17. Visual perception

Reading

Glassner, *Principles of Digital Image Synthesis*, pp. 5-32.

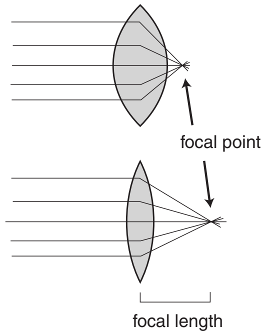
Brian Wandell. *Foundations of Vision*. Sinauer Associates, Sunderland, MA, pp. 45-50, 1995.

Optics

The human eye employs a lens to focus light.

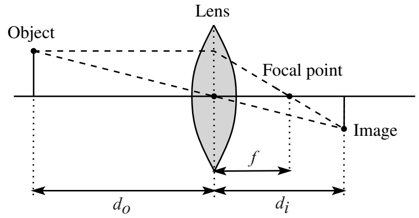
To quantify lens properties, we'll need some terms from *optics* (the study of sight and the behavior of light):

- **Focal point** - the point where parallel rays converge when passing through a lens.
- **Focal length** - the distance from the lens to the focal point.
- **Diopter** - the reciprocal of the focal length, measured in meters.
  - Example: A lens with a "power" of 10D has a focal length of ________.



Optics, cont'd

By tracing rays through a lens, we can generally tell where an object point will be focused to an image point:

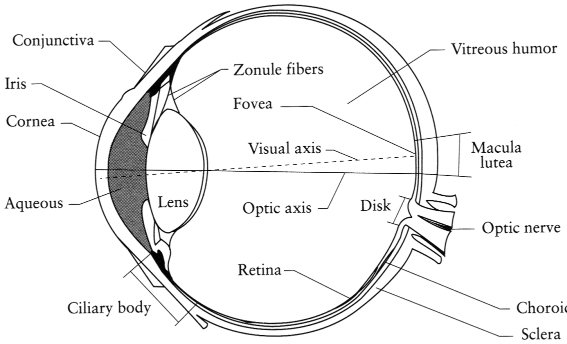


This construction leads to the Gaussian lens formula:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

Q: Given these three parameters, how does the human eye keep the world in focus?

Structure of the eye

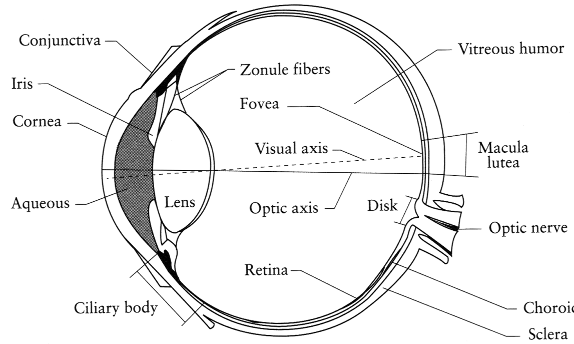


Physiology of the human eye (Glassner, 1.1)

The most important structural elements of the eye are:

- **Cornea** - a clear coating over the front of the eye:
  - Protects eye against physical damage.
  - Provides initial focusing (40D).
- **Iris** - Colored annulus with radial muscles.
- **Pupil** - The hole whose size is controlled by the iris.

Structure of the eye, cont.

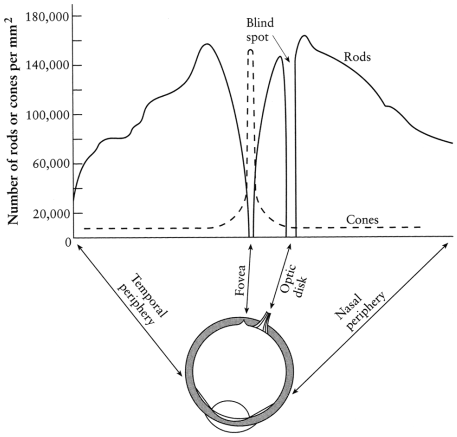


Physiology of the human eye (Glassner, 1.1)

- **Crystalline lens** - controls the focal distance:
  - Power ranges from 10 to 30D in a child.
  - Power and range reduces with age.
- **Ciliary body** - The muscles that compress the sides of the lens, controlling its power.

Q: As an object moves closer, do the ciliary muscles contract or relax to keep the object in focus?

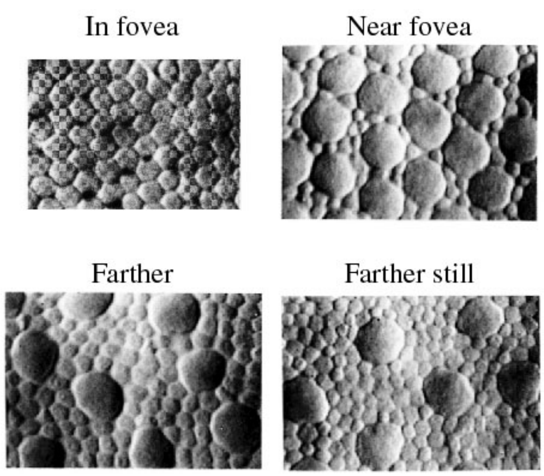
Retina



Density of photoreceptors on the retina (Glassner, 1.4)

- **Retina** - a layer of photosensitive cells covering 200° on the back of the eye.
  - **Cones** - responsible for color perception.
  - **Rods** - Limited to intensity (but 10x more sensitive).
- **Fovea** - Small region (1 or 2°) at the center of the visual axis containing the highest density of cones (and no rods).

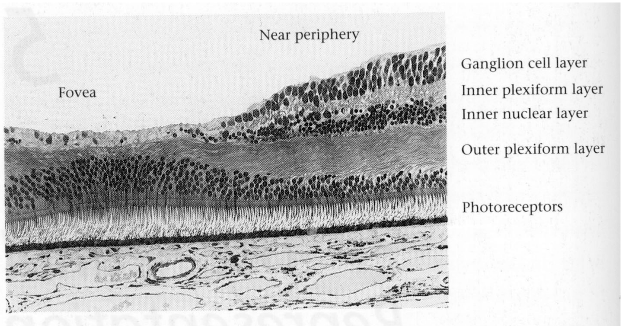
The human retina



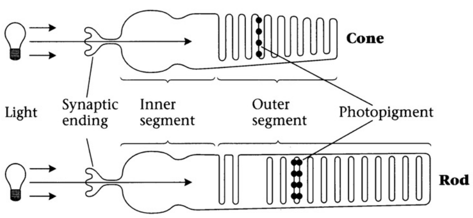
Photomicrographs at increasaing distances from the fovea. The large cells are cones; the small ones are rods. (Glassner , 1.5 and Wandell, 3.4).

Photomicrographs at increasing distances from the fovea. The large cells are cones; the small ones are rods.

The human retina, cont'd



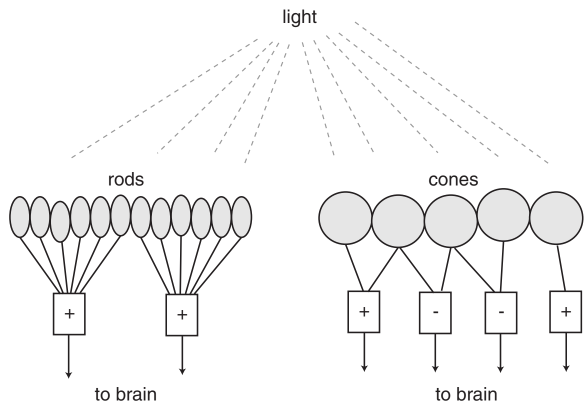
Photomicrograph of a cross-section of the retina near the fovea (Wandell, 5.1).



Light gathering by rods and cones (Wandell, 3.2)

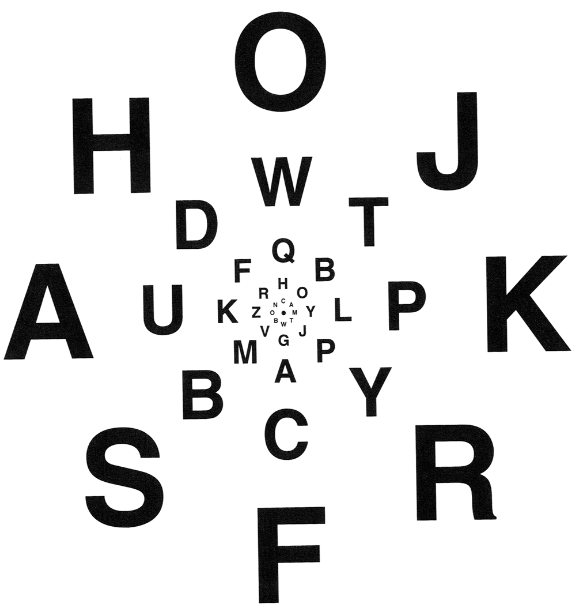
Neuronal connections

Even though the retina is very densely covered with photoreceptors, we have much more acuity in the fovea than in the periphery.



In the periphery, the outputs of the photoreceptors are averaged together before being sent to the brain, decreasing the spatial resolution. As many as 1000 rods may converge to a single neuron.

Demonstrations of visual acuity



With one eye shut, at the right distance, all of these letters should appear equally legible (Glassner, 1.7).

Blind spot demonstration (Glassner, 1.8)

Perceptual light intensity

The human eye is highly adaptive to allow us a wide range of flexibility.

One consequence is that we perceive light intensity as we do sound, I.e., on a *relative* or *logarithmic* scale.

Example: The perceived difference between 0.20 and 0.22 is the same as between 0.80 and ______.

Ideally, to display *n+1* equally-spaced intensity levels

$$\frac{I_1}{I_0} = \frac{I_2}{I_1} = \cdots = \frac{I_n}{I_{n-1}}$$

Example: Suppose I_0=1/8, I_3=1, and n = 3. What are the four intensity levels to be displayed?

Lightness contrast and constancy

The apparent brightness of a region depends largely on the surrounding region.

The **lightness contrast** phenomenon makes a constant colored region seem lighter or darker depending on the surround:

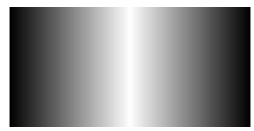
The **lightness constancy** phenomenon makes a surface look the same under widely varying lighting conditions.

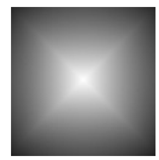
Mach bands

Mach bands were first dicussed by Ernst Mach, an Austrian physicist.

Appear when there are rapid variations in intensity, especially at C^0 intensity discontinuities:

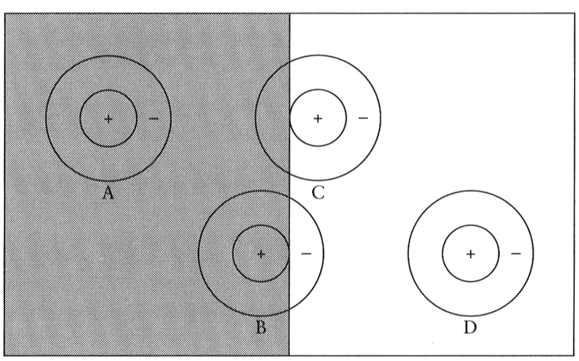
And at C^1 intensity discontinuities:





Mach bands, cont.

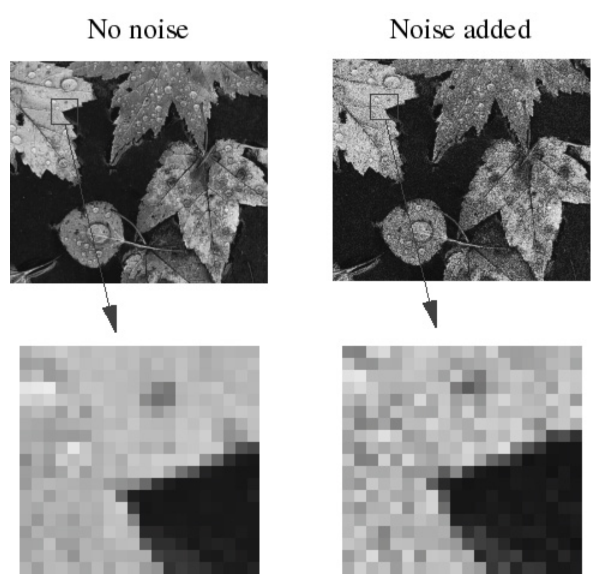
Possible cause: lateral inhibition of nearby cells.



Lateral inhibition effect (Glassner, 1.25)

Q: What image processing filter does this remind you of?

Noise



Noise can be thought of as randomness added to the signal.

The eye is relatively insensitive to noise.

Flicker

The photoreceptive cells provide a time-averaged response:

more photons → more response

Above a **critical flicker frequency (CFF)**, flashes of light will fuse into a single image.

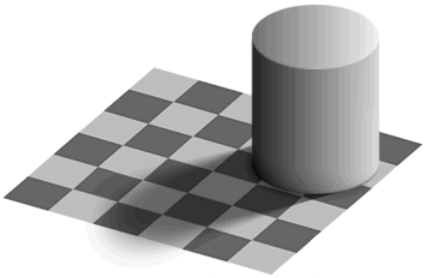
CFF for humans is about 60 Hz. (For a bee it's about 300 Hz.)

Q: Do all parts of the visual field have the same CFF?

Higher Level Reasoning

Most of the perceptual effects we've discussed today happen at a very early stage of visual processing (e.g., in the retina itself).

Many other phenomena occur at a higher level in the brain



Checker Shadow Effect (Edward Adelson, 1995)

Higher Level Reasoning

Clinton Gore Illusion