Human Visual Perception

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Psychology
Human Visual Perception

The importance of...

- Neuronal Convergence
- Lateral Inhibition
Vision and the Eye

Structure of the Eye

Iris

Pupil

Sclera
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
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 photoreceptors 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

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The Blind Spot

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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**.
Vision and the Eye

The Retina
(vertical organization)

- Photoreceptors
- Bipolar cells
- Ganglion cells

light -> optic nerve
Vision and the Eye

The Retina (horizontal organization)

- **Horizontal cells**
  modulate activity between the photoreceptors and the bipolar cells

- **Amacrine cells**
  modulate activity between the bipolar and the ganglion cells
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

[Diagram of the eye with labels for Iris, Pupil, Cornea, Lens, Ciliary muscle, Vitreous humor, Macula, Blind spot, Fovea, Retina (rods and cones), and Optic nerve.]
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)
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.
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Vision and the Eye

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- 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
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.

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).
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.
Convergence

The more photoreceptors 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

<table>
<thead>
<tr>
<th>Rods</th>
<th>Cones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral vision</td>
<td>Central vision</td>
</tr>
<tr>
<td>~120 million</td>
<td>5-8 million</td>
</tr>
<tr>
<td>Poor spatial resolution</td>
<td>Good spatial resolution</td>
</tr>
<tr>
<td>More light sensitive</td>
<td>Less light sensitive</td>
</tr>
<tr>
<td>Function in dim light</td>
<td>Function in daylight</td>
</tr>
<tr>
<td>Achromatic</td>
<td>Color vision</td>
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</tbody>
</table>
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
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

Rod photoreceptors
interneurons
Ganglion cell

The more receptors stimulated, the greater B’s response
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
Receptive Fields

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

B will not 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 Firing

“spike train”

Receptive Fields

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For other locations there is a vigorous response.

Neuronal Computation
Receptive Fields

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For other locations there is a vigorous response.

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

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.

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

Center-Surround Organization

- excitatory "on" center
- inhibitory "off" surround

Receptive Field
Center-Surround Organization

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

Center-Surround Organization

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

Optimal Stimulus

Receptive Field
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
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
Hermann Grid

Grey dots appear at each of the four intersections
Hermann Grid

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

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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).
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).
The center cell receives lateral inhibitory inputs from all four neighbors.
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

Large response

Small response
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?
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.
Hermann Grid

Large RFs with inhibitory surrounds extending into the grid cells
Small RFs will not have inhibitory surrounds extending into the grid cells
Neuronal Computation

Hermann Grid

dots jump around

dots remain stable
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.
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

dark line

light line
Neuronal Computation

Mach Bands

illustration of the illusion
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.
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

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

Photoreceptor response

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 Bands

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Neuronal Computation

Mach Bands
Neuronal Computation

Mach Bands

Simulation of lateral inhibition

Perceptual experience

Mach Band

Final response

Cell

Perception of lightness

Distance
Neuronal Computation

Lateral Inhibition

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

Neuronal Computation

Lateral Inhibition?

White’s Illusion