Summary

Light
The eye
The retina
Rods and Cones
Light and dark adaptation
Center Surround organization

Wavelength and frequency

\[
\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}}
\]

(1 THz = 1 trillion Hz)

<table>
<thead>
<tr>
<th>Color</th>
<th>Wavelength (nm)</th>
<th>Frequency (THz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>780 - 622</td>
<td>384 - 482</td>
</tr>
<tr>
<td>Orange</td>
<td>622 - 597</td>
<td>482 - 503</td>
</tr>
<tr>
<td>Yellow</td>
<td>597 - 577</td>
<td>503 - 520</td>
</tr>
<tr>
<td>Green</td>
<td>577 - 492</td>
<td>520 - 610</td>
</tr>
<tr>
<td>Blue</td>
<td>492 - 455</td>
<td>610 - 659</td>
</tr>
<tr>
<td>Violet</td>
<td>455 - 390</td>
<td>659 - 769</td>
</tr>
</tbody>
</table>

the speed of light \( c = 299792458 \text{ m/s} \)
Light is the Stimulus for Vision

- Electromagnetic spectrum
  - Energy is described by wavelength
  - Spectrum ranges from short wavelength gamma rays to long wavelength radio waves
  - Visible spectrum for humans ranges from 400 to 700 nanometers
  - Most perceived light is reflected light

Reflected light is a combination of the light source and the reflectance properties of the surface
Anatomy of the human eye

Focusing Images on the Retina

- The cornea, which is fixed, accounts for about 80% of focusing
- The lens, which adjusts shape for object distance, accounts for the other 20%
  - Accommodation results when ciliary muscles are tightened which causes the lens to thicken
Focusing Images on the Retina

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Why lenses bend light
Fatter (convex) lenses bend light more.
The more the lens is like a pane of glass, the less it will bend light.
Basic Optics

The shape of the lens affects the distance between the lens and the focal point.
A fatter, more curved lens brings the focal point closer to the lens.
Fish have bulgy eyes because light travels more slowly in water. This is also why things look blurry to us underwater.

Why do swim goggles help?
Presbyopia - “old eye”

- Distance of near point increases
- Due to hardening of lens and weakening of ciliary muscles
- Corrective lenses are needed for close activities, such as reading

Fig. 1-4. Why things look blurry when you open your eyes under water. Light travels at a similar speed in water and through the cornea, so the cornea fails to act as good lens. The solution is to wear goggles, which re-establish an air/cornea boundary.
Presbyopia - “old eye”

As we get older our lenses get harder, and yellower.

Astigmatism is where the lens is squished along one axis so not all orientations can be in focus at the same time.

Check to see if you have astigmatism in the book.
Fig. 1. Human retina as seen through an ophthalmoscope.
The retina is organized 'backwards' with respect to incoming light.

There are no photoreceptors where the ganglion cells leave the eye.
"When King Charles II heard about the blind spot, he took great delight in walking around his court decapitating his ladies in waiting or beheading criminals with his blind spot before they were actually guillotined. I must confess I sometimes sit in faculty meetings and enjoy decapitating our departmental chairman." – V.S. Ramachandran

To experience your blind spot, close your left eye, fixating on the F in part (a) with your right eye. Hold the book about 15 cm away from your eye, and adjust the distance of the book from your eyes until the red circle disappears. This is your blind spot. Ordinarily you are not aware of it, because the visual system "fills in" the blind spot with information from the surrounding area. If you fixate on the F in part (b) and again adjust the distance, when the gap in the line falls in your blind spot, it will fill in and you will see a continuous red line.
The fovea is free from capillaries, ganglion cells, and inner layer cells. It only contains cones.
Octopus, squid and terrestrial gastropods (slugs and snails) have photoreceptors in the 'correct' side of the retina. They have no blind spot.

The Hermann Grid
Retinal Processing - Rods and Cones

- Differences between rods and cones:
  
  **Shape**
  - Rods: large and cylindrical
  - Cones: small and tapered
  
  **Function**
  - Cones: daylight vision and color (photopic light levels)
  - Rods: night vision (scotopic light levels)
  
  **Number**
  - 120 million rods in each eye
  - Only 5 million cones
  
  Also distribution on retina …

- Distribution on retina
  - Fovea consists solely of cones
  - Peripheral retina has both rods and cones
  - More rods than cones in periphery
Diseases that Affect the Retina

- Genetic disease
- Rods are destroyed first
- Foveal cones can also be attacked
- Severe cases result in complete blindness

Transduction of Light into Nerve Impulses

- Receptors have outer segments, which contain:
  - Visual pigment molecules, which have two components:
    - Opsin - a large protein
    - Retinal - a light sensitive molecule
  - Visual transduction occurs when the retinal absorbs one photon
    - Retinal changes its shape, called isomerization
How sensitive is the human eye?

- Experiment by Hecht et al. (1942)
  - Determine the absolute threshold for detecting a light was 100 photons
  - Estimated that 100 photons would be absorbed by ~7 visual pigment molecules - almost no molecules would absorb more than one
  - Only one photon was needed to excite a visual pigment molecule

Normally, we have three cone types, with pigments that absorb best at 419nm, 532nm, & 558nm.

More on that later when we get to color vision (Chapter 7)
Huge variations in the number of red (L), green (M) & blue (S) cones across individuals

**Properties of the fovea and periphery in human vision**

<table>
<thead>
<tr>
<th>Property</th>
<th>Fovea</th>
<th>Periphery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoreceptor type</td>
<td>Mostly cones</td>
<td>Mostly rods</td>
</tr>
<tr>
<td>Bipolar cell type</td>
<td>Midget</td>
<td>Diffuse</td>
</tr>
<tr>
<td>Convergence</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Receptive-field size</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Acuity (detail)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Light sensitivity</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

**Properties of human photopic and scotopic vision**

<table>
<thead>
<tr>
<th>Property</th>
<th>Photopic system</th>
<th>Scotopic system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoreceptors</td>
<td>4–5 million cones</td>
<td>90 million rods</td>
</tr>
<tr>
<td>Location in retina</td>
<td>Throughout retina with the highest concentration close to fovea</td>
<td>Outside of fovea</td>
</tr>
<tr>
<td>Acuity (detail)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Low</td>
<td>High</td>
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</table>
Light/Dark Adaptation

Adaptation allows you to adjust your sensitivity to see detail within a particular light range.

Light intensities range across 9 orders of magnitude.

A piece of white paper can be 1,000,000,000 times brighter in outdoor sunlight than in a moonless night.

But in a given lighting condition, light ranges over only about two orders of magnitude.

If we were sensitive to this whole range all the time, there wouldn't be able to discriminate lightness levels in a typical scene.
The visual system solves this problem by restricting the 'dynamic range' of its response to match the current overall or 'ambient' light level.

Mechanisms for Dark adaptation

1. The pupil changes in diameter from about 2mm to 8mm. Helps reduce the range by 1 order of magnitude. (We still have 8 orders of magnitude to go)
Psychophysical Measurement of Dark Adaptation

Measure detection thresholds as function of time in the dark.
Observer looks at fixation point but pays attention to a test light to the side.
The dark adaptation curve

Threshold

Time in the dark (minutes)

Normal dark adaptation curve

The dark adaptation curve

Rod monochromat – only has rods

Sensitivity mediated by rods

Cones detect the light at first until rods take over.

Time in the dark (sec)
The dark adaptation curve

Mechanisms of light adaption:
1. Shift from rod to cone vision
2. Changes in sensitivity within rods and cones

Demonstration of dark adaptation:

Dark spots – unisomerized molecules in a cone (ready for a photon)
Demonstration of dark adaptation:

Dark spots – unisomerized molecules in a cone (ready for a photon)

In the dark, all retinal molecules are ready for a photon
The photoreceptor is very sensitive to light

This is a good state to be in for walking around in the dark. But not if you walk outside.
Demonstration of dark adaptation:

Dark spots – unisomerized molecules in a cone (ready for a photon)
Bright spots: isomerized molecules

In bright light, nearly all molecules are isomerized.
The photoreceptor is not sensitive to light

Now you're not overexposed outside, but you can't see in the dark.

Demonstration of dark adaptation:

Back in the dark, the molecules slowly recover and are ready to receive photons again. The cone recovers its sensitivity over time.
Light adaptation in the frog retina

Time in the light

Figure 2.25 A frog retina was dissected from the eye in the dark and then exposed to light. (a) This picture was taken just after the light was turned on. The dark red color is caused by the high concentration of visual pigment in the receptors. As the pigment bleaches, the retina becomes lighter, as shown in (b) and (c).

With digital cameras and software, you can combine pictures with different exposures to expand the 'dynamic range'. You get detail at all light levels.
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Receptive Fields

- Area of retina that affects firing rate of a given neuron in the circuit
- Receptive fields are determined by monitoring single cell responses
- Stimulus is presented to retina and response of cell is measured by an electrode
Receptive Fields

- Area of retina that affects firing rate of a given neuron in the circuit

Processing in the Retina

- Rods and cones send signals vertically through
  - Bipolar cells
  - Ganglion cells
  - Ganglion axons
- Signals sent horizontally by
  - Horizontal cells
  - Amacrine cells
Hubel and Wiesel's recording of an 'on centered' cat LGN cell.
Hubel and Wiesel's recording of an 'off-centered' cat LGN cell.

The Hermann Grid
Hermann Grid

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Mach band illusion

(a) 

(b)

Intensity

Position
Mach band illusion

\[ \text{Intensity} \]
\[ \text{Position} \]

Mach band illusion

\[ \text{Intensity} \]
\[ \text{Position} \]
Mach band illusion

\[ \begin{align*}
\text{Intensity} & \quad \text{Position} \\
\text{D} & \quad \text{B} \\
\end{align*} \]

Mach band illusion

\[ \begin{align*}
\text{Intensity} & \quad \text{Position} \\
\text{D} & \quad \text{B} \\
\end{align*} \]
3 main cell types in retina/LGN

• Midget (P cells, Parvocellular pathway)
• Parasol (M cells, Magnocellular pathway)
• Bistratified (K cells, Koniocellular pathway)

Midget (P cells, Parvocellular pathway)

Small dendritic trees and cell bodies
About 70% of RGCs are midget cells.
They receive inputs from relatively few rods and cones.
They have slow conduction velocities
Respond to changes in color but only weakly to changes in contrast
They have simple center-surround receptive fields
Parasol (M cells, Magnocellular pathway)

- Large dendritic trees and cell bodies.
- About 10% of RGCs are parasol cells.
- Receive inputs from lots of rods and cones.
- Fast conduction velocity
- Respond to low-contrast stimuli, but not very sensitive color
- Larger receptive fields, but also center-surround.

Bistratified (K cells, Koniocellular pathway)

- Identified only relatively recently. Koniocellular “cells as small as dust”.
- About 10% of RGCs
- Receive inputs from intermediate numbers of rods and cones.
- Moderate spatial resolution, moderate conduction velocity, respond to moderate-contrast stimuli.
- Large receptive fields that only have centers (no surrounds) always ON to blue cones OFF to both red and green cones.
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