Visual Perception

CSE 457, Autumn 2003
Graphics

http://www.cs.washington.edu/education/courses/457/03au/

Readings and References

Other References

- *Principles of Digital Image Synthesis*, Glassner, pp. 5-32.
- *Foundations of Vision*, Brian Wandell, pp. 45-50

Outline

- Image formation
- Structure of the eye
- Photoreceptors
- Visual phenomena

Forming an image

- First, we need some sort of sensor to receive and record light.
- Is this all we need?

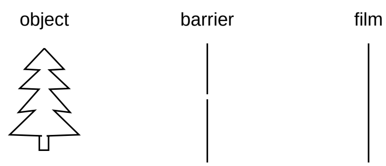
Do we get a useful image?

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 is called a **pinhole camera**.

Advantages:
everything is in focus
easy to simulate

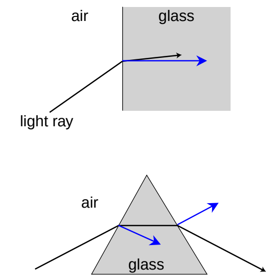
Disadvantages:
everything is in focus
needs a bright scene (or long exposure)



Collecting the light

- 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.
  - » To do this, we need to be able to change the path of a light ray.

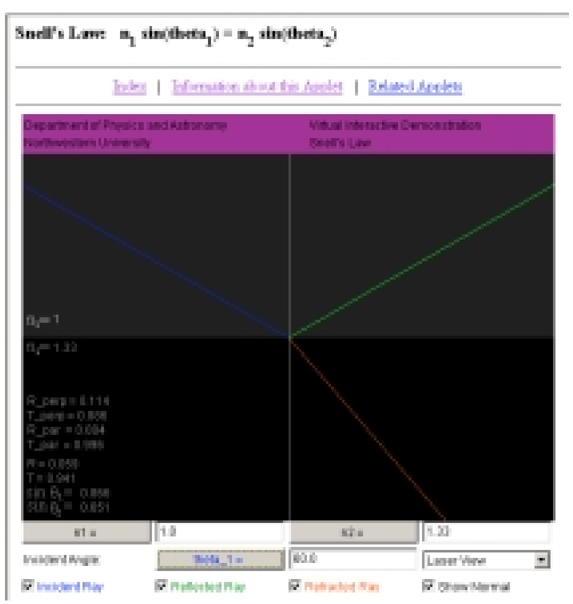
Fortunately, we have **refraction**. Light passing from one medium into a denser one will bend towards the **normal** of the interface.



Refraction

material	*index*
Vacuum	1
Air	1.0003
Water	1.33
Ethyl Alcohol	1.36
Fused Quartz	1.4585
Whale Oil	1.46
Crown Glass	1.52
Salt	1.54
Asphalt	1.635
Heavy Flint Glass	1.65
Diamond	2.42
Lead	2.6

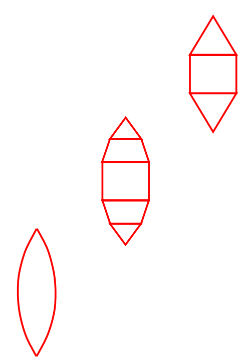
Values come from the CRC Handbook of Chemistry and Physics



Stacking prisms

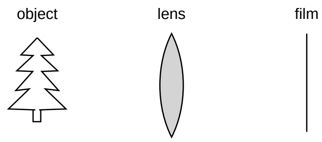
- We can use variously shaped prisms to take light rays of various angles and bend them to pass through a single point.

As we use more and more prisms, the shape approaches a curve, and we get a **lens**.



Forming an image with a lens

- We can now replace the pinhole barrier with a lens, and we still get an image.



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

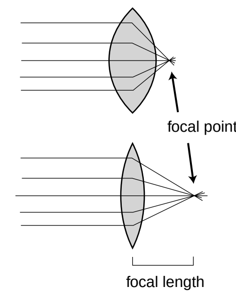
•To quantify lens properties, we'll need some terms from *optics* (the study of sight and the behavior of light)

Focal point - the point where parallel rays converge when passing through a lens.

Focal length - the distance from the lens to the focal point.

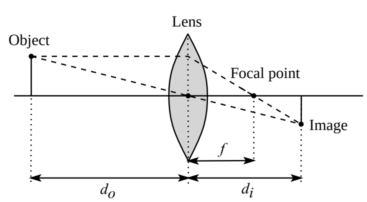
Diopter - the reciprocal of the focal length, measured in meters.

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:

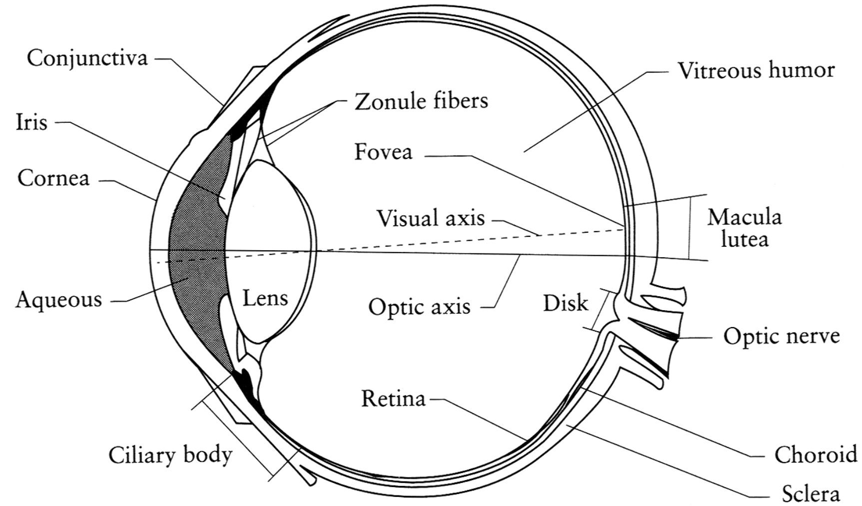


This construction leads to the Gaussian lens formula: $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

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

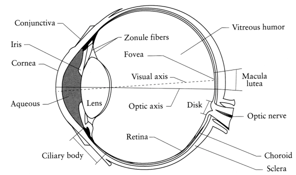
Structure of the human eye

Physiology of the human eye (Glassner, 1.1)



Structure of the human eye

- Important elements of the eye are:

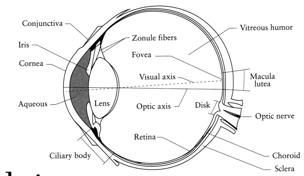


Cornea - a clear coating over the front of the eye:
Protects eye against physical damage.
Provides 80% (~40D) of refracting power of the eye.

Iris - Colored annulus with radial muscles.

Pupil - The hole whose size is controlled by the iris.

Structure of the human eye, cont.



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 control the thickness of the lens.

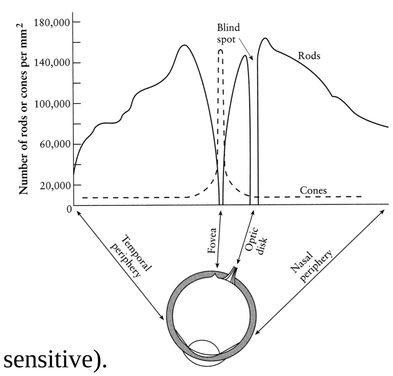
» When the muscles are relaxed, the lens is stretched radially and flattened.

» When the muscles are tensed, the lens is compressed and it gets thicker.

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

Retina

Density of photoreceptors on the retina (Glassner, 1.4)



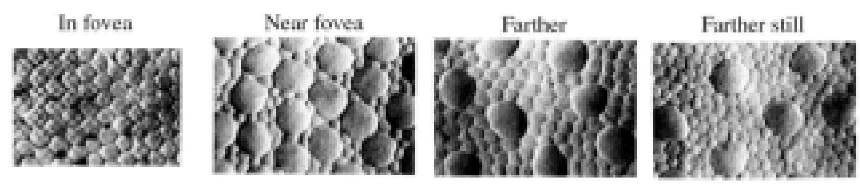
Retina - a layer of photosensitive cells covering 200° on the back of the eye.

Cones - responsible for color perception.

Rods - Limited to intensity (but 10x more sensitive).

The human retina

Photomicrographs at increasing distances from the fovea. (Glassner , 1.5 and Wandell, 3.4).

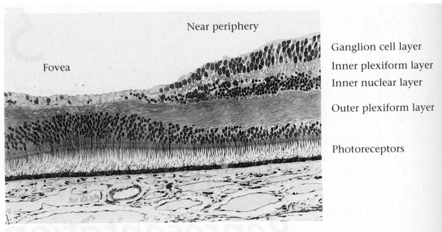


All cells in the fovea are cones

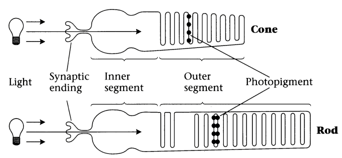
The large cells are cones; the small ones are rods.

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, cont'd



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

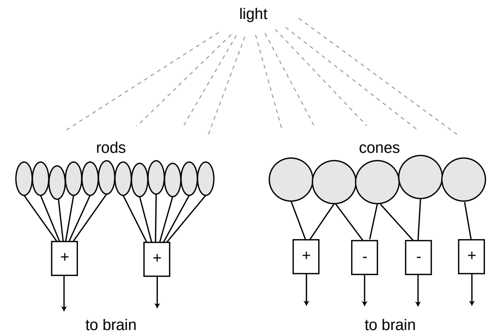


Light gathering by rods and cones (Wandell, 3.2)

The eye is just one part of the entire visual system implementation by the nervous system.

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. (120M rods+ 6M cones) : 1M nerve fibers.

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.
  - » 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 we want: $\frac{I_1}{I_0} = \frac{I_2}{I_1} = \cdots = \frac{I_n}{I_{n-1}}$

I_0	I_1	I_2	I_3
$\frac{1}{8}$			1

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.

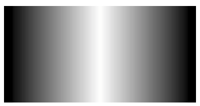
The **lightness contrast** phenomenon makes a constant colored region seem lighter or darker depending on the surround:

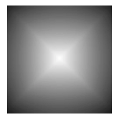
The **lightness constancy** phenomenon makes a surface look the same under widely varying lighting conditions. Again, the brain is perceiving ratios and giving us a consistent interpretation.

Mach bands

- **Mach bands** were first discussed by Ernst Mach, an Austrian physicist.
- Appear when there are rapid variations in intensity, especially at C^0 intensity discontinuities:

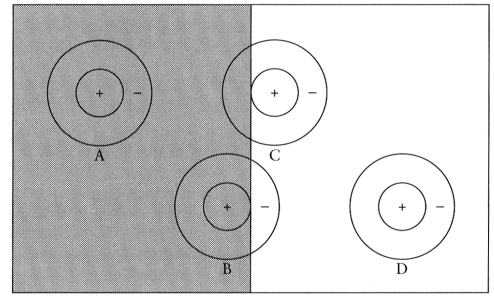
- And at C^1 intensity discontinuities:





Mach bands, cont.

- **Possible cause:** lateral inhibition of nearby cells.

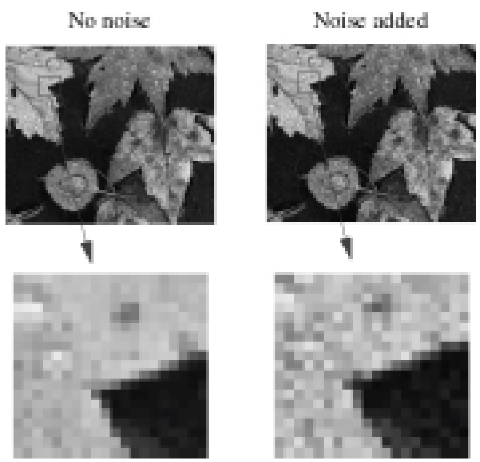


Lateral inhibition effect (Glassner, 1.25)

Q: Why is this summation pattern useful?

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?

Summary

- Note all the **boldfaced** terms.
- How a lens forms an image.
- The basic structures of the eye and how they work.
- How light intensity is perceived on a logarithmic scale and is a function of wavelength.
- The phenomena of lightness contrast.
- The eye's relative sensitivity to intensity discontinuities, but insensitivity to noise.