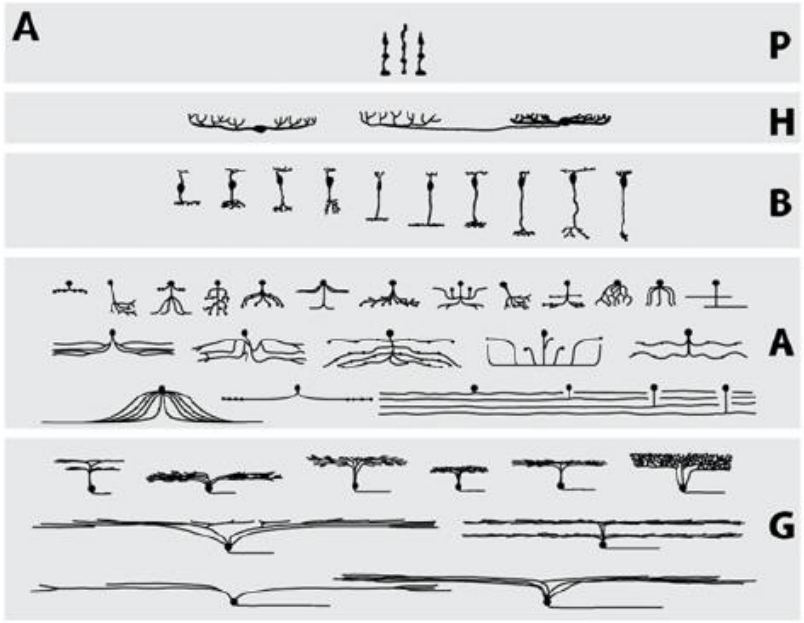
Flat retina

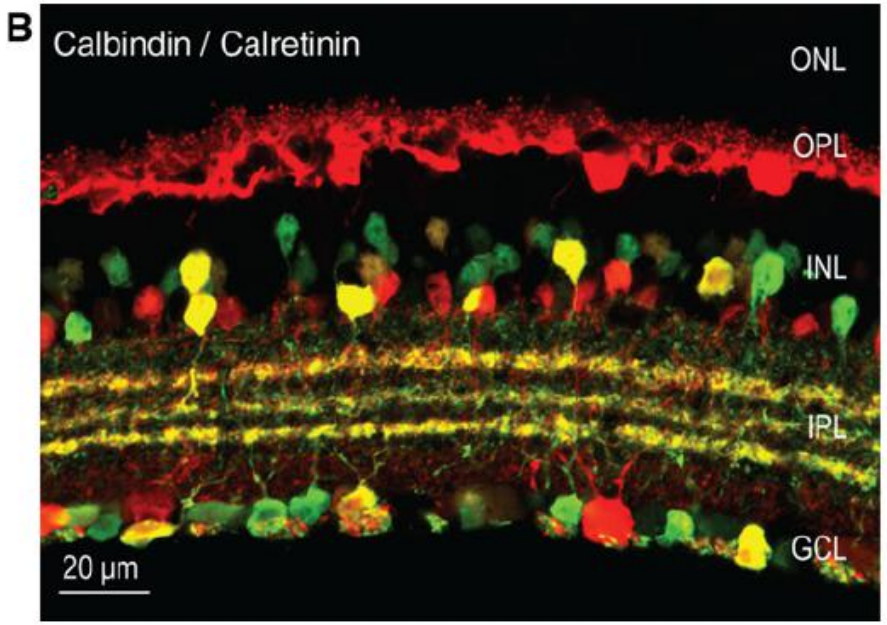


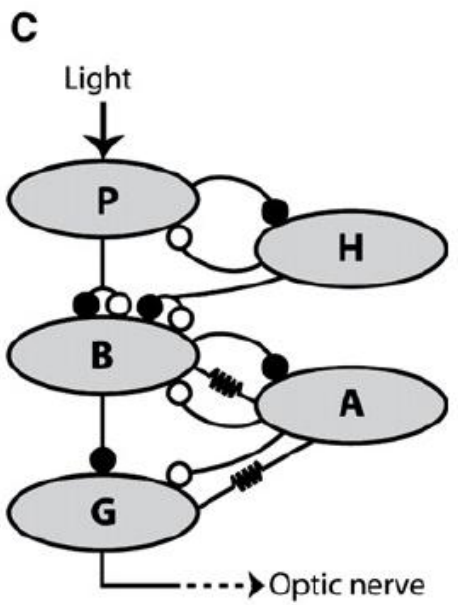


Gollish, eye's smarter than scientists believe

Flat retina







Gollish, eye's smarter than scientists believe

Flat retina: many functions on the base level

- Light detection (photo-receptors)

Flat retina: many functions on the base level

- Light detection
- Whitening: remove 2nd order correlations (next class)

Flat retina: many functions on the base level

- Light detection
- Whitening
- Contrast and pattern adaptation

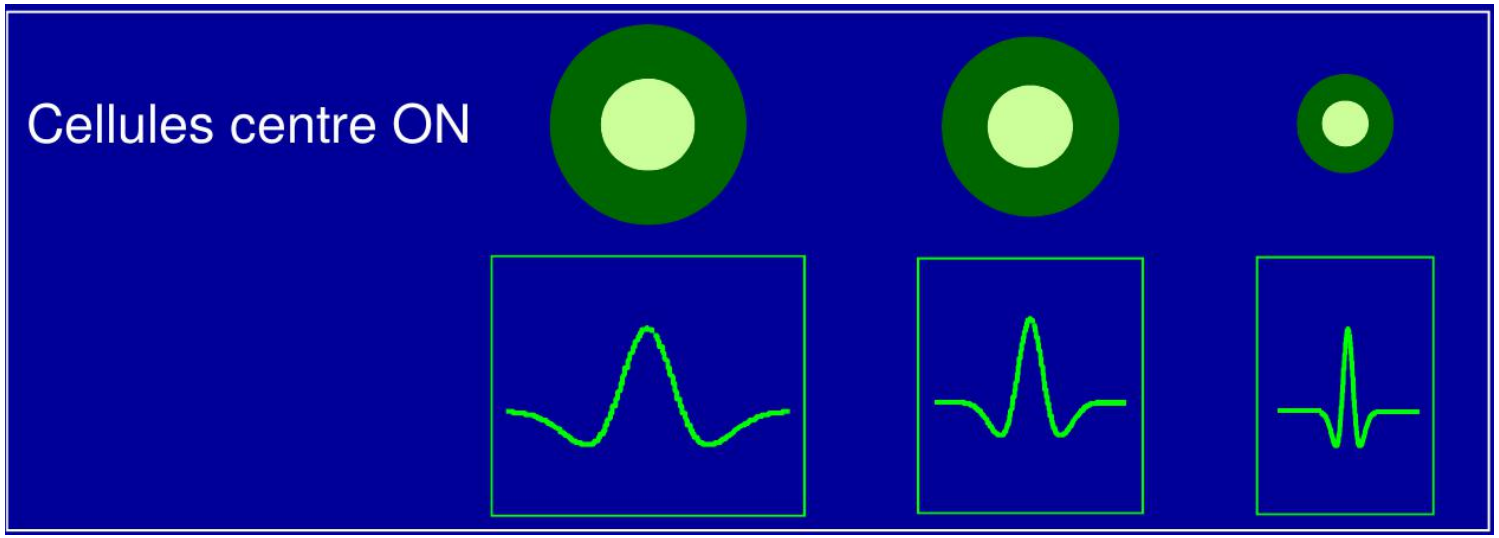
Contrast adaptation

Contrast adaptation

Flat retina: many functions on the base level

- Light detection
- Whitening
- Contrast and pattern adaptation
- Texture motion

Texture Motion



If the bars do not move the cells do not respond (the gray values cancel out)

If the bars move the cells respond

Flat retina: many functions on the base level

- Light detection
- Whitening
- Contrast and pattern adaptation
- Texture motion
- Object motion

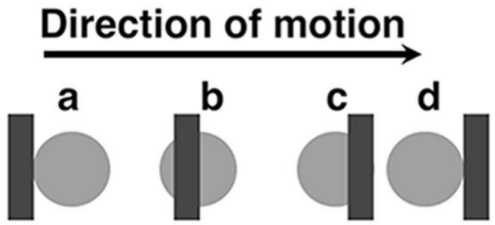
Flat retina: many functions on the base level

- Light detection
- Whitening
- Contrast and pattern adaptation
- Texture motion
- Object motion
- Approaching motion

Flat retina: many functions on the base level

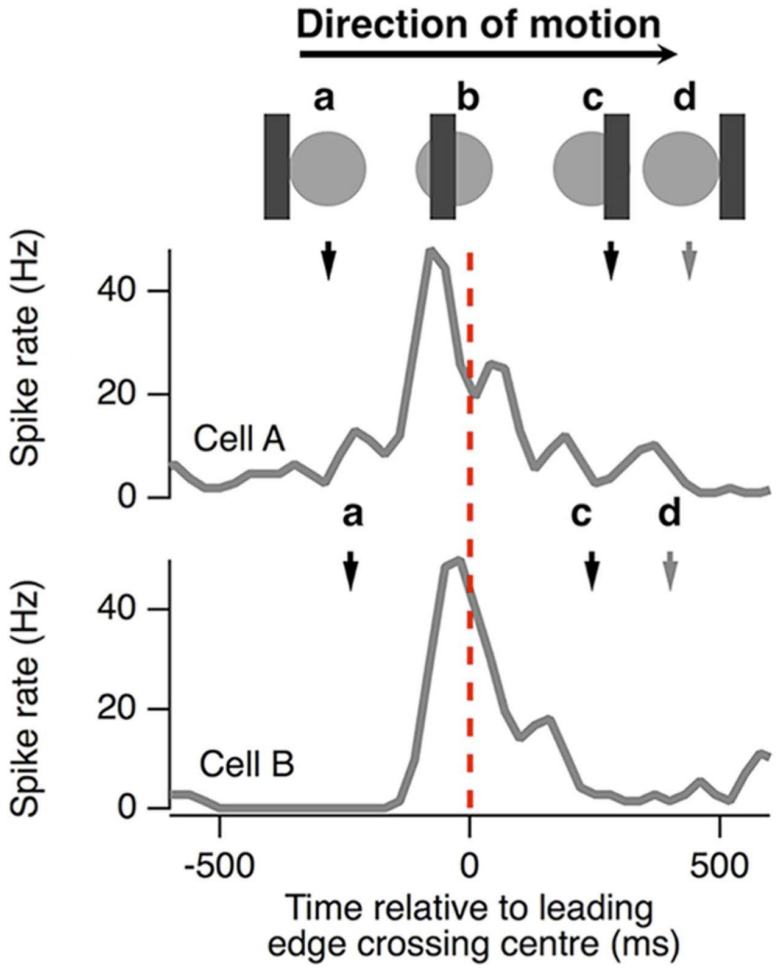
- Light detection
- Whitening
- Contrast and pattern adaptation
- Texture motion
- Object motion
- Approaching motion
- Motion extrapolation

Motion extrapolation



Johnston and Lagnado, General features of the retinal connectome determine the computation of motion anticipation

Motion extrapolation



Johnston and Lagnado, General features of the retinal connectome determine the computation of motion anticipation

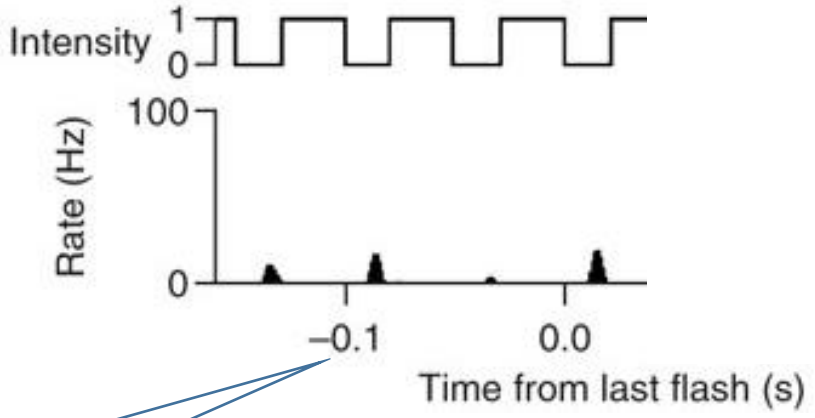
Flat retina: many functions on the base level

- Light detection
- Whitening
- Contrast and pattern adaptation
- Texture motion
- Object motion
- Approaching motion
- Motion extrapolation
- Omitted stimulus response

Omitted stimulus response

Schwartz et al, Detection and prediction of periodic patterns by the retina,

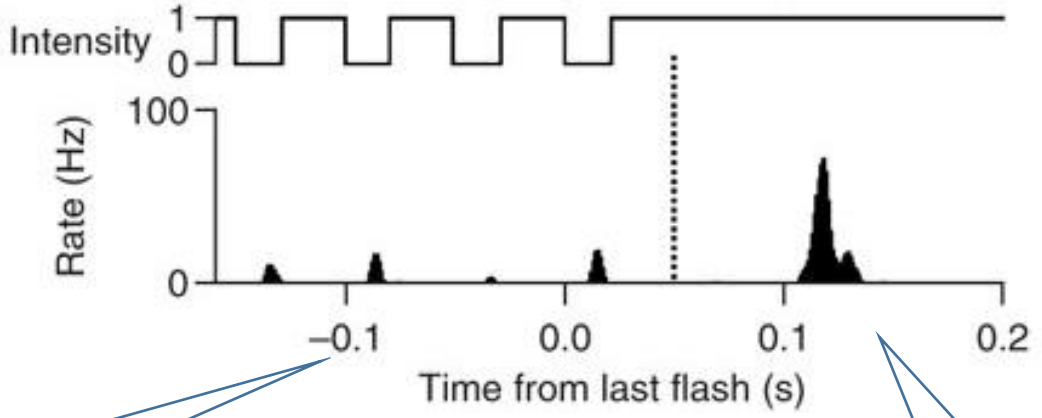
Omitted stimulus response



Off-center cell?

Schwartz et al, Detection and prediction of periodic patterns by the retina,

Omitted stimulus response



Off-center cell?

No!

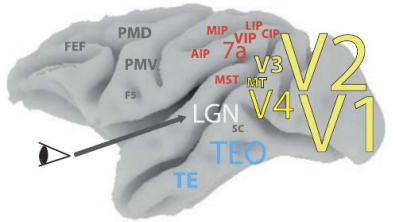
Schwartz et al, Detection and prediction of periodic patterns by the retina,

Flat retina: many functions on the base level

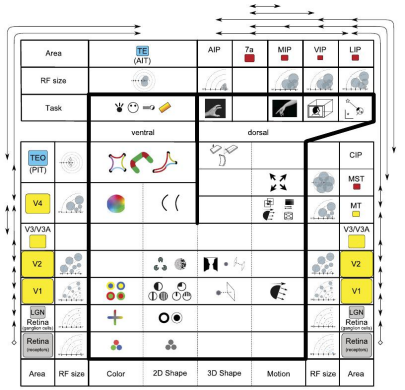
- Light detection
- Whitening
- Contrast and pattern adaptation
- Texture motion
- Object motion
- Approaching motion
- Motion extrapolation
- Omitted stimulus response
- …

Summary

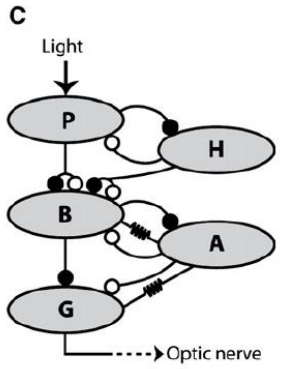
- Visual Pathway



- Hierarchical view of the visual system



- Flat view of the retina



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