Spatial Vision: Primary Visual Cortex
(Chapter 3, part 1)

Lecture 6

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Sensation & Perception
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Eye growth regulation

Chicks’ emmetropic response to hyperopic defocus

KL Schmid, CF Wildsoet - Vision Research, 1996
FJ Rucker, J Wallman - Vision research, 2009
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Defocus detection

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No optic nerve  \(\rightarrow\) still proper emmetropization
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Defocus detection

Chicks’ emmetropic response to hyperopic defocus

No optic nerve $\rightarrow$ still proper emmetropization
remaining Chapter 2 stuff
**phototransduction**: converting light to electrical signals

**rods**
- respond in low light ("scotopic")
- only one kind: don’t process color
- 90M in humans

**cones**
- respond in daylight ("photopic")
- 3 different kinds: responsible for color processing
- 4-5M in humans
**phototransduction**: converting light to electrical signals

- **outer segments**
  - packed with discs
  - discs have **opsins** (proteins that change shape when they absorb a photon - amazing!)
  - different opsins sensitive to different wavelengths of light
  - **rhodopsin**: opsin in rods
  - **photopigment**: general term for molecules that are photosensitive (like opsins)
dark current

- In the dark, membrane channels in rods and cones are open by default (unusual!)
- current flows in continuously
- membrane is depolarized (less negative)

- neurotransmitter is released at a high rate to bipolar cells
transduction & signal amplification

- photon is absorbed by an opsin
- channels close (dark current turns off)
- membrane becomes more polarized (more negative)

- neurotransmitter is released at a lower rate

![Diagram of phototransduction](image)
transduction & signal amplification

inner segments

machinery for amplifying signals from outer segment

neurotransmitter release
graded potential (not spikes!)

to bipolar cells
Photoreceptors: not evenly distributed across the retina

- fovea: mostly cones
- periphery: mostly rods

Q: what are the implications of this?
Photoreceptors: not evenly distributed across the retina

- not much color vision in the periphery
- highest sensitivity to dim lights: 5° eccentricity
Vision scientists measure the size of visual stimuli by how large an image appears on the retina rather than by how large the object is.
Retinal Information Processing: Kuffler’s experiments

“ON” Cell

(a) ON-center ganglion cell

Spot in center

Response

Light on

Spot in surround

Response
Retinal Information Processing: Kuffler’s experiments

“OFF” Cell

- **OFF-center ganglion cell**
  - **Spot in center**
  - **Spot in surround**

- **Response**
  - **Light on**
Receptive field: “what makes a neuron fire”

- weighting function that the neuron uses to add up its inputs”

Response to a dim light

![Diagram of ON cell with patch of light and light level calculation]

\[1 \times (+5) + 1 \times (-4) = +1 \text{ spikes}\]
Receptive field: “what makes a neuron fire”

- weighting function that the neuron uses to add up its inputs”

Response to a spot of light

patch of bright light

ON cell

light level

1 \times (+5) + 0 \times (-4) = +5 \text{ spikes}

“center” weight

“surround” weight
Mach Bands

Each stripe has constant luminance ("light level")
Response to a bright light

light=+2

2 × (+5) + 2 × (-4) = +2 spikes

higher light level

“center”  “surround” weight

weight
Response to an edge

\[ 2 \times (+5) + 2 \times (-3) + 1 \times (-1) = +3 \text{ spikes} \]
Mach Band response

\[ 2 \times (+5) + 2 \times (-3) + 1 \times (-1) = +3 \text{ spikes} \]
**Mach Band response**

edges are where light difference is greatest

$$2 \times (+5) + 2 \times (-3) + 1 \times (-1) = +3 \text{ spikes}$$

“center” weight

“surround” weight
Also (partially) explains:

Lightness illusion
ON and OFF retinal ganglion cells’ dendrites arborize (“extend”) in different layers:

Parvocellular
(“small”, feed pathway processing shape, color)

Magnocellular
(“big”, feed pathway processing motion)
“Channels” in visual processing

Incoming Light

- ON, M-cells (light stuff, big, moving)
- OFF, M-cells (dark stuff, big, moving)
- ON, P-cells (light, fine shape/color)
- OFF, P-cells (dark, fine shape/color)

The Retina

Optic Nerve

the brain
Luminance adaptation

remarkable things about the human visual system:
• incredible range of luminance levels to which we can adapt
  (six orders of magnitude, or 1 million times difference)

Two mechanisms for **luminance adaptation**
(adaptation to levels of dark and light):
  (1) Pupil dilation
  (2) Photoreceptors and their photopigment levels

/ the more light, the more photopigment gets “used up”,
→ less available photopigment,
→ retina becomes less sensitive
The possible range of pupil sizes in bright illumination versus dark:

- 16 times more light entering the eye

(a) Bright illumination

2-mm pupil

(b) Dark

8-mm pupil
Contrast = difference in light level, divided by overall light level

Contrast = difference in light level, divided by overall light level

\[ C = \frac{\Delta I}{I} \]

(Think back to Weber’s law!)
**Luminance adaptation**

“center-surround” receptive field

Contast is (roughly) what retinal neurons compute, taking the difference between light in the center and surround!

\[
\Delta I = (5 \cdot I_{\text{ctr}}) - (4 \cdot I_{\text{surround}})
\]

**Contrast** = difference in light level, divided by overall light level

\[
C = \frac{\Delta I}{I}
\]

(Think back to Weber’s law!)

• from an “image compression” standpoint, it’s better to just send information about local differences in light
summary: Chap 2

- transduction: changing energy from one state to another
- Retina: photoreceptors, opsins, chromophores, dark current, bipolar cells, retinal ganglion cells.
- “backward” design of the retina
- rods, cones; their relative concentrations in the eye
- Blind spot & “filling in”
- Receptive field
- ON / OFF, M / P channels in retina
- contrast, Mach band illusion
- Light adaptation: pupil dilation and photopigment cycling
Spatial Vision: From Stars to Stripes
Motivation

We’ve now learned:
• how the eye (like a camera) forms an image.
• how the retina processes that image to extract contrast (with “center-surround” receptive fields)

Next:
• how does the brain begin processing that information to extract a visual interpretation?