Human Visual Perception

Greg Zelinsky

Psychology

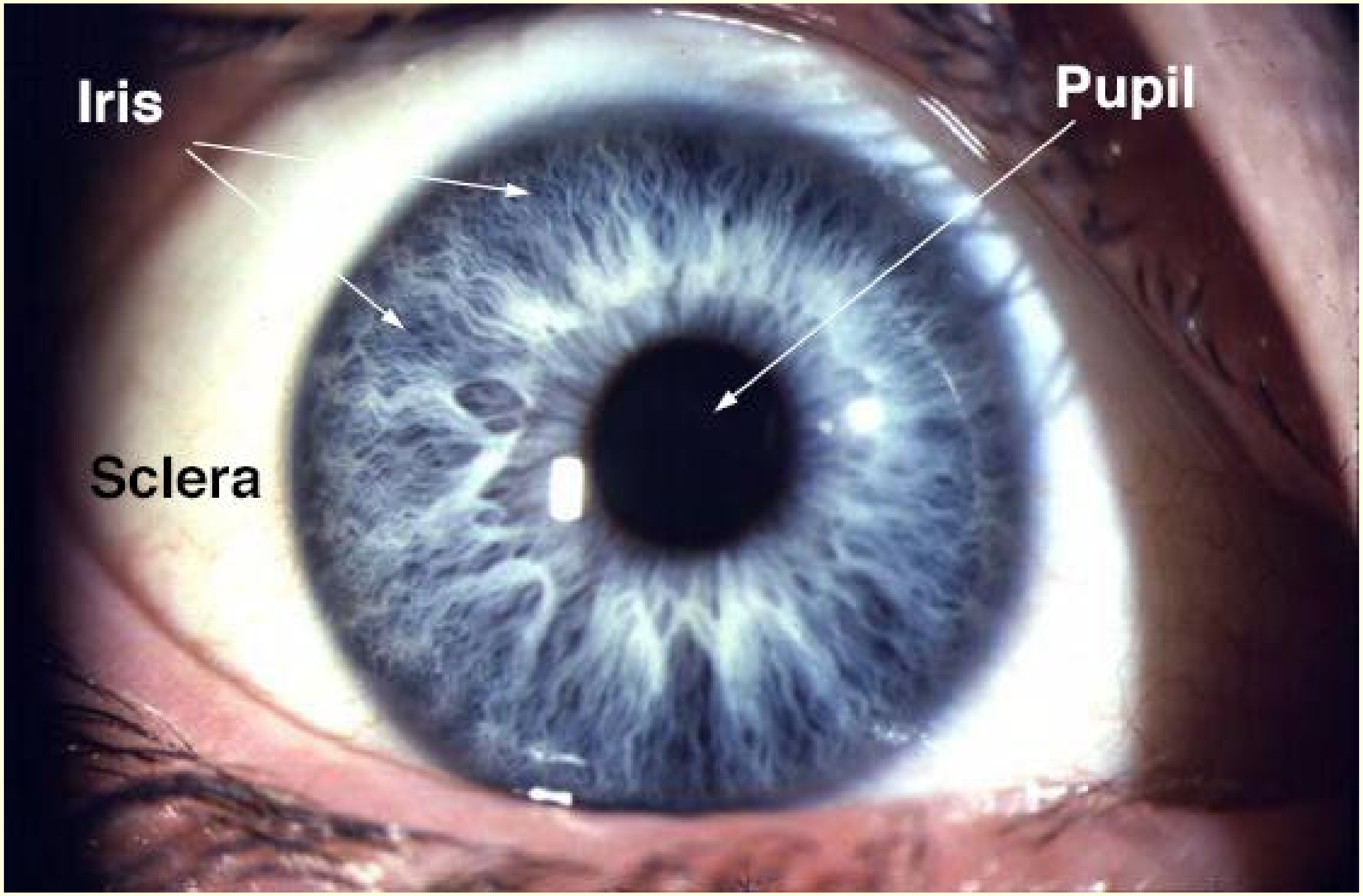
Human Visual Perception

The importance of…

- **Neuronal Convergence**
- **Lateral Inhibition**

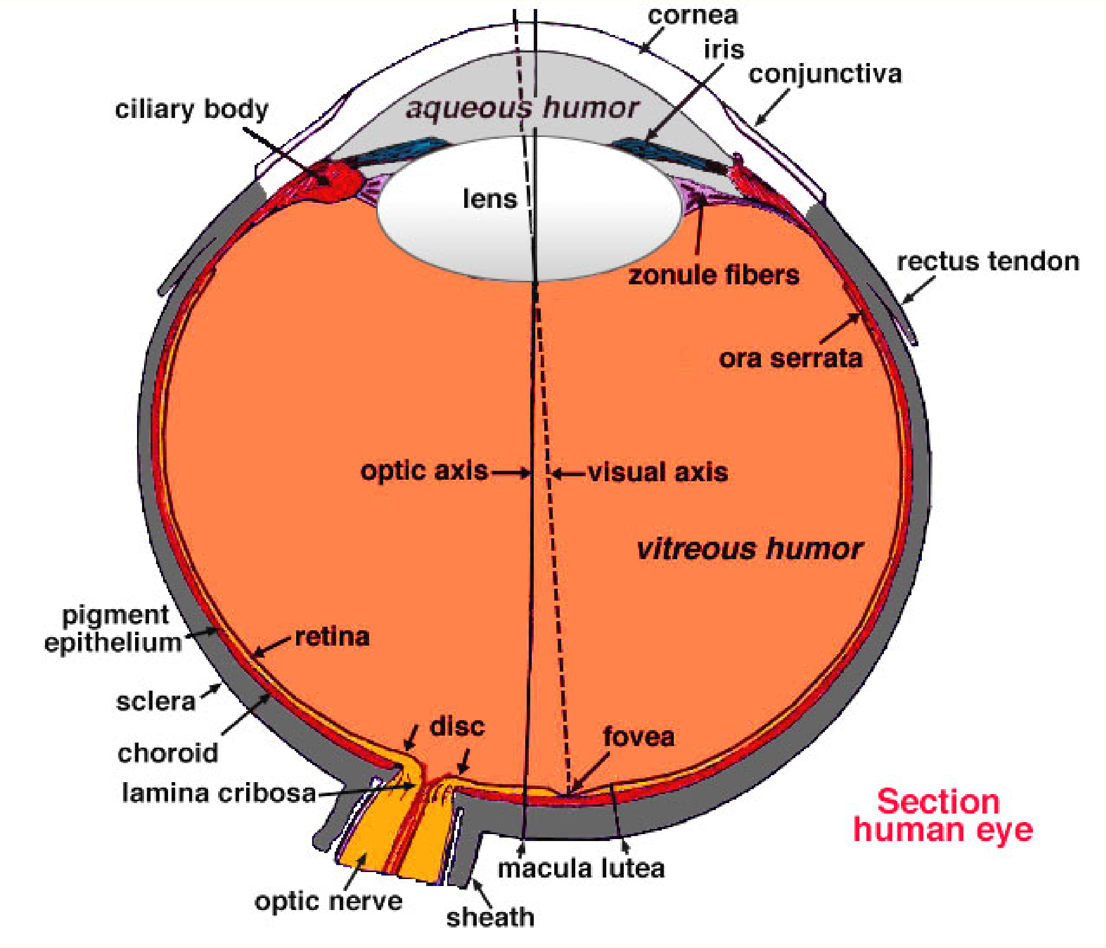
Vision and the Eye

Structure of the Eye

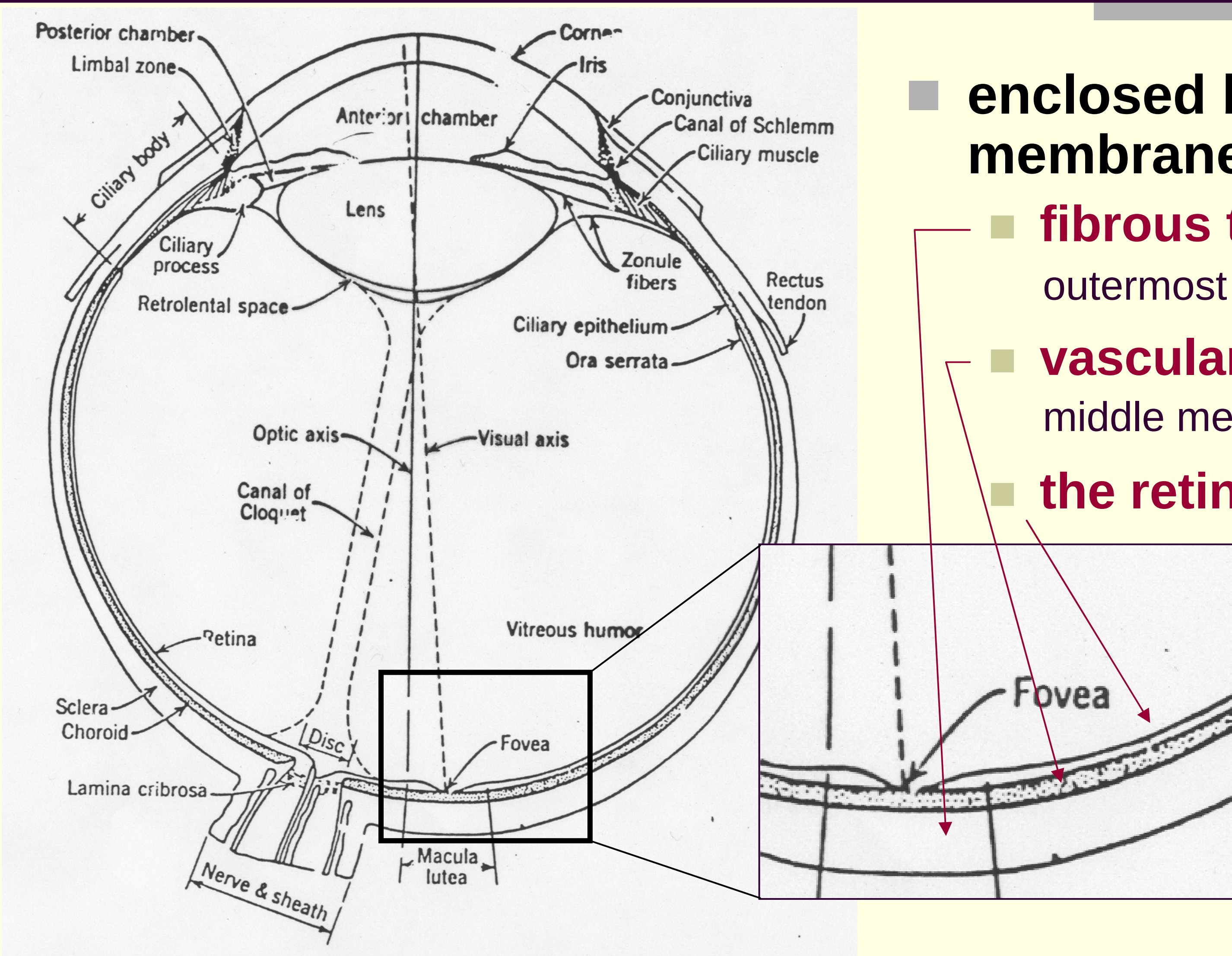


Vision and the Eye

Structure of the Eye



Vision and the Eye

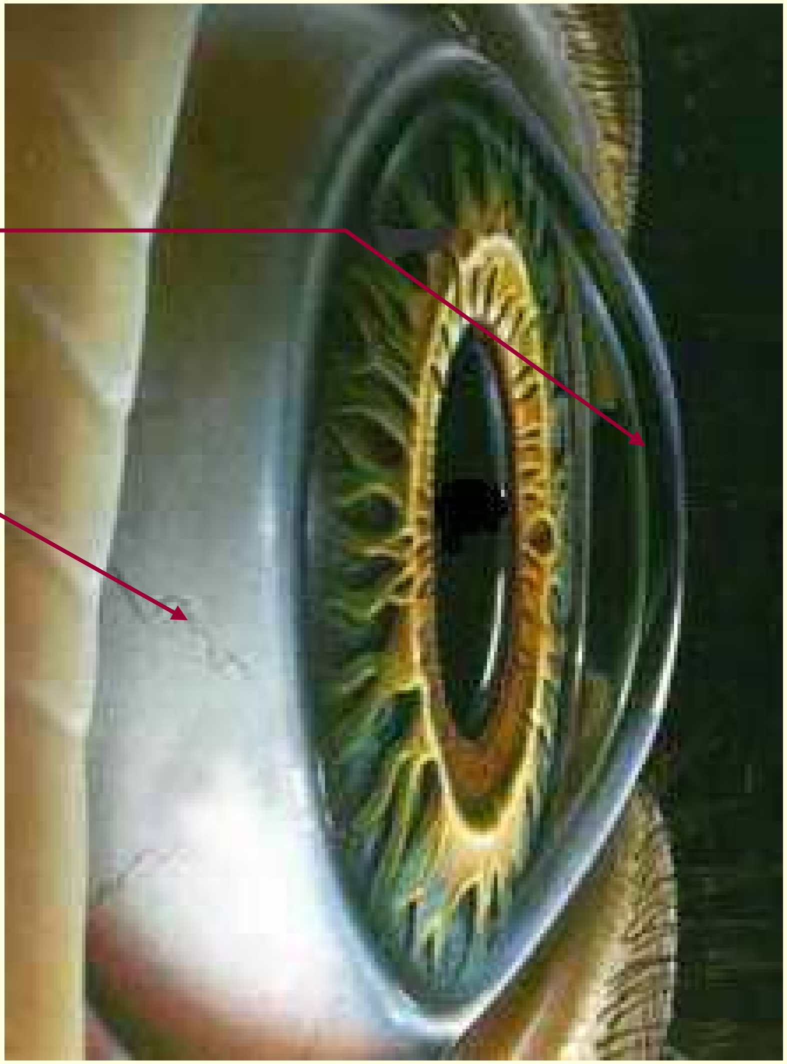


- **enclosed by three membranes**
  - **fibrous tunic**
    outermost membrane
  - **vascular tunic**
    middle membrane
  - **the retina** inner membrane

Vision and the Eye

Fibrous Tunic

- **Cornea**
  - transparent front part of the eye
- **Sclera**
  - the “white” of the eye
  - very tough; gives the globe its structure
  - opaque



Vision and the Eye

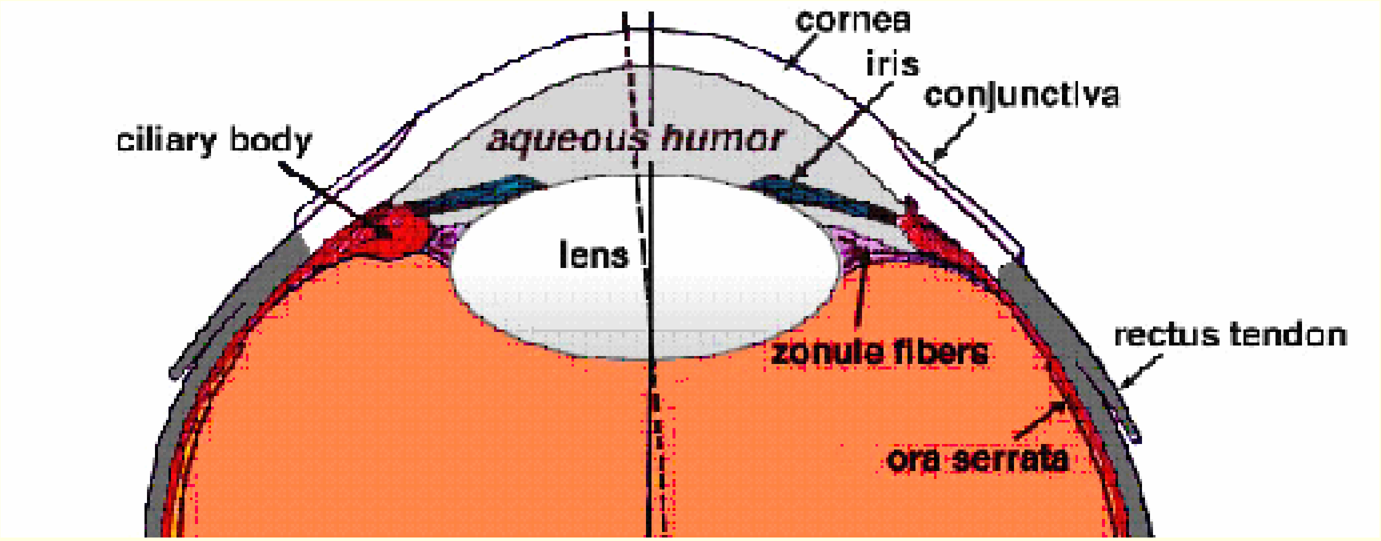
Vacular Tunic (Choroid Layer)

- contains the blood vessels that feed the eye
- heavily pigmented to absorb scattered light (pigment epithelium)

Vision and the Eye

Vacular Tunic (Choroid Layer)

- **Iris**: colored diaphragm muscle that determines pupil size
- **Pupil**: the aperture through which light enters the globe



Vision and the Eye

The Retina (vertical organization)

- **Photoreceptors**
  (rods and cones)

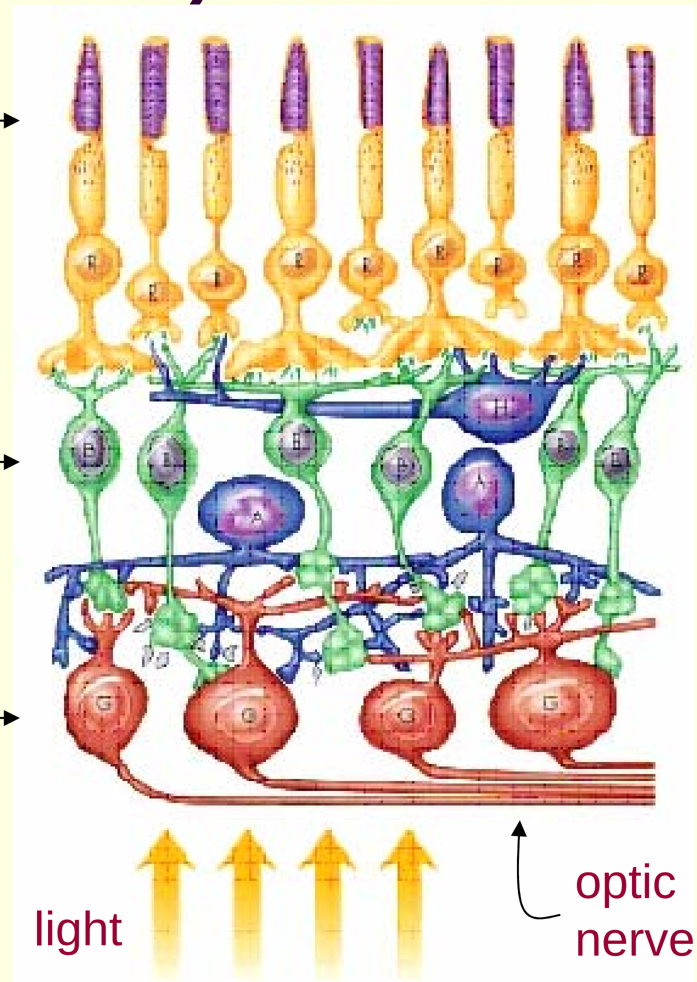
  pigmented cells that produce
  electrical signals when struck by light

- **Bipolar cells**

  synaptically connects cones and rods
  with ganglion cells

- **Ganglion cells**

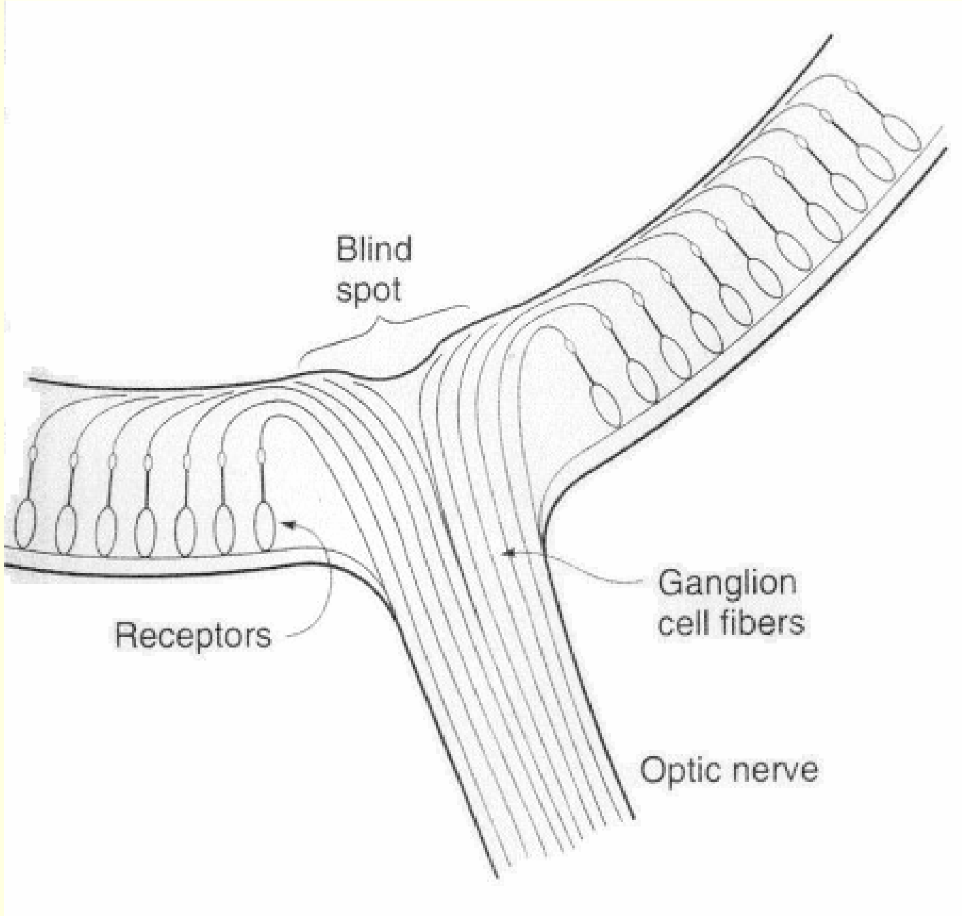
  Axons compose the optic nerve and
  leave the eye via the optic disc
  (blind spot)



Vision and the Eye

The Blind Spot

- A hole in the retina through which the ganglion cell axons leave the eye and travel to the brain
- We are blind at this location in our visual field due to the absence of photorecepters at the optic disc



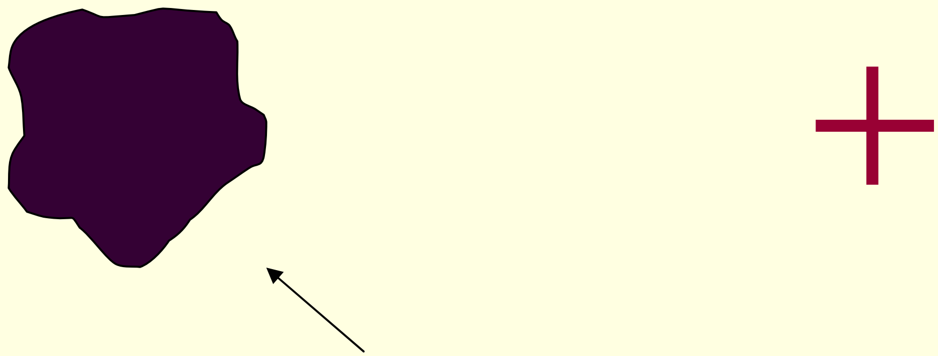
Vision and the Eye

The Blind Spot

If you close your right eye and look at the cross, the spot will seem to disappear when it falls on your blind spot

Vision and the Eye

The Blind Spot



Instead of seeing this…

If you close your right eye and look at the cross, the spot will seem to disappear when it falls on your blind spot

Vision and the Eye

The Blind Spot

...you see this

Rather than seeing a black hole in our vision, our visual system fills this hole with the color and texture of the region surrounding the blind spot. This process is known as **perceptual filling-in**.

If you close your right eye and look at the cross, the spot will seem to disappear when it falls on your blind spot

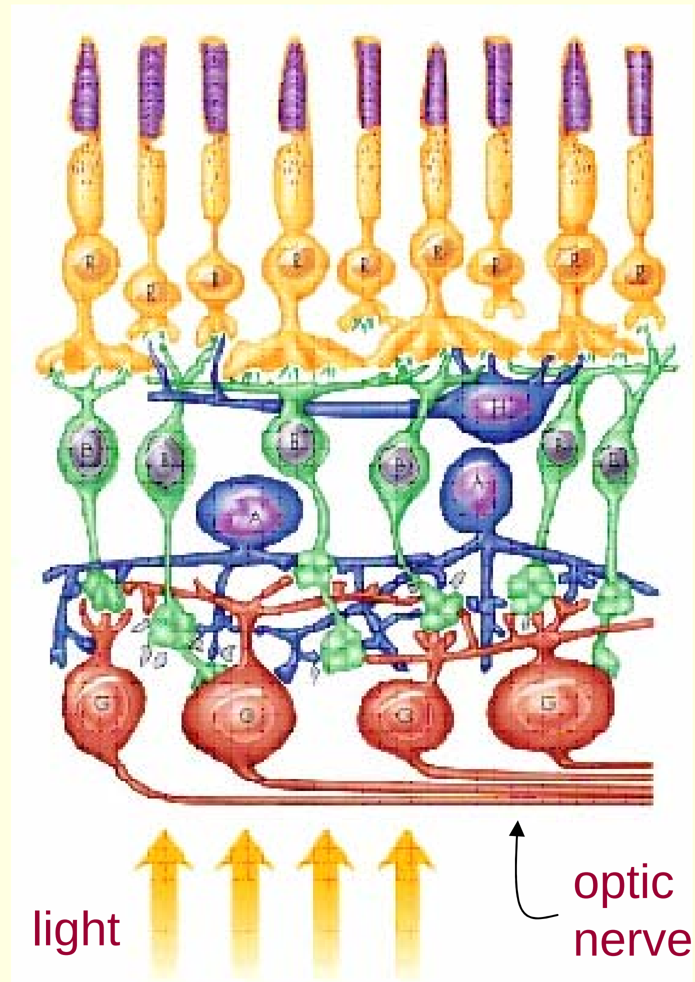
Vision and the Eye

The Retina
(vertical organization)

Photoreceptors

Bipolar cells

Ganglion cells



Vision and the Eye

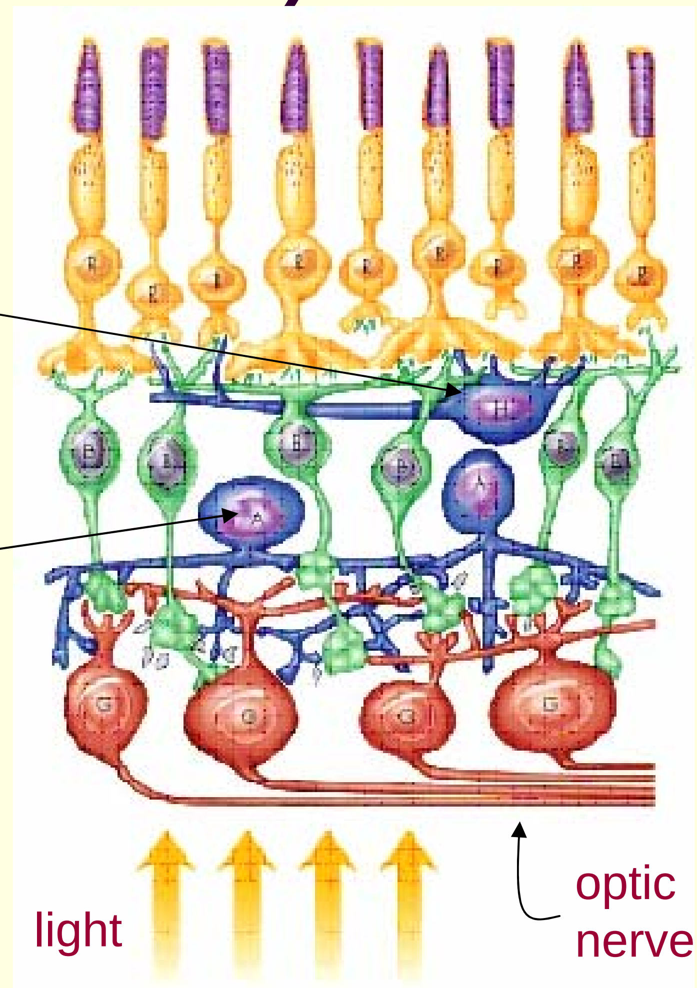
The Retina (horizontal organization)

- **Horizontal cells**

  modulate activity between the photo-receptors and the bipolar cells

- **Amacrine cells**

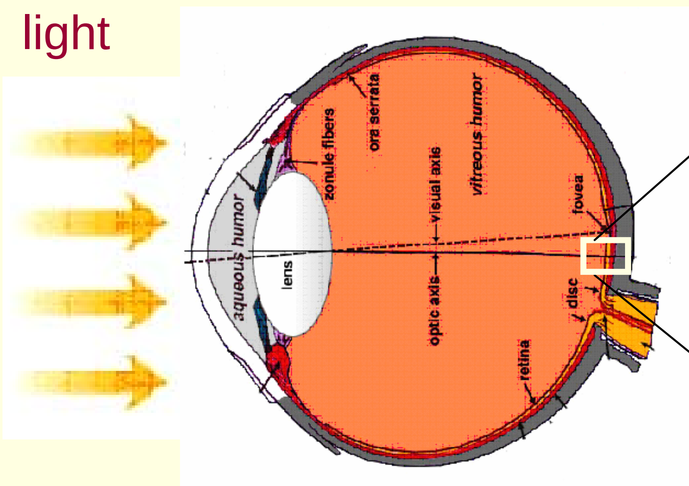
  modulate activity between the bipolar and the ganglion cells



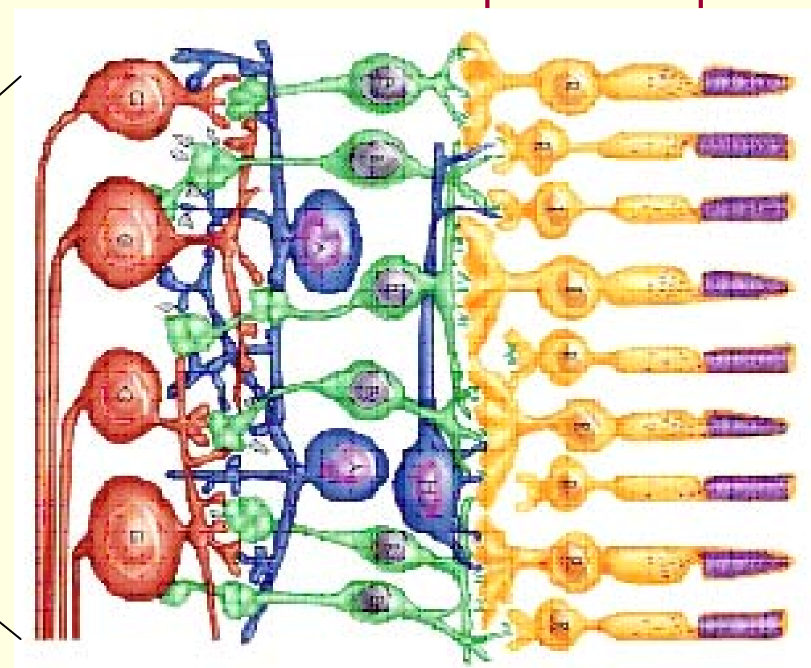
Vision and the Eye

The Retina (backwards organization?)

light



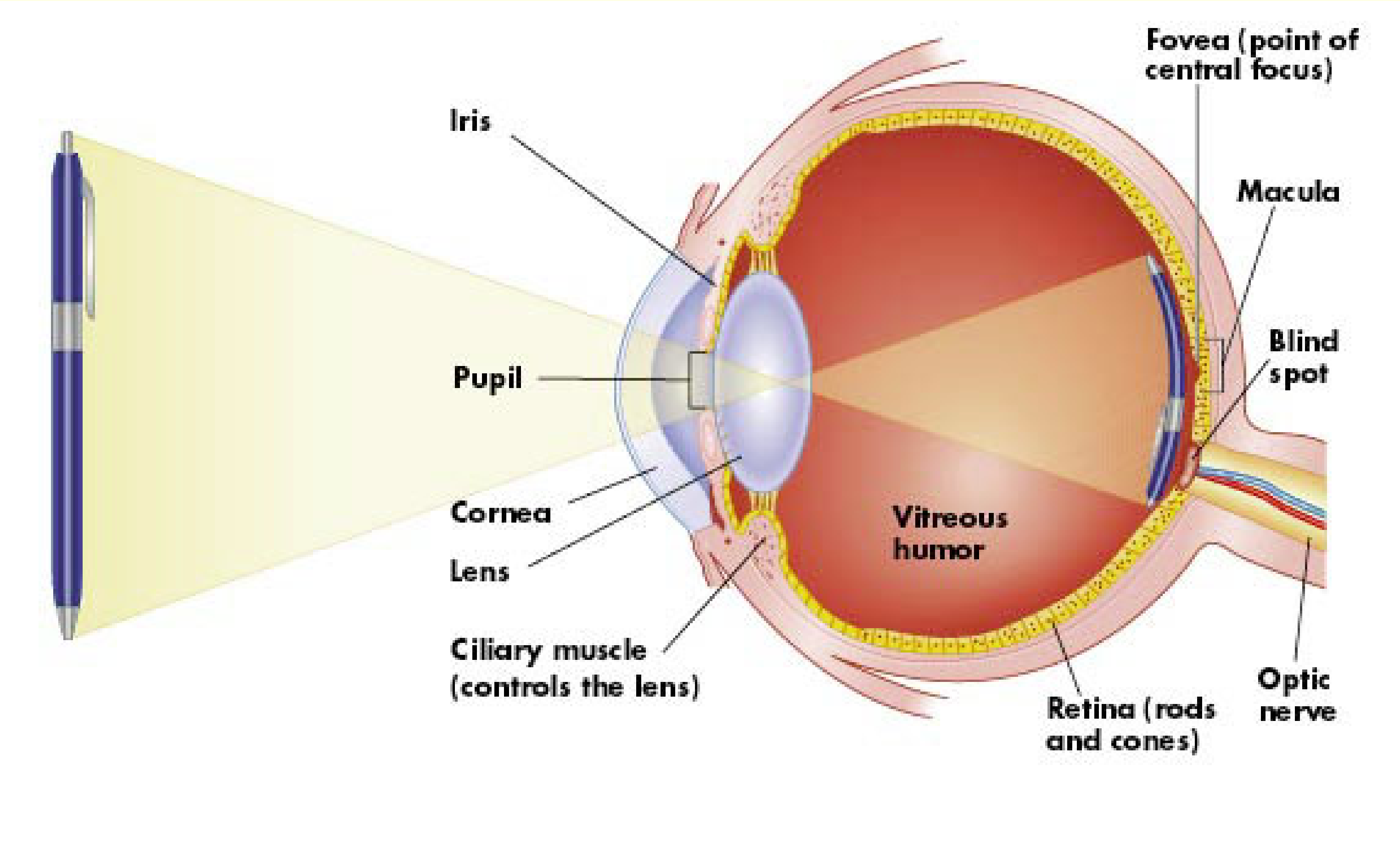
photoreceptors



Light coming through the pupil must pass, not only through the cornea, lens, and the aqueous and vitreous humors, but also through the ganglion, amacrine, bipolar, and horizontal cells before reaching the photoreceptors.

Vision and the Eye

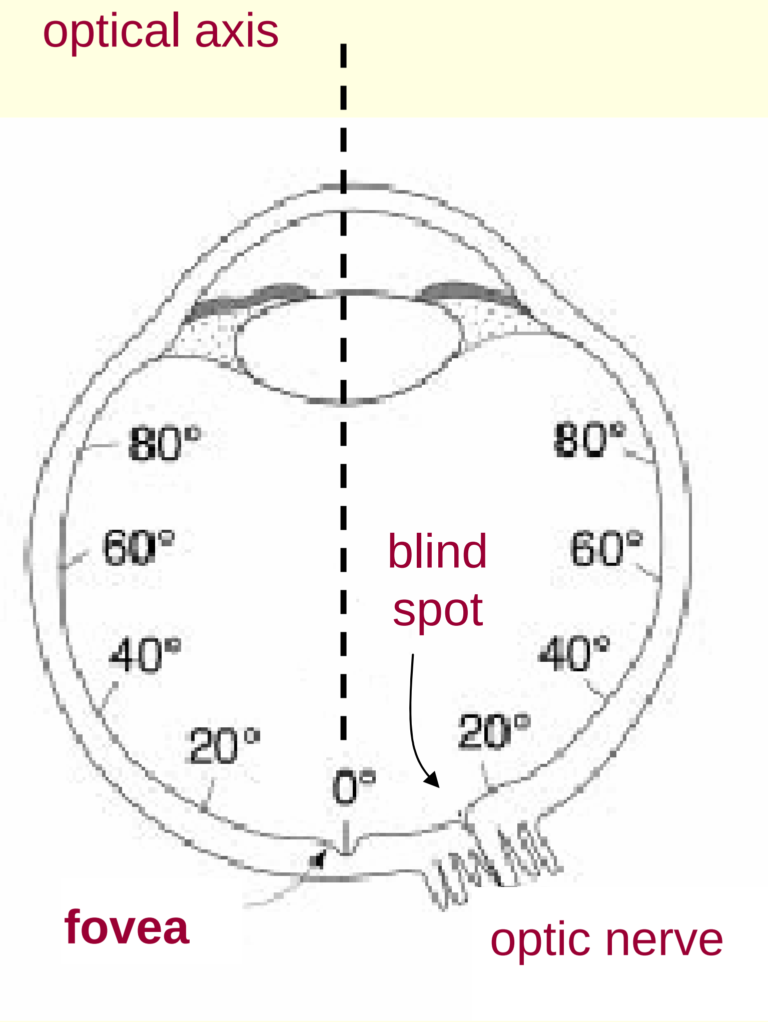
The Fovea



Vision and the Eye

The Fovea

- The part of the retina with the best visual acuity (i.e., the ability of the eye to resolve fine details)
- In order to have the clearest possible view of an object, we want to image the object on our fovea
- Visual acuity decreases with increasing distance from the fovea



Vision and the Eye

The Fovea

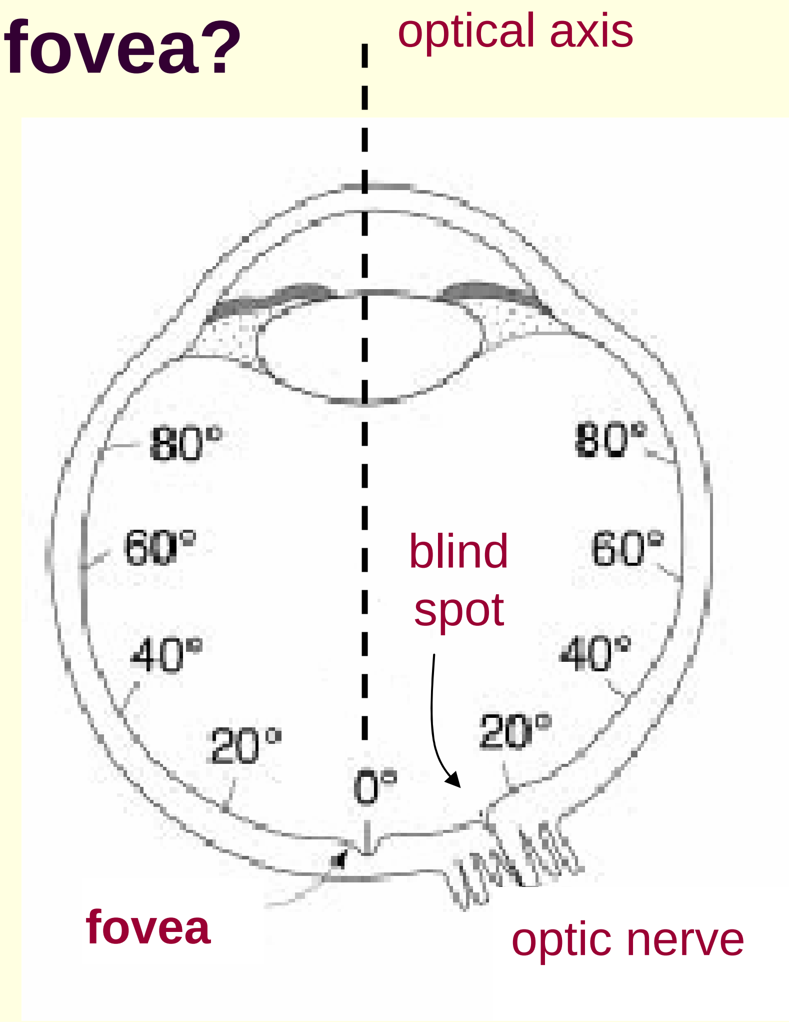
- **Keep your eyes on the bee!**

(Wilson S. Geisler & Jeffrey S. Perry, University of Texas)

Vision and the Eye

Why is acuity best at the fovea?

- The fovea is very near the optical axis; images at the fovea therefore have the fewest lens distortions

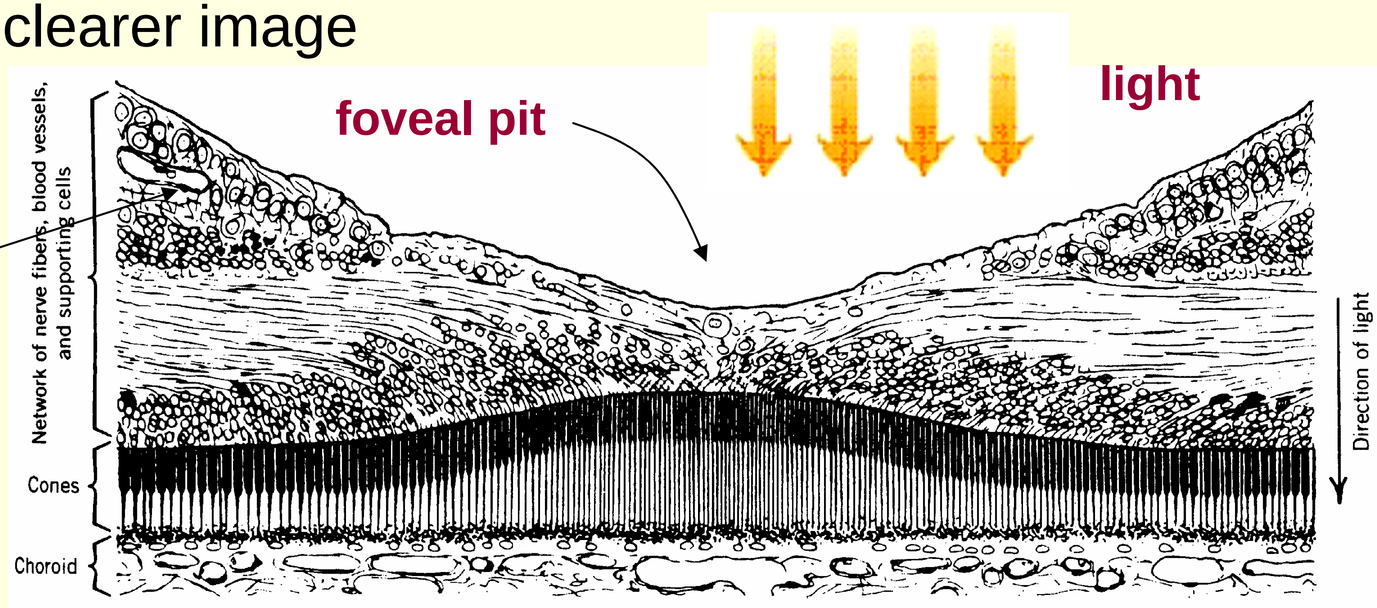


Vision and the Eye

Why is acuity best at the fovea?

- The fovea is very near the optical axis; images at the fovea therefore have the fewest lens distortions
- Very few cell bodies are located at the fovea. Given that these cells would normally scatter light, their absence allows a clearer image

Cell bodies avoid blocking the light



Vision and the Eye

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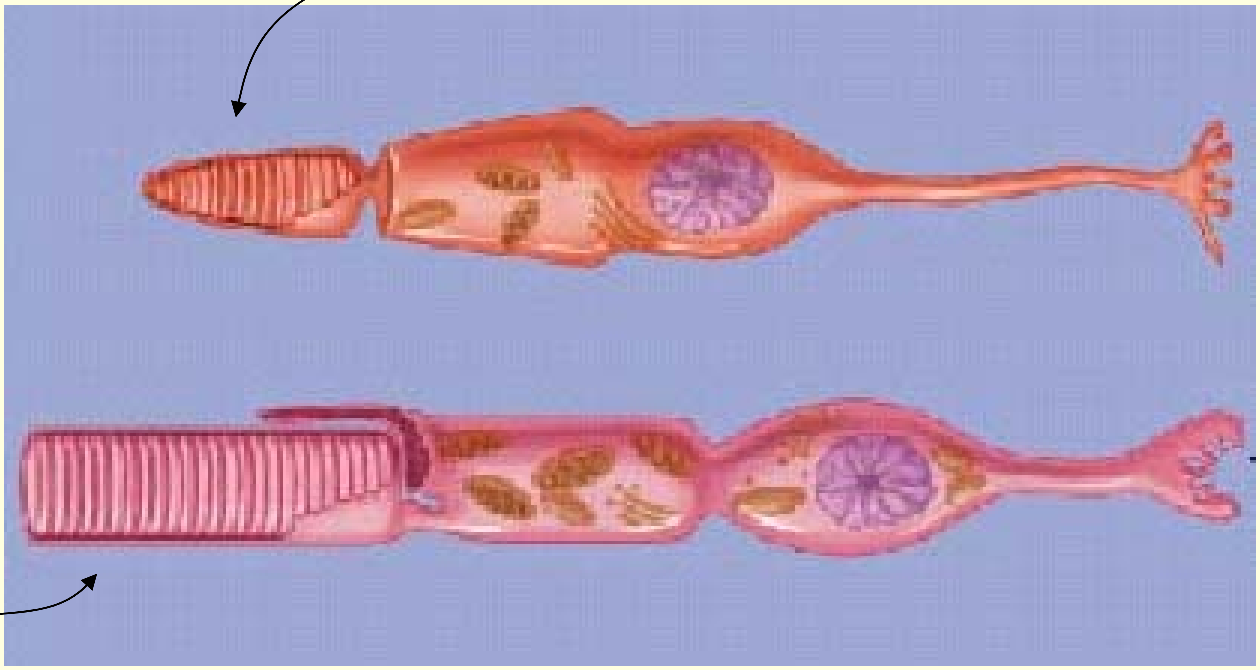
- The fovea is very near the optical axis; images at the fovea therefore have the fewest lens distortions
- Very few cell bodies are located at the fovea. Given that these cells would normally scatter light, their absence allows a clearer image
- The type and distribution of photoreceptors at the fovea affect visual acuity. The fovea contains mainly 'cone' photoreceptors, which are specialized for detailed pattern vision.

Vision and the Eye

Photoreceptors

Cone

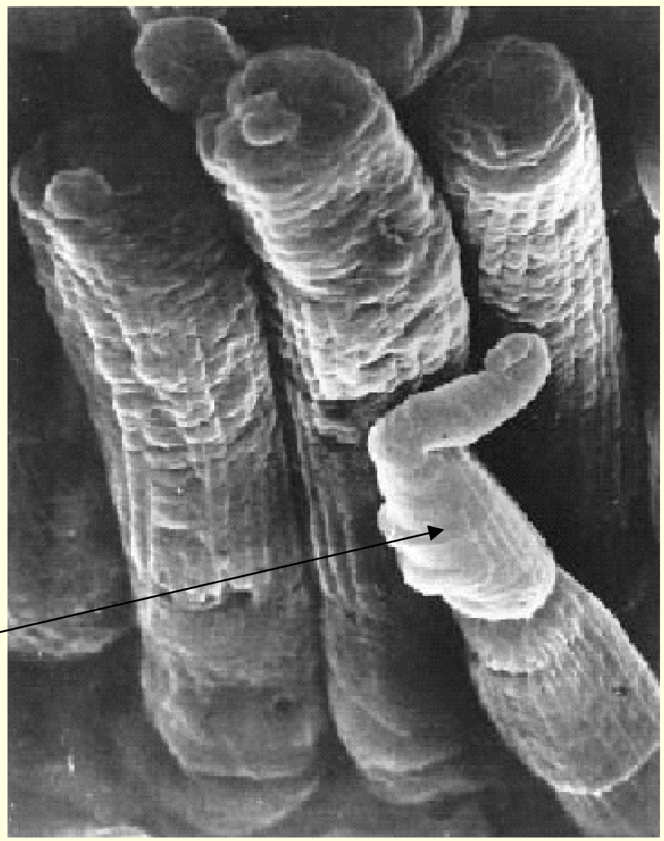


Rod

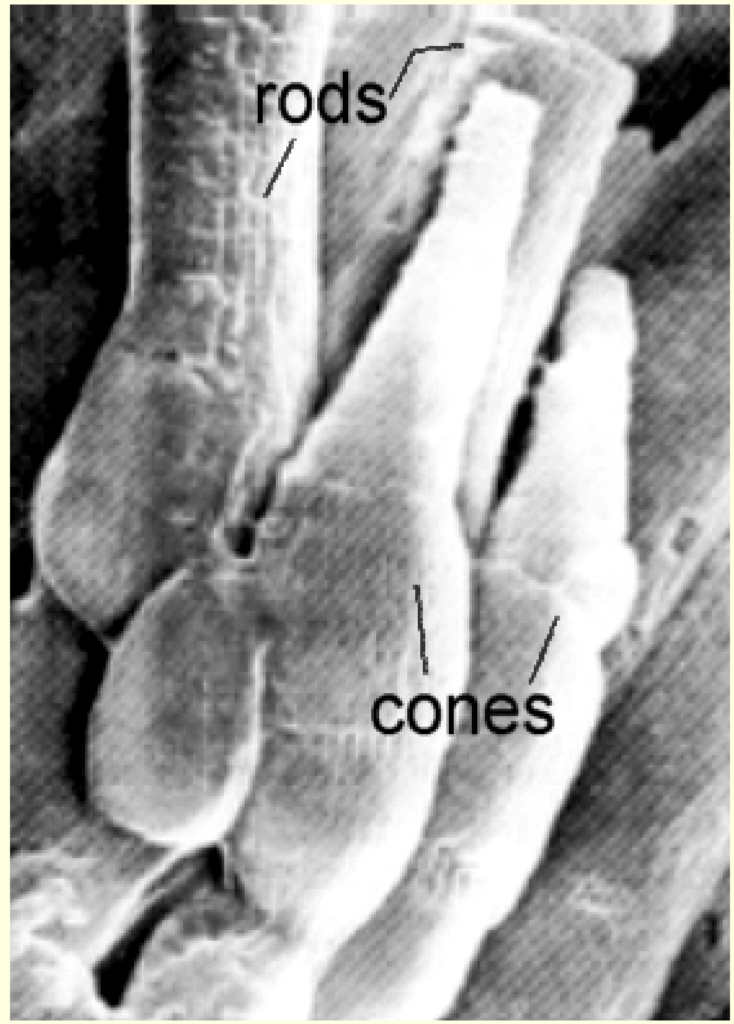
Vision and the Eye

Photoreceptors

rods



cone



Vision and the Eye

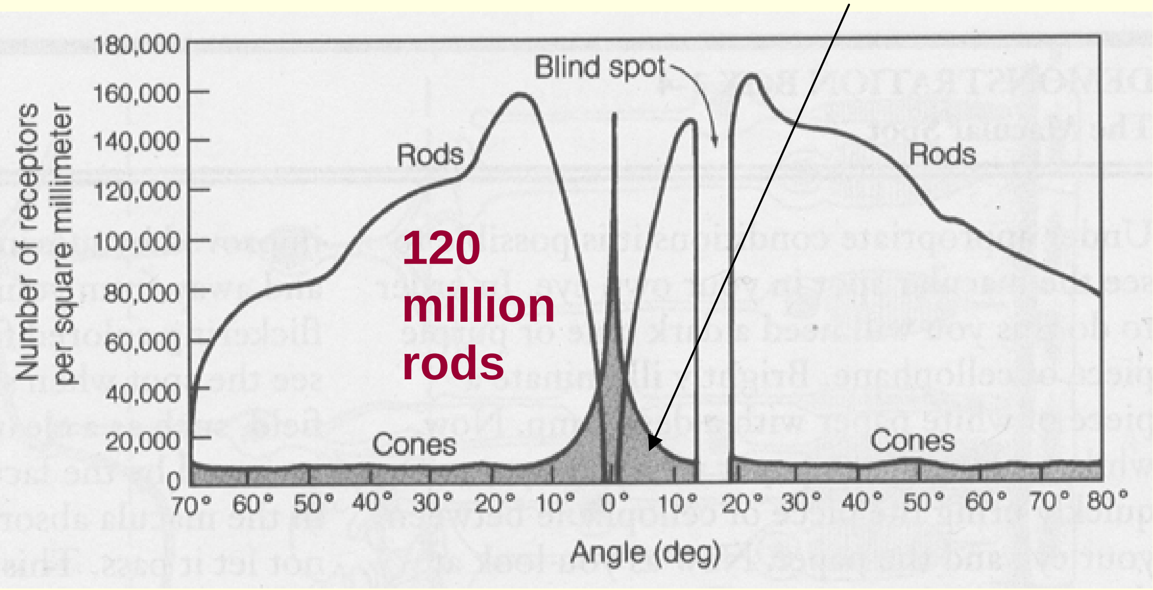
Differences between Rods and Cones

- They are distributed differently on the retina. The fovea contains only cones; the peripheral retina contains rods and cones, but mainly rods

5-8 million cones

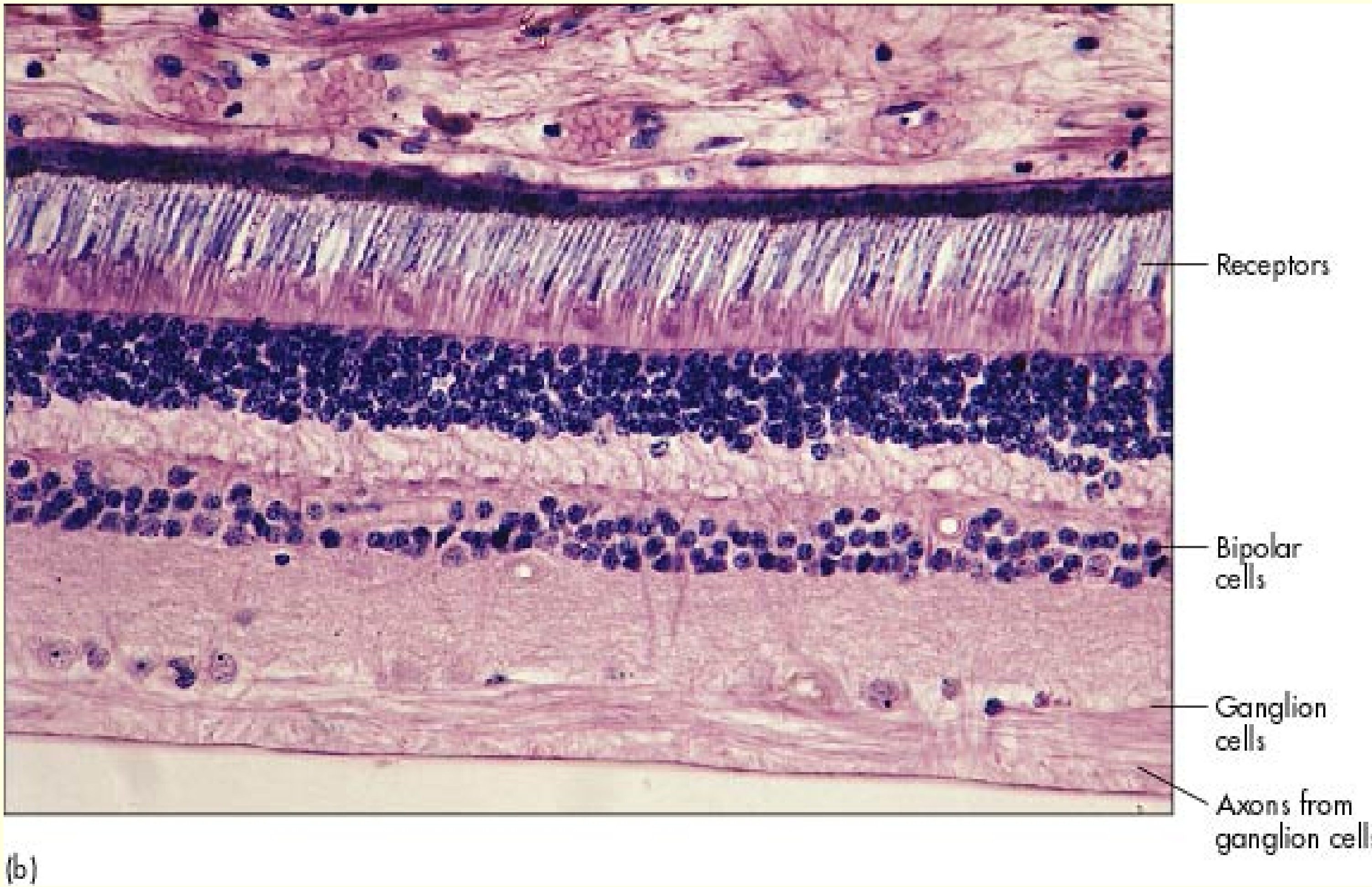
The size of the rod-free fovea is defined as the central 1-1.7 degrees of visual angle.

Two separate visual systems: central (cones) and peripheral (rods)



Vision and the Eye

The Retina (vertical organization)



Vision and the Eye

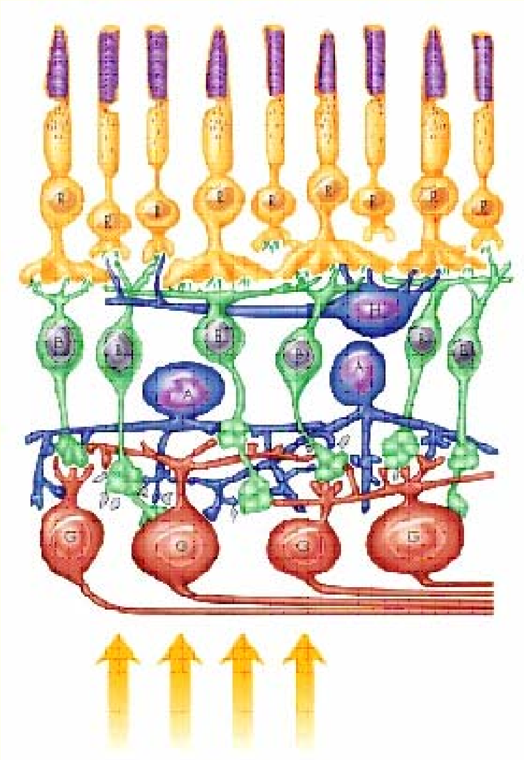
Differences between Rods and Cones

- They are distributed differently on the retina. The fovea contains only cones; the peripheral retina contains rods and cones, but mainly rods
- Rods and cones are wired differently to the ganglion cells
  - Neuronal Convergence: many cells projecting to a smaller number of cells. On average…
    - 120 rods project to 1 ganglion cell
    - 1-5 cones project to 1 ganglion cell

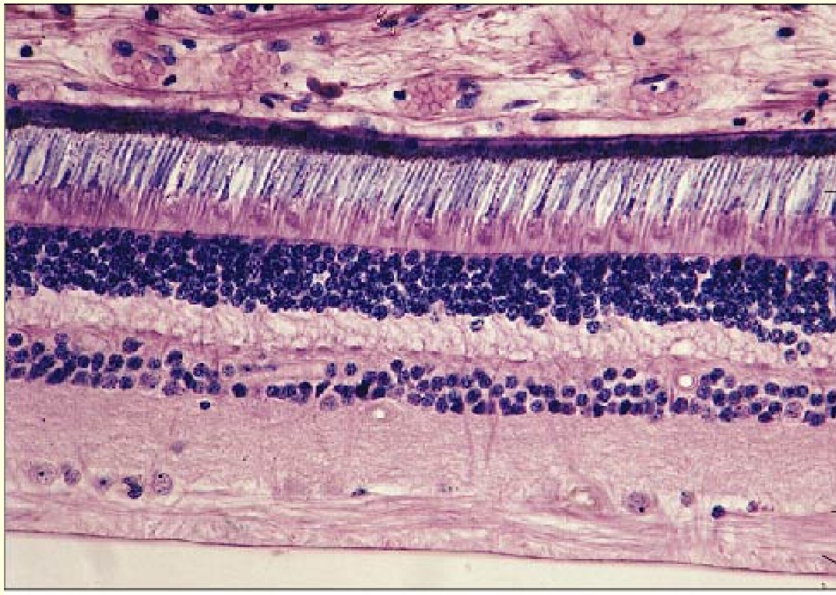
Vision and the Eye

Convergence

foveal retina



peripheral retina



Vision and the Eye

Differences between Rods and Cones

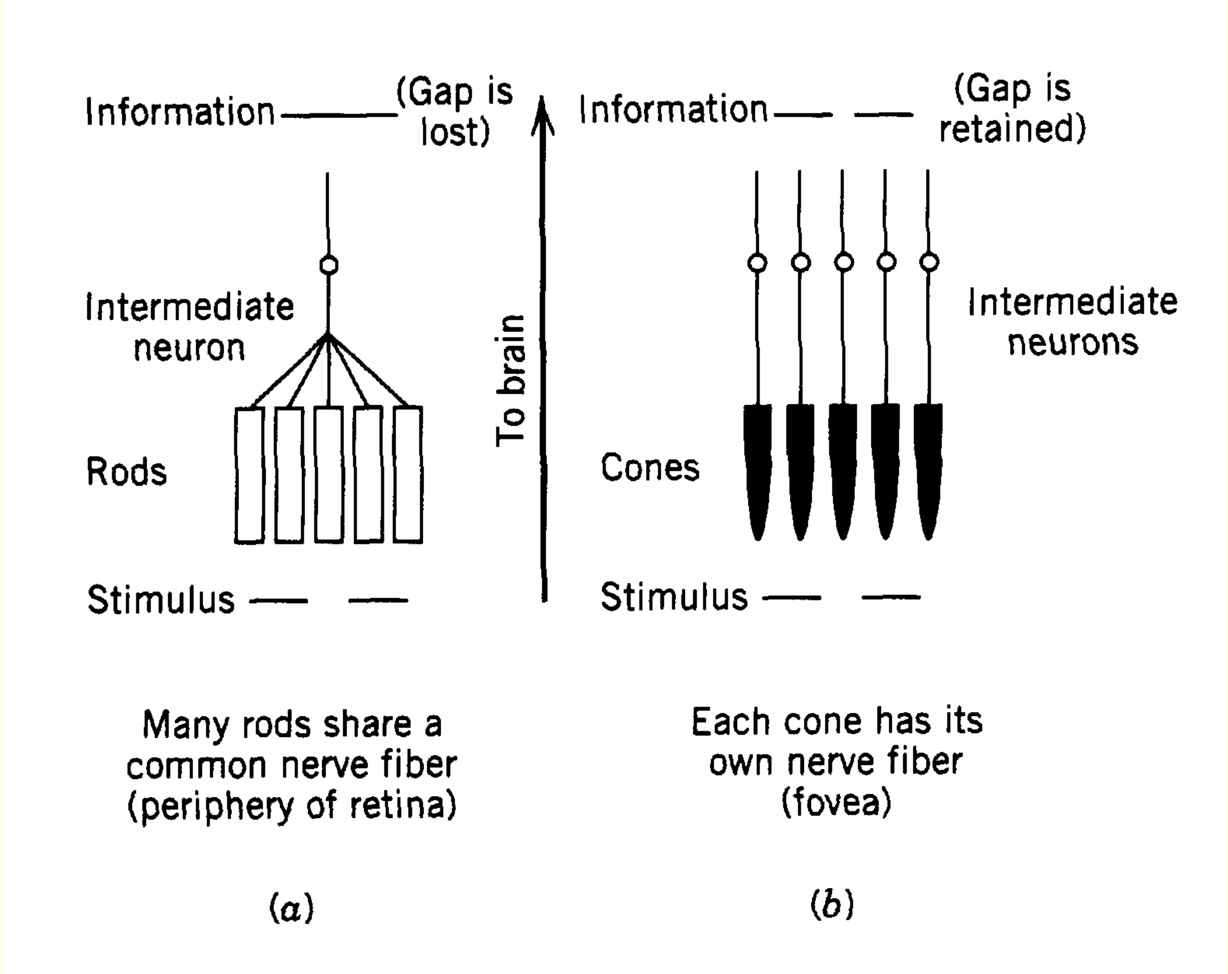
- They are distributed differently on the retina. The fovea contains only cones; the peripheral retina contains rods and cones, but mainly rods
- Rods and cones are wired differently to the ganglion cells
  - Neuronal Convergence: many cells projecting to a smaller number of cells.
    - Cone vision: good spatial resolution, poor luminance sensitivity
    - Rod vision: poor spatial resolution, good luminance sensitivity

Vision and the Eye

Convergence

The more photo-receptors converging on a ganglion cell, the greater the loss of spatial information

This is a big reason why visual acuity is better in the fovea compared to the peripheral retina



Vision and the Eye

Differences between Rods and Cones

Rods	Cones
Peripheral vision	Central vision
~120 million	5-8 million
Poor spatial resolution	Good spatial resolution
More light sensitive	Less light sensitive
Function in dim light	Function in daylight
Achromatic	Color vision

Neuronal Computation

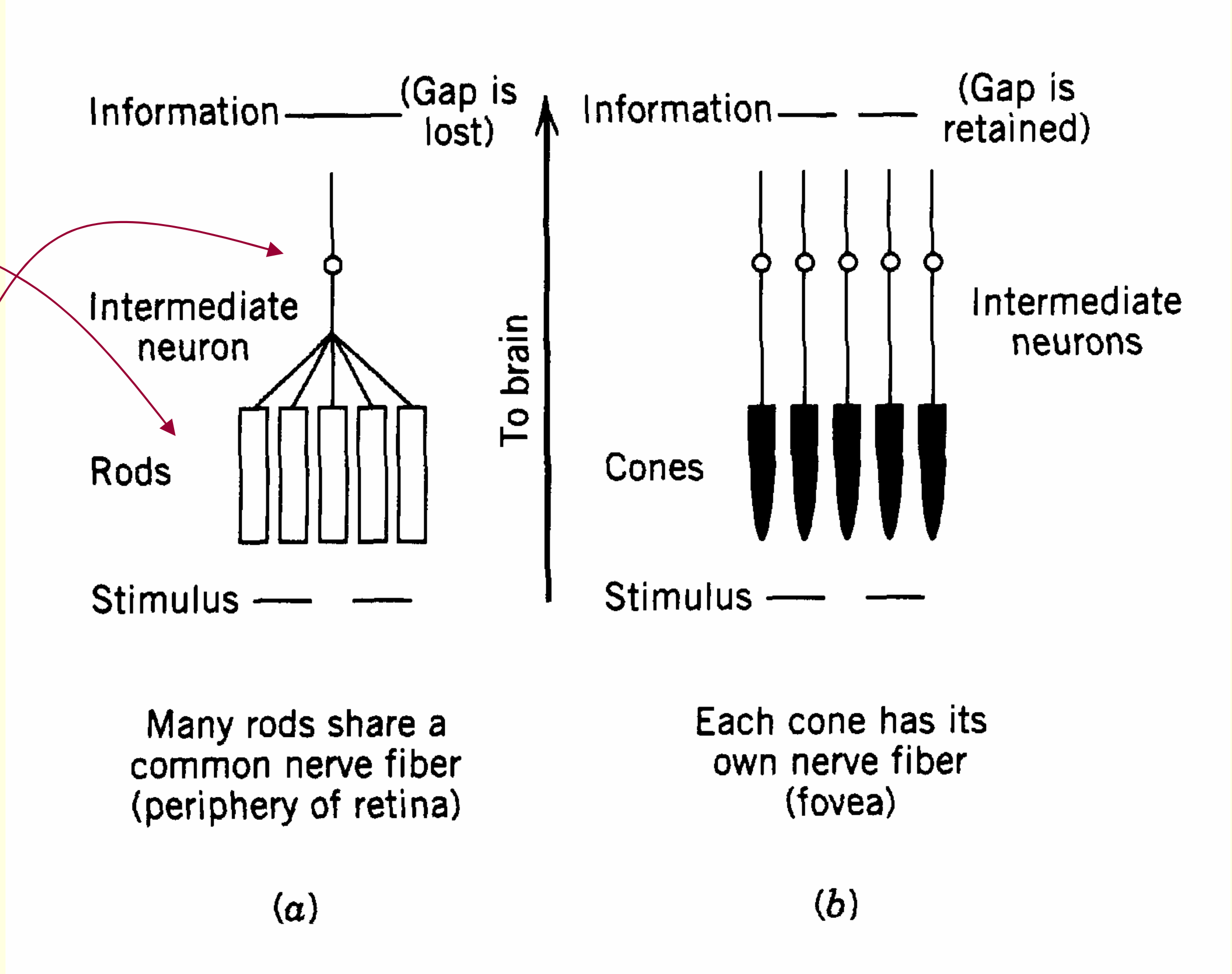
- All of our behavior, including perception, can be ultimately reduced to a complex pattern of activation within a population of neurons in the brain.
- Models of human behavior should therefore be **biologically plausible**, meaning that the model should not require mechanisms or processes that do not exist in the brain.
- The field of **neurocomputation** describes how neuron systems interact to produce behavior
  - **Spatial interactions**: convergence, lateral connectivity
  - **Temporal interactions**: delay circuits, feedback loops

Neuronal Computation

Convergence

Many rod photoreceptors converge on a single retinal ganglion cell

The signals from these receptors are being added or summed by the ganglion cell



Neuronal Computation

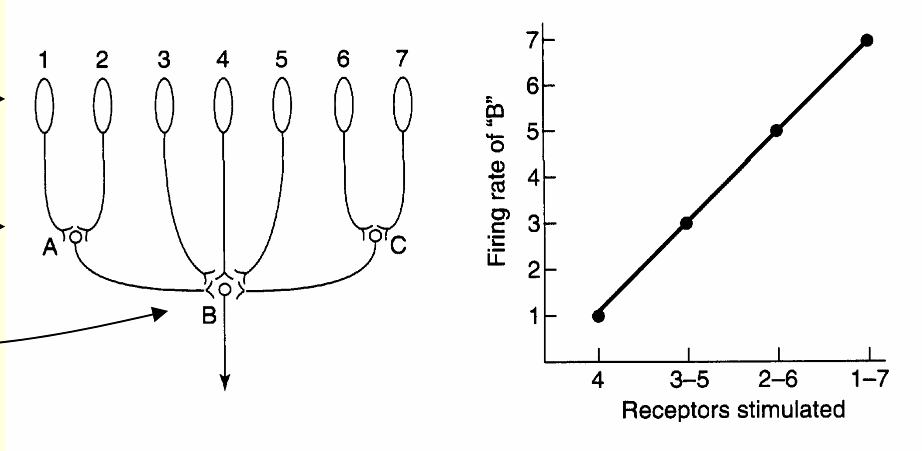
Convergence

The more receptors stimulated, the greater B's response

Rod photoreceptors

interneurons

Ganglion cell

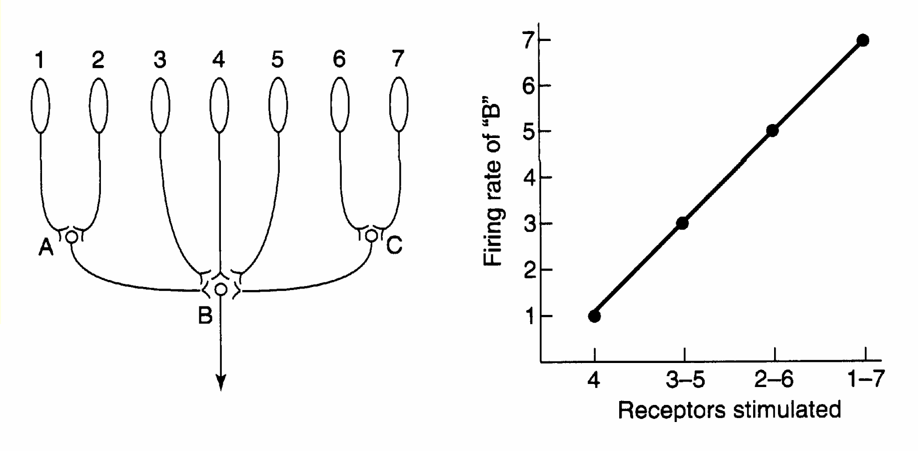


Neuronal Computation

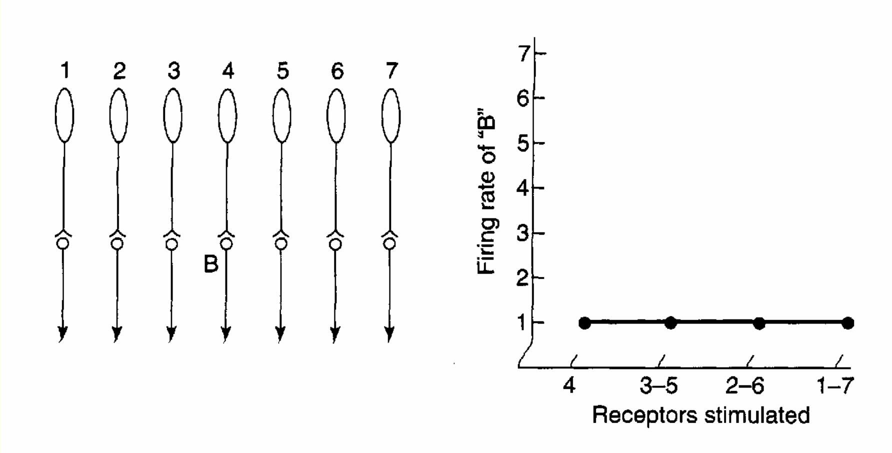
Convergence

The more receptors stimulated, the greater B's response

with convergence



without convergence



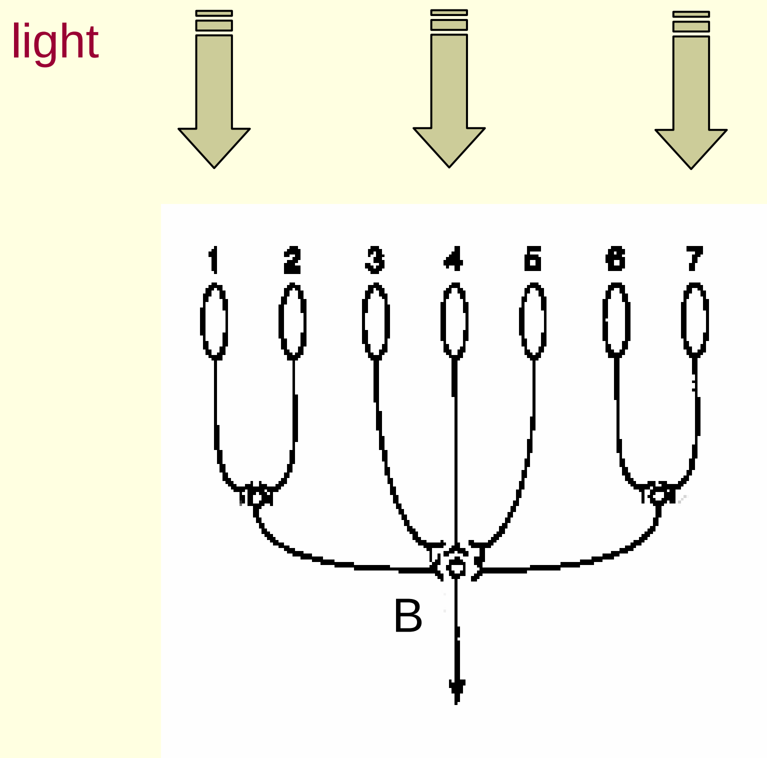
The firing rate of B is independent of the number of stimulated receptors

Neuronal Computation

Receptive Fields

- The region of your visual field that a given cell "sees"

B will fire because the stimulus falls within its **receptive field**

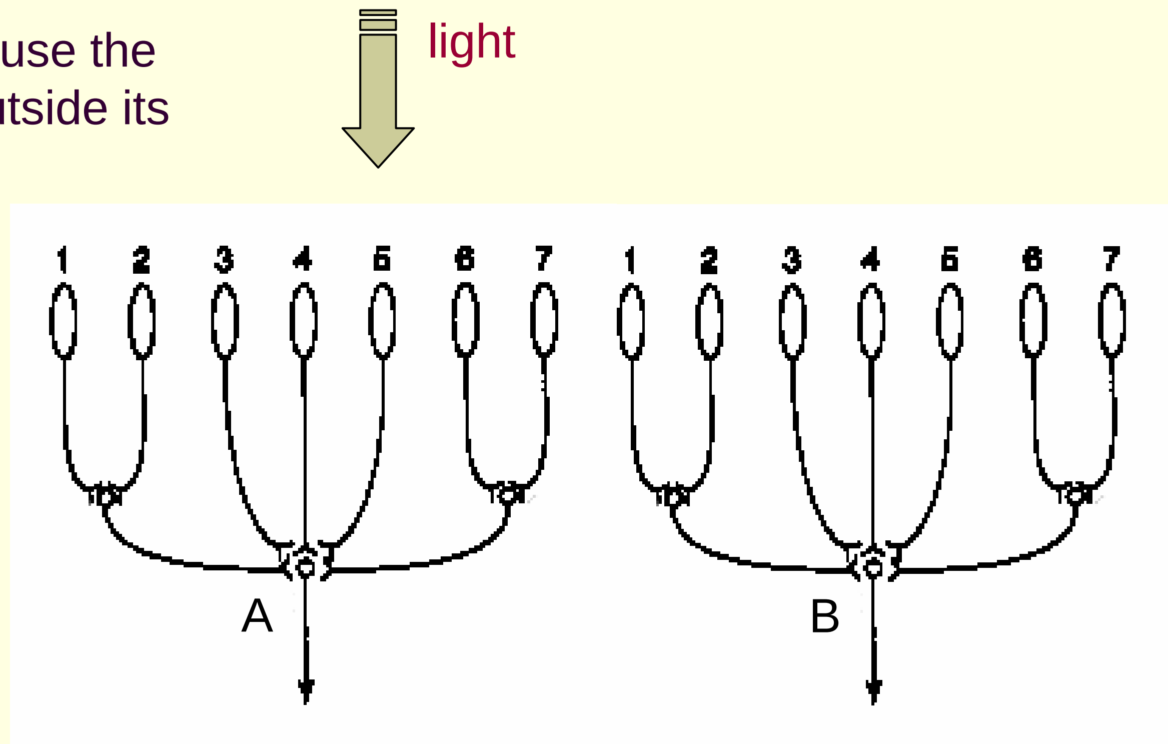


Neuronal Computation

Receptive Fields

- The region of your visual field that a given cell “sees”

B <u>will not</u> fire because the stimulus will fall outside its **receptive field**

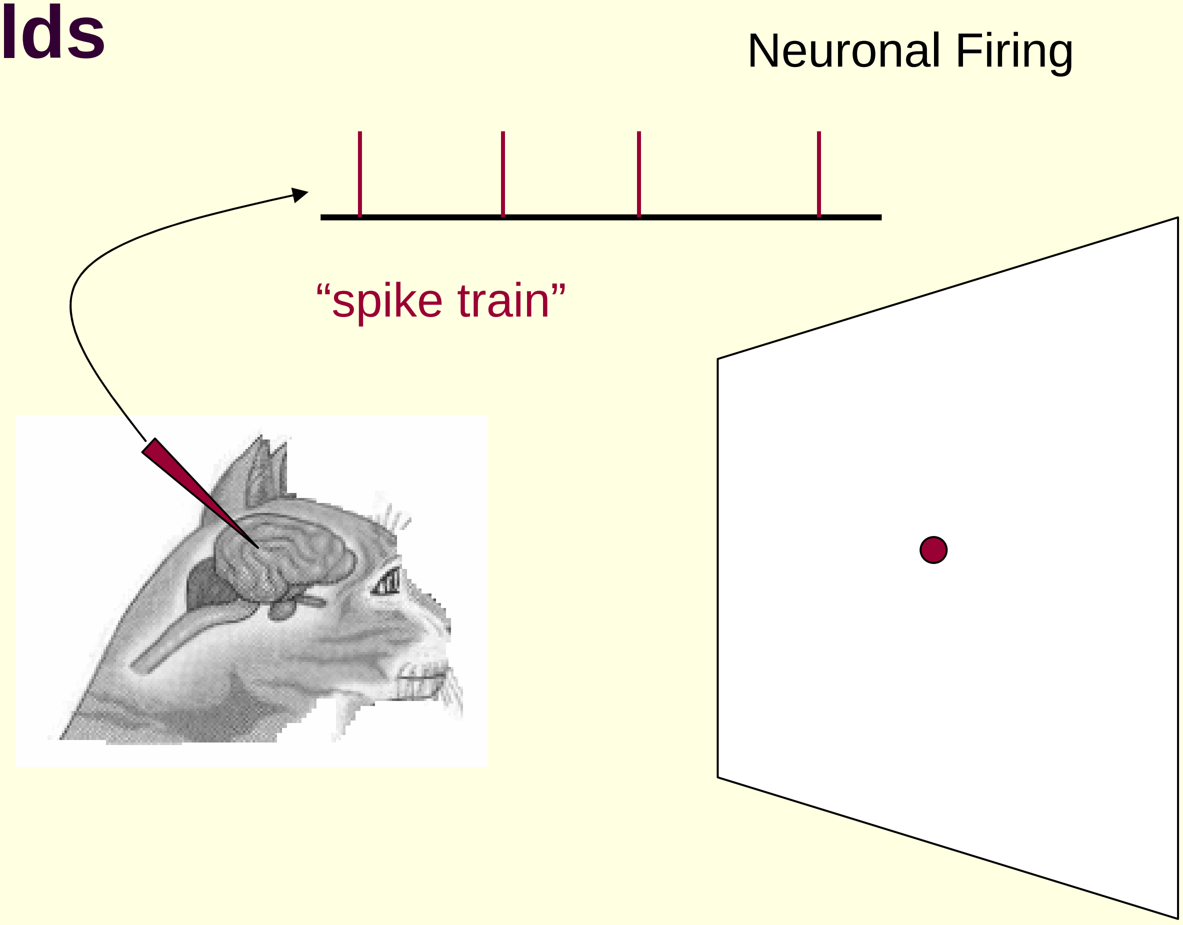


Neuronal Computation

Receptive Fields

An electrode is inserted into a brain cell; the experimenter observes where a stimulus must be presented in order for the cell to fire.

For many locations, the cell fires weakly



Neuronal Computation

Receptive Fields

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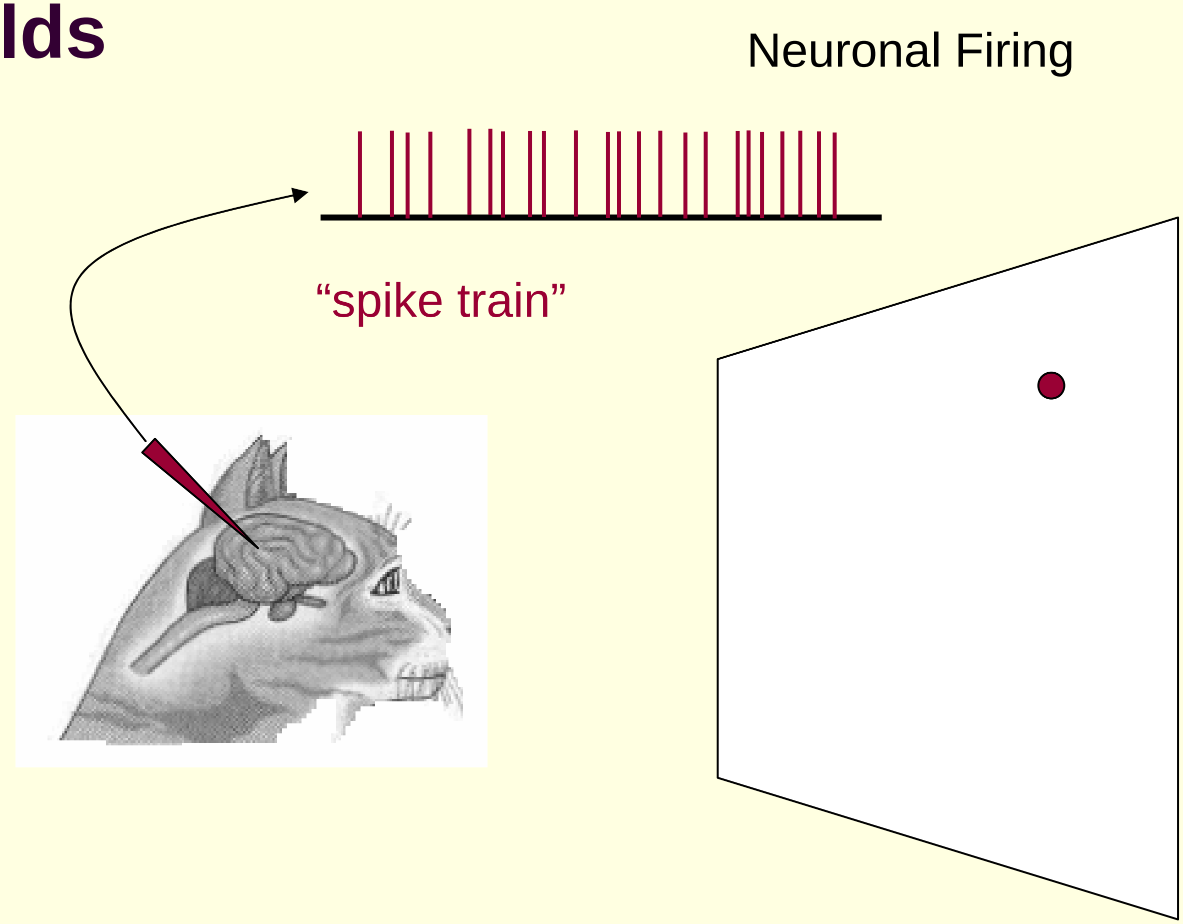
For many locations, the cell fires weakly

For other locations there is a vigorous response



Neuronal Computation

Receptive Fields

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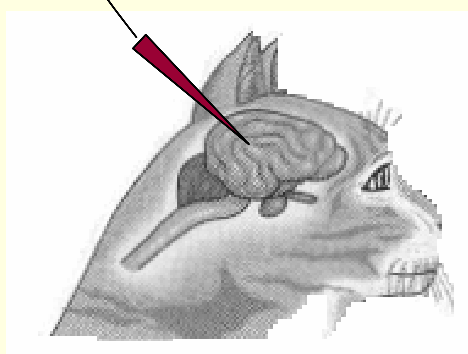
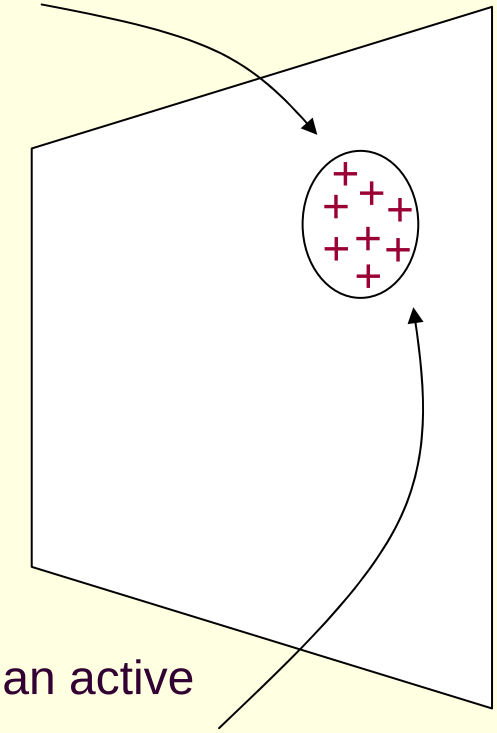
The **receptive field** for this cell





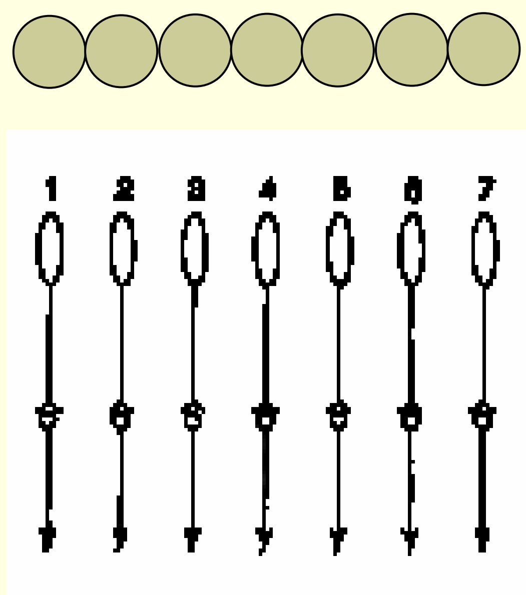
If you plot all the locations of an active response, you get a map like…

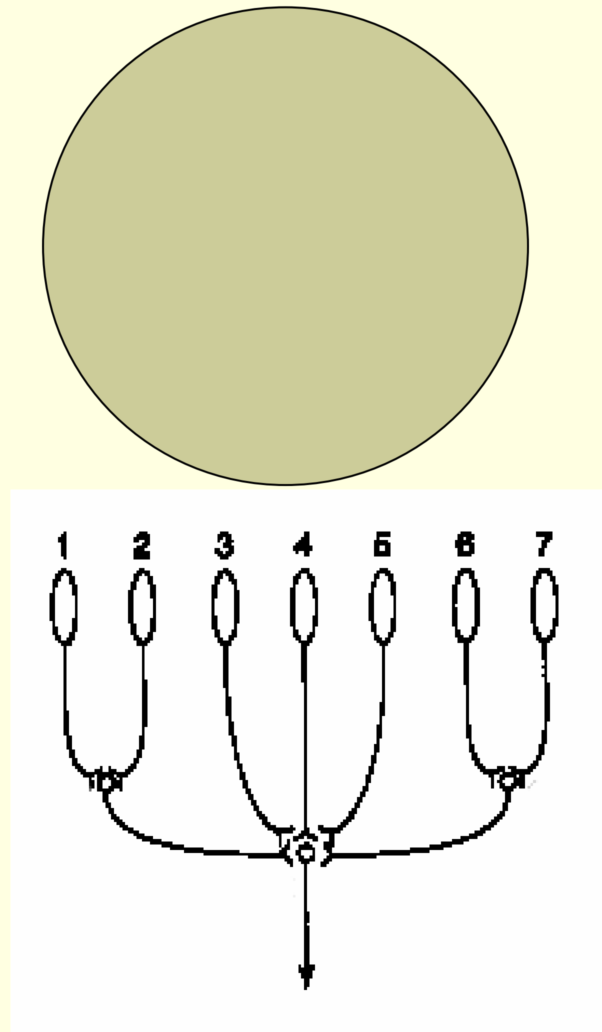
Neuronal Computation

Receptive Fields

large receptive field

small receptive fields





In general, the greater the convergence, the larger the size of the receptive field

Neuronal Computation

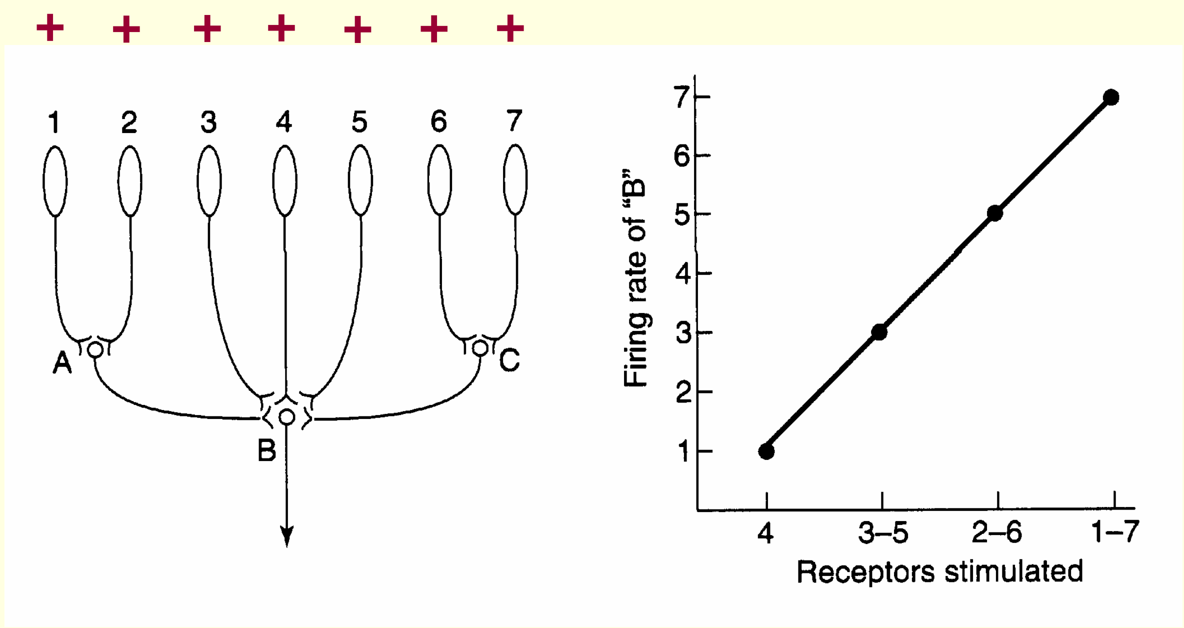
Receptive Fields

- The region of your visual field that a given cell “sees”
- Roughly circular in shape
- RF diameter generally increases with convergence
  - This is one reason why cells coding central vision have small RFs whereas cells coding peripheral vision have larger RFs
- Center-Surround antagonistic organization

Neuronal Computation

Center-Surround Organization

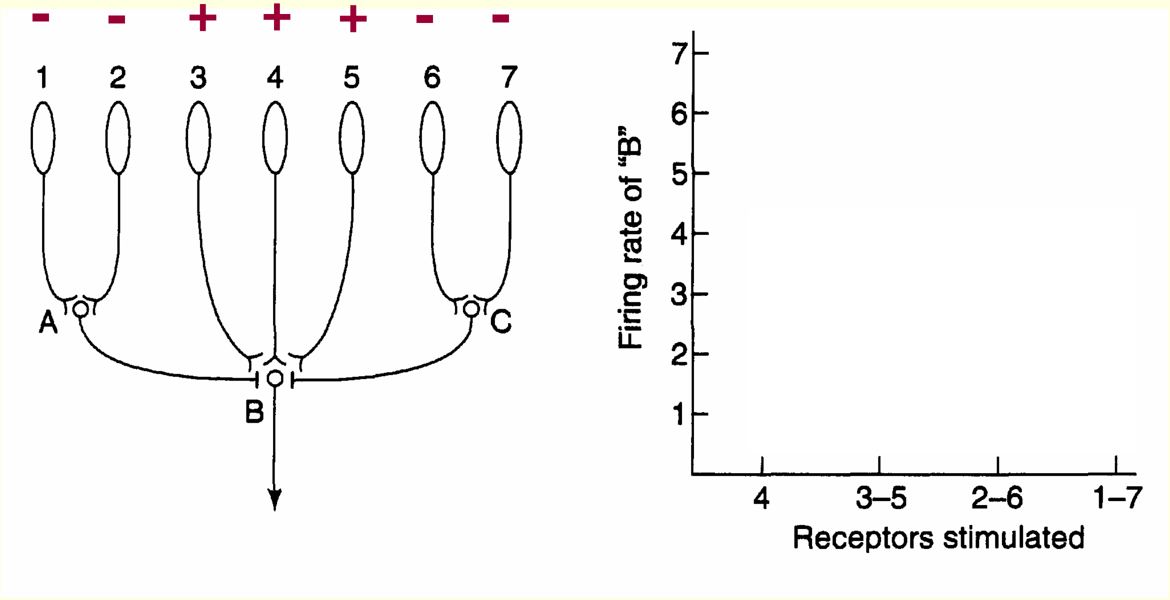
Instead of having a circuit in which all of the connections between the receptors and the ganglion cell are excitatory…



Neuronal Computation

Center-Surround Organization

Consider a circuit in which Receptors 3-5 have an excitatory connection with Cell B, but Receptors 1-2 and 6-7 have an inhibitory connection to Cell B



Neuronal Computation

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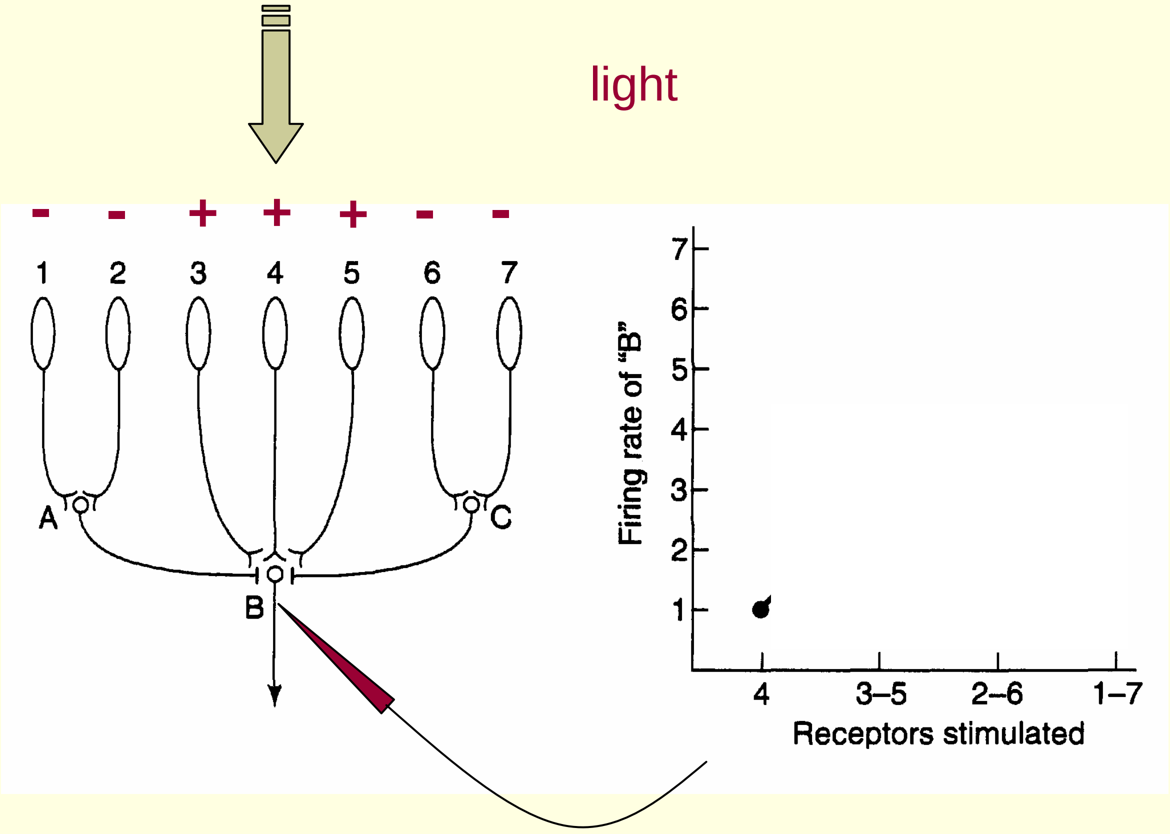

The firing rate of Cell B increases with stimulation of the excitatory center, and decreases with stimulation of the inhibitory surround

Neuronal Computation

Center-Surround Organization

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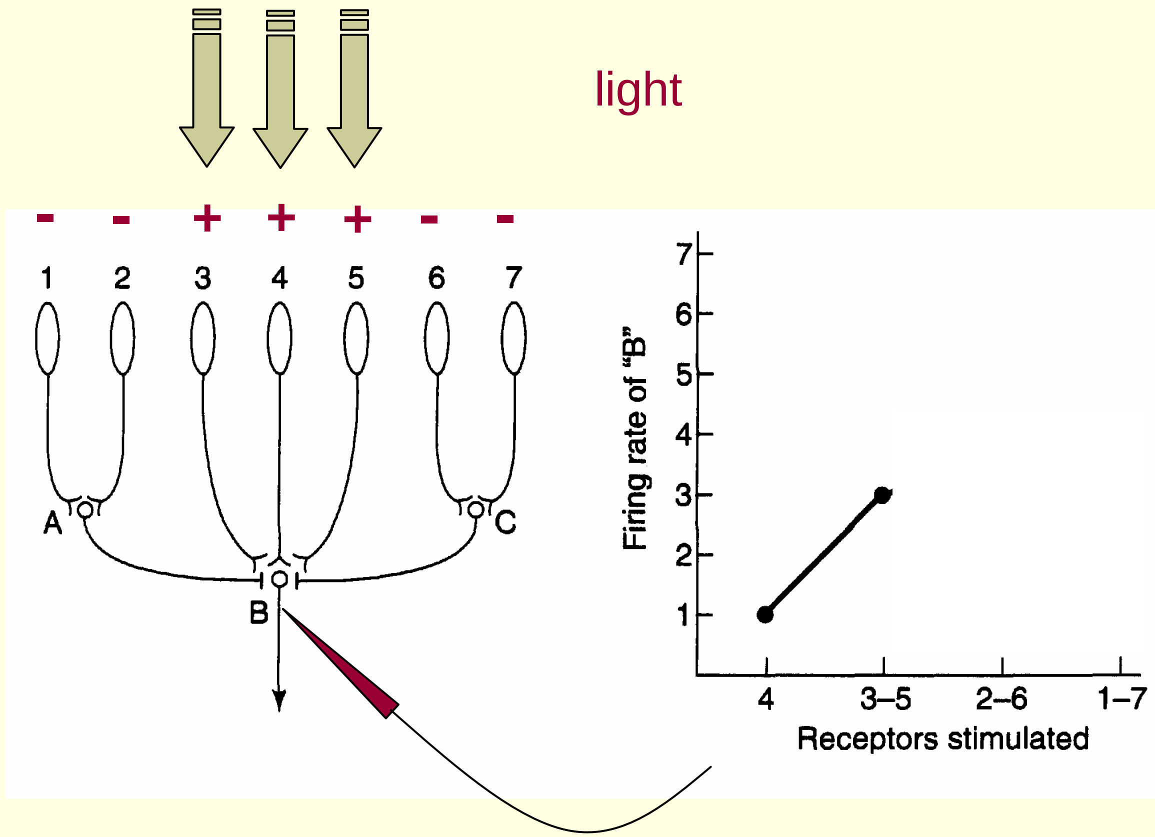

The firing rate of Cell B increases with stimulation of the excitatory center, and decreases with stimulation of the inhibitory surround

Neuronal Computation

Center-Surround Organization

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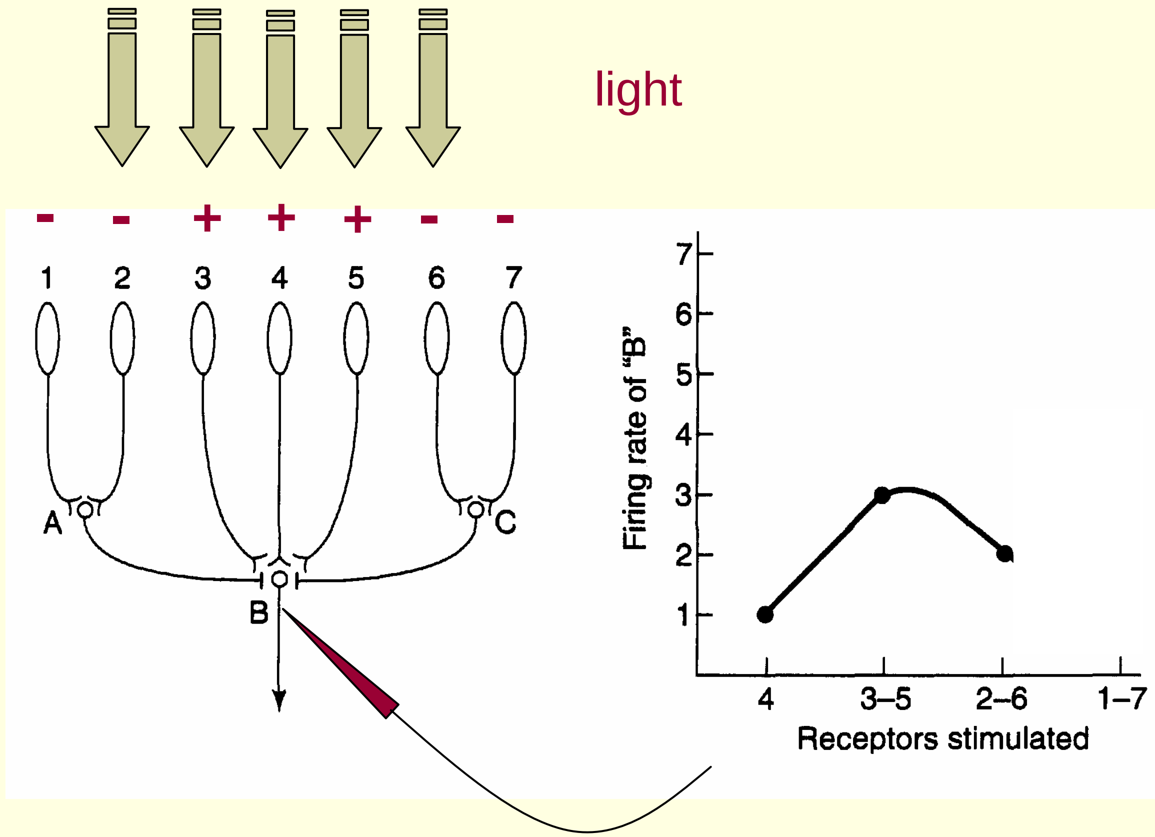

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Neuronal Computation

Center-Surround Organization

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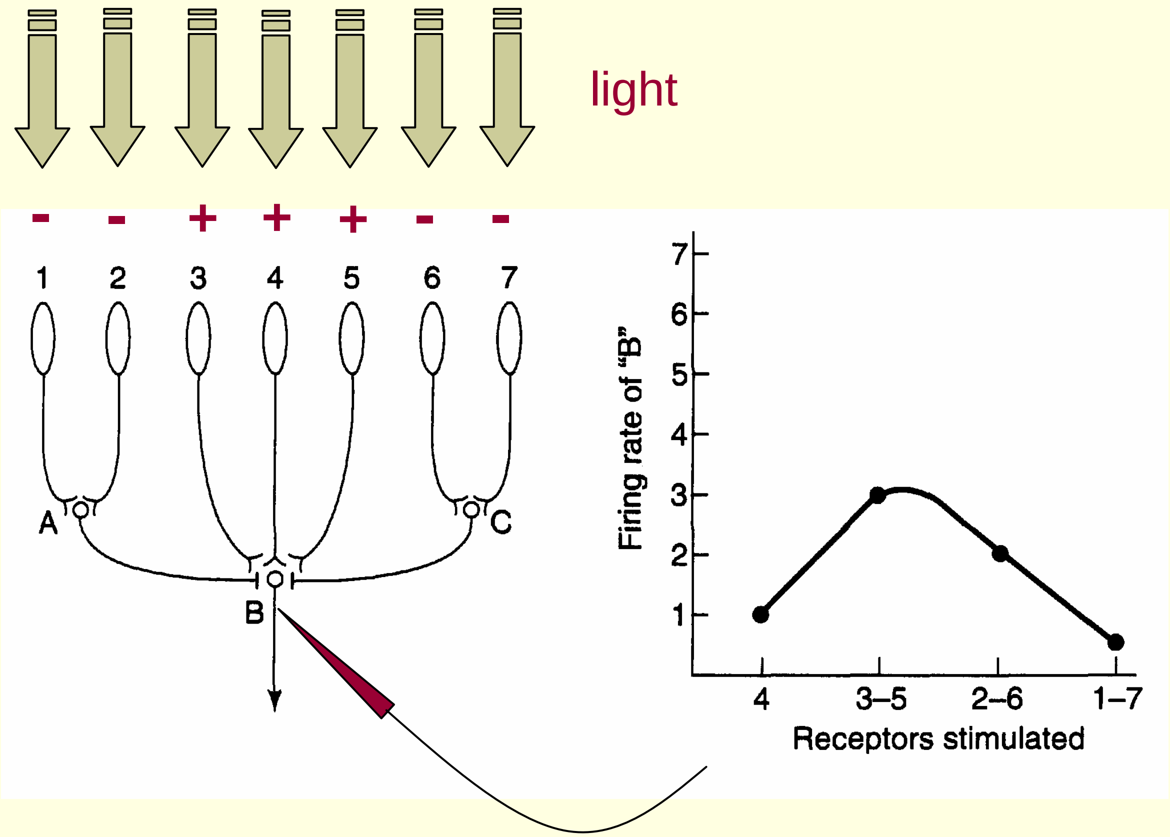

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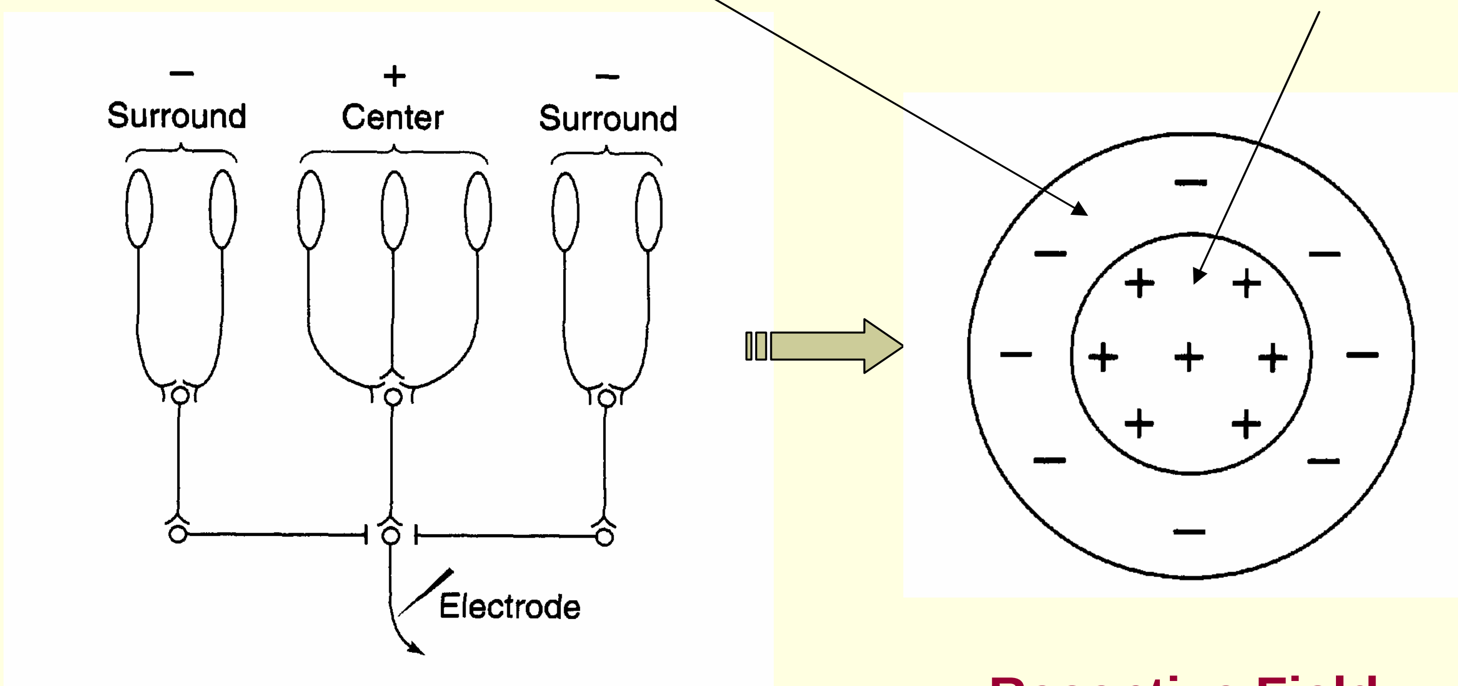
Neuronal Computation

Center-Surround Organization

inhibitory “off” surround

excitatory “on” center

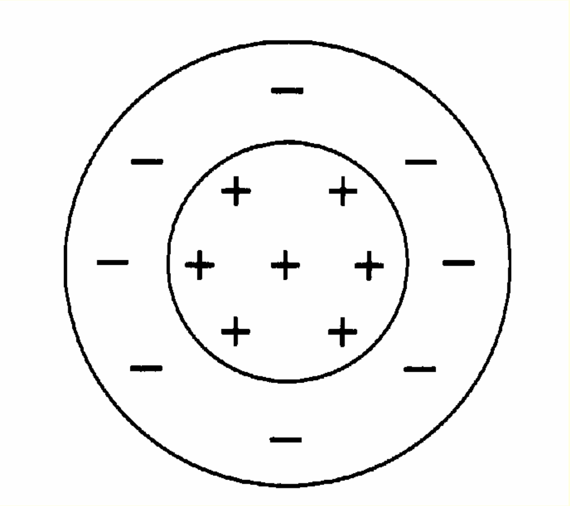


Receptive Field

Neuronal Computation

Center-Surround Organization

What is the optimal stimulus for a cell having this receptive field?



Receptive Field

Neuronal Computation

Center-Surround Organization

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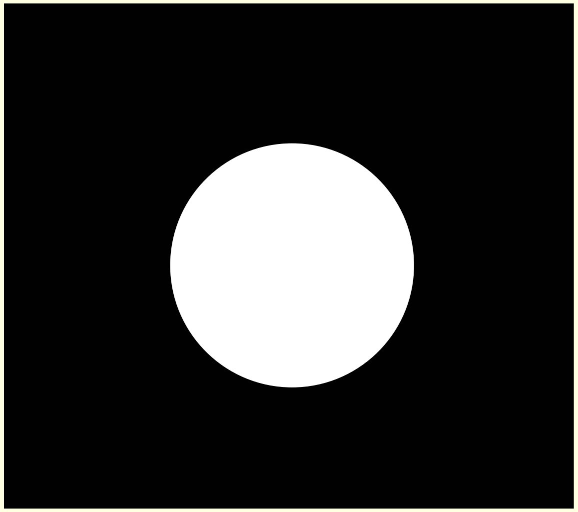
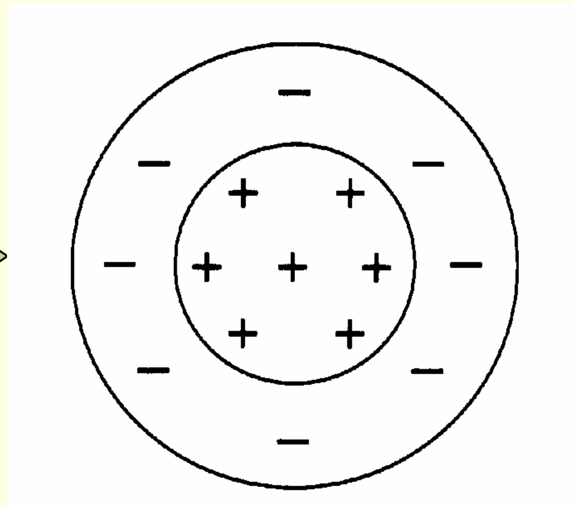




Optimal Stimulus

Receptive Field

Neuronal Computation

Receptive Fields

- The region of your visual field that a given cell “sees”
- Roughly circular in shape
- RF diameter generally increases with convergence
  - This is one reason why cells coding central vision have small RFs whereas cells coding peripheral vision have larger RFs
- Center-Surround antagonistic organization
  - A product of **lateral interactions** in a neural circuit
  - Some RFs have the opposite organization; inhibitory center and excitatory surround

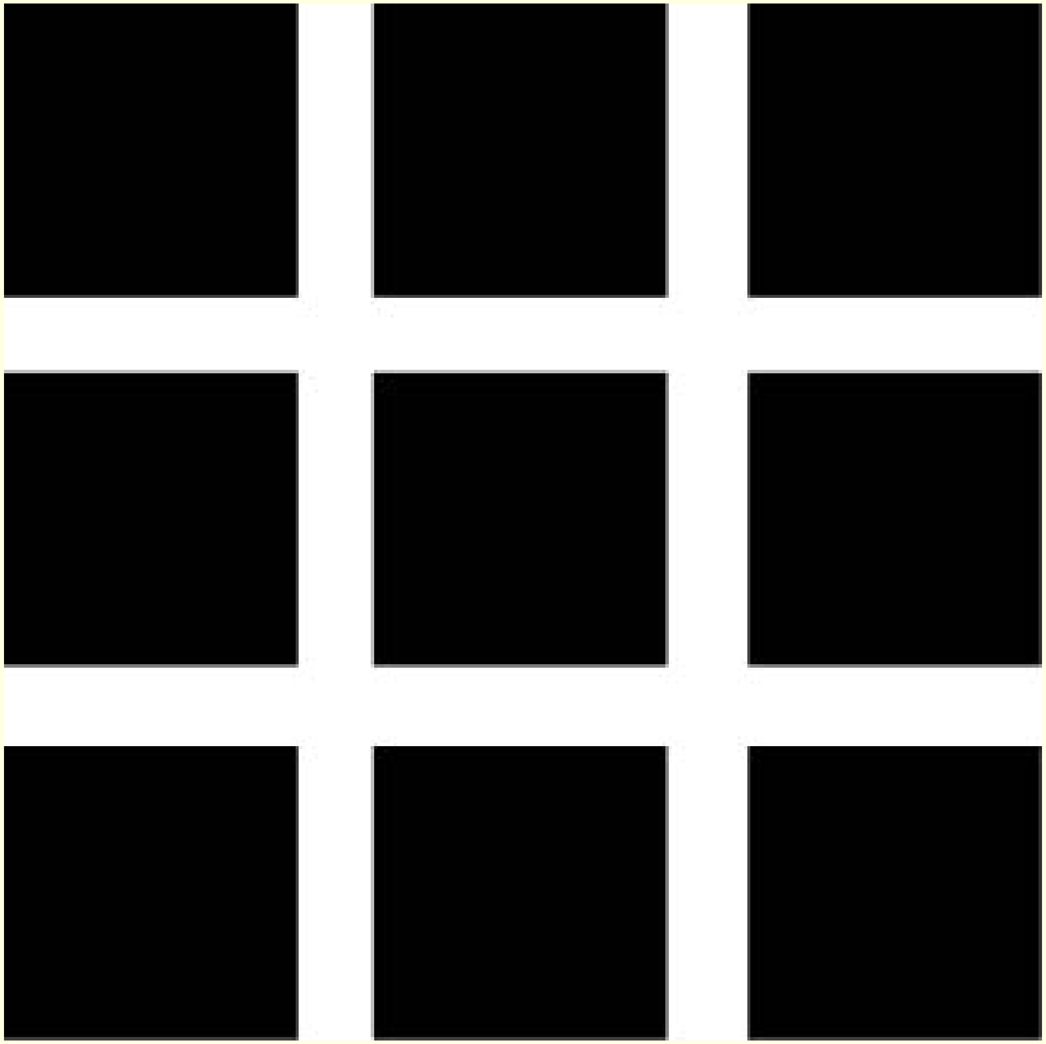
Neuronal Computation

Lateral Inhibition

- Inhibition that spreads laterally in a neuronal circuit.
  - In the retina, the horizontal and amacrine cells laterally inhibit the ganglion cells, resulting in the center-surround RF organization.
- Lateral inhibition explains two perceptual illusions: the Hermann Grid and Mach Bands.

Neuronal Computation

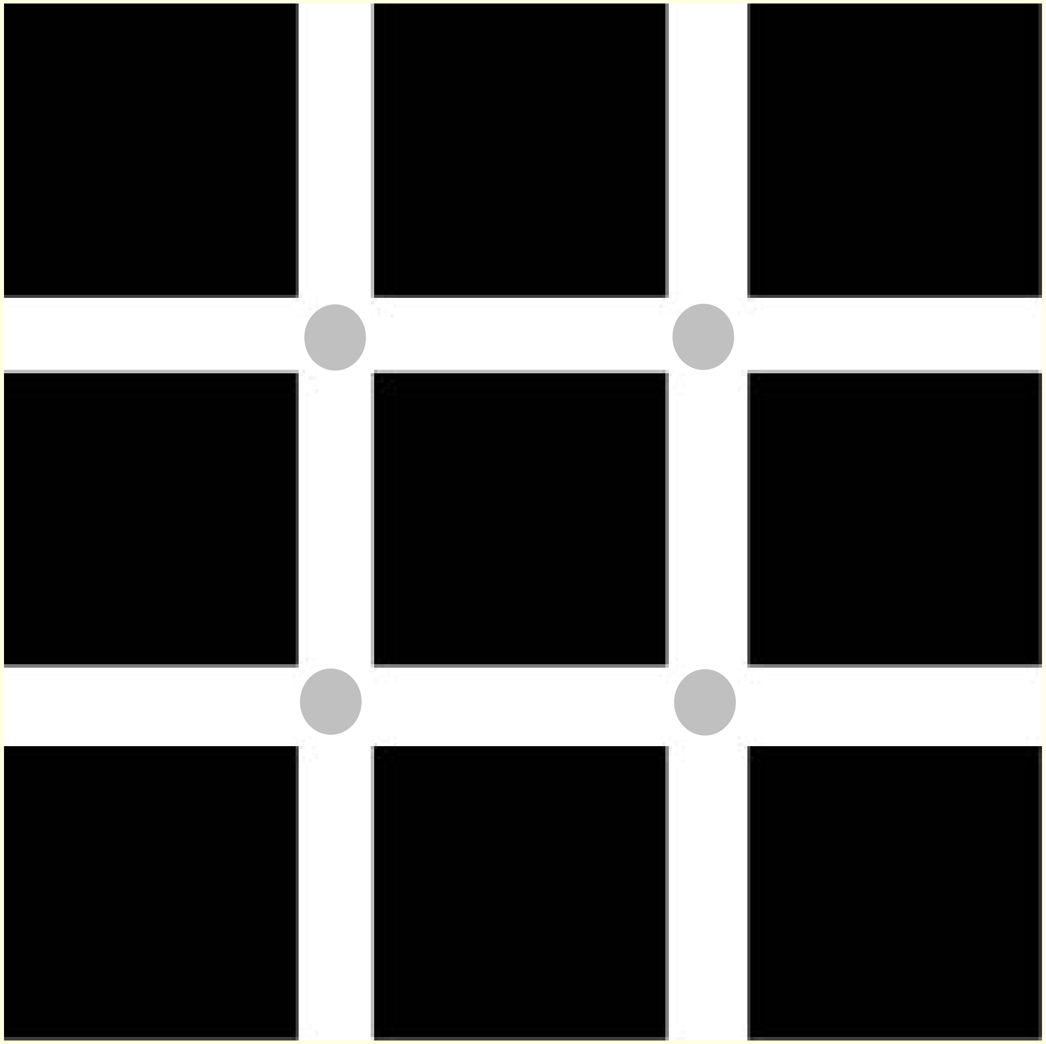
Hermann Grid



Neuronal Computation

Hermann Grid

Grey dots appear at each of the four intersections

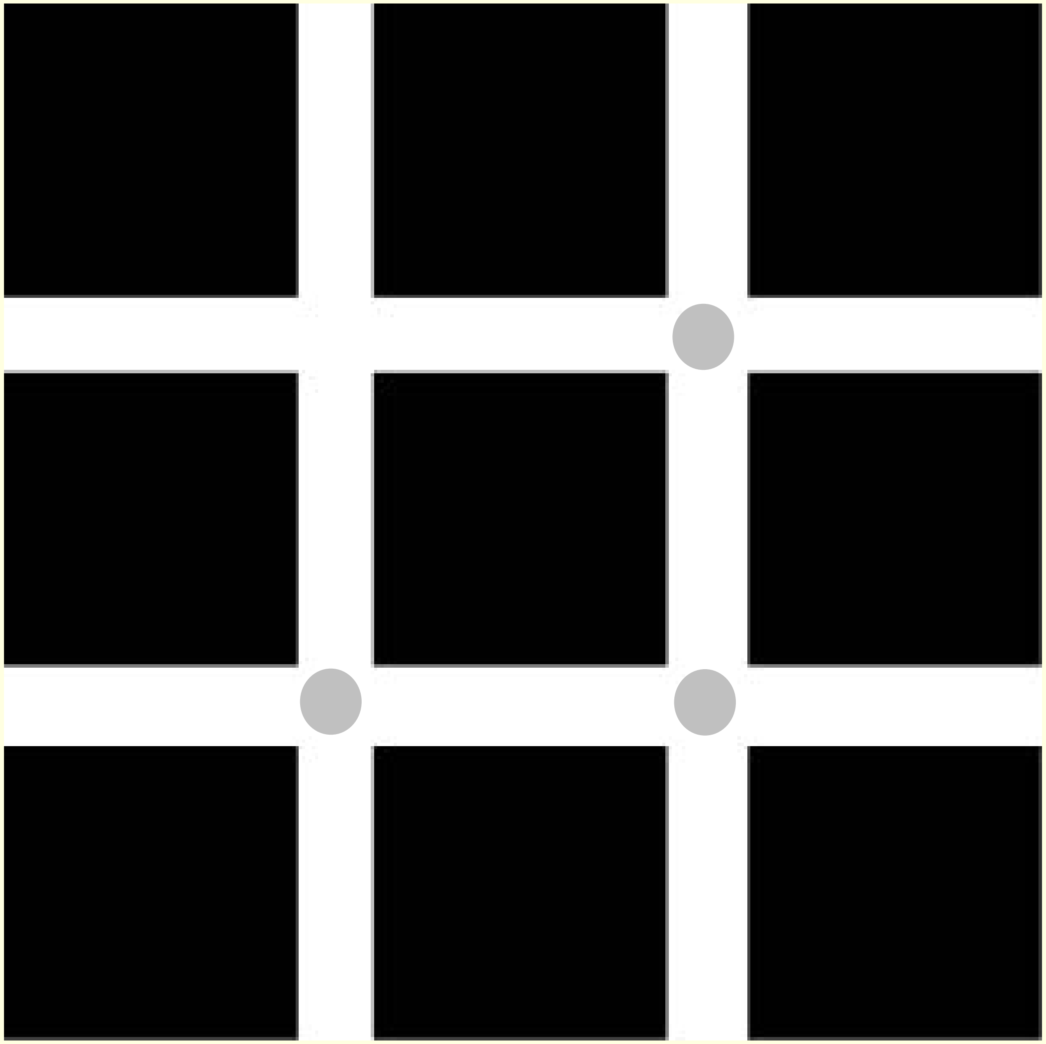


Neuronal Computation

Hermann Grid

Grey dots appear at each of the four intersections

The dots appear to jump around, appearing and disappearing at these intersections



Neuronal Computation

Hermann Grid

Grey dots appear at each of the four intersections

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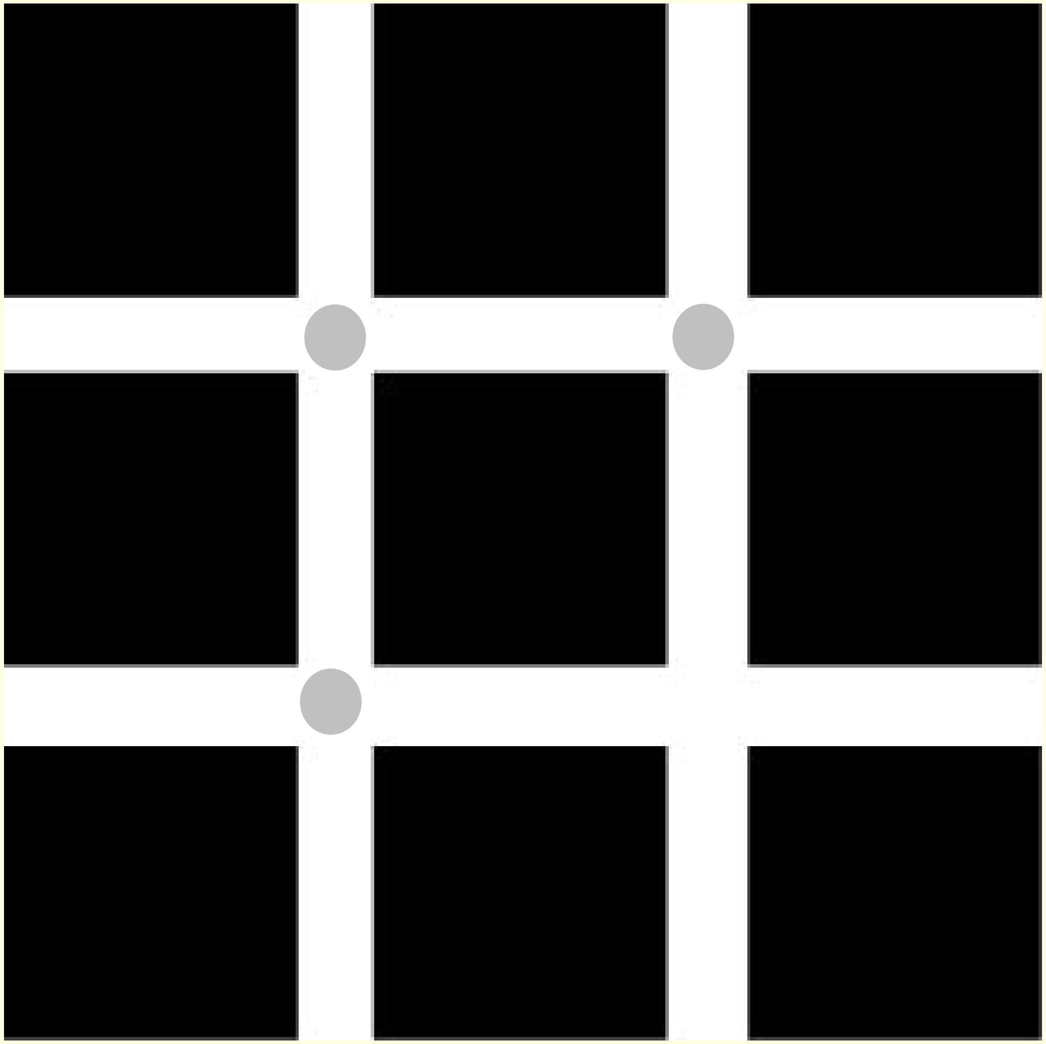

Neuronal Computation

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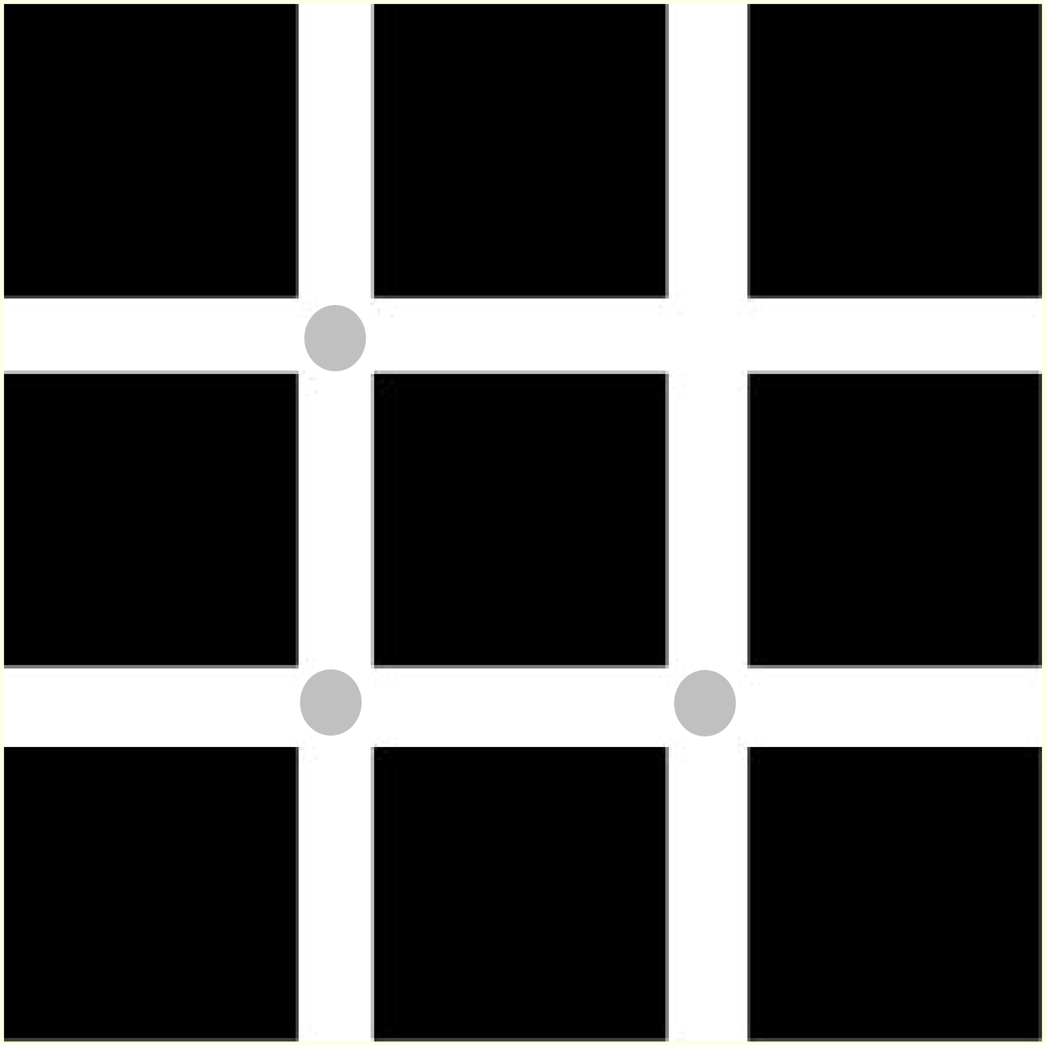

Neuronal Computation

Hermann Grid

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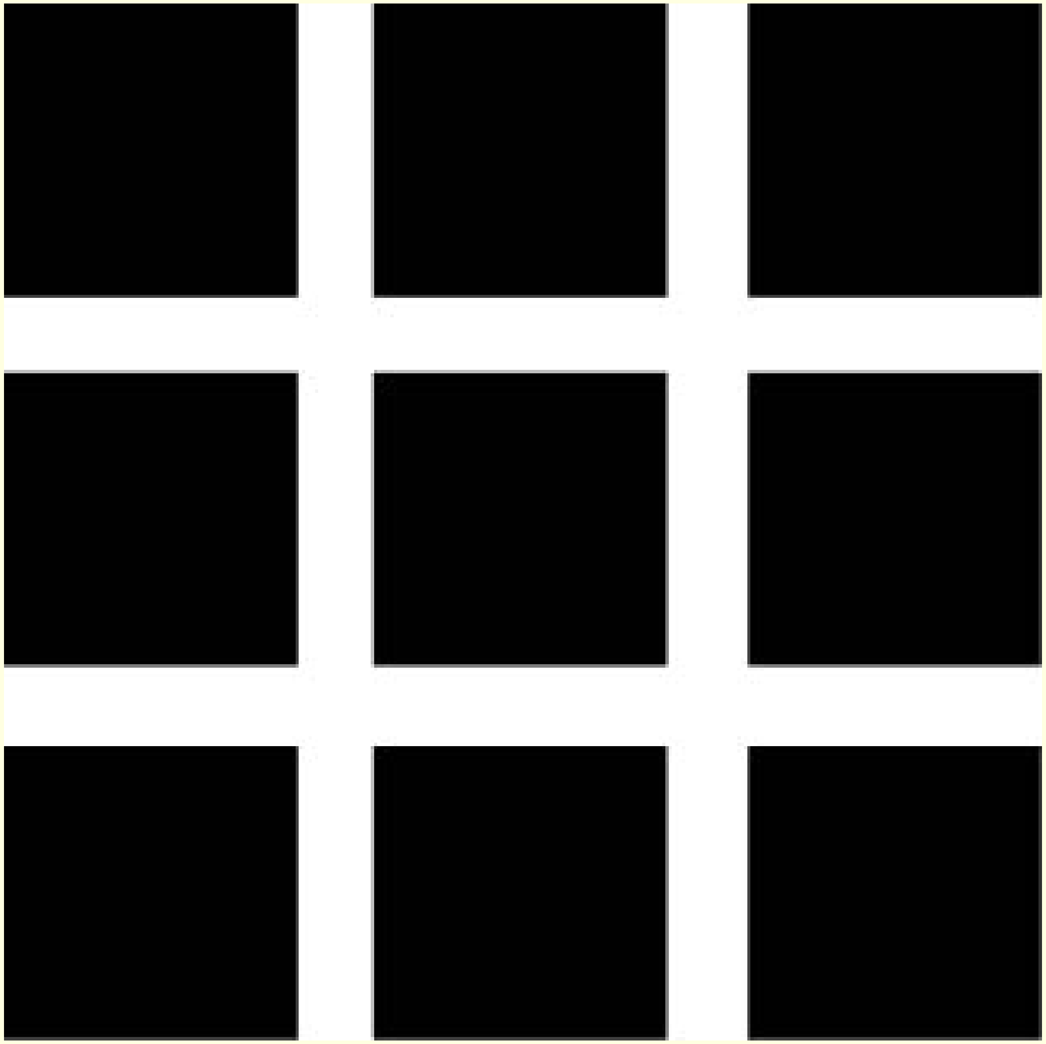
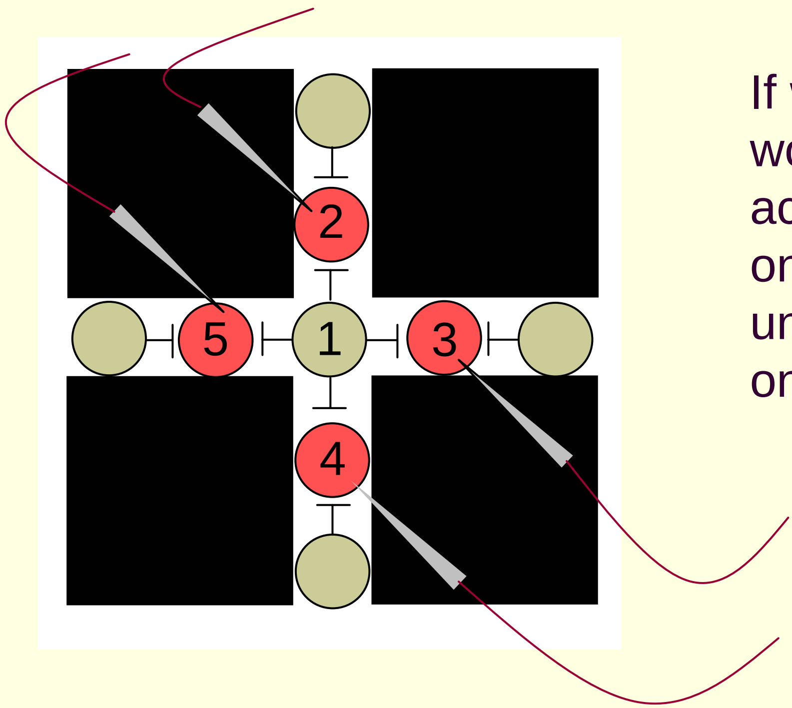


Neuronal Computation

Hermann Grid

The circles correspond to 9 ganglion cells located on the intersection of a Hermann Grid

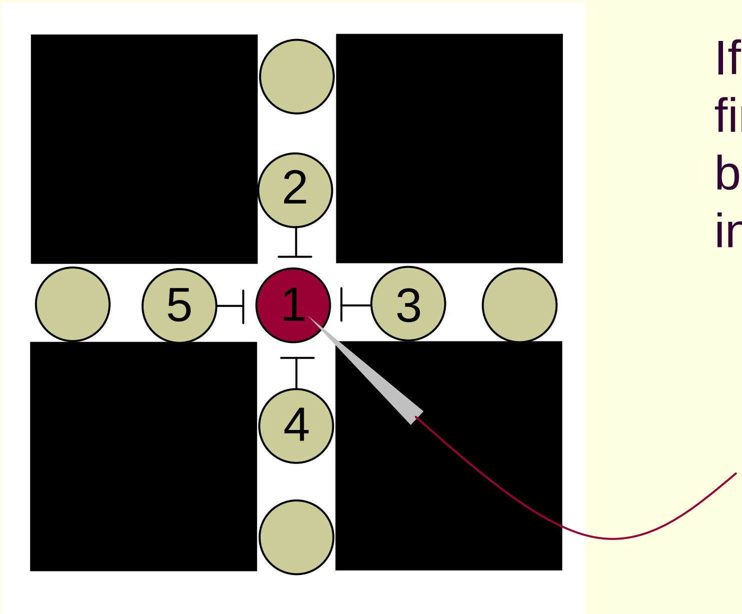


If we record from Cells 2-5, we would find that they are relatively active because they each receive only 2 units of lateral inhibition (1 unit from Cell 1, and the other from one of the unnumbered cells).

Neuronal Computation

Hermann Grid

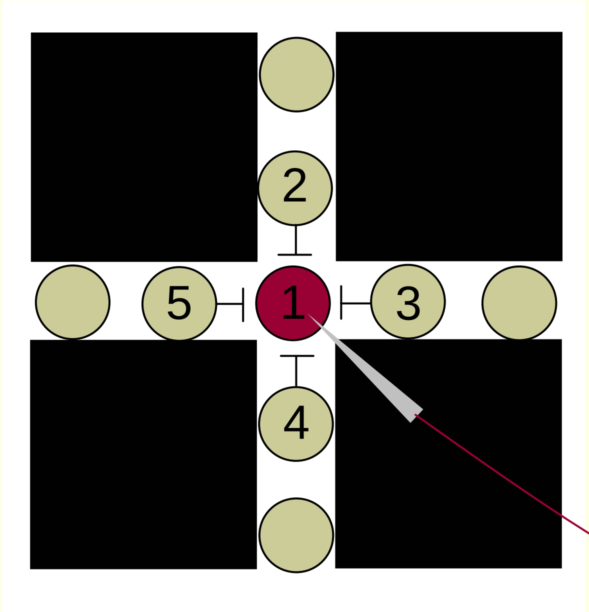
The circles correspond to 9 ganglion cells located on the intersection of a Hermann Grid

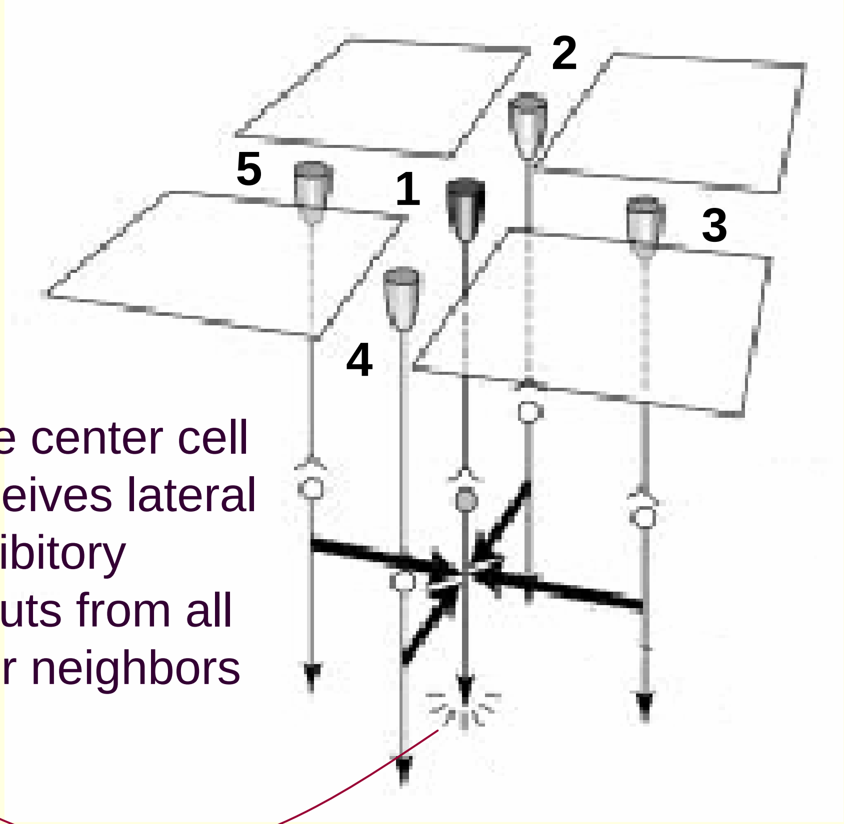


If we record from Cell 1, we would find that it is relatively inactive because it receives 4 units of lateral inhibition (1 unit each from Cells 2-5)

Neuronal Computation

Hermann Grid



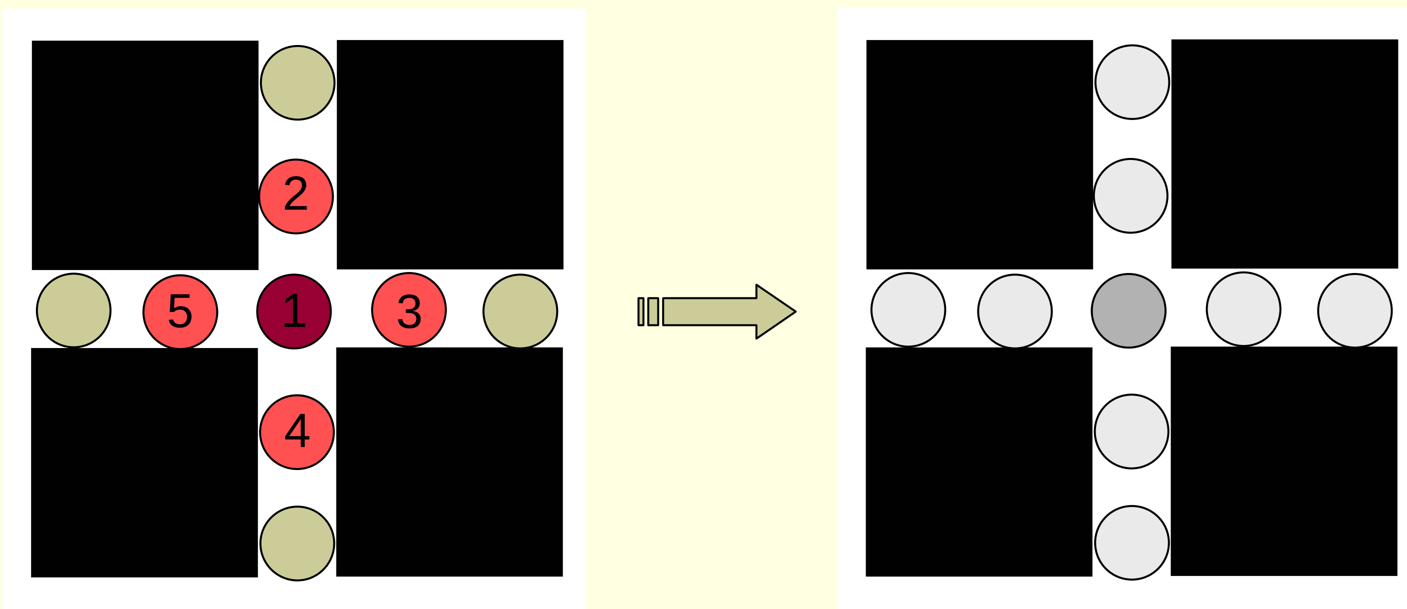


The center cell receives lateral inhibitory inputs from all four neighbors

Neuronal Computation

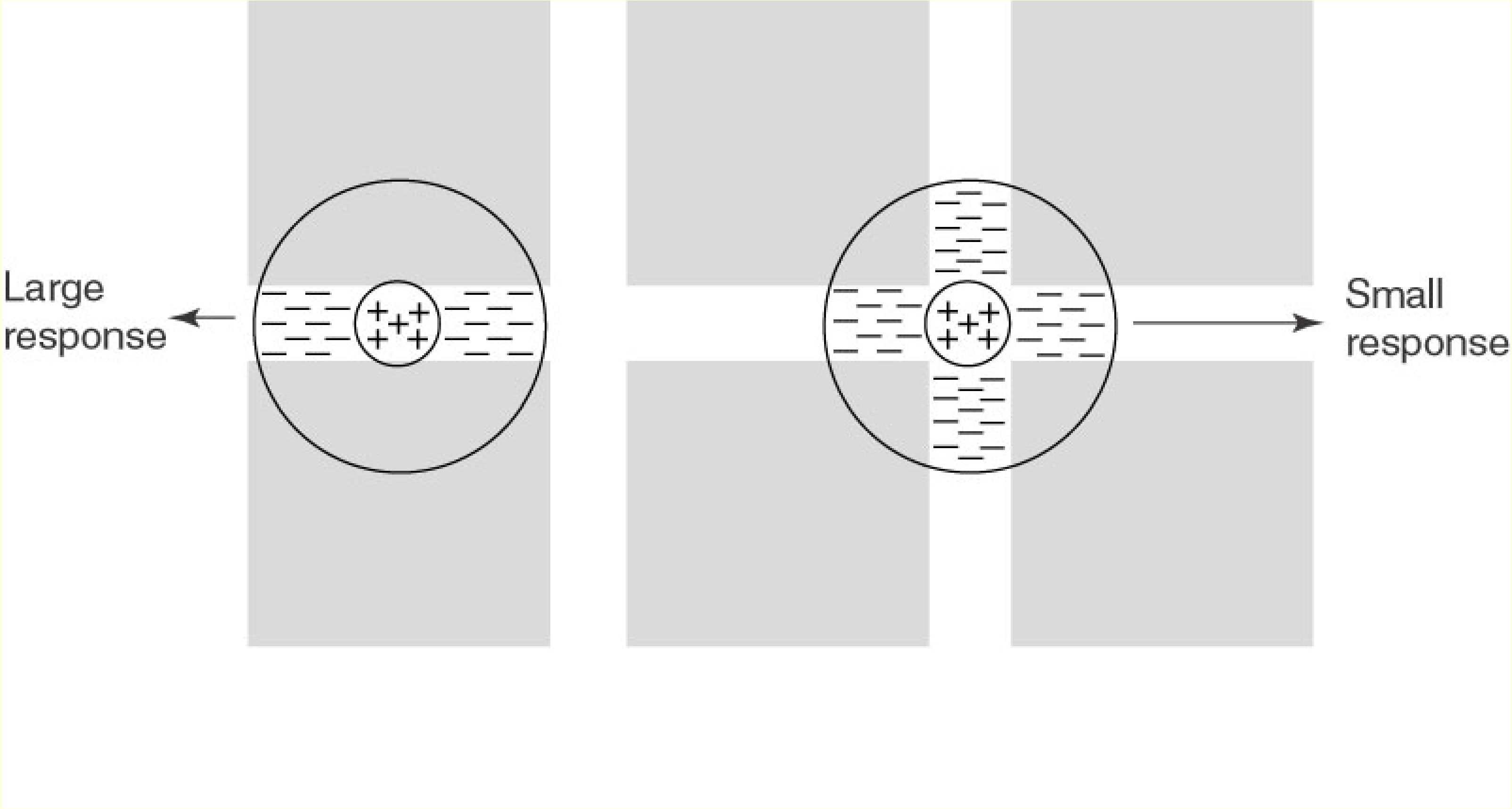
Hermann Grid

Cells coding the grid intersections are more laterally inhibited than other cells along the grid path; this greater inhibition is perceived as a dark spot.



Neuronal Computation

Hermann Grid



Neuronal Computation

Lateral Inhibition

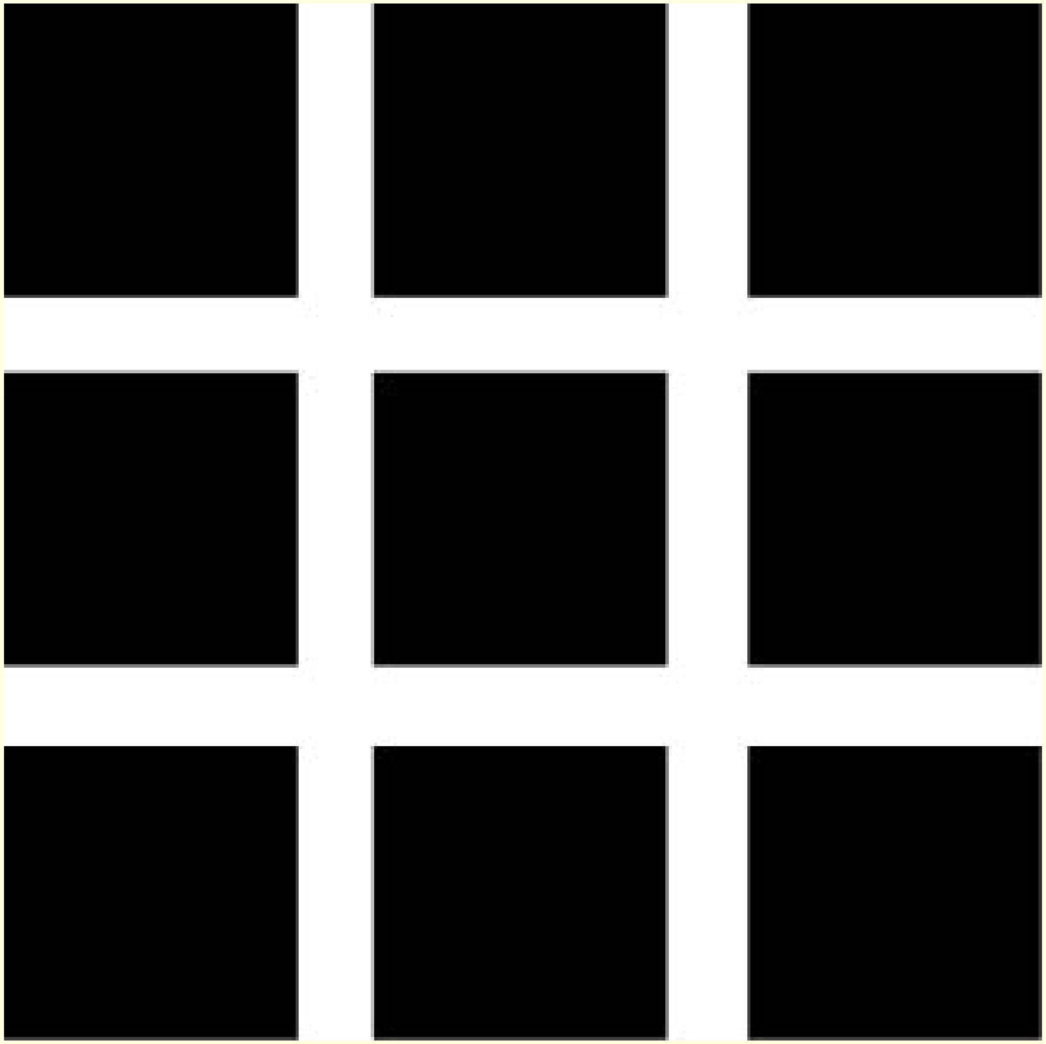
- Inhibition that spreads laterally in a neuronal circuit.
- Lateral inhibition explains two perceptual illusions: the Hermann Grid and Mach Bands.
- The dots in the Hermann grid are caused by strong lateral inhibition at the grid intersections (relative to the rest of the grid) and center-surround RFs.
- But why do they appear to jump around?

Neuronal Computation

Hermann Grid

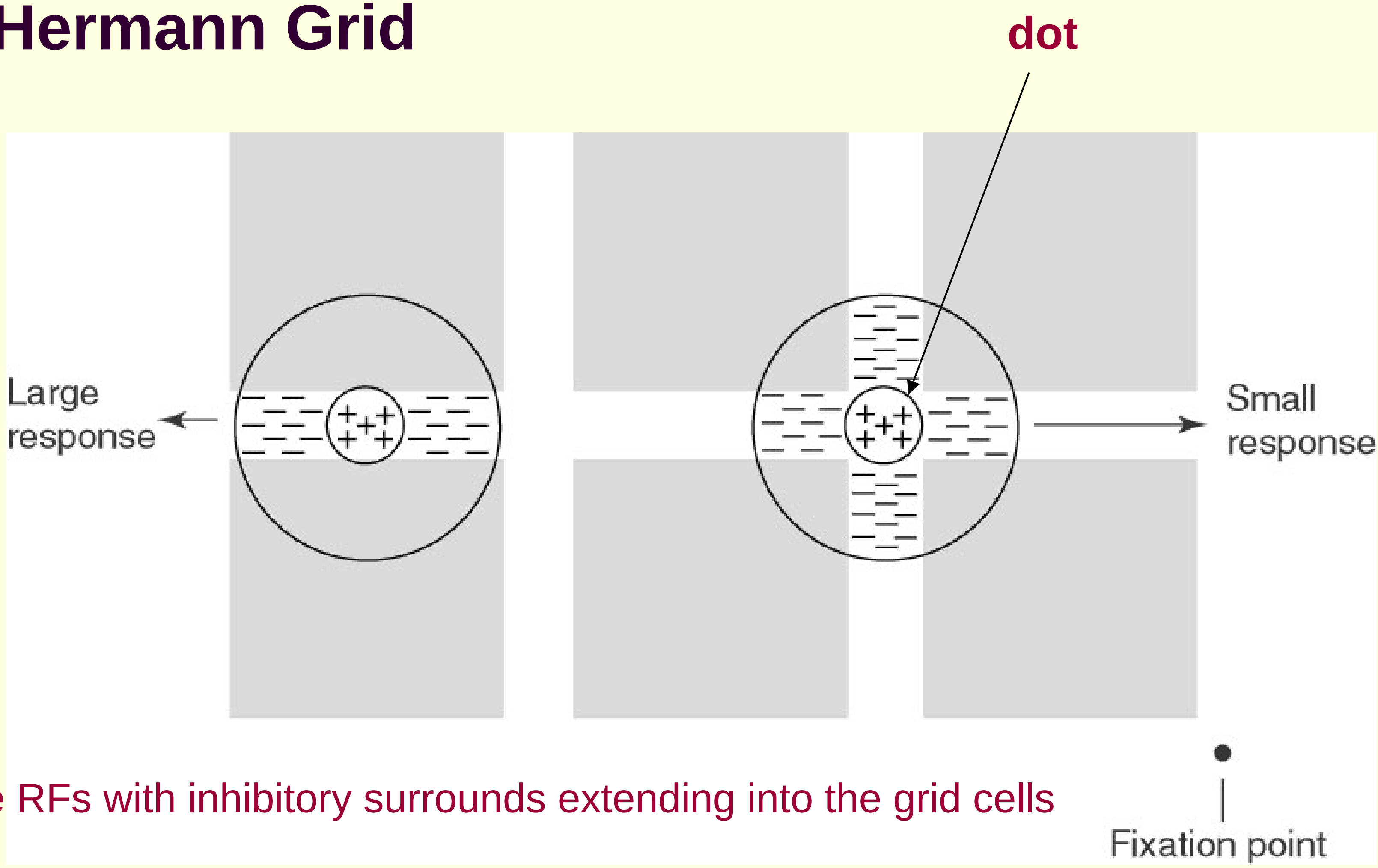
You only see the dots out of the corner of your eye; when you try to look at them directly, they disappear

The perception of dots depends on the size of the RF; RFs are large in the visual periphery and small in central vision



Neuronal Computation

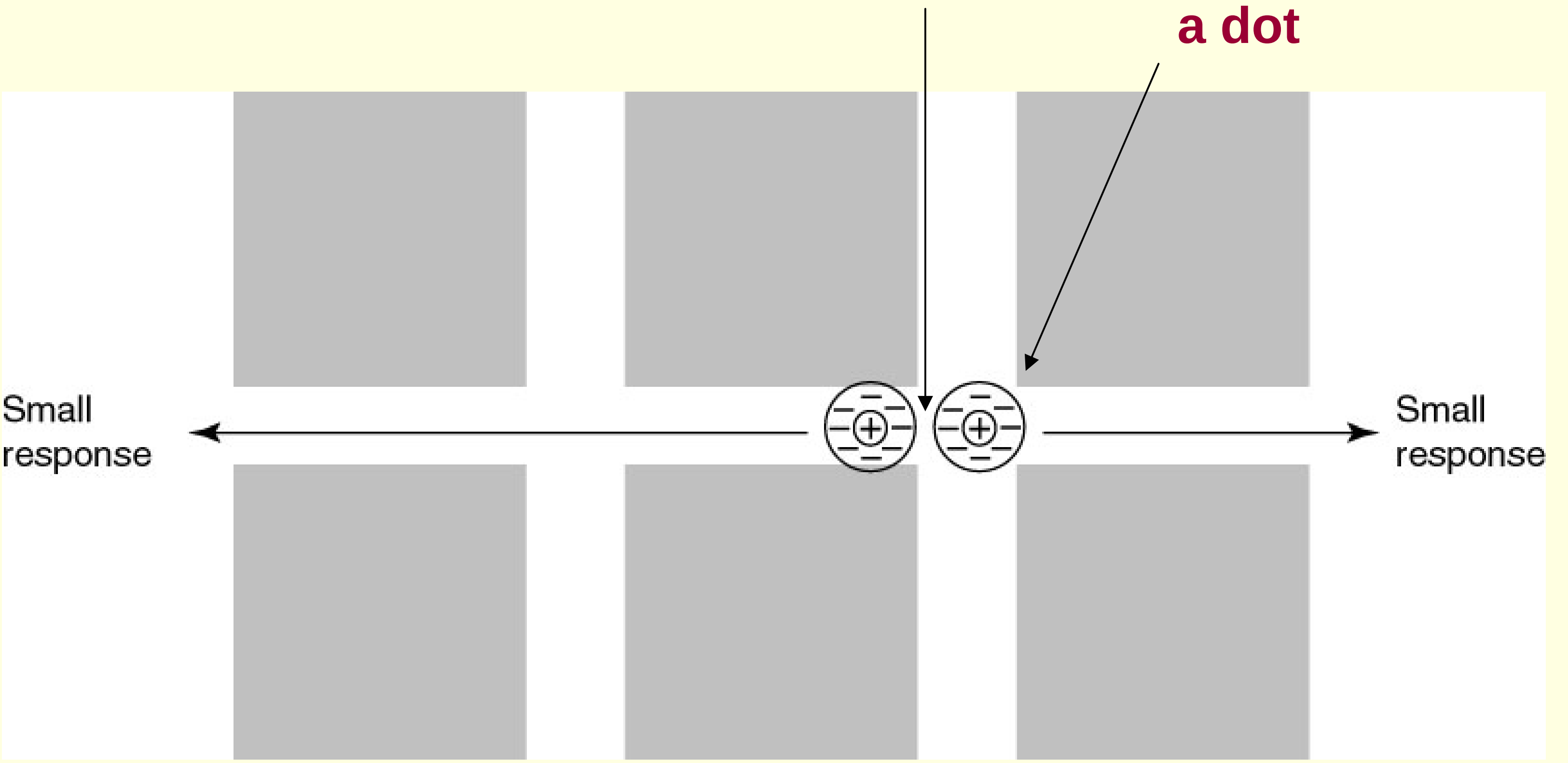
Hermann Grid



Large RFs with inhibitory surrounds extending into the grid cells

Neuronal Computation

Hermann Grid

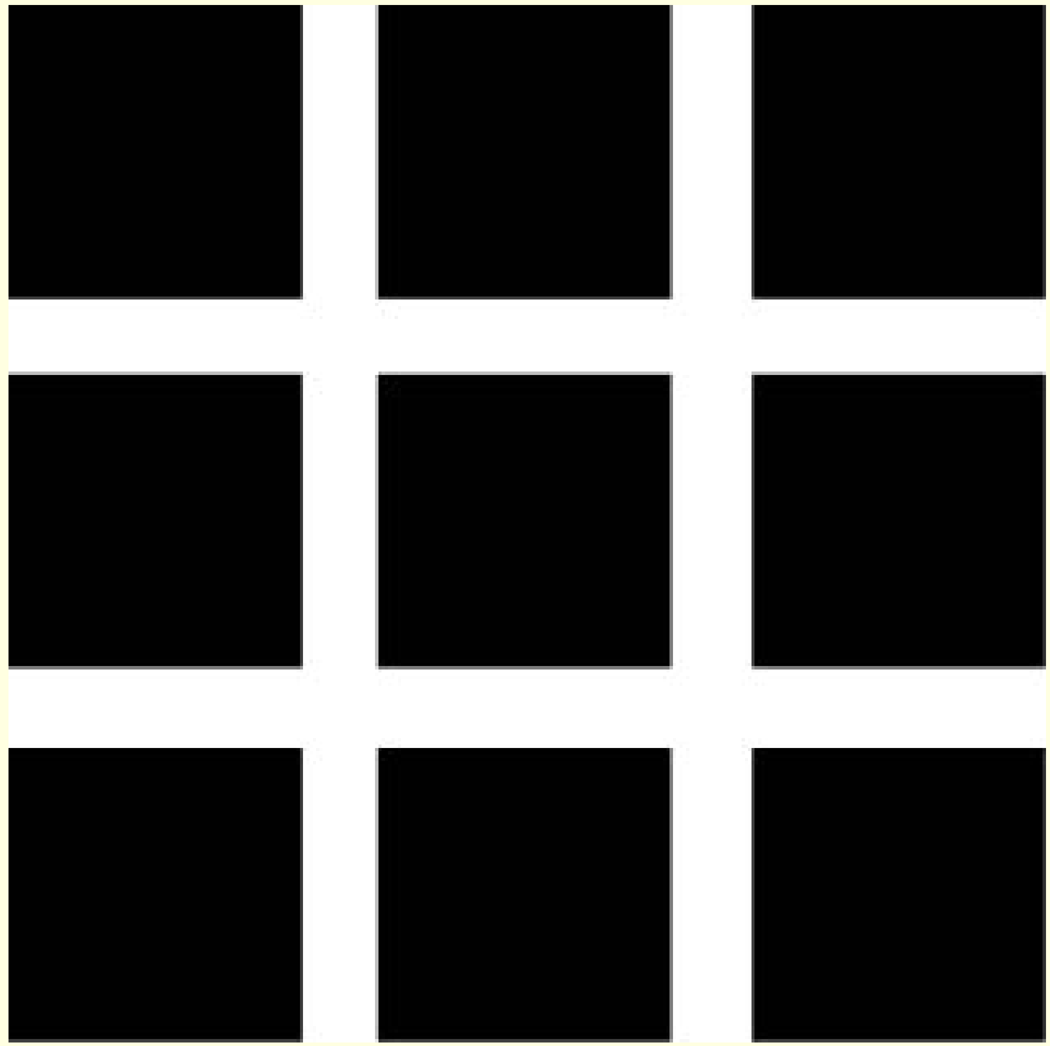


Small RFs will not have inhibitory surrounds extending into the grid cells

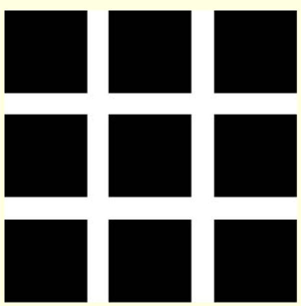
Neuronal Computation

Hermann Grid

dots jump around



dots remain stable



Neuronal Computation

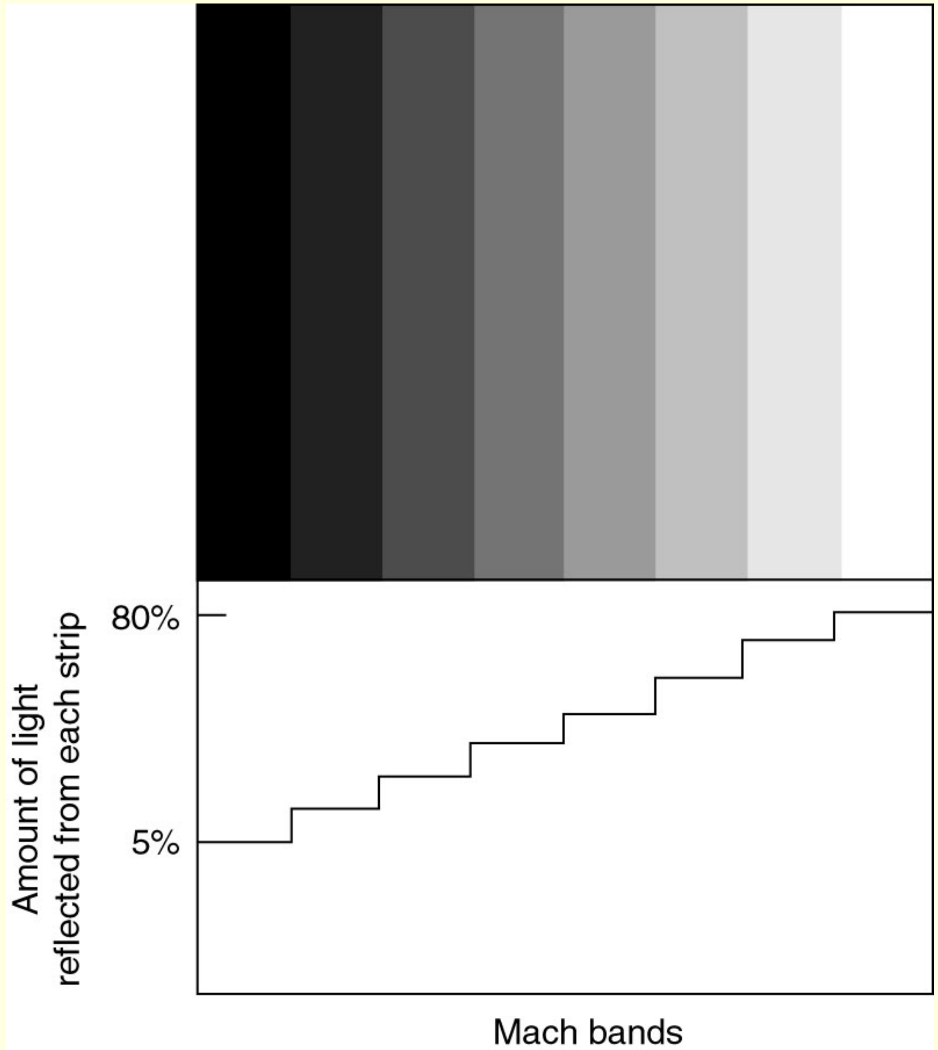
Lateral Inhibition

- Inhibition that spreads laterally in a neuronal circuit.
- Lateral inhibition explains two perceptual illusions: the Hermann Grid and Mach Bands.
- The dots in the Hermann grid are caused by strong lateral inhibition at the grid intersections (relative to the rest of the grid) and center-surround RFs.
- The dots jump around because they disappear when you fixate them directly due to small central RFs
- Mach Bands are caused by differential lateral inhibition from cells on either sides of the band

Neuronal Computation

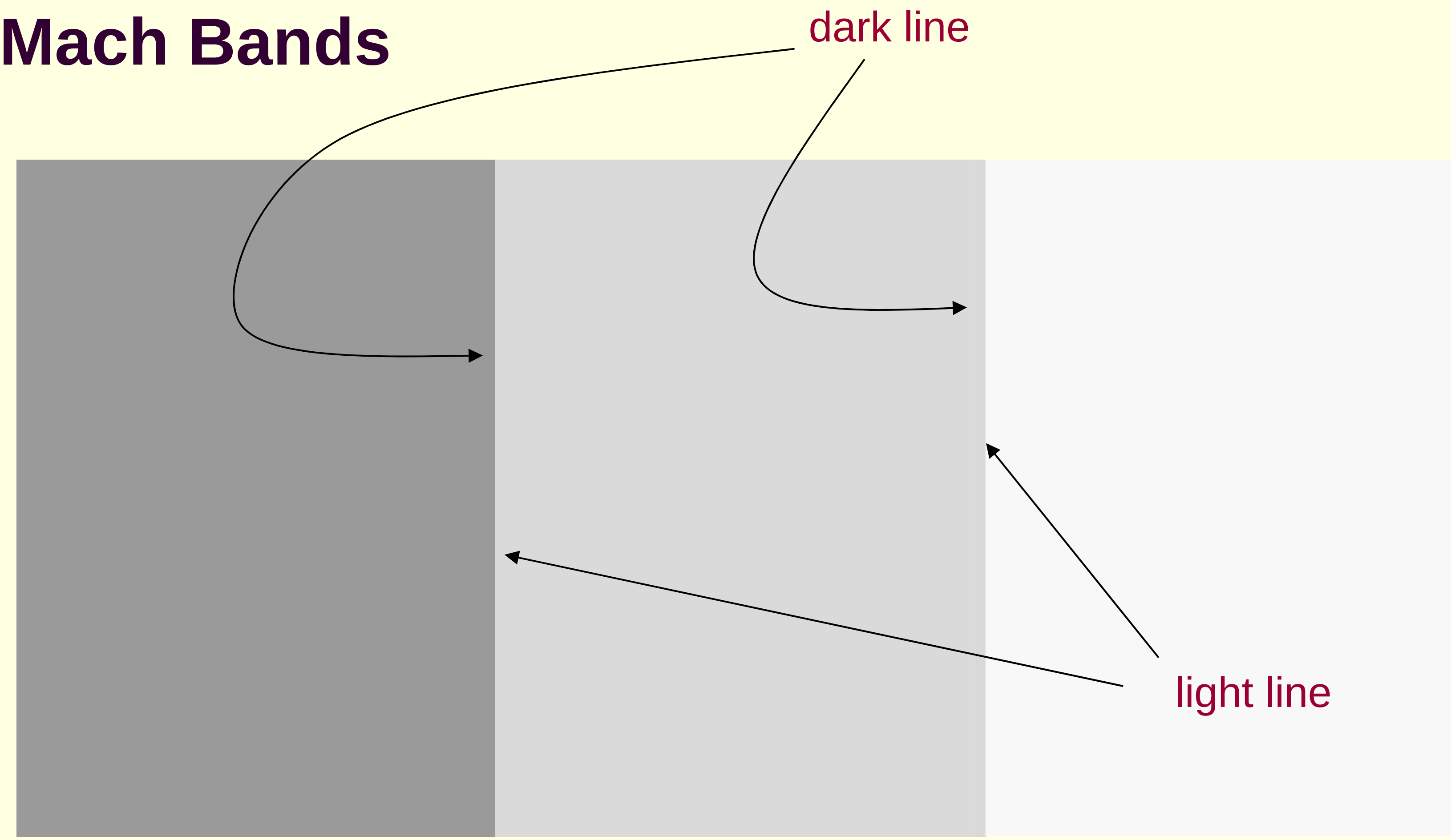
Mach Bands

The stimulus consists of dark-to-light (or light-to-dark) bars forming equal-sized and perfectly flat luminance steps



Neuronal Computation

Mach Bands



Neuronal Computation

Mach Bands

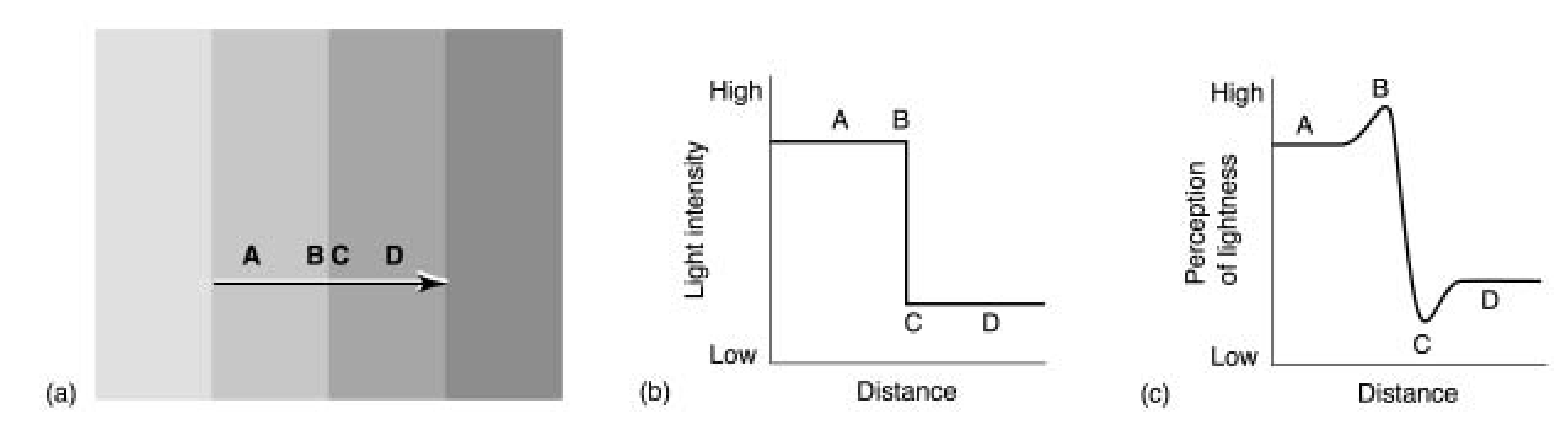
illustration of the illusion

Neuronal Computation

Mach Bands

actual changes in luminance

Perceptual experience



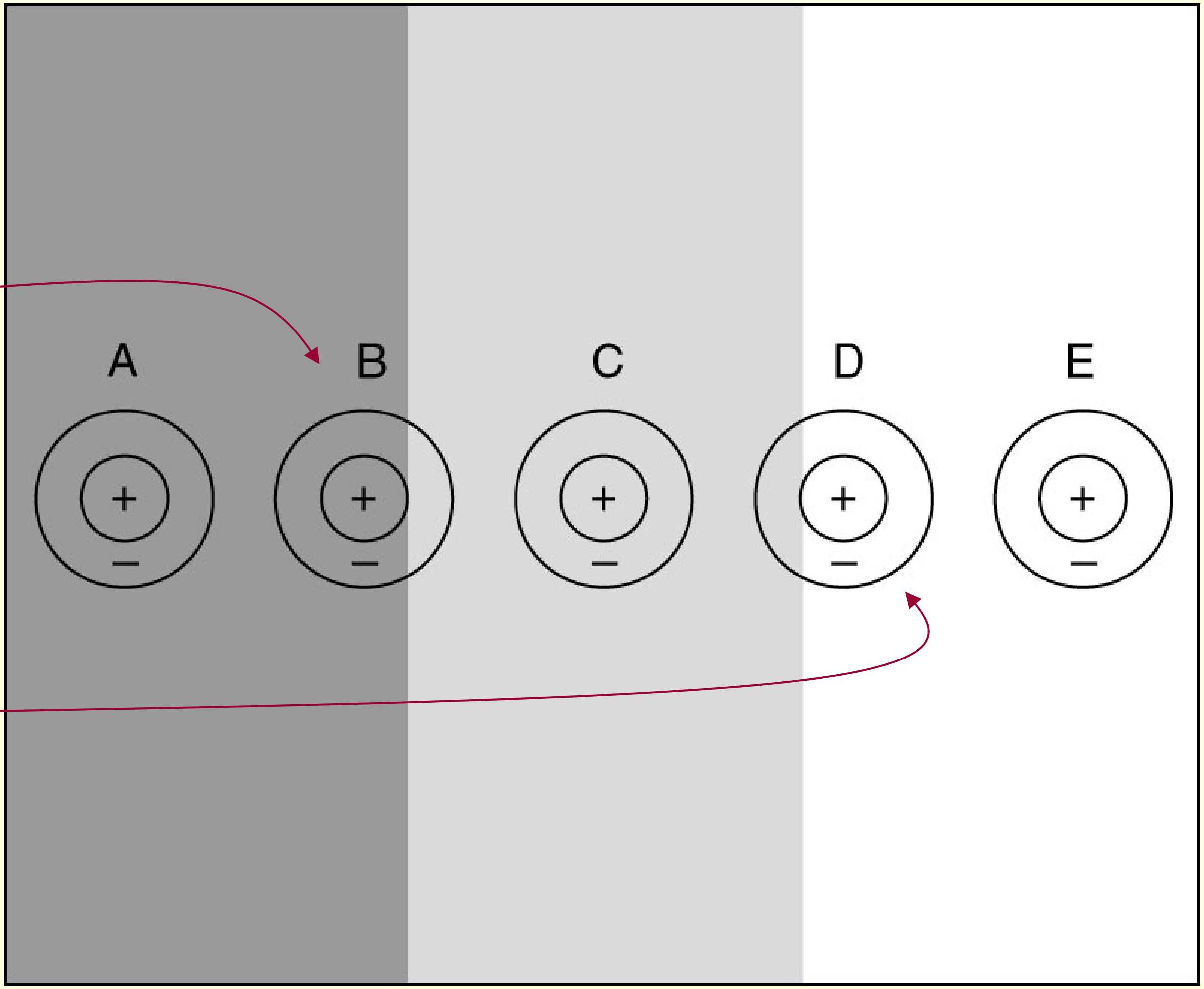
Mach Bands may serve to enhance perceptual edges. Edge enhancement is a term referring to the low-level accentuation of an edge so as to make that edge more easily used by a perceptual system.

Neuronal Computation

Mach Bands

More lateral inhibition means less firing; Cell B codes a dark Mach Band

Less lateral inhibition means more firing; Cell D codes a light Mach Band



Neuronal Computation

Mach Bands

stimulus

high intensity low intensity

Assume an activation of 100 units in receptors A-C, and 20 units in receptors D-F

Photoreceptor response

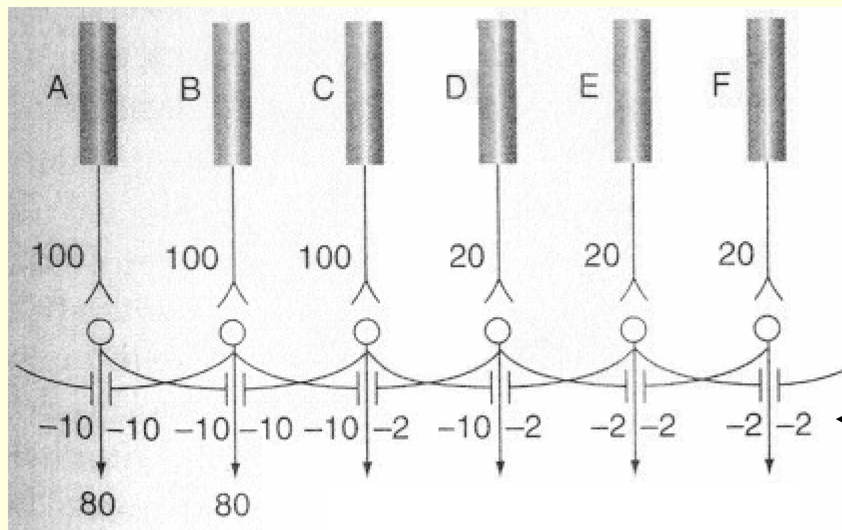


Photo-receptors

Bipolar cells

Lateral inhibition

Assume that each cell inhibits its neighbor by one-tenth of its own activation (10% LI)

Subtract the total inhibition from the activation to get the bipolar cell's response

Neuronal Computation

Mach Bands

stimulus

high intensity   low intensity

Assume an activation of 100 units in receptors A-C, and 20 units in receptors D-F

Photoreceptor response

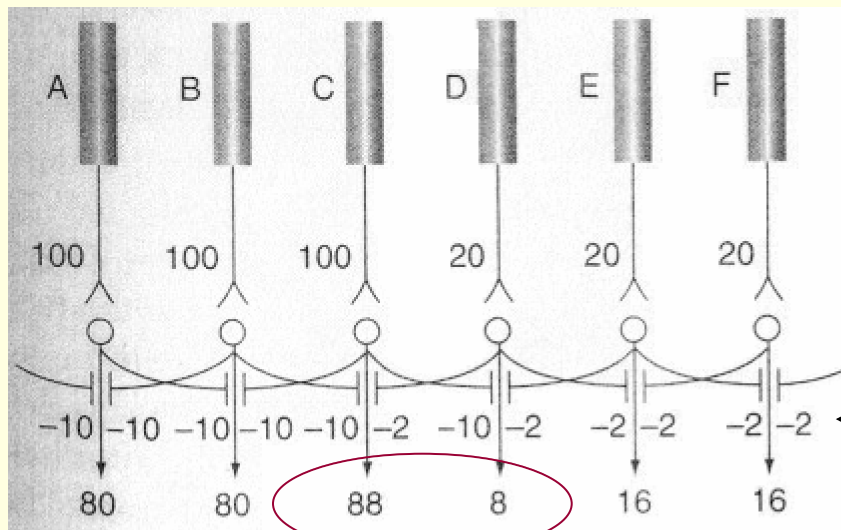


Photo-receptors

Bipolar cells

Lateral inhibition

Assume that each cell inhibits its neighbor by one-tenth of its own activation (10% LI)

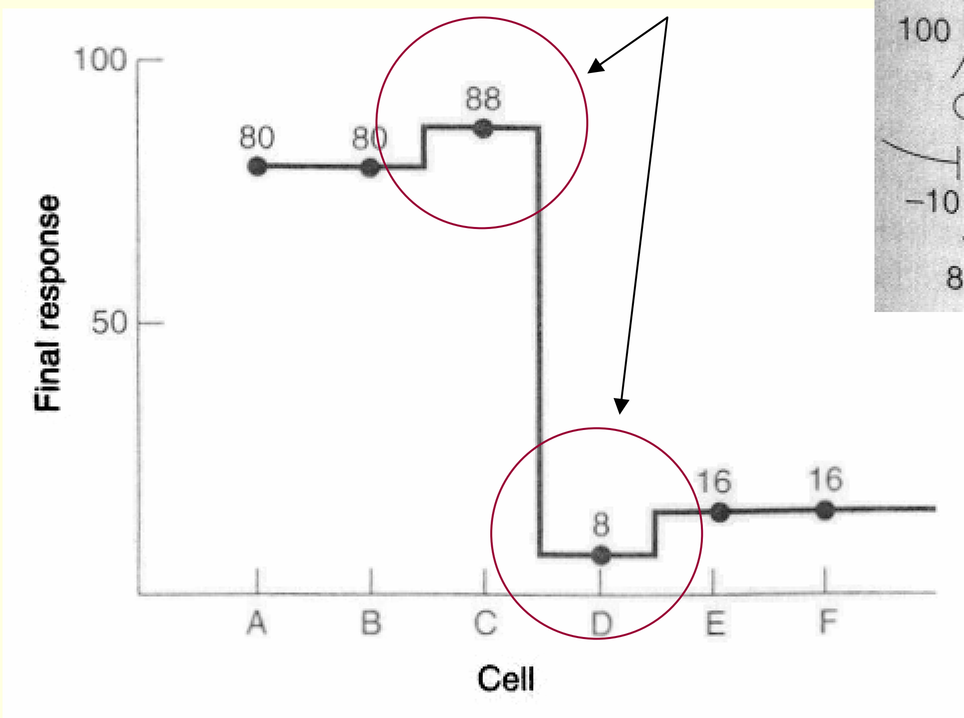
Subtract the total inhibition from the activation to get the bipolar cell's response

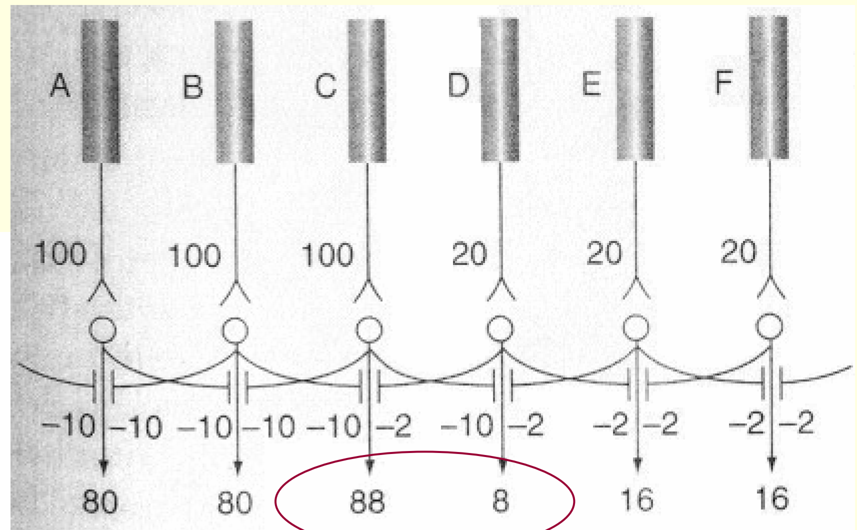
Mach Band

Neuronal Computation

Mach Bands

Mach Band





Mach Band

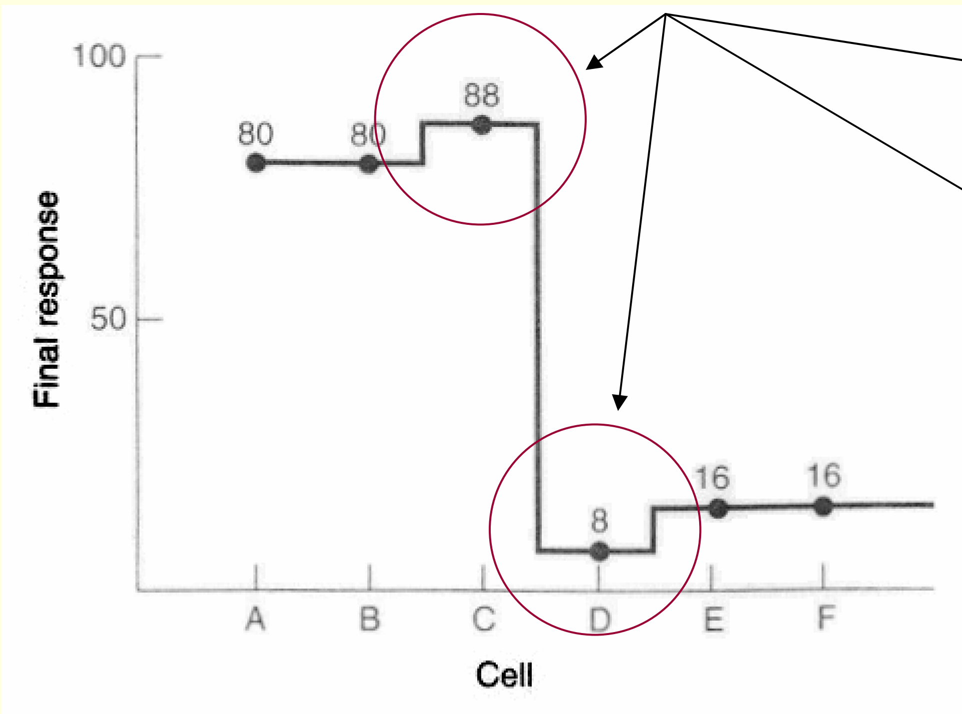
Neuronal Computation

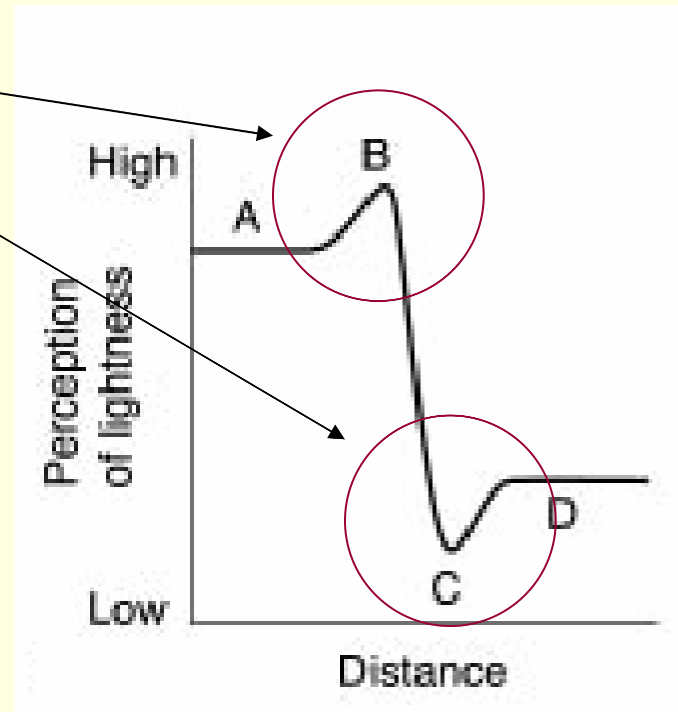
Mach Bands

Simulation of lateral inhibition

Mach Band

Perceptual experience





Neuronal Computation

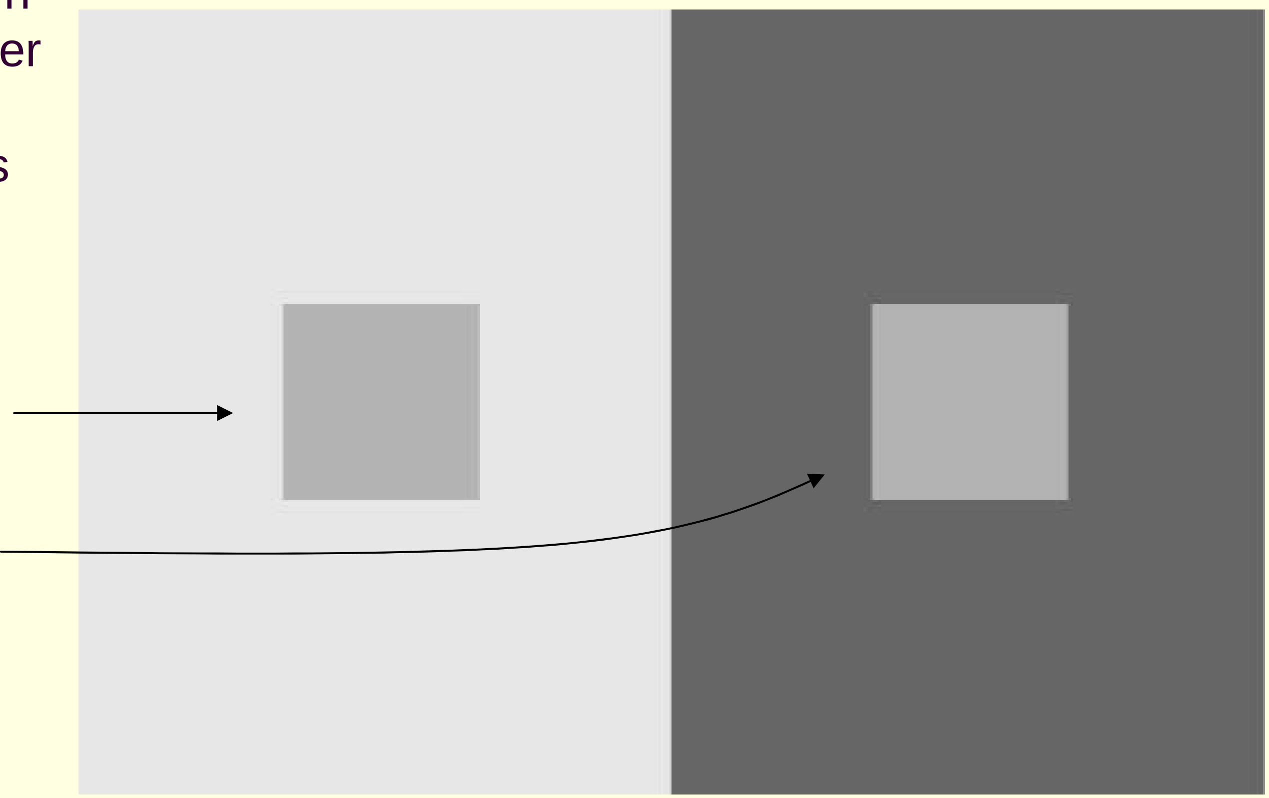
Lateral Inhibition

Simultaneous Lightness Contrast

Surrounding a pattern with a lighter or darker region changes the perceived brightness of the surrounded pattern

appears darker

appears lighter



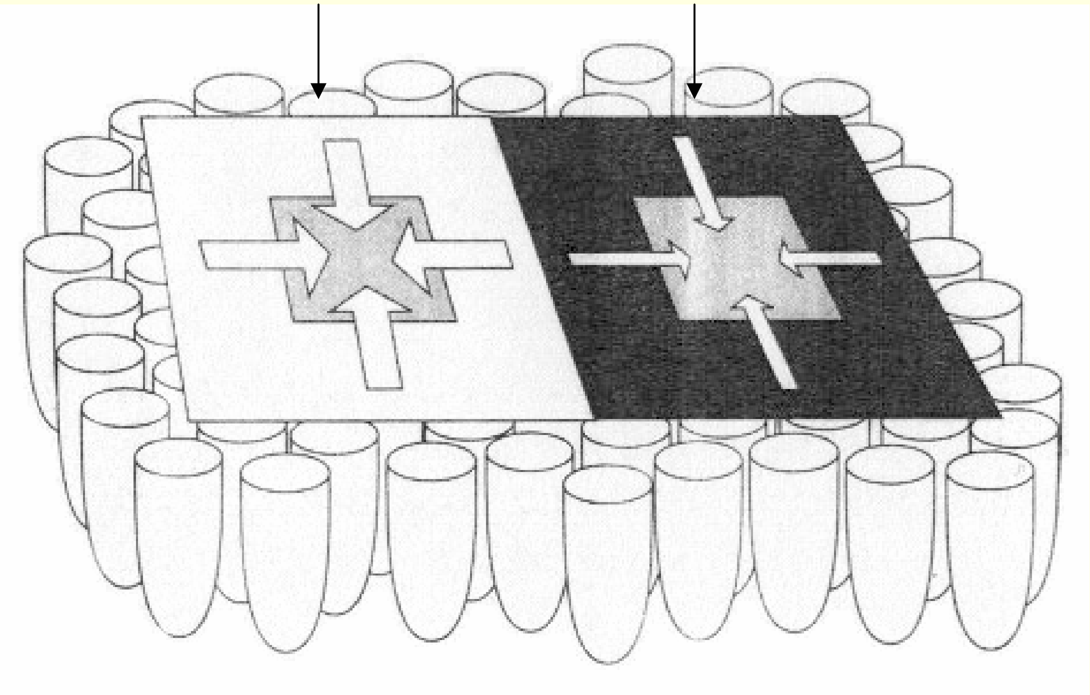
Both squares are equally intense

Neuronal Computation

Lateral Inhibition?

Perhaps simultaneous lightness contrast is caused by lateral inhibition of the center pattern from the background?

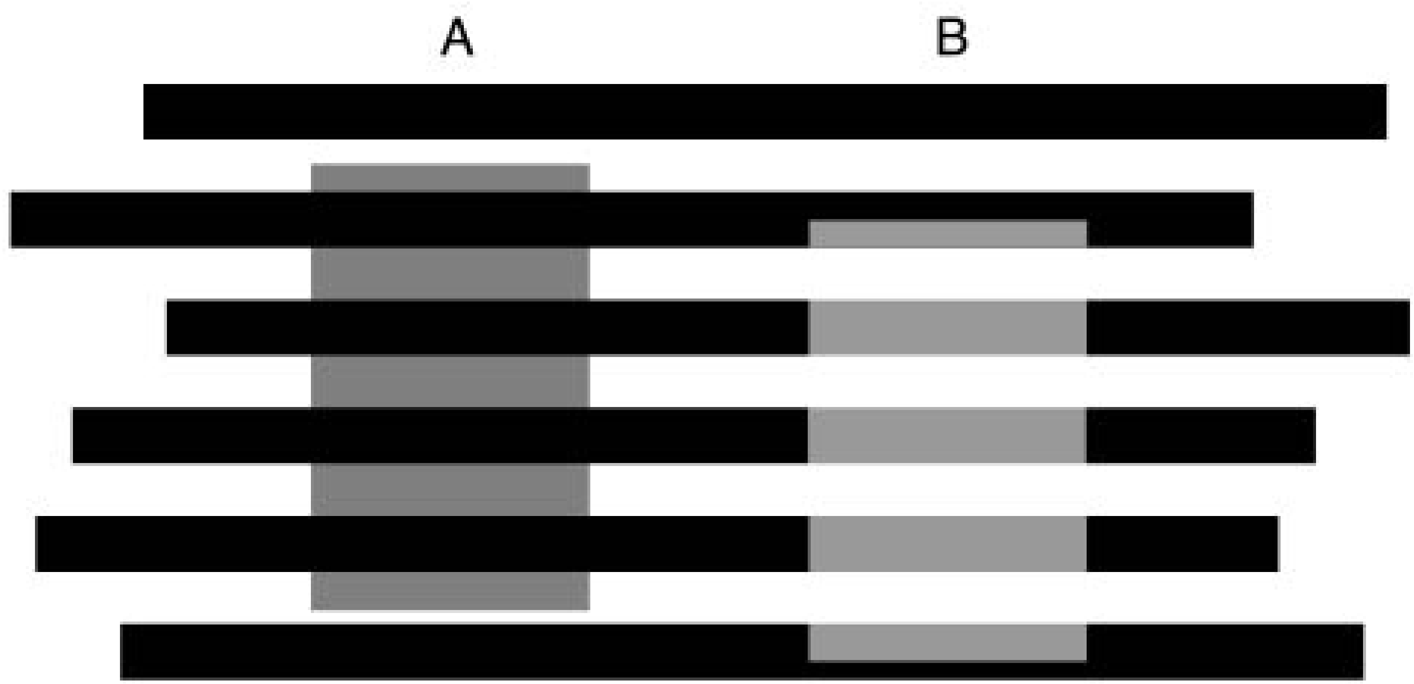
But, if this were true, why does the entire square appear lighter or darker?



Neuronal Computation

Lateral Inhibition?

White's Illusion



The perceived brightness differences between these two bars cannot be explained in terms of lateral inhibition