Visual Perception

Reading

Optional

Glassner, *Principles of Digital Image Synthesis*, sections 1.1-1.6.

Brian Wandell. *Foundations of Vision*. Sinauer Associates, Sunderland, MA 1995.

Research Papers

Spencer, Shirley, Zimmerman, and Greenberg. *Physically-based glare effects for digital images*. SIGGRAPH 95.

Ferwerda, Pattanik, Shirley, and Greenberg. *A model of visual adaptation for realistic image synthesis*. SIGGRAPH 96.

Forming an image

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

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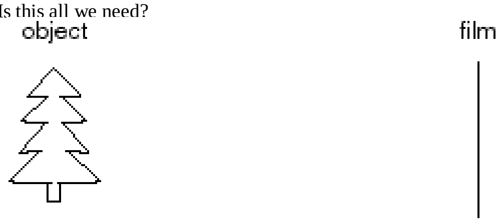
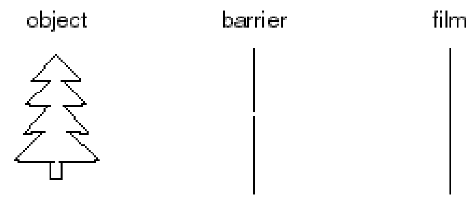
Is this all we need?



Do we get a useful image?

Restricting the light

Pinhole Camera



Advantages:

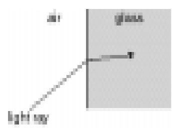
- easy to simulate
- everything is in focus

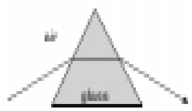
Disadvantages:

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

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.

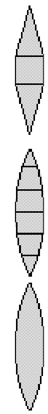




To do this, we need to be able to change the path of a light ray.

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

Stacking prisms

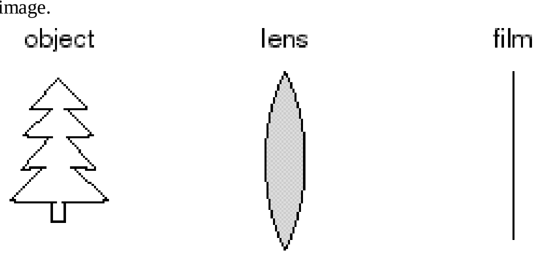


We can use variously shaped prisms to take light rays of various angles and bend them to pass through a single point.

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.

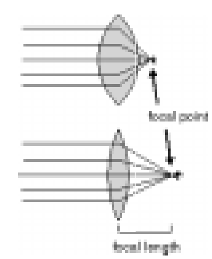


Now there is a specific distance at which objects are “in focus”.

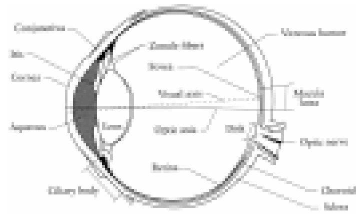
By changing the shape of the lens, we change how it bends the light.

Optics

- **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 ________.

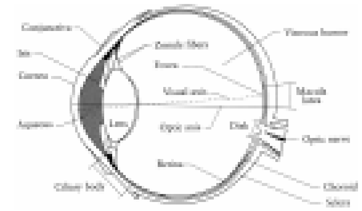


Structure of the eye



- **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.

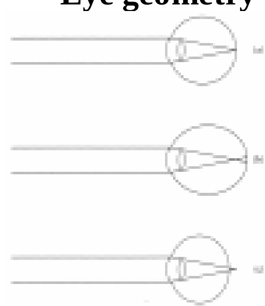
Structure of the eye, cont.



- **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.

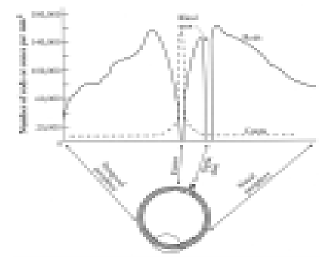
  Q: As an object moves closer, do the ciliary muscles contract or relax to keep the object in focus?

Eye geometry



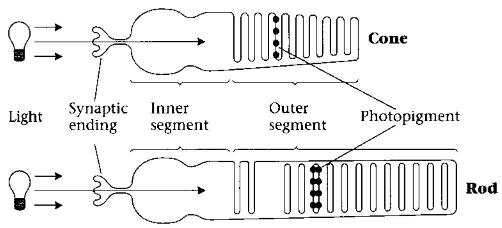
- **Emmetropic eye** - resting eye has focal point on retina.
- **Myopic eye** - eye too long (near-sightedness)
- **Hyperopic eye** - eye too short (far-sightedness)

Retina



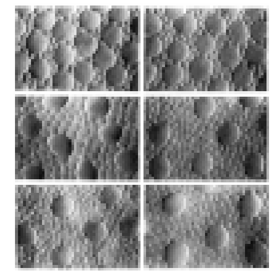
- **Retina** - a layer of photosensitive cells covering 200° on the back of the eye.
  - **Cones** - responsible for color perception.
  - **Rods** - Limited to intensity (but 10x more sensitive).
- **Fovea** - Small region (1 or 2°) at the center of the visual axis containing the highest density of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

Light Gathering



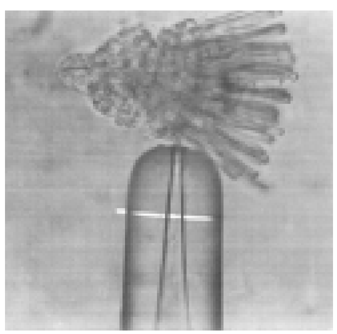
The human retina

nasal temporal



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

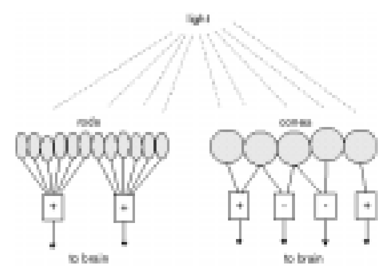
Photoreceptive cells



Cone on a stick.

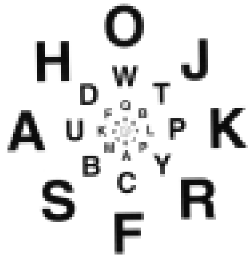
Neuronal connections

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.

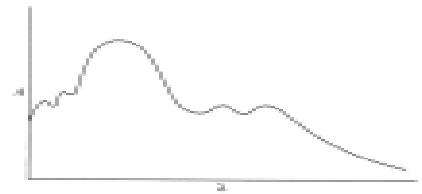
Demonstrations of visual acuity



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

Blind spot demonstration.

Wavelength sensitivity

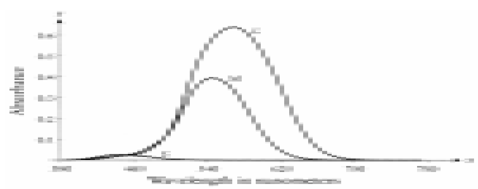


Electromagnetic radiation comes in all wavelengths, from 10^{-14} to 10^{8} meters.

The eye is sensitive to EMR with wavelengths from 380 to 780 nanometers (10^{-9} meters), called “visible light”.

Q: What color is the light at 380nm? at 780nm?

Photopigments



Photopigments are the chemicals in the rods and cones that react to light. Can respond to a single photon!

- Rods contain **rhodopsin**, which has peak sensitivity at 500nm.
- Cones come in three varieties: S, M, and L.

Principle of univariance: No information is transmitted describing the wavelength of the photon. **Q:** why not?

Transmitting color

Color information is transmitted to the brain in three nerve bundles or **channels**:

- **Achromatic channel** A = M + L
- **Red-green chromatic channel** R/G = M - L
- **Blue-yellow chromatic channel** B/Y = S - A

Saturation is perceived as the ratio of chromatic to achromatic response.

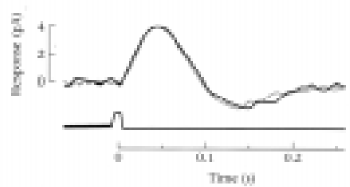
Flicker

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?



solid: response at 550nm; gray: response at 659 nm

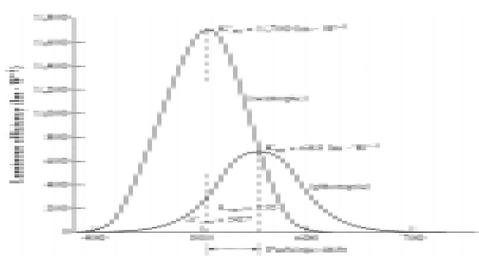
Adaptation

Adaptive processes can adjust the base activity ("bias") and scale the response ("gain").

Through **adaptation**, the eye can handle a large range of illumination:

Background	Luminance (cd/m²)
Moonless overcast night	0.00003
Moonless clear night	0.03
Twilight	3
Overcast day	300
Day with sunlit clouds	30,000

Luminous efficiency



You can plot the **luminous efficiency** of:

- Rods (**scotopic** vision)
- Cones (**photopic** vision)

as a function of wavelength.

The **Purkinje shift** refers to the change in peak wavelength perception between the two types of vision.

Perceptual light intensity

We perceive light intensity as we do sound: 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

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

Noise

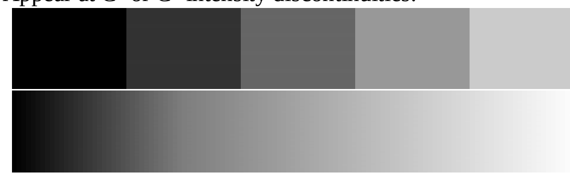
Noise can be thought of as randomness added to the signal.

The eye is relatively insensitive to noise.

Mach bands

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

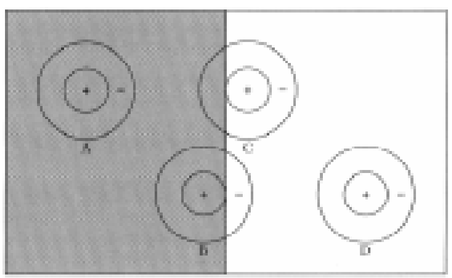
Appear at C^0 or C^1 intensity discontinuities.



Also appear when there is a rapid intensity change.

Mach bands, cont.

Possible cause: lateral inhibition of nearby cells.



Q: Why is this summation pattern useful?

Lightness contrast

A related phenomenon is known as:

- **lightness contrast**
- **simultaneous contrast**
- **color contrast** (for colors)

This phenomenon helps us maintain a consistent mental image of the world, under dramatic changes in illumination.

Summary

- How a camera forms an image.
- The basic structures of the eye and how they work.
- How light is a form of EMR.
- How light intensity is perceived on a logarithmic scale and is a function of wavelength.
- The eye's relative sensitivity to intensity discontinuities, but insensitivity to noise.
- The phenomena of adaptation and lightness contrast.