Image Processing

Digital Image Fundamentals
Chapter 2

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Overview

- Mechanisms of HVS (Human Visual System)
- Light
- Imaging sensors
- Image sampling and intensity quantization
- Pixel relationships
- Mathematical tools for IP

Structure of the human eye

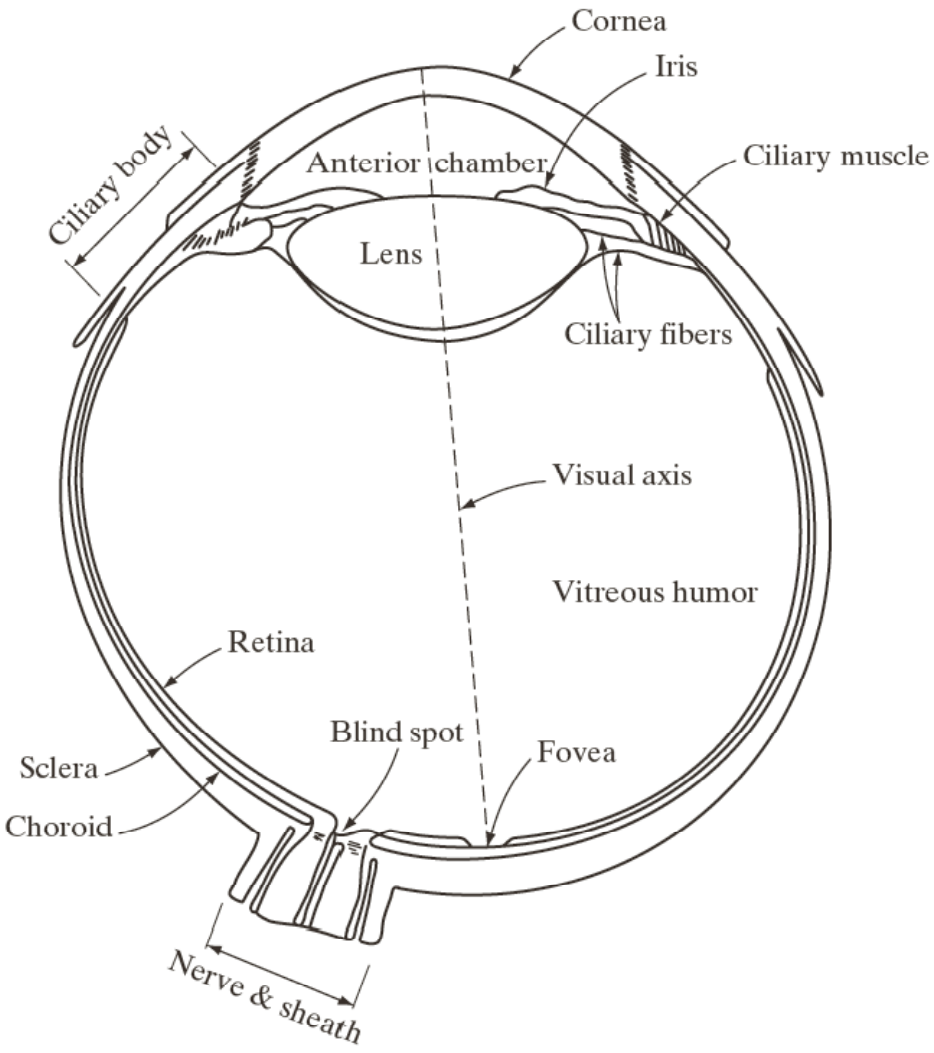


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

Retina

- Retina-innermost membrane of eye
- Light receptors are cones and rods
- Cones-sensitive to color (photopic or bright-light vision)
- Rods-sensitive to low-levels of illumination (scotopic or dim-llight vision)
- Fovea –square sensor array of 1.5mm x 1.5 mm
- Density is 150,000 elements / mm^2
- Raw resolving power of eye - 337,000 elements compared to current electronic imaging sensor (CCD array) of 5mm x 5mm

Image formation in the eye

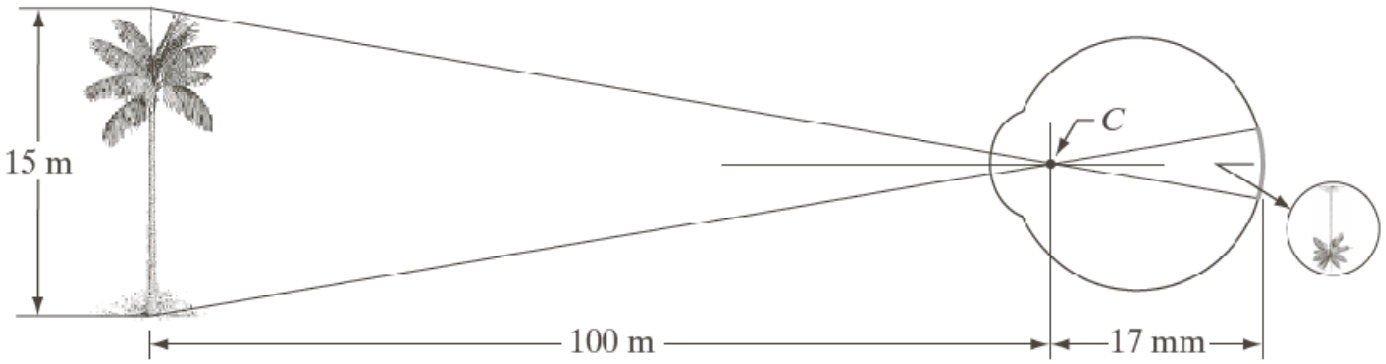


FIGURE 2.3
Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Image formation in the eye

- The shape of the lens is adjusted for focusing on near or distant object
- Contrary to photographic camera where lens has a fixed focal length
- Focal length of eye =17 mm
- h =15 m – height of the object, distance of person from object = 100m
- 15/100 = h/17, h = 2.55 mm
- Image focused on the fovea
- Perception –excitation of light receptors, signals passed to the brain where they are decoded (V1, IT and PFC)

Brightness adaptation and discrimination

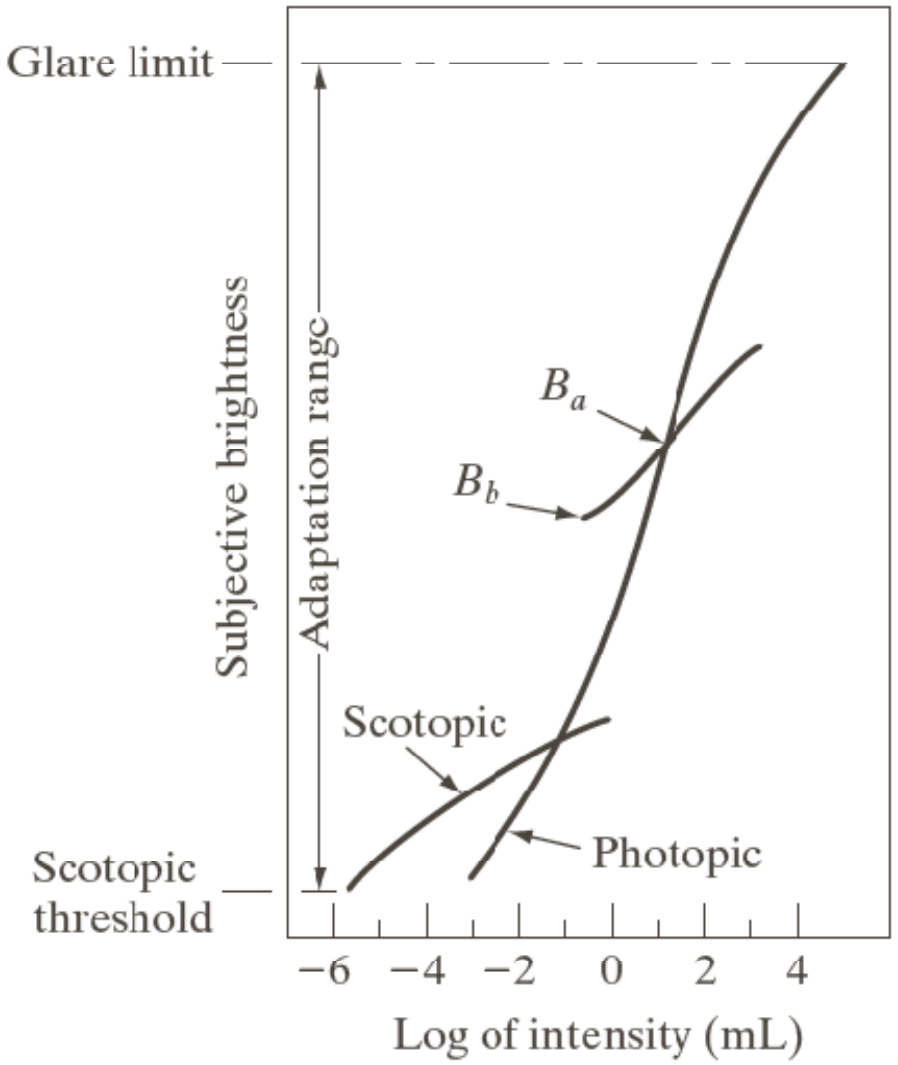
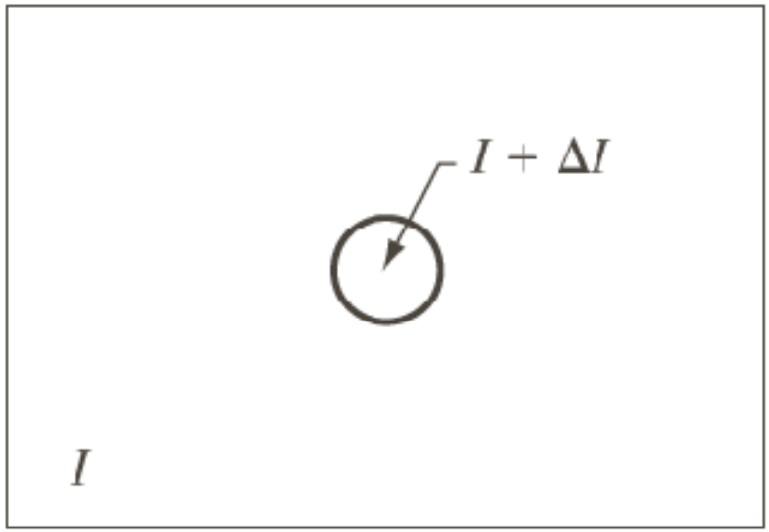


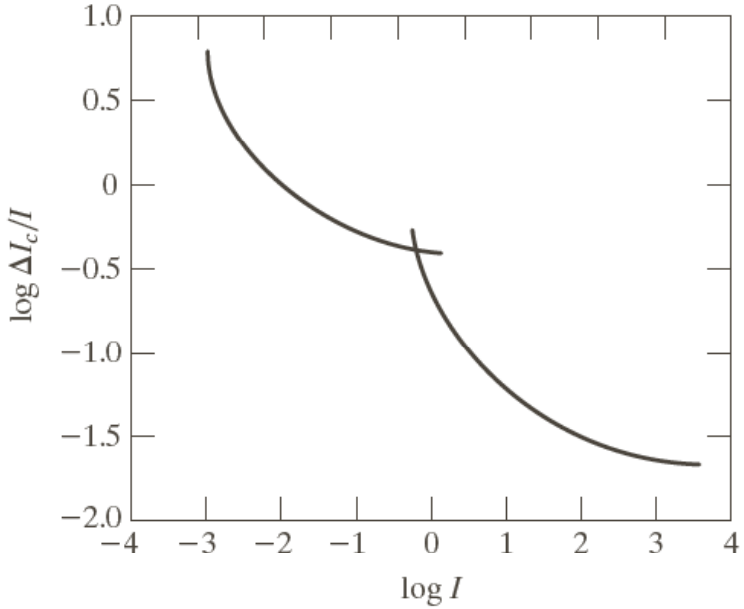
FIGURE 2.4
Range of subjective brightness sensations showing a particular adaptation level.

Brightness discrimination

- Subjective brightness – logarithmic function of the light intensity incident on the eye
- Range of intensities – 10^6
- Current sensitivity level – brightness adaptation level (Ba)
- Intensity of light source, I is varied by ΔI
- When ΔI is strong enough, the subject will respond ‘yes’
- Weber ratio : $\Delta c/I$ increment of illumination discriminable

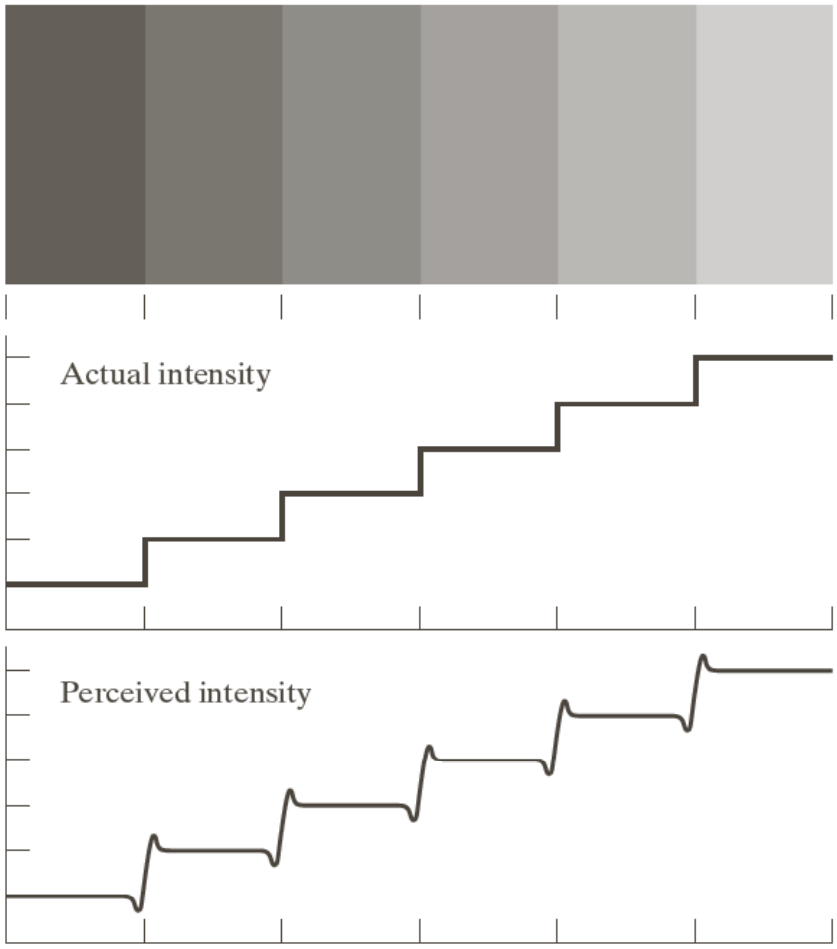
Weber ratio



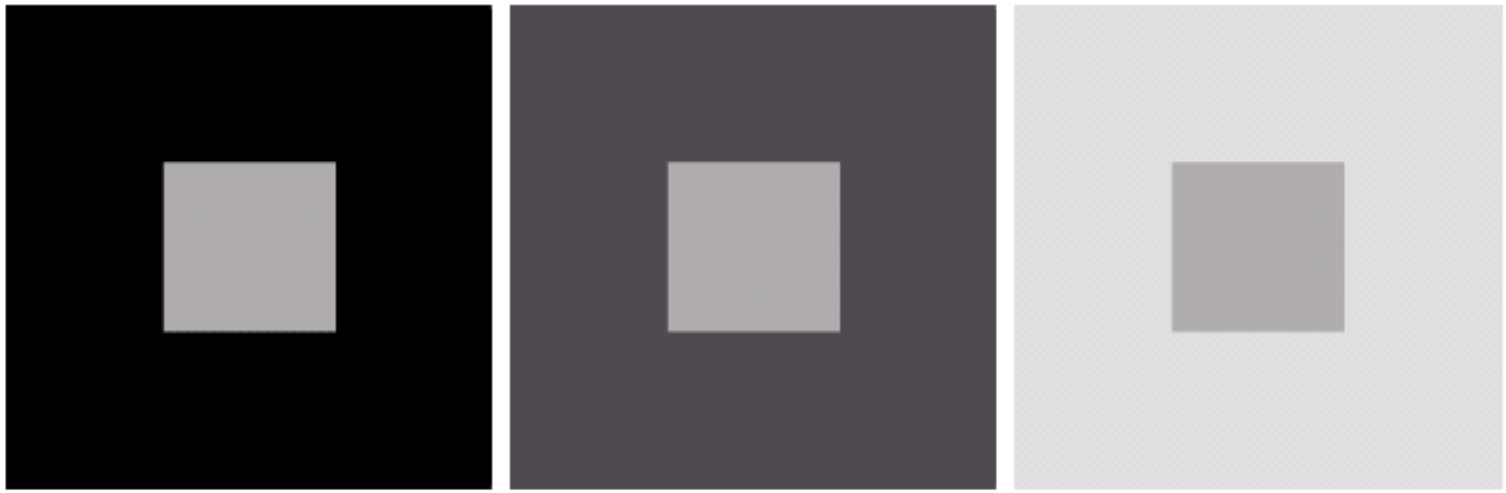


- At low levels of illumination – vision is by rods
- High levels of illumination – by cones
- Perceived brightness is not a simple function of intensity
- HVS undershoots or overshoots around the boundary of regions of different intensities
- Mach bands – scalloped intensities
- Simultaneous contrast – background influence

Mach bands



Simultaneous contrast



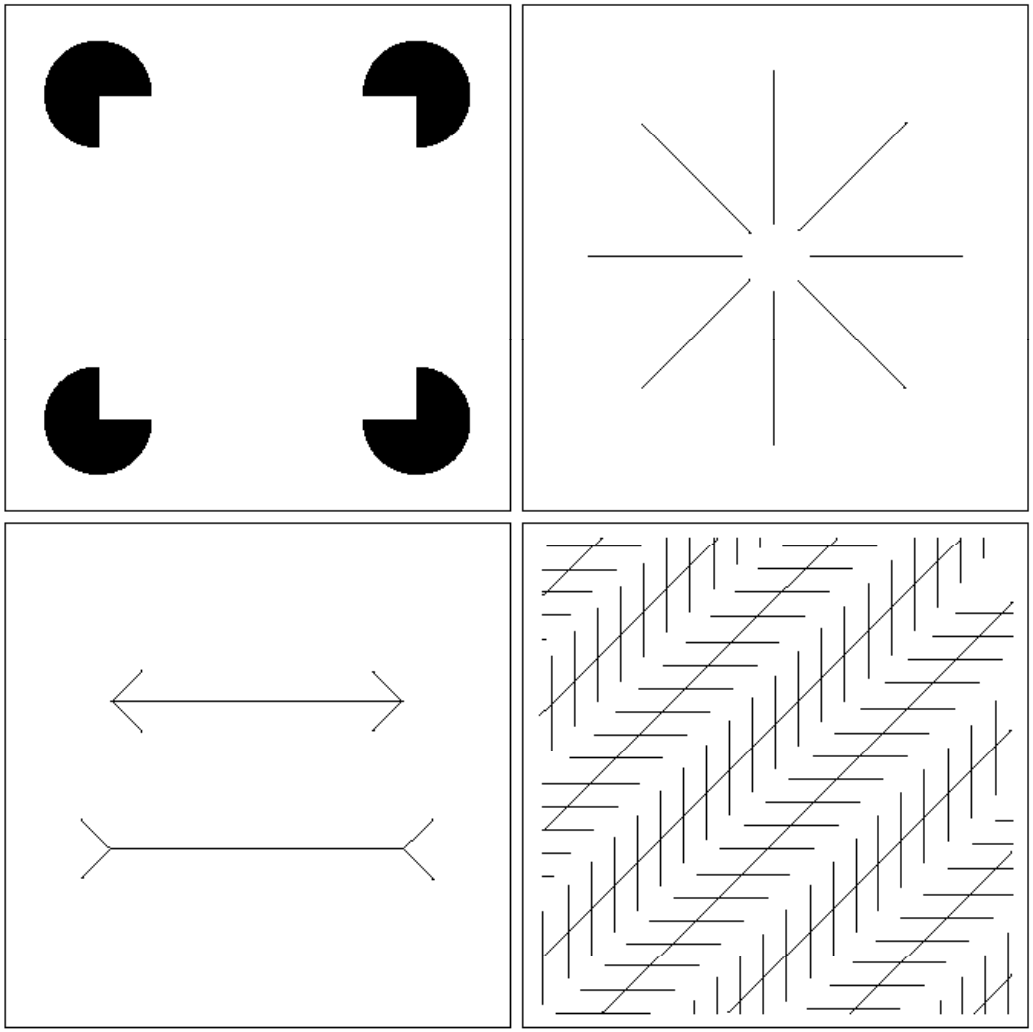
a b c

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 illusion

a b
c d

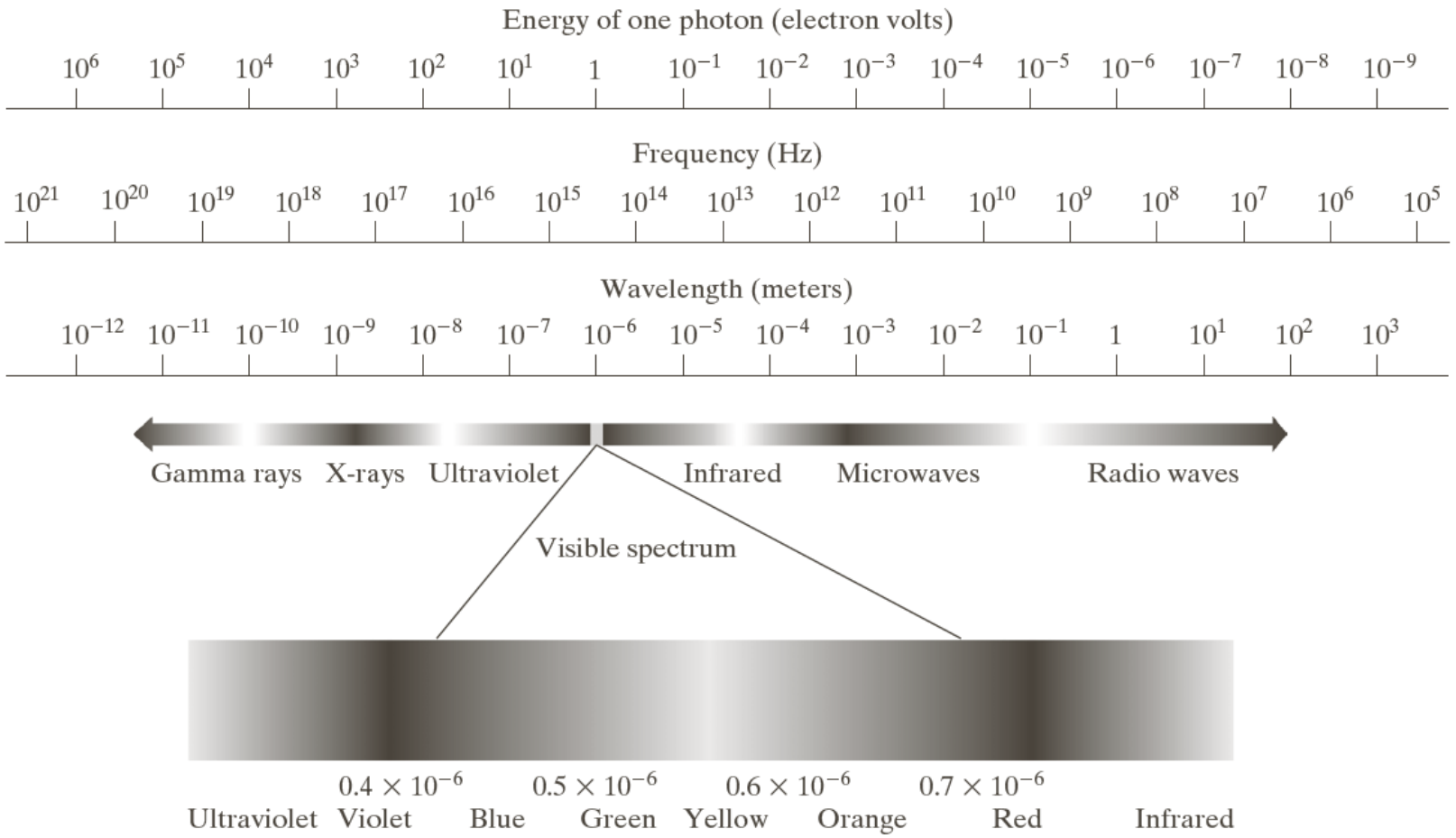
FIGURE 2.9 Some well-known optical illusions.



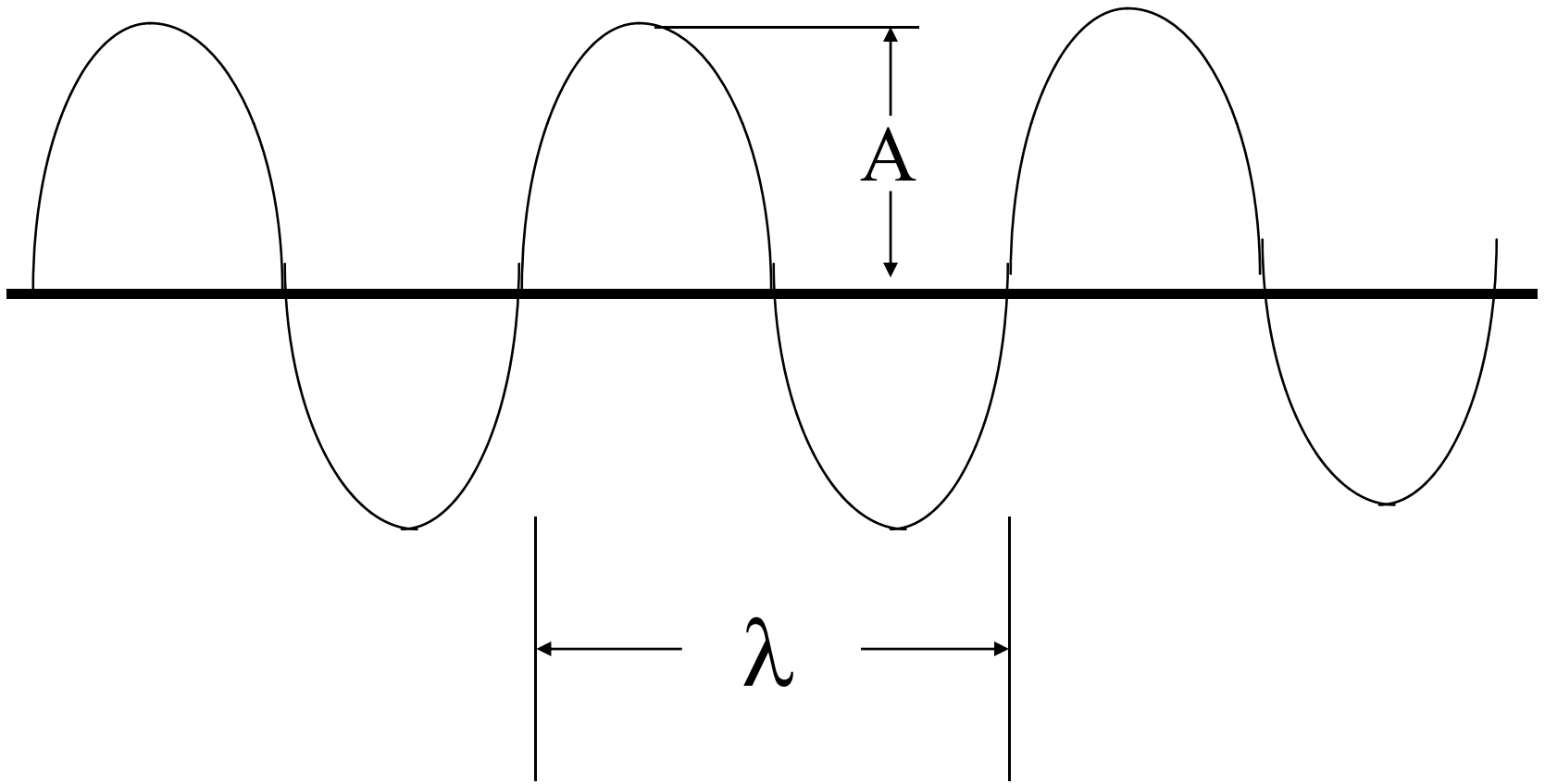
Electromagnetic Spectrum

- Radio waves-Wavelengths longer than visible light
- Gamma rays-wavelengths small than visible light
- $\lambda=c/\nu$; λ-wavelength (m), ν-frequency, c-speed of light
- Energy $E=h\nu$, h-planck's constant
- Electromagnetic waves-stream of massless particles with energy moving at speed of light
- Higher frequency (shorter wavelength) carry more energy per photon

Electromagnetic spectrum



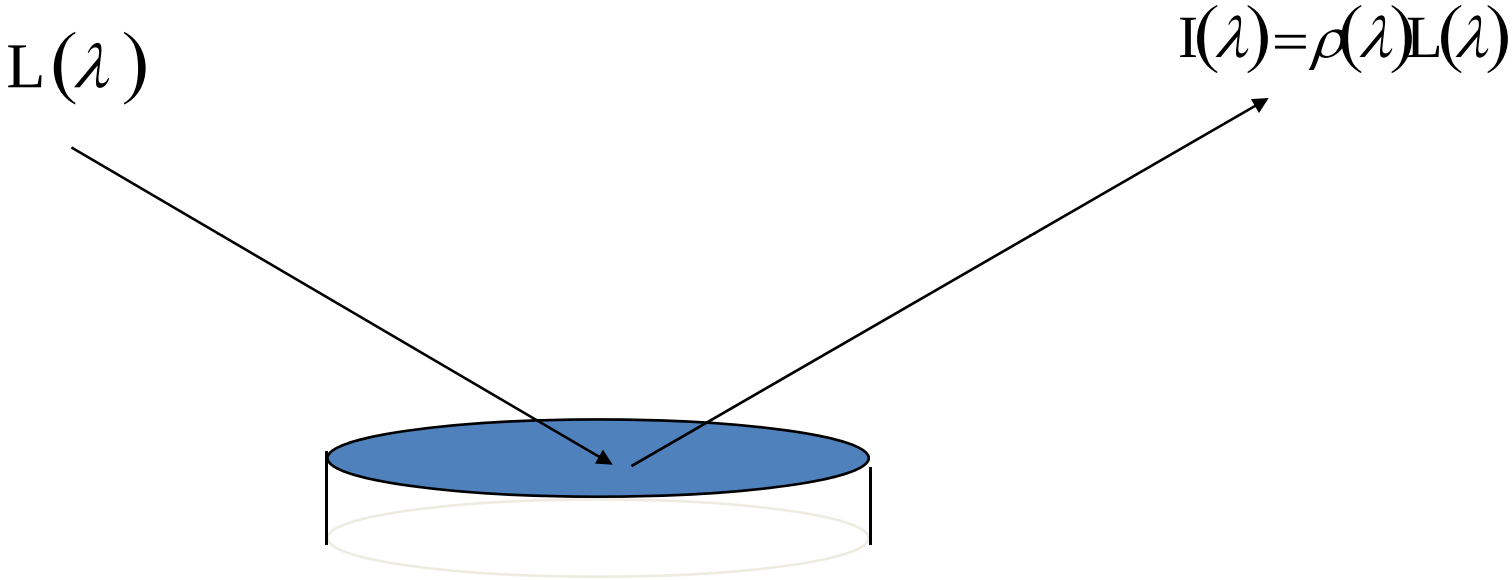
Electromagnetic Wavelength (Light)



Light

- Electromagnetic spectrum sensed by the human eye
- Visible (0.43μm) to red (0.79 μm)
- White color –object that reflects light balanced in all visible wavelengths
- Green objects – reflect wavelengths in 500-570 nm, absorbing energy at other wavelengths
- Monochromatic (achromatic) – light without color
- Intensity - denoted by gray levels
- Gray scale – range of measured values of monochromatic light from black to white

Illumination and Reflection



Chromatic (color) light

- Radiance: total amount of energy that flows from the light source (Watts)
- Luminance: amount of energy perceived by an observer, lumens(lm)
- Brightness: subjective descriptor of light perception
- Infrared band radiates heat useful in imaging applications that rely on heat signatures

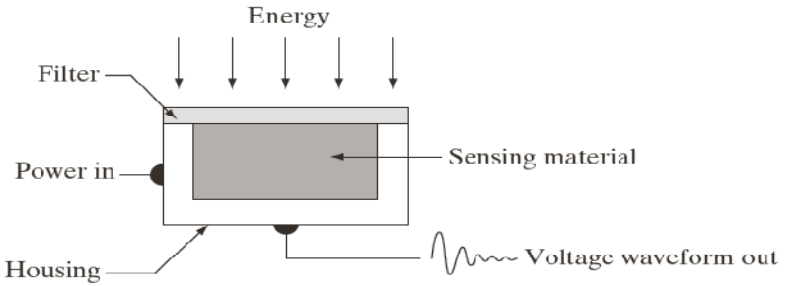
Imaging objects

- Wavelength required to see an object depends on the size of the object
- Example, water molecule has diameter of 10^-10 m
- Hence, source to study water needs emitting in far UV or soft X-ray region
- Image generation

Image Sensing and Acquisition

- Illumination source and reflection or absorption of energy by elements of the scene
- Sources: light, radar, X-rays, infrared
- Objects: real world, molecules, cells, biological
- Incoming energy is transformed to a voltage by combination of electrical power and sensor material
- The output voltage waveform is digitized

Imaging Sensors



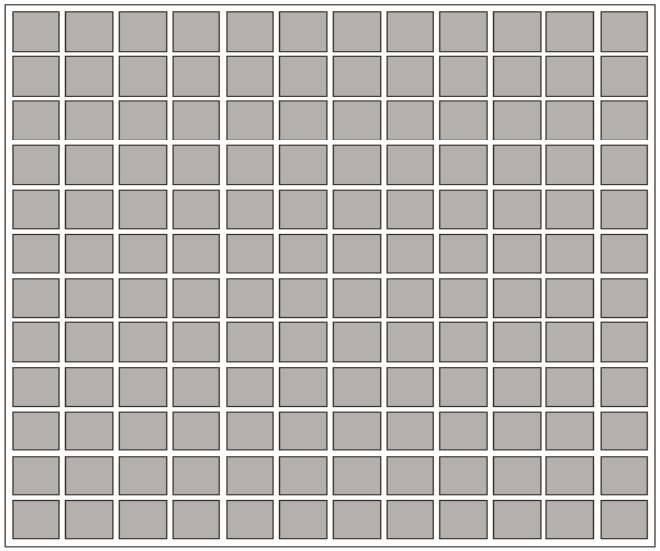


Image acquisition using a single sensor

- Photodiode: silicon material with outut voltage proportional to light
- Green filter: favors response to green band
- For 2-D imaging: lead screw rovides motion in perpendicular direction
- Microdensitometers: sensors moving in two linear directions

Single Sensor with motion to generate 2-D image

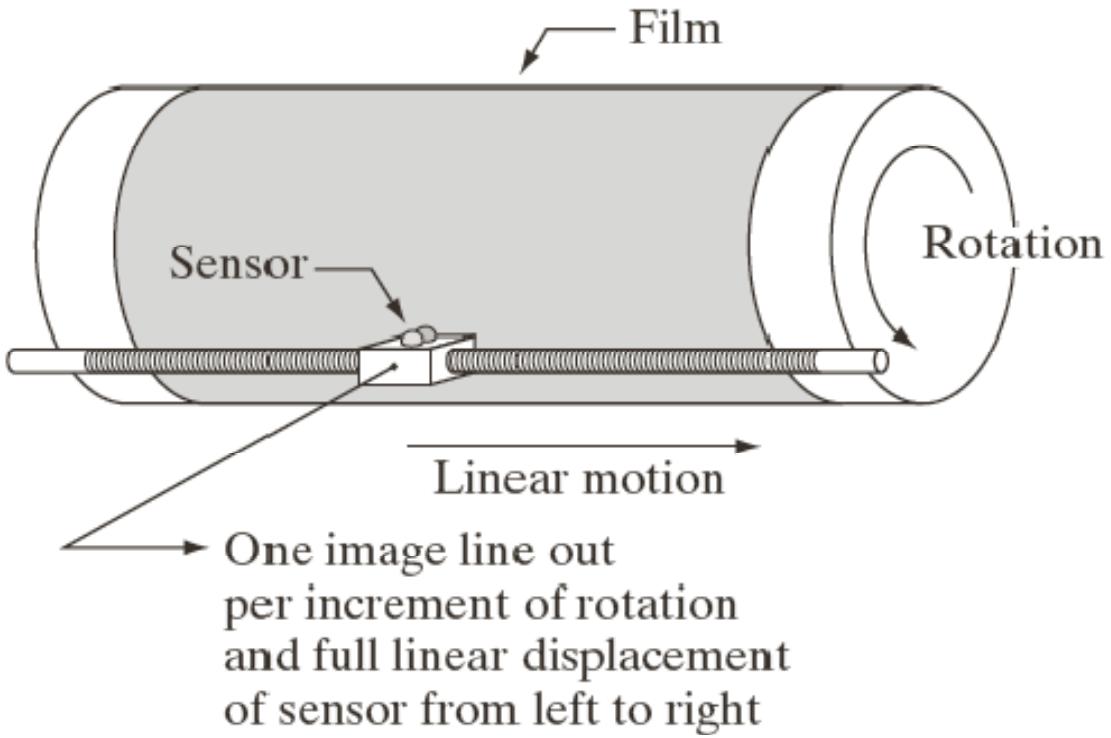
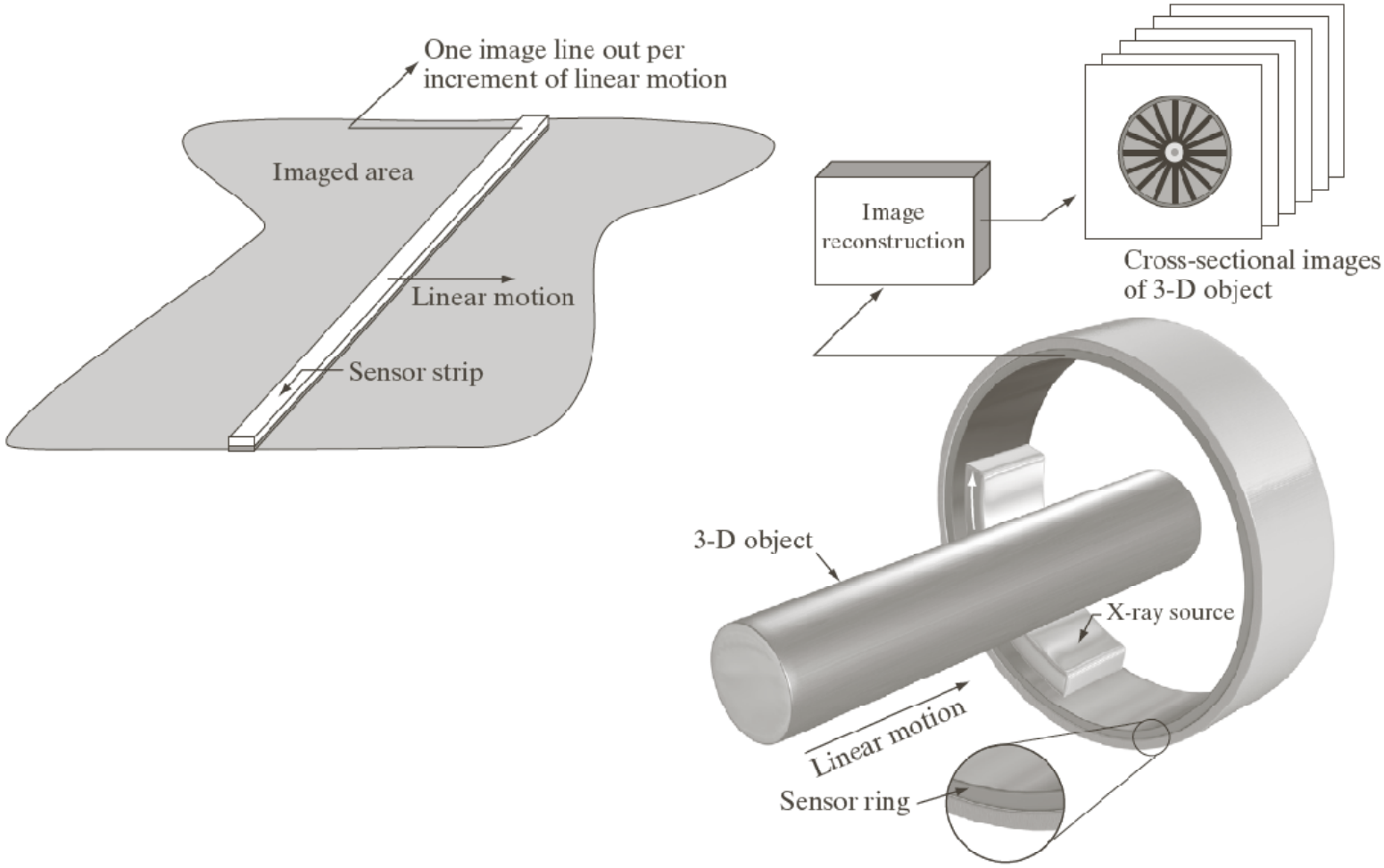


Image sensing using sensor strips

- In-line arrangement of sensors (one direction)
- Perpendicular motion provides imaging in other direction
- 4000 in-line sensors: airborne imaging application
- 1-D imaging sensor strips mounted perpendicular to direction of flight
- Lenses are used for focusing area to be scanned on to sensor

Linear sensor strip and circular sensor strip

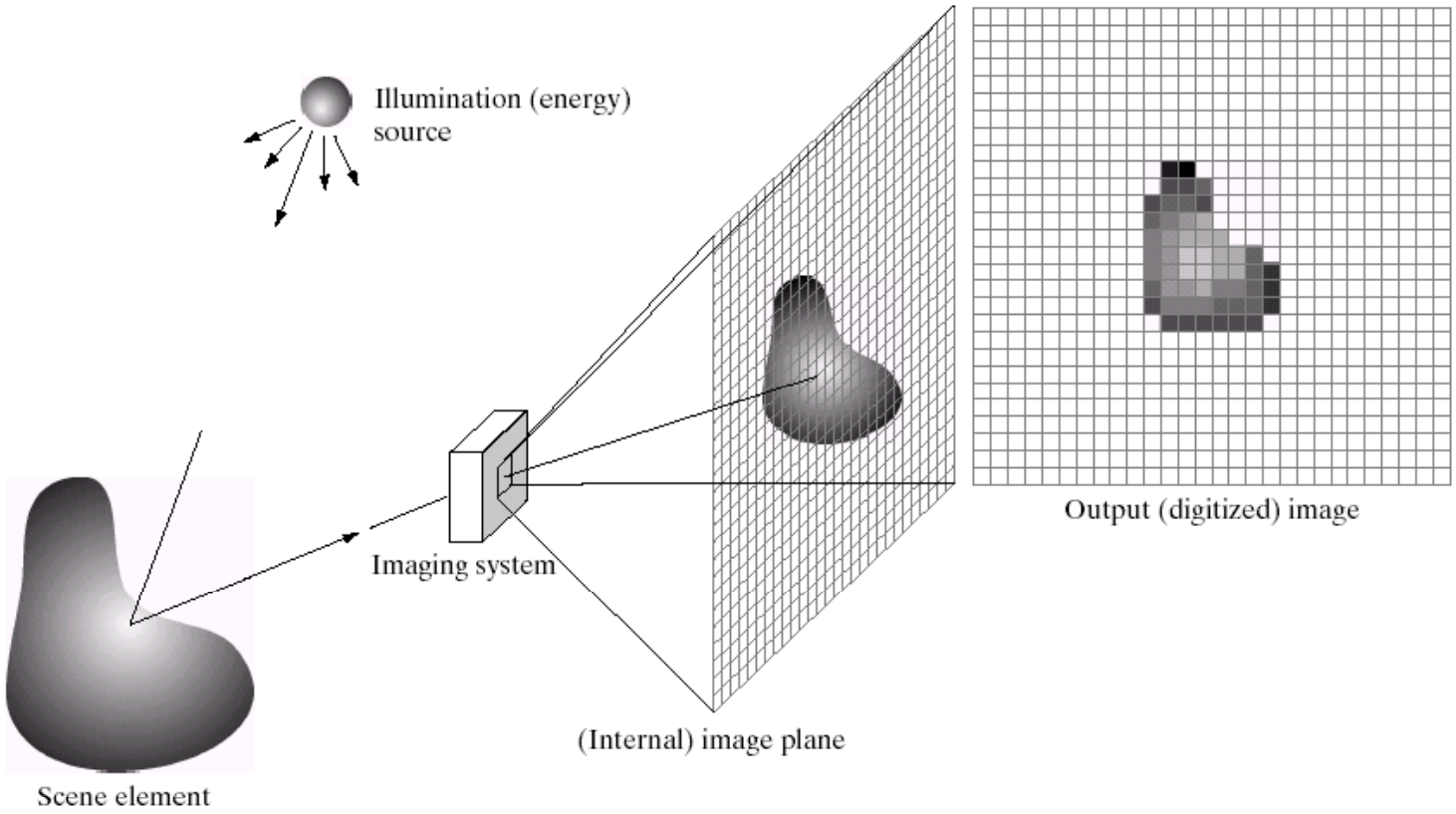


- Ring configuration used in medical and industrial imaging : crosssection (slice of 3-D objects)
- Illumination by rotating X-ray source,s ensor opposite colects X-ray energy that passes through the object.
- CAT: Computerized axial tomography
- Require extensive processing of the 3-D digital volume of stacked images
- MRI, PET (Positron Emission Tomography)

Image acquisition using sensor arrays

- Electromagnetic and ultrasonic sensing devices have sensors in 2-D array
- Digital camera: CCD array (4000x4000 elements)
- Complete image is obtained by focusing energy pattern on surface of array
- For light illumination, optical lens projects the viewed scene on lens focal plane
- Output is integral of light received at each sensor
- Digitized by other section of imaging system

Image acquisition process



a
b c d e

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.

Current state-of-the-art in Human Visual Perception and Digital Perceptual Models

Supplement material for reading

Human Visual Perception -A summary

- The *HVS has a hierarchical organization* with gradual increase in invariance and complexity of the stimuli along the visual stream.
- Early or low-level processing occurs in retina, Lateral Geniculate Nucleus (LGN) and primary visual cortex (V1) cells. For example, the cells in V1 are responsive to orientation and position. Beyond V1, from V2 to V4 cells are responsive to complex features of the object.
- In Interotemporal (IT) cortex cells are selective to color, orientation texture, pose, illumination, direction of motion and shape tuning. In Anterior Interotemporal cortex (AIT) cells are tuned to body parts such as faces and hands. Invariant recognition takes place in IT.
- Beyond IT, in prefrontal cortex (PFC) task specific classification is performed based on learning the target object from previous layers in the hierarchy. This layer performs immediate recognition, identification and categorization (classification).

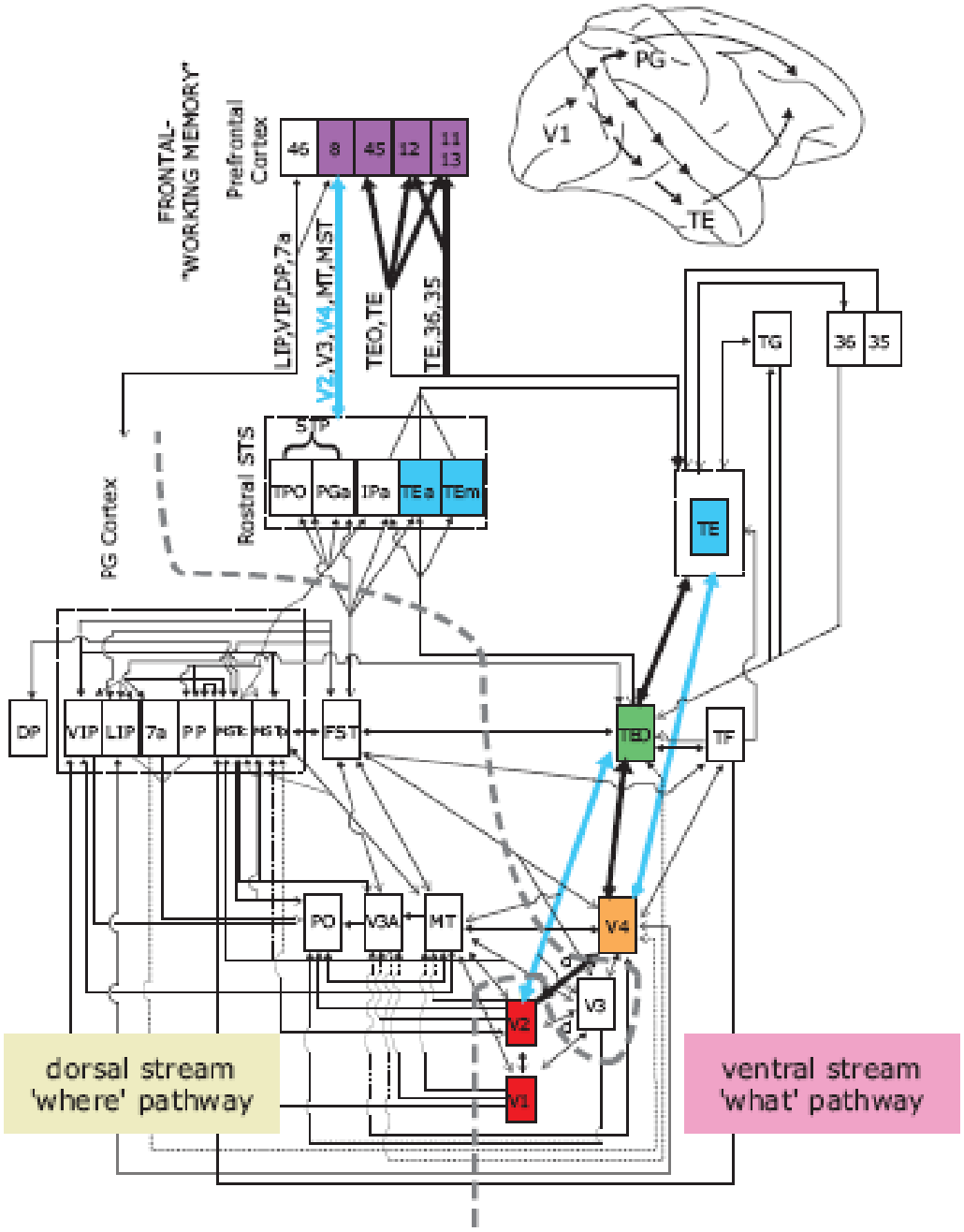


Figure 1-1: The ventral stream of visual cortex and object recognition. Modified from Ungerleider & Van Essen [Gross, 1998].

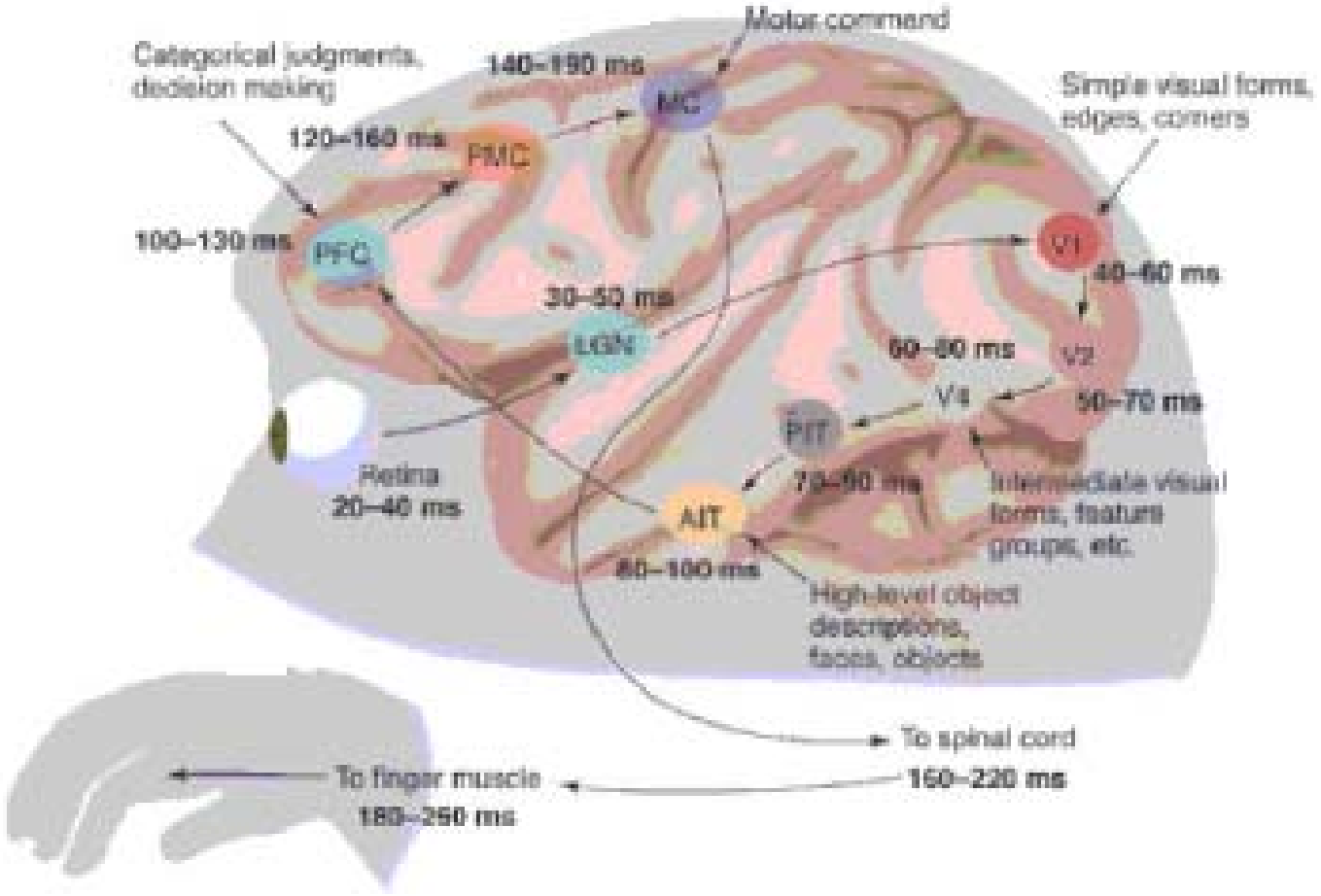


Figure 1-3: The feedforward circuits involved in rapid categorization tasks. Numbers for each cortical stage corresponds to the shortest latencies observed and the more typical mean latencies [Nowak and Bullier, 1997; Thorpe and Fabre-Thorpe, 2001]. Modified from [Thorpe and Fabre-Thorpe, 2001].

Recent advances in modeling of Human visual perception

- T. Serre, “Learning a dictionary of shape components in visual cortex: comparison with neurons, humans and machines,” PhD Thesis, MIT, 2000.
- R. Raizada and S. Grossberg, “Context-sensitive bindings by the laminar circuits of V1 and V2: A unified model of perceptual grouping, attention, and orientation contrast,” *Vis. Cognition*, Vol. 8, pp. 431-466, 2001.
- M. Riesenhuber and T. Poggio, “Neural mechanisms of object recognition,” *Neurobiology*, Vol. 12, pp 162-168, 2002.
- R. P. N. Rao, “Brain: the next generation,” MIT Press, Cambridge, Mass., 2002.

Suggested reading topics

- T. Serre, “Learning a dictionary of shape components in visual cortex: comparison with neurons, humans and machines,” PhD Thesis, MIT, 2000.
- R. Raizada and S. Grossberg, “Context-sensitive bindings by the laminar circuits of V1 and V2: A unified model of perceptual grouping, attention, and orientation contrast,” *Vis. Cognition*, Vol. 8, pp. 431-466, 2001.
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Exercise in group

- When you enter a dark theater on a bright day, it takes an appreciable interval of time before you can see well enough to find an empty seat. Which of the visual processes explained is at play in this situation?
- Alternating current certainly is part of the electromagnetic spectrum. Commercial AC in the US has a frequency of 60 Hz. What is the wavelength in kilometers of this component of the spectrum.

HW for 23 January 2009

- Bring a recent paper on human visual perception and perceptual model for image processing that interests you for discussion in class on 23 January 2009.

- Using the background information provided in Section 2.1, and thinking purely in geometric terms, estimate the diameter of the smallest printed dot that the eye can discern if the page on which the dot is printed is 0.2m away from the eyes. Assume for simplicity that the visual system ceases to detect the dot when the image of the dot on the fovea becomes smaller than the diameter fo one receptor (cone) in that area of the retina. Assume further that the fovea can be modeled as a square array of dimensions 1.5mmx1.5mm, and that the cones and spaces between the cones are distributed unfiromly throughout this array.