Eyes That See Light (cont’d)

• Using the ophthalmoscope, doctors can view the back surface of patients’ eyes: fundus
Eye Factoids

• The retina is pink, but when we look into someone's eye, it looks black - why is that?
  – Need an ophthalmoscope to see the inside of an eye

• Why does the back of the eye of cats, raccoons and many nocturnal animals shine at night?
  – Reflective coating on their retinas

• Why do you get "red-eye" in photos taken with a flash?

Light receptor cells in the retina

• Retina contains two types of cells that react to light

• Photoreceptors
  – Rods
    • All rods contain the same type of light reactive “pigment”
  – Cones
    • There are three different types of cones
    • They differ only in the type of light reactive “pigment” they contain
      – Each is most sensitive to a specific wavelength
Rods and Cones
Transduction for visual stimuli

- light strikes photoreceptor
- splits rhodopsin into retinal and opsin (called “isomerization”)
- closes cation channel
  - cations no longer enter
- causes photoreceptor to hyperpolarize
  - stops releasing transmitter substance
- causes bipolar cell depolarization
- causes ganglion cell depolarization

In the dark (at rest), the photoreceptors are quite active, constantly releasing neurotransmitter.

After absorption of a photon, the resulting hyperpolarization of the photoreceptor decreases the amount of neurotransmitter released (this means that light actually turns receptors off).

These hyperpolarizations are graded responses (that is, gradual increases in light intensity have gradual effects on neurotransmitter release).

The rods and cones are connected to horizontal and bipolar cells, which then connect to the retinal ganglion cells.
Distribution and function of photoreceptors ....

- 126 million in each eye

<table>
<thead>
<tr>
<th></th>
<th>Rods</th>
<th>Cones</th>
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<tbody>
<tr>
<td>Number</td>
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<td>Location</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>fovea</td>
</tr>
<tr>
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<tr>
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<tr>
<td>Sensitivity</td>
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<td>low</td>
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“Spectral Sensitivity”

- Spectral Sensitivity refers to how sensitive the receptors (rods and cones) are to different wavelengths of light
  - Generally the cones are more sensitive to the higher wavelengths while the rods are more sensitive the lower wavelengths.
Spectral sensitivity curves….

Photoreceptor Density across the Retina
Details of Retinal Circuitry

Other types of cells and their functions in the retina (other than photoreceptors)

- **Vertical Processing**
  - bipolar cells
    - connects photoreceptors to ganglion cells
  - ganglion cells
    - last processing cell in the retina
    - axons form optic nerve

- **Lateral Processing**
  - amacrine cells
    - connect ganglion cells
  - horizontal cells
    - connect photoreceptors

Retinal Information Processing (cont’d)

- The vertical pathway: Photoreceptors, bipolar cells, ganglion cells
Retinal Information Processing (cont’d)

• A variety of bipolar cells, for instance:
  • **Diffuse bipolar cells**: Receive input from multiple cones
  • **Midget bipolar cells**: Receive input from a single cone

Retinal Information Processing (cont’d)

• Various regions of the retina interact via lateral inhibition: Horizontal cells and amacrine cells
Why the rods and cones differ in acuity and sensitivity to light…

- Differences result in how the receptors are connected to the ganglion cells
  - Cones have closer to a one-to-one connection
  - Rods have a many-to-one connection
Figure 2.1
Cross section of the primate retina showing the five major cell types and their interconnections. Notice that the re- 
capts are divided into inner segments and outer segments.

Figure 2.2
A linear circuit (left) and the responses of neuron B generated as we increase the number of receptors stimulated (right). 
Stimulating receptor 4 causes neuron 8 

Convergence
(or “spatial summation”)

Figure 2.30

Mosaic of retinal neurons in the periphery of the
rabbit retina. Each dot in the top panel represents three
receptors, and each dot in the bottom panel represents one
ganglion cell. The large difference between the number of
receptors and the number of ganglion cells means that
signals from many receptors converge onto each ganglion
cell. (From Maeland, 1988.)

Figure 2.30

When we add convergence to the circuit, so that B receives inputs from all of the
receptors, increasing the size of the
stimulation increases the size of maximum RF's
response.

Figure 2.31

When we add inhibition to the circuit, so
that stimulation of receptors 1, 2, 6, and
7 onto inhibits B, because B responds best
to stimulation of receptors 3-5.
Lateral Inhibition

- Visual neurons do not simply "pipe" the output of the retina through the visual pathways
- Instead, the activity of a given neuron is affected by the activity of nearby neurons; lateral inhibition in the retinal ganglion cells is a prime example
- When a retinal ganglion cell fires action potentials, it also inhibits the firing of nearby (lateral) ganglion cells
Receptive Fields

- Retinal ganglion cells fire action potentials in response to certain types of retinal stimulation
  - The part of the retina that needs to be stimulated in order to elicit a spike is the retinal ganglion cell's receptive field
- The receptive field of a neuron can be defined, more generally, as:
  - The part of the visual world that the neuron is responsive to (that it "sees")
  - What the visual stimulus needs to be in order to elicit spikes
Center-Surround Receptive Fields

- These receptive fields are divided into 2 parts (center/surround), one of which is excitatory ("ON"), the other inhibitory ("OFF")
- For an ON/OFF center/surround cell, a spot of light shown on the inside (center) of the receptive field will elicit spikes, while light falling on the outside ring (surround) will suppress (or inhibit) firing below the baseline rate
- Opposite results for an OFF/ON cell

Retinal ganglion cells have concentric (center-surround) receptive fields
Types of Center-Surround Cells

The Receptive Field (Part 1)

(a) ON-center ganglion cell

Spot in center

Response

Spot in surround

Light on

Response
The Receptive Field (Part 2)

Hermann Grid: Perceptual consequence of these receptive fields

- When you stare at a set of dark squares separated by a grid of white lines, you will see darkness at the intersections of the lines.
Hermann Grid Explained

• Note that at the intersections, there is relatively more light (white) falling on the inhibitory surround of ON/OFF receptive fields (compare to the amount of white falling on the inhibitory surround of receptive fields that are not centered over intersections)
• This relatively-larger amount of inhibition suppresses the firing of cells with receptive fields that overlie the intersections, decreasing their firing rates, and yielding the perception of darkness.

Hermann Grid Explained

• Once again, it is a matter of lateral inhibition between the center and surround of the receptive field.
• Below, the receptive field that lies at the intersection of the white cross has more light falling on its inhibitory surround than does the receptive field that lies between the two black squares.
However, note that the darkness disappears at an intersection that you stare at directly. Why do you think this happens?

- Receptive fields in the central fovea are much smaller than in the rest of the retina.
- This is represented in the upper right of the diagram. In the Hermann grid you probably did not see a dark area when you looked directly at the intersection of the white cross, but did see dark areas in your peripheral vision.
Mach Bands

- Lateral inhibition performs edge (contrast) enhancement
- A perceptual example of this edge enhancement: Mach bands
- The borders between light and dark parts of the image are exaggerated and appear as extra-light and extra-dark bars
- So…your perceptual experience can be predicted by the responses of the retinal ganglion cells

Lateral inhibition….

- evident in Mach Bands
  - right part of each bar “seems” darker - left side seems lighter
Lateral Inhibition example….

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<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
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<tr>
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<td>37</td>
<td>67</td>
<td>64</td>
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importance of change….

- retinal bleaching will result if no “change” occurs in the visual stimulus
  - retinal bleaching is caused by the depletion of photoreactive chemicals in the rods and cones
  - *involuntary eye movements* insure constant change
    - constantly “sweep” image across multiple cells
  - cells have a chance to “recover”
    - small, 10-20 cones
    - trembling, 1-2 cones
Representation of the Visual Field in the Brain

• As the pattern of light reflected off objects in the world enters the eye, it is flipped upside-down
• This upside-down pattern of light is the *retinal image*

• The spatial structure of the retinal image is preserved as neurons from the retina connect to the LGN, and is still preserved further along in the cortex