An introduction to the visual system

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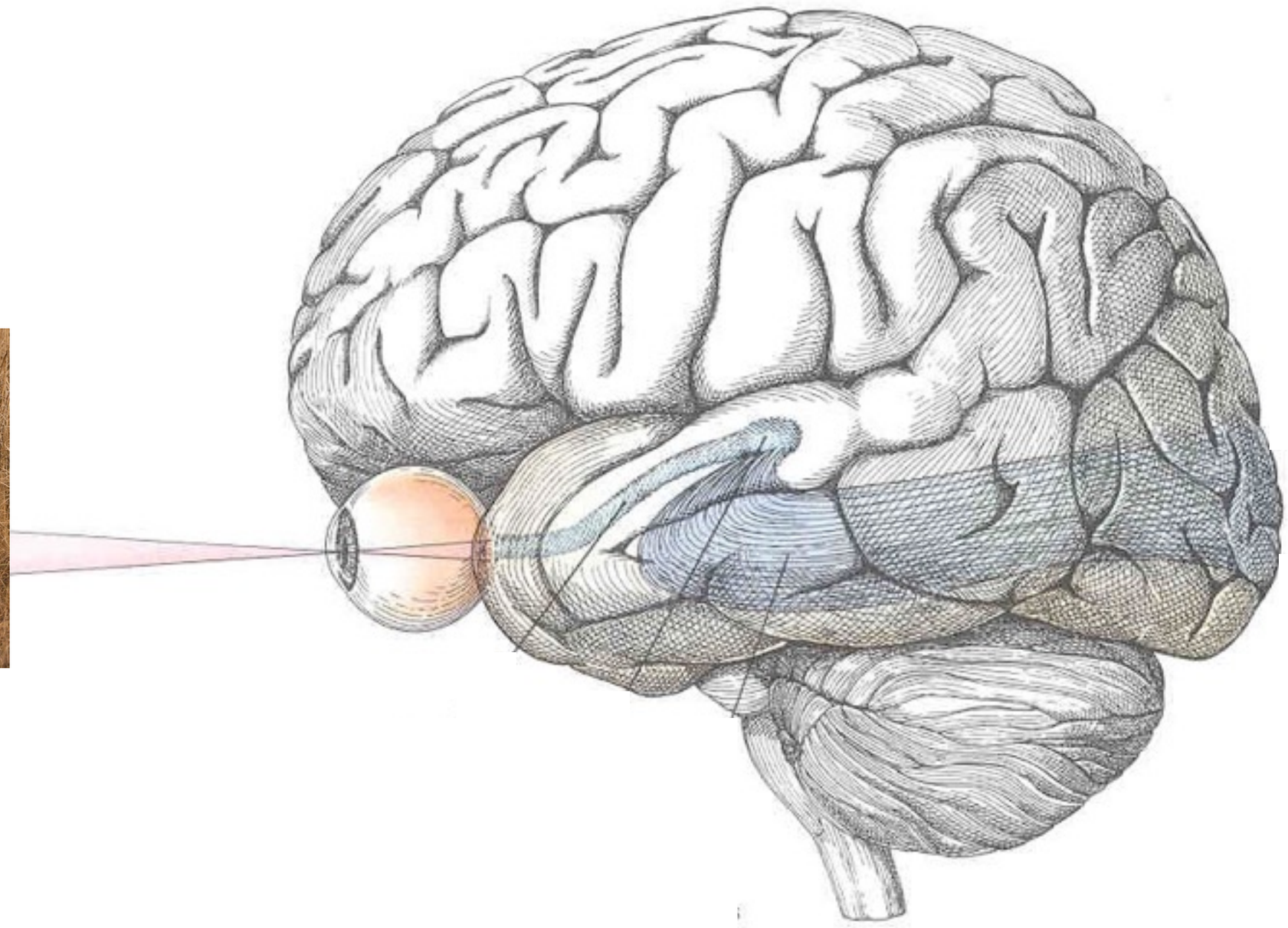
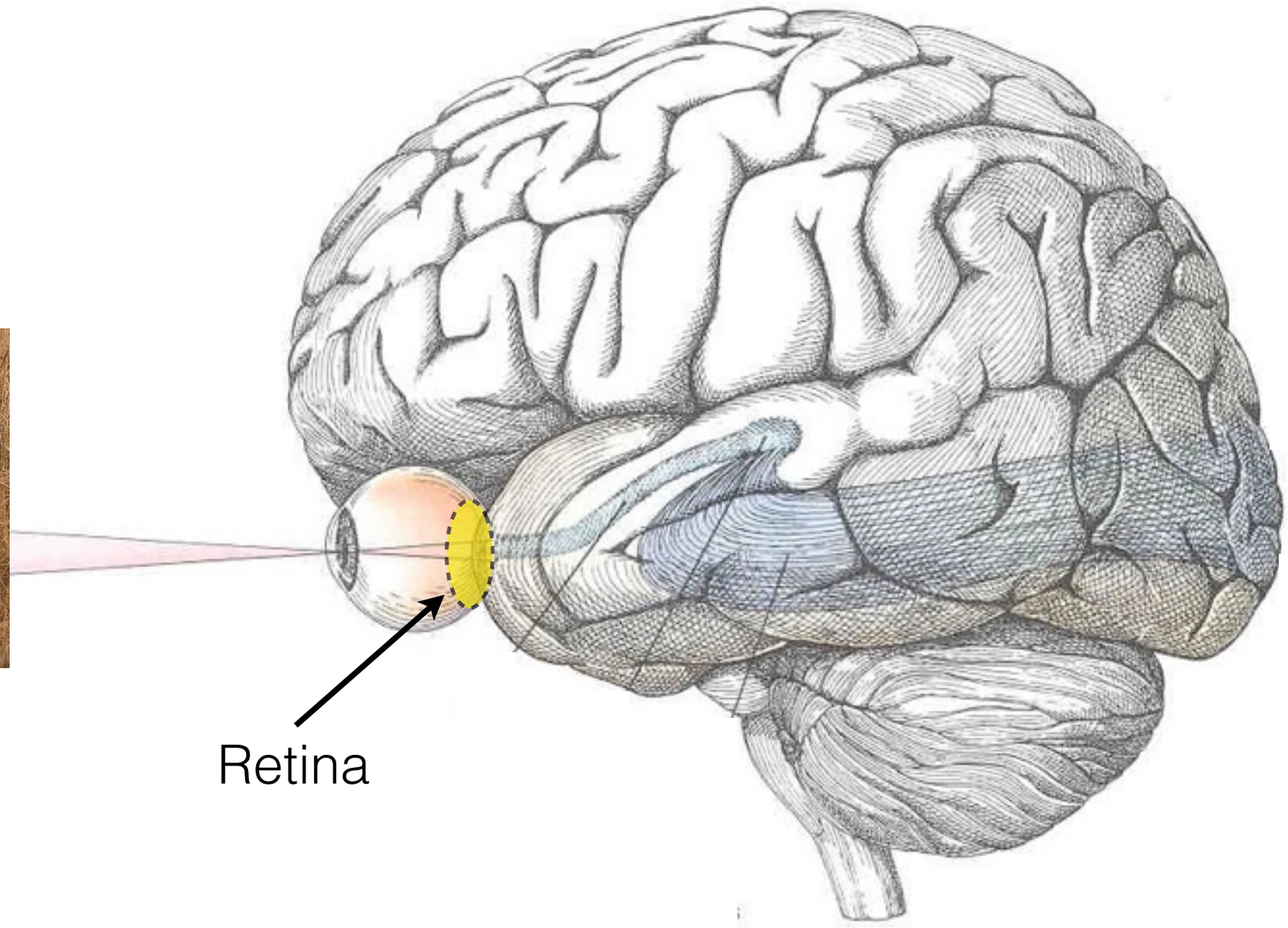
23 June 2015

http://www.mydestination.com/users/photogravy/bbb#.UfainmTXj7Y



http://www.mit.edu/~kardar/research/seminars/CorticalMaps/VisualSystem.html



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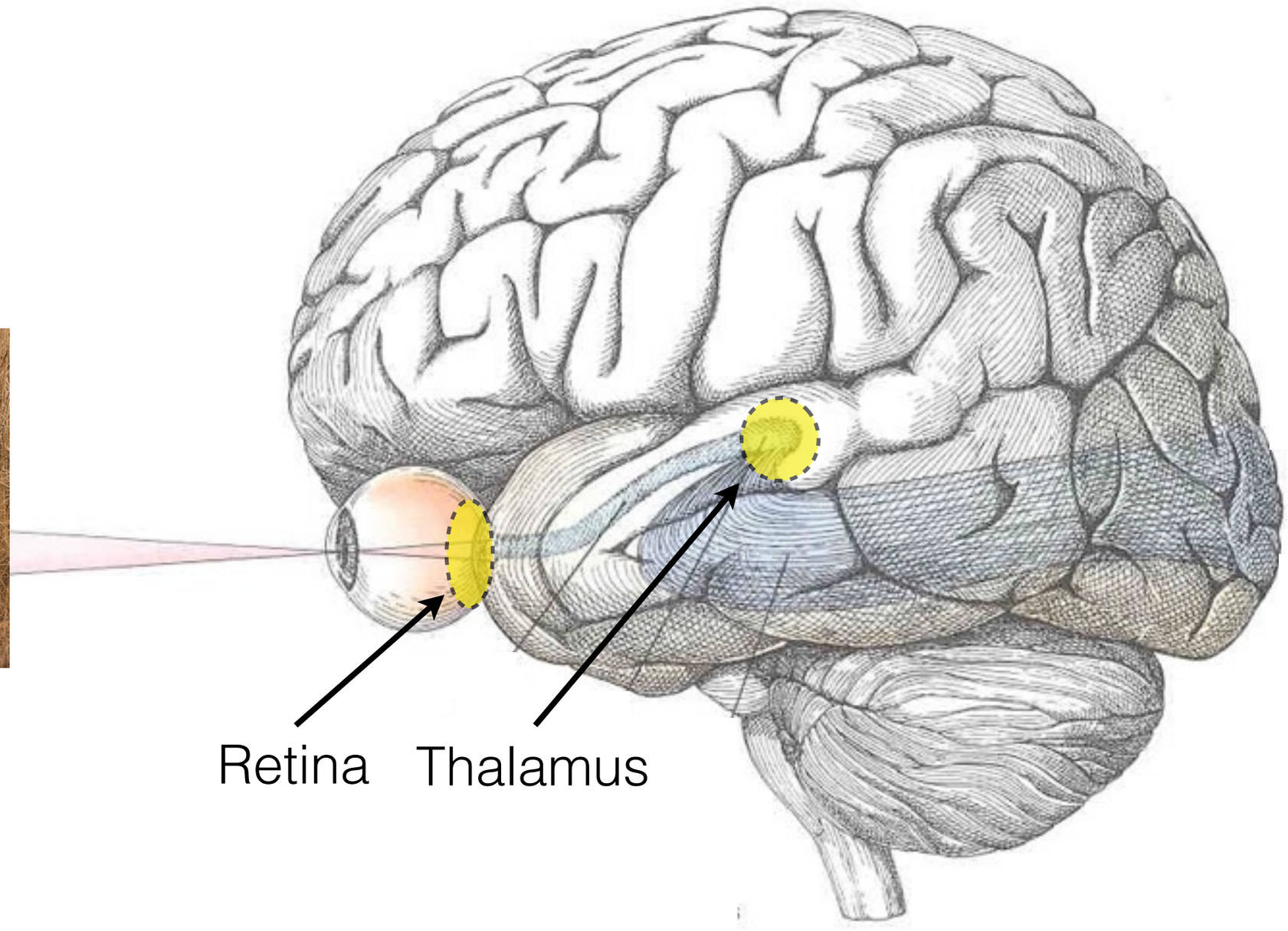

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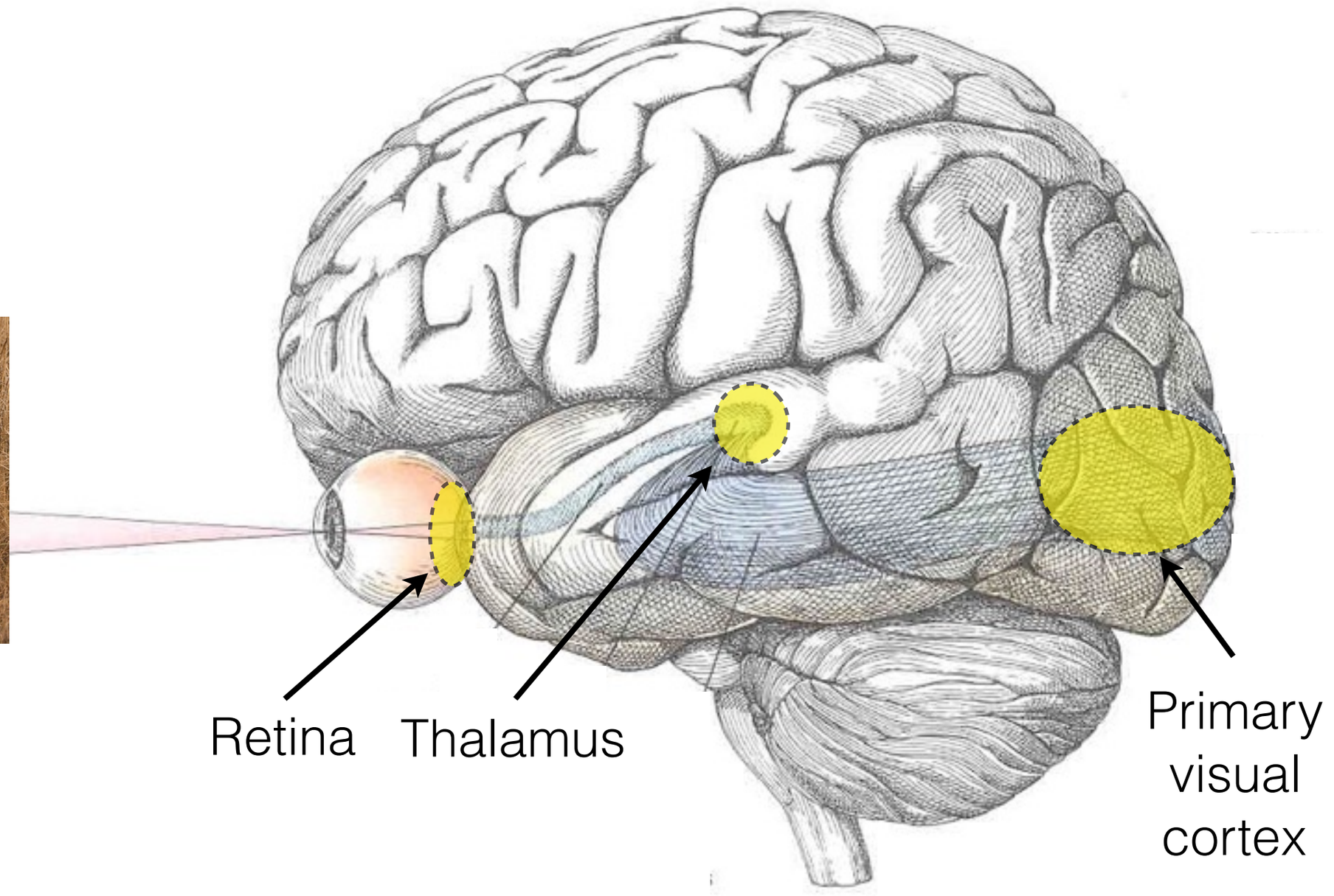

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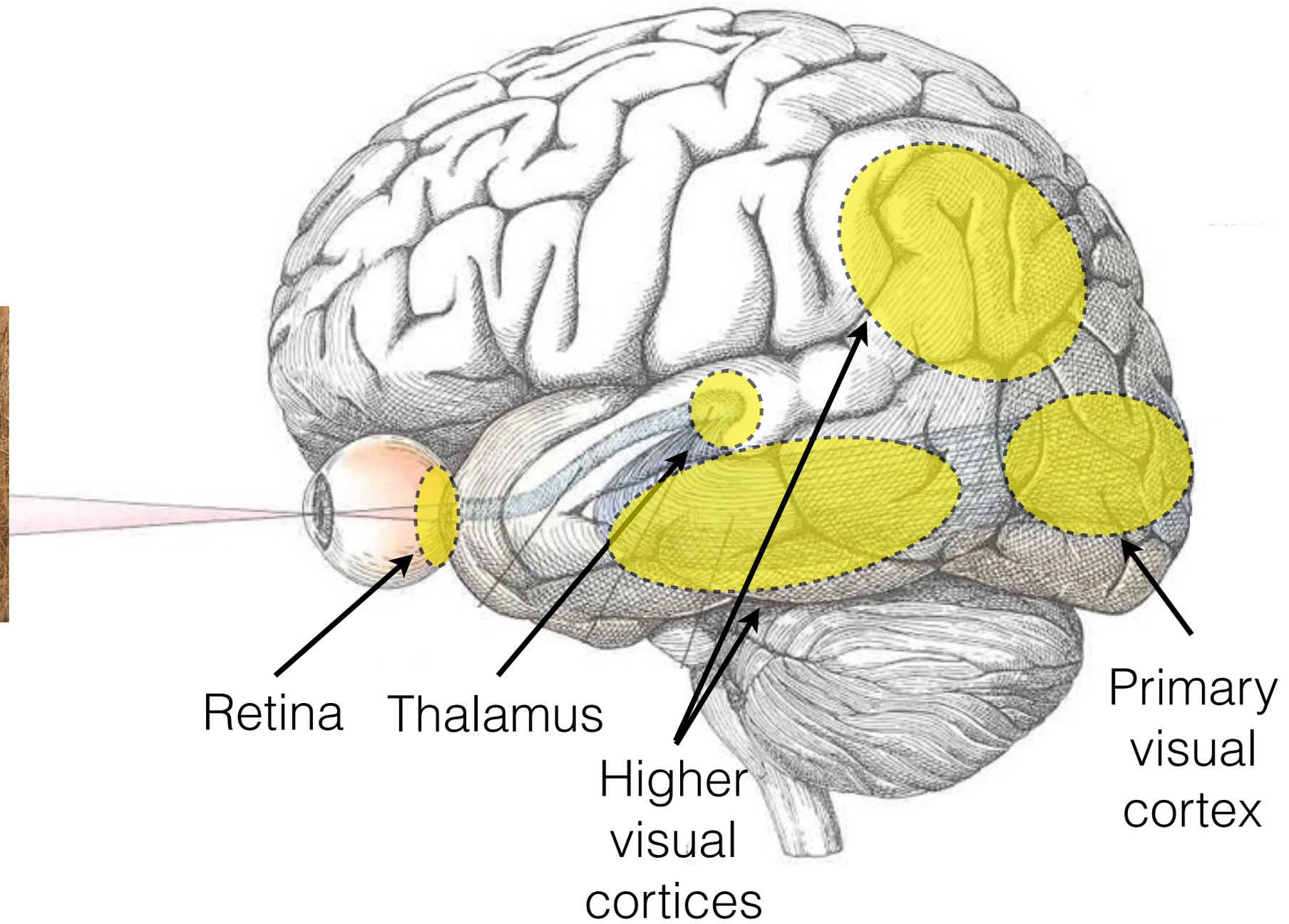

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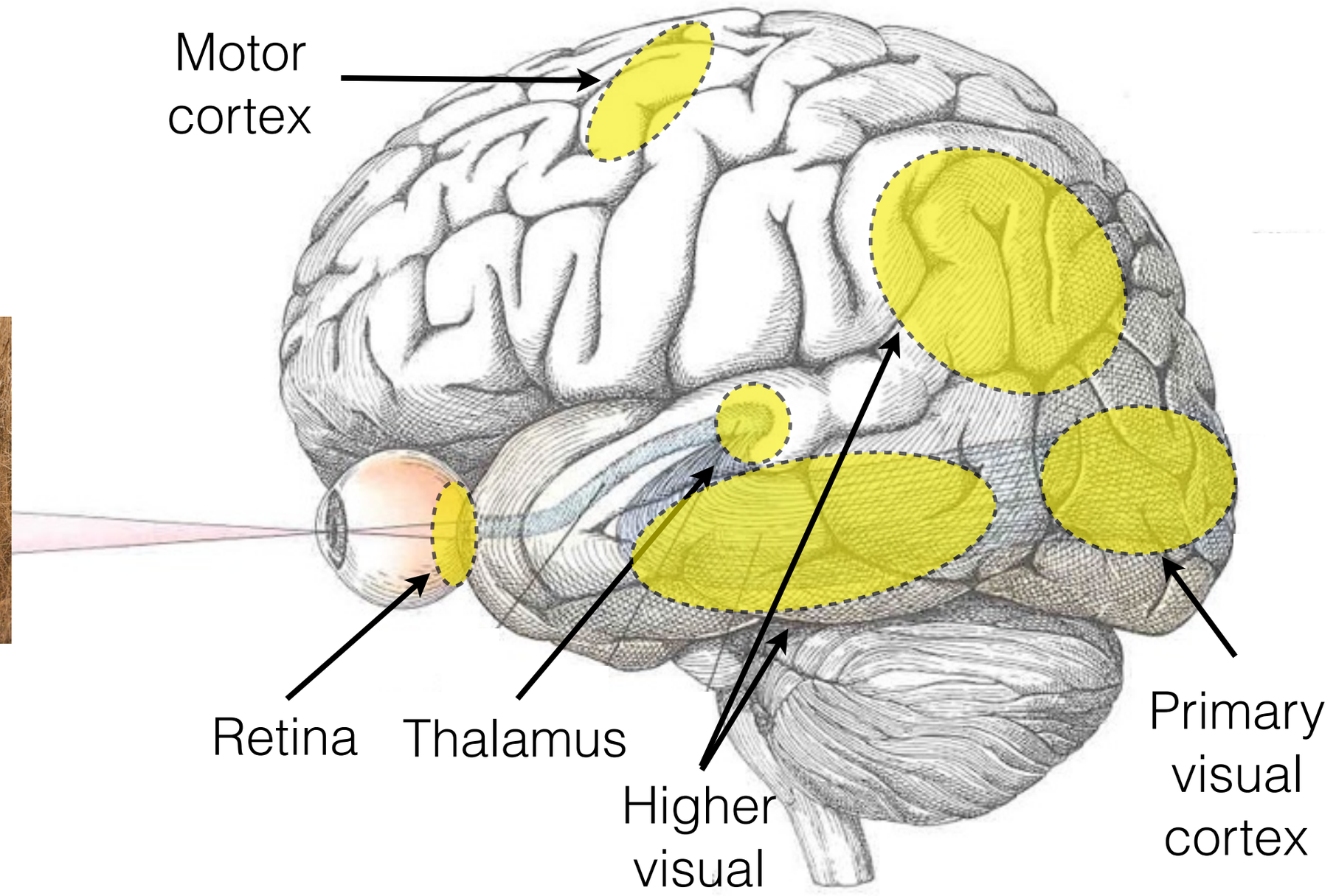


http://www.mit.edu/~kardar/research/seminars/CorticalMaps/VisualSystem.html

Do a bunch of stuff

Do a bunch of stuff

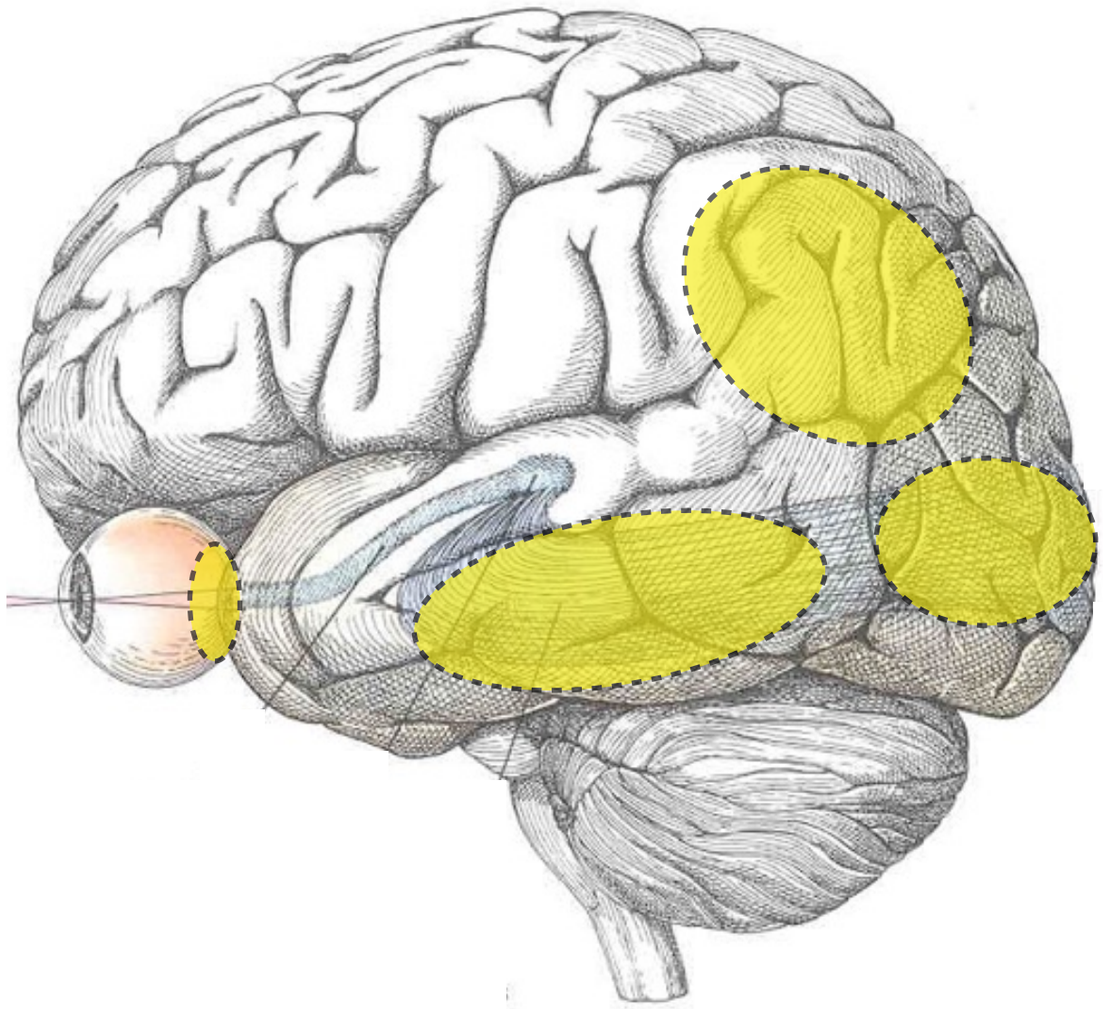
Do a bunch of stuff

≈ ½ second

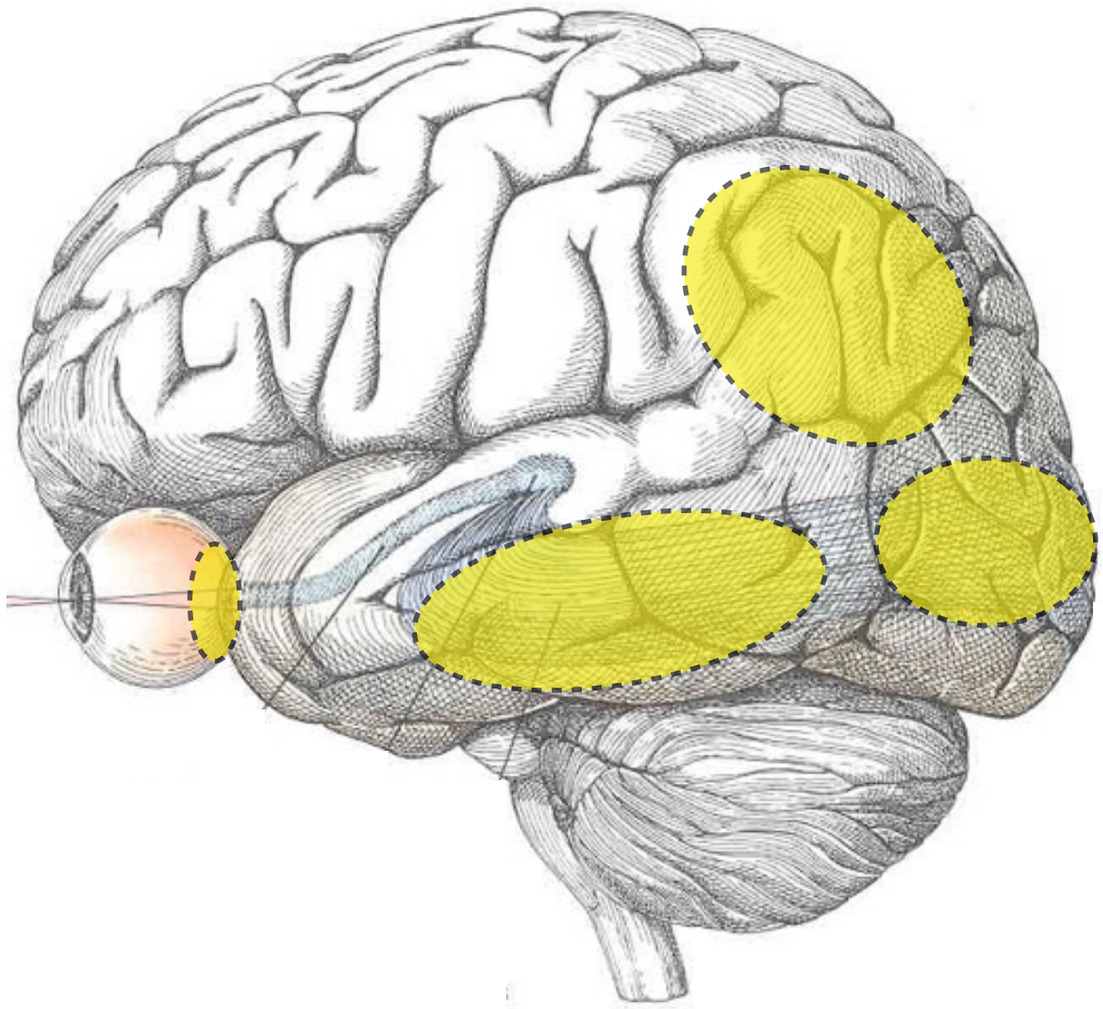
How does this happen?

An introduction to the visual system

An introduction to the visual system

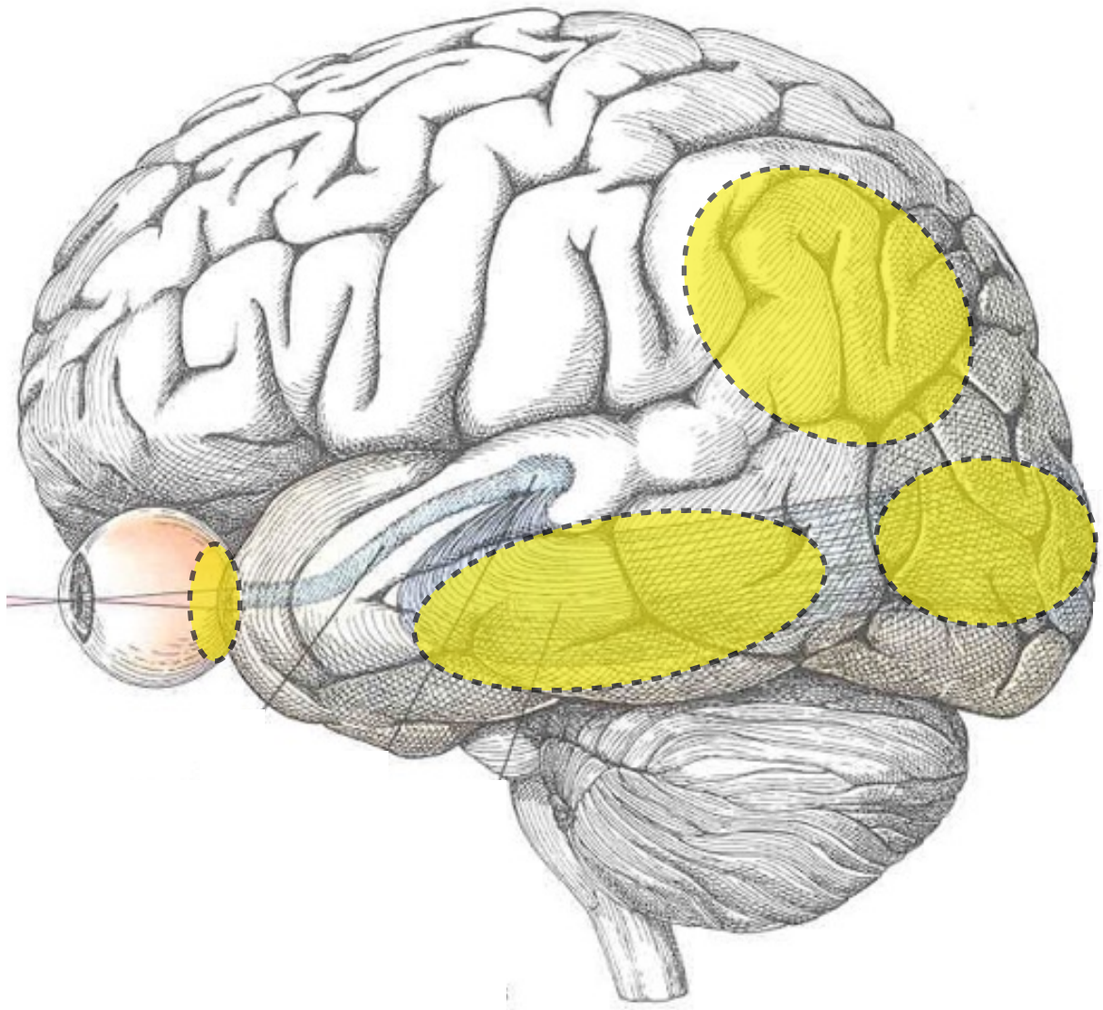


An introduction to the visual system



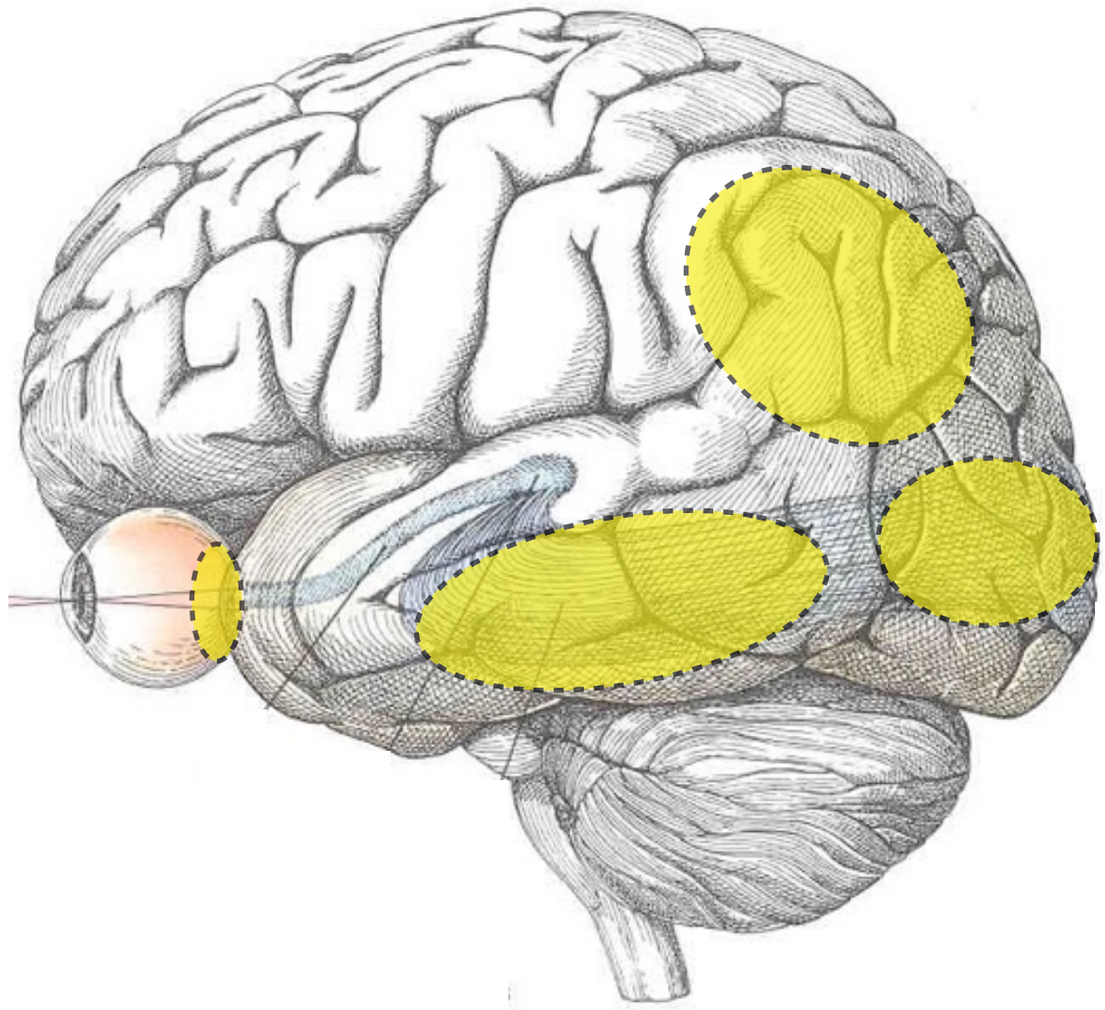
- The retina

An introduction to the visual system



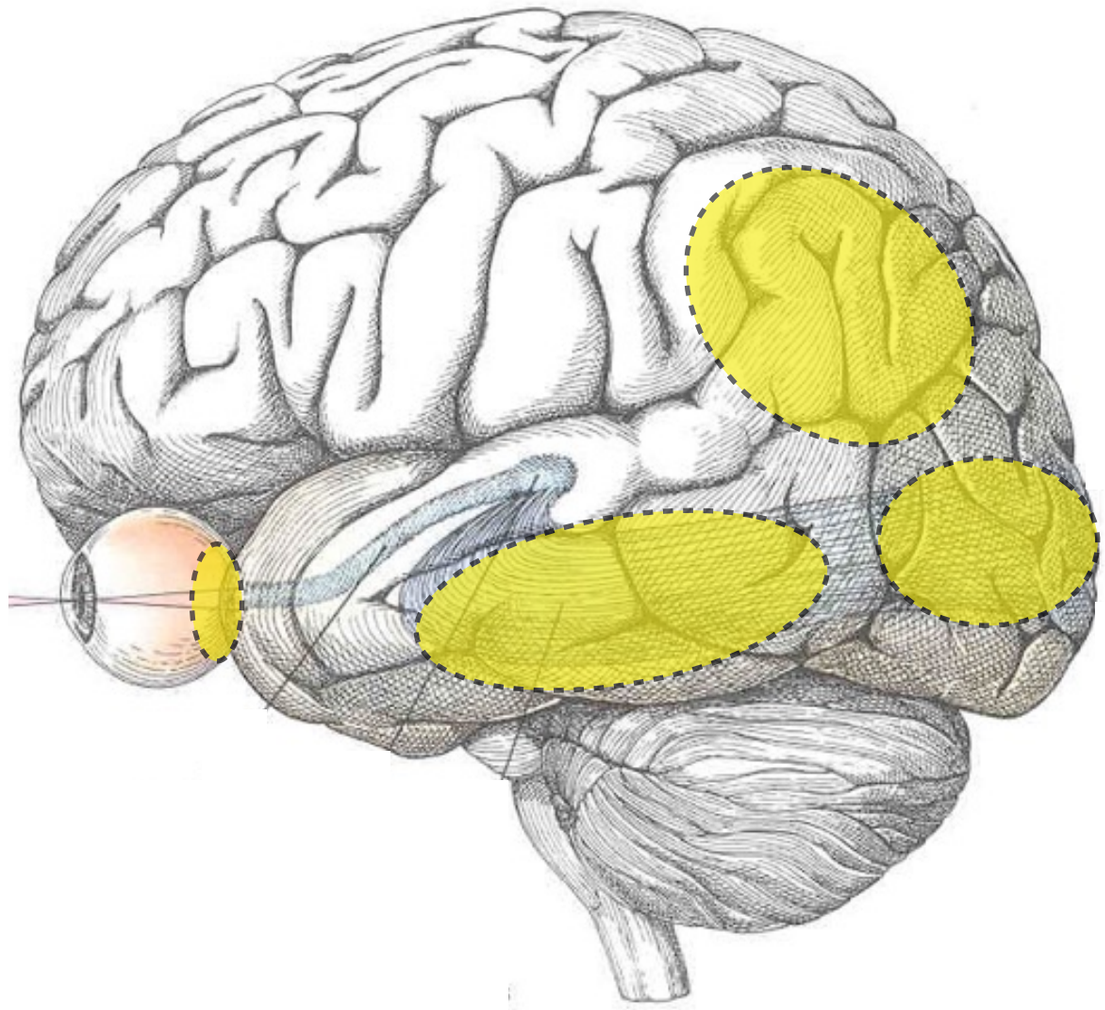
- The retina
- Primary visual cortex

An introduction to the visual system



- The retina
- Primary visual cortex
- Higher visual cortices

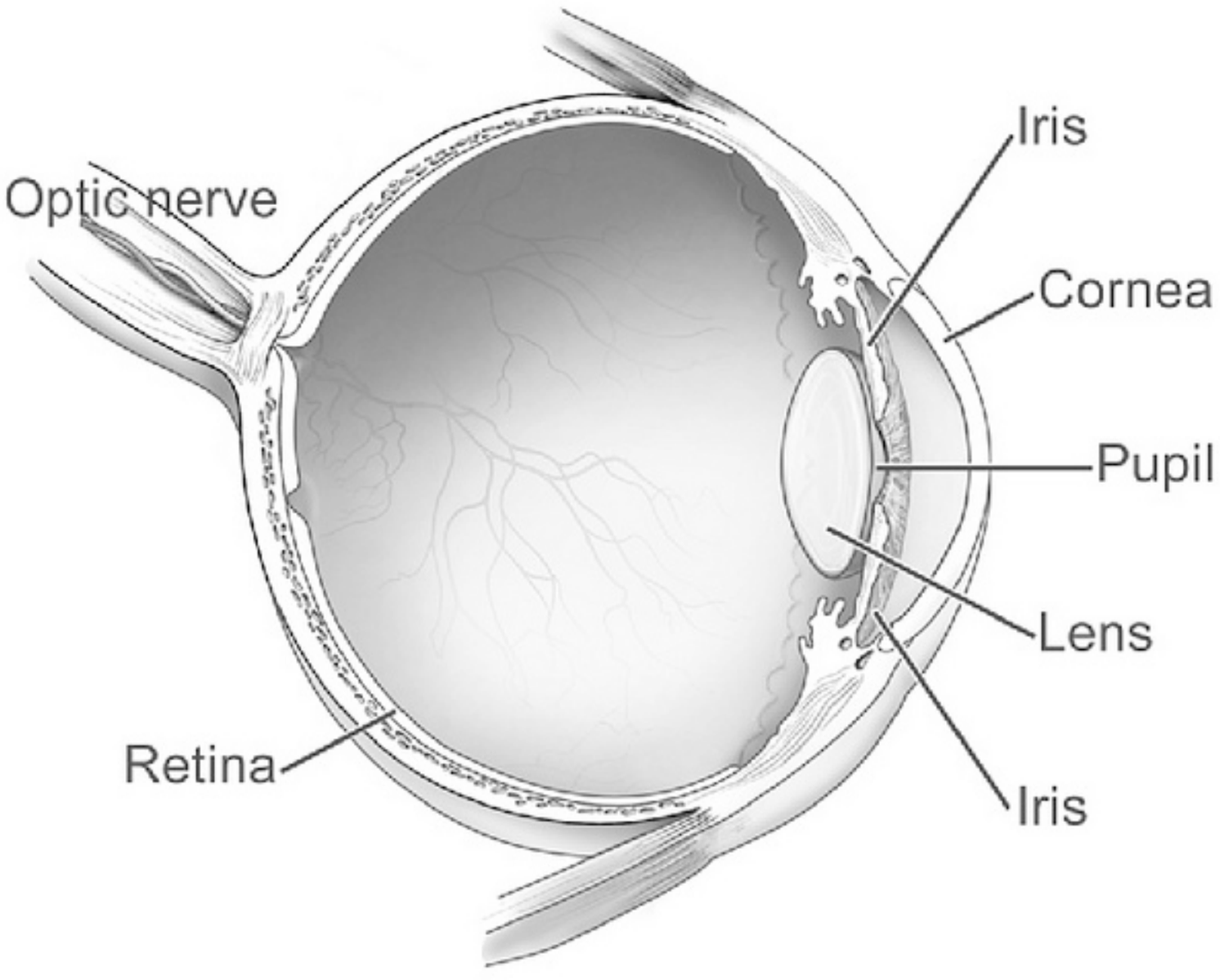
An introduction to the visual system



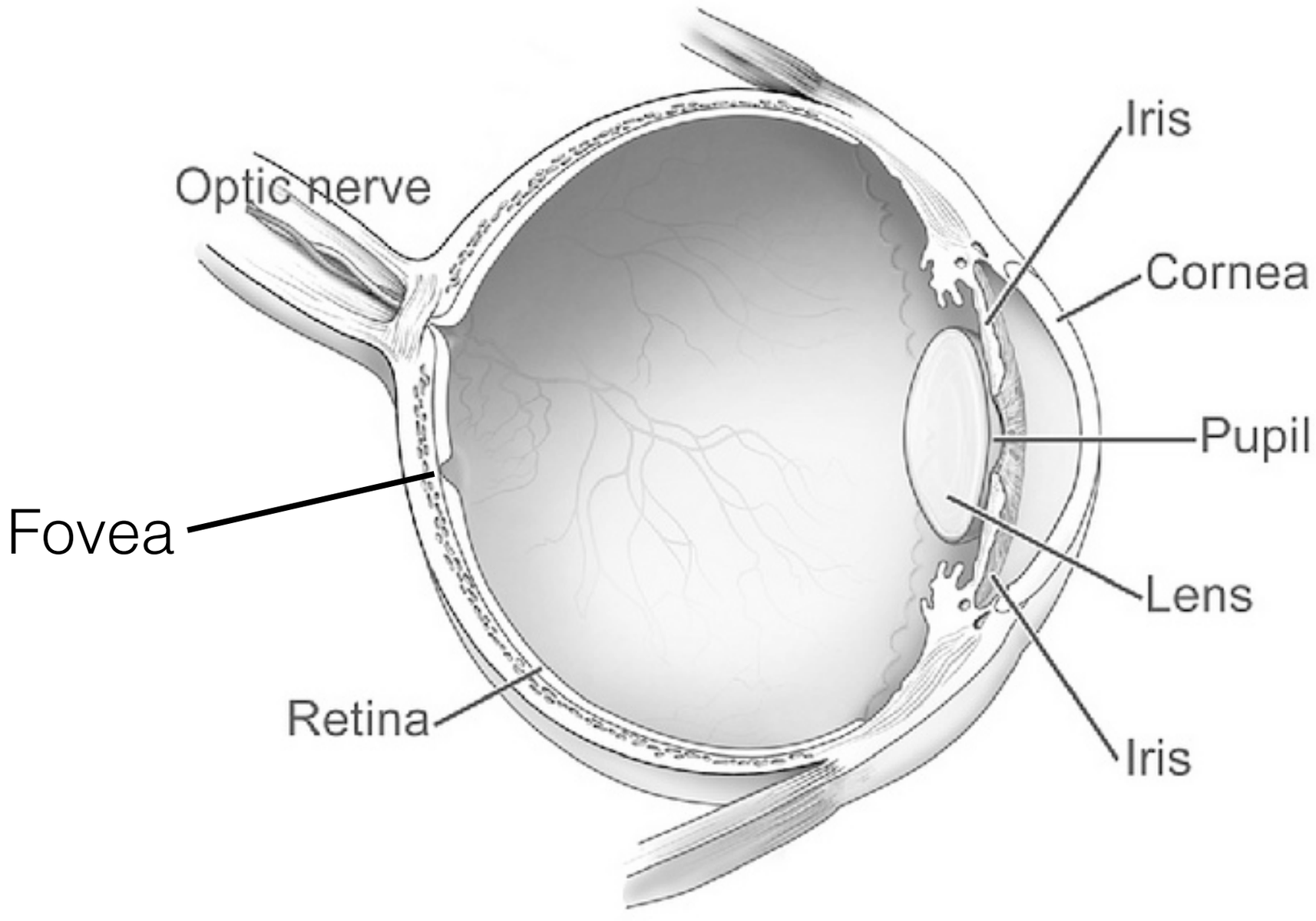
- The retina
- Primary visual cortex
- Higher visual cortices
- Current research in visual neuroscience

Eye and retina

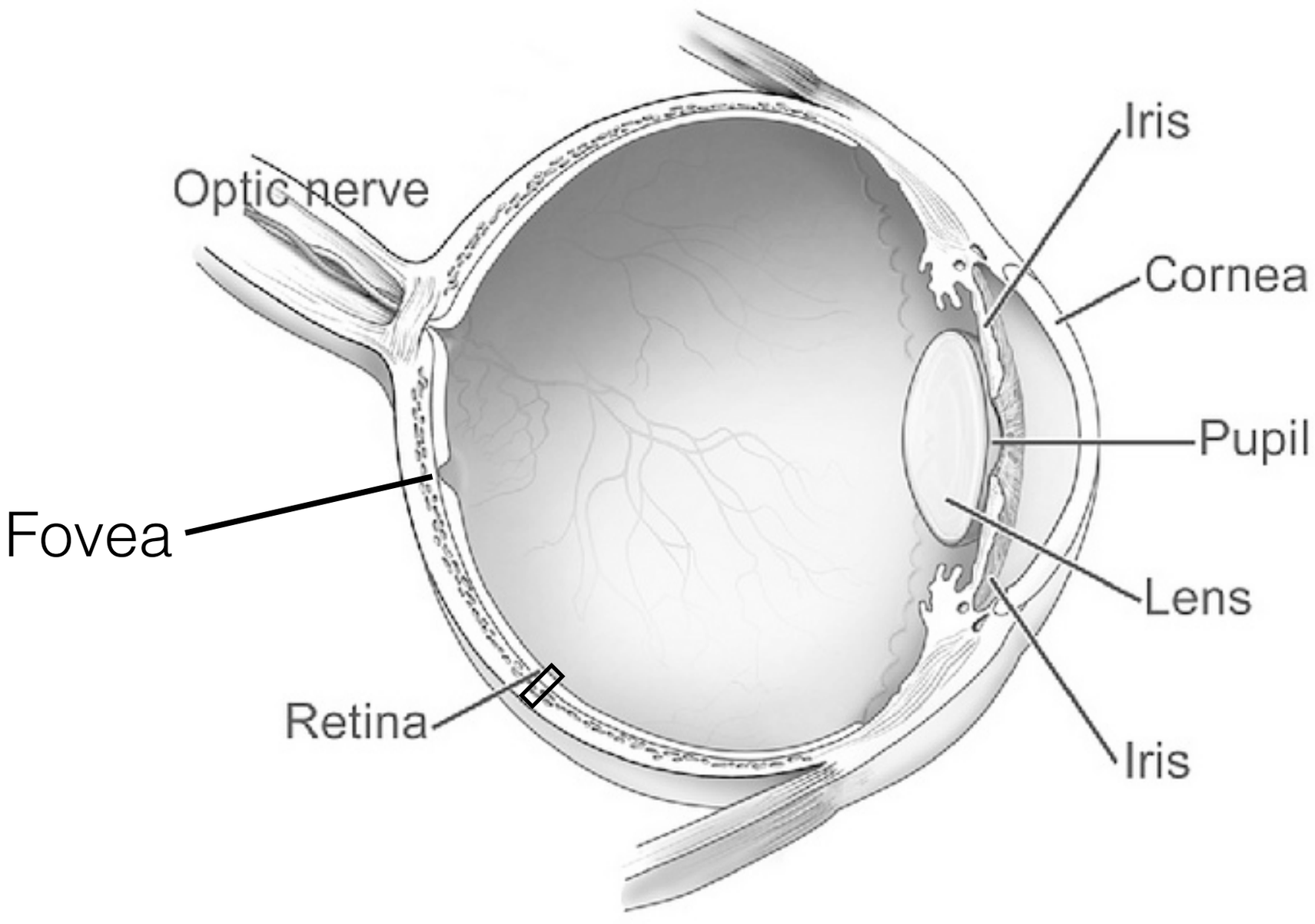
Eye and retina



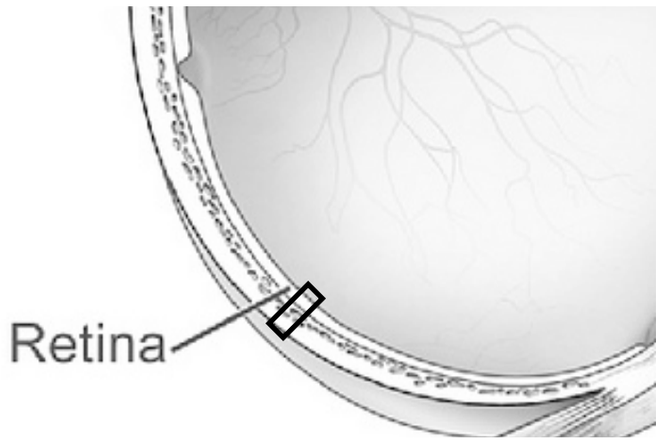
Eye and retina



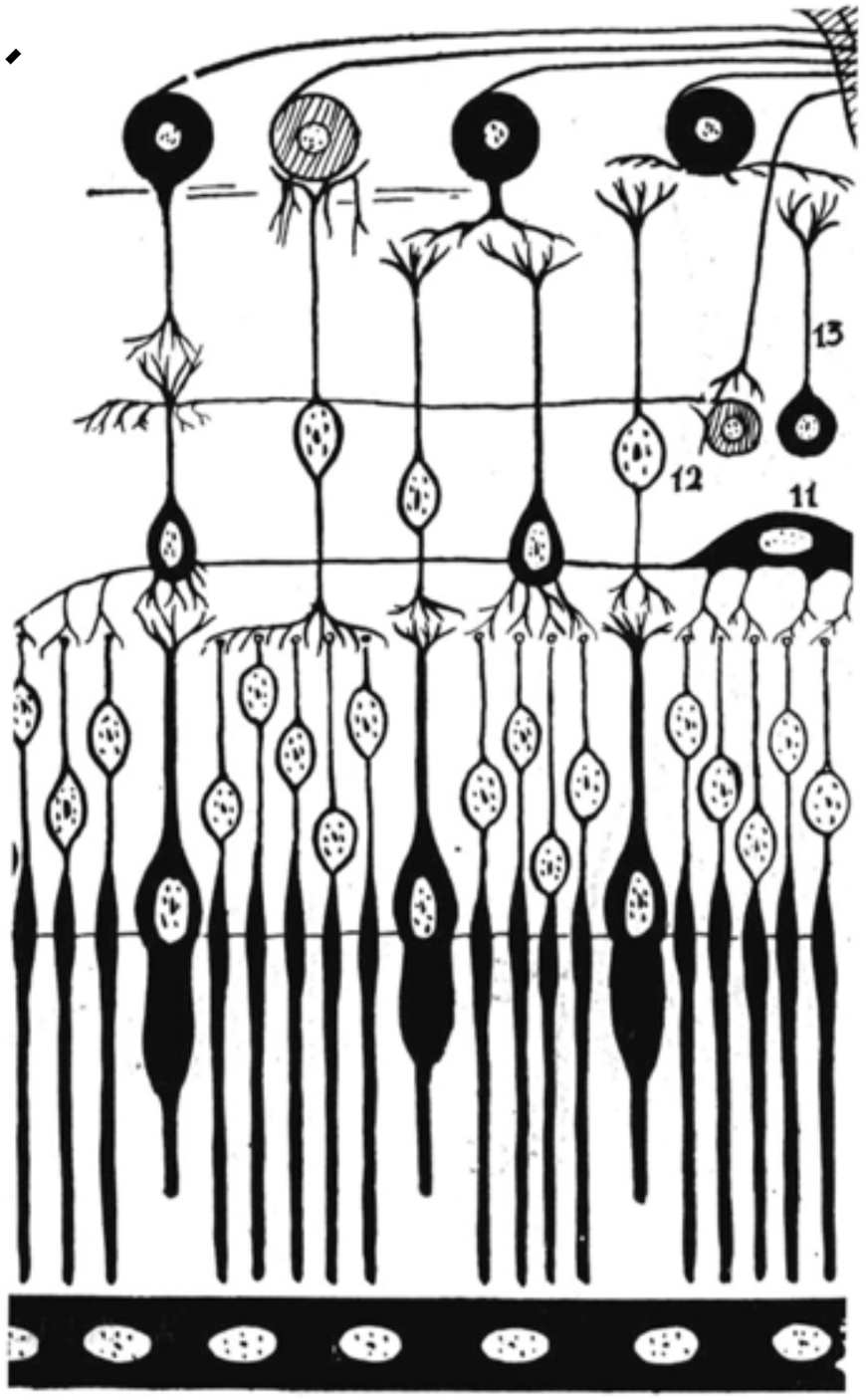
Eye and retina



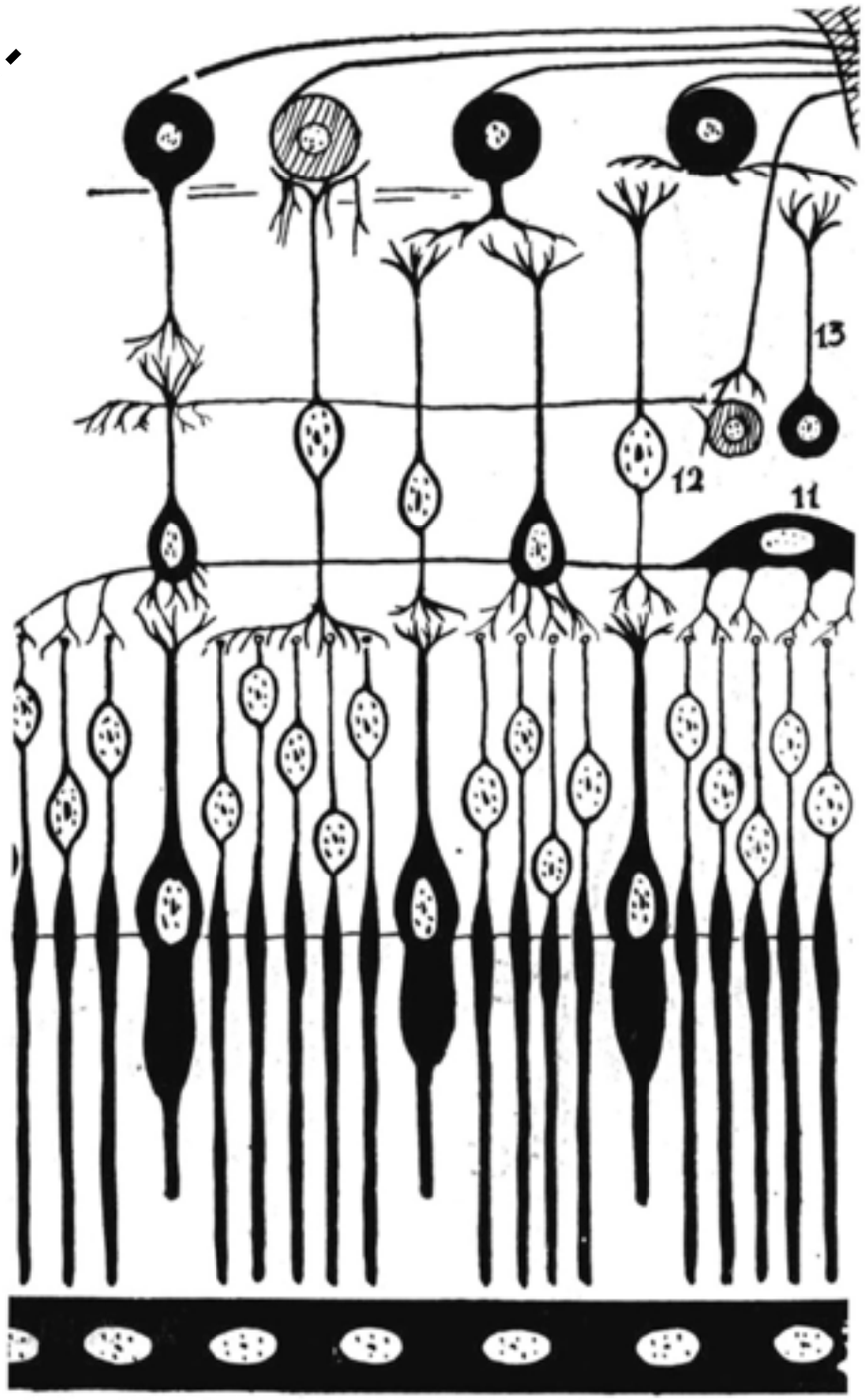
Eye and retina



Eye and retina



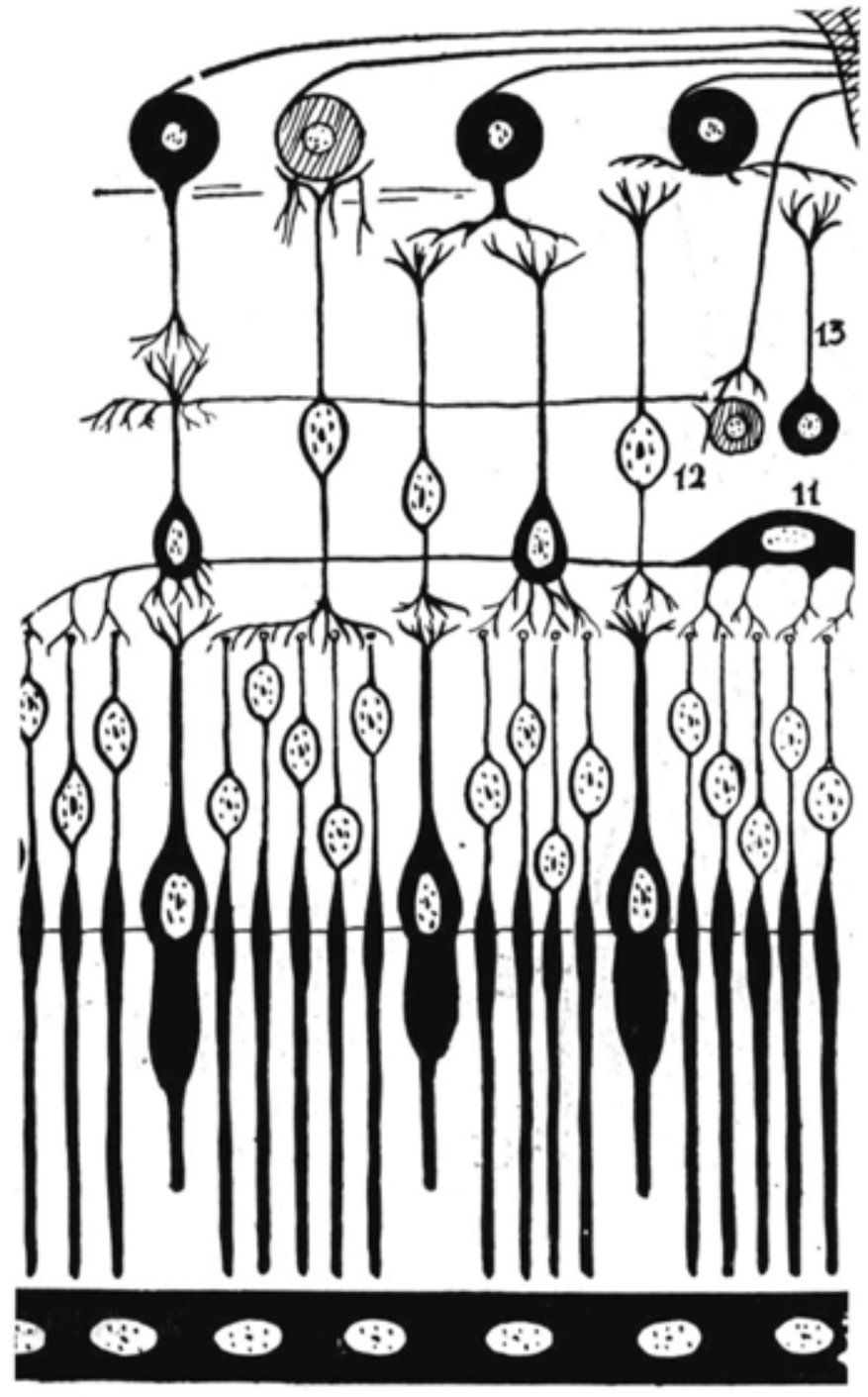
Eye and retina



LIGHT

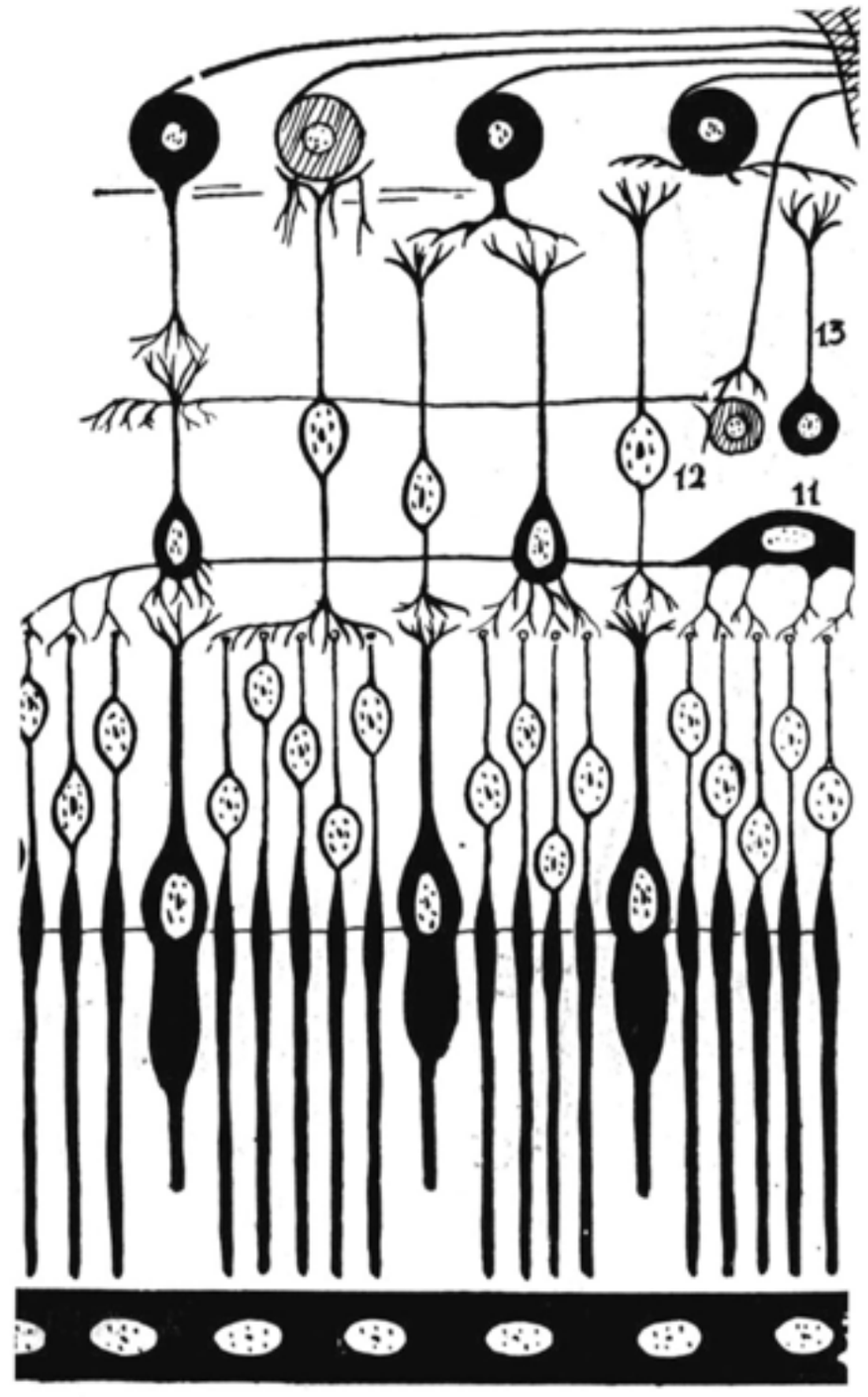
Eye and retina

Eye and retina

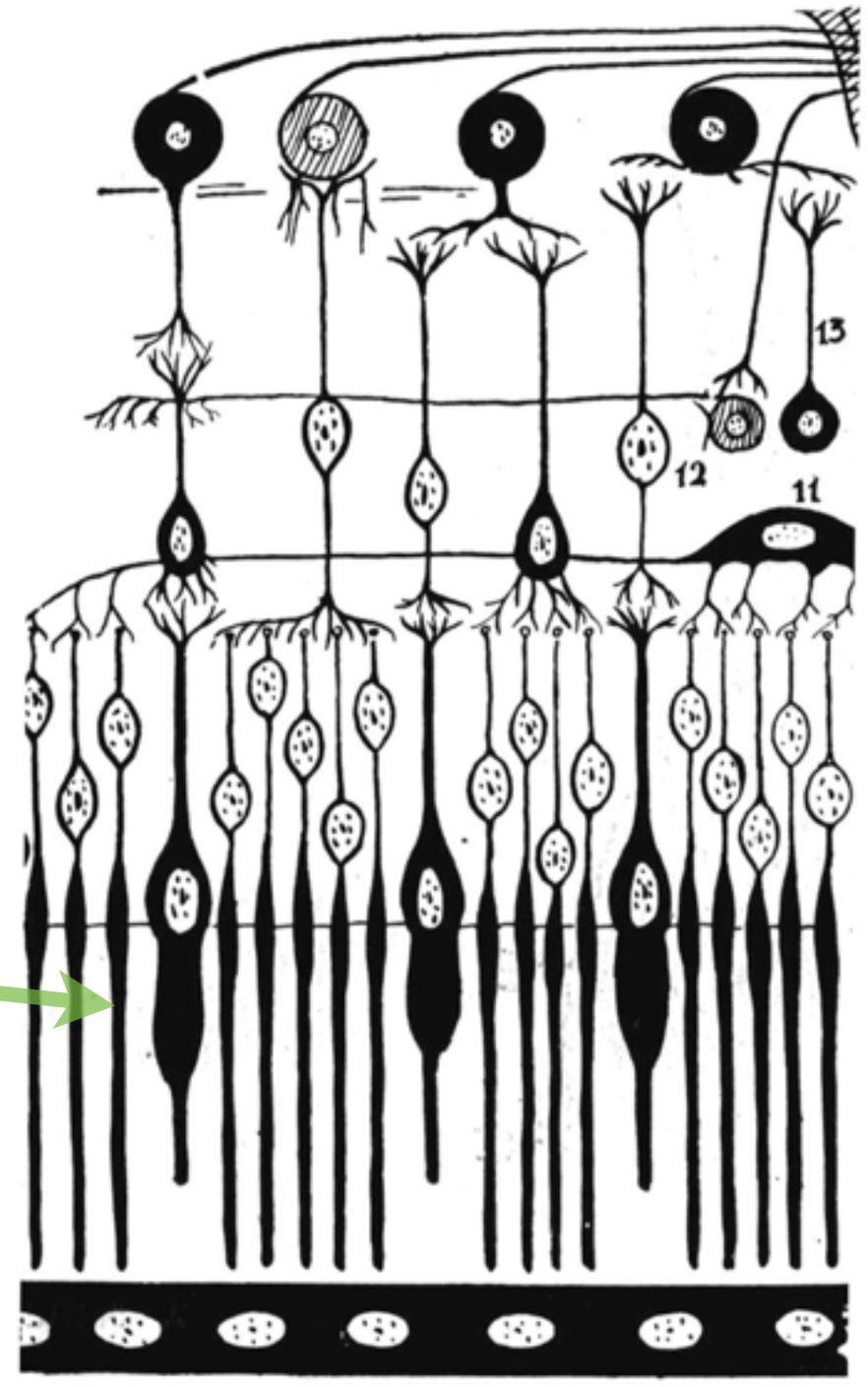


Eye and retina

Outer nuclear layer



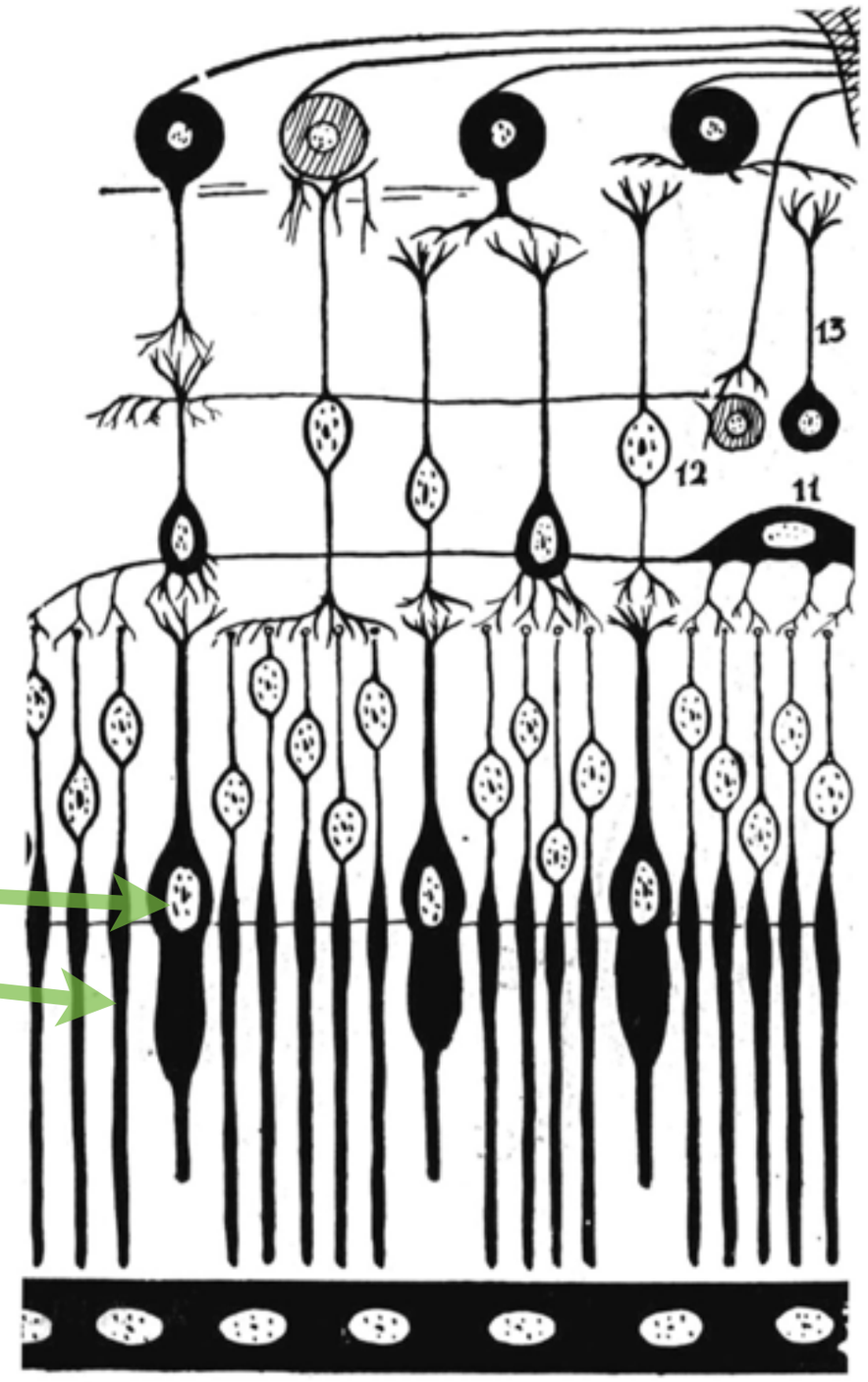
Eye and retina



Outer nuclear layer

Rods

Eye and retina



Outer nuclear layer

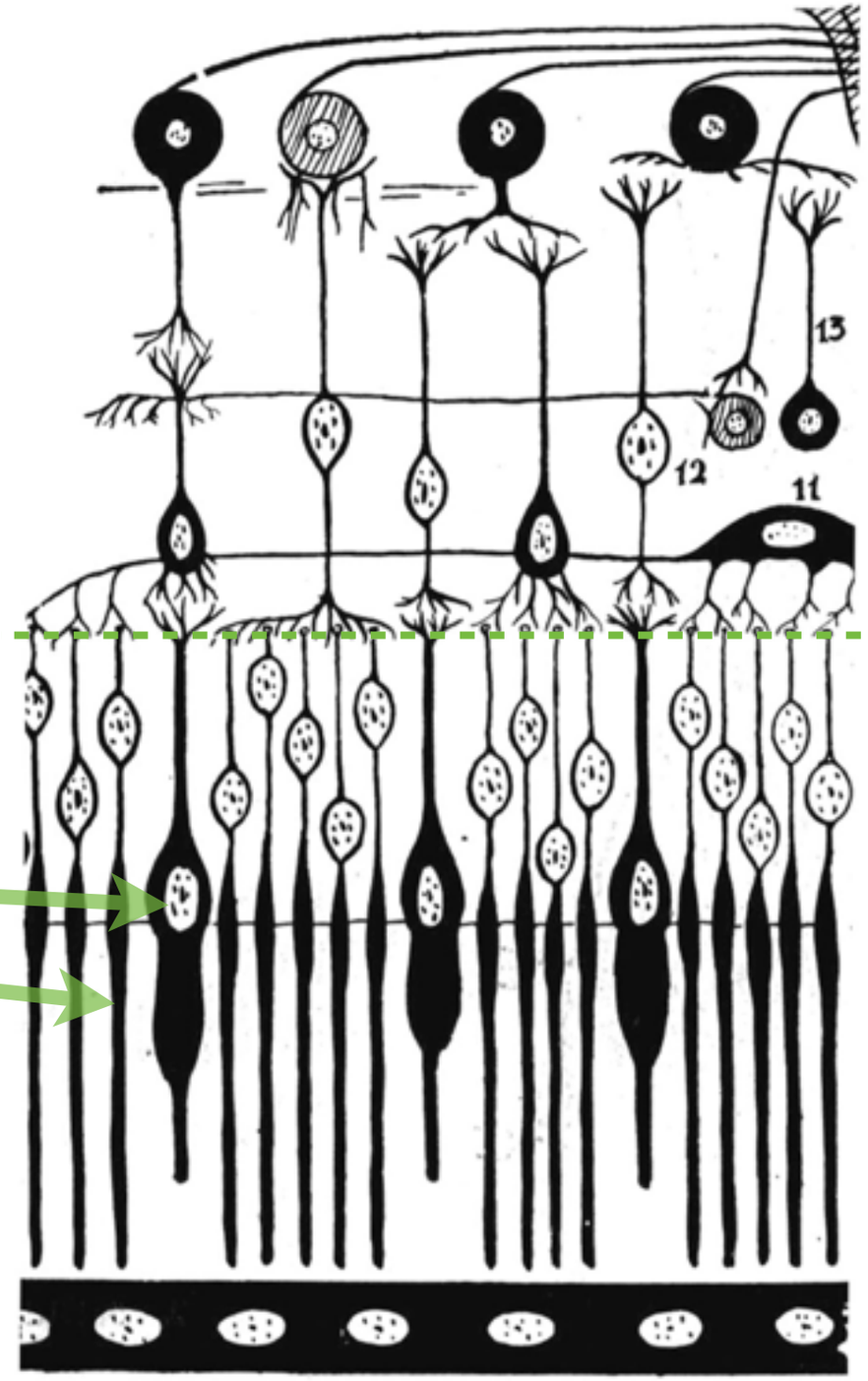
Cones

Rods

Eye and retina

Inner nuclear layer

Outer nuclear layer



Eye and retina

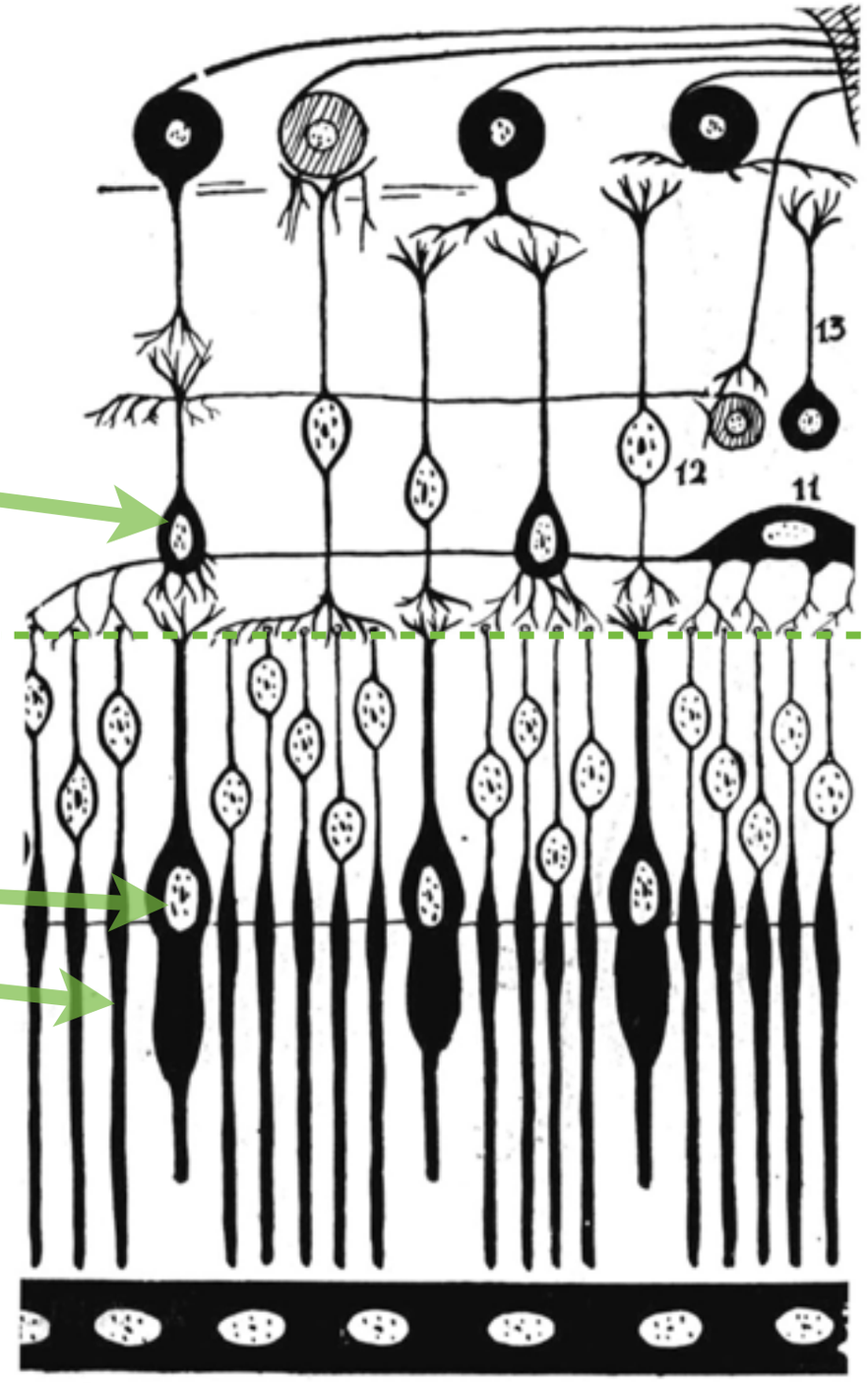
Inner nuclear layer

Bipolar

Outer nuclear layer

Cones

Rods



Eye and retina

Inner nuclear layer

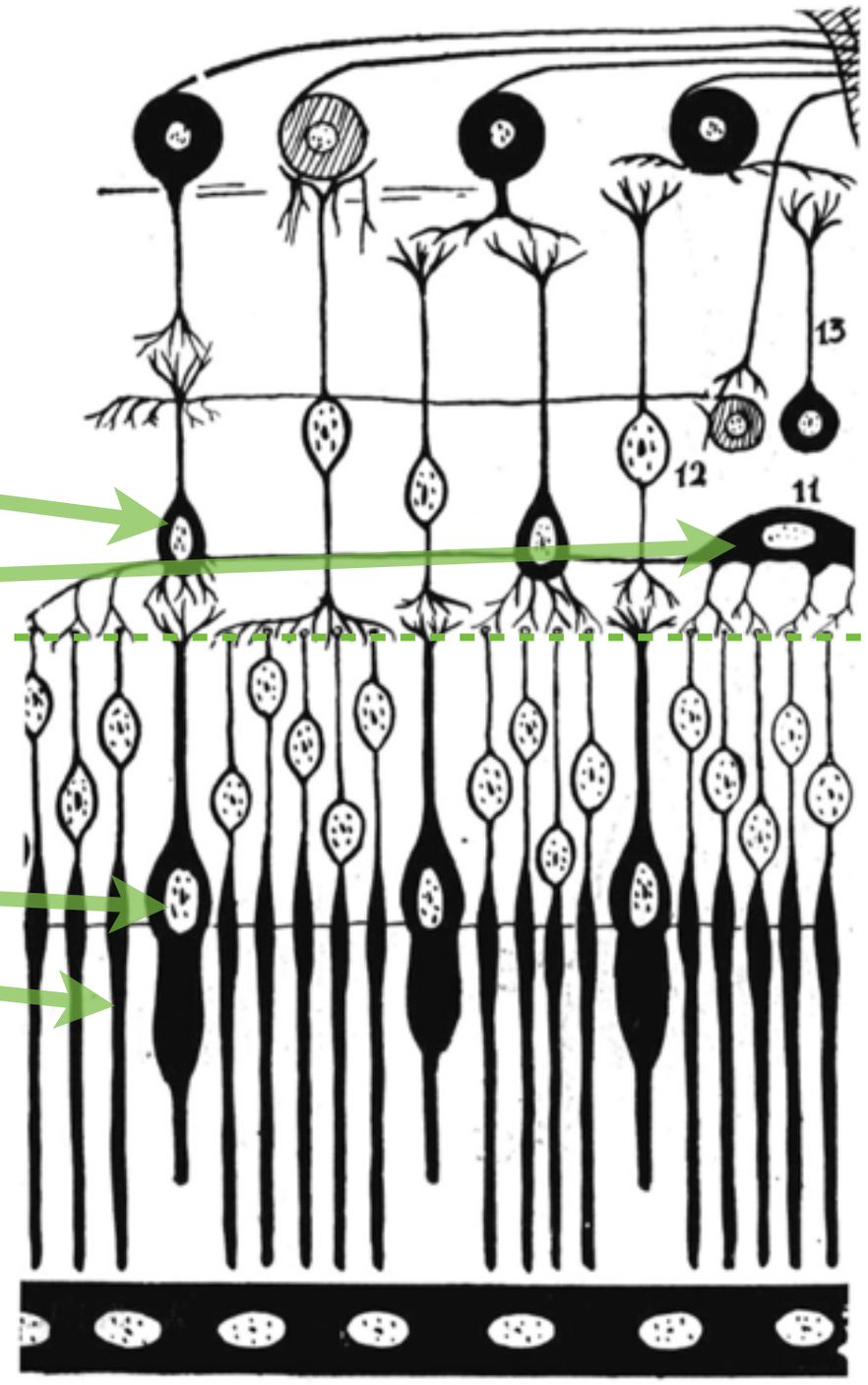
Bipolar

Horizontal

Outer nuclear layer

Cones

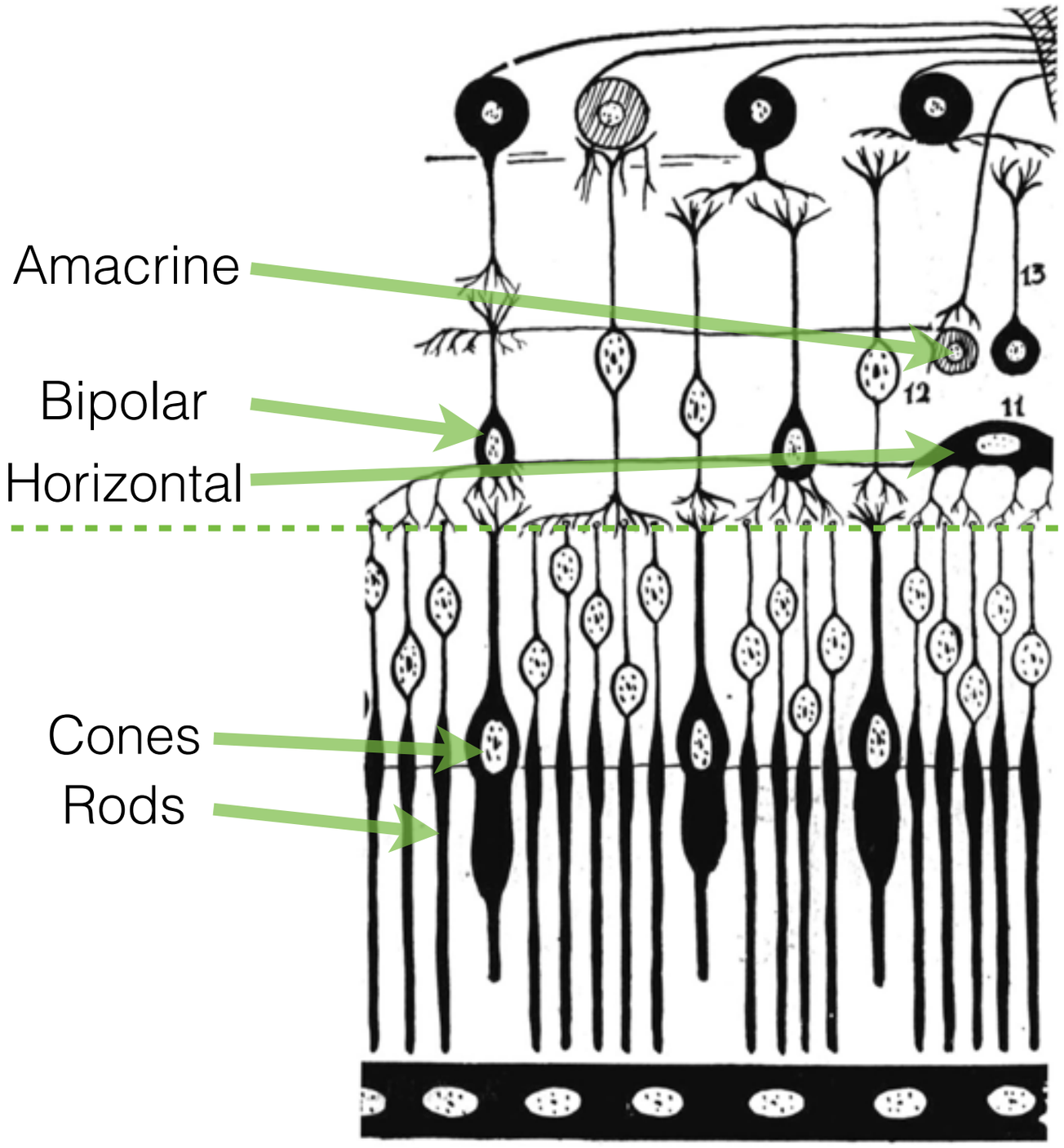
Rods



Eye and retina

Inner nuclear layer

Outer nuclear layer

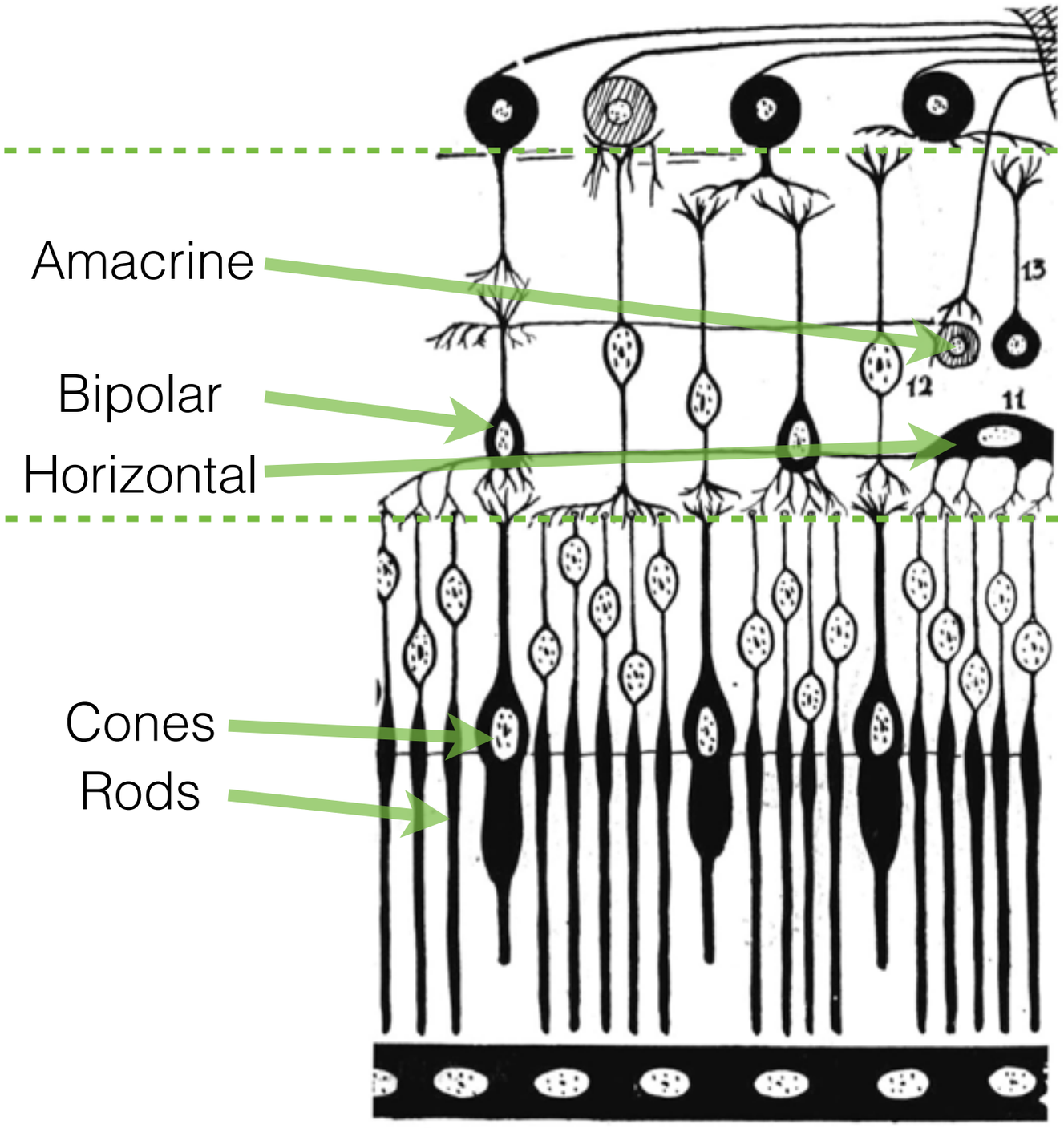


Eye and retina

Ganglion cell layer

Inner nuclear layer

Outer nuclear layer

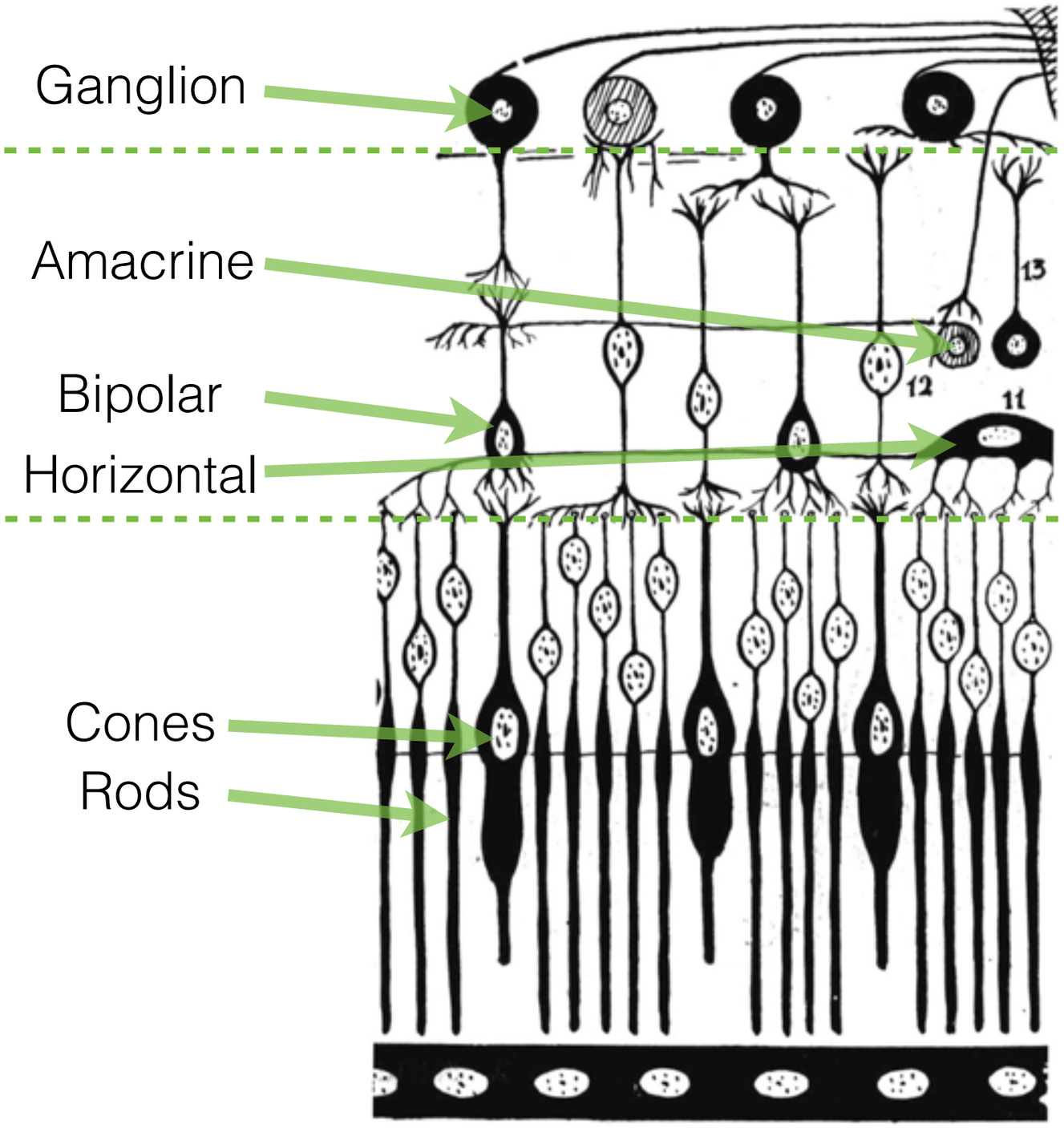


Eye and retina

Ganglion cell layer

Inner nuclear layer

Outer nuclear layer

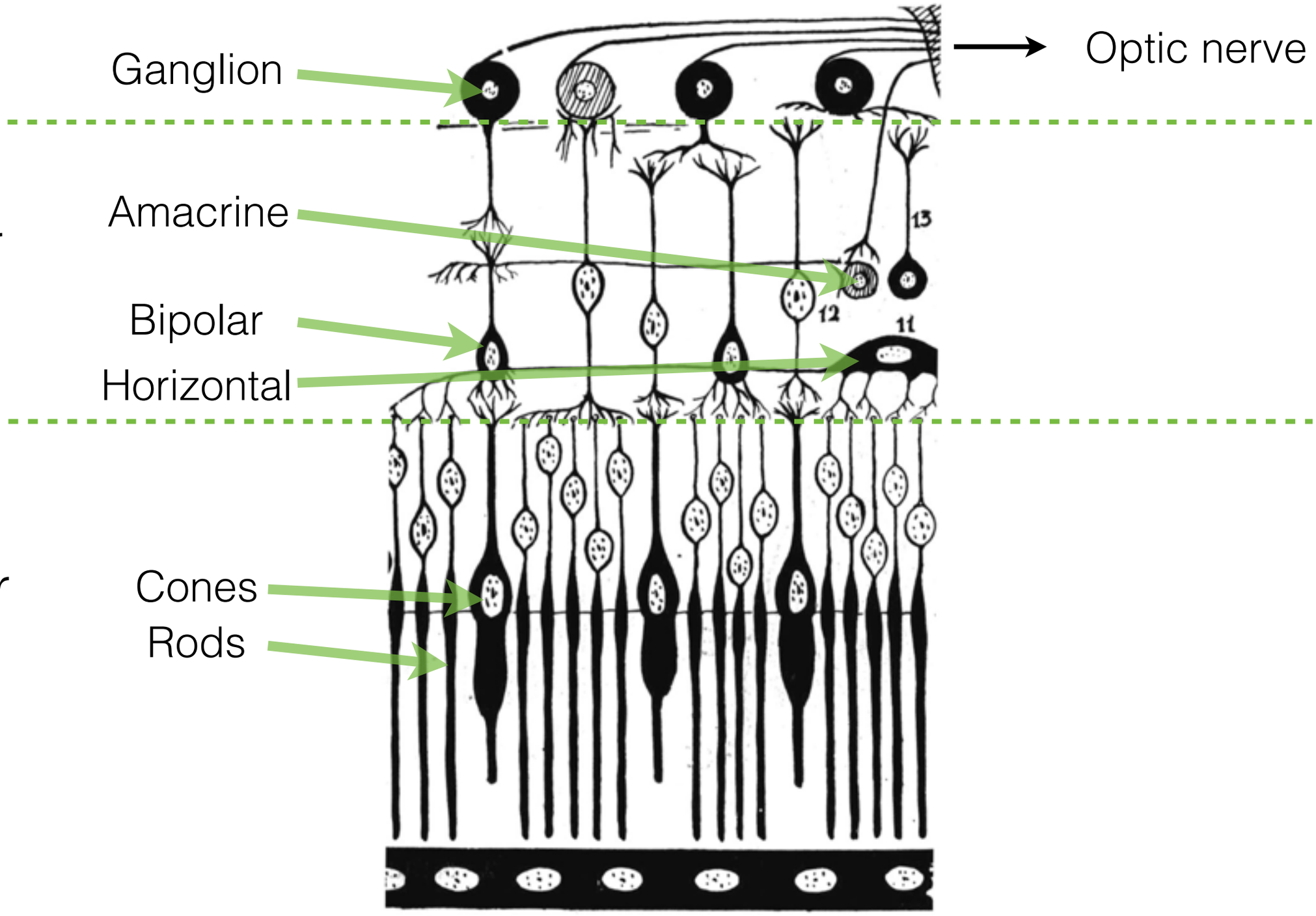


Eye and retina

Ganglion cell layer

Inner nuclear layer

Outer nuclear layer

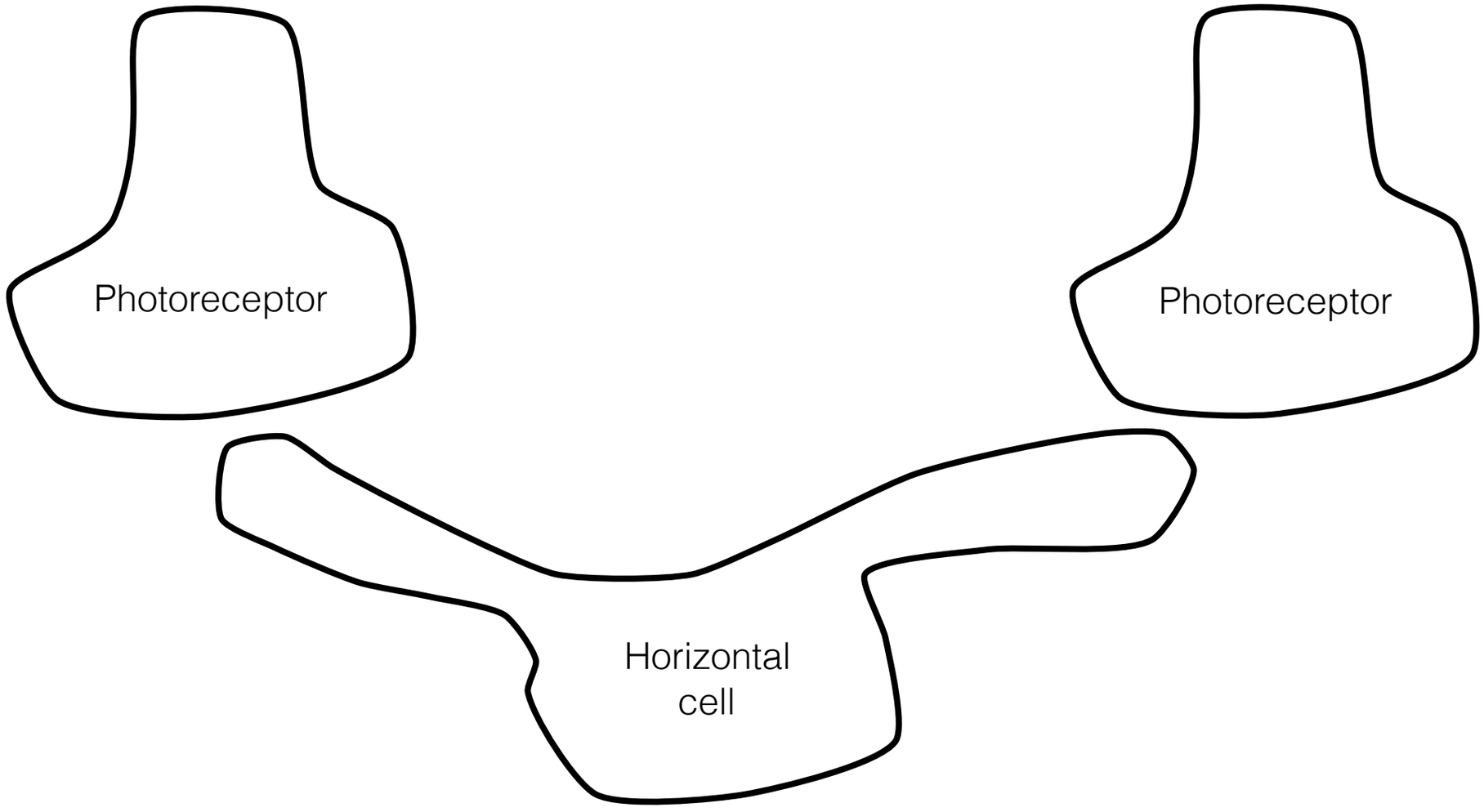


What does the retina *do*?

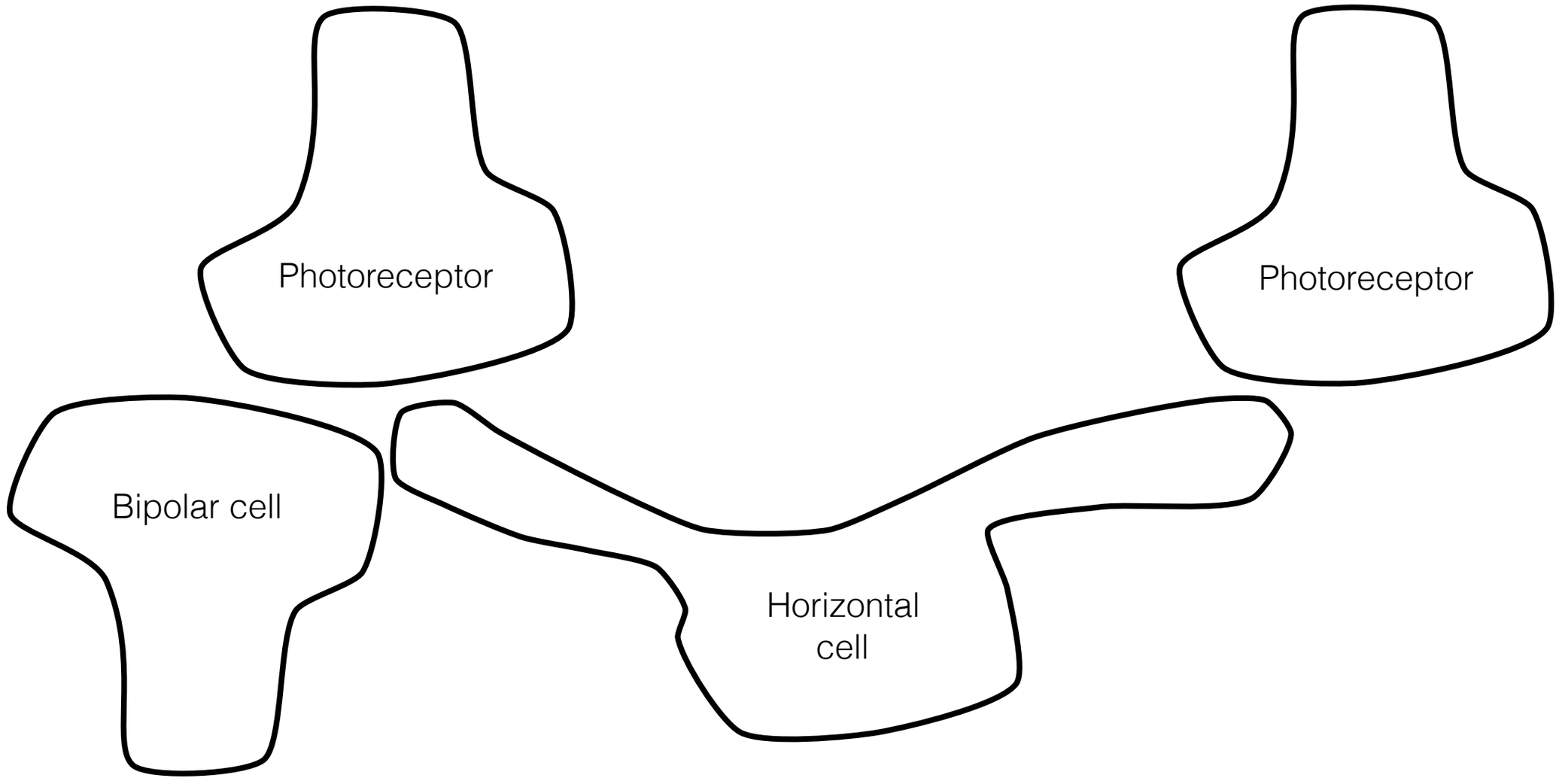
Functional organization of the retina

Functional organization of the retina

Functional organization of the retina



Functional organization of the retina



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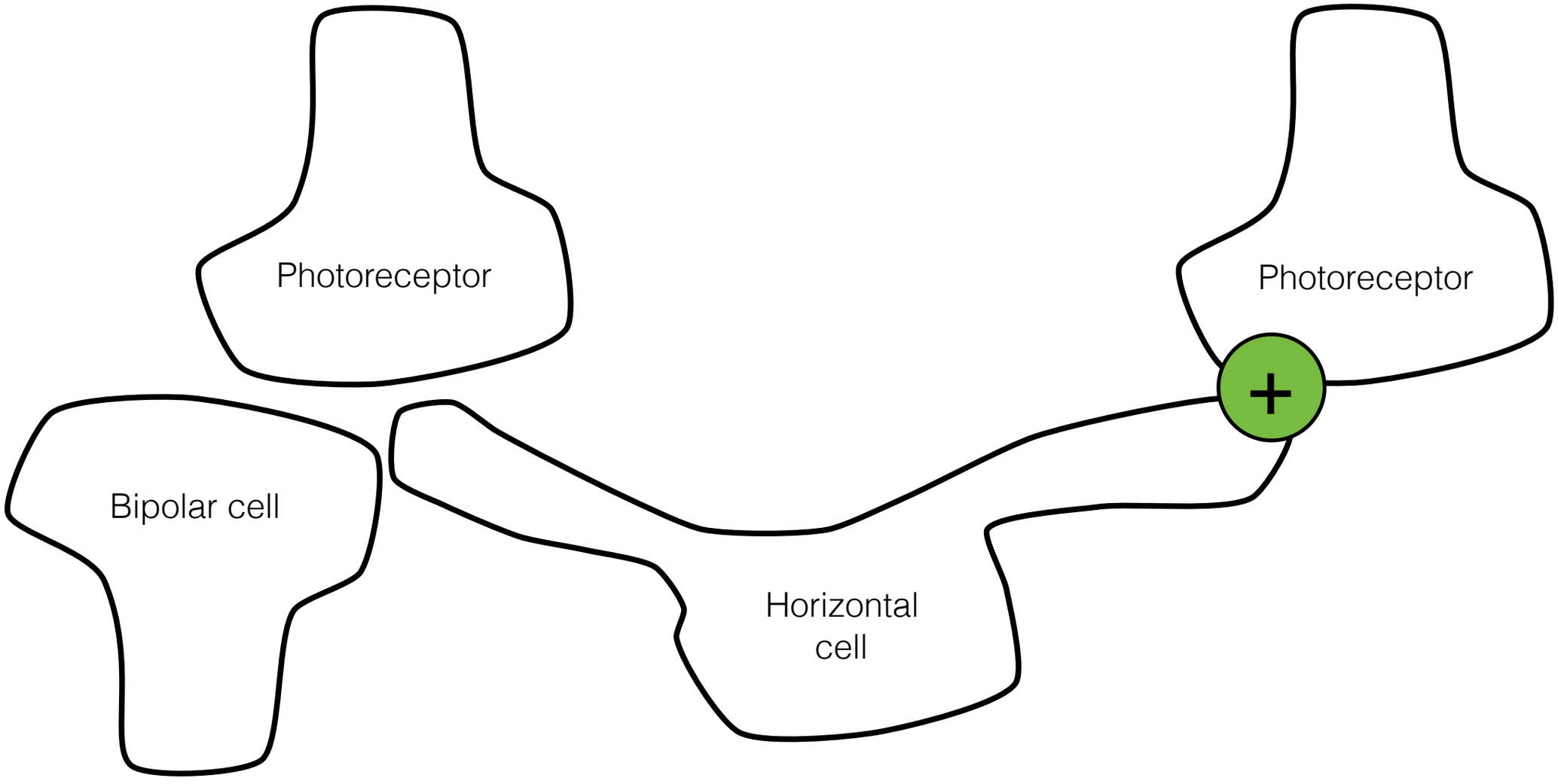

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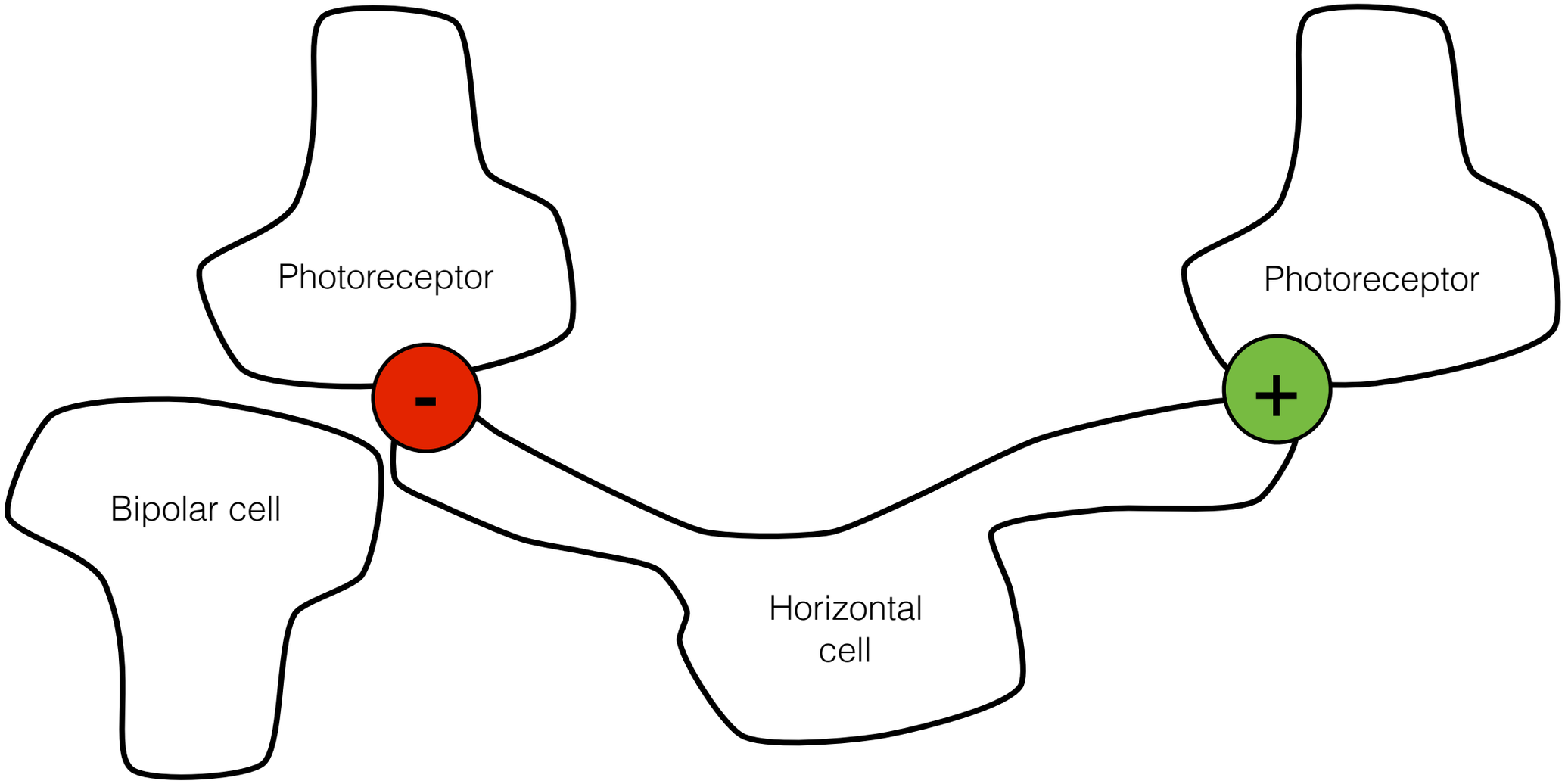
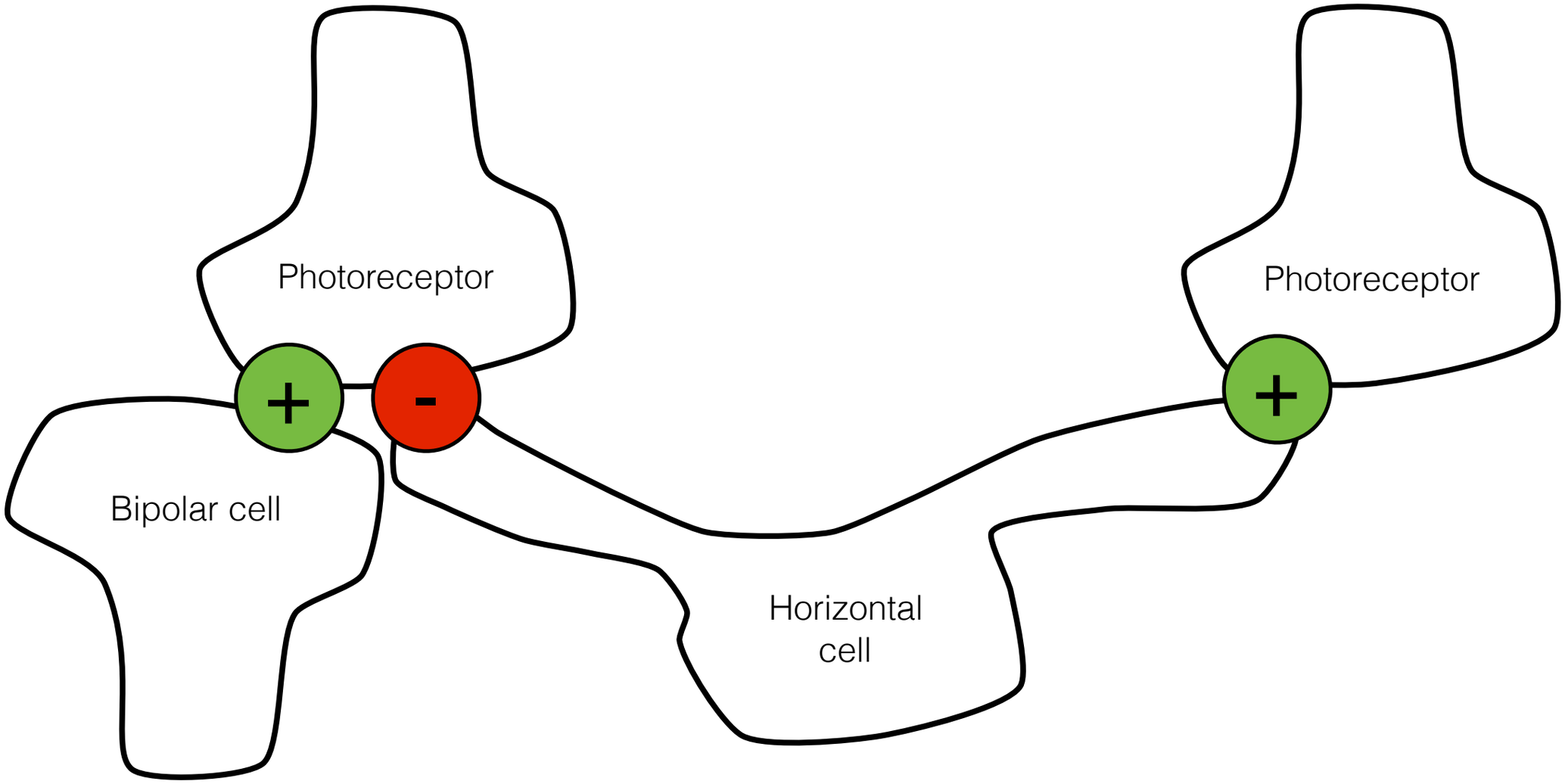
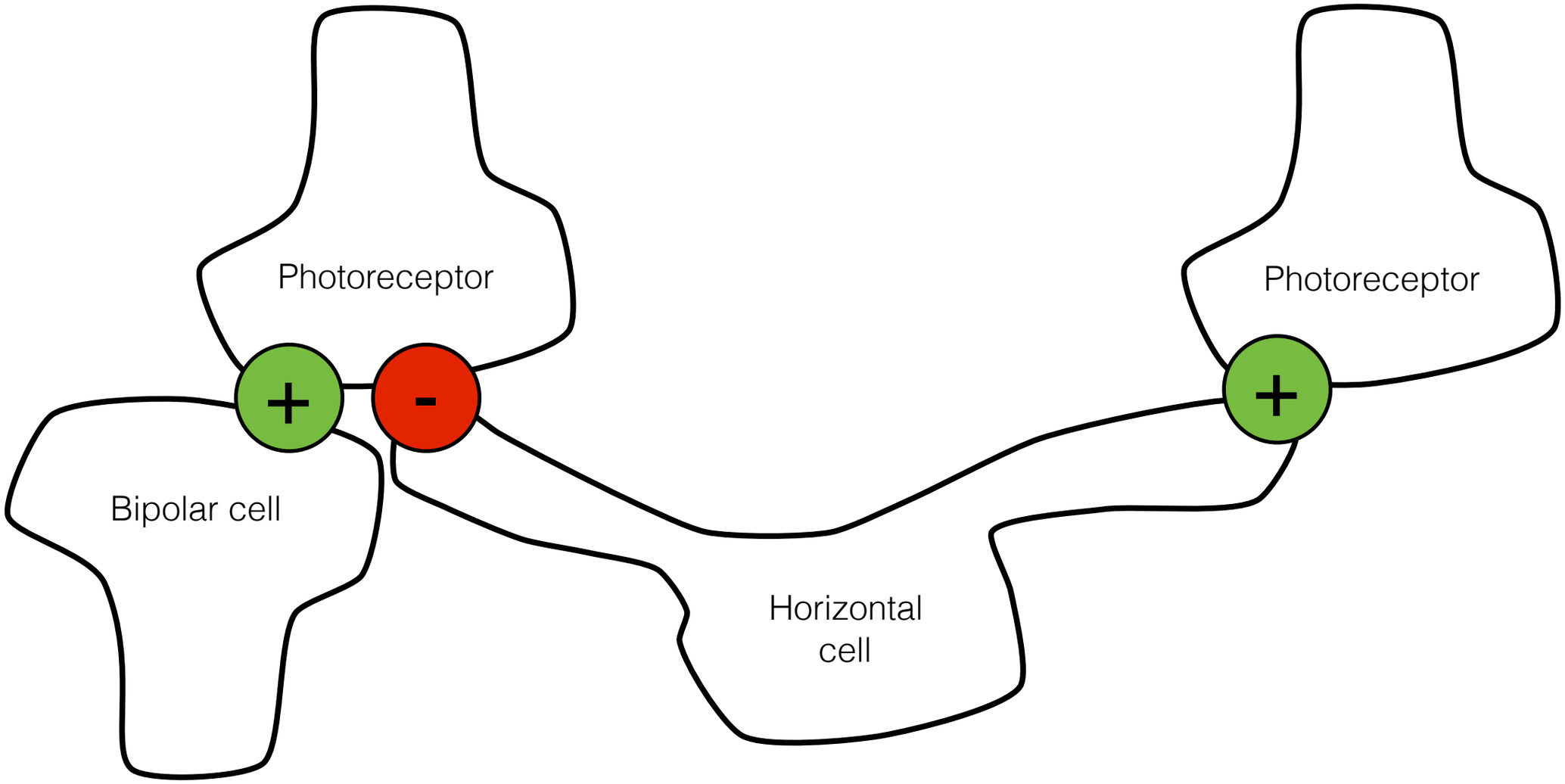


Functional organization of the retina

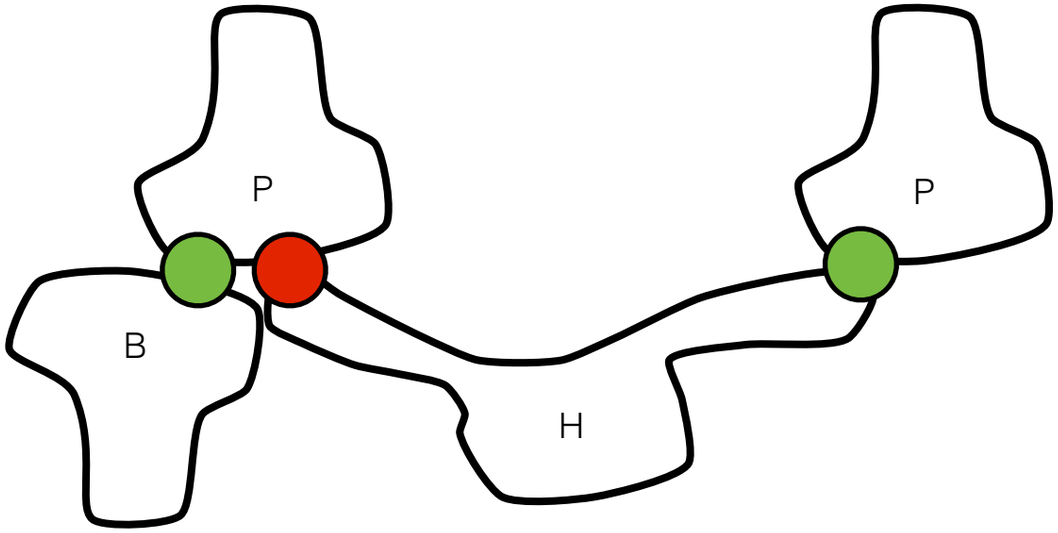


Functional organization of the retina

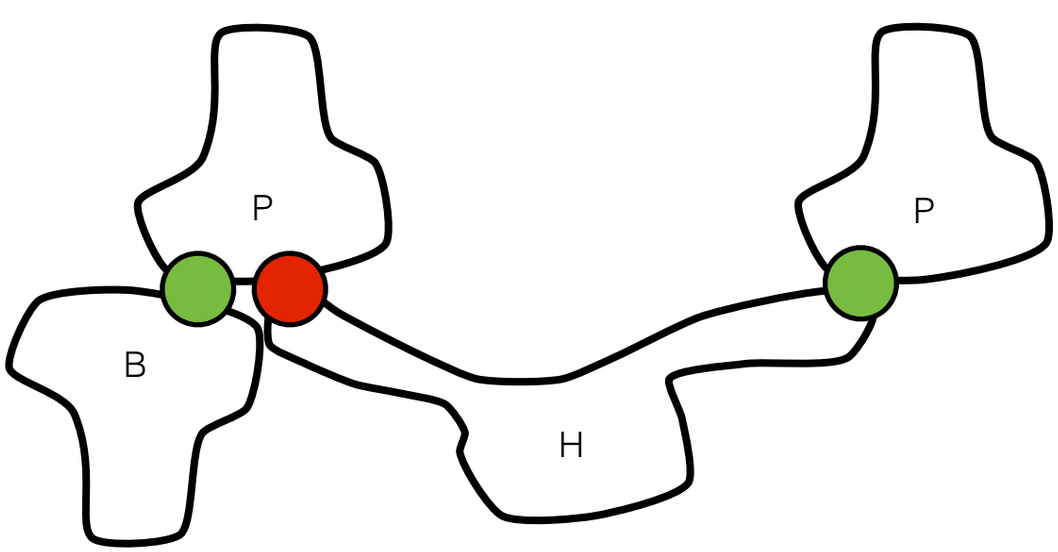


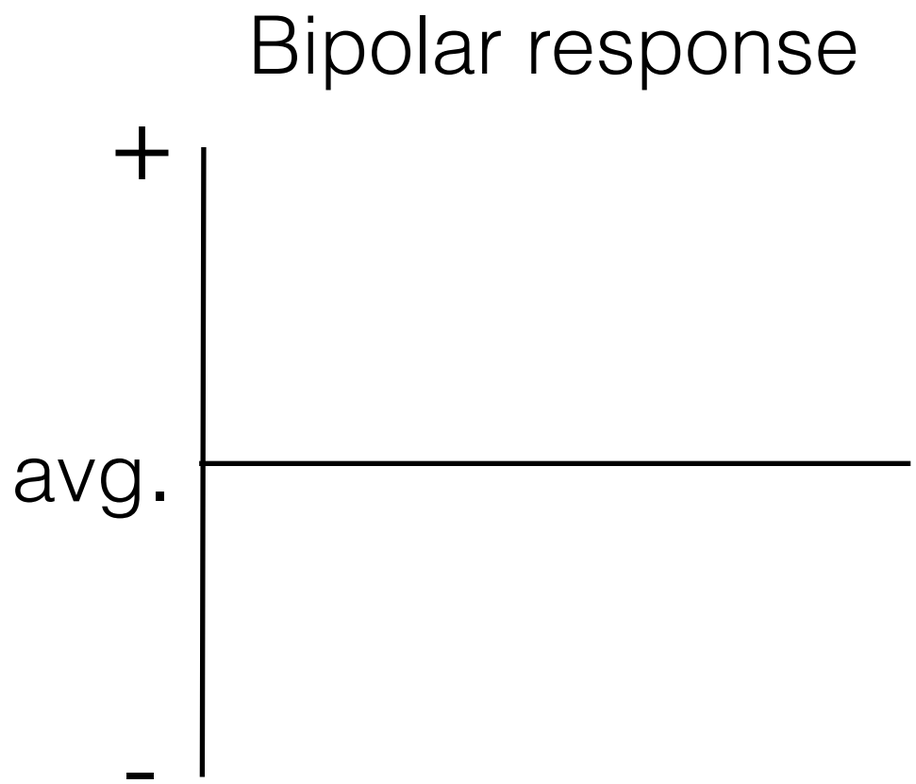
Lateral inhibition

Functional organization of the retina

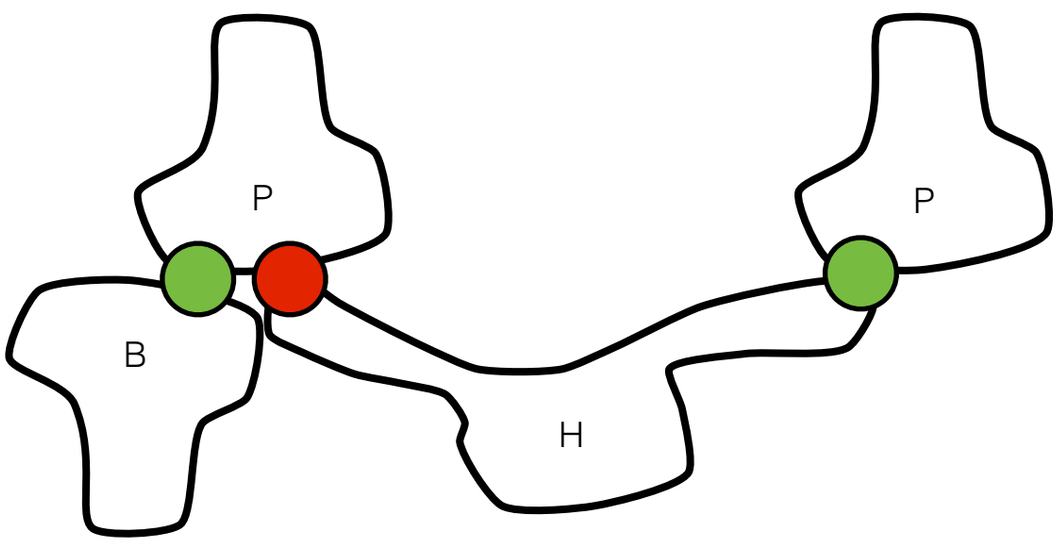


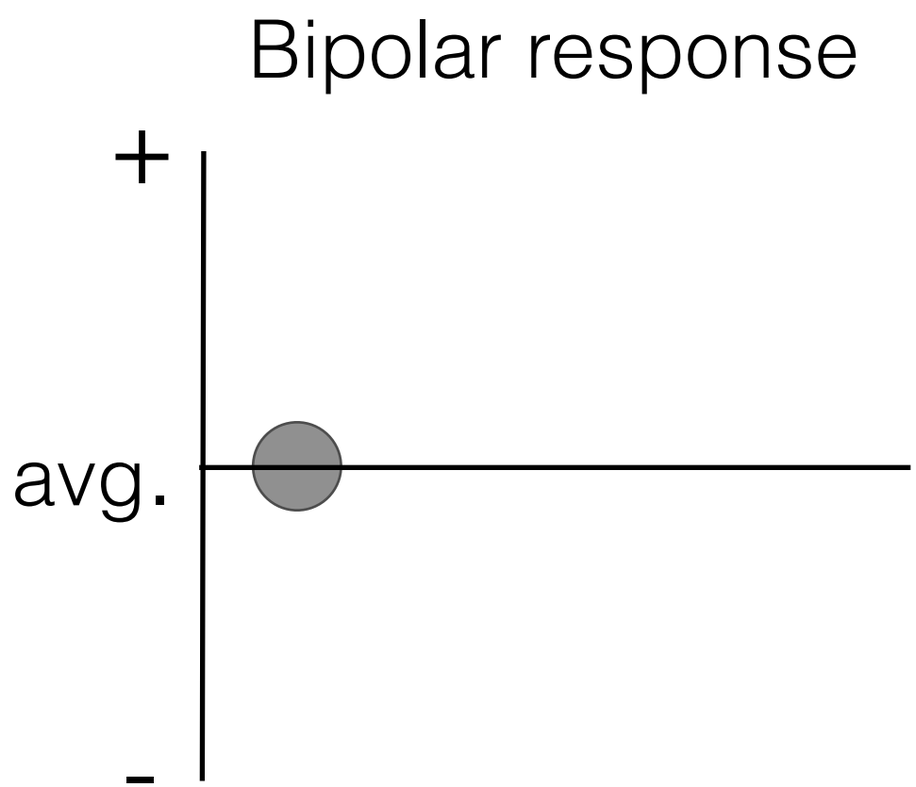
Functional organization of the retina





Functional organization of the retina





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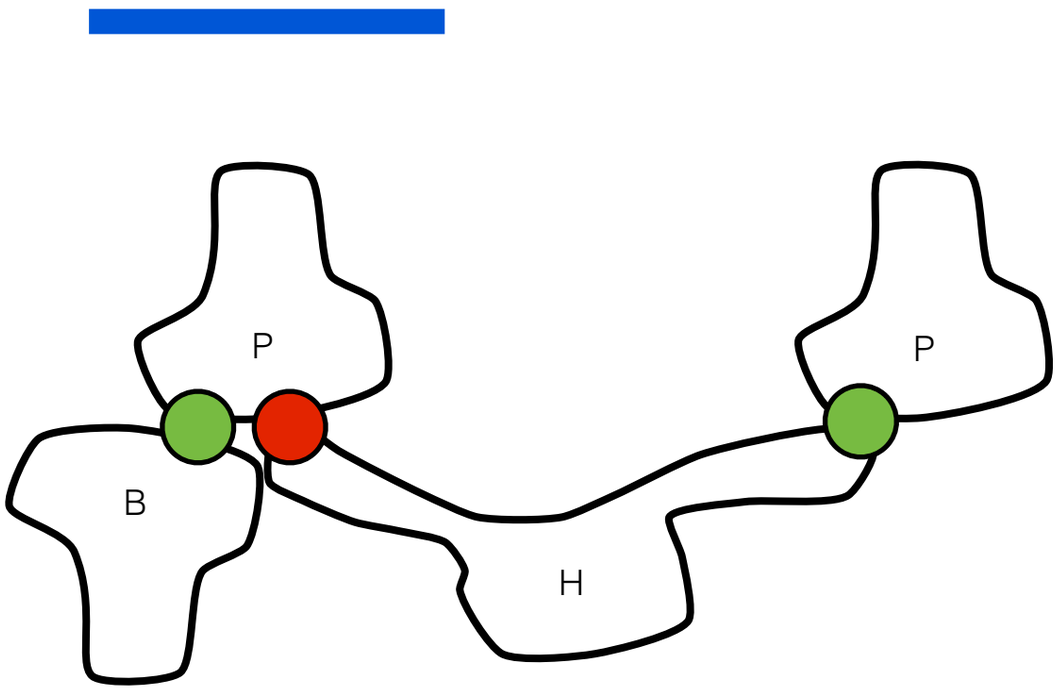

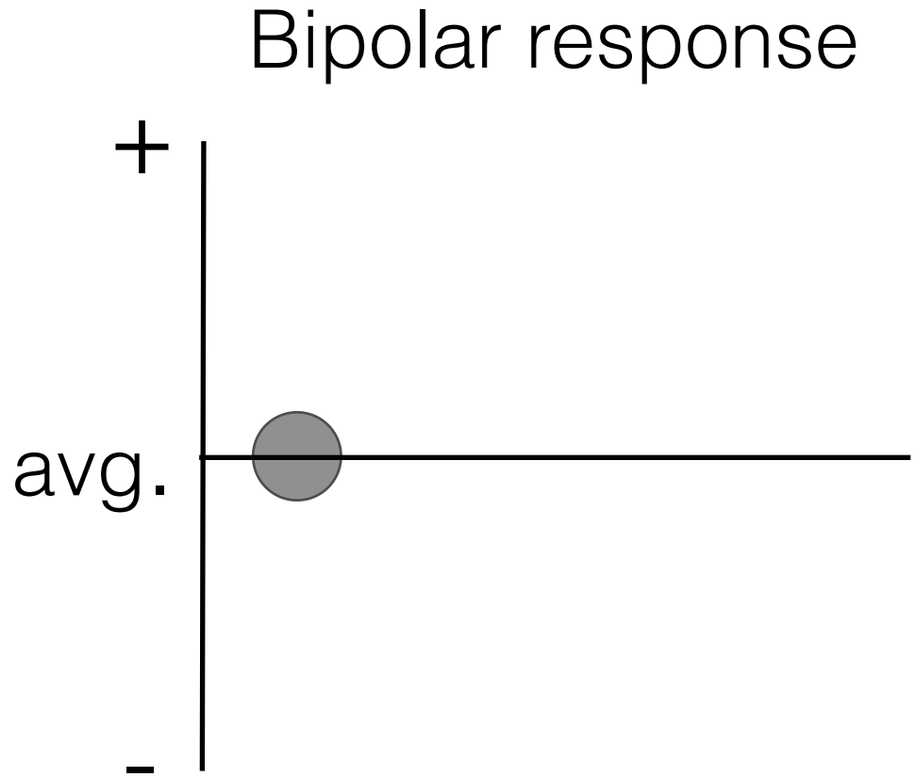

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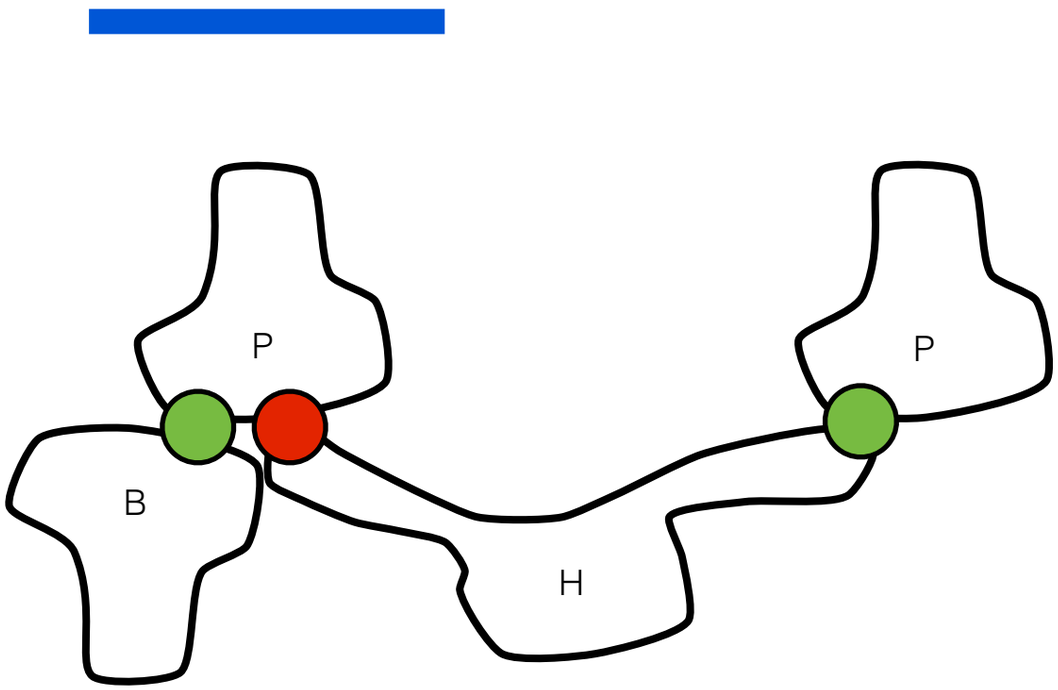
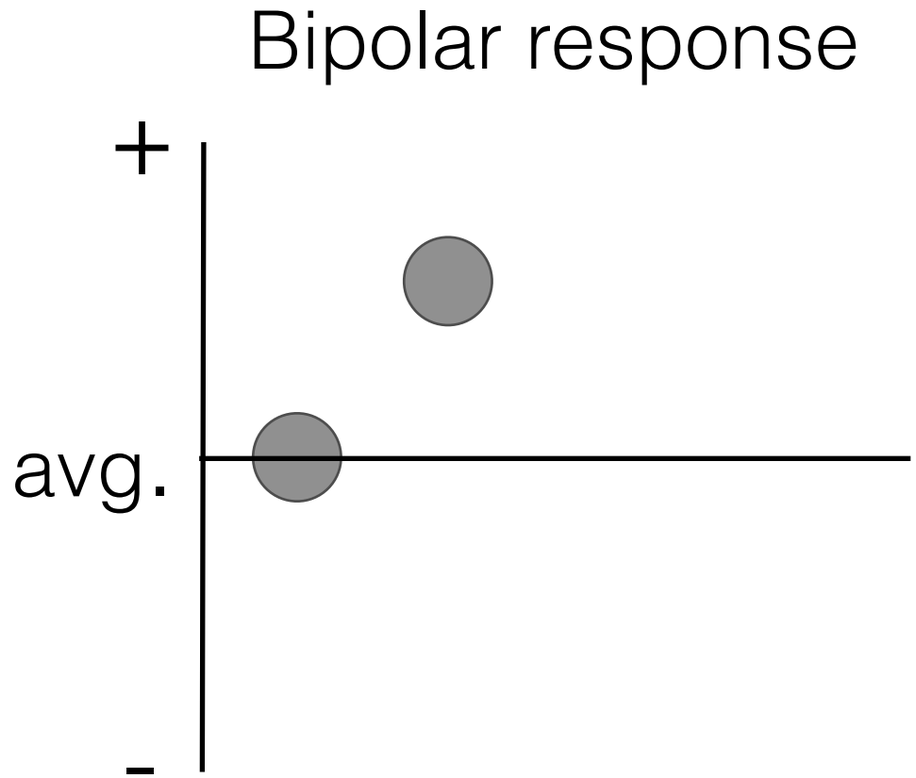
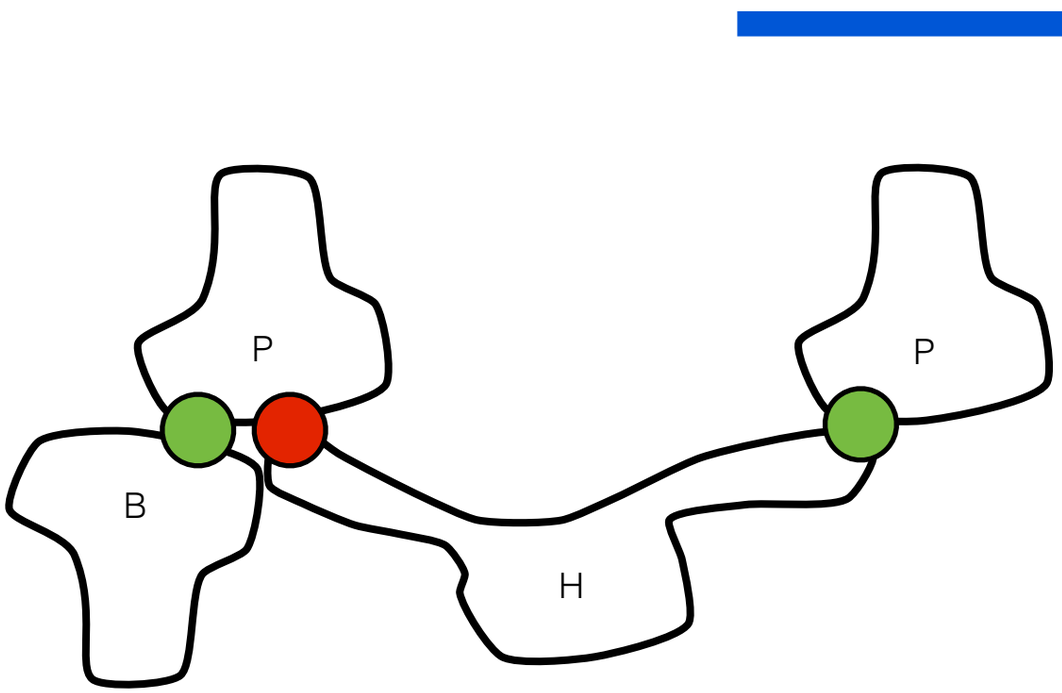
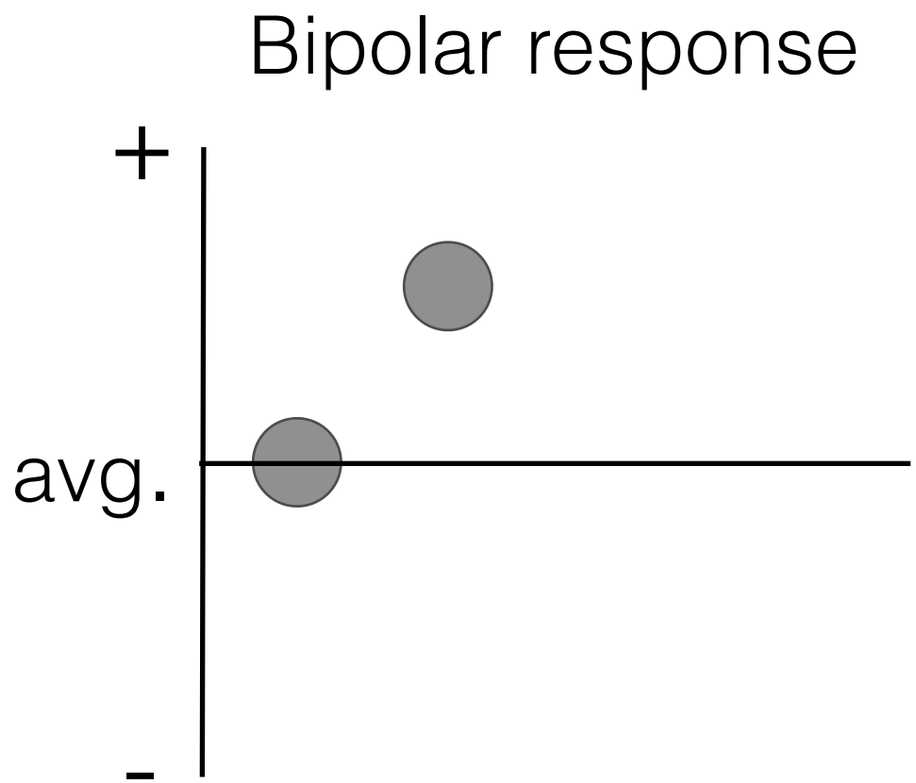




Functional organization of the retina





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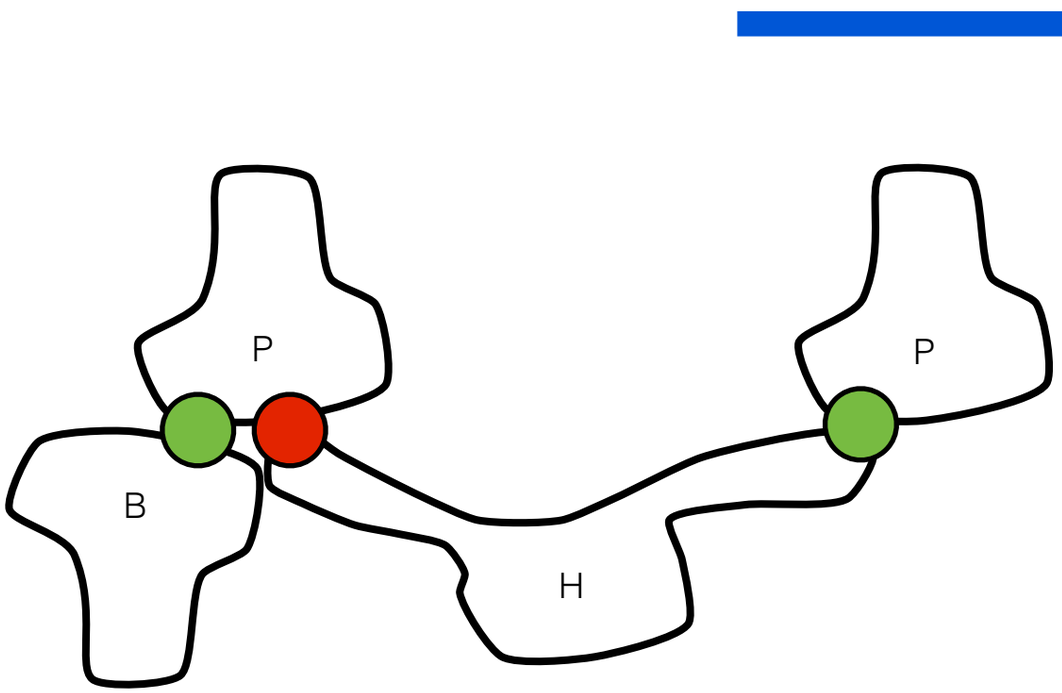
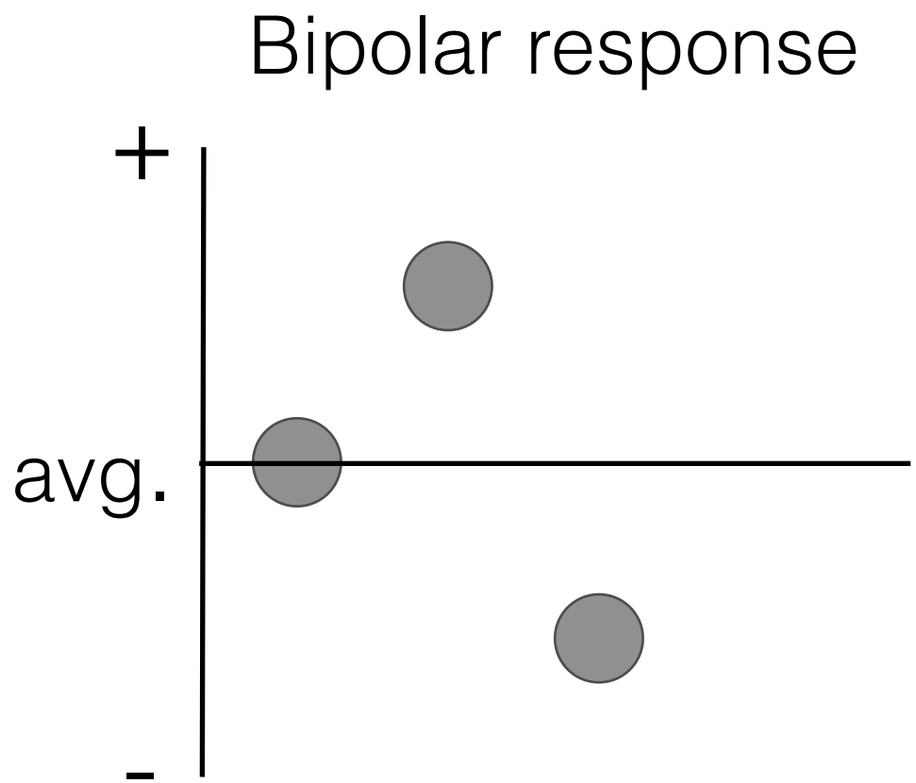
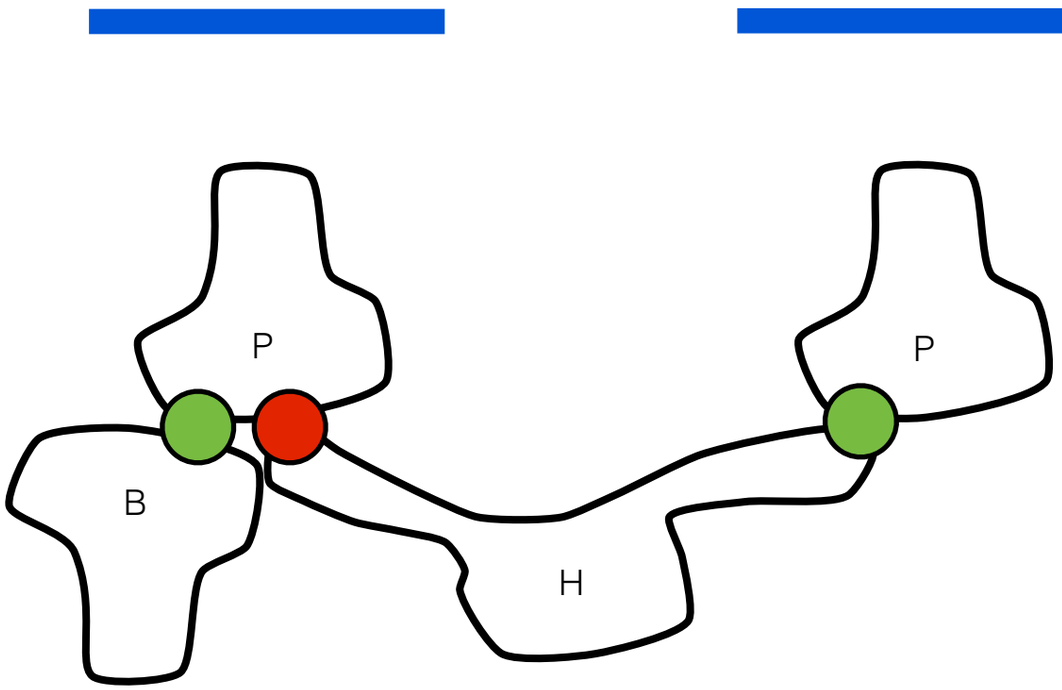
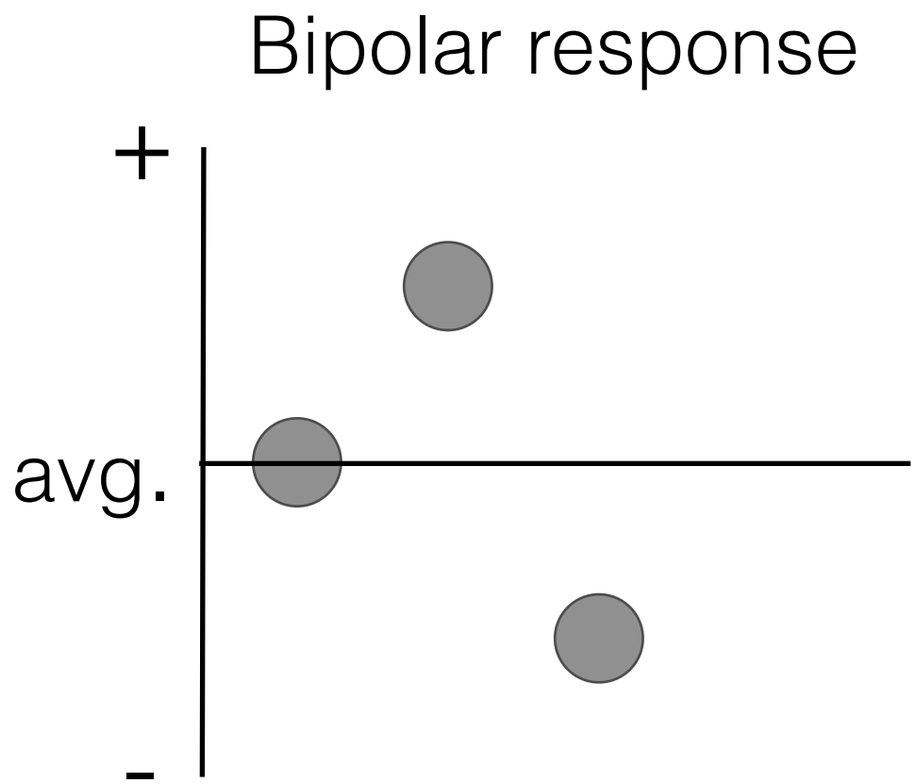




Functional organization of the retina





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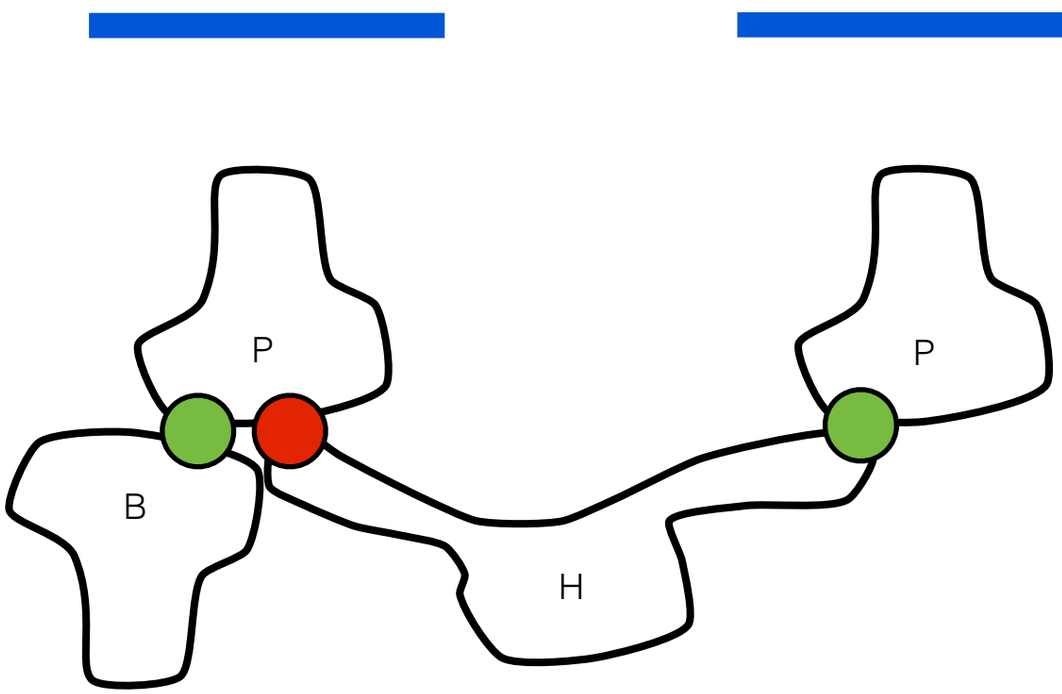

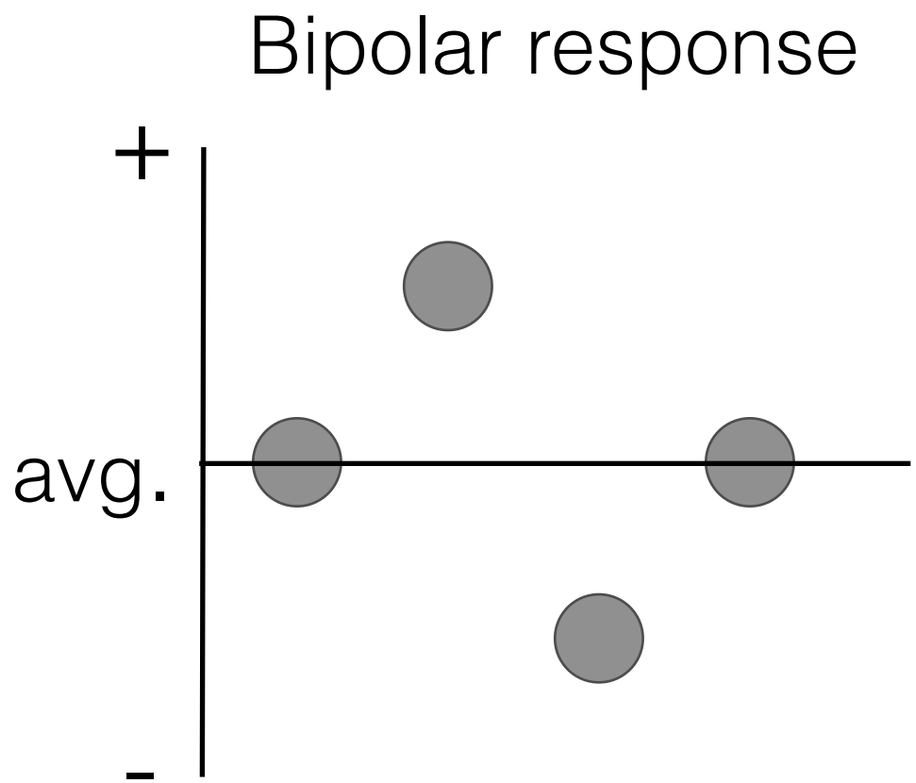

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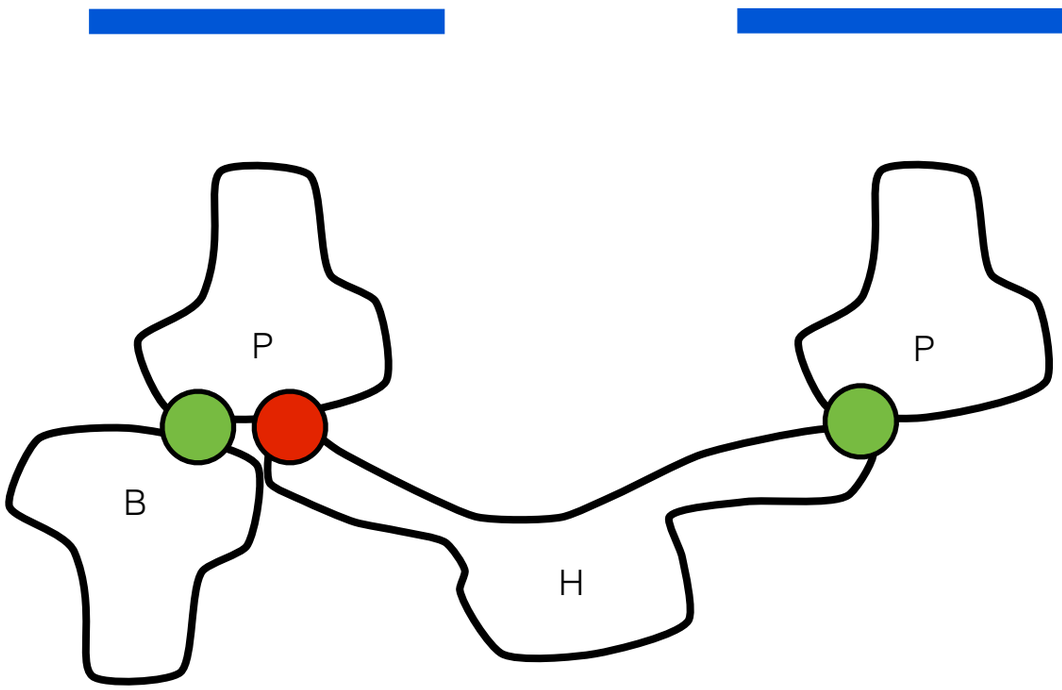
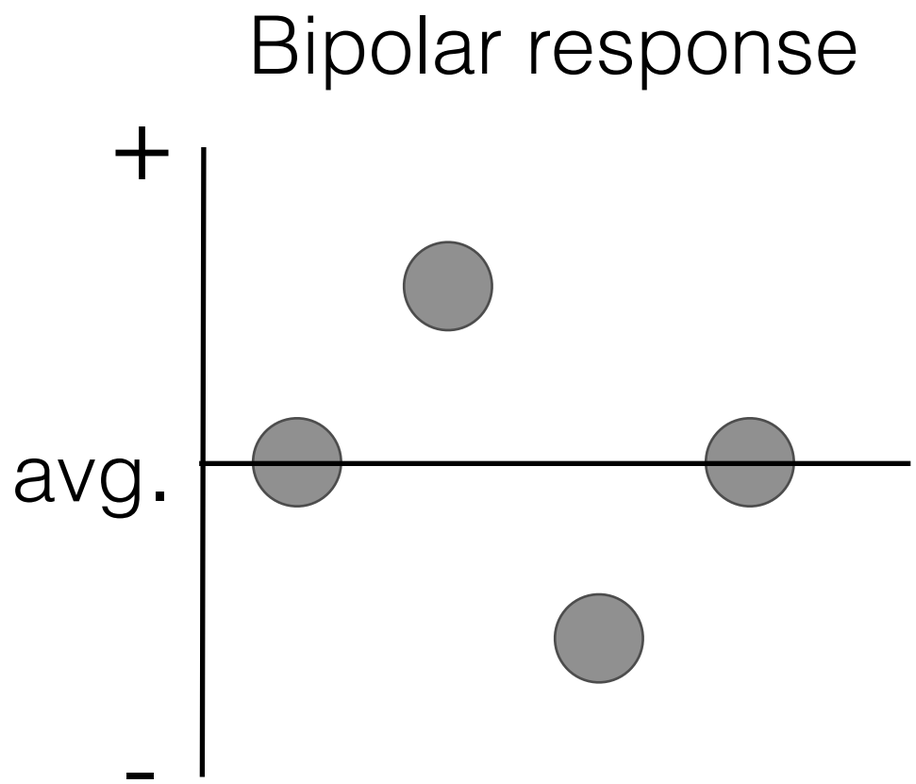
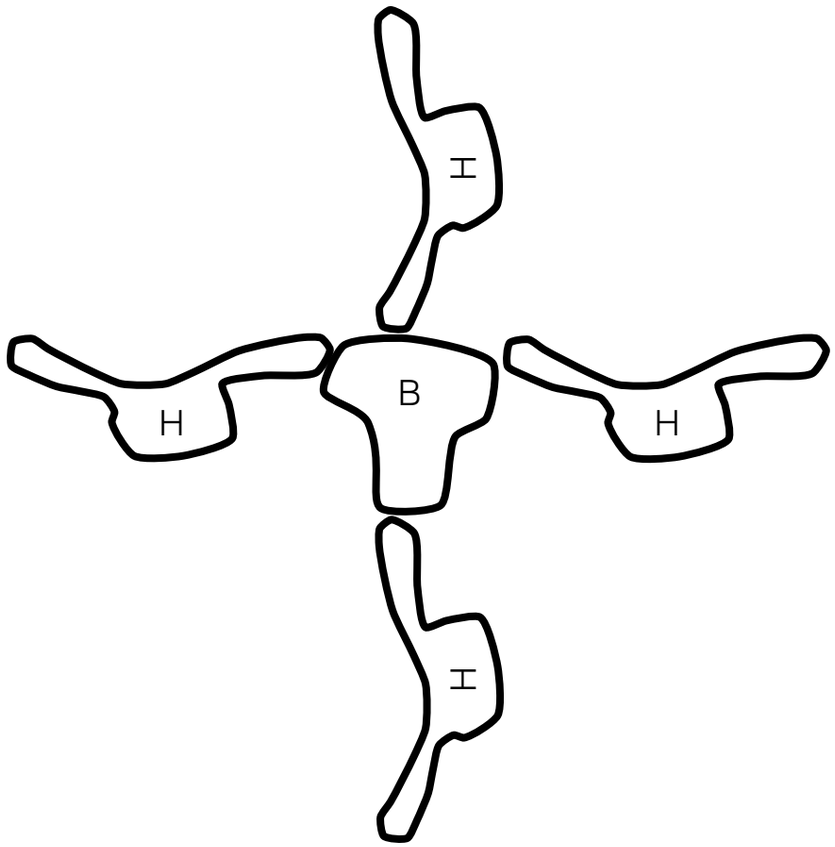




Signals *differences* in light

Functional organization of the retina

Functional organization of the retina



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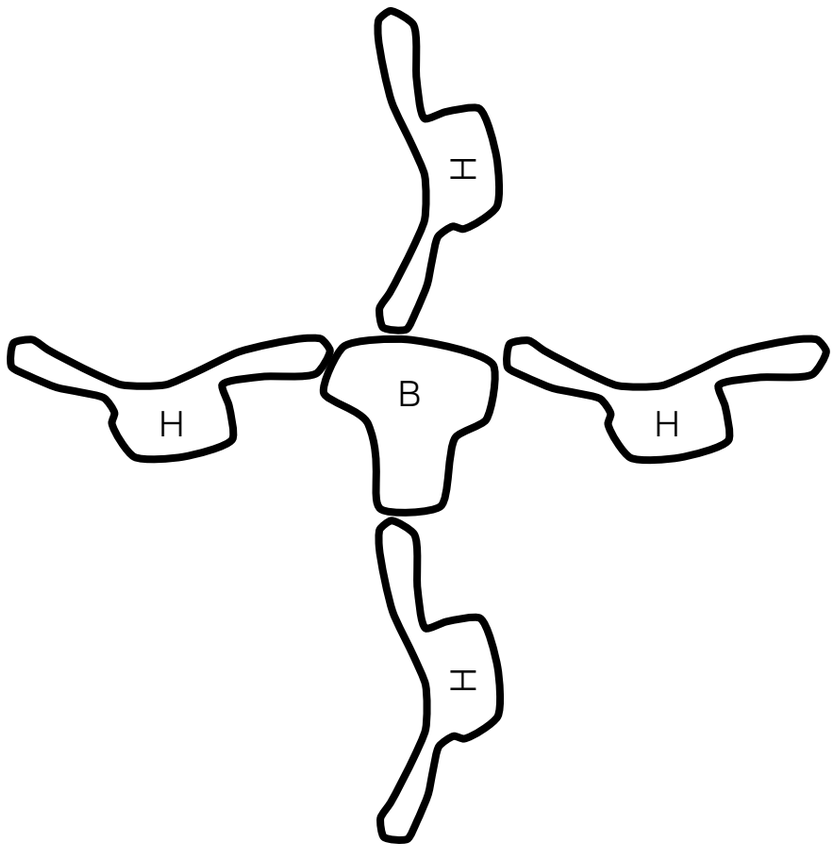
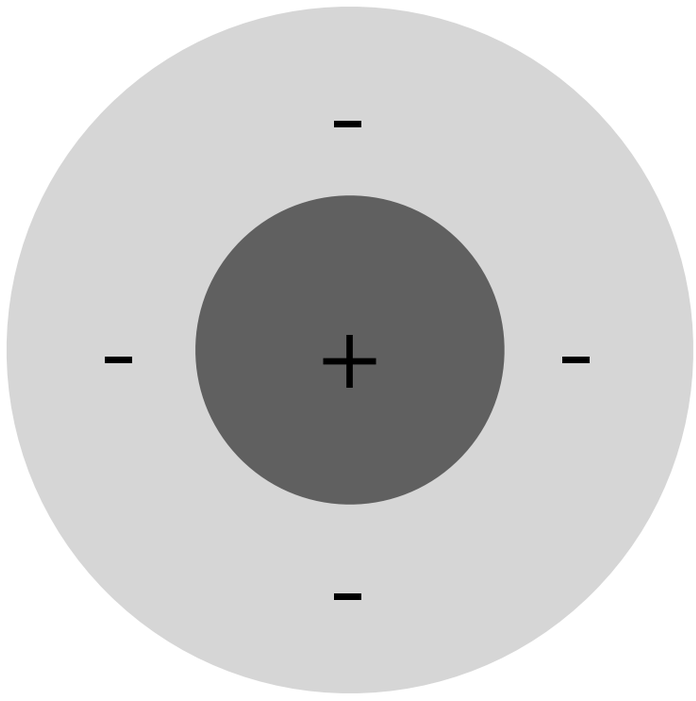
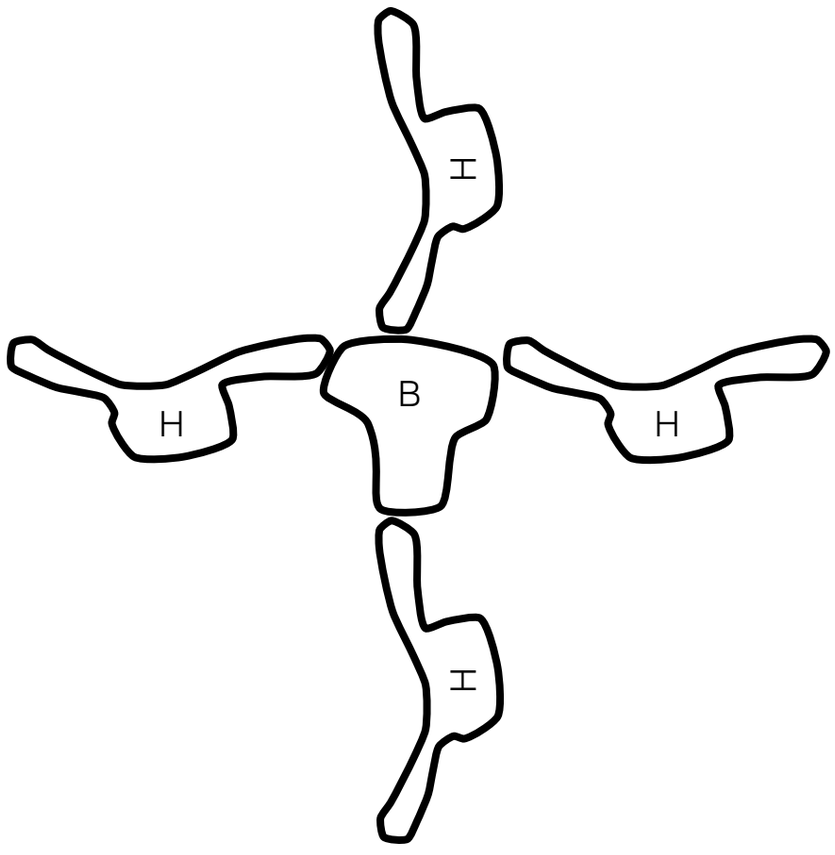
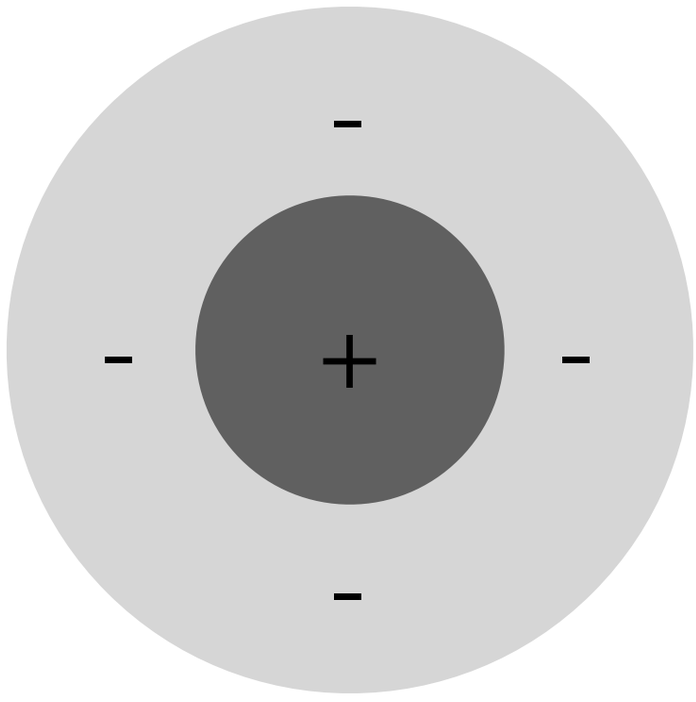




Functional organization of the retina





Center-surround receptive field

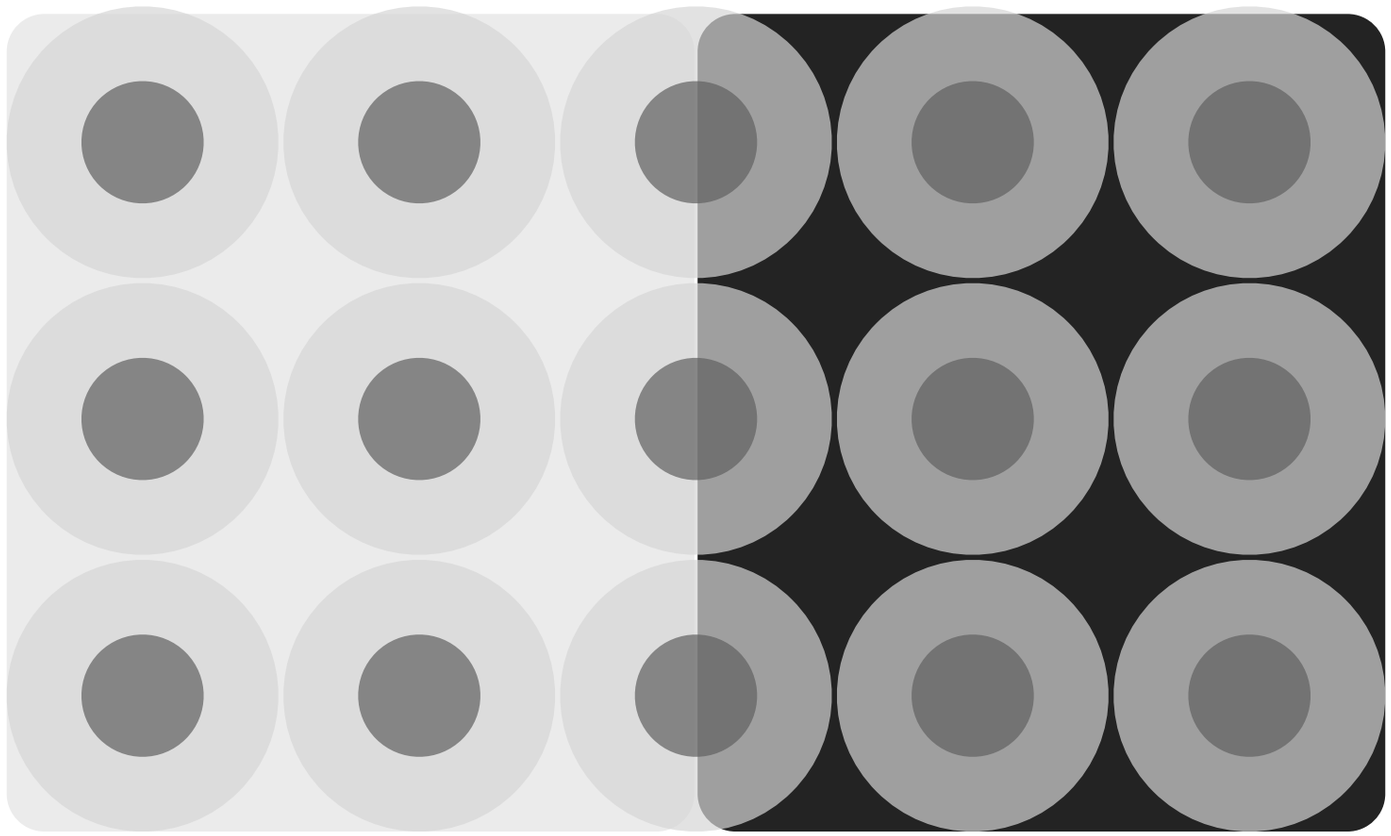
Center-surround receptive fields

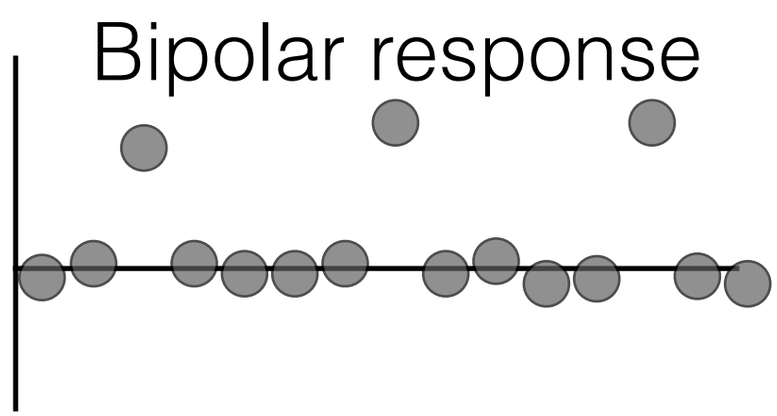
Center-surround receptive fields

Center-surround receptive fields

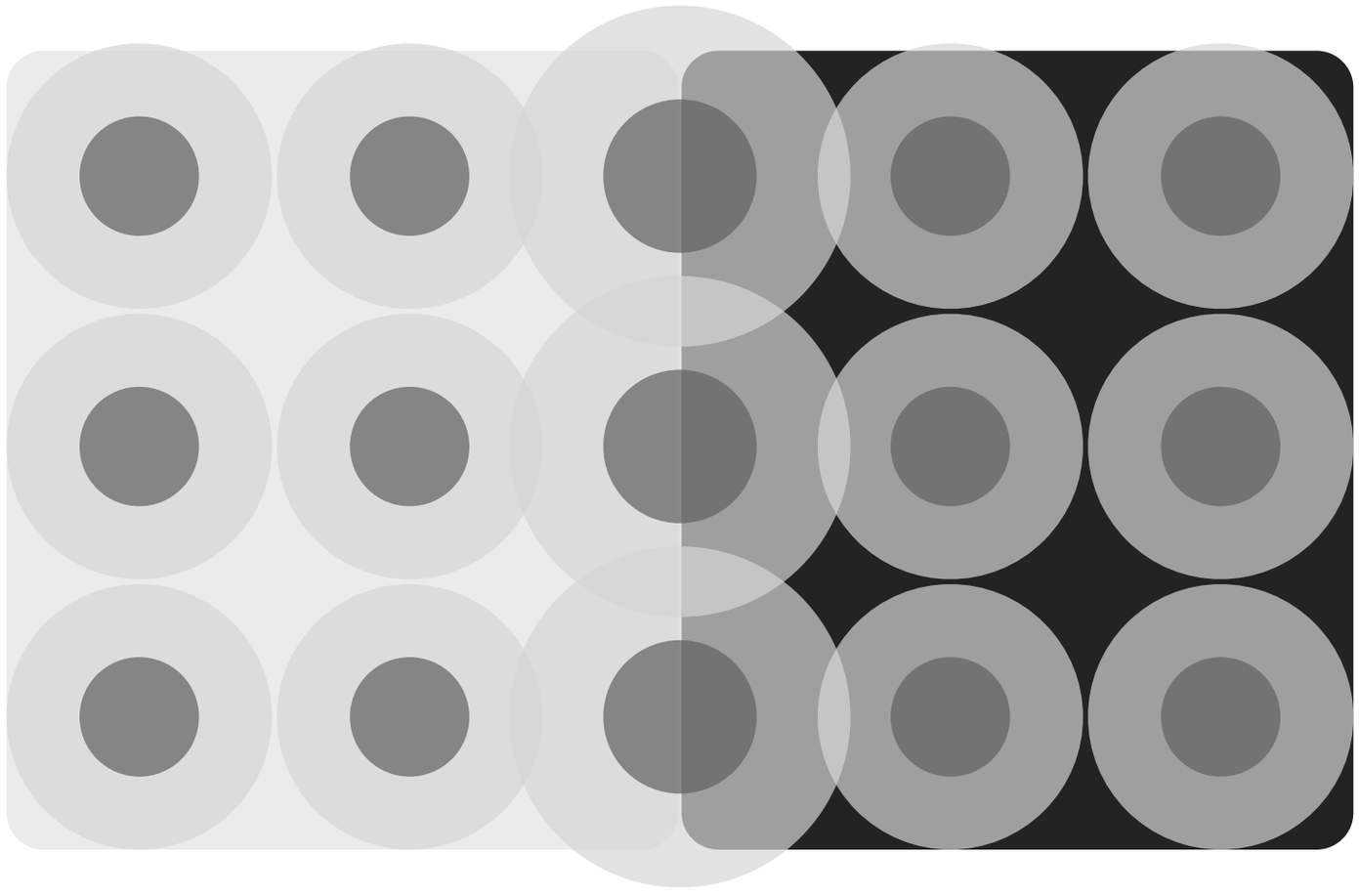
Bipolar response

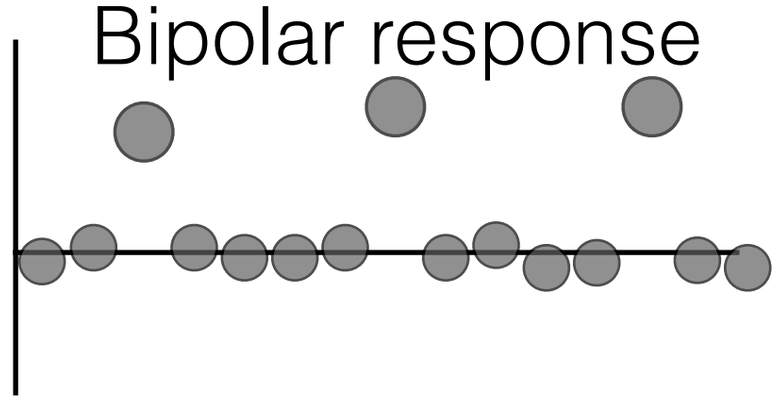
Center-surround receptive fields





Center-surround receptive fields





Center-surround receptive fields

Center-surround receptive fields

Signal *differences* in light

Center-surround receptive fields

~~Signal *differences* in light~~

Center-surround receptive fields

~~Signal *differences* in light~~

Edge detectors!

Center-surround receptive fields

Center-surround receptive fields

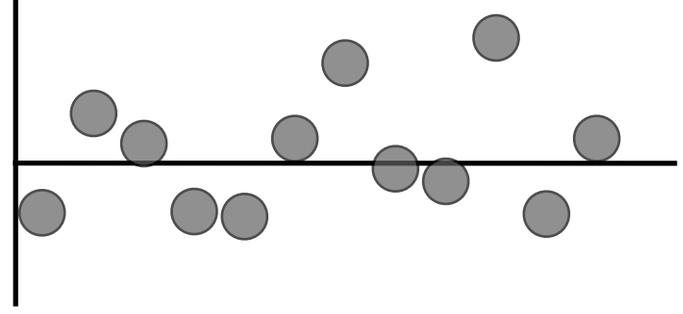
Center-surround receptive fields

Center-surround receptive fields

Bipolar response

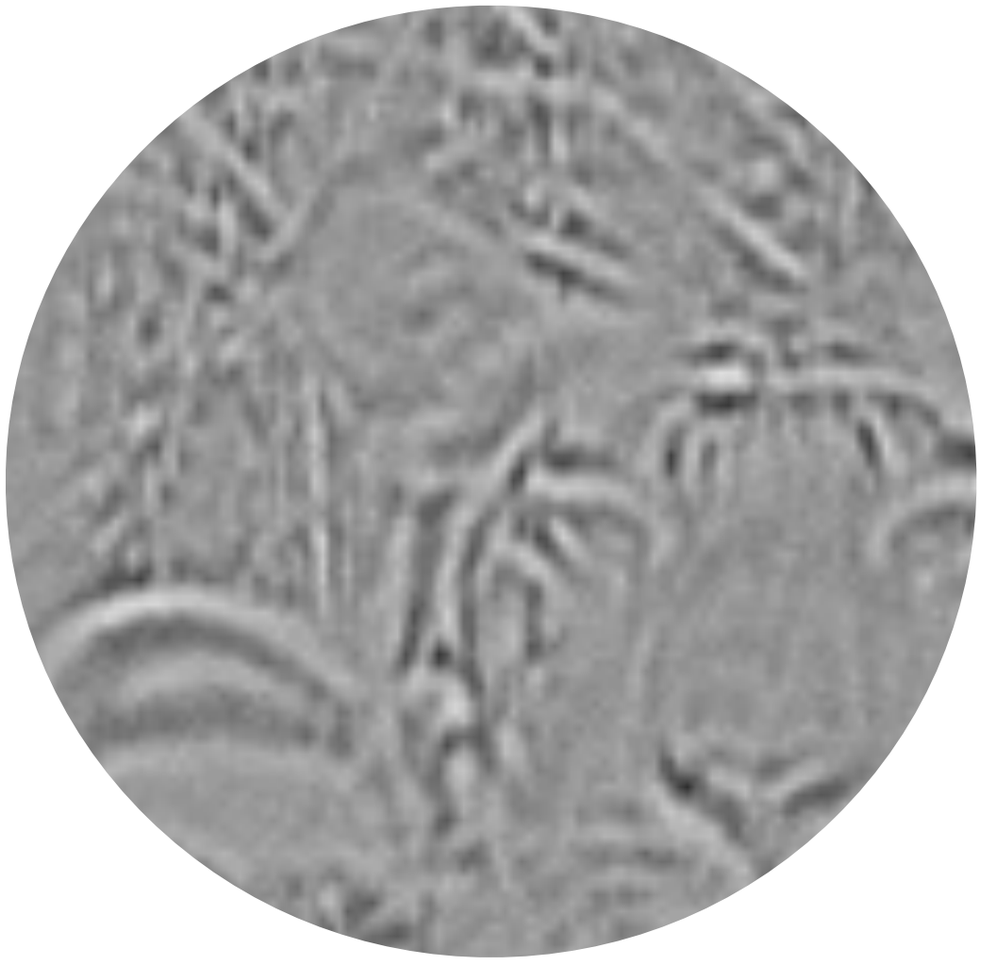
Center-surround receptive fields

Bipolar response

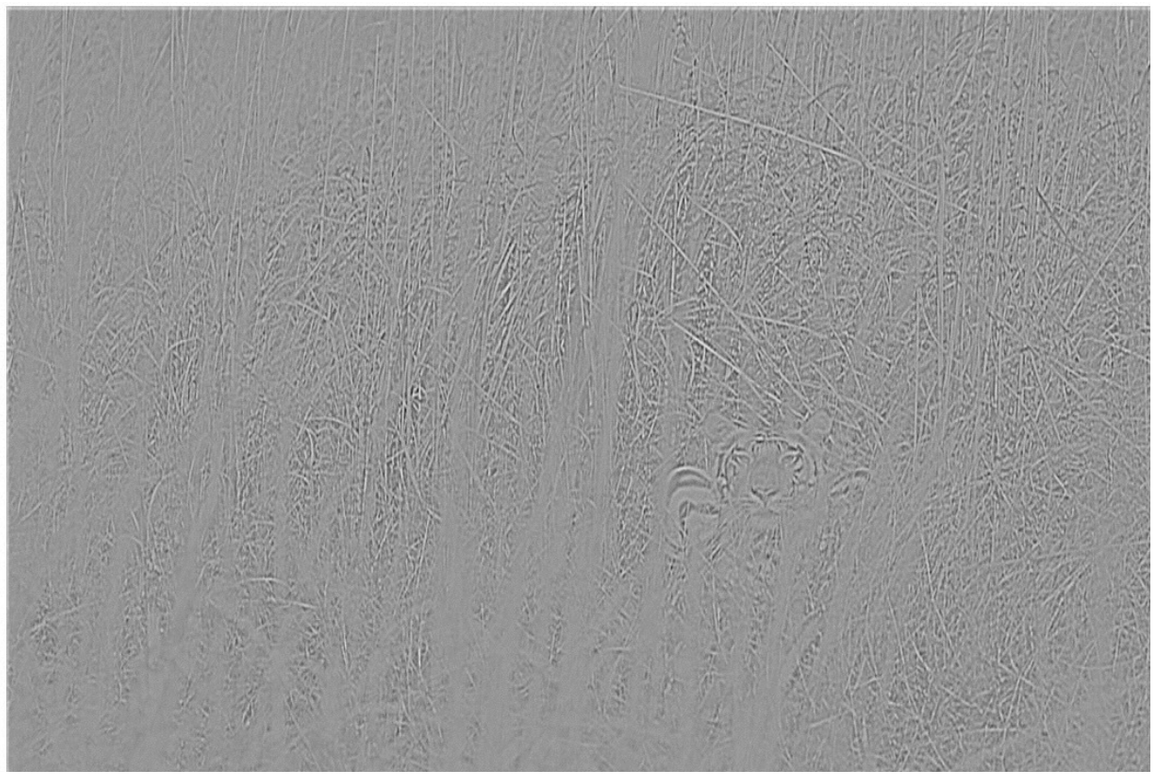


Center-surround receptive fields

Center-surround receptive fields

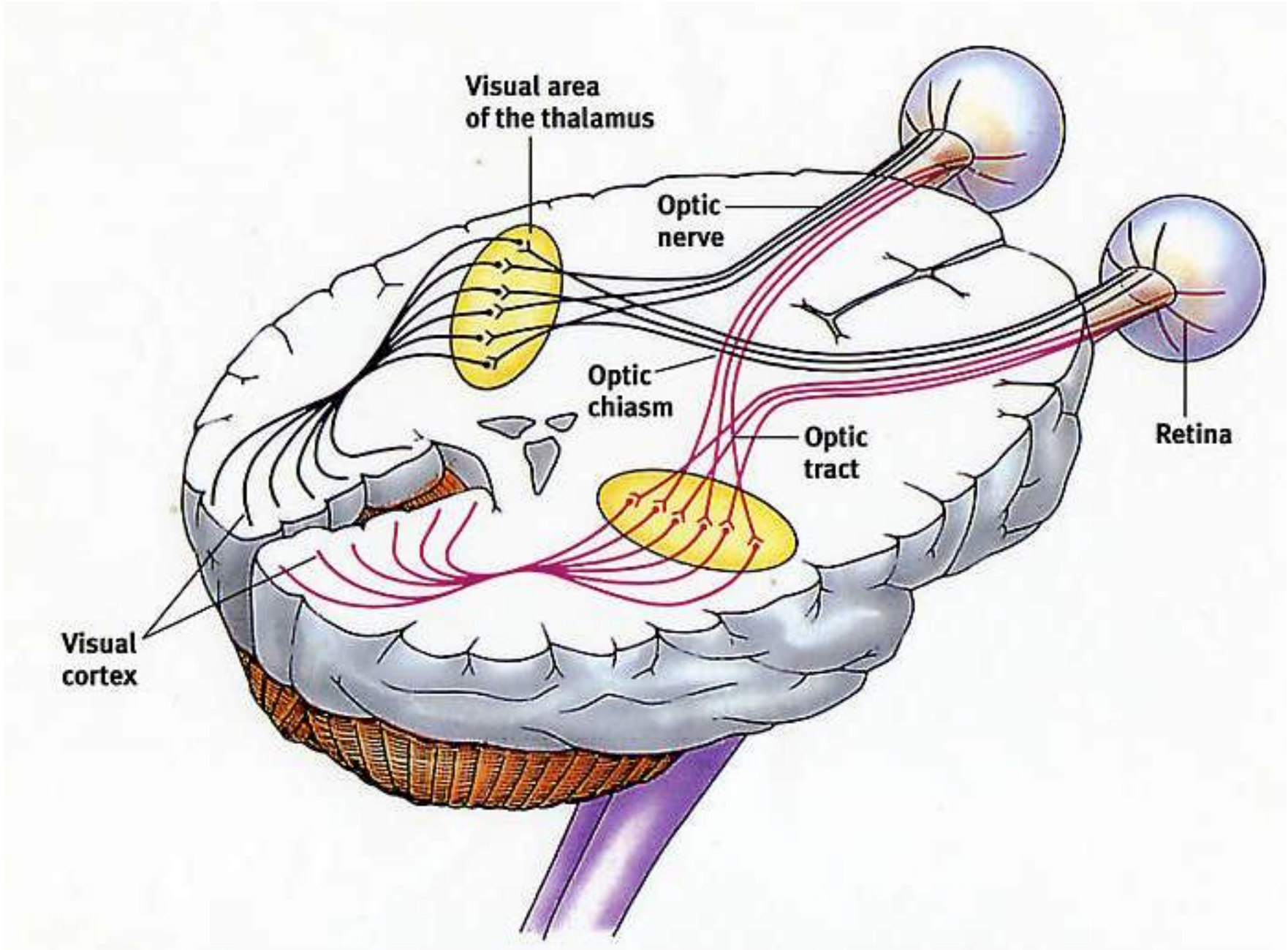


Center-surround receptive fields



Primary visual cortex

Primary visual cortex



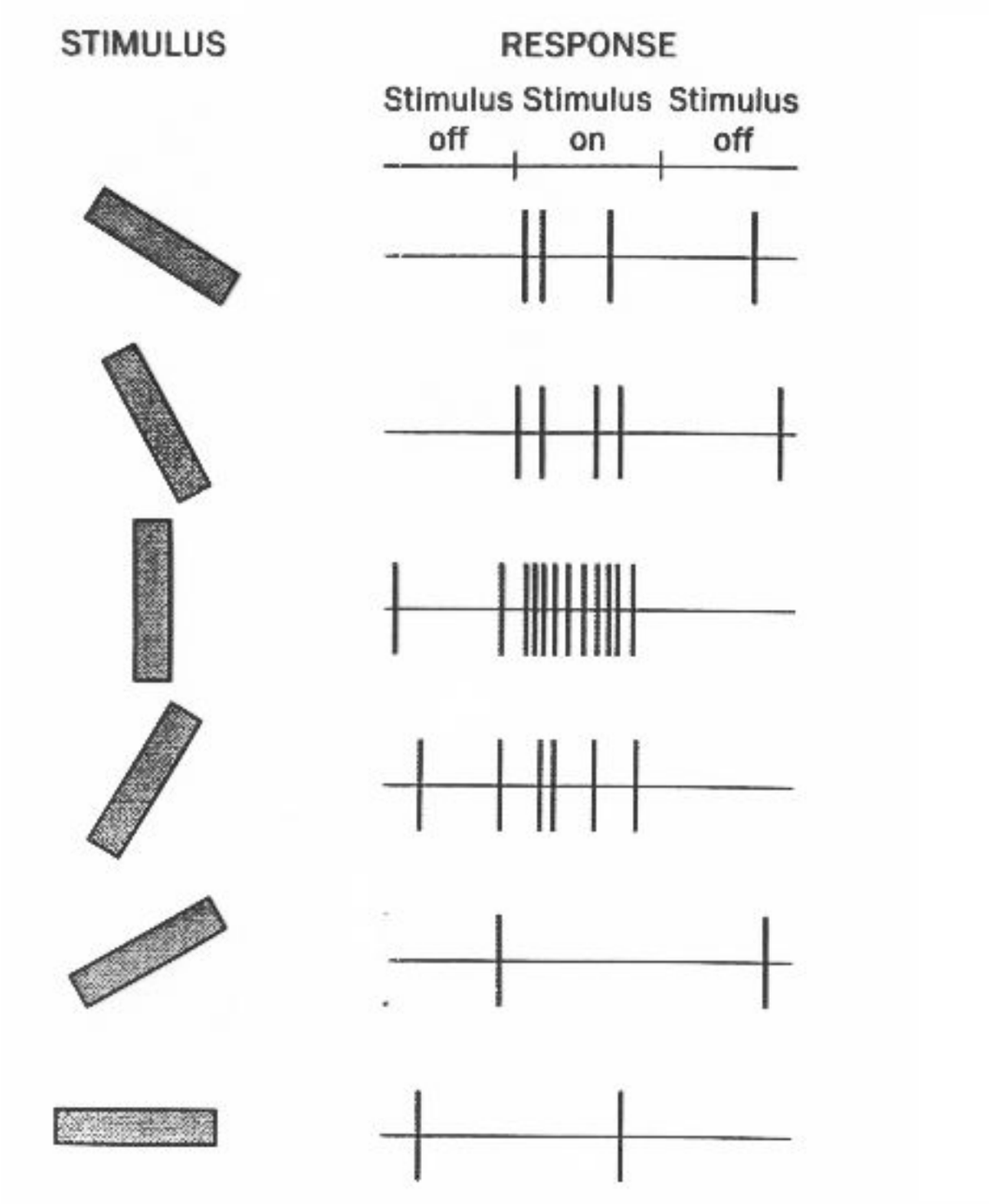
http://www.rewiring-neuroscience.com/retina-of-memory-we-caught-breeze-after/

Primary visual cortex

Primary visual cortex

http://ruccs.rutgers.edu/~ikovacs/SandP2000/prepI_3_1.html

Primary visual cortex



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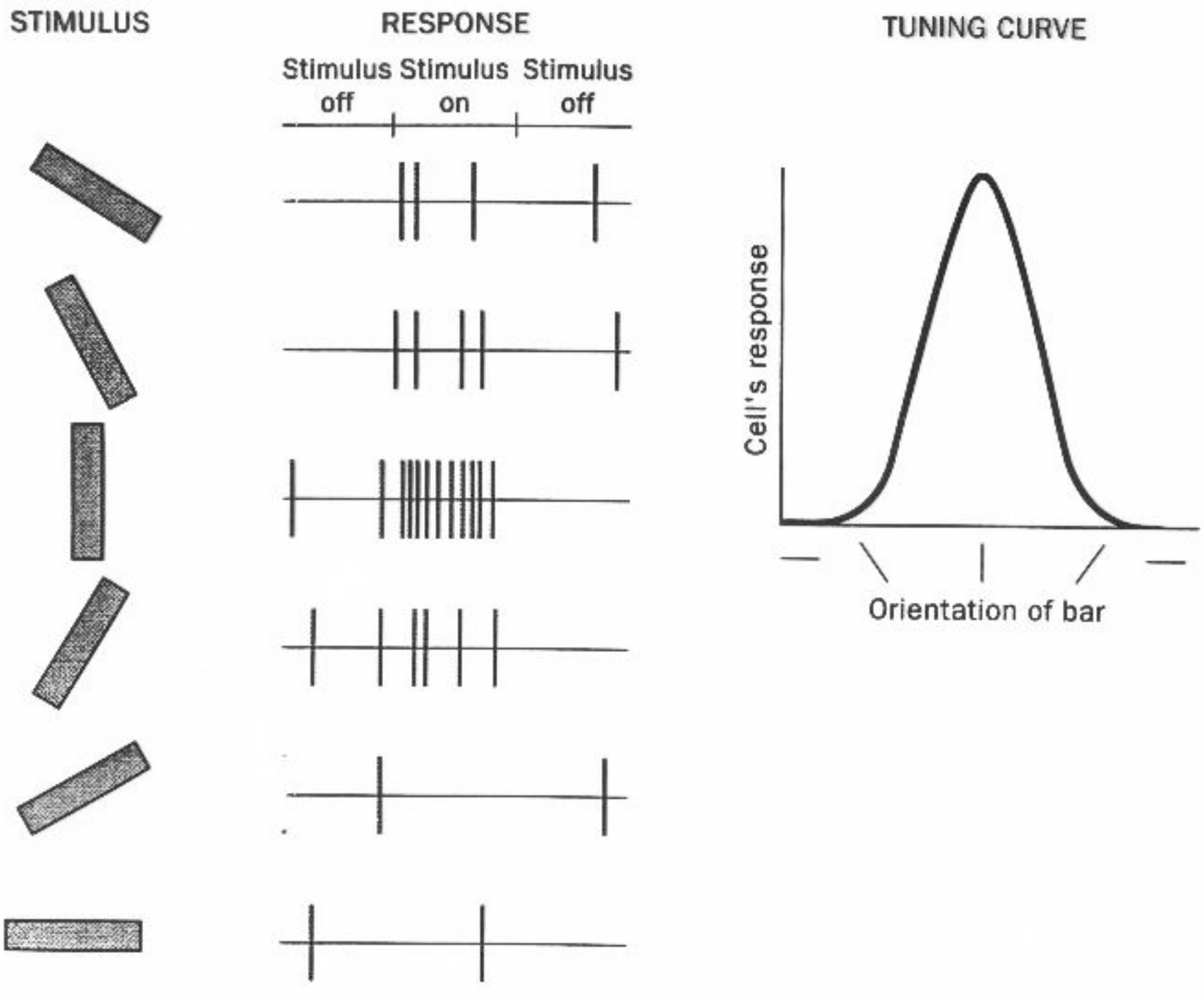
Primary visual cortex



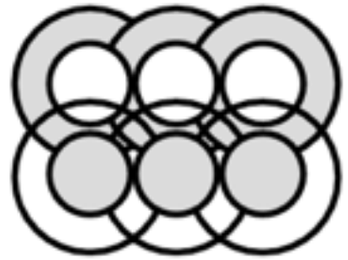
http://ruccs.rutgers.edu/~ikovacs/SandP2000/prepI_3_1.html

Building orientation selectivity

https://www.stanford.edu/group/vista/cgi-bin/FOV/chapter-6-the-cortical-representation/

Building orientation selectivity

Center-surround
receptive fields



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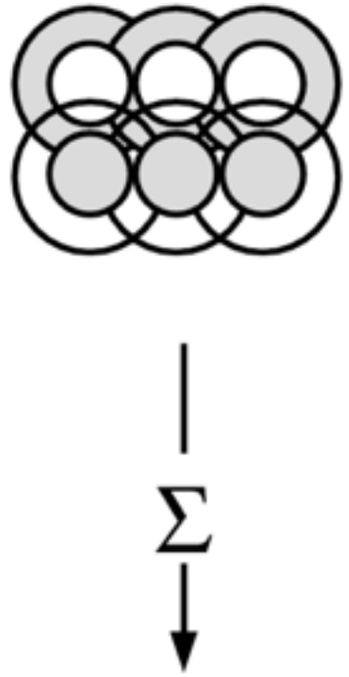
Building orientation selectivity

Center-surround receptive fields

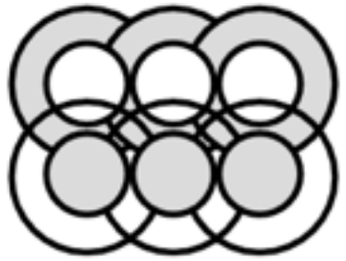


Sum over space

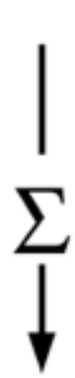
https://www.stanford.edu/group/vista/cgi-bin/FOV/chapter-6-the-cortical-representation/

Building orientation selectivity

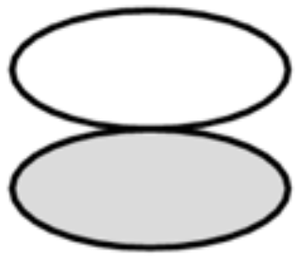
Center-surround receptive fields



Sum over space



Produce orientation-selective V1 receptive fields



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Why orientation selectivity?

Why orientation selectivity?

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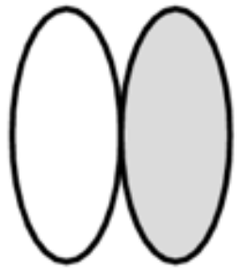
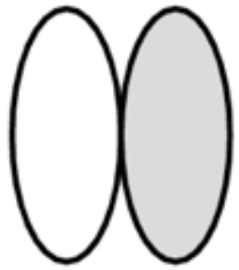


Why orientation selectivity?



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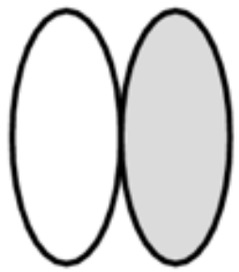

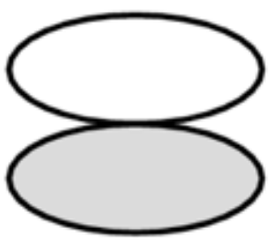

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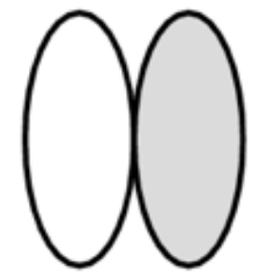

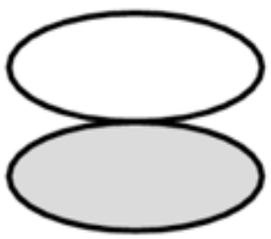

Why orientation selectivity?

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Signal *differences* in light

Why orientation selectivity?

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Edge detectors

Why orientation selectivity?

~~Signal *differences* in light~~

~~Edge detectors~~

Why orientation selectivity?

~~Signal *differences* in light~~

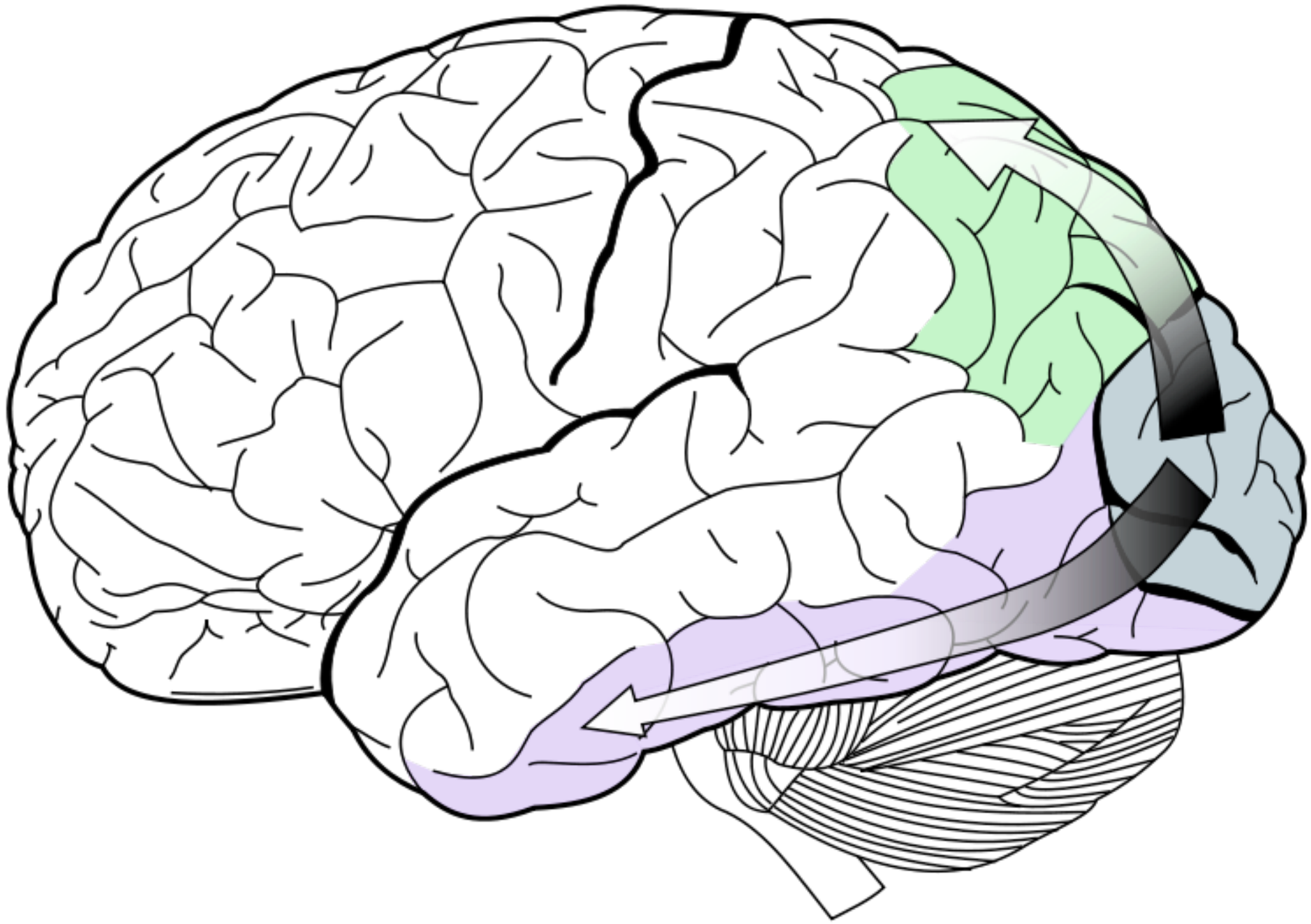
~~Edge detectors~~

Oriented edge detectors

What to do with all that information?

https://en.wikipedia.org/wiki/Visual_cortex

What to do with all that information?



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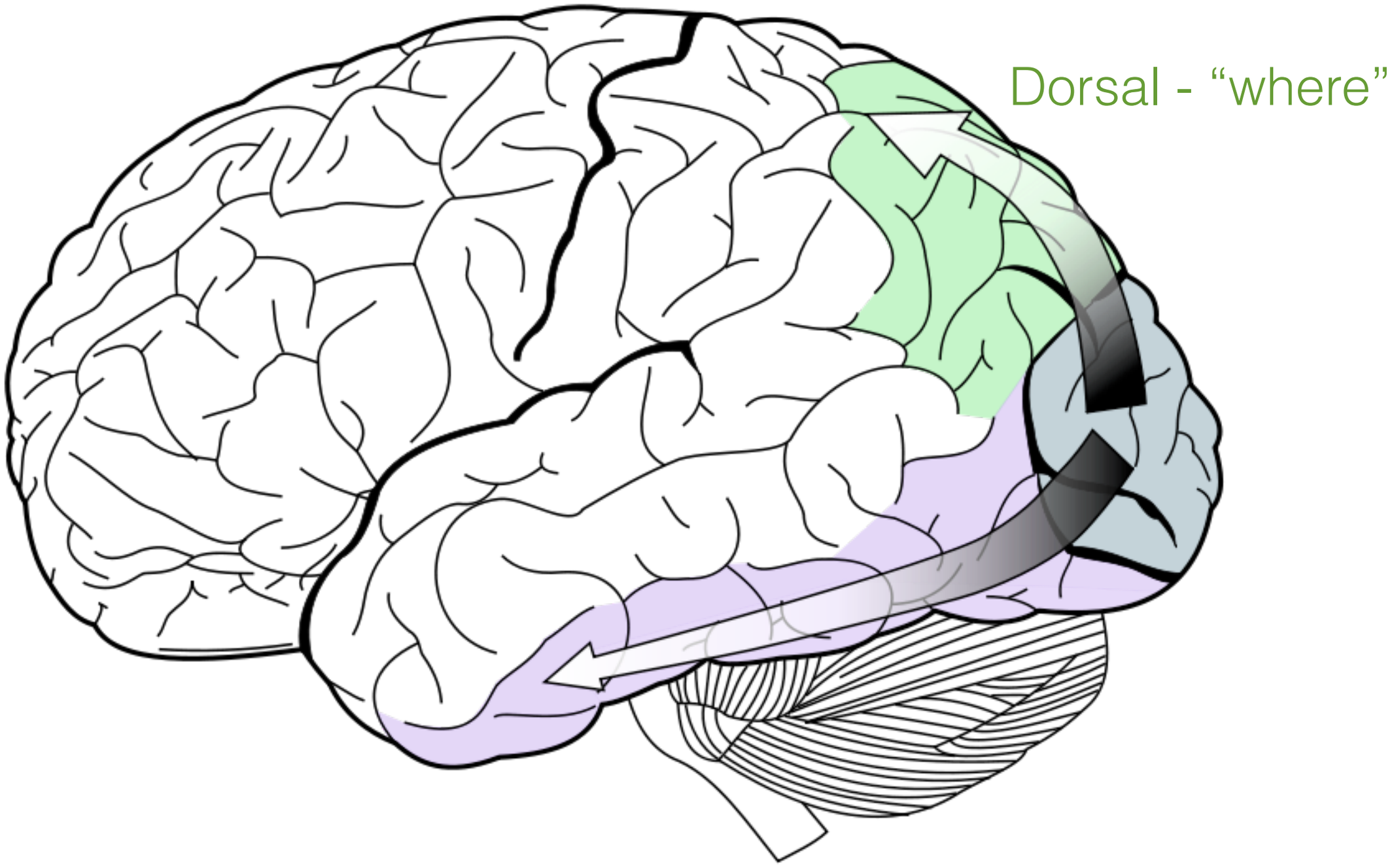

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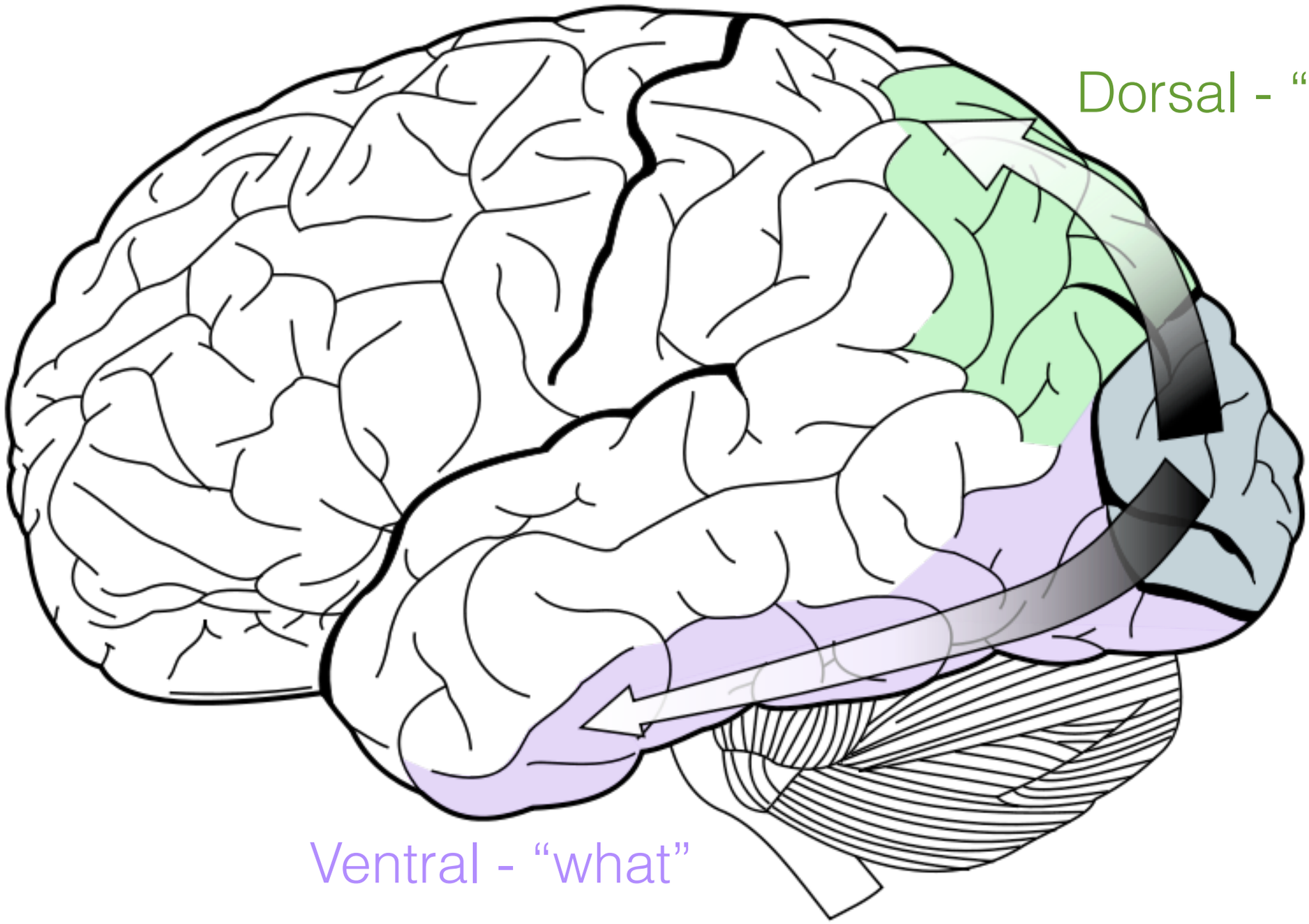

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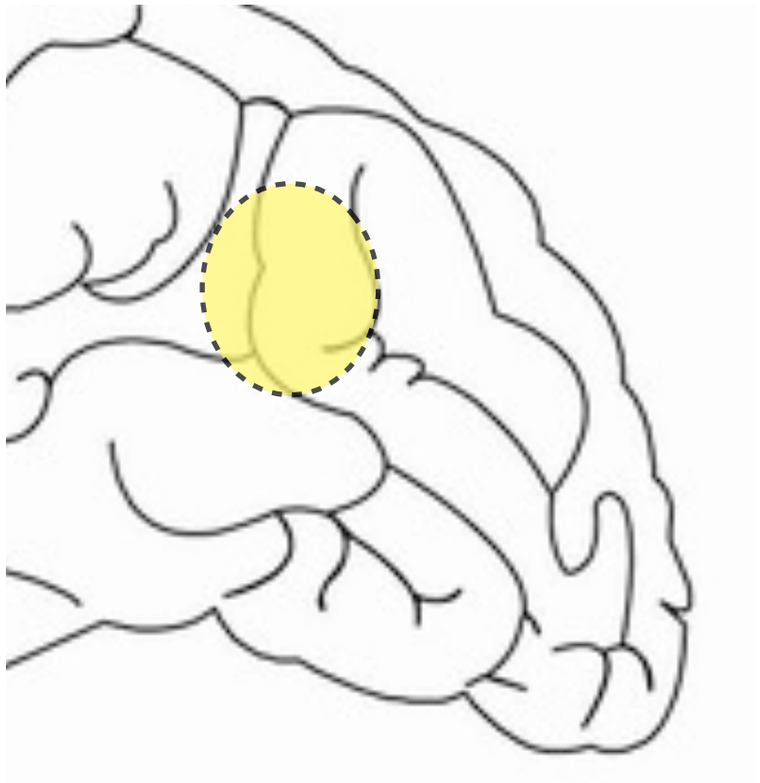
Dorsal visual pathway

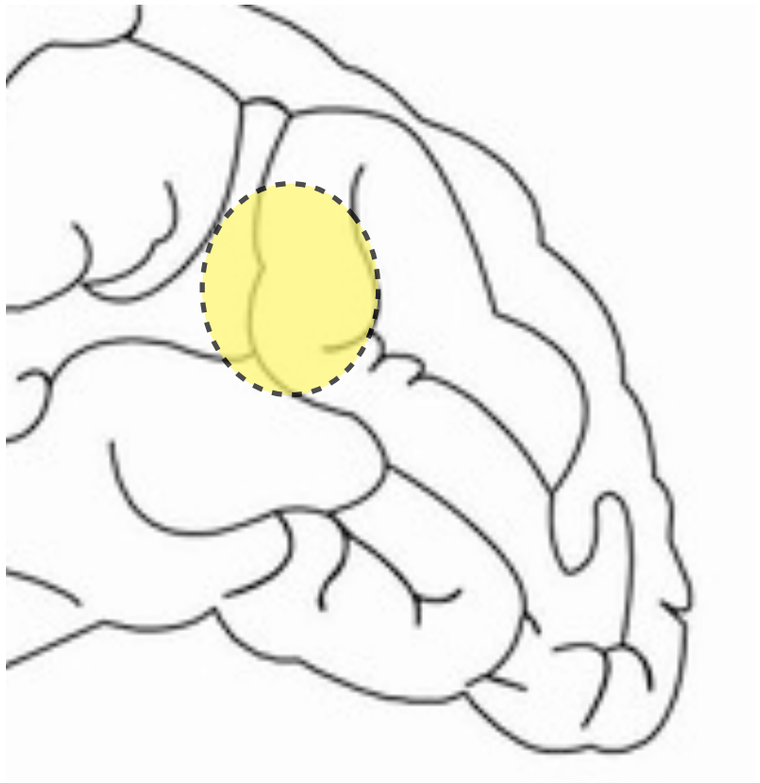
Dorsal visual pathway

Area MT



Dorsal visual pathway

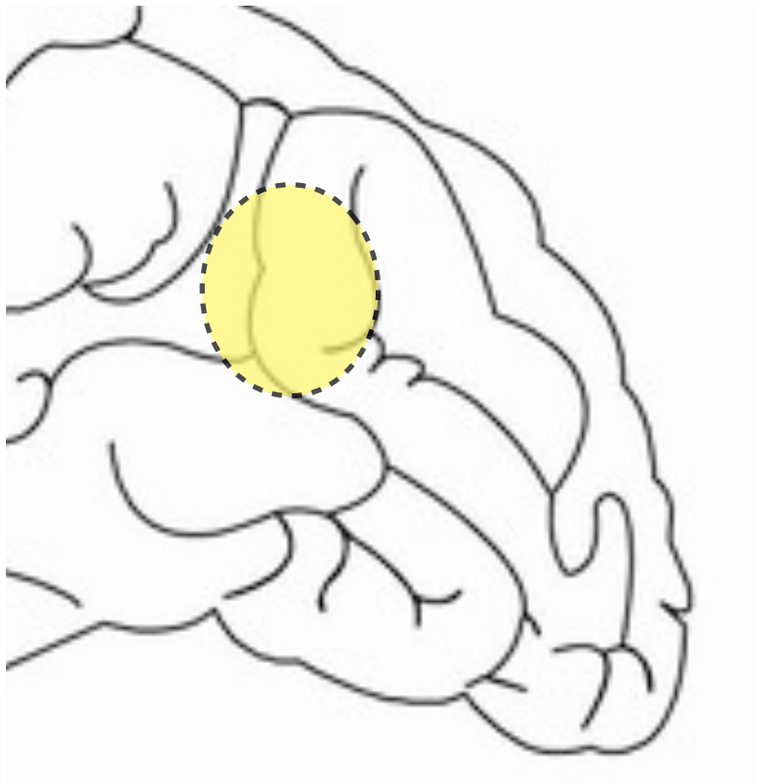
Area MT



- Large visual fields

Dorsal visual pathway

Area MT



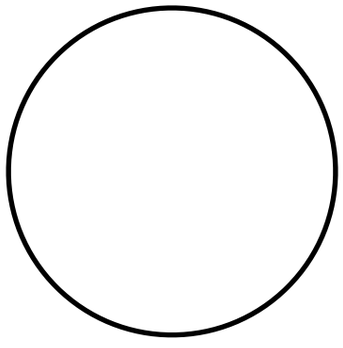
- Large visual fields
- Responds to moving objects

Dorsal visual pathway

Area MT

- Large visual fields
- Responds to moving objects

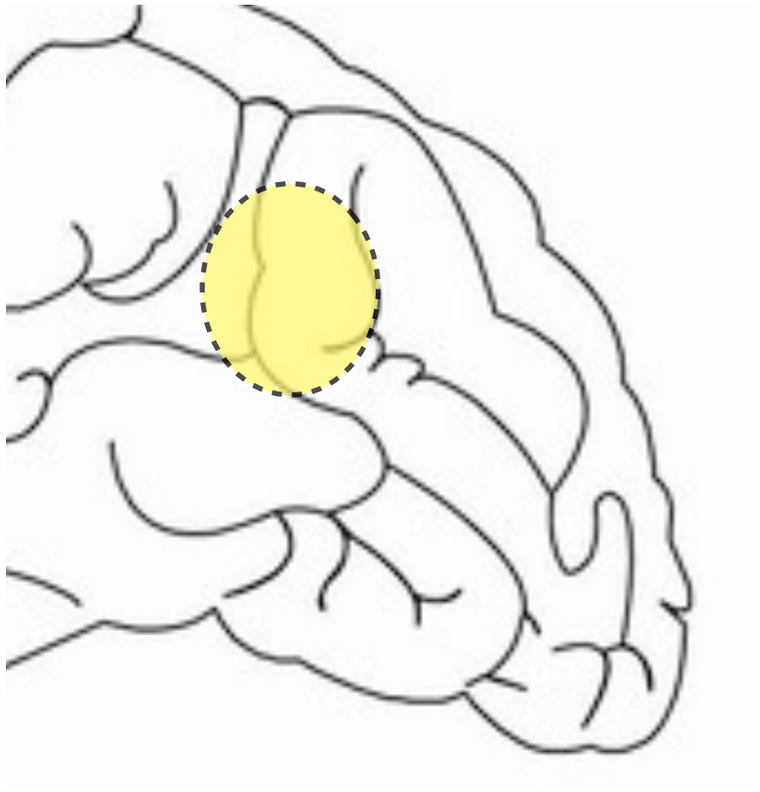
Stimulus



MT response

Dorsal visual pathway

Area MT



- Large visual fields
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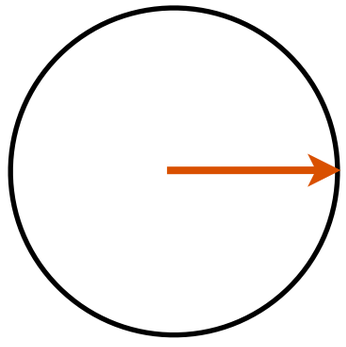
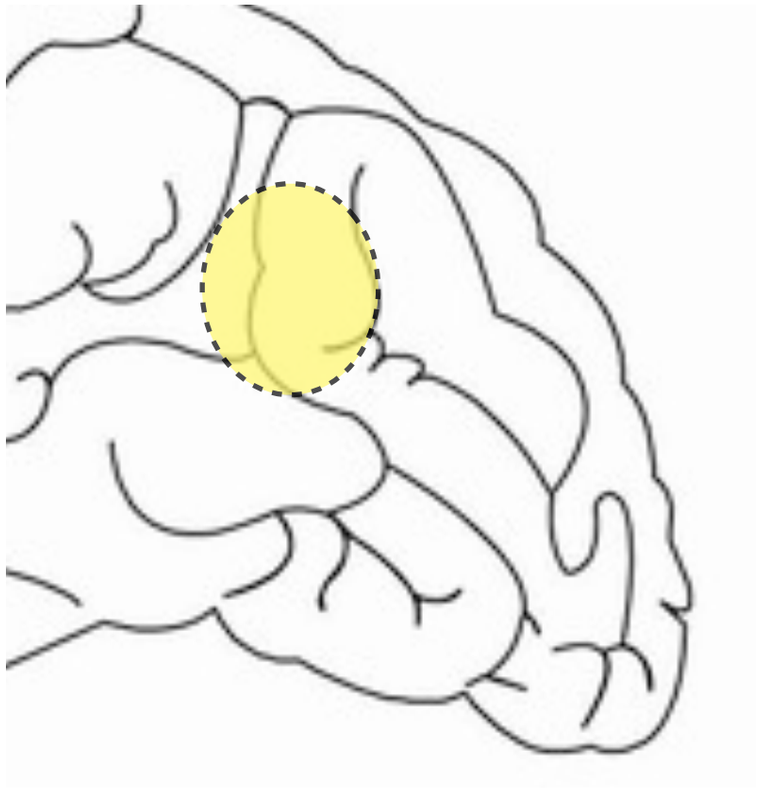
Stimulus



MT response

Dorsal visual pathway

Area MT



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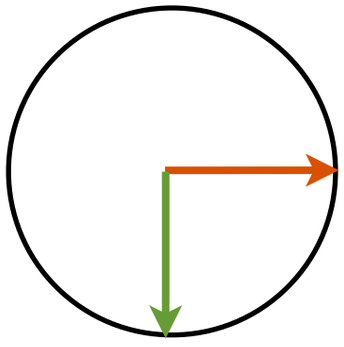
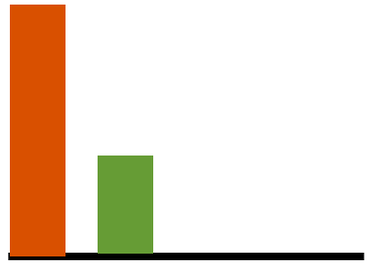
Stimulus



MT response

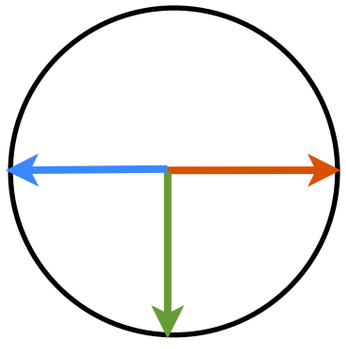


Dorsal visual pathway

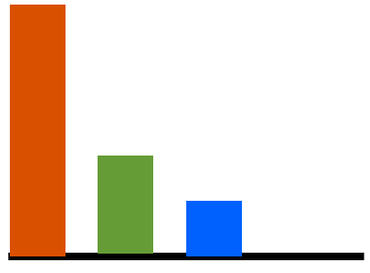
Area MT

- Large visual fields
- Responds to moving objects

Stimulus

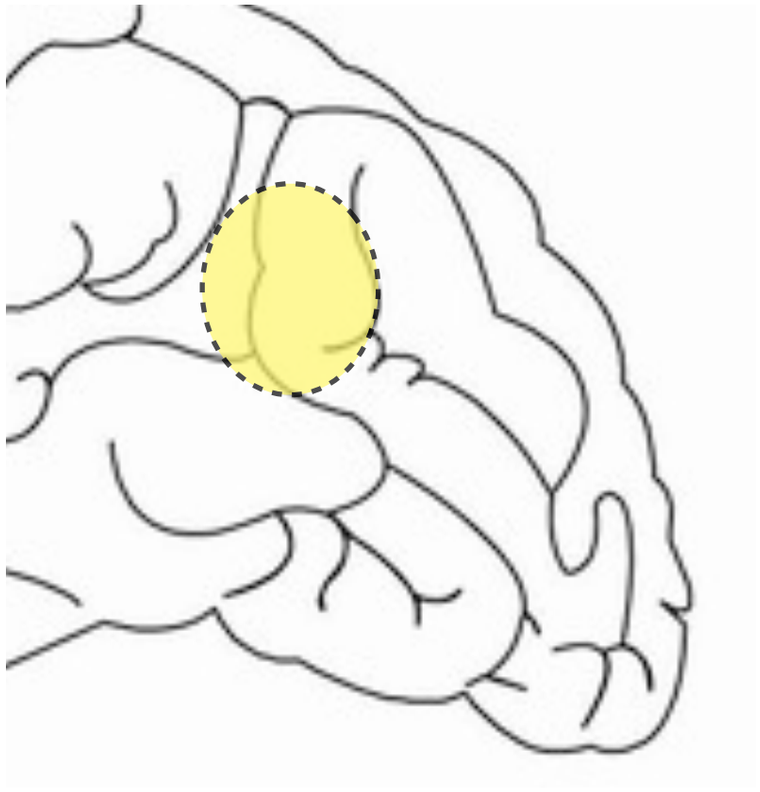


MT response



Dorsal visual pathway

Area MT



- Large visual fields
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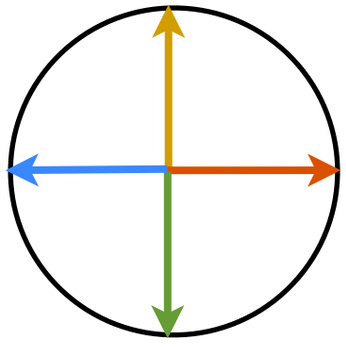
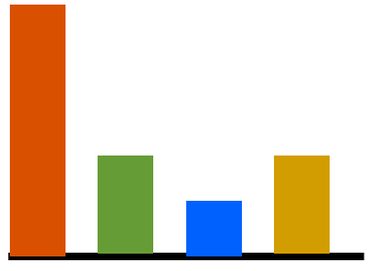
Stimulus

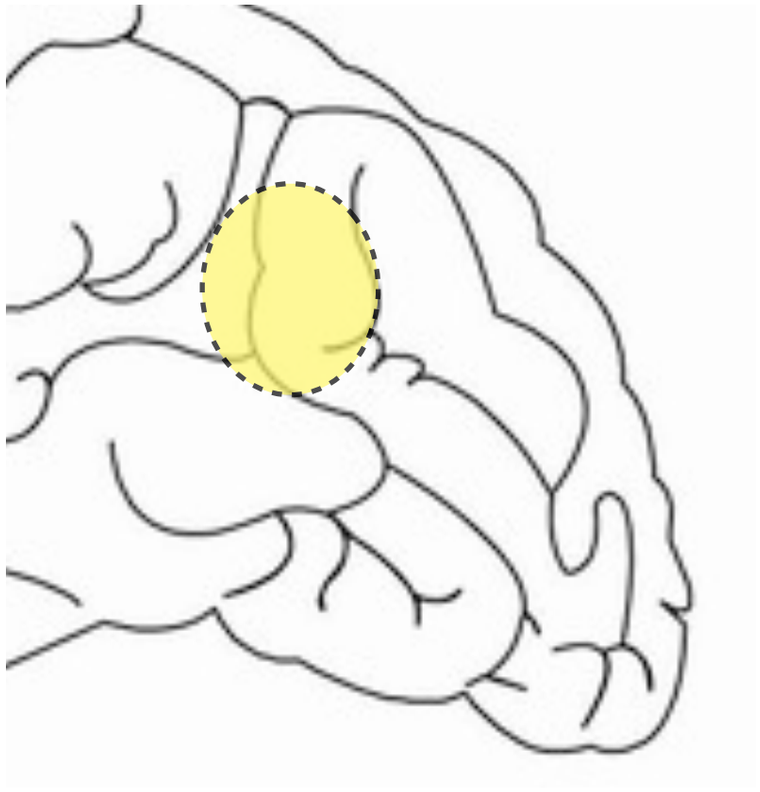


MT response



Dorsal visual pathway

Area MT



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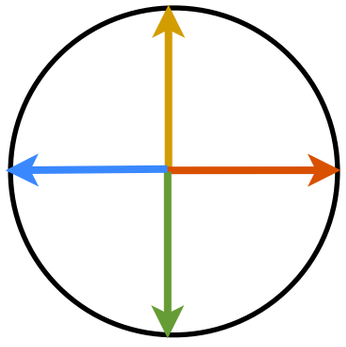
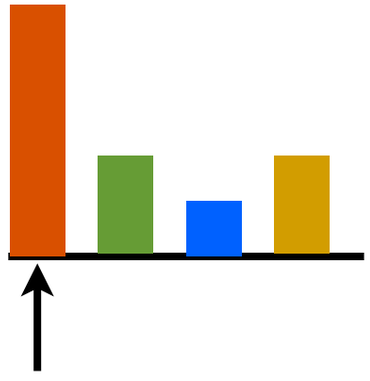


MT response

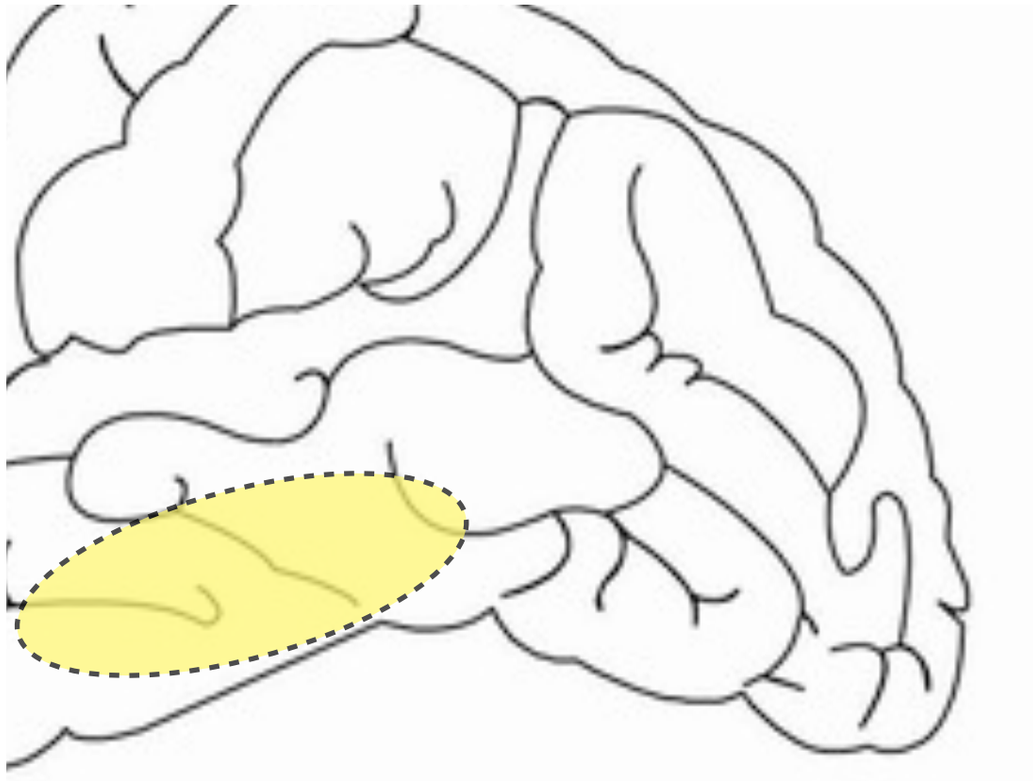


preferred direction

Ventral visual pathway

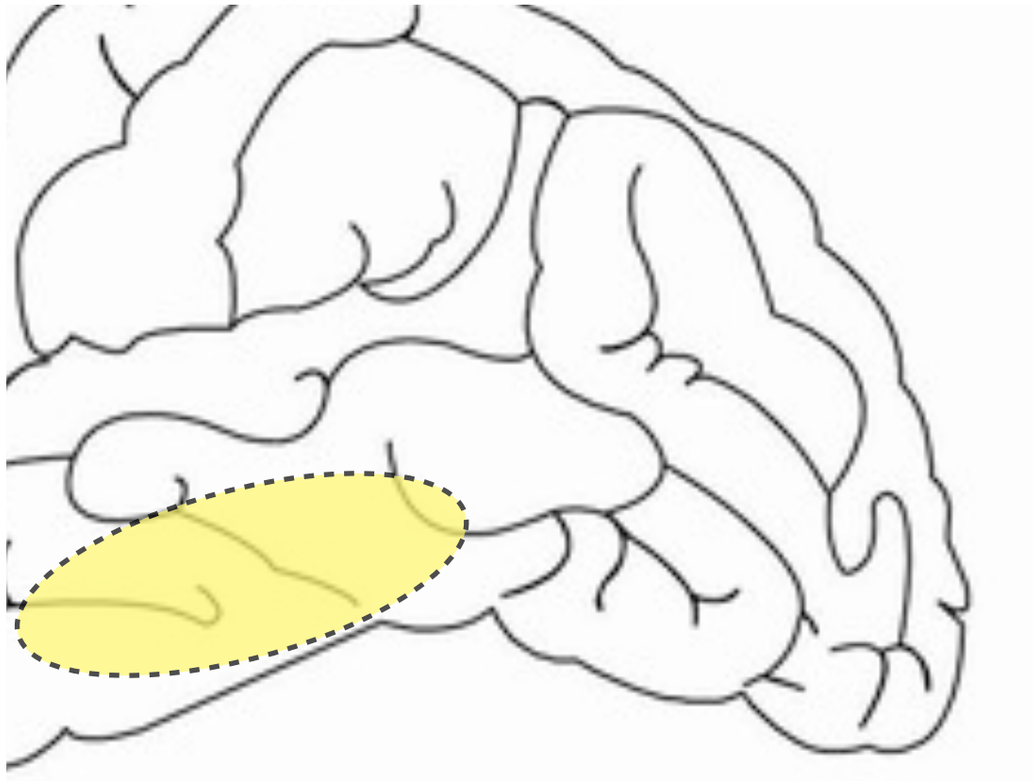
Ventral visual pathway

Inferior temporal cortex



Ventral visual pathway

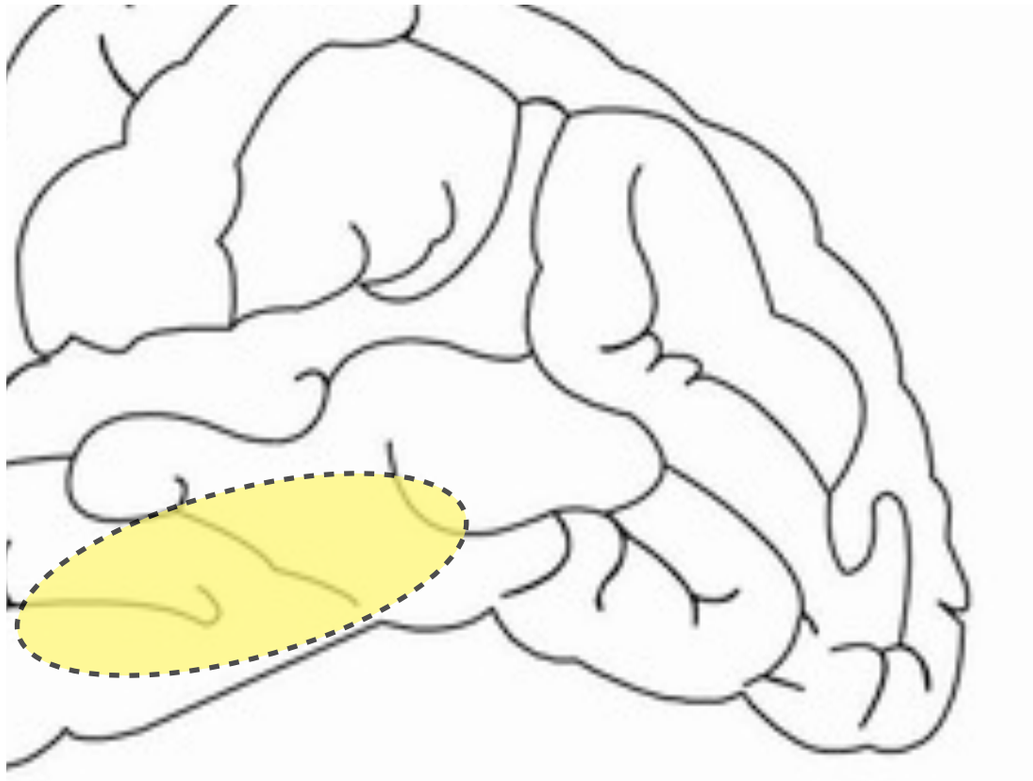
Inferior temporal cortex



- Large visual fields

Ventral visual pathway

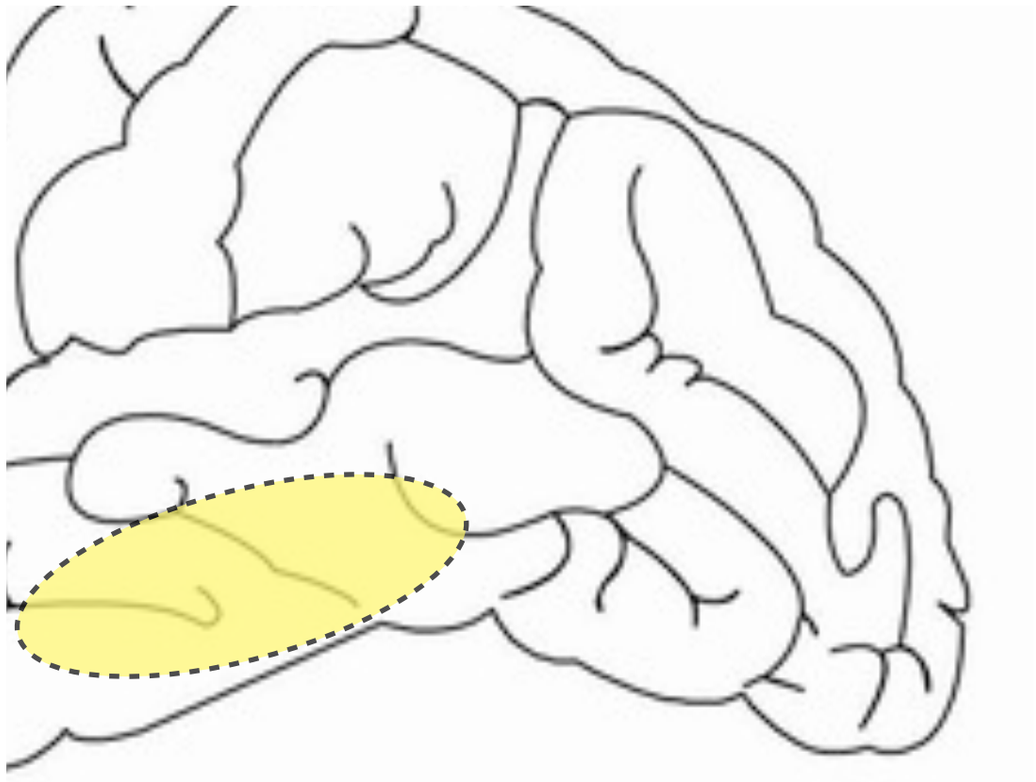
Inferior temporal cortex



- Large visual fields
- Responds to complex visual objects

Ventral visual pathway

Inferior temporal cortex



- Large visual fields
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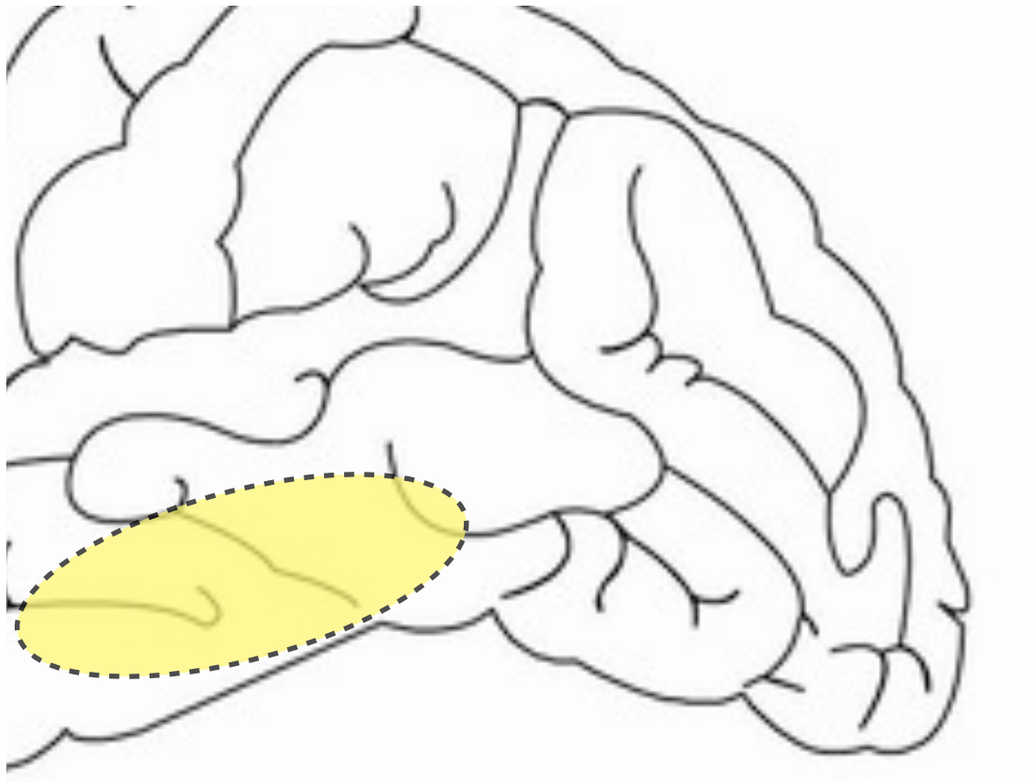
Ventral visual pathway

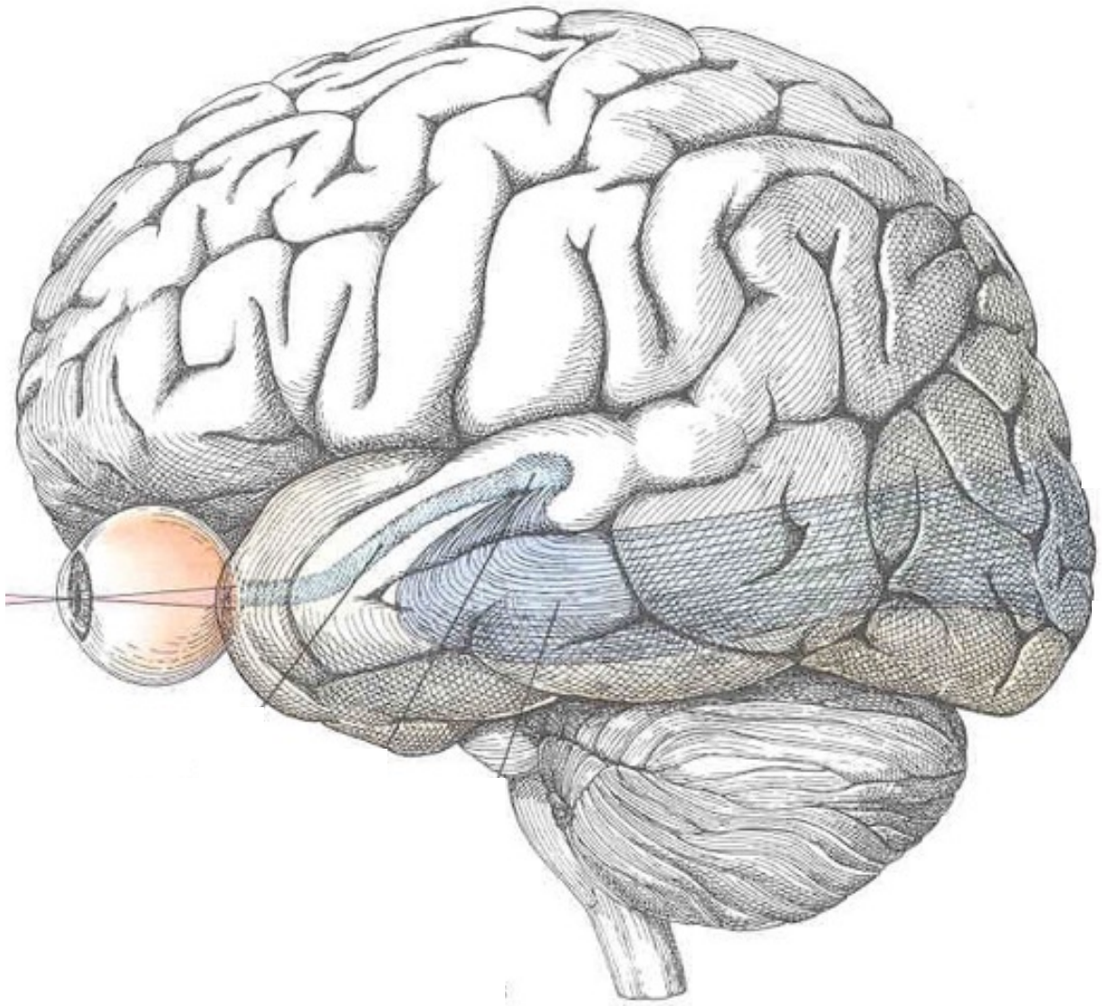
Inferior temporal cortex



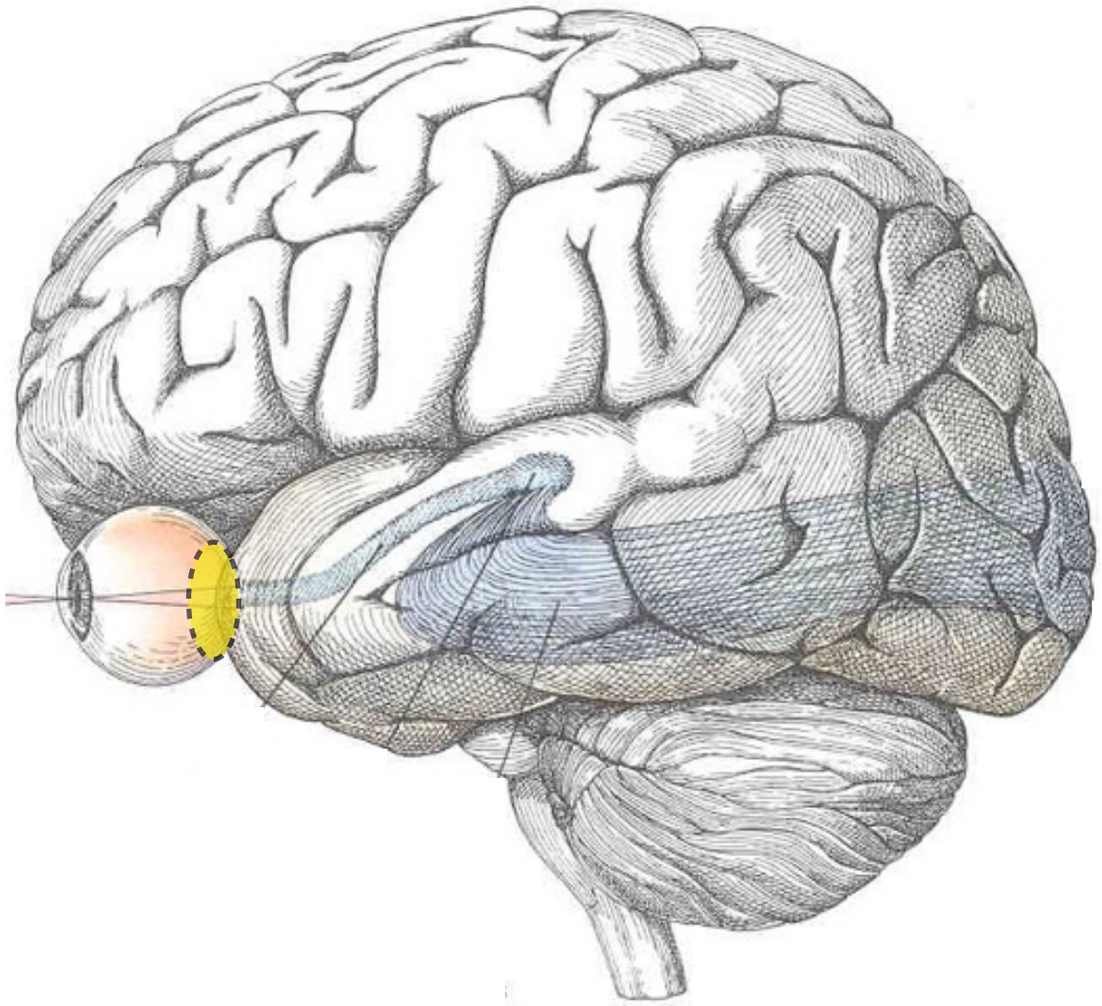
- Large visual fields
- Responds to complex visual objects

Building complex from simple

Building complex from simple

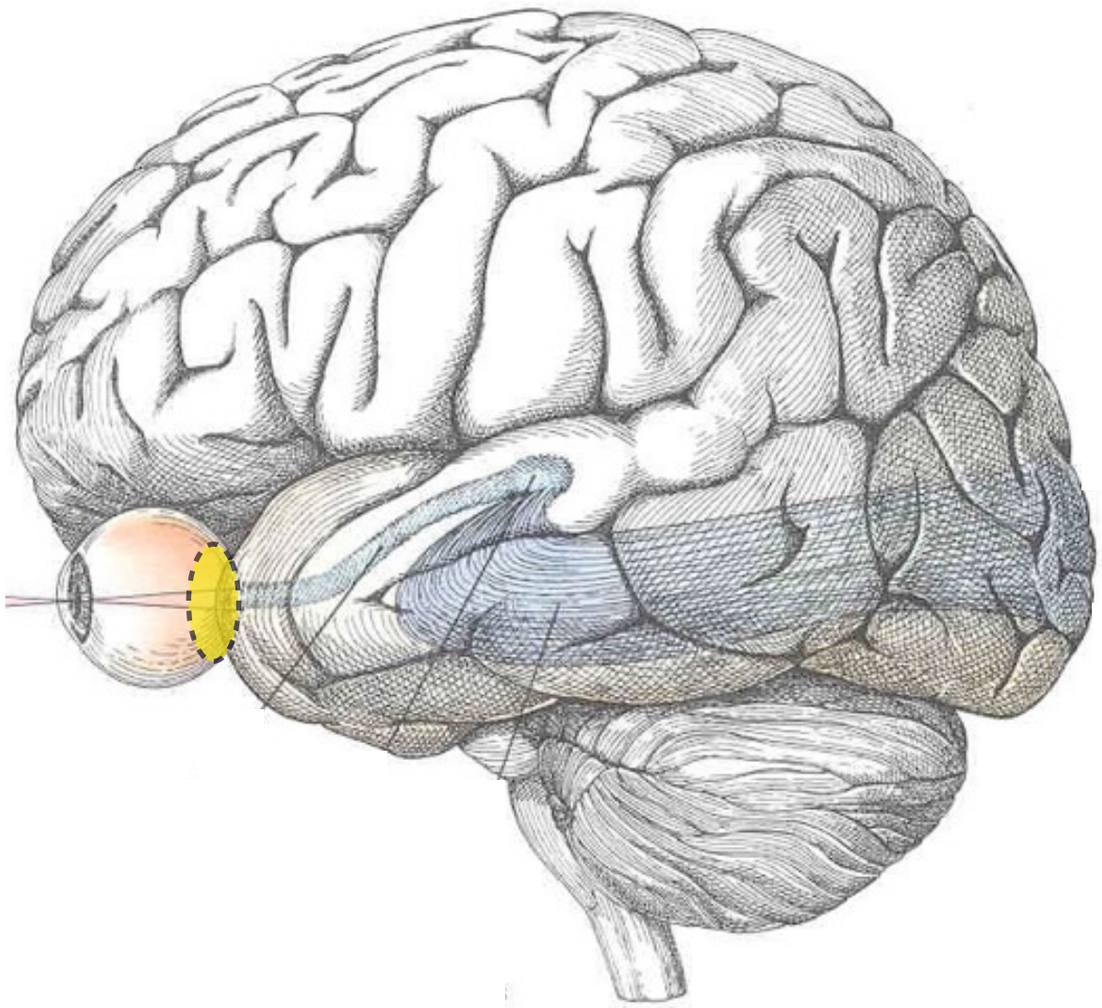


Building complex from simple



Retina

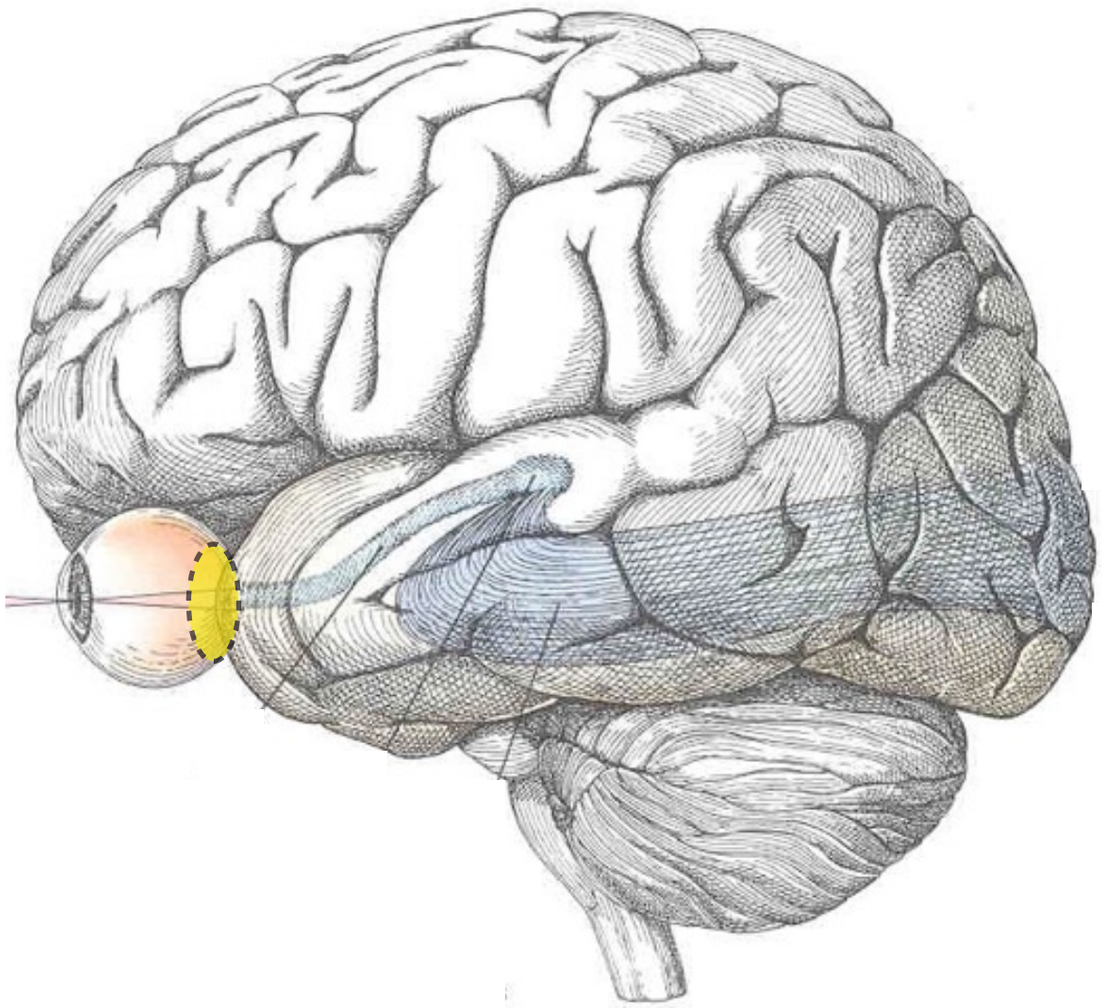
Building complex from simple



Retina

- Center-surround fields

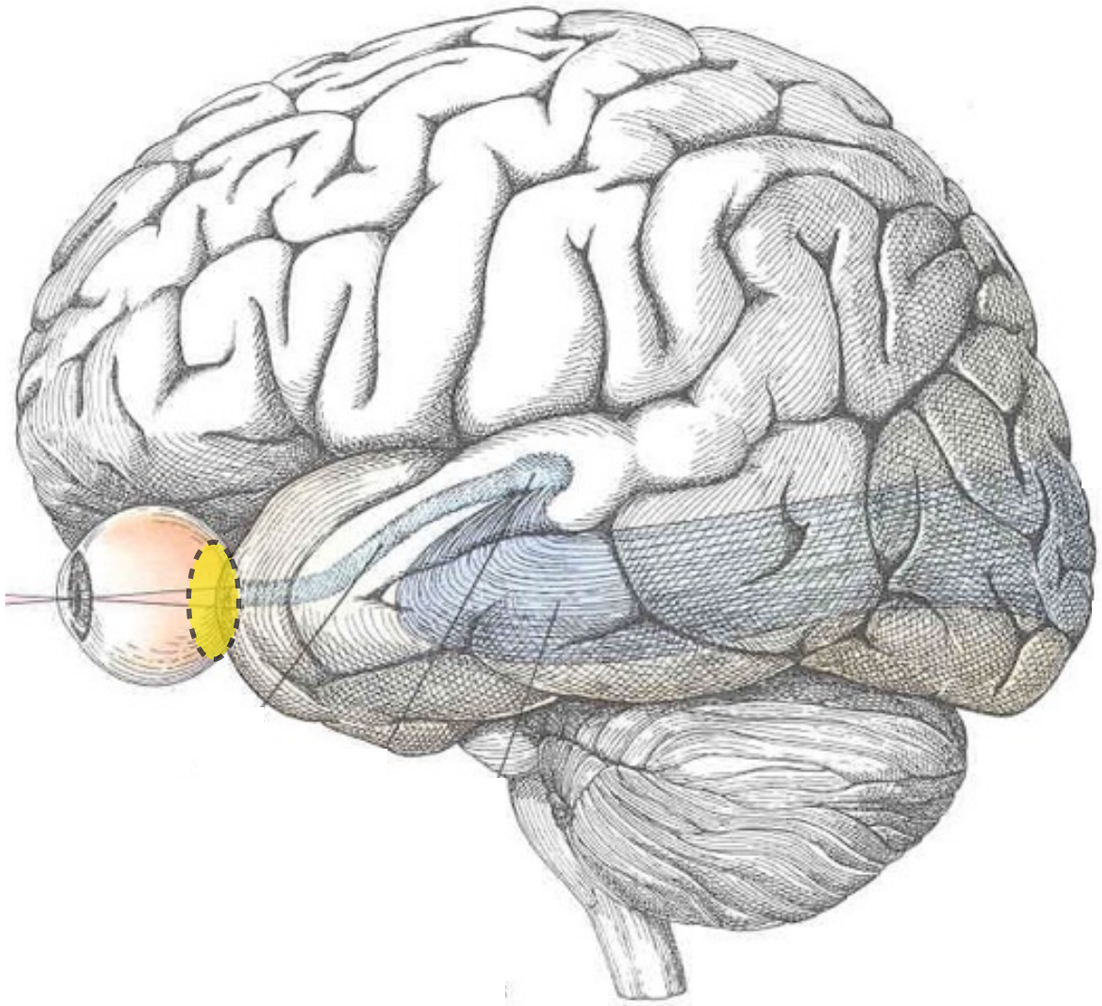
Building complex from simple



Retina

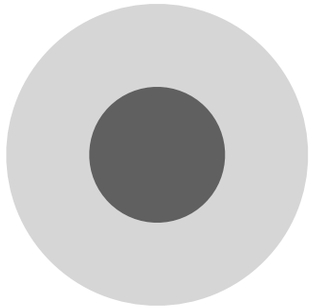
- Center-surround fields
- Contrast in space and time

Building complex from simple

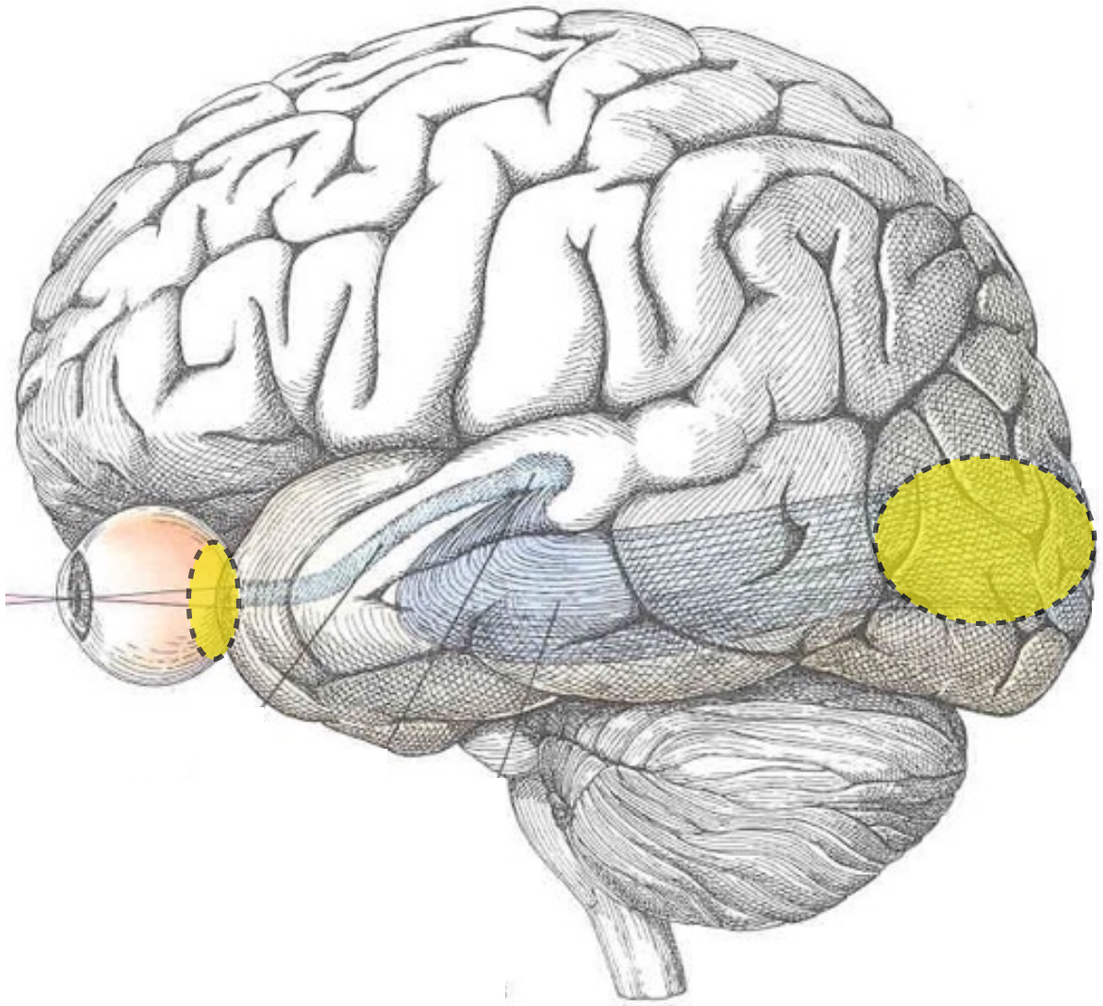


Retina

- Center-surround fields
- Contrast in space and time

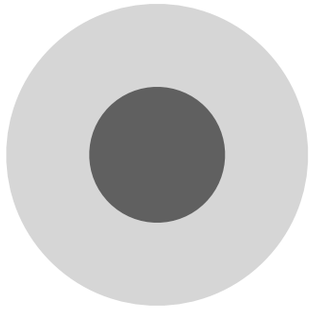


Building complex from simple



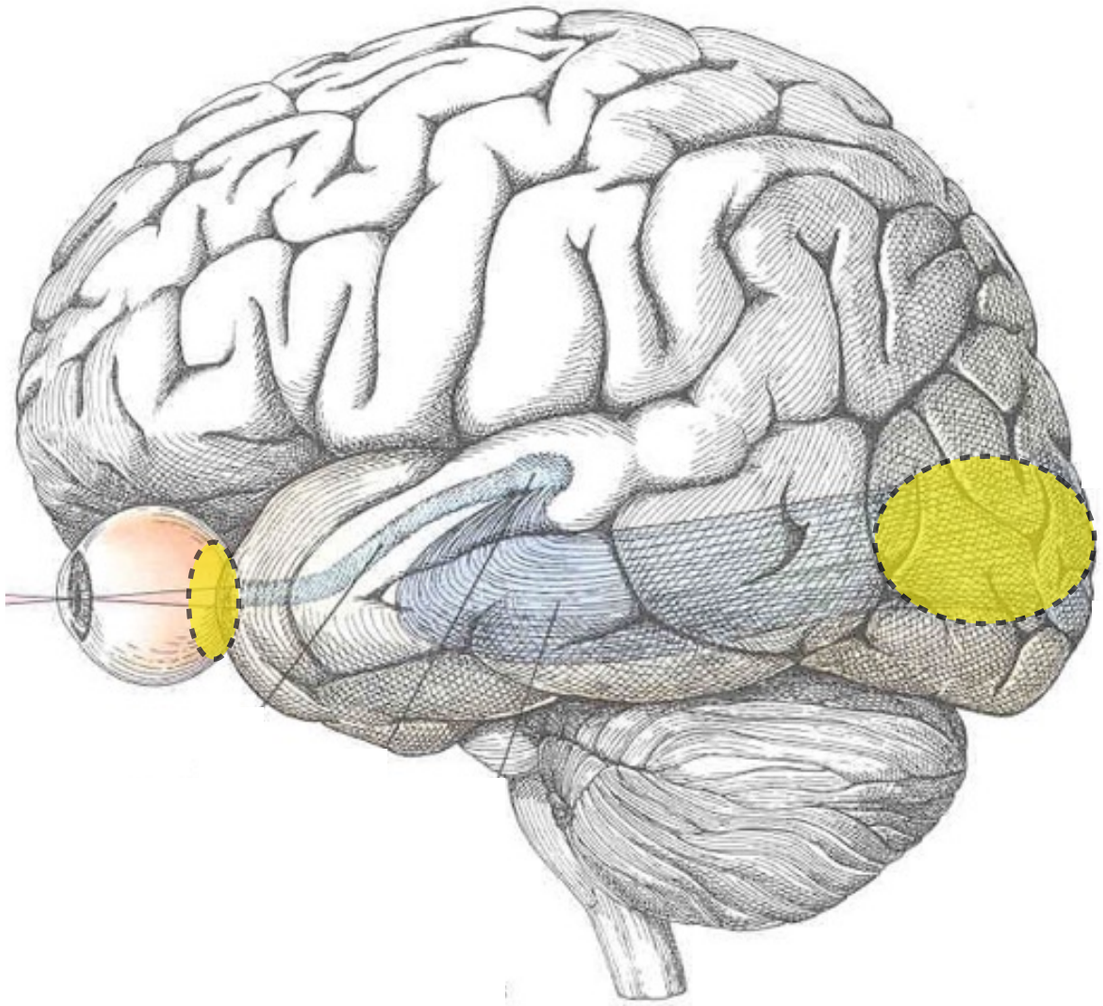
Retina

- Center-surround fields
- Contrast in space and time



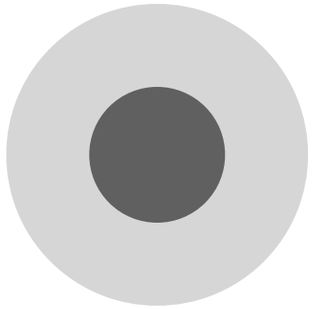
V1

Building complex from simple



Retina

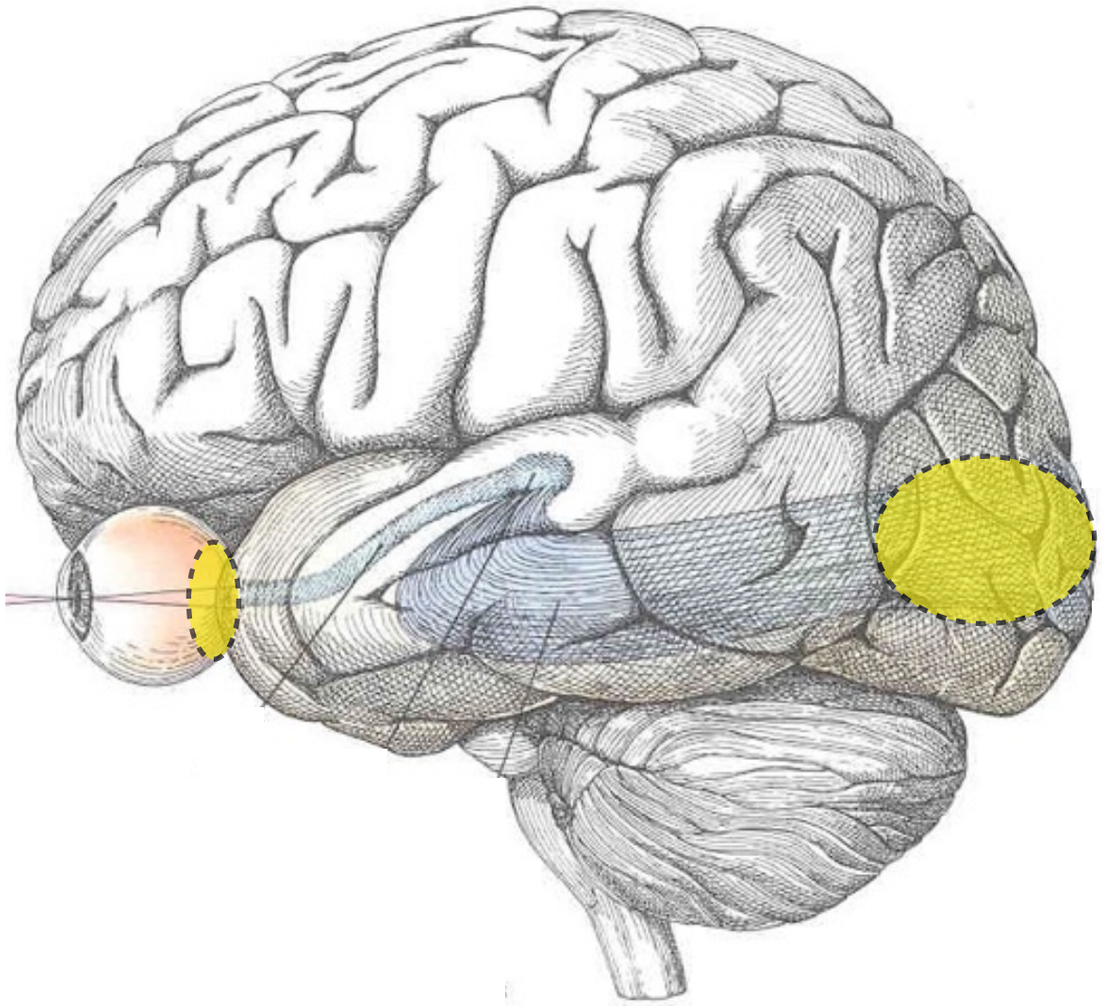
- Center-surround fields
- Contrast in space and time



V1

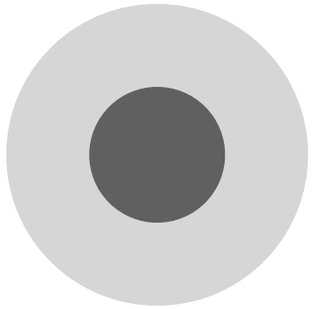
- Simple visual features

Building complex from simple



Retina

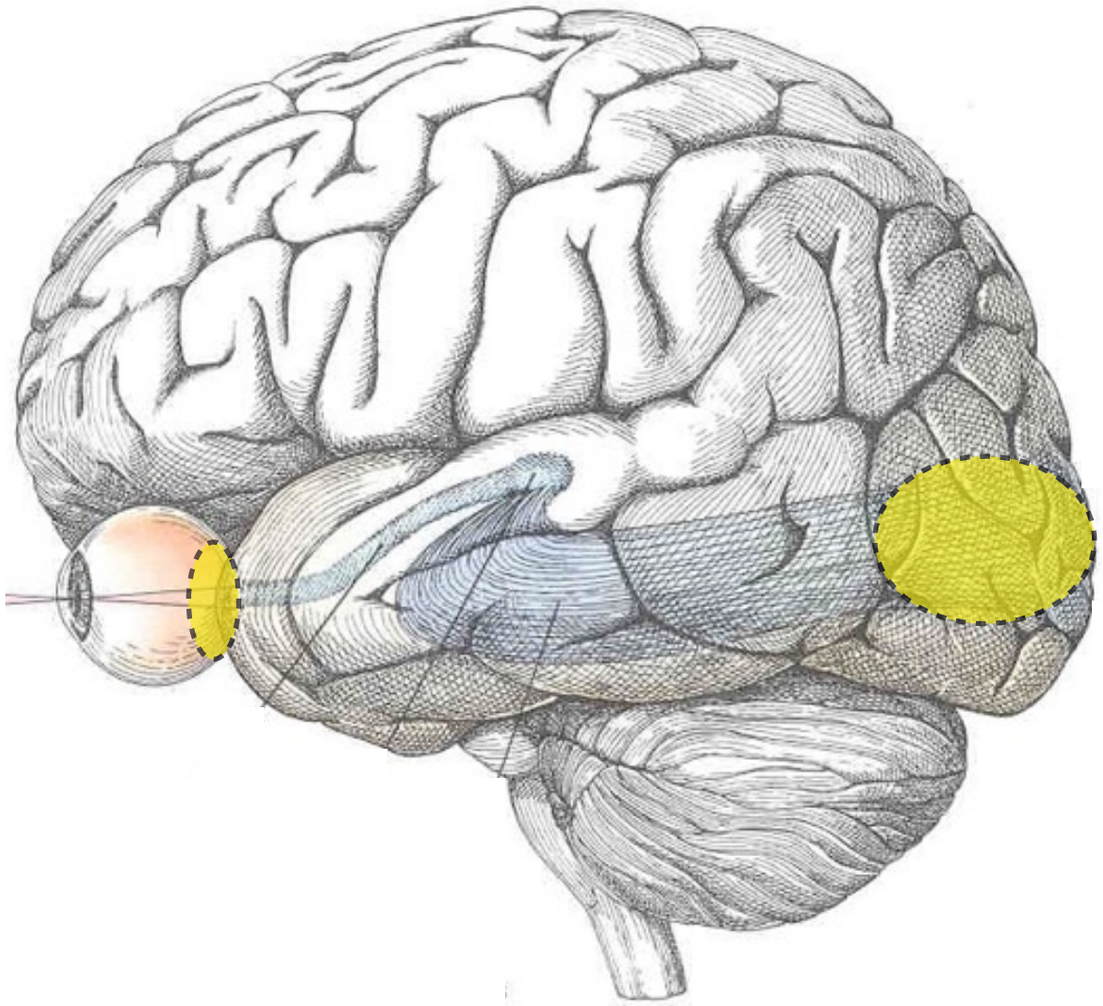
- Center-surround fields
- Contrast in space and time



V1

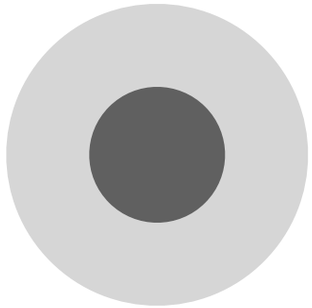
- Simple visual features
- Orientation tuning

Building complex from simple



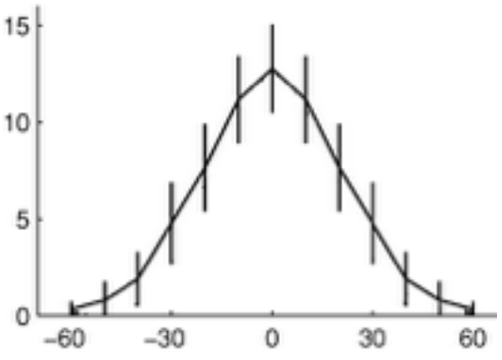
Retina

- Center-surround fields
- Contrast in space and time



V1

- Simple visual features
- Orientation tuning



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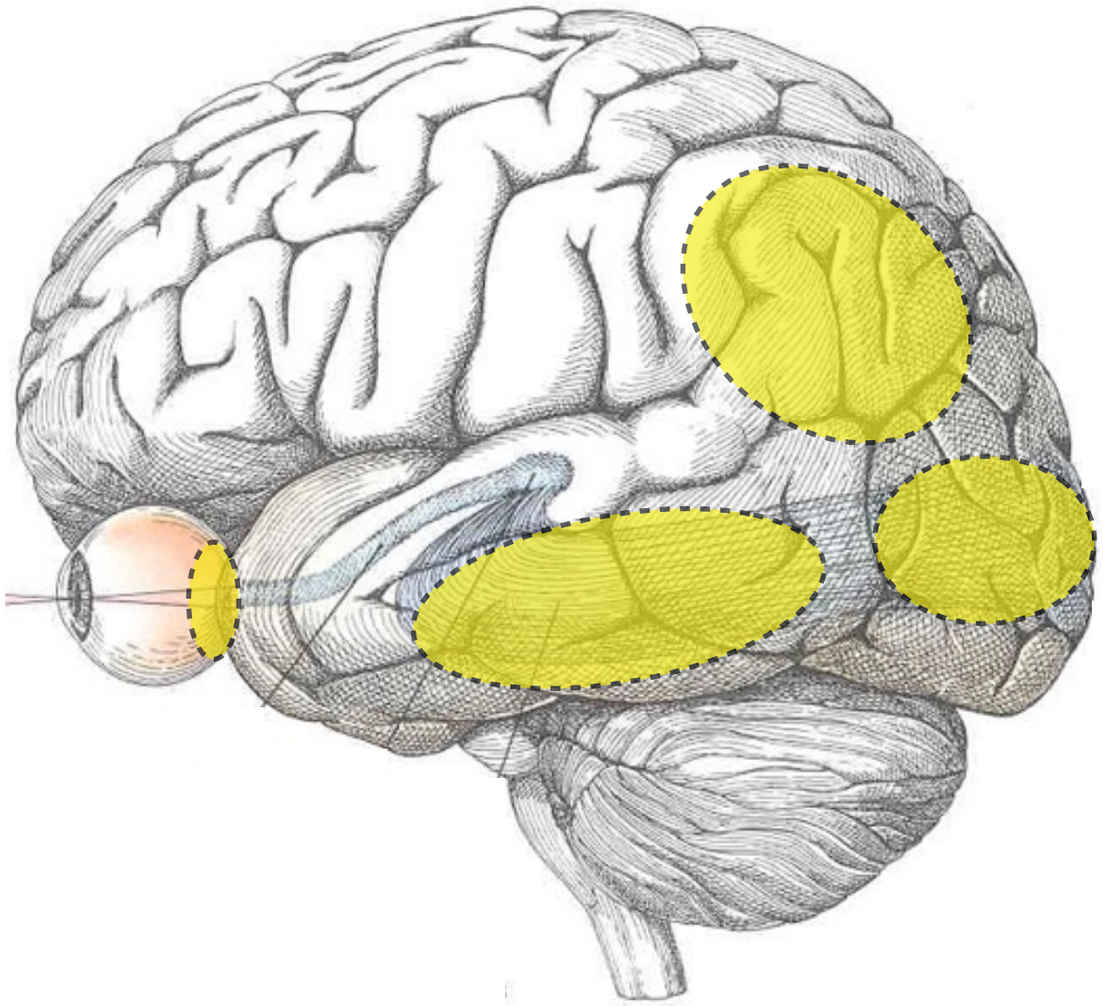
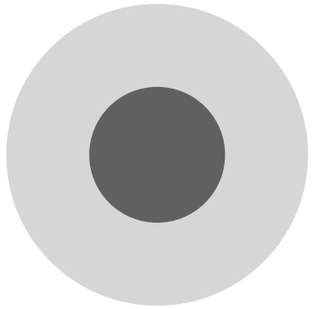


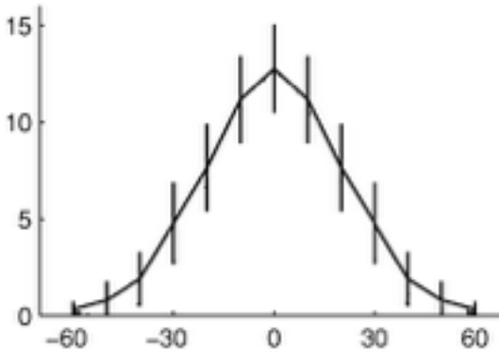
Retina

- Center-surround fields
- Contrast in space and time



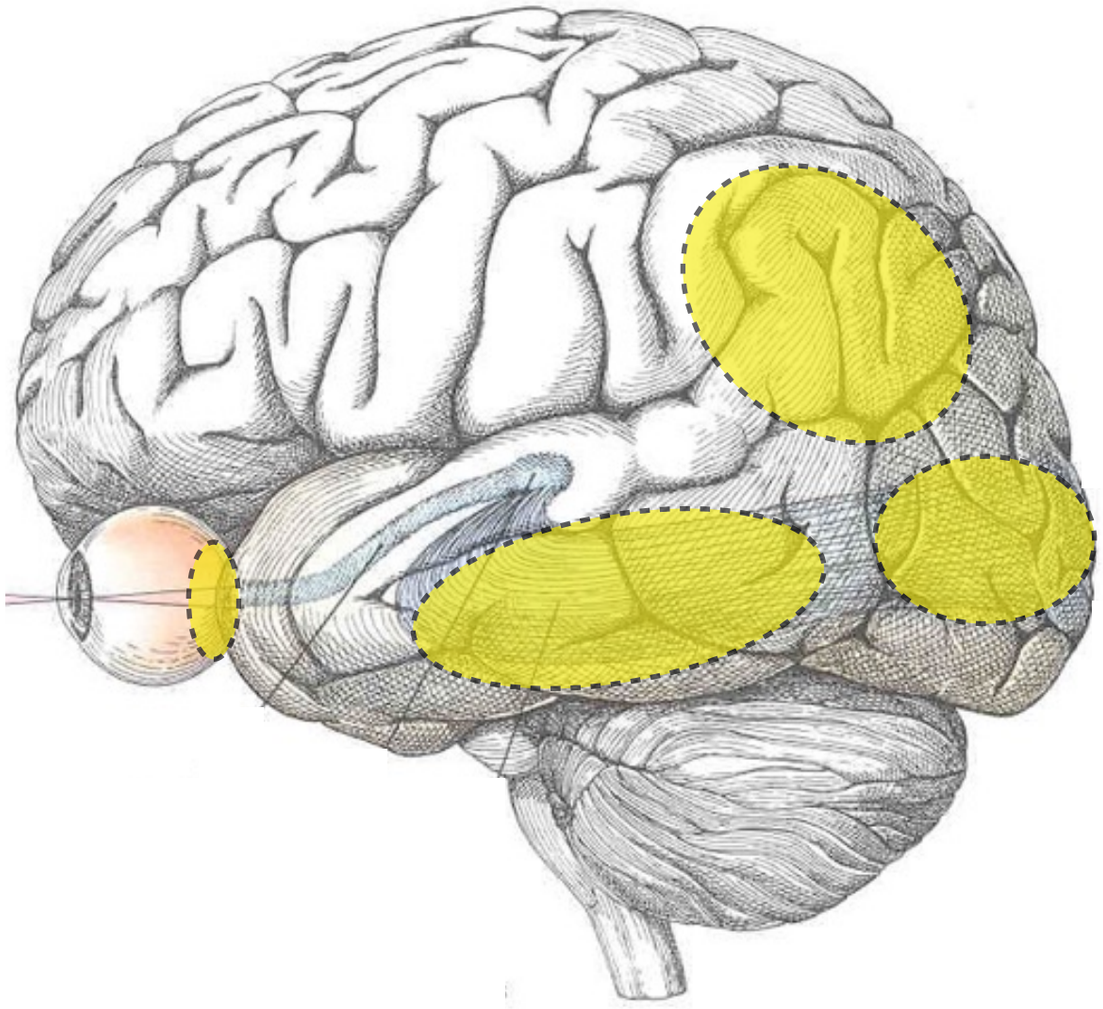
V1

- Simple visual features
- Orientation tuning



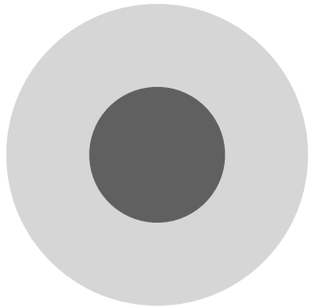
Higher visual areas

Building complex from simple



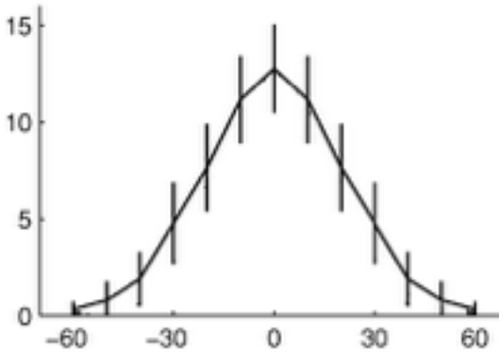
Retina

- Center-surround fields
- Contrast in space and time



V1

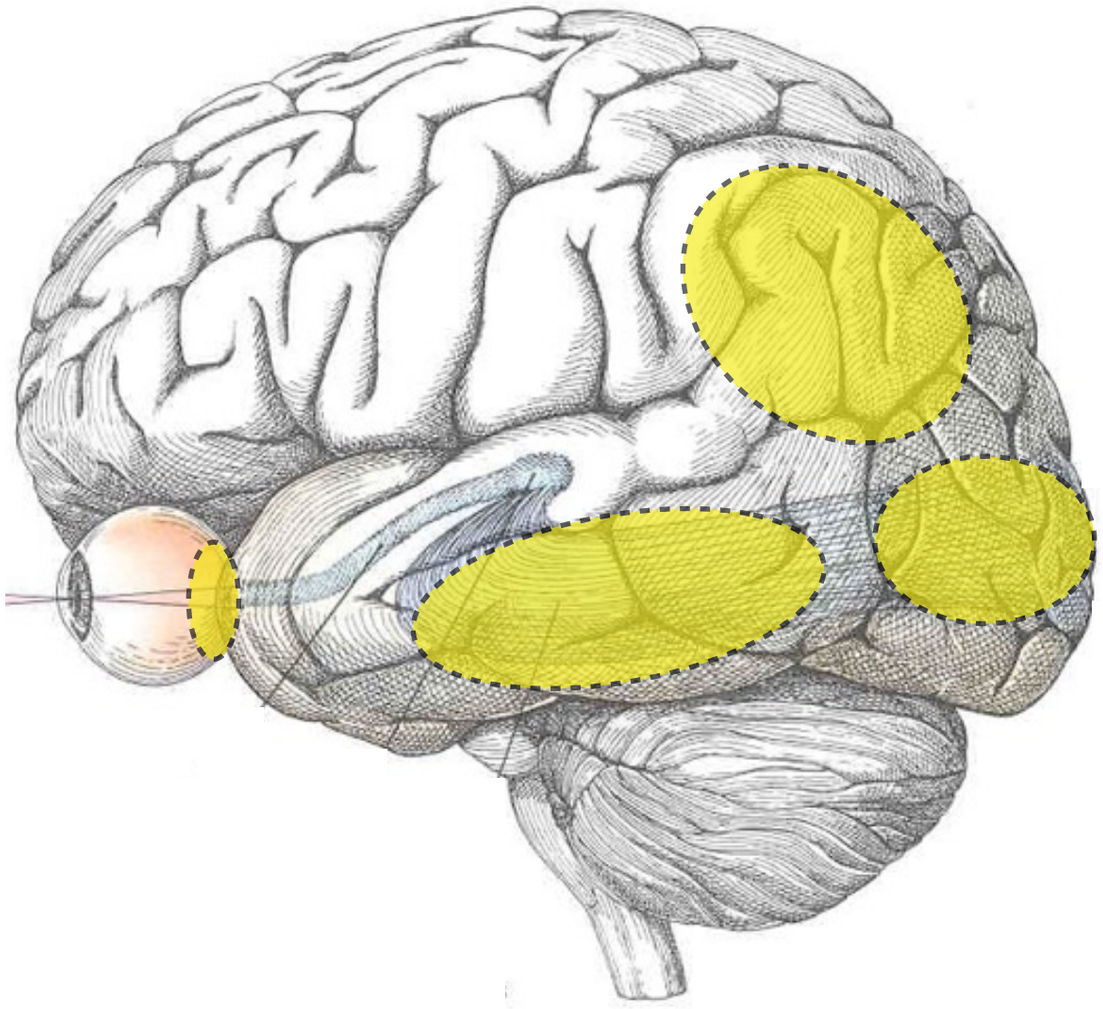
- Simple visual features
- Orientation tuning



Higher visual areas

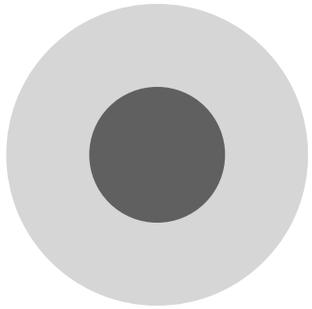
- MT: motion tuning

Building complex from simple



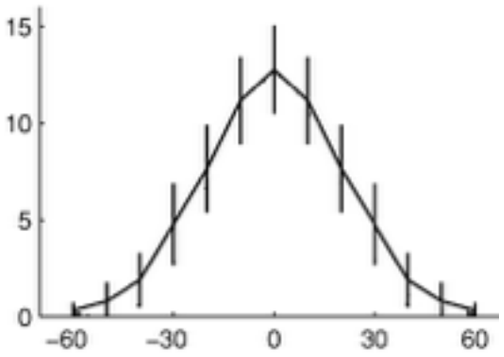
Retina

- Center-surround fields
- Contrast in space and time



V1

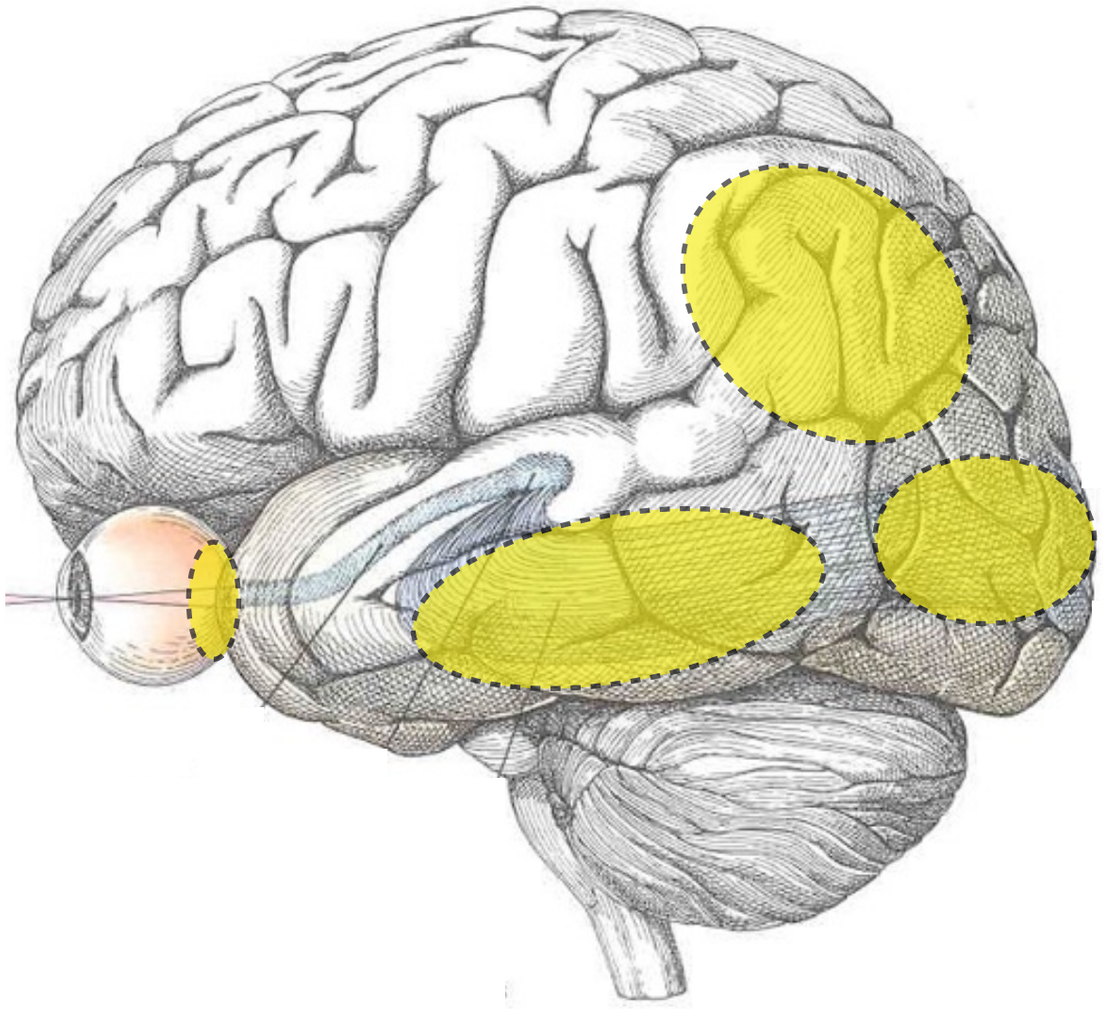
- Simple visual features
- Orientation tuning



Higher visual areas

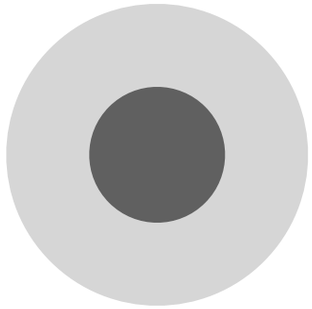
- MT: motion tuning
- IT: complex objects

Building complex from simple



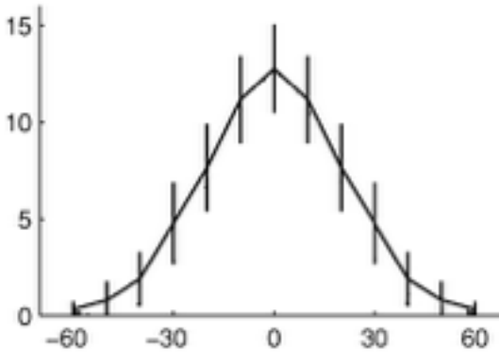
Retina

- Center-surround fields
- Contrast in space and time



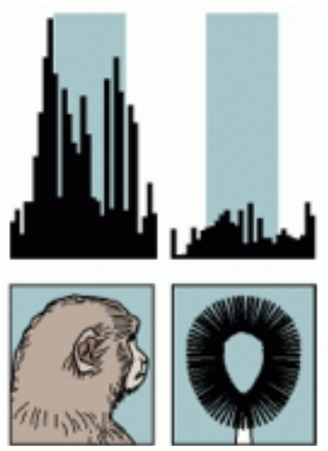
V1

- Simple visual features
- Orientation tuning



Higher visual areas

- MT: motion tuning
- IT: complex objects



Building complex from simple

Building complex from simple

An ‘algorithm’ for the visual system

Building complex from simple

An ‘algorithm’ for the visual system

- Break visual world into simple, easy-to-represent pieces

Building complex from simple

An ‘algorithm’ for the visual system

- Break visual world into simple, easy-to-represent pieces
- Build up selectivity to relevant features from these pieces

Building complex from simple

<u>An ‘algorithm’ for the visual system</u>

- Break visual world into simple, easy-to-represent pieces
- Build up selectivity to relevant features from these pieces

edge here

Building complex from simple

<u>An ‘algorithm’ for the visual system</u>

- Break visual world into simple, easy-to-represent pieces
- Build up selectivity to relevant features from these pieces

edge here + color here

Building complex from simple

<u>An ‘algorithm’ for the visual system</u>

- Break visual world into simple, easy-to-represent pieces
- Build up selectivity to relevant features from these pieces

edge here + color here + motion there + ...

Building complex from simple

<u>An ‘algorithm’ for the visual system</u>

- Break visual world into simple, easy-to-represent pieces
- Build up selectivity to relevant features from these pieces

edge here + color here + motion there + ... = **TIGER!**

The state of the art

The state of the art

What does the visual system *do*?

The state of the art

The state of the art

Represent the visual world

The state of the art

Represent the visual world

“Guess” what’s out there!

Vision as inference

Vision as inference

- ‘Infer’ something about the world

Vision as inference

- ‘Infer’ something about the world
- Should take into account past experiences

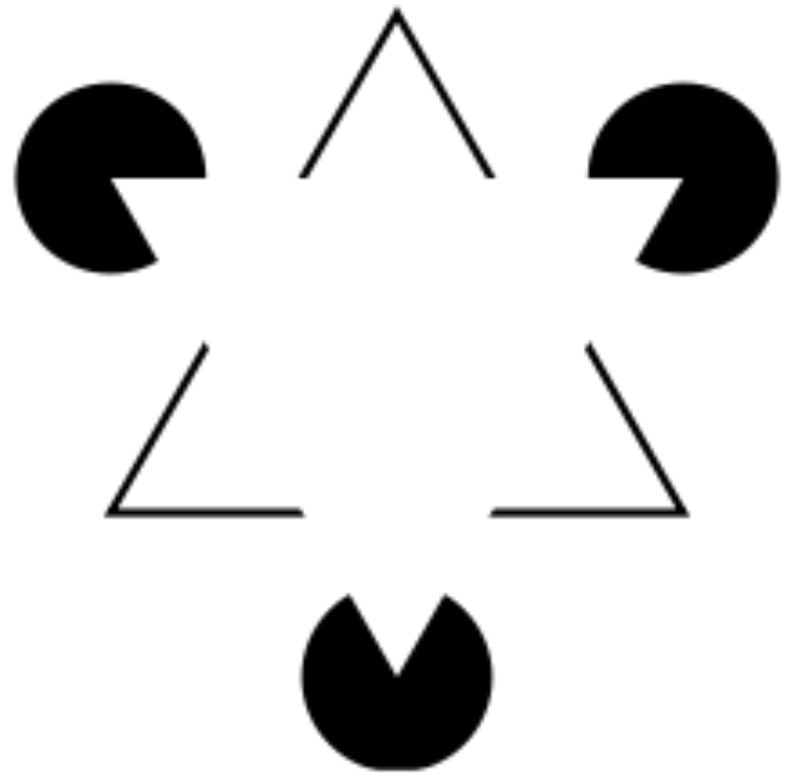
Vision as inference

Vision as inference

Illusory contours

Vision as inference

Illusory contours



https://en.wikipedia.org/wiki/Illusory_contours

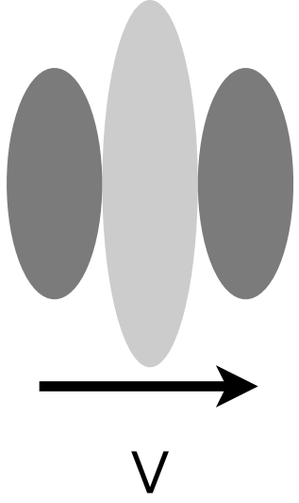
Vision as inference

Vision as inference

Objects perceived as moving more slowly than they are

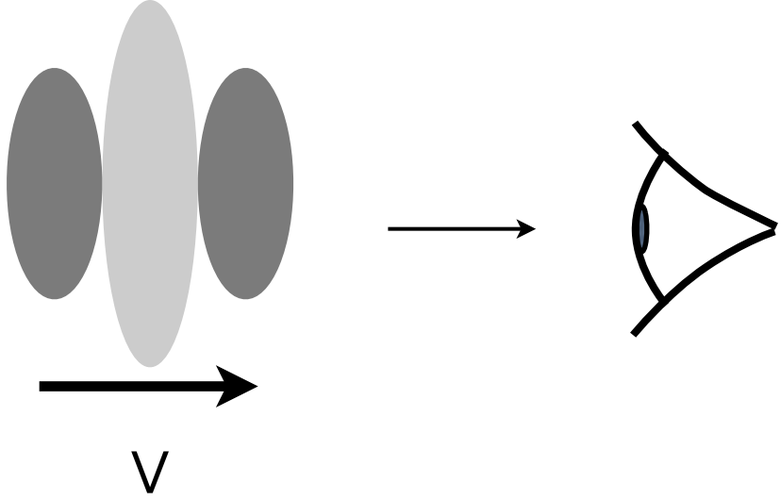
Vision as inference

Objects perceived as moving more slowly than they are



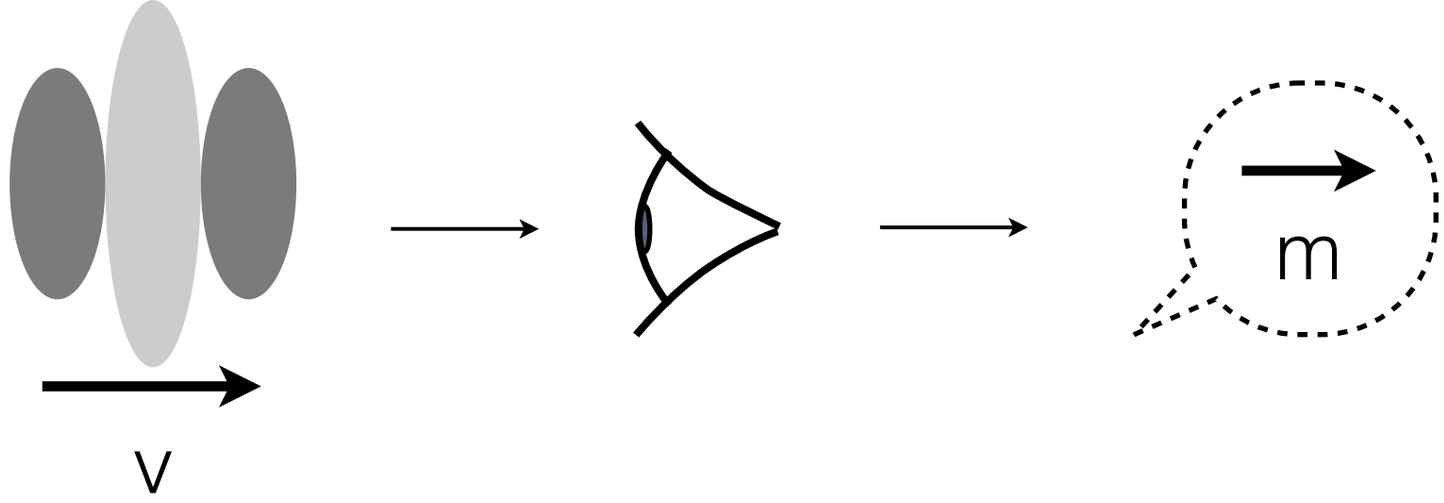
Vision as inference

Objects perceived as moving more slowly than they are



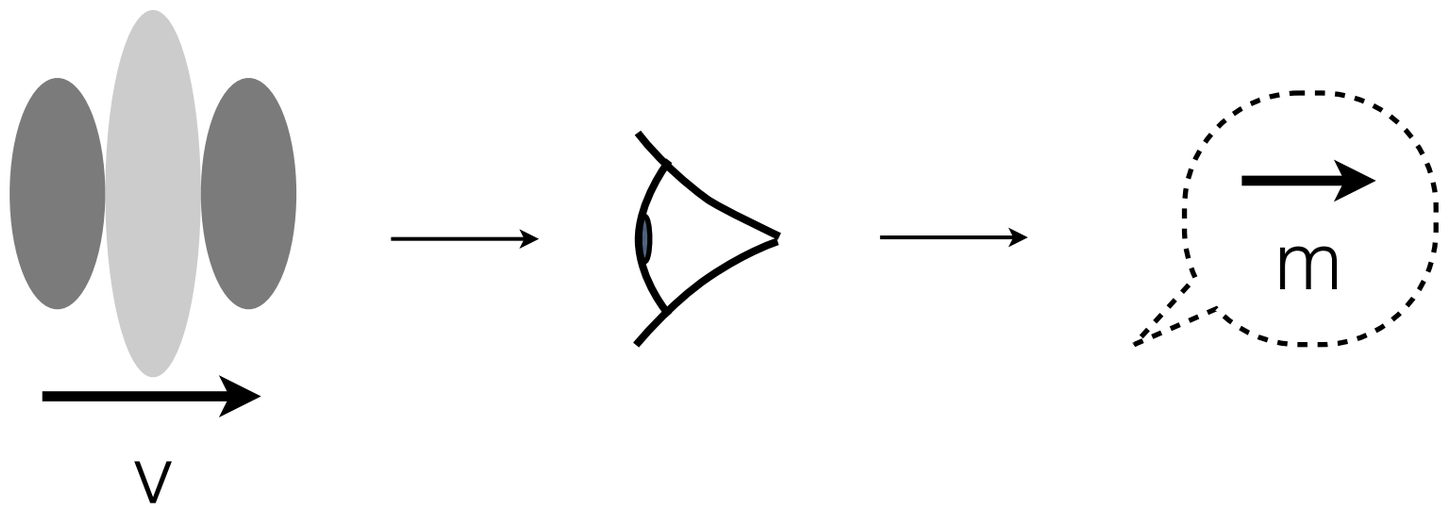
Vision as inference

Objects perceived as moving more slowly than they are



Vision as inference

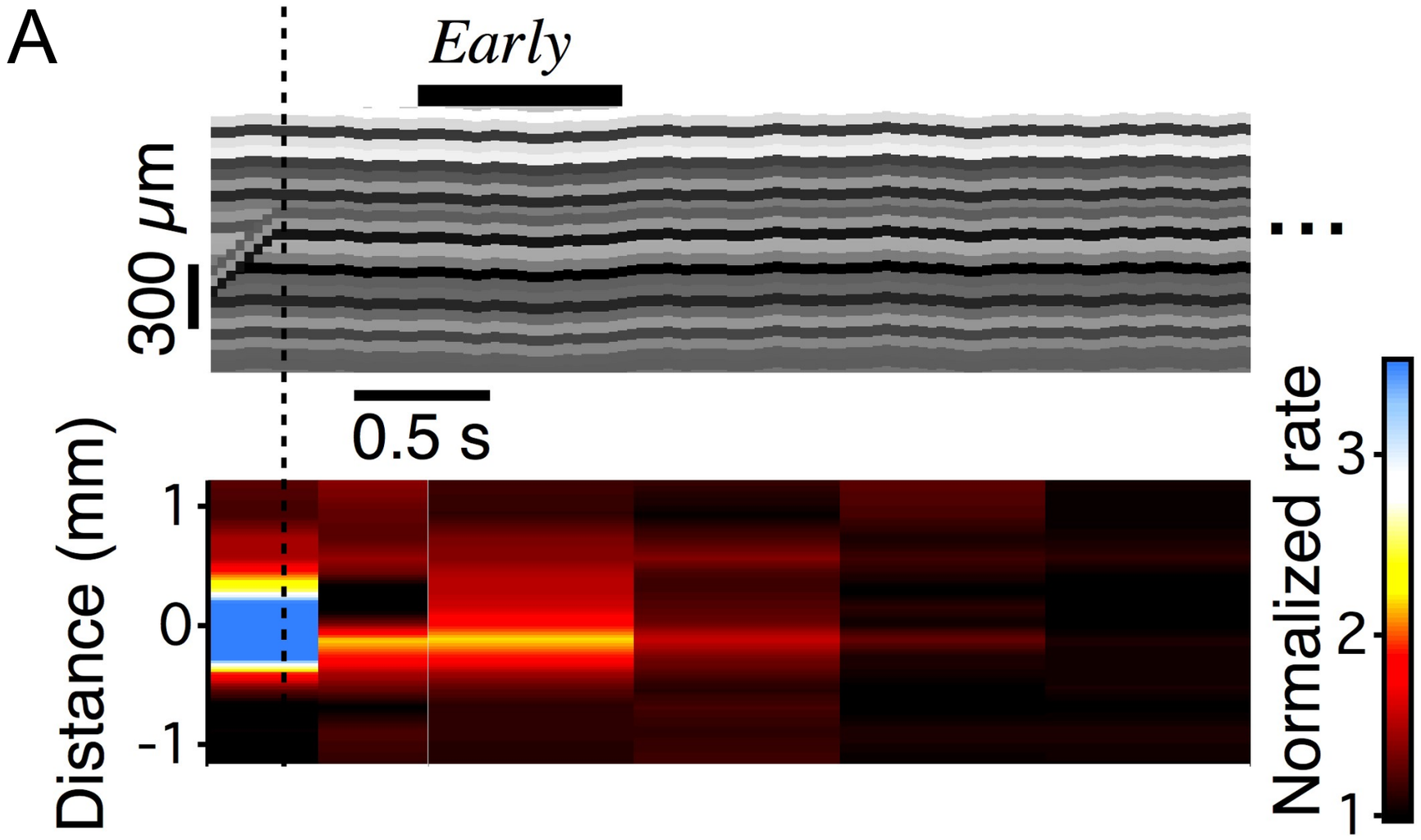
Objects perceived as moving more slowly than they are



But things move slowly!

Vision as inference

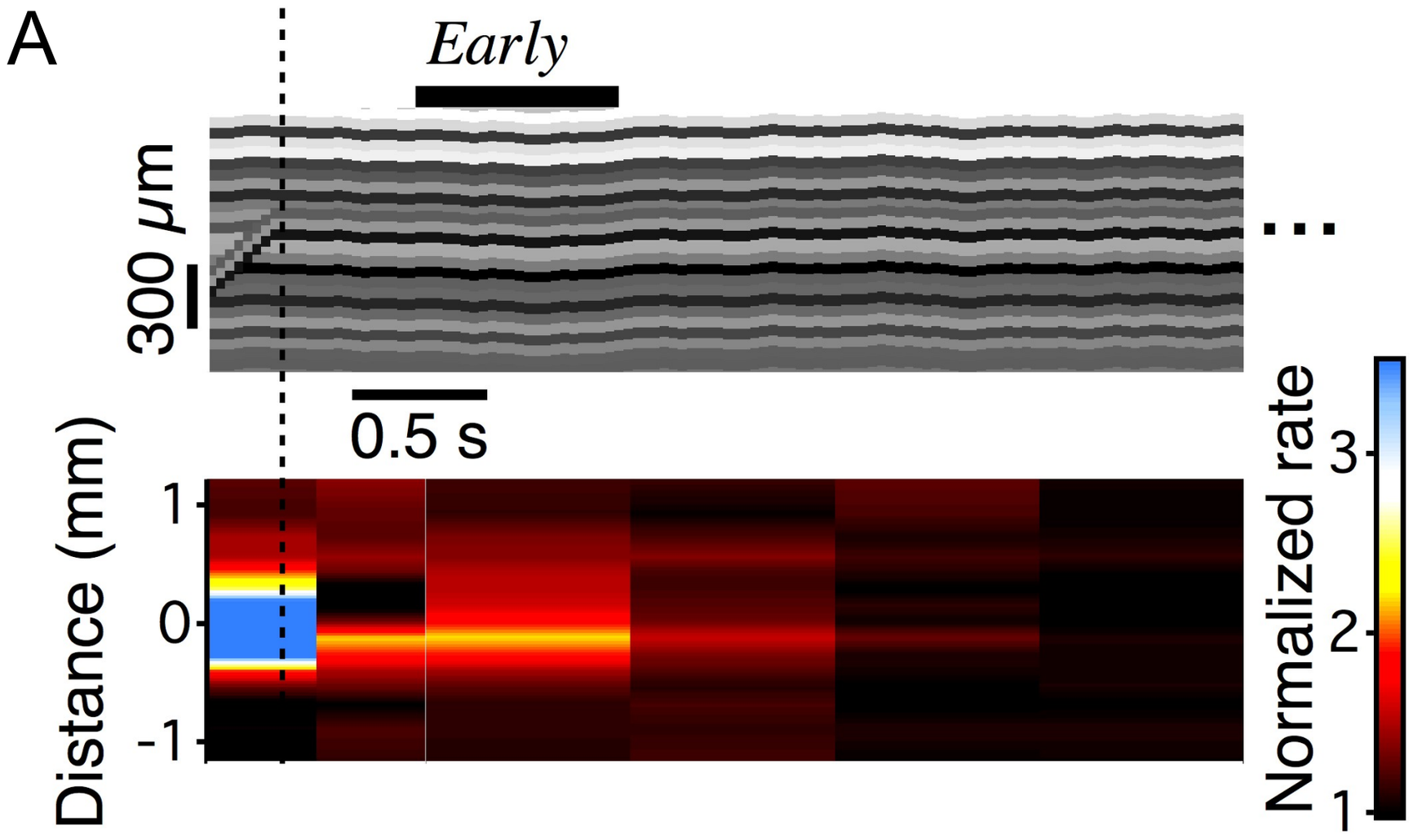
Vision as inference



Kastner & Baccus, 2013

Vision as inference

Certain ganglion cells ‘remember’ an object’s location



Kastner & Baccus, 2013

Looking forward

Looking forward

It is possible that we've dramatically underestimated the complexity of the visual system

http://www.mydestination.com/users/photogravy/bbb#.UfainmTXj7Y

An introduction to the visual system

Thank you!

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bnaecker@stanford.edu