Credit: Getty Images

Processing & Encoding Visual Information

10/20/14

Reminders

- Midterm 1 next Monday.
- Review likely on Sunday afternoon (3ish).
- Check Ted for review materials.
- Check participation credit on Ted.
- Leave to the left.

Today

Processing visual information

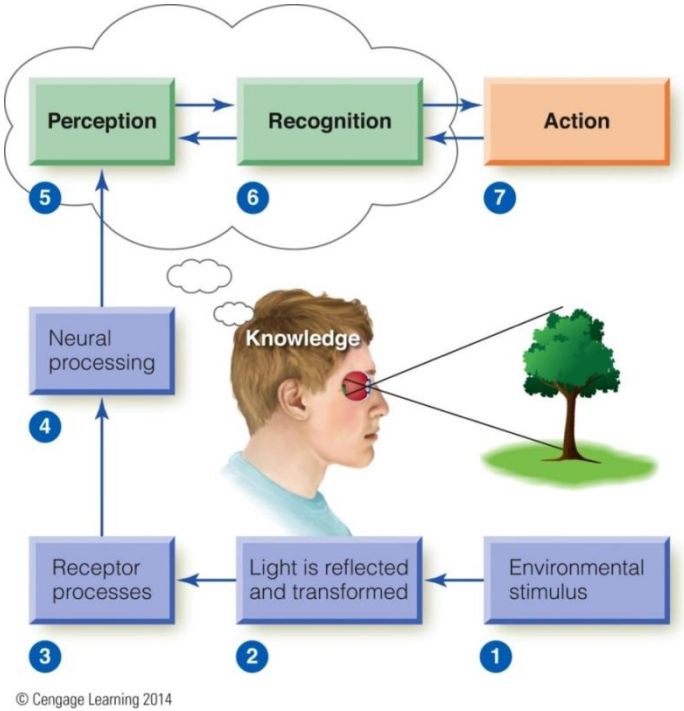
- Convergence and lateral inhibition
- Lateral inhibition and lightness perception
- Convergence and receptive fields

How does neural convergence influence perception?

From earlier

Basic organization and wiring of the sensory systems

- Sensory organs and receptors are specialized to detect environmental energy.
- These receptors lead to neural circuits that initially process specific environmental information (sensory modularity).
- We can measure specific neural activity with single-unit recordings.
- *Neural processing: How do converging receptor patterns yield different perceptual experiences?*

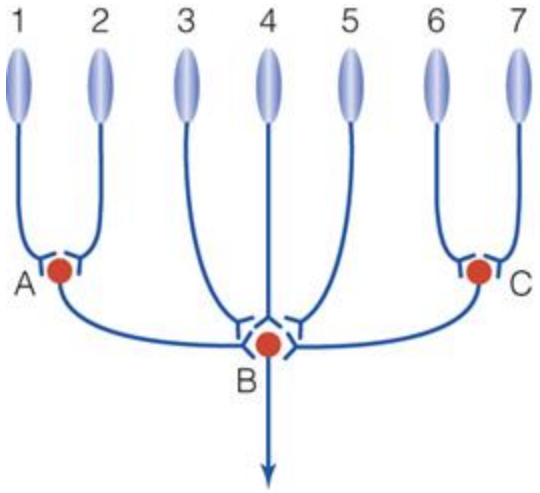


From earlier: Neural convergence

How do retinal cells converge?

- 126 million rods and cones **converge** onto 1 million ganglion cells in each eye.

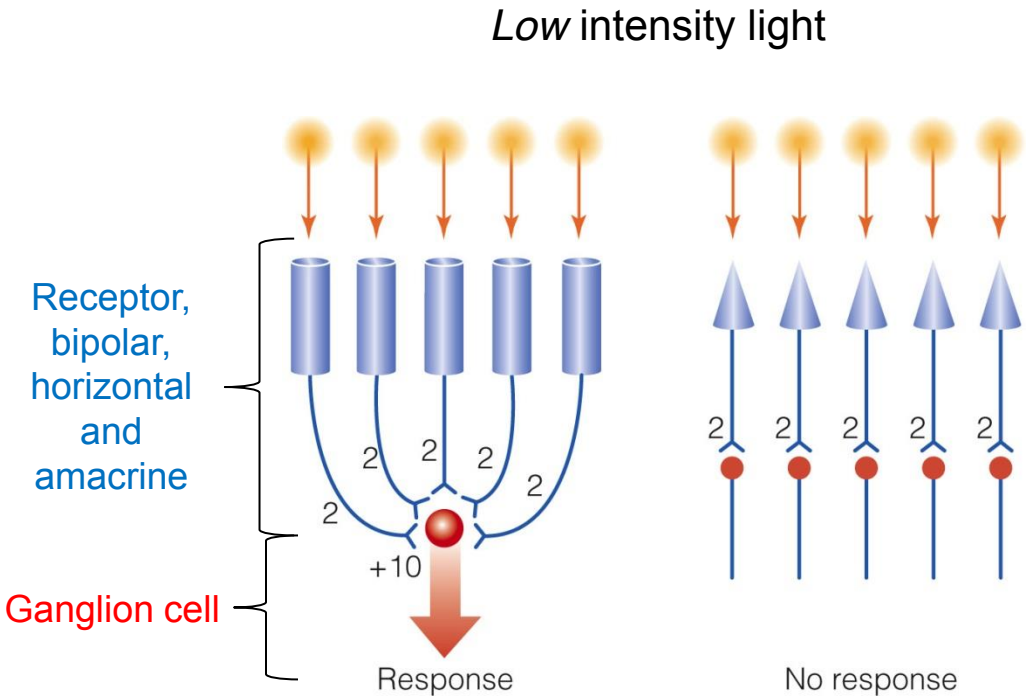
- Higher convergence of rods than cones
  - Average of 120 rods to one ganglion cell
  - Average of 6 cones to one ganglion cell
  - *Cones in fovea* have one-to-one relation to ganglion cells



Neural convergence

Rods are more sensitive to light than cones

- Rods take less light to respond.
- Rods have greater convergence which results in summation of the inputs of many rods onto ganglion cells, increasing the likelihood of response.
- Trade-off is that rods cannot distinguish detail.



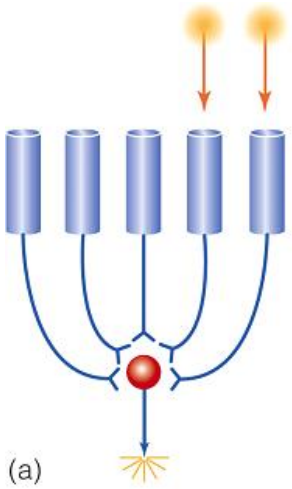
(Assume 10 units of activation needed for response.)

Neural convergence

All-cone vision in fovea results in high visual acuity.

- One-to-one wiring leads to ability to discriminate fine details.
- However, cones need more light to respond than rods.

High intensity light



"see one light"

Neural convergence

All-cone vision in fovea results in high visual acuity.

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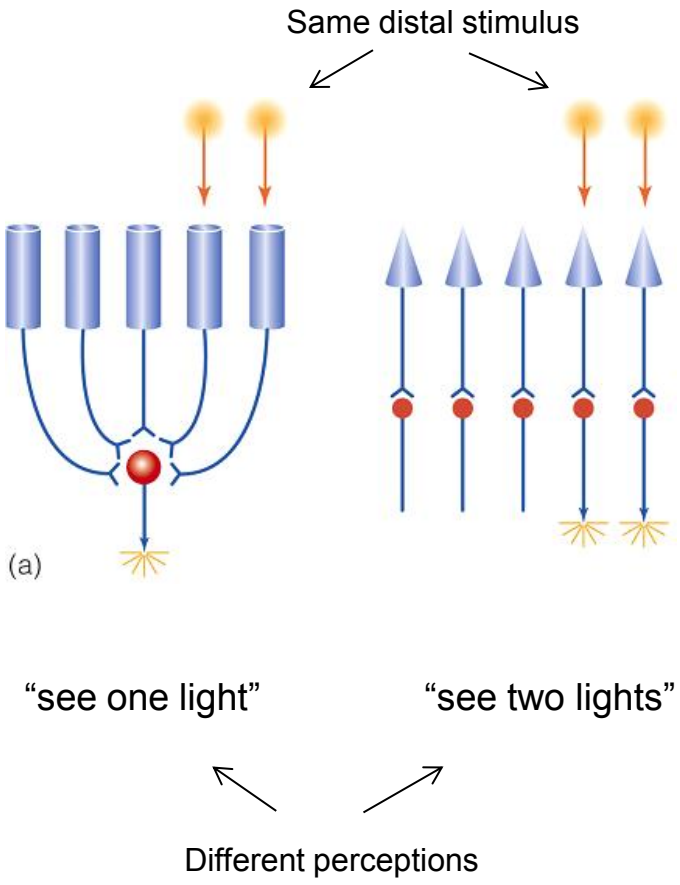


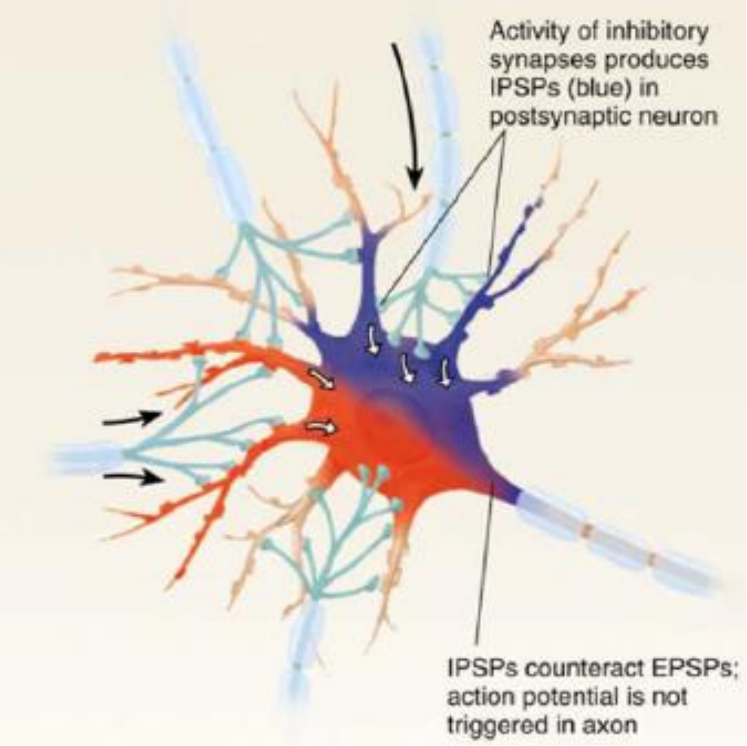
From earlier

EPSPs and IPSPs can summate on the same neuron.

An action potential is only triggered if the EPSPs can push the neuron to depolarization faster than the IPSPs pull it toward hyperpolarization.

This summation also determines the *rate* of firing.

Let's build a model of how this might work.

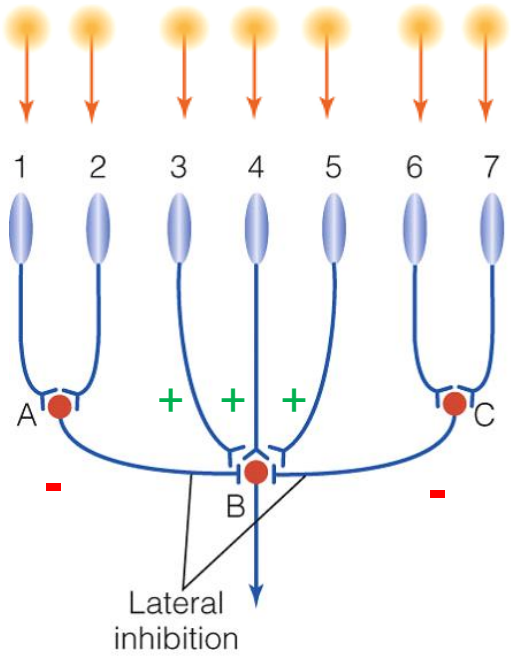


Convergence & lateral inhibition

Convergence can be either excitatory or inhibitory

- Receptors 3, 4, and 5 excite (EPSPs) the neuron at point B.
- However, activity at receptors 1, 2, 6, and 7 converge on inhibitory neurons (IPSPs) that reduce activity at B.
- This **lateral inhibition** decreases activity at B, even if the stimulus intensity at receptors 3, 4, and 5 remain constant.

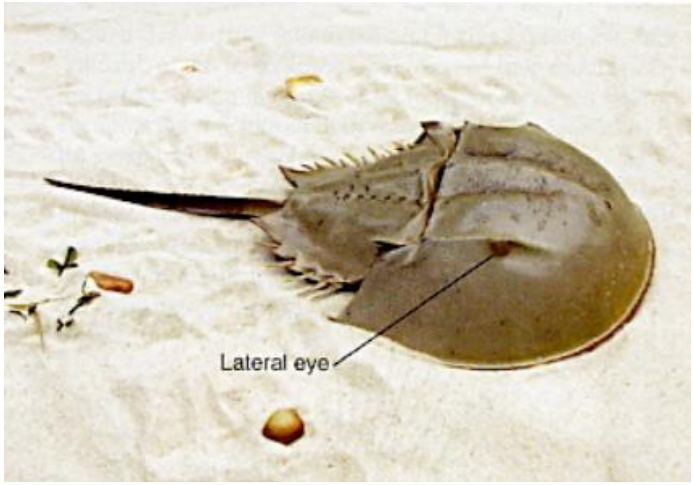
How do we know if this is (approximately) how it works?

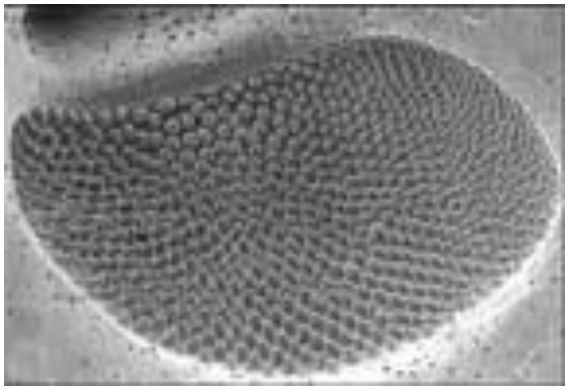


Convergence & lateral inhibition

Experiments with eye of *Limulus* (Horseshoe crab)

- Lateral eye is made up of tiny structures called ommatidia, each with its own lens and receptor.
- We can record from each ommatidia receptor separately.
- Light shown into a single receptor leads to rapid firing rate of receptor.
- Adding light into neighboring receptors leads to reduced firing rate of initial nerve fiber.

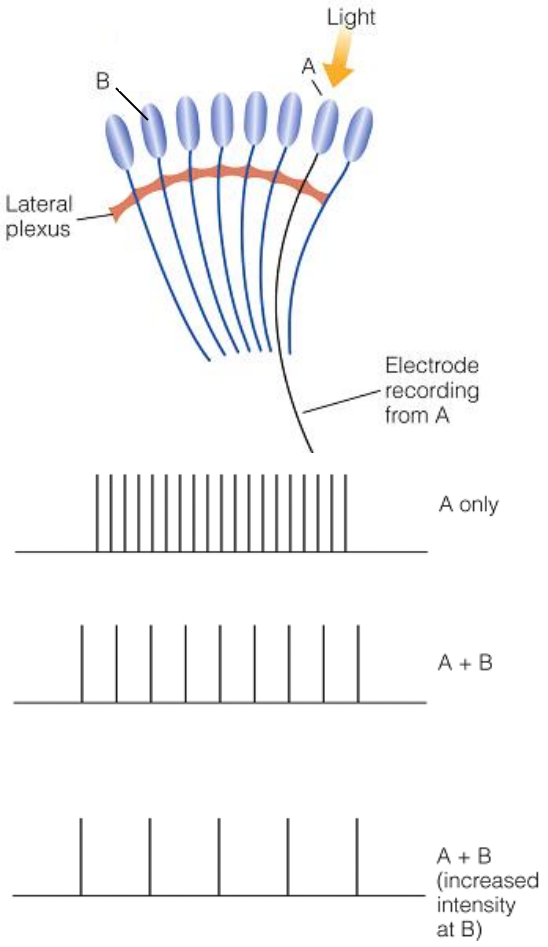




Convergence & lateral inhibition

Experiments with eye of *Limulus*
(Horseshoe crab)

- Operating at Marr's 3rd level of analysis (implementation) we record signals from receptor A.
- When only receptor "A" is activated with light, the receptor fires rapidly.
- If light is also shown on "B" we see a **decrease** in activation recorded from"A".
- Increasing the intensity at "B" reduces activity from "A" even further.
- Signals from neighboring receptors travel across the lateral plexus and **laterally inhibit** the receptor at "A".



Convergence & lateral inhibition

Progress check

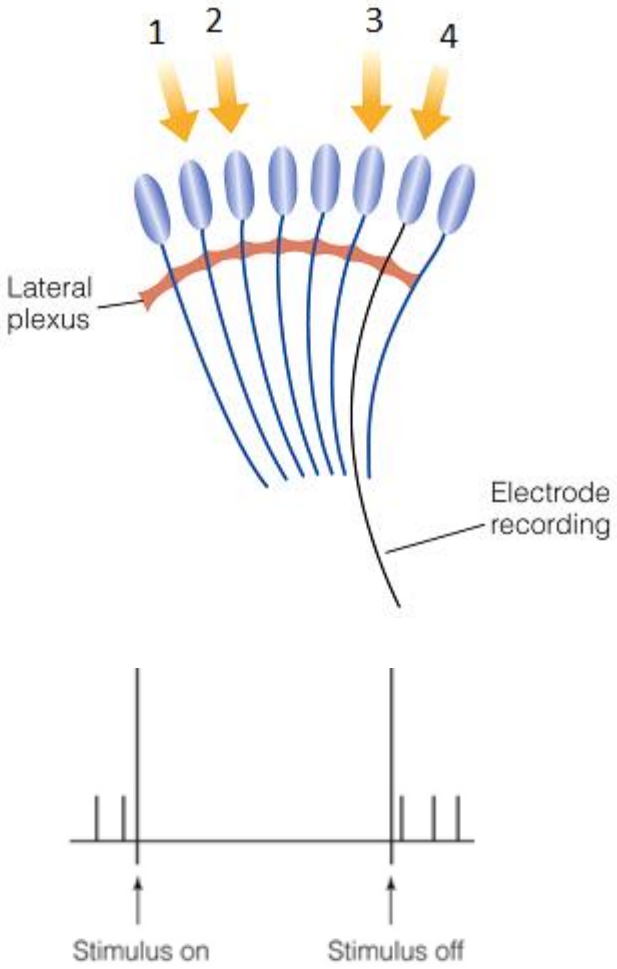
Which combination of light stimuli is most likely to produce the firing pattern shown on the right when recording from receptor 4?

A. 4

B. 3 and 4

C. 1, 2, 3 and 4 We would see 4 if so

D. 1 and 2



Lateral inhibition & perception

We have linked models (algorithms) with neural activity in animals.

What psychophysical effects should we expect in humans?

How is this linked to our perception?

Lateral inhibition & lightness perception

The simple notion of lateral inhibition can be used to explain some aspects of lightness perception.

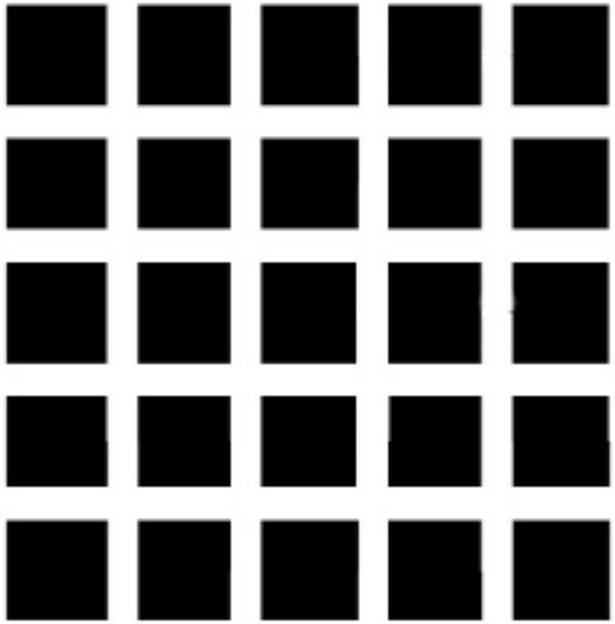
1. **The Hermann Grid**: Seeing spots at an intersection

2. **Mach Bands**: Seeing borders more sharply

3. **Simultaneous Contrast**: Seeing areas of different brightness due to adjacent areas

Lateral inhibition & lightness perception

The Hermann Grid: Seeing spots at an intersection



you see dark circle in the intersection.
if you focus on the intersection then the dot goes away.

Move your eyes across the image to make them appear, then stare at one to see it fade slightly.

Lateral inhibition & lightness perception

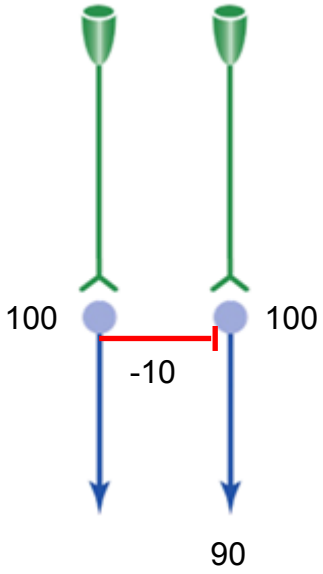
How does the Hermann grid illusion work?

Consider the following hypothetical algorithm:

1. Directly shining a light on a receptor sends 100 units of **excitatory** activity to a target **bipolar** cell.

2. When each bipolar cell is activated, it sends 10 units of **inhibitory** activity to neighboring bipolar cells.

3. The target bipolar cell sums this activity from receptor and neighboring cells. This becomes the output of the target bipolar cell.

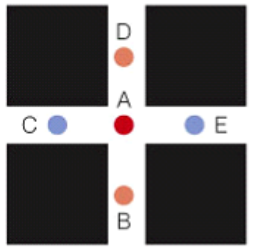


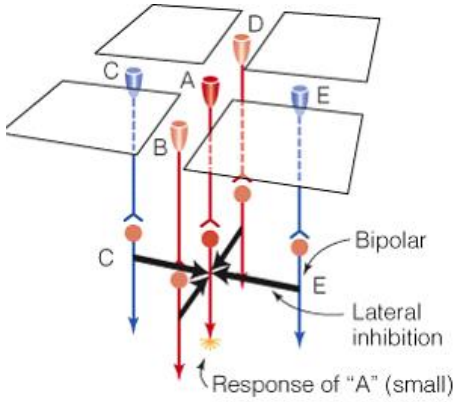
See page 56

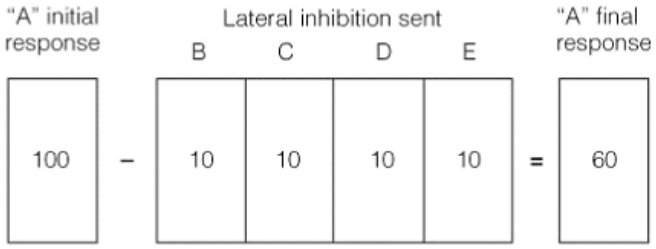
Lateral inhibition & lightness perception

Now we make predictions using that algorithm.

1. Five receptors are in the visual field. Each receptor synapses on a target bipolar cell.
2. Using our algorithm, we assume that the "A" receptor send 100 units of activity to it's bipolar cell.
3. The 4 neighboring bipolar cells send 10 units of inhibition to "A's" bipolar cell.
4. The summed output is 60, meaning a dim patch will be perceived at that spot.



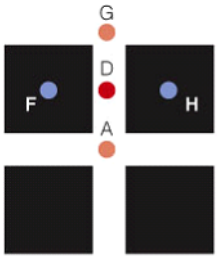


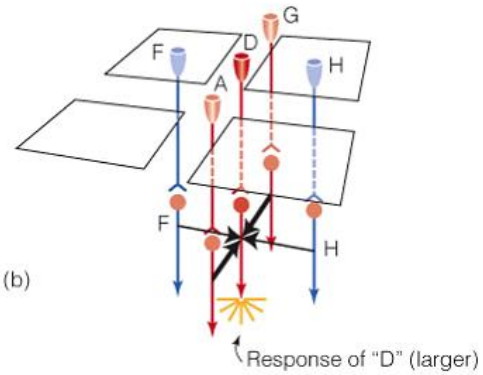


Lateral inhibition & lightness perception

We test this algorithm by next looking at activity in a different location, “D”.

1. Five receptors; each synapse on a target bipolar cell.
2. The same amount of inhibition comes from “A” and “G”, but since “F” and “H” are less activated, they inhibit “D” less.
3. The summation at “D” is 76; at “A” it was 60. So, the spot at “A” should appear dimmer than “D”.





“D” initial response		Lateral inhibition sent					“D” final response
		A	F	G	H		
100	–	10	2	10	2	=	76

Lateral inhibition & lightness perception

Progress check

Why does the dim spot fade when you look directly at the intersection?

A. The cones are more sensitive to the light.

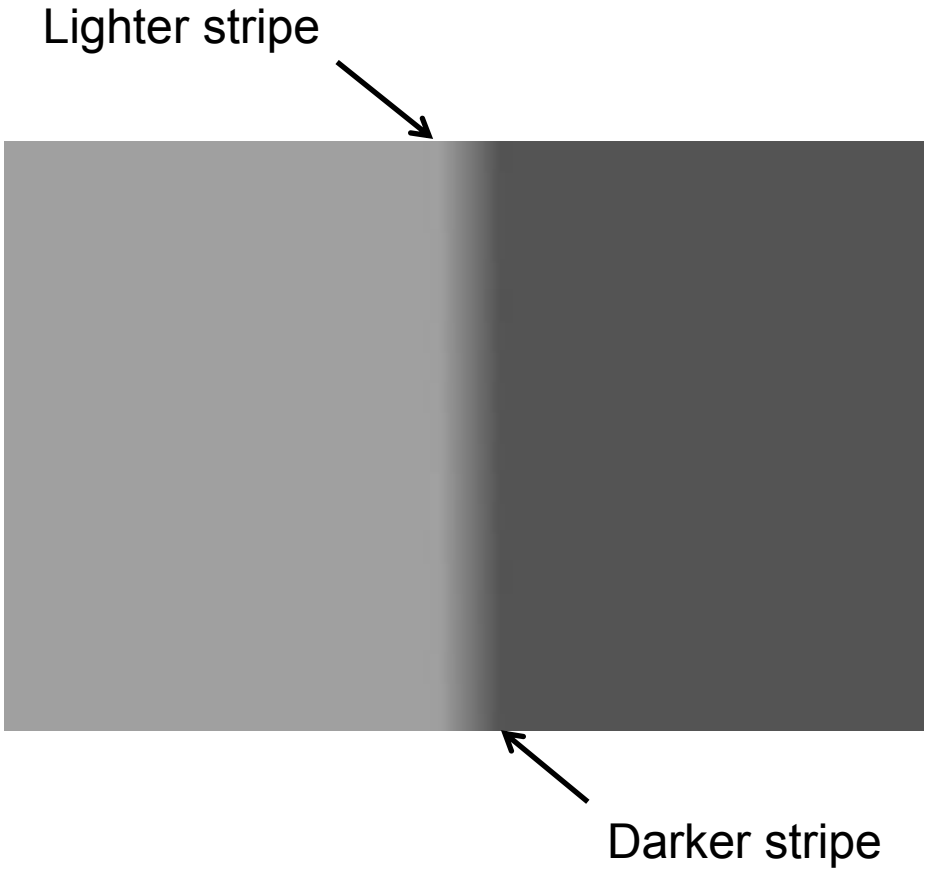
B. The rods are more sensitive to the light.

C. The convergence is greater in the fovea.

D. The convergence is less in the fovea.

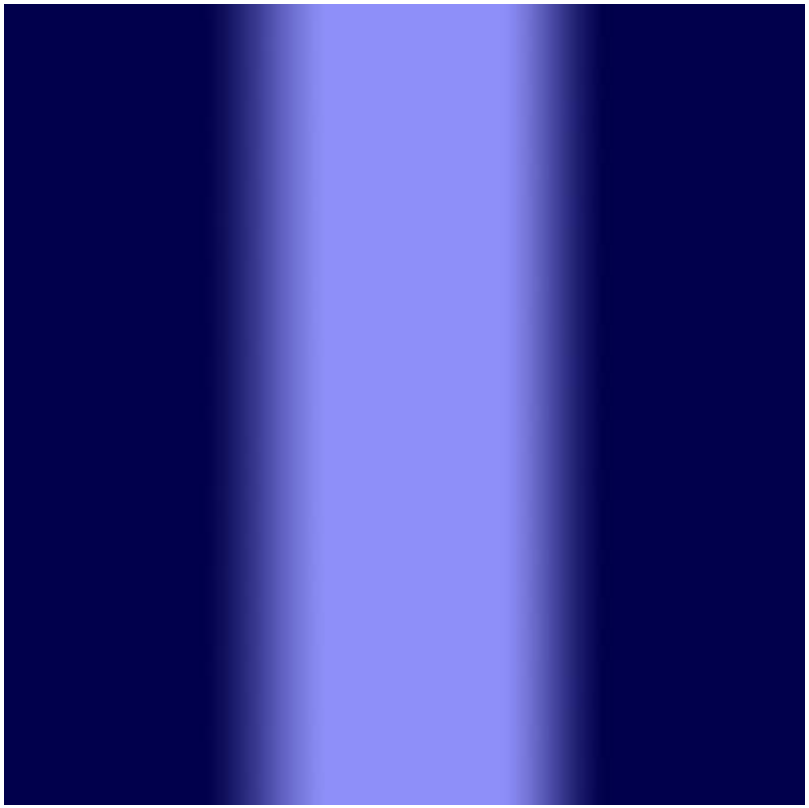
Lateral inhibition & lightness perception

Mach Band: illusory light and dark bands near a border.



Lateral inhibition & lightness perception

Also works for colored objects.

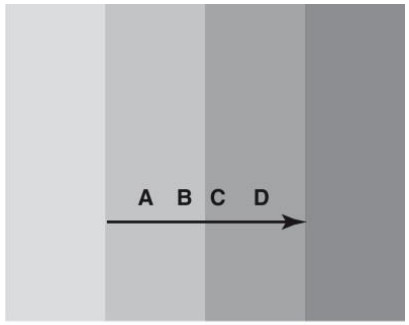


Lateral inhibition & lightness perception

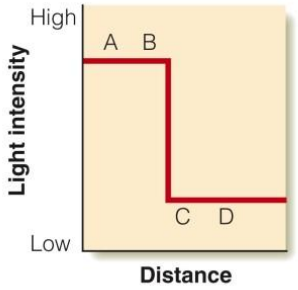
Mach Bands:

The perception of enhanced lightness and darkness at borders is a construction of the visual system.

- Actual physical intensities (distal stimulus) indicate that this is not in the stimulus itself.
- Receptors responding to low intensity (dark) area have smallest output (and least lateral inhibition).
- Receptors responding to high intensity (light) area have largest output (and most lateral inhibition).

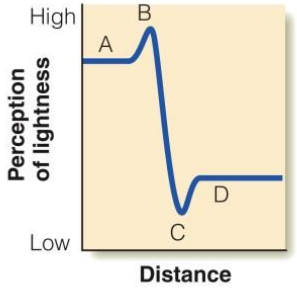


(a)



(b)

distal stimulus



(c)

perception stimulus

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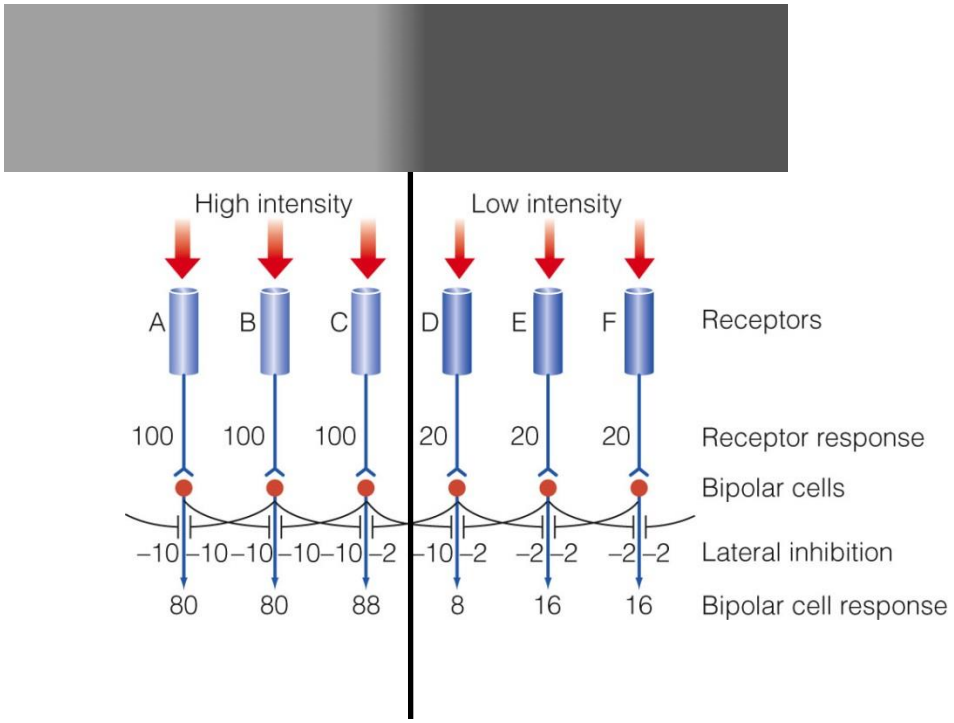
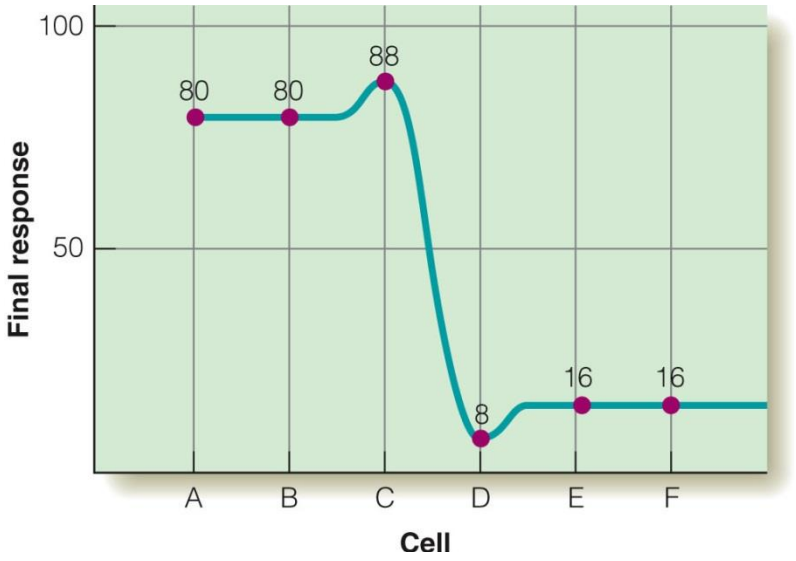
Lateral inhibition & lightness perception

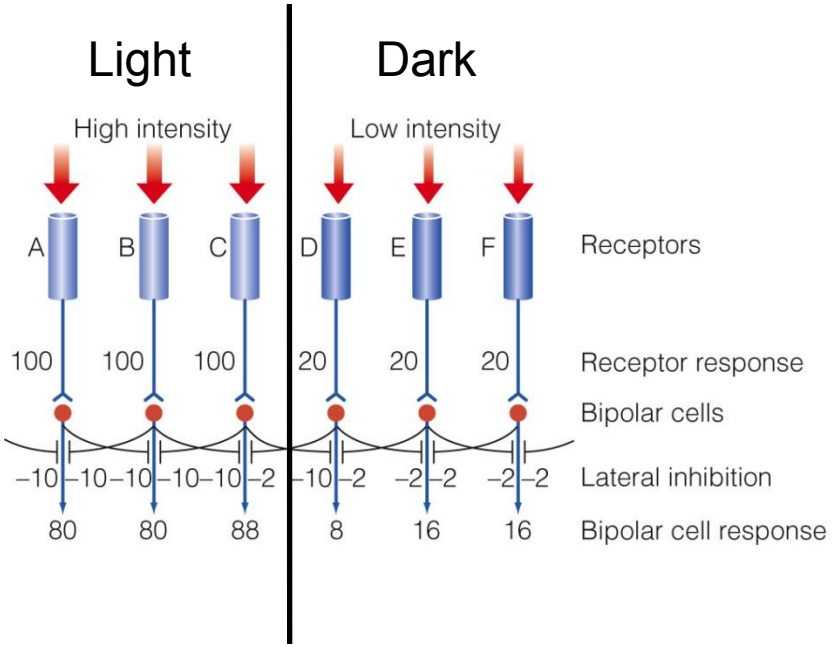
Mach bands:

- All receptors are receiving lateral inhibition from neighbors
- In purely low and high intensity areas, the amounts of inhibition at a receptor is the same as its neighbors.
- Receptors on the border, however, receive differing levels of inhibition.



Lateral inhibition & lightness perception



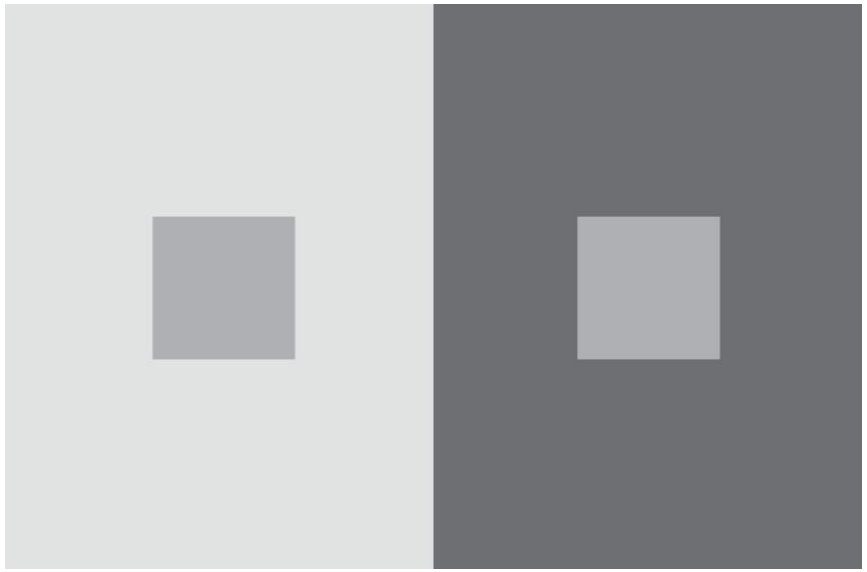


Border

Lateral inhibition & lightness perception

Simultaneous contrast: an illusion of changed brightness or color due to effect of adjacent area.

- An area that is of the same physical intensity appears:
  - lighter when surrounded by a dark area.
  - darker when surrounded by a light area.



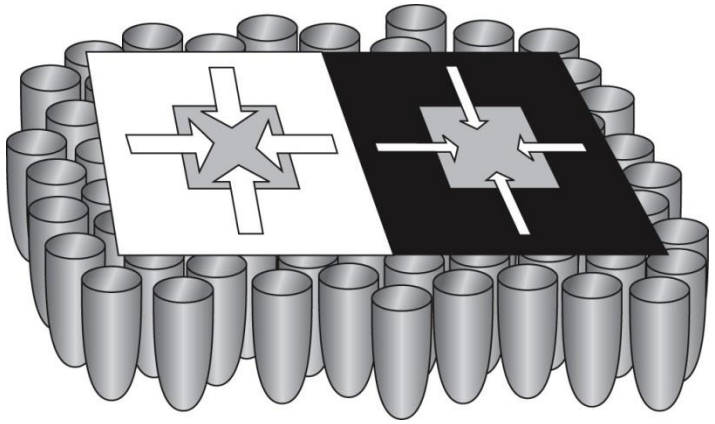
Lateral inhibition & lightness perception

Receptors stimulated by bright surrounding area send a large amount of inhibition to cells in center.

– Receptor cells in the middle are inhibited, and the resulting perception is of a darker area than when this stimulus is viewed alone.

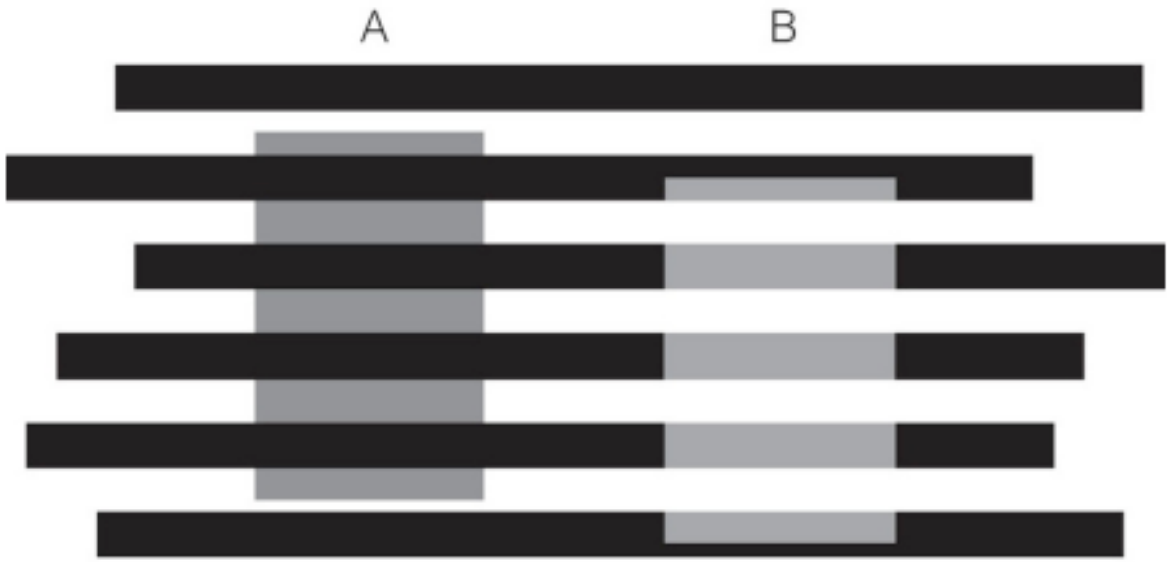
Receptors stimulated by dark surrounding area send a small amount of inhibition to cells in center.

– Resulting perception is of a lighter area than when this stimulus viewed alone.



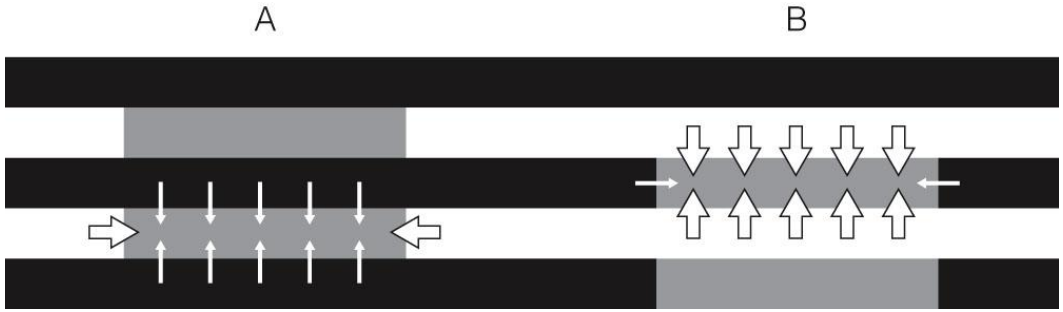
Lateral inhibition & lightness perception

Lateral inhibition fail: White's illusion



Lateral inhibition & lightness perception

Lateral inhibition would predict that bars at A should be less inhibited than B – so A should be brighter.



Lateral inhibition & lightness perception

Possible explanation is that the bars are perceived more strongly as "belonging to" (rectangular) objects.

- Effect probably occurs in cortex rather than retina.
- Exact physiological mechanism is unknown
- Would likely take research done at Marr's 3rd level of analysis to get more raw data, then build a new model for 2nd level algorithm.

Convergence & lateral inhibition

Progress check

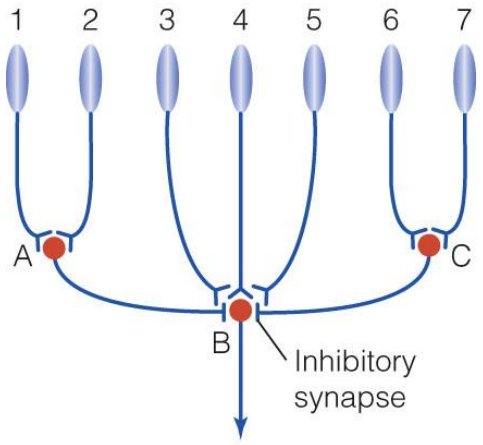
When an image is focused onto the retina, in which part of the retina should you have the greatest amount of lateral inhibition?

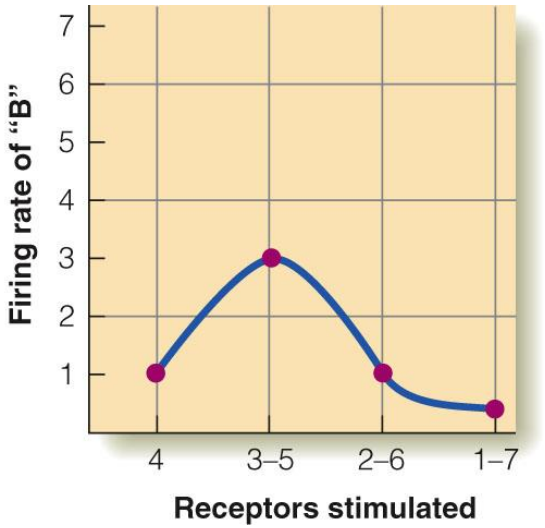
A. Macula
B. Fovea
C. Blind spot
D. Periphery

Convergence & receptive fields

The lateral inhibition effects we've seen so far occur at the level of the retina. How does neural convergence affect processing further on in the brain?

The summation of excitatory and inhibitory connections in the retina creates **receptive fields** for neurons in the visual system.

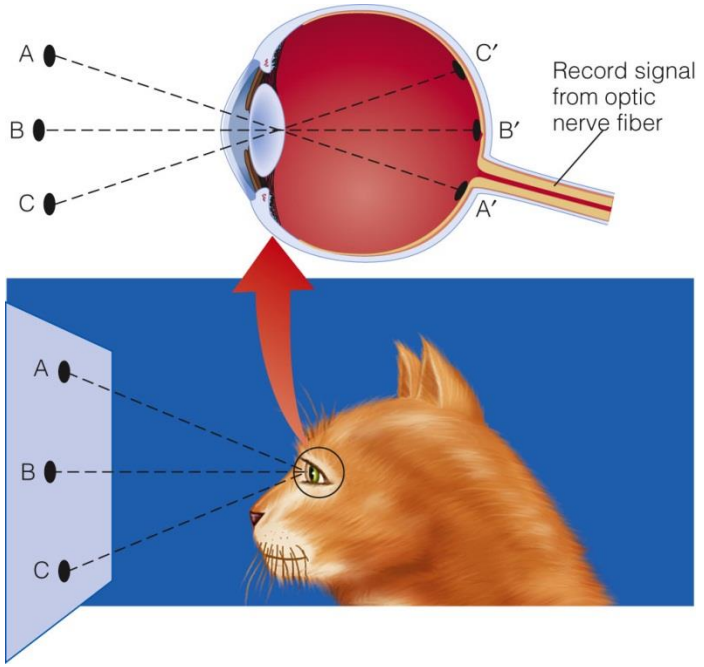




Convergence & receptive fields

The **receptive field** of a given neuron is the area on the retina that affects the neuron's firing rate (both excitatory and inhibitory).

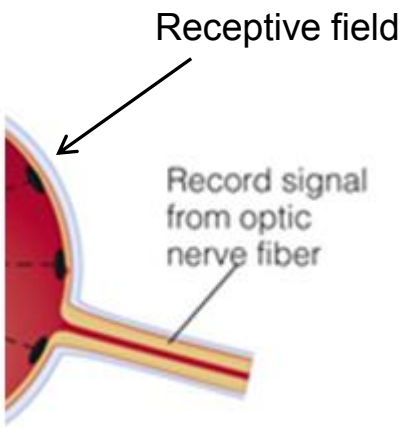
Note that the receptive field corresponds to a region in space (the visual field).

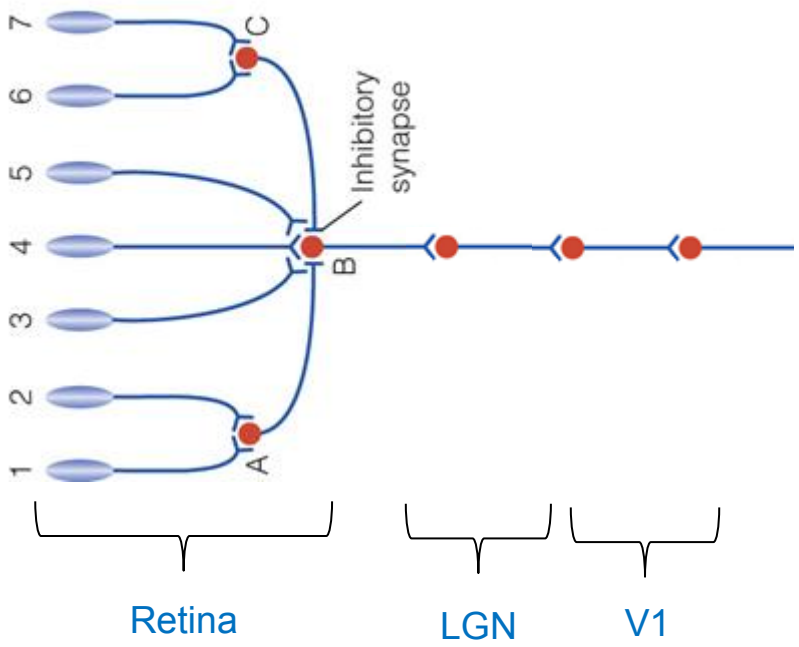


Convergence & receptive fields

The **receptive field** on the retina influences neurons throughout the visual system.

All neurons beyond “B” have the same receptive field in this example.



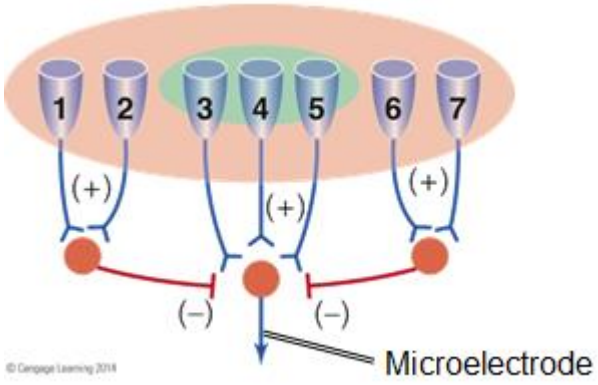


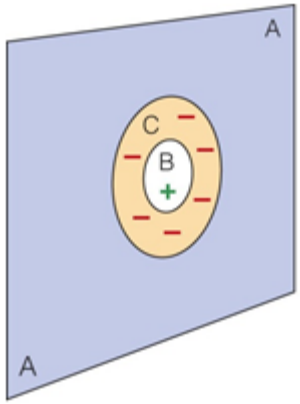
Convergence & receptive fields

Microelectrodes can measure the activity of a neuron while different environmental stimuli are presented in its receptive field.

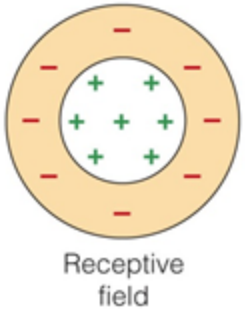
The example here is of an excitatory center-surround receptive field.

See page 62.

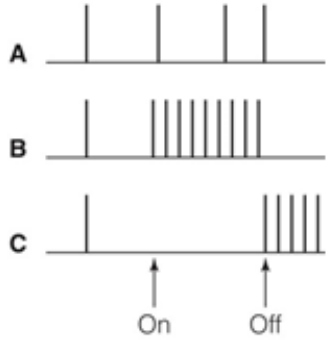




Visual field mapping of receptive field.



Pattern of activation on retina.



Ganglion cell action potentials.

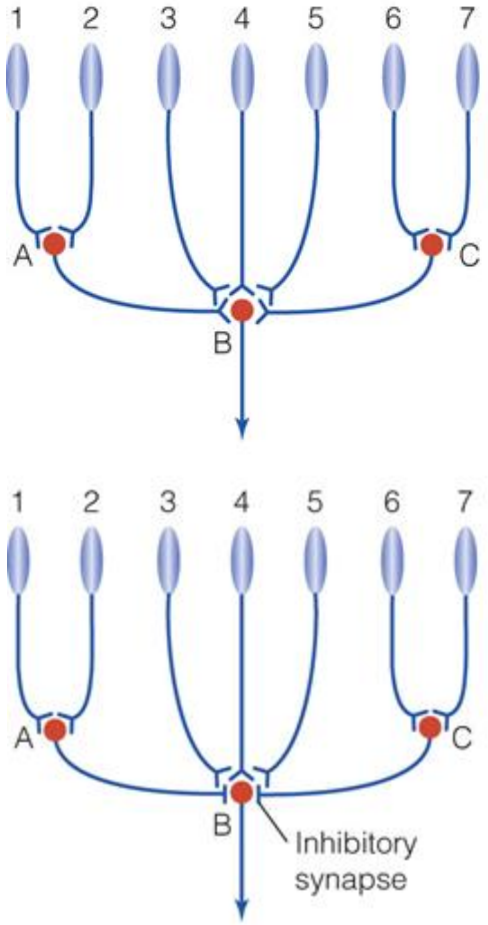
Convergence & receptive fields

Progress check

(T/F) In the top diagram, receptor 1 is part of the receptive field for neuron B. However, in the bottom diagram, the receptor 1 in not part of the receptive field for neuron B because it connects to an inhibitory neuron.

A. True

B. False



Summary

- Algorithmic models can be used to relate psychophysical phenomena to biological systems. [light detection → convergence & lateral inhibition → retinal anatomy]
- Non-human animal models are often used for proof of concept. [horseshoe crab]
- To be useful, the models need to explain human perceptual experiences. [lightness perception]
- Eventually, models will break down – either because they make bad predictions or the physiology doesn't match. [White's illusion]
- The new data is then used to make better models.
- Neural convergence can often lead us to perceive things that are not objectively present in the distal stimulus.

Next time

- Lab 1 due in section.
- Lab 2 in section this week.
- Read chapter 4.