EEE-6512: Image Processing and Computer Vision

August 25, 2017

Lecture #3: Fundamentals of Imaging Pt. 1

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Chapter Outline

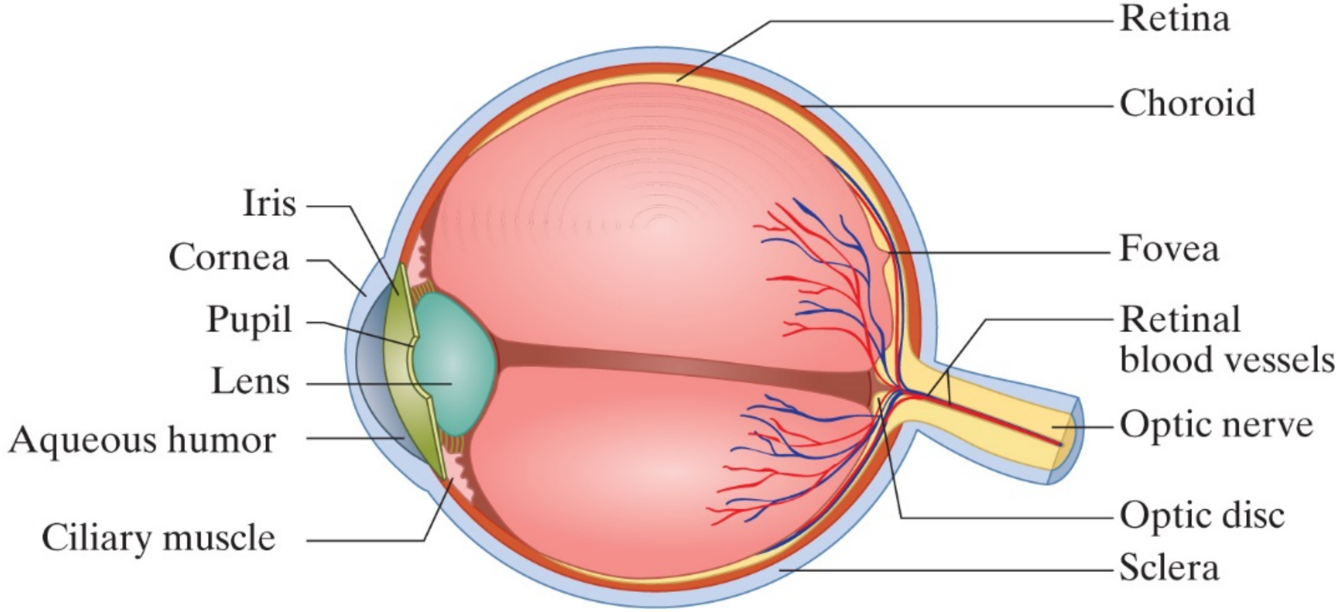
- Fundamental concepts of imaging.
- A quick tour of natural vision systems, with particular attention paid to the human visual system.
- Topics of image formation and acquisition, such as the pinhole camera model, lenses, sampling, and quantization.
- A survey of alternative imaging modalities.
- A detailed look at the electromagnetic spectrum.

A Single Photoreceptor

- **Photoreceptor:** The most fundamental component of any natural vision system.
  - When a single photon of light hits a single photoreceptor, it sets off a wonderfully complex chain of events that leads to the surprising ability to see.
  - The absorption of a photon causes a change in shape of a small organic molecule called *retinal*. This change in shape causes the larger protein, called *rhodopsin*, holding the retinal molecule to change shape.

Structure of the Eyes

Figure 2.1 Cross section of the human eyeball.



The Visual Pathway

- The photoreceptors connect directly to the inputs of either rod or cone **bipolar cells**.

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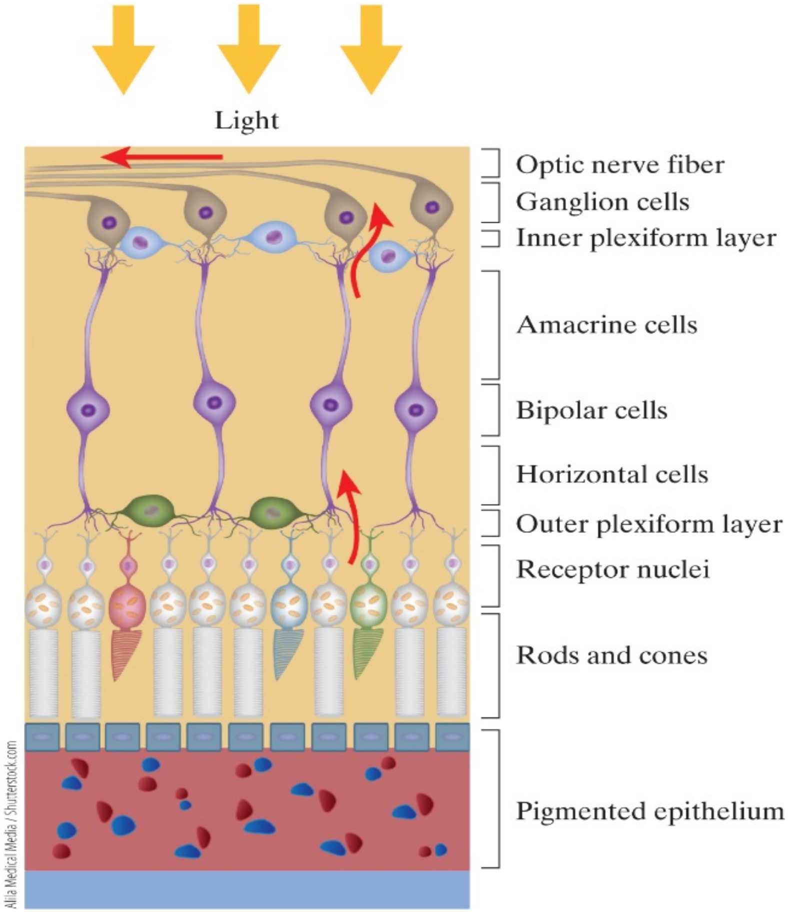
- The outputs of bipolar cells connect to the inputs of the **ganglion cells**.
- The outputs of the ganglion cells form the **optic nerve**.
- **Horizontal cells** are connected to the receptors, as well as amacrine cells, which are connected to the bipolar and ganglion cells.

The Visual Pathway (cont'd)

Figure 2.7 After a photoreceptor absorbs a photon, the information is passed through several layers of cells before exiting via the optic nerve. Surprisingly, the light passes through these same layers of cells before landing on the photoreceptors.



Human Visual Perception

- The human visual system can respond to levels of light ranging an astounding 14 orders of magnitude.

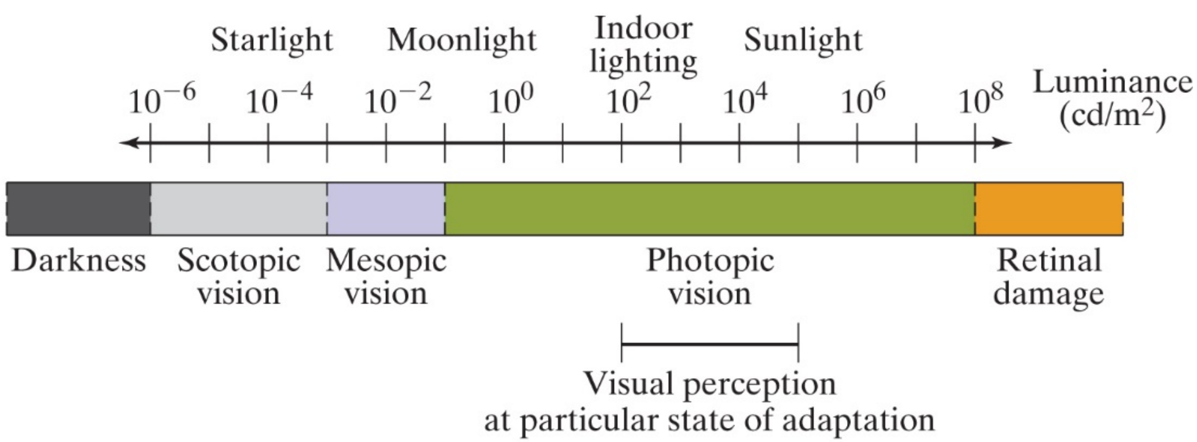


Figure 2.8 Scotopic, mesopic, and photopic vision at different light levels. While the human visual system is capable of sensing light in approximately a range of 10^{14} overall (from 10^{-6} to 10^{8} cd/m^2), light can be sensed in a range of 10^3, at any particular state of adaptation.

Human Visual Perception (cont'd)

- **Luminous efficiency function (LEF):** captures the relative sensitivity of the visual system to different wavelengths.
- **Photopic LEF:** corresponds to normal light levels where the cones dominate due to the saturation of the rods.
- **Scotopic LEF:** corresponds to low light levels where the rods dominate due to the lack of sensitivity of the cones.
- **Purkinje effect:** the difference in peak wavelength.

Animal Vision

- The imitation of natural systems is known as **biomimicry** (or *biomimetics*).
  - It is an important approach to discovering novel solutions in both software and hardware.
- In a compound eye, the photoreceptors are arranged in small groups called **ommatidia**.
  - Each ommatidium views the world from a different direction, yielding a mosaic of images providing a fairly low-resolution representation of the scene.

Animal Vision (cont'd)

Figure 2.10 The common housefly has the fastest visual response of any animal, leading to extreme maneuverability in flight. Tiny flying robots (such as this one from Centeye) have been inspired to mimic the housefly's navigation ability based on optic flow.

mrfiza / Shutterstock.com, Courtesy of Centeye

Animal Vision (cont'd)

Figure 2.11 Raptors, such as this hawk, have the highest visual acuity of any animal. Megapixel video cameras with similar ability are now commercially available.

Ronnie Howard / Shutterstock.com, ymgerman / Shutterstock.com

Animal Vision (cont'd)

Figure 2.14 Bees have ultraviolet filters enabling them to detect the flower center, which is helpful for pollinization. The middle image shows the flower (left) as it appears to a bee. Ultraviolet cameras are also used to detect heavenly bodies, such as the sun (right).

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Figure 2.16 The lobster eye focuses by reflection, not refraction, and is the inspiration for a new generation of telescope. Based on *Trilobite Eyes—Ultimate Optics* by Kurt Wise https://answersingenesis.org/extinct-animals/trilobite-eyes-ultimate-optics/

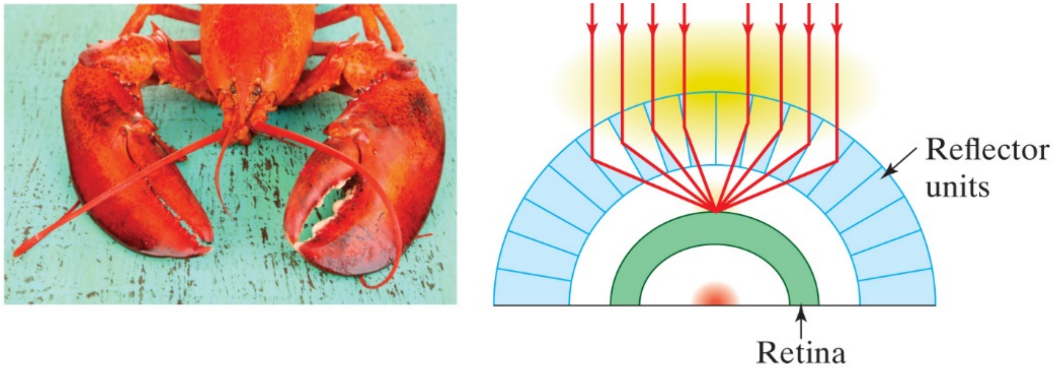

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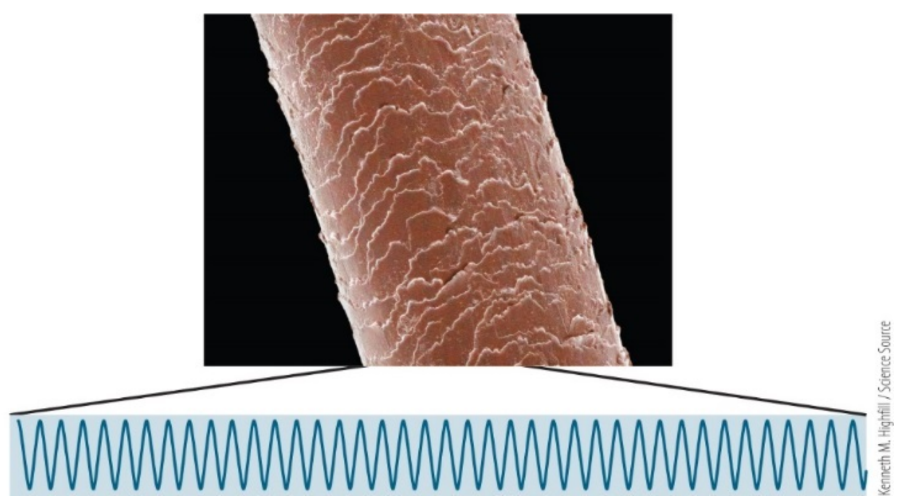
Image Formation - Light and the Electromagnetic Spectrum

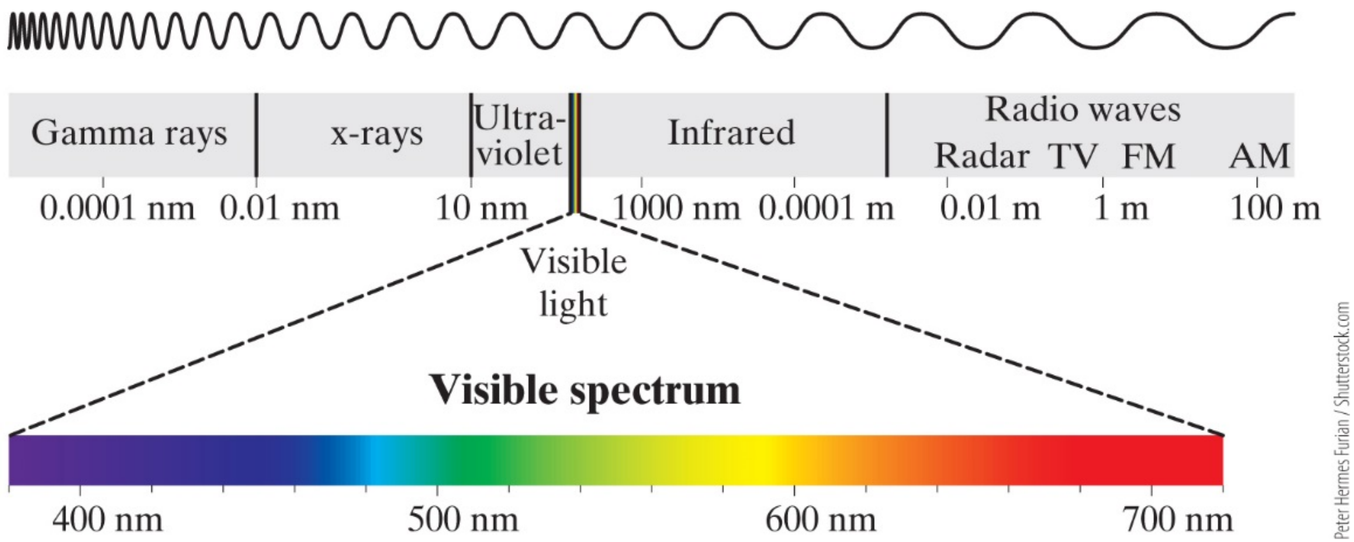
- **Wavelength λ (measured in meters):** the distance between successive peaks in the sinusoid of a wave.
- **Frequency *v* (measured in hertz):** inversely related to the wavelength.
  - **λ** times ***v*** is the speed of light in the medium.

Figure 2.19 The wavelength of visible light is about 1/100th the diameter of a human hair.



Electromagnetic Spectrum

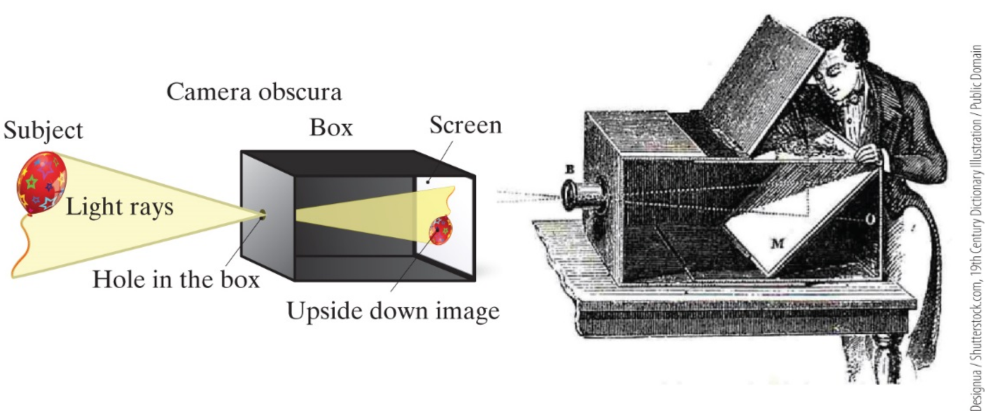
Figure 2.20 The electromagnetic spectrum consists of gamma rays and X-rays at one end, and radio waves and microwaves at the other end. The visible spectrum is between about 380 and 720 nm.



Pinhole Camera

- To form a recognizable image, the light rays must be constrained.
  - One way to do this is to construct an empty, opaque box that is so tight that no light can enter the box.
  - Then, a small hole the size of a pin is pierced into one side of the box, which allows light to enter the box only through the hole.

Figure 2.22 In a pinhole camera, light rays pass through the tiny aperture and form an upside-down image on the opposite wall. A camera obscura was an early form of pinhole camera in which light rays pass through the small aperture, reflect off the mirror, and form an image on the top horizontal surface near the rear of the enclosed box.



Pinhole Camera (cont'd)

- **Focal point:** the pinhole through which all rays of light pass.
- **Image plane:** the sensor surface on which the image is formed.
- **Optical axis:** the line through the focal point perpendicular to the image plane.
- **Focal length:** the distance from the focal point to the image plane along this line.

Pinhole Camera (cont'd)

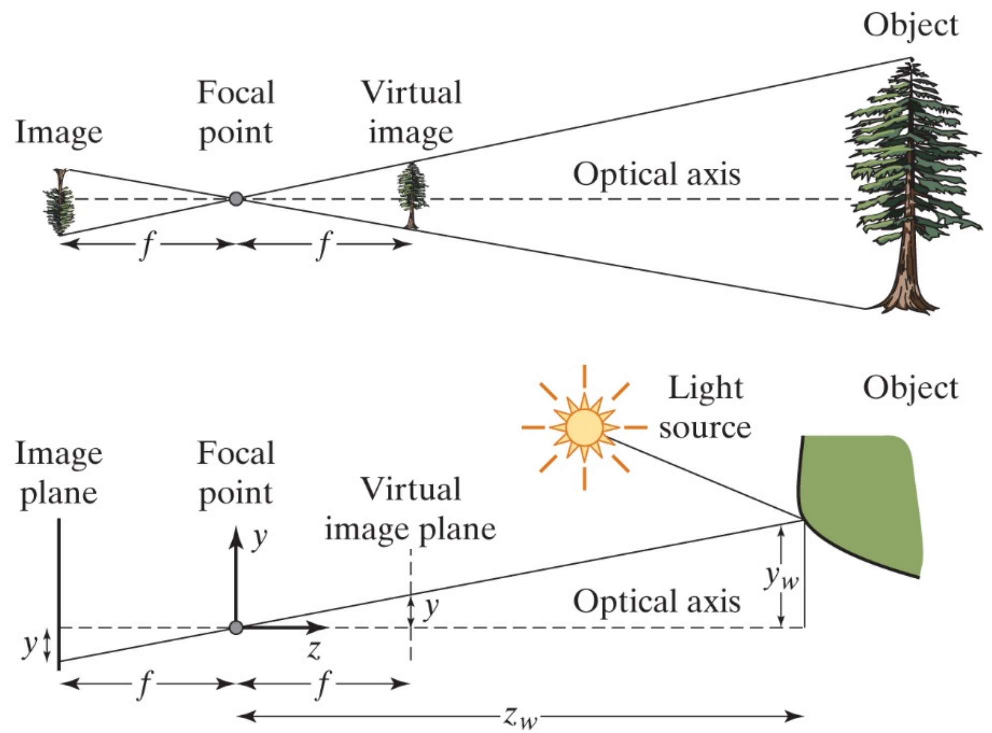
- **Perspective projection:** Light rays from the source reflect off the surface of an object in the scene, travel through the focal point (also called the center of projection), then land on the image plane.

- (x_w, y_w, z_w): the 3D coordinates of the world point.
- (x, y): the 2D coordinates of its projection onto the image.

$$x = f\frac{x_w}{z_w} \qquad y = f\frac{y_w}{z_w}$$

Pinhole Camera (cont'd)

Figure 2.23 Perspective projection caused by a pinhole camera, showing the focal point (pinhole), image plane, focal length, and optical axis. The light rays emitted by the light source reflect off the surface in the world and pass through the aperture to form an upside-down image on the image plane. This is mathematically equivalent to producing a rightside-up image on the virtual image plane in front of the focal point.

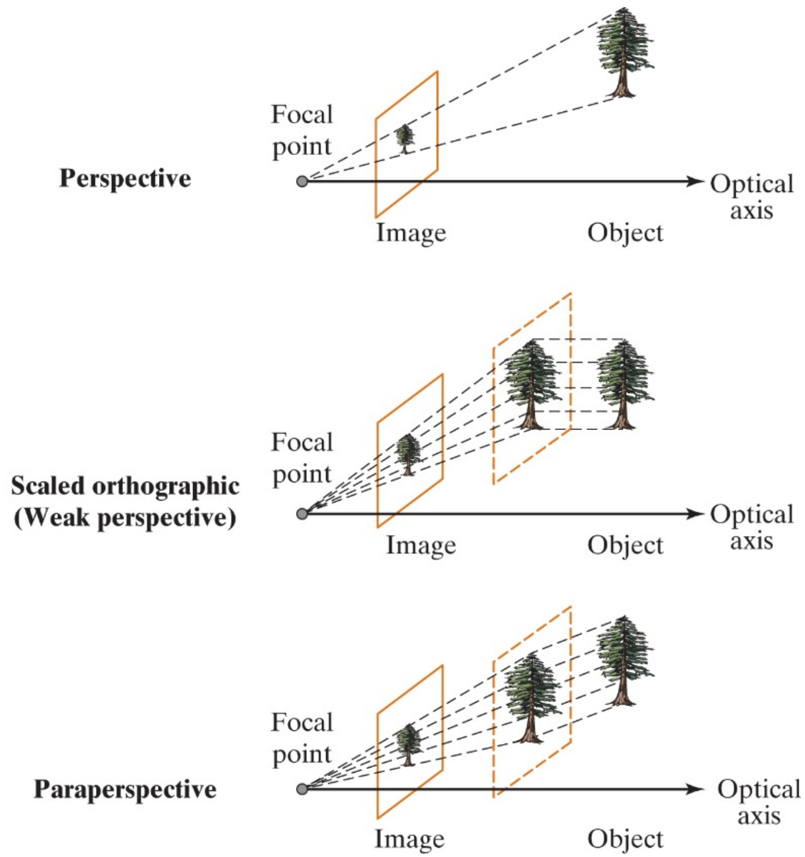


Pinhole Camera (cont'd)

- **Orthographic projection:** occurs when all the light rays are parallel to the image plane.
- **Scaled orthographic projection**: orthographic projection with a single uniform scaling factor.

Pinhole Camera (cont'd)

Figure 2.24 Perspective, weak perspective (scaled orthographic), and paraperspective projection models. Based on V. S. Nalwa. *A Guided Tour of Computer Vision*. Reading, MA: Addison-Wesley, 1993; S. E. Palmer. *Vision Science: Photons to Phenomenology*. Cambridge, Mass.: The MIT Press, 1999.



Questions?