The eye and the retina

Light
A electromagnetic radiation with wavelength within the range of about 380-740 nanometers.

Vision: the process of interpreting the surrounding on the basis of the information contained in visible light.
A camera obscura

Homework: Build a camera obscura. It is extremely instructive and all you need is an empty box!

Structures in the Eye

Cornea: The transparent “window” into the eyeball. Highly ordered fibers no blood vessels. Rich in (transparent) nerve endings to continually produce tears. Heals quickly to scratches.

Aqueous humor: The watery fluid in the anterior chamber that supplies nutrients to the cornea and lens.

Pupil: The dark circular opening at the center of the iris (a muscular structure), where light enters the eye. Controls the amount of light to the retina via the pupillary light reflex. (Not the only light reflex we have, e.g., the photic sneeze reflex.)

Vitreous humor: The transparent fluid that fills the vitreous chamber in the posterior part of the eye (80% of the eye volume). Viscous and transparent, may contain floaters.

Retina: A light-sensitive membrane in the back of the eye that contains rods and cones. It transforms light in neural signals which are sent to the brain via the optic nerve.

Crystalline lens: The lens inside the eye, which allows changing focus. It is a regular array of crystallins to ensure transparency. But opacities, like cataracts, may occur.

Refraction is necessary to focus light rays and this is accomplished by the cornea and the lens.

Accommodation: The process in which the lens changes its shape, thus altering its refractive power.

Emmetropia: The happy condition of no refractive error.
**Eyes That See Light**

- Problems of refraction:
  - Sometimes the way the lens refracts light causes the point of focus of the image to be either in front of or behind the retina. In these cases, corrective lenses are needed to allow for normal vision.
  - Myopia: When the light entering the eye is focused in front of the retina and distant objects cannot be seen sharply; *nearsightedness*.
  - Hyperopia: When light entering the eye is focused behind the retina; *farsightedness*.
  - Astigmatism: A visual defect caused by the unequal curving of one or more of the refractive surfaces of the eye, usually the cornea.

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**Focusing on nearby objects**

**Accommodation:** The process in which the lens changes its shape, thus altering its refractive power.

**Diopter:** Unit of refractive power that is equal to the reciprocal of the focal length (in meters) of a given lens. (e.g., to focus the image of an object at 0.5 m you need 2 diopters.)
Accommodation: focusing on nearby objects

Distant Vision  
Close Vision

- F-stop: Iris/pupil. Regulates the amount of light coming into the eye.
- Focus: Lens. Changes shape to change focus.
- Film: Retina. Records the image.

But the camera only records an image, the visual system interprets the scene.

Presbyopia

Eye with Presbyopia

- The cornea still lets light pass into the eye.
- The lens hardens and can’t change its shape as easily. Chose objects are no longer focused clearly on the retina.

The image is focused behind the retina.

Cataracts

The lens is transparent because crystallins are packed very regularly.

Cataracts: Opaquities in the lens caused by irregularity in the crystallins. They absorb and scatter light, so that less light reaches the retina.

Congenital cataracts: cataracts that are present at birth. They can severely affect visual development.
Impression, soleil levant (1872)

From Wikipedia: In 1923, Monet underwent two operations to remove his cataracts. The paintings done while the cataracts affected his vision have a general reddish tone, which is characteristic of the vision of cataract victims.
In 1911, Monet wrote to a friend: “Three days ago, I realized with terror that I didn’t see anymore with my right eye.” During the next years, his left eye lost gradually its acuity, and he had to stop painting in Summer of 1922. He was then almost blind. Nevertheless, his friend Georges Clemenceau convinced him to undergo surgery. In 1923, he could see again with his right eye, wearing special green glasses. But his vision was still altered, and he refused to undergo surgery for the left eye.
Photomicrograph of the retina

Converting light in electrical signals

**Photoreceptors**: Cells in the retina that initially transduce light energy into neural signals

- **Rods**: Photoreceptors that are specialized for night vision. Respond well in low lighting. Do not process color.
- **Cones**: Photoreceptors that are specialized for daylight vision, fine visual acuity and color. Respond best with lots of light.

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**Rods and Cones**

- Three regions: outer segment, inner segment, synaptic terminal.
- Visual pigment molecules are generated in the inner segment.
- Pigments are incorporated into the membrane of the outer segment.
- Pigments contain an opsin and a chromophore.
- Each cone contains one of three pigments.
- Rods contain rhodopsin. Cones contain three different opsins.

Melanopsin is used by receptors within ganglion cells which send their signals to the suprachiasmatic nucleus to regulate the circadian rhythm.

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**Photoactivation**: A biochemical cascade of events leading to change of glutamate concentration

- A photon is absorbed by the visual pigment.
- The pigment changes shape.
- Channels that normally allow Na⁺ to enter the cell close.
- The cell hyperpolarizes (its inside becomes more negatively charged).
- Less glutamate is released at the synaptic terminal (graded potentials).

The following bipolar cell will become hyperpolarized or depolarized depending on its type.

All this in a few milliseconds!
Humans have ~90 million rods and ~4-5 million cones. Their distributions change with **eccentricity** (distance from the fovea).

- 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.
- The standard way to measure retinal size is in terms of "degrees of visual angle."
- The rule of thumb: If you hold your thumb out at arms length, the width of your thumb is about 2 degrees of visual angle.
- In summary: The visual angle of an object is a function of both its actual size and distance from the observer.

Blue, green, and red represent the S-, M-, and L-cones, respectively, of a human retina.

- Humans have three types of cones.
  - S-cones are 5-10% of the total number of cones. They are not present in the fovea.
  - There are twice as many L-cones as M-cones.
  - The actual number and distribution of cones vary greatly among individuals.
Normalized response spectra of human cones, S, M, and L types, to monochromatic spectral stimuli, with wavelength given in nanometers.