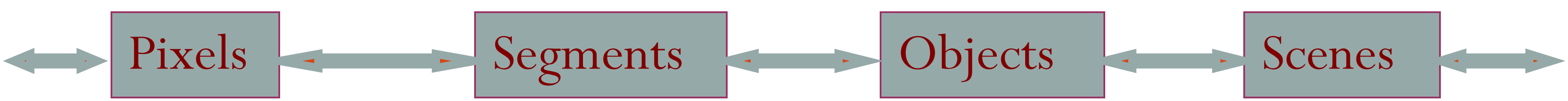
Chapter 2

Digital Image Fundamentals

Image Representations

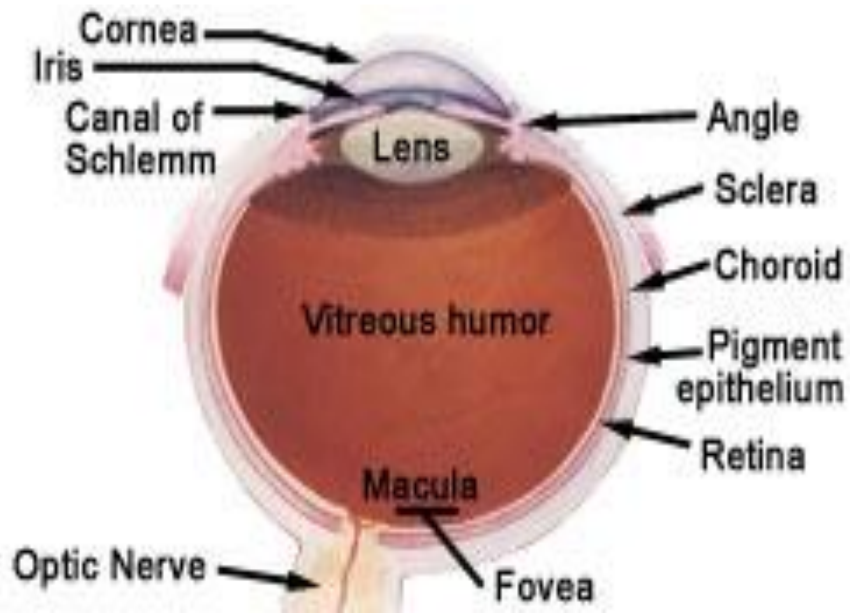
- Image requires to be represented at various levels
- Bottom-up approach : From Pixel to Scenes
- Top-down approach : From Scene to Pixel level



Elements of Visual Perception

Structure of the Human Eye

- Eye: Sphere, diameter of 20 mm
- Consists of 3 membranes:
  1. Cornea and sclera (outer cover)
  2. Choroid
  3. Retina
- Cornea: transparent
- Sclera: opaque, connected to cornea
- Choroid: network of blood vessels



- Iris: contracts or expands to control amount of light
- Pupil: central opening of iris, 2 to 8 mm in diameter

The Eye

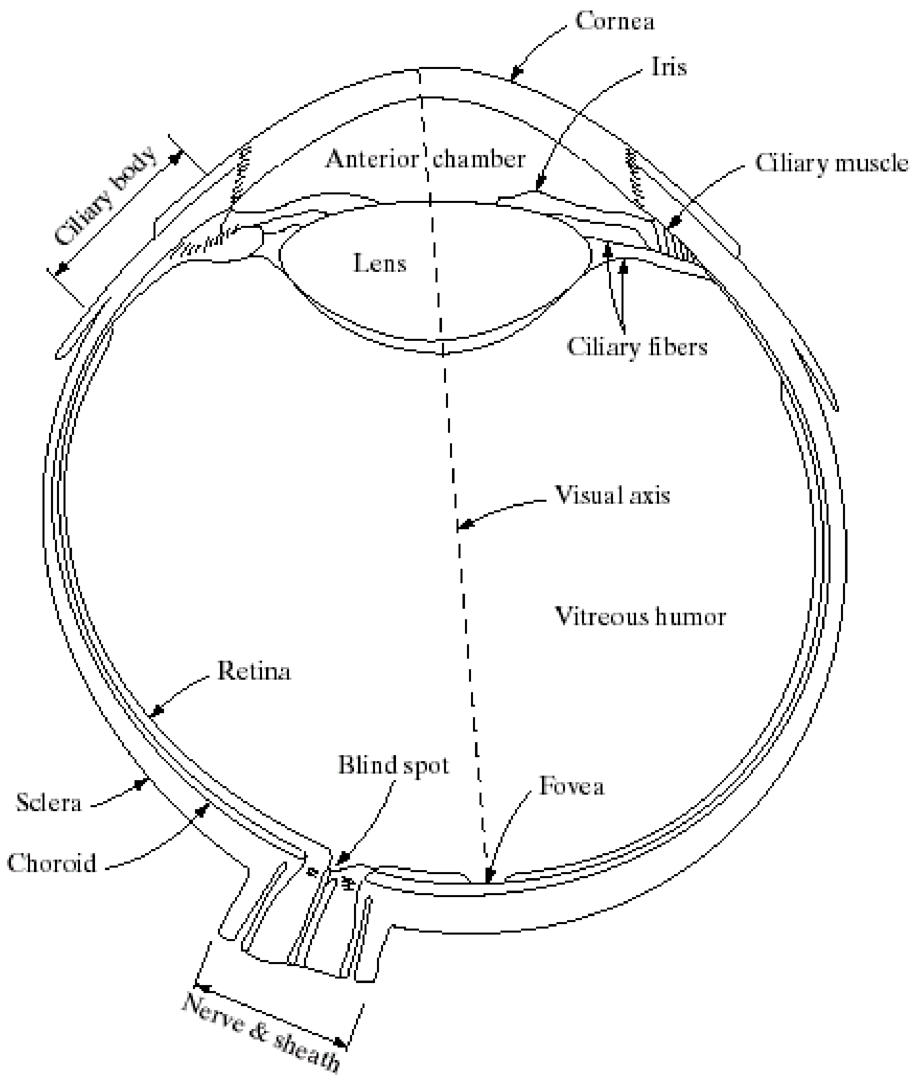
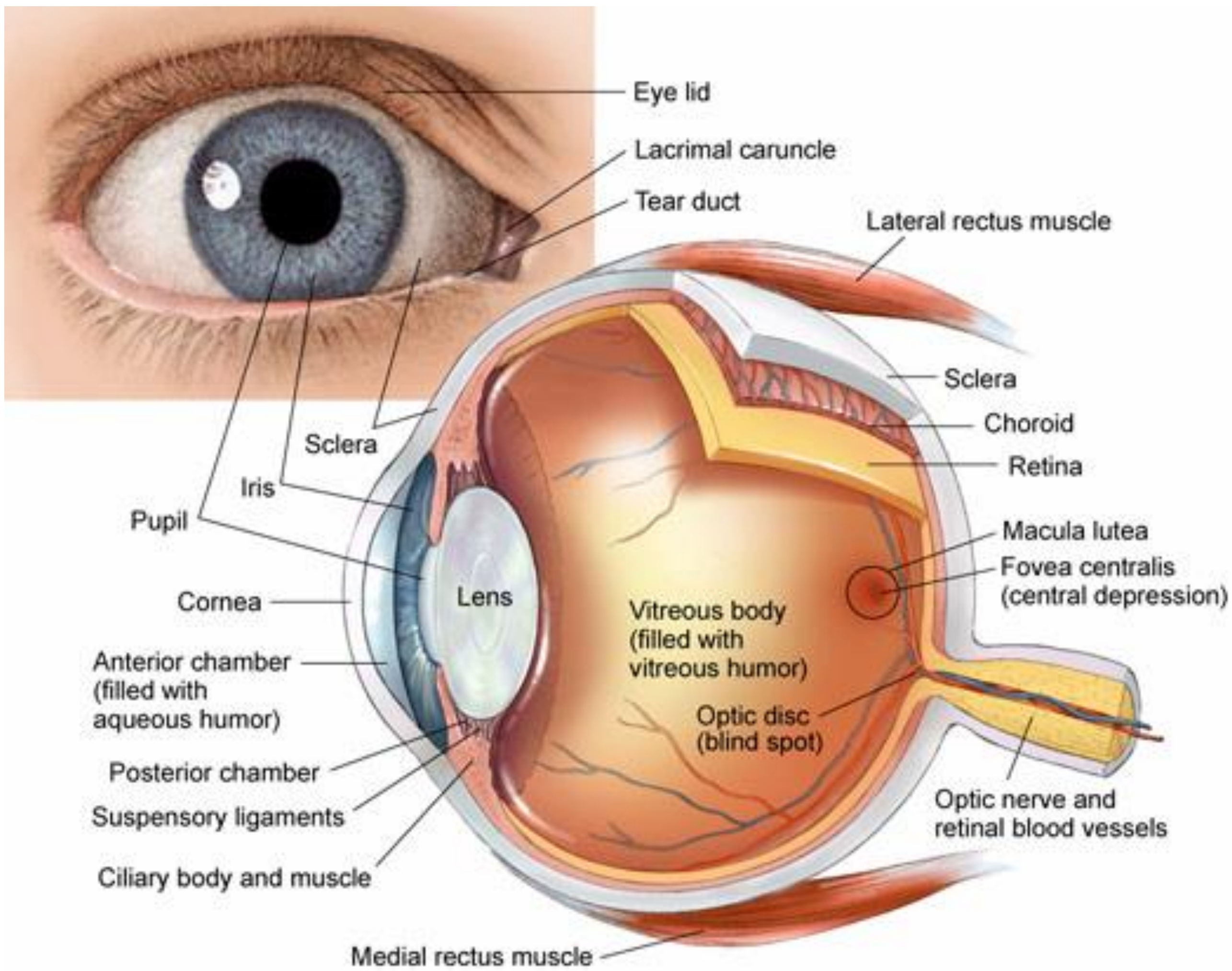


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

The Eye



Right Eye (viewed from above)

Structure of the Human Eye

Lens:

- focuses light on retina
- Contains 60% to 70% water
- Absorbs 8% of visible light, with relatively higher absorption at shorter wavelengths
- High absorption in infrared and ultraviolet (can cause damage to eye)

Retina: the inner most layer, covers the posteriori portion of eye

- When eye is properly focused, light from an object is imaged on the retina
- Light receptors are distributed over the surface of retina

Structure of Human Eye

Retina contains light receptors: Cones & rods

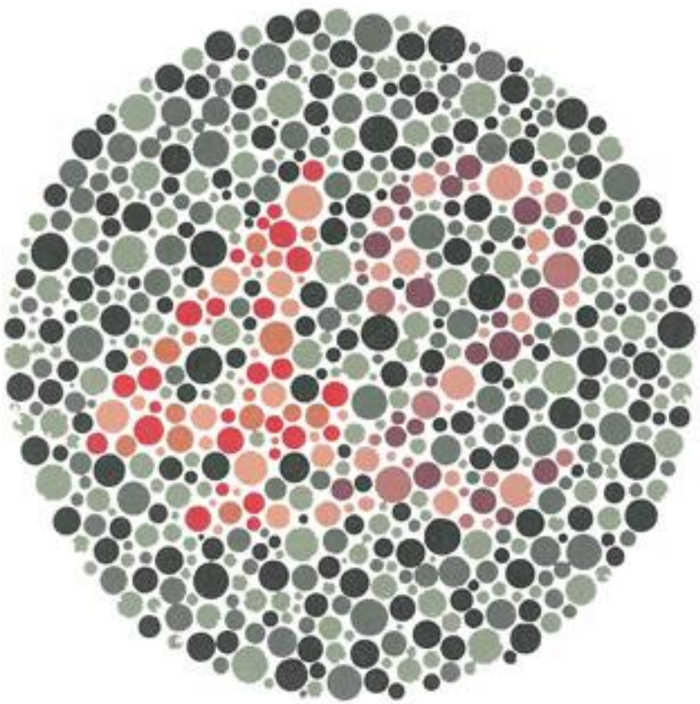
Cones:

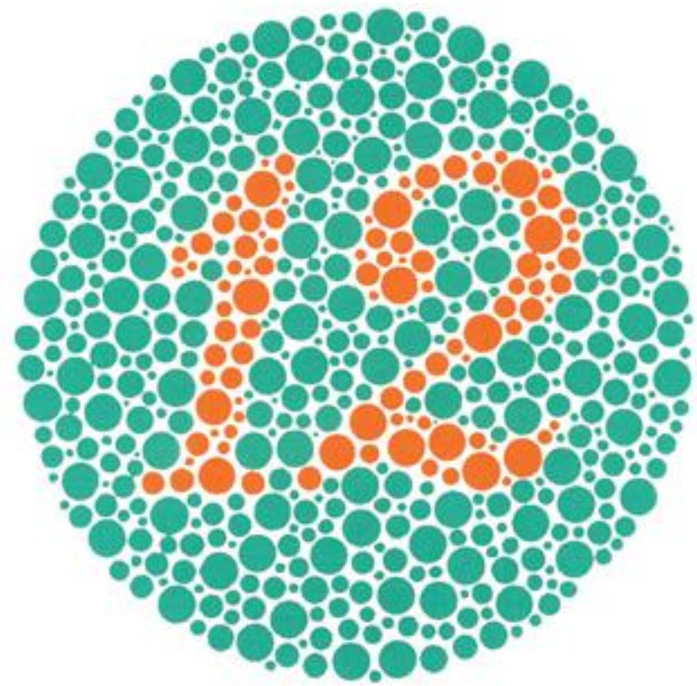
- 6 to 7 million,
- located mainly in central part of retina (fovea)
- Sensitive to color
- Can resolve fine details because each one is connected to its nerve
- Muscles controlling the eye rotate the eyeball until the image of an object of interest falls on the fovea.
- Cone vision: photopic or bright-light vision

Rods:

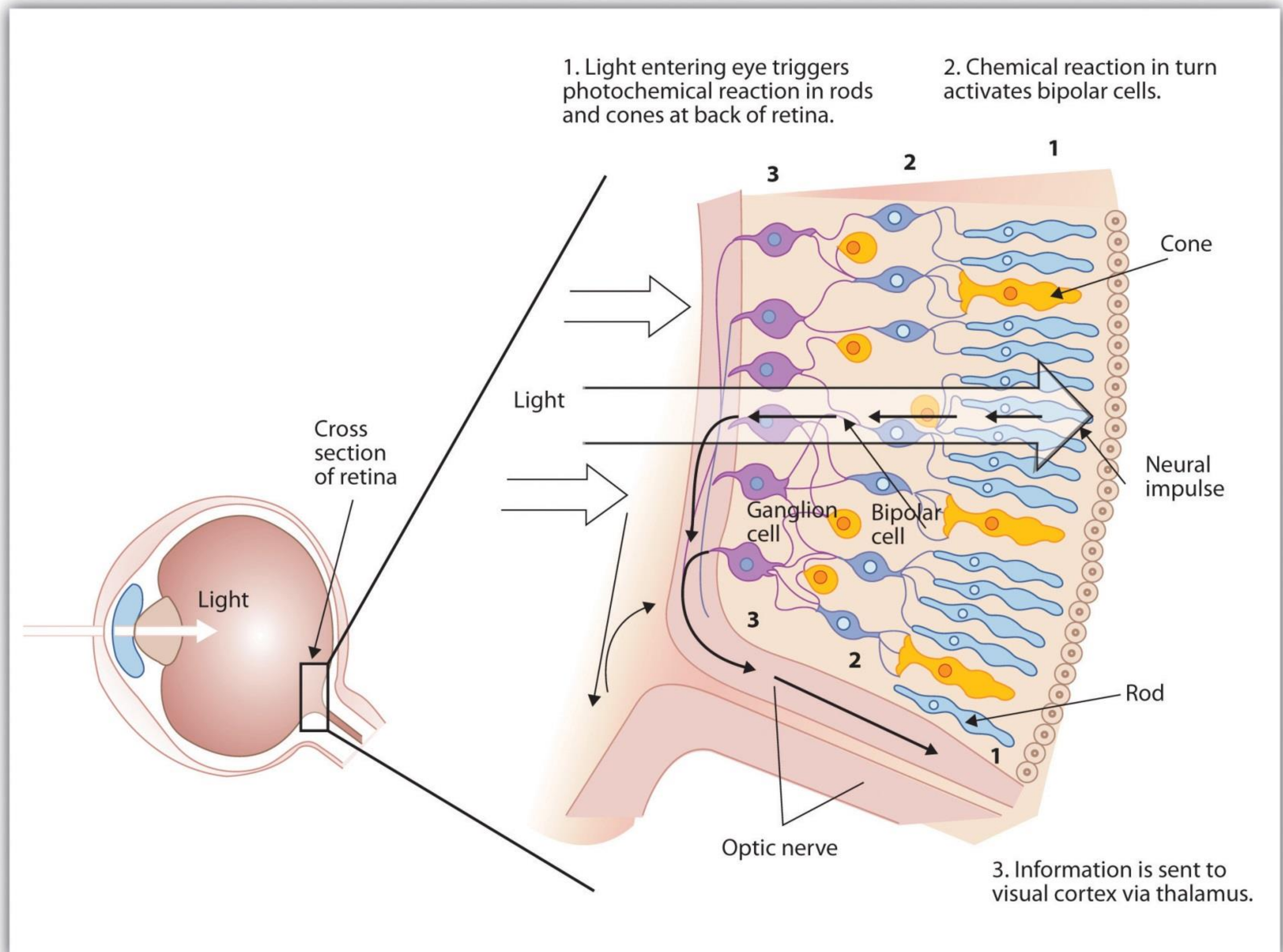
- 75 to 150 million
- No color vision, responsible for low light vision
- Distributed a wide region on the retina
- Gives overall picture of field of view
- Rod vision: scotopic or dim-light

Color Test



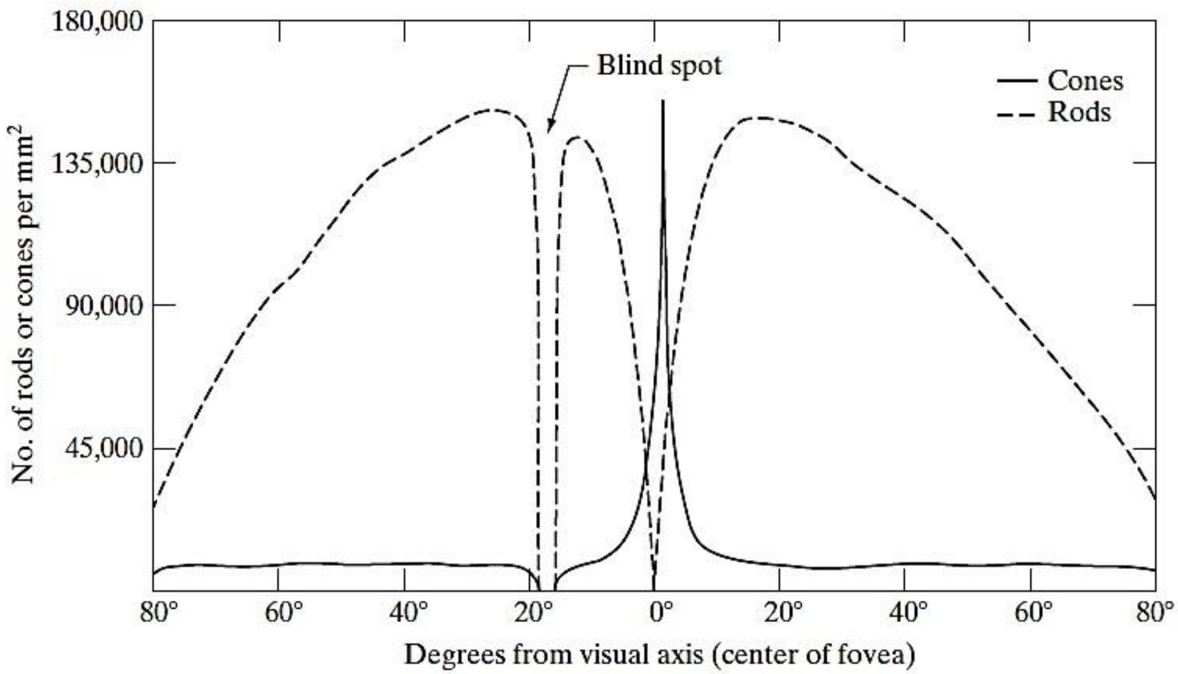


People with normal color vision can see the number 42 in the first image and the number 12 in the second (they are vague but apparent). However, people who are color blind cannot see the numbers at all.

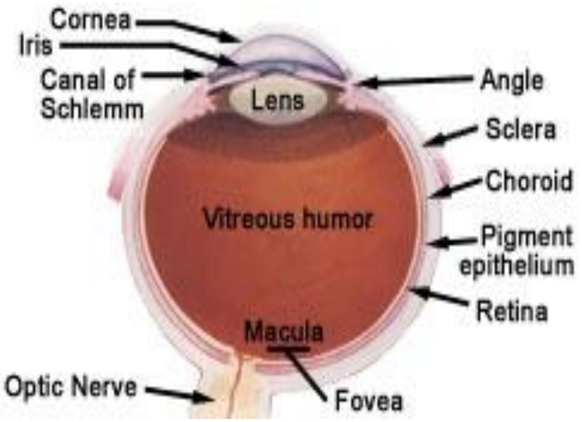


Light enters the eye through the transparent cornea, passing through the pupil at the center of the iris. The lens adjusts to focus the light on the retina, where it appears upside down and backward. Receptor cells on the retina send information via the optic nerve to the visual cortex.

- Optical Sensors in retina:
  - Cones: Highly Sensitive to Color ≈(6-7)×10^6
  - Rods: Highly Sensitive to Low Levels of Illumination
  - ≈(75-150) ×10^6

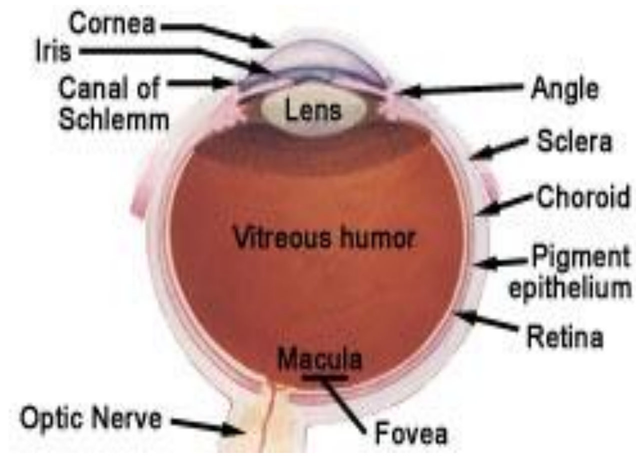


Structure of Human Eye

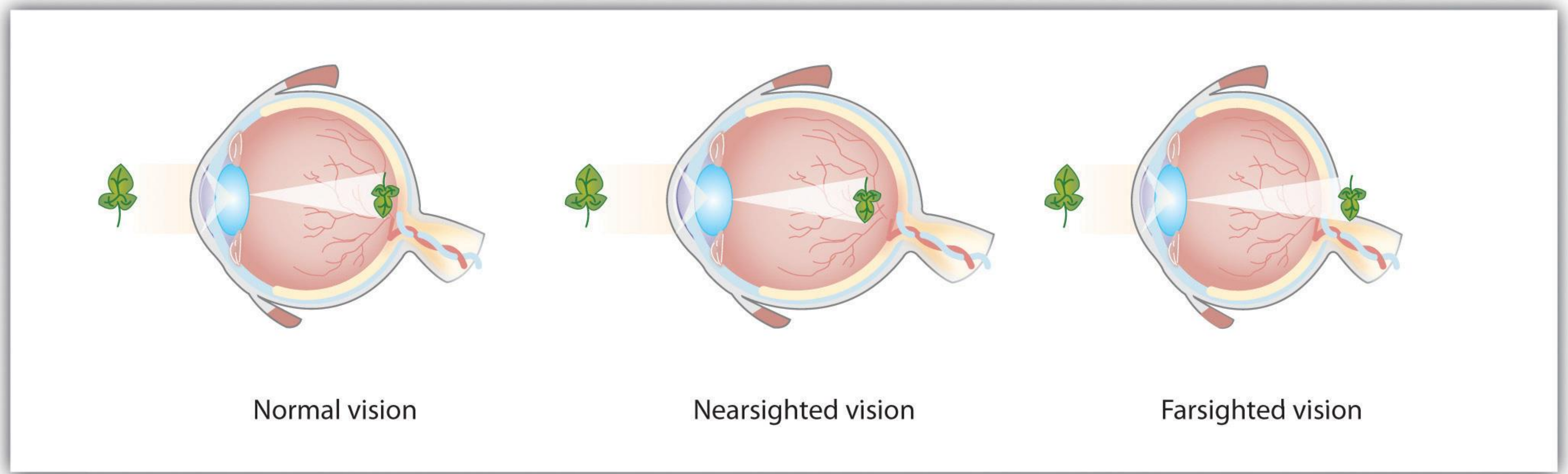


- Blind spot: a region of retina without receptors, optic nerves go through this part.
- Fovea: area of about 1.5 mm in diameter.
- A comparison between eye (fovea) and a CCD camera
- Fovea : a square sensor array of size 1.5 x 1.5 mm^2
- Density of cones in fovea: 150,000 $/mm^2$
- Total Number of cones: 337,000
- A medium resolution CCD chip has the same number of elements in a 5 mm x 5 mm area.

Image Formation in the Eye



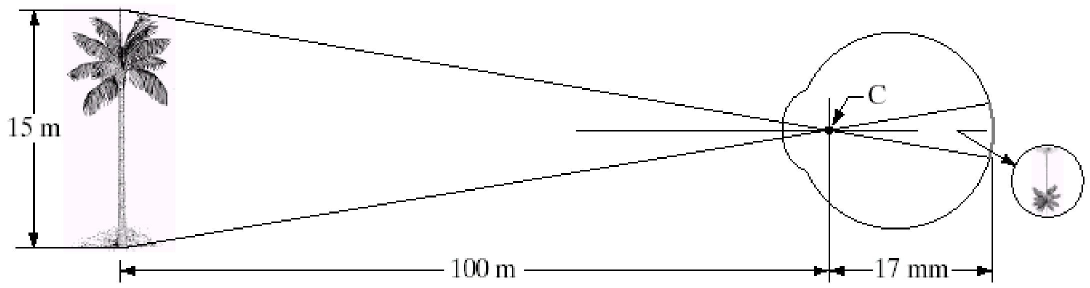
- Lens is flexible
- Refraction of lens is controlled by its thickness.
- Thickness is controlled by the tension of muscles connected to the lens.
- Focus on distance objects: lens is relatively flattened, refractive power is minimum.
- Focus on near objects: lens is thicker, refractive power is maximum.



For people with normal vision (left), the lens properly focuses incoming light on the retina. For people who are nearsighted (center), images from far objects focus too far in front of the retina, whereas for people who are farsighted (right), images from near objects focus too far behind the retina. Eyeglasses solve the problem by adding a secondary, corrective, lens.

h : height of object in the retina

FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.



15/100 = h/17

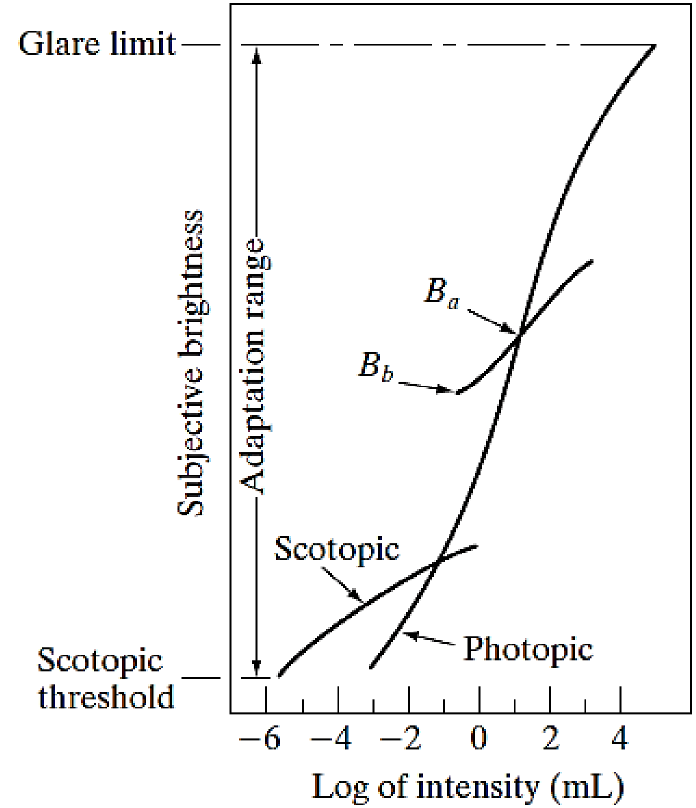
h = 2.55 mm

Brightness Adaptation and Discrimination

- The dynamic range of light intensity to which eye can adapt is enormous – (on the order of 10^{10}) from the scotopic threshold to the glare limit

- HVS can not operate over the entire range (see figure) simultaneously. It accomplishes large variations due to brightness adaptation

- Ability of the eye to discriminate between changes in brightness at any specific adaptation level.



- Brightness (light perceived by visual system) is a logarithmic function of light intensity.

Weber Experiments – brightness discrimination of HVS

Weber Ratio

- I : Intensity at some point
- ΔI : Increment of illumination
- If ΔI is not bright, the subject says “no”
- If ΔI is strong enough, the subject says “yes”
- Weber ratio : ΔIc / I
- ΔIc : Increment discriminable
- A small Weber ratio means good brightness

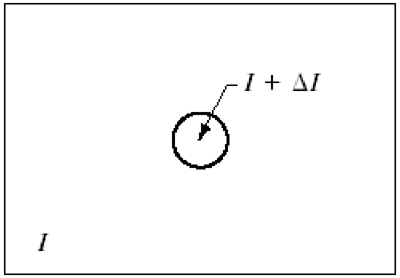
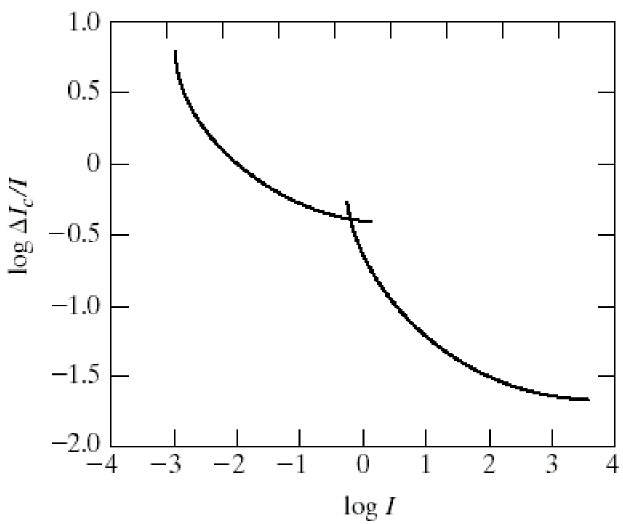


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

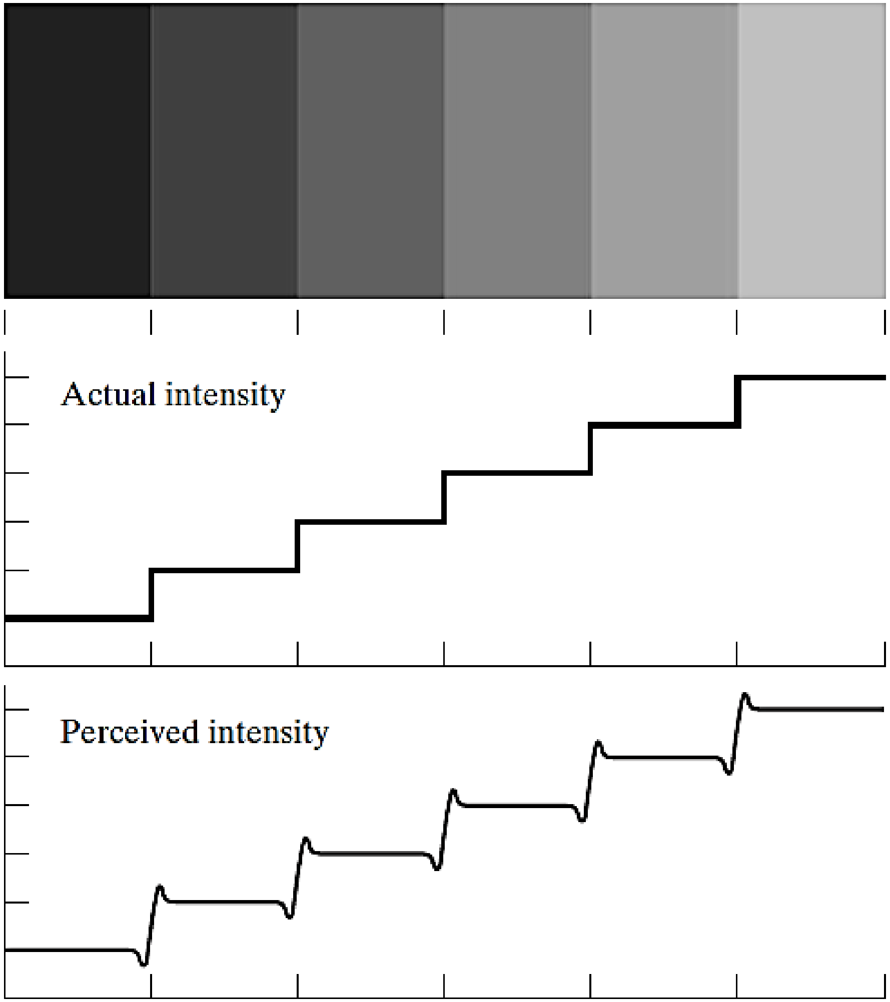
- Poor Brightness discrimination at low level of illumination (Weber ratio is higher)
- Higher brightness discrimination at high level of background illumination (Weber ratio is lower)
- At low level of illumination : rods are active
- At high level of illumination : cones are active (showing better discrimination)

FIGURE 2.6 Typical Weber ratio as a function of intensity.

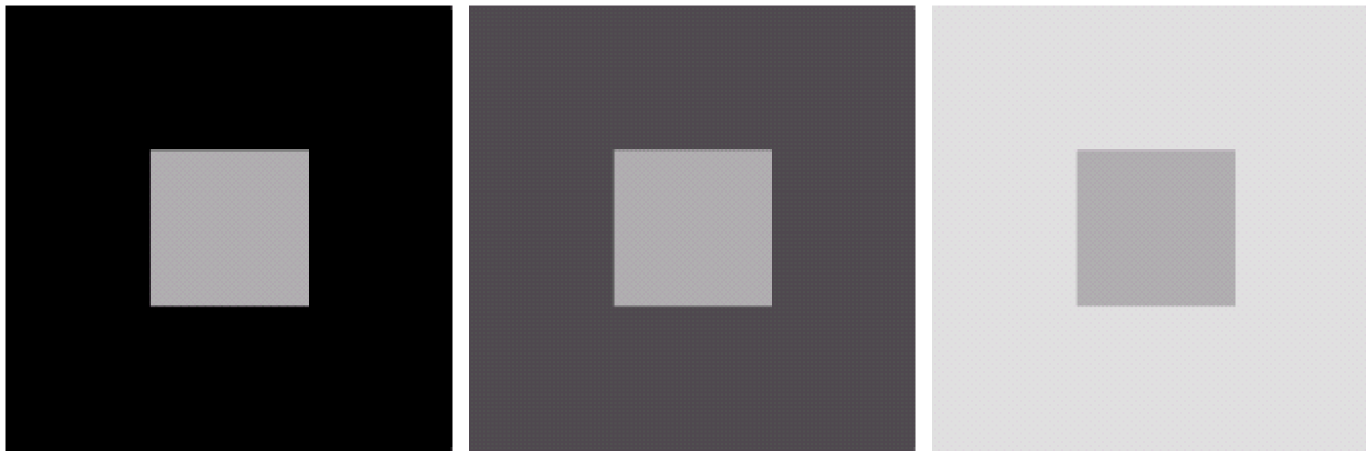


Mach Band Effect

- Perceived brightness is not a simple function of intensity.



Simultaneous Contrast



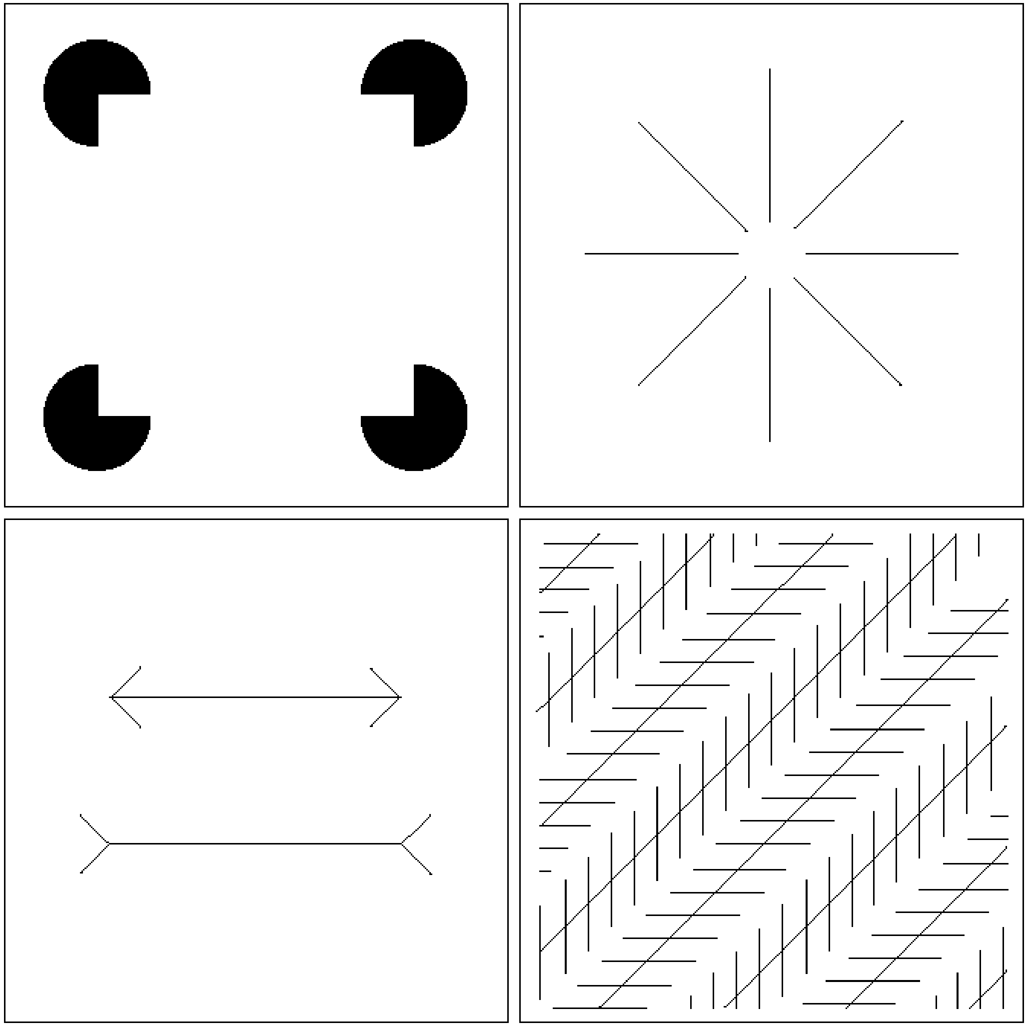
a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Optical Illusions

a b
c d

FIGURE 2.9 Some well-known optical illusions.



Light and the Electromagnetic Spectrum

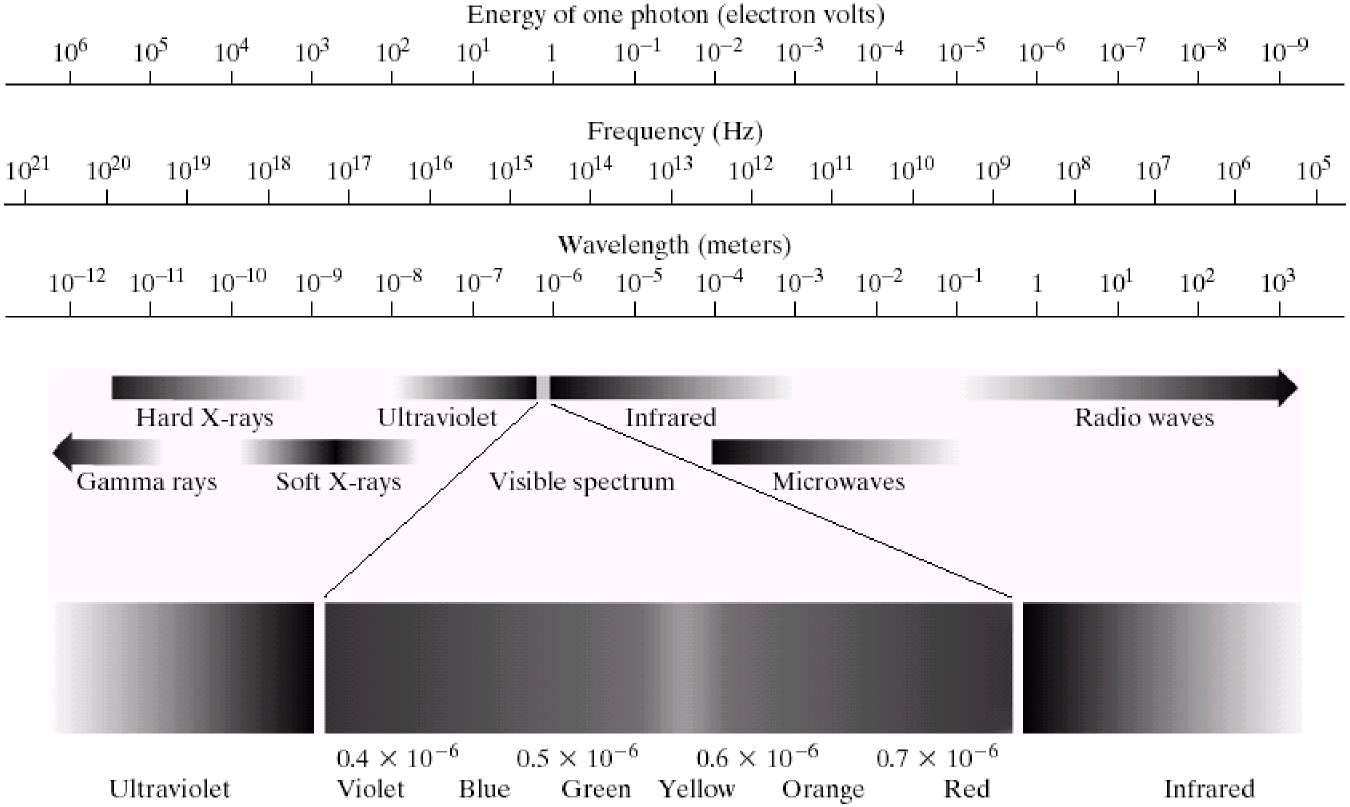


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Radiance, Luminance and Brightness

- **Radiance** is the total amount of energy that flows from the light source (Watts).
- **Luminance** (measured in lumens lm), gives a measure of the amount of energy an observer perceives from a light source.
  - In case of far infrared, luminance is zero
- **Brightness** is a subjective descriptor of light perception that is practically impossible to measure.

Sensors

- Sensors are used to transform illumination energy into digital images.
- In principle, if a sensor can be developed that is capable of detecting energy radiated by a band of the EM spectrum, we can image events of interest in that band.
- The wavelength of an EM wave required to "see" an object must be of the same size as or smaller than the object.
  - Size of water molecule : order of 10^{-10}. Soft X-Ray Region
- This limitation + physical properties of the sensor material establishes the fundamental limits on the capability of imaging sensors, such as visible, infrared and other sensors in use today.

Image Sensing and Acquisition

- Illumination Source:
  - EM Spectrum: Visible light, Radar, Infrared, X-Ray, Gamma Rays etc
  - Ultrasound, or Computer generated illumination pattern
- Scene
  - Familiar objects: Human being, Animals, Buildings
  - Molecules, Human Brain, Buried Rock Formation
- Illumination energy is either reflected from, or transmitted through, objects depending on the nature of the source.
- The reflected or transmitted energy is focused onto a photo-converter, which converts the energy into visible light.

Types of sensors

a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

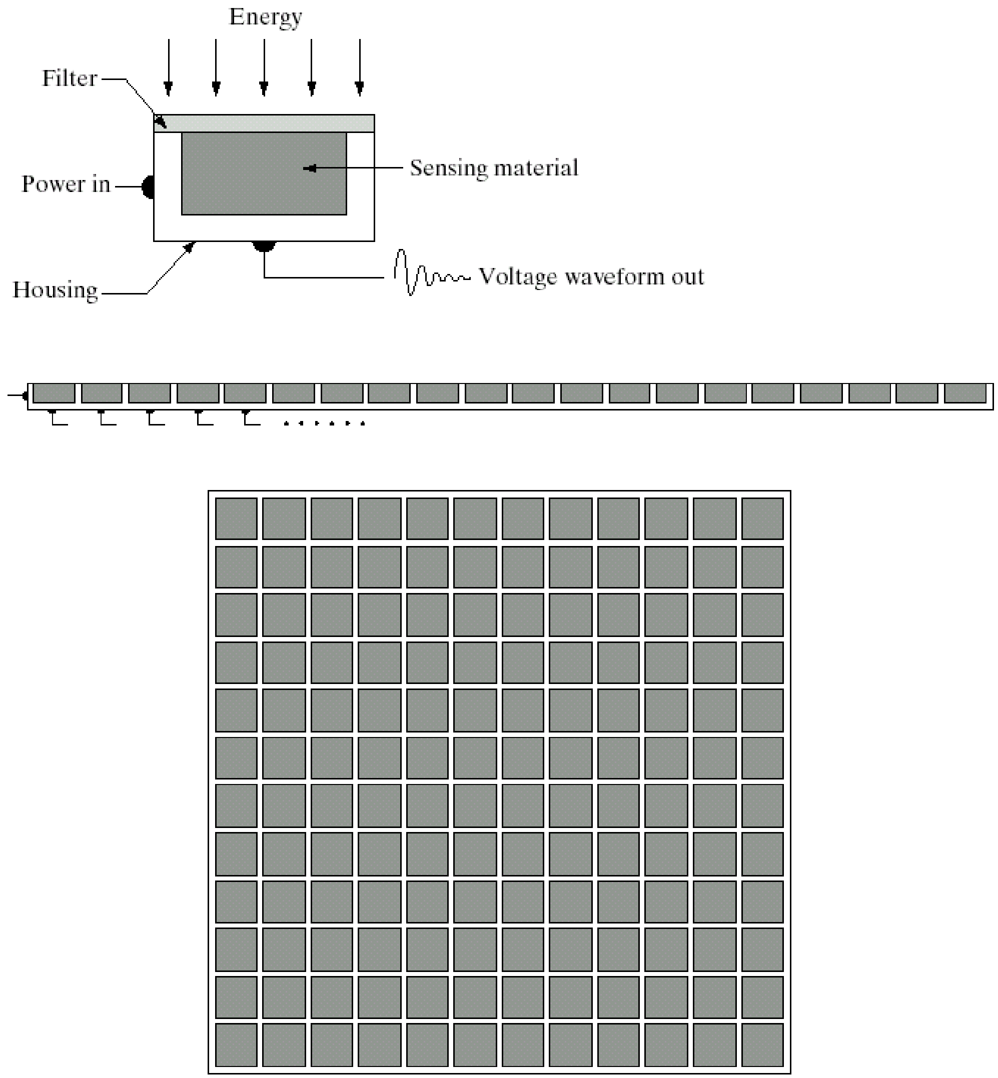


Image Acquisition using Single Sensor

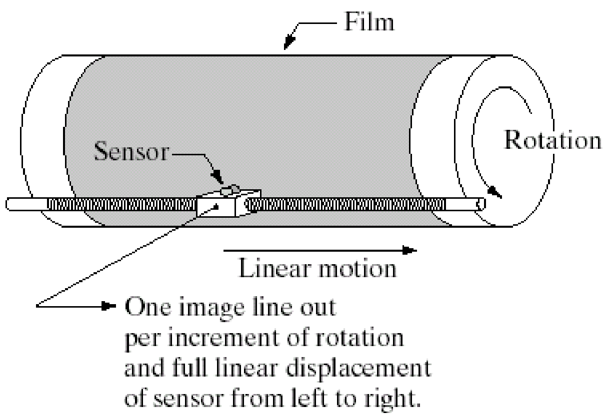
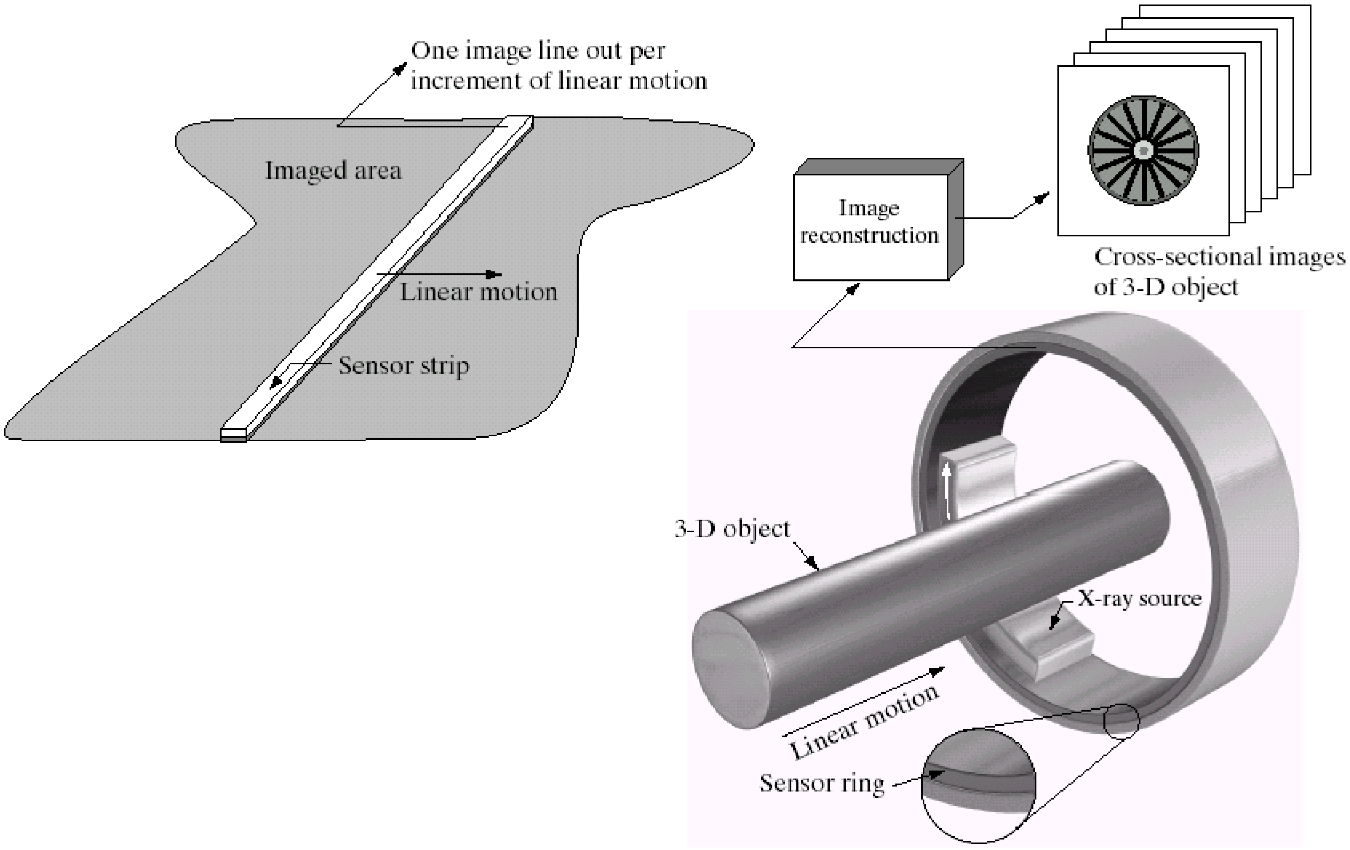


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

Image Acquisition using Sensor Strips



a b

FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Image Acquisition using Sensor Arrays

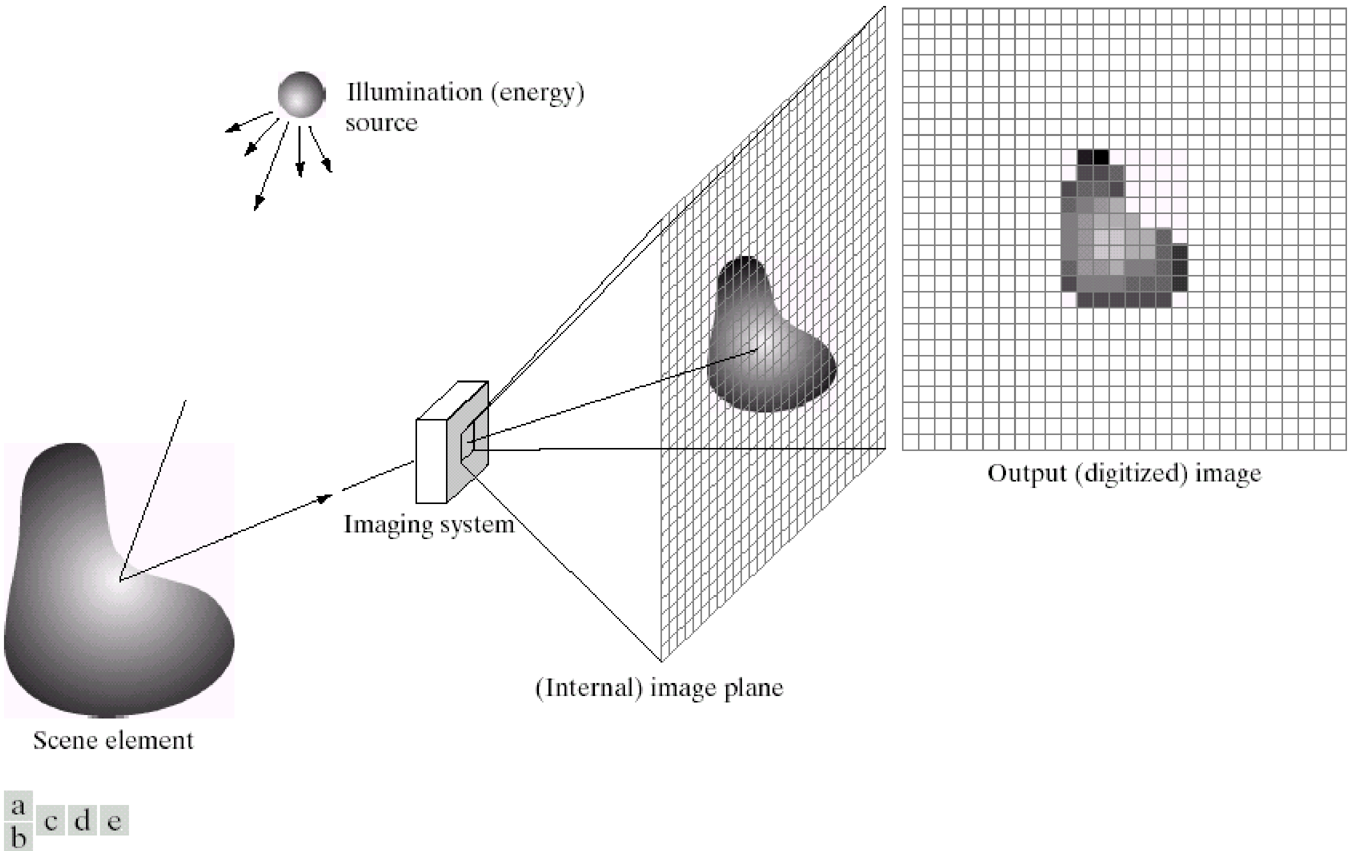


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.