Optics and perception

Reading

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

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

Outline

1. Image formation
2. Structure of the eye
3. Visual phenomena

Forming an image

First, we need some sort of sensor to receive and record light.

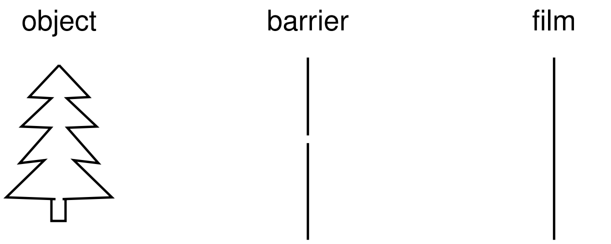
Is this all we need?

Do we get a useful image?

Restricting the light

To get rid of the blurriness, we could use a barrier to select out some of the light rays and block the rest.

This creates a **pinhole camera**.



Advantages:

- easy to simulate
- everything is in focus

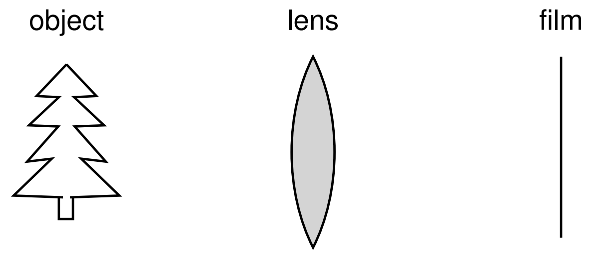
Disadvantages:

- needs a bright scene (or long exposure)
- everything is in focus

Forming an image with a lens

Instead of throwing away all but a single ray, let's try to collect a bunch of rays and concentrate them at a single point on the sensor.

That's what a lens does, with the help of *refraction*



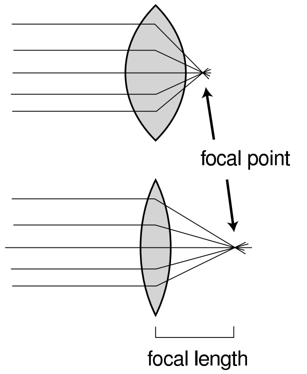
Now there is a specific distance at which objects are "in focus".

By changing the shape of the lens, we change how it bends the light.

Optics

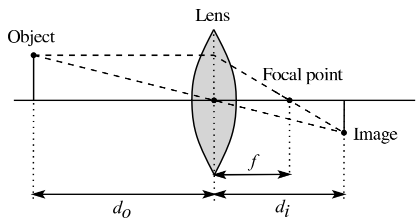
To quantify lens properties, we'll need some terms from *optics* (the study of sight and the behavior of light):

- **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:

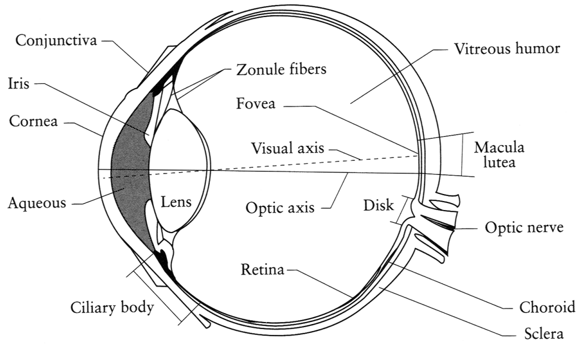


This construction leads to the Gaussian lens formula:

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

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

Structure of the eye

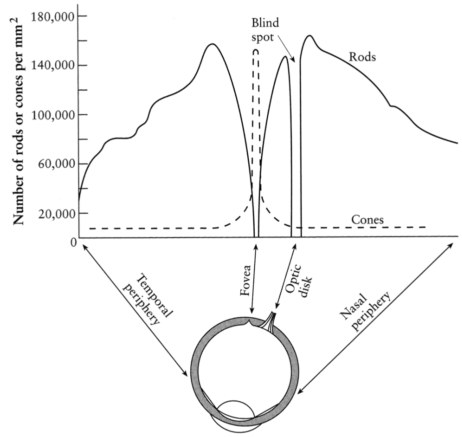


Physiology of the human eye (Glassner, 1.1)

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.
- **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.

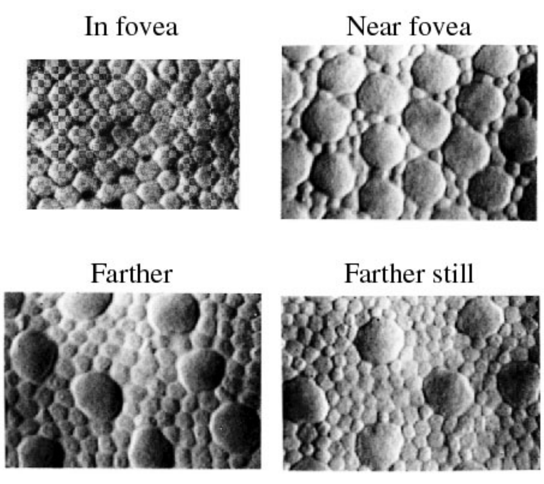
Retina



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).

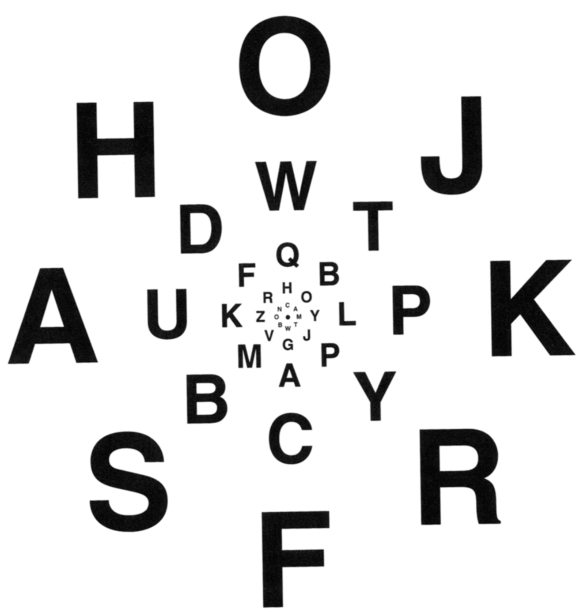
The human retina



Photomicrographs at incresasing 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.

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

Our eyes have an incredible dynamic range

Background	Luminance (candelas per square meter)
Horizon sky	
Moonless overcast night	0.00003
Moonless clear night	0.0003
Moonlit overcast night	0.003
Moonlit clear night	0.03
Deep twilight	0.3
Twilight	3
Very dark day	30
Overcast day	300
Clear day	3,000
Day with sunlit clouds	30,000
Daylight fog	
Dull	300–1,000
Typical	1,000–3,000
Bright	3,000–16,000
Ground	
Overcast day	30–100
Sunny day	300
Snow in full sunlight	16,000

FIGURE 1.13
Luminance of everyday backgrounds. *Source:* Data from Rea, ed., *Lighting Handbook 1984 Reference and Application*, fig. 3-44, p. 3-24.

9 orders of magnitude!! Compare with 8-bit images...

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:

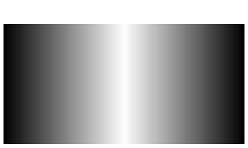
The **lightness constancy** phenomenon makes a surface look the same under widely varying lighting conditions.

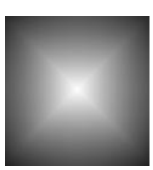
Mach bands

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

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

And at C^1 intensity discontinuities:





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.

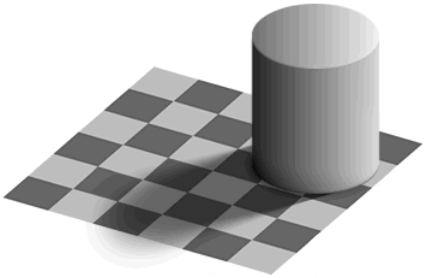
CFF for humans is about 60 Hz. (For a bee it's about 300 Hz.)

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

Summary

Here's what you should take home from this lecture:

- All the **boldfaced terms**.
- How a camera forms an image.
- The basic structures of the eye
- How light intensity is perceived