Ch.2 Digital Image Fundamentals

DIP by Gonzalez 3rd.

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Introduction

- The mechanics of the human visual system, including:
  - image formation in the eye and its capabilities for brightness adaptation and discrimination

Structure of the human eye

- The eye is nearly a sphere with average diameter ~ 20mm

- Three membranes enclose the eye:
  - The cornea and sclera (outer cover)

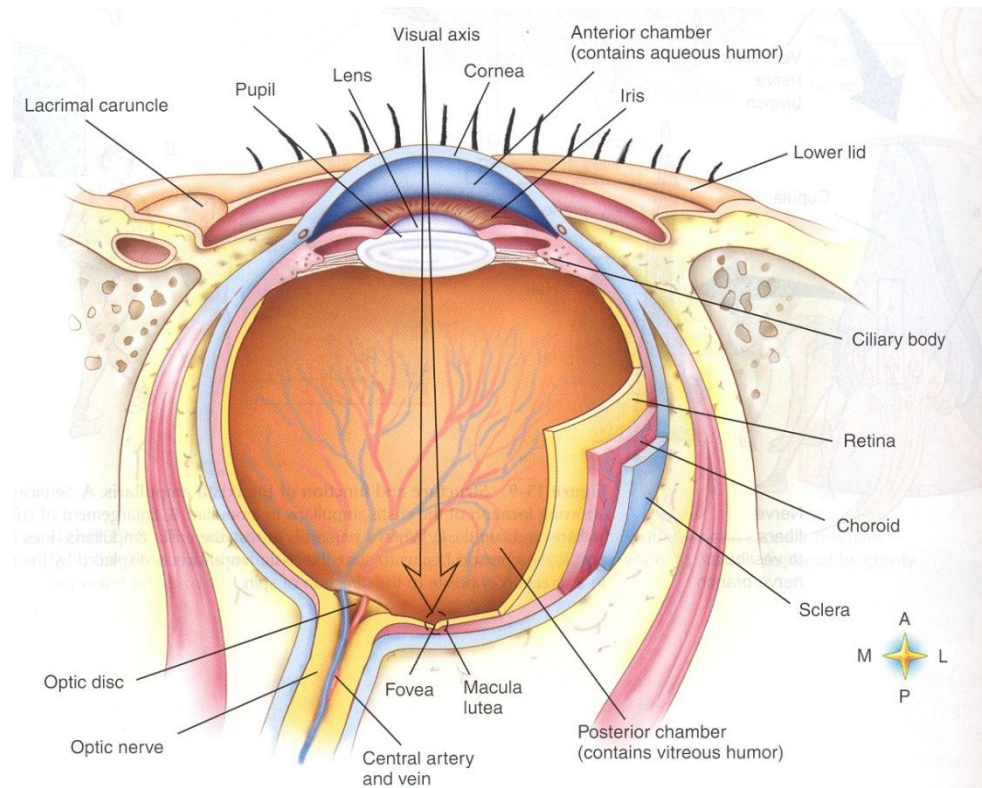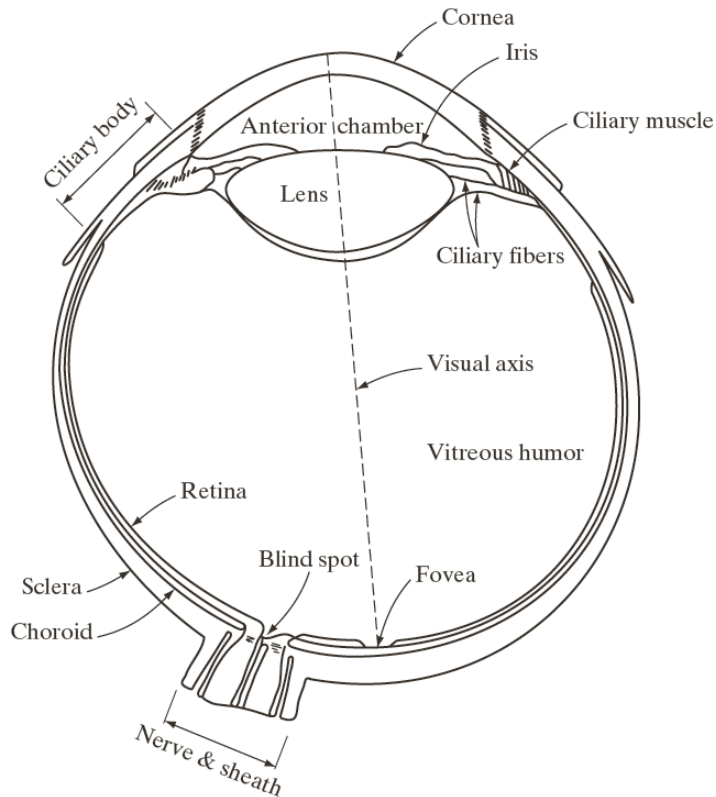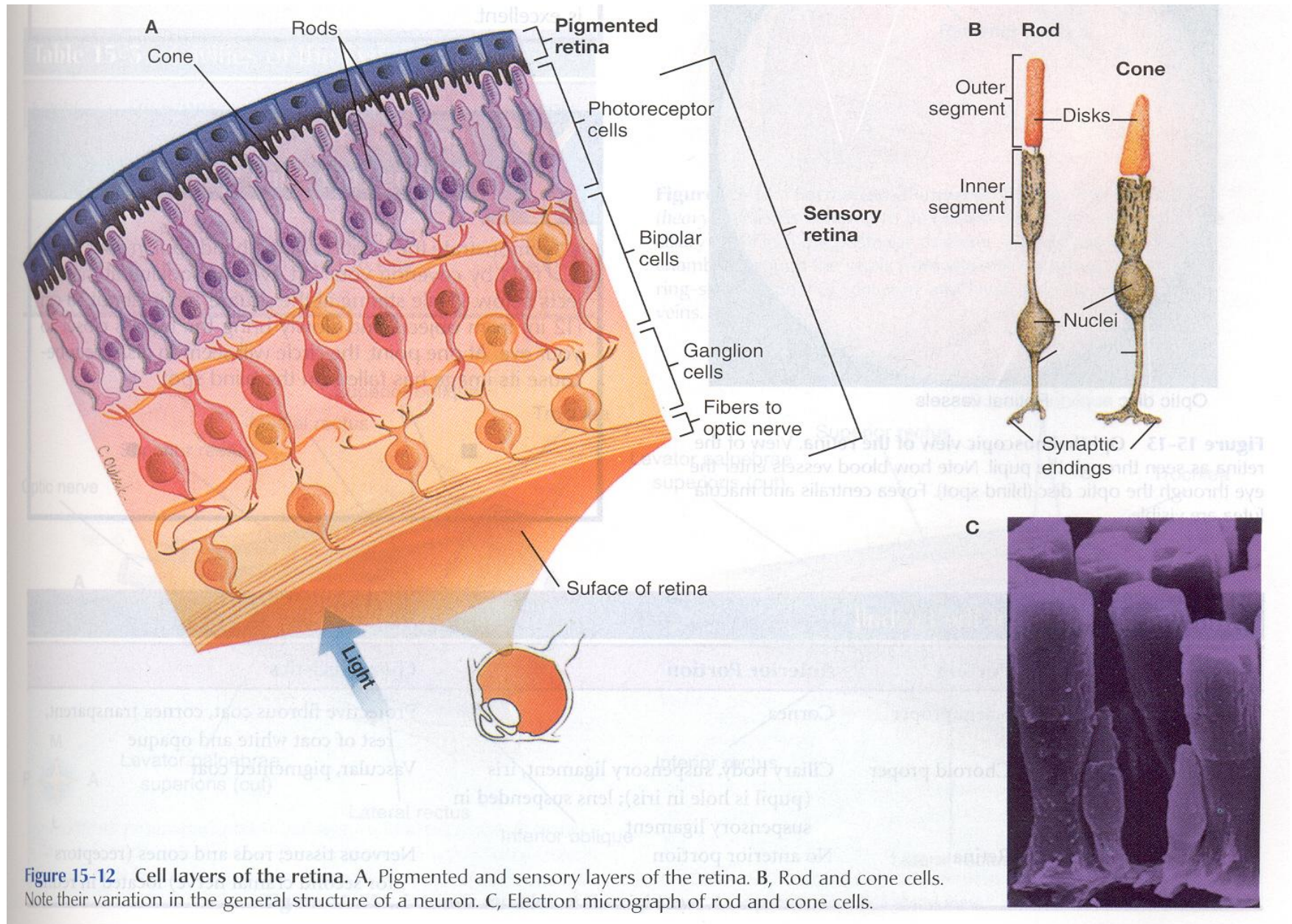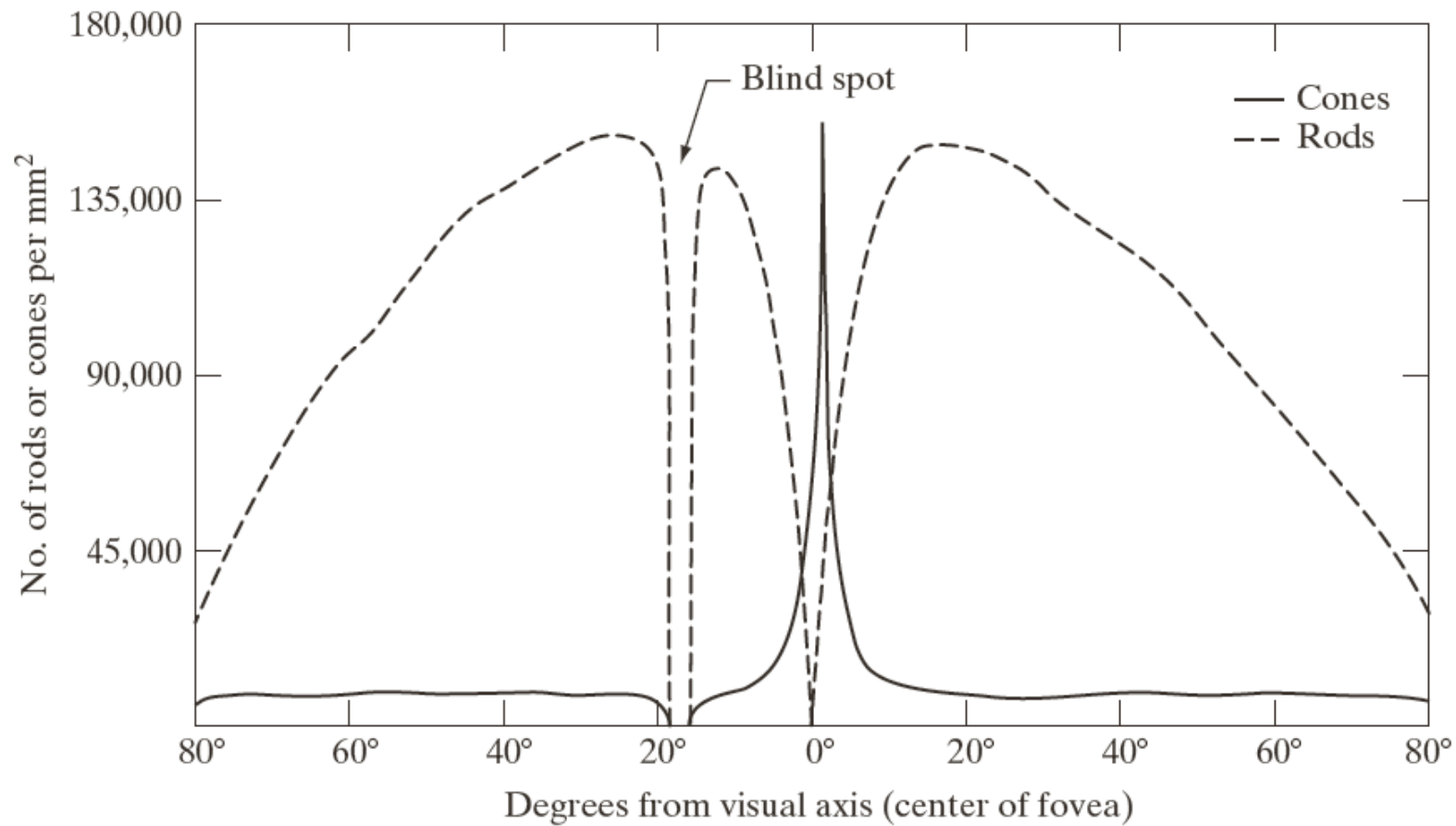# 2.1 Elements of Visual Perception

- ## 2.1.1 Human Eye

Figure 15-10 Horizontal section through the left eyeball. The eye is viewed from the side.

A Rods

Cone

Pigmented retina

Photoreceptor cells

Bipolar cells

Sensory retina

Ganglion cells

Fibers to optic nerve

Suface of retina

Light

B Rod

Cone

Outer segment

Disks

Inner segment

Nuclei

Synaptic endings

C

Figure 15-12 **Cell layers of the retina.** **A,** Pigmented and sensory layers of the retina. **B,** Rod and cone cells. Note their variation in the general structure of a neuron. **C,** Electron micrograph of rod and cone cells.

Blind spot

Cones ——
Rods - - -

No. of rods or cones per mm²

180,000

135,000

90,000

45,000

80°   60°   40°   20°   0°   20°   40°   60°   80°
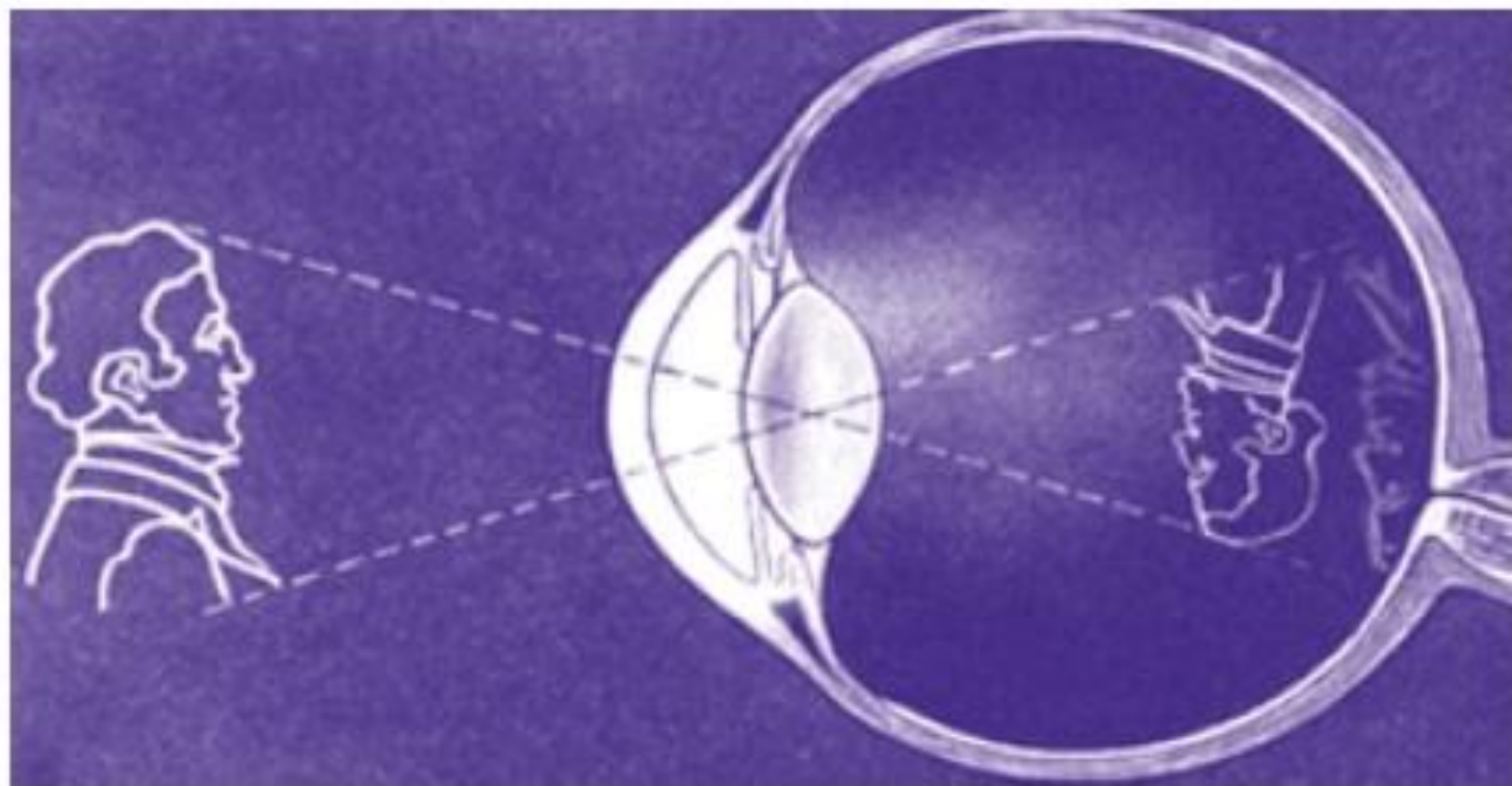
Degrees from visual axis (center of fovea)

- Retina : Cone & Rod
  - Cones 6~7 mil. around fovea
    - Photopic or Bright-light vision, Color Vision
  - Rod : 75~150 mil. Distributed over retina
    - Scoptic or dim-light vision, Non color vision
  - Blind Spot : 20 degree off from fovea
  - Fovea : d~1.5mm

How does the human eye work?

- Light passes through the cornea and the pupil, is focused by the lens and its projected onto the black wall of the eye, which is called retina
- The retina is made up of several layers of cells
- It is on the back of the of the retina where images are captured, much like film in a camera

- Two kinds of light-sensitive receptor cells, called rods and cones, convert light into "messages"
- These messages are sent to the brain via the optic nerve
- Each eye has what is called a blind spot
  - This is where the optic nerve leaves the eye and there are no rods and cones
  - One does not usually notice the blind spot in each eye because the left eye sees what the right eye misses and vice versa

- Rod cells enable us to see in dim light
- Rod cells perceive black, white and grays, but not color
- At night, it is the rod cells that enable us to see in black, white, and shades of gray
- Cone cells do not respond to dim light but do allow us to see colors in a lighted environment. They also detects fine details

- There are about 125 million rods and 6 million cons in each retina
- They help us see between 150 and 200 different colors!
-

Find our Blind spot!

- A blind spot, also known as a scotoma
- In medical literature is the place in the visual field that corresponds to the lack of light-detecting photoreceptor cells on the optic disc of the retina where the optic nerve passes through it
- So the blind spot is not normally perceived

A	O		X

- Take a blank sheet of paper and draw   the above table
- Your face should be very close to blank sheet of paper
- Cover right eye and focus the left eye   on the **X.**
- Now slowly move away from the screen
- The **O** will disappear, when the **O** disappears, the image is focused on **your blind spot**

How is the eye like a camera?

EYE	CAMERA
• The lens and cornea focus light onto the back of the retina • Muscles change the shape of the lens to focus the image •The mussels in the iris regulate the amount of light that reaches the retina	• The lens focuses light onto a light-sensitive surface called film • The lens of a camera can be moved back or forward to focus images •The aperture, like the iris, regulate the amount of light that reaches the retina

How is the eye like a camera?

EYE	CAMERA
• As light enters the eye and passes through the lens and cornea, it refracts, or bends. When the light refracts, it turns the image upside down and backward onto the retina	• Light that enters the camera refracts and turns images, upside down and backward onto the film

Differences between a camera and an eye

- *Main difference:* An eye is a physiological computational element but a camera is a mechanical device. Eye doest work independently and its operation correlated with brain, whereas a camera that does what let it to do

- *Retina and film:* Retina can automatically change its sensitivity to light sensitivity depending upon the amount of illumination presented to it. On the other hand in the camera can never change their sensitivity automatically

- *Binocular vision:* an eye has a blind spot through which all nerves leave to brain. So, normally all living beings have two eyes. The part of image that blind spot of one eye cannot cover will cover by the second eye.

- Unlike eyes, *cameras don't have any blind spot* and hence need only one lens. That   is most cameras don't have "binocular vision" which is a key characteristic of eye.

- *Automatic focusing:* Eye has automatic focusing capability which is controlled by brain. It is neurological. Eyes can focus objects at any distance automatically but in the case of cameras it is to be accomplished by a photographer. So it is manual in cameras.

Monocular vs. Binocular vision

- Human are able to see with both eyes-call this binocular vision (both eye are in the front of the face, and the eyes point in same direction)
- Some animal species (most birds-their eyes are opposite side of the face and point in opposite direction) have one eyed vision or monocular vision, which means their eyes see the world separately and produce two pictures rather than one
- BV is responsible for depth perception, is important for athletes who must quickly and accurately judge the distance between player, the ball, the boundary lines and other objects

Monocular vision

Binocular vision

2.2 Light & Electromagnetic Spectrum

- In 1666, Sir Isaac Newton discovered that when a beam of sunlight is passed through a glass prism, the emerging beam of light is not white
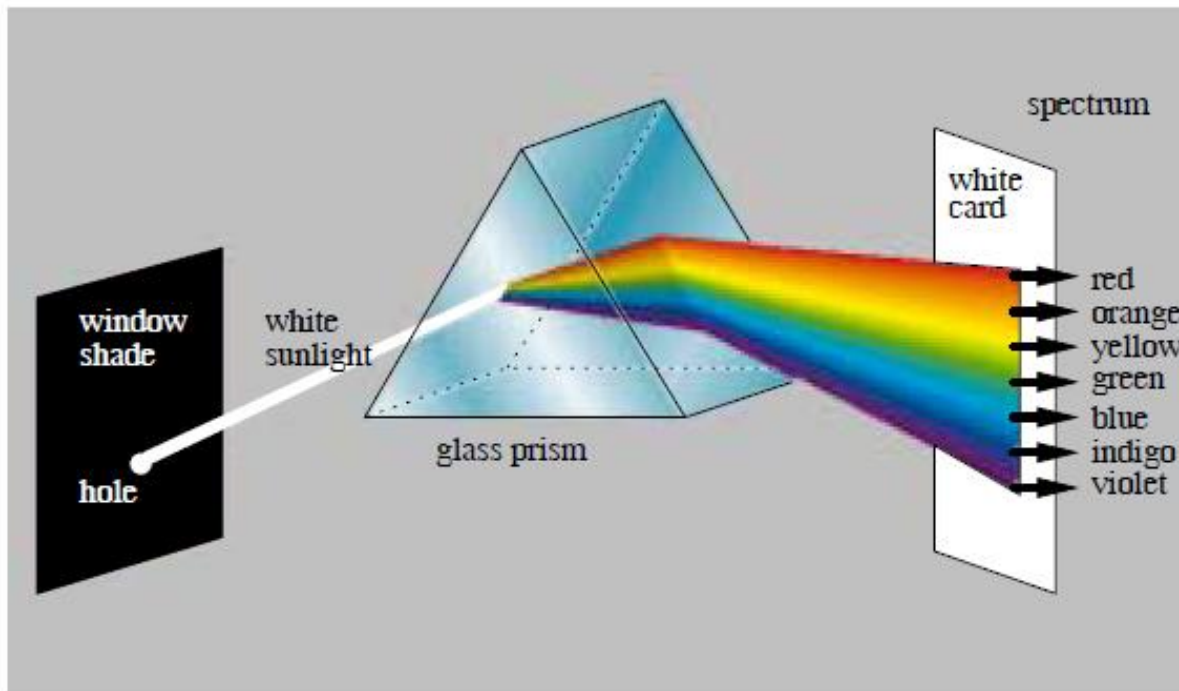

Figure 2.1: Newton's experiment with sunlight and a prism which led to the realization that the color of light depended on its spectral composition.

2.2 Light & Electromagnetic Spectrum

- But consists a continuous spectrum of colors ranging from *violet at one end to red at the other*
- The visible light represents *a very small portion* of the electromagnetic spectrum
- On one end of the spectrum are radio waves with wavelengths billions of times longer than those of visible light
- On the other hand of the spectrum are gamma rays with wavelengths millions of time smaller than those of visible light

2.2 Light & Electromagnetic Spectrum

Energy of one photon (electron volts)

| 10^6 | 10^5 | 10^4 | 10^3 | 10^2 | 10^1 | 1 | 10^{-1} | 10^{-2} | 10^{-3} | 10^{-4} | 10^{-5} | 10^{-6} | 10^{-7} | 10^{-8} | 10^{-9} |

Frequency (Hz)

| 10^{21} | 10^{20} | 10^{19} | 10^{18} | 10^{17} | 10^{16} | 10^{15} | 10^{14} | 10^{13} | 10^{12} | 10^{11} | 10^{10} | 10^9 | 10^8 | 10^7 | 10^6 | 10^5 |

Wavelength (meters)

| 10^{-12} | 10^{-11} | 10^{-10} | 10^{-9} | 10^{-8} | 10^{-7} | 10^{-6} | 10^{-5} | 10^{-4} | 10^{-3} | 10^{-2} | 10^{-1} | 1 | 10^1 | 10^2 | 10^3 |

Gamma rays   X-rays   Ultraviolet   Infrared   Microwaves   Radio waves

Visible spectrum

0.4×10^{-6} 0.5×10^{-6} 0.6×10^{-6} 0.7×10^{-6}

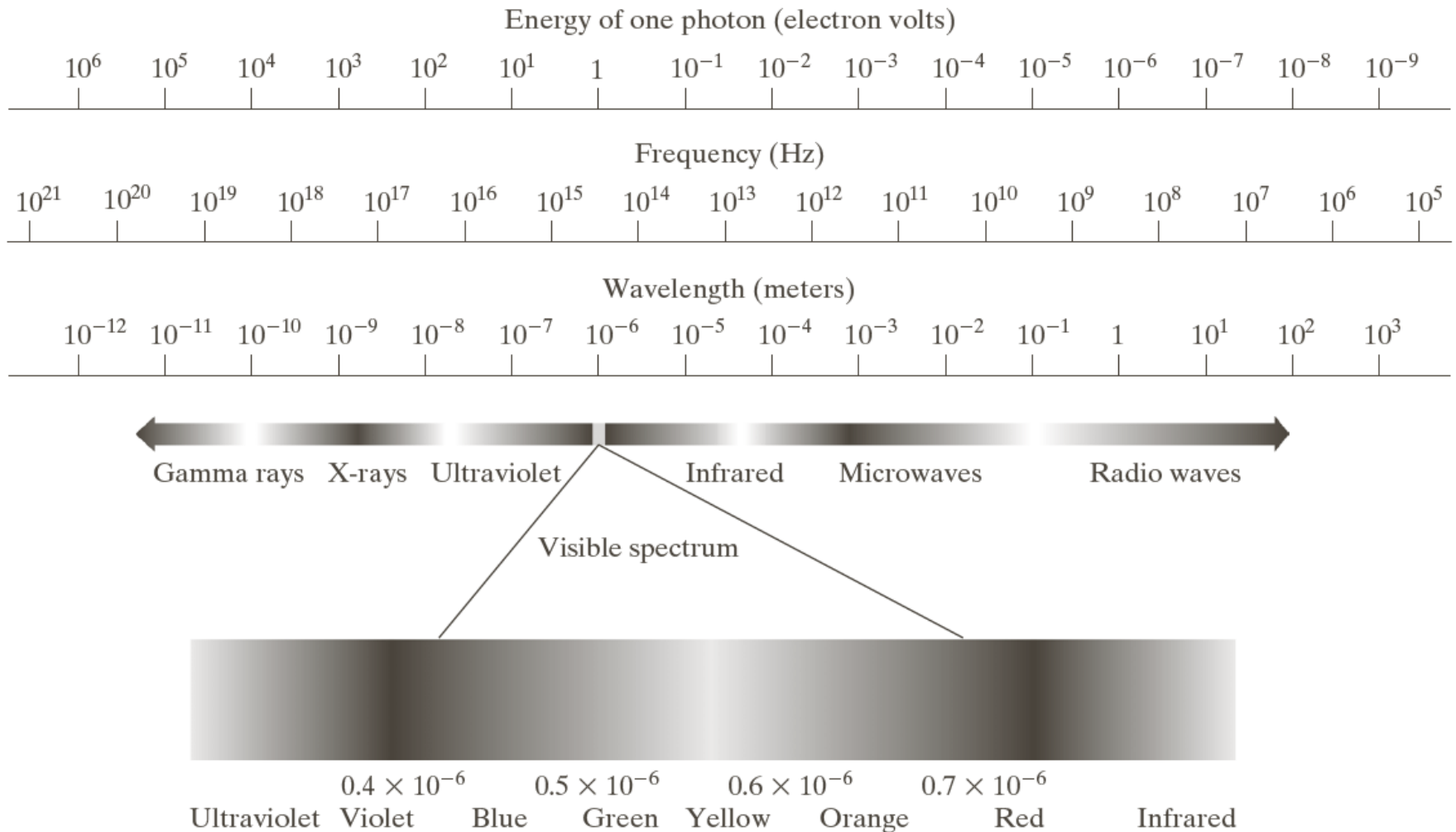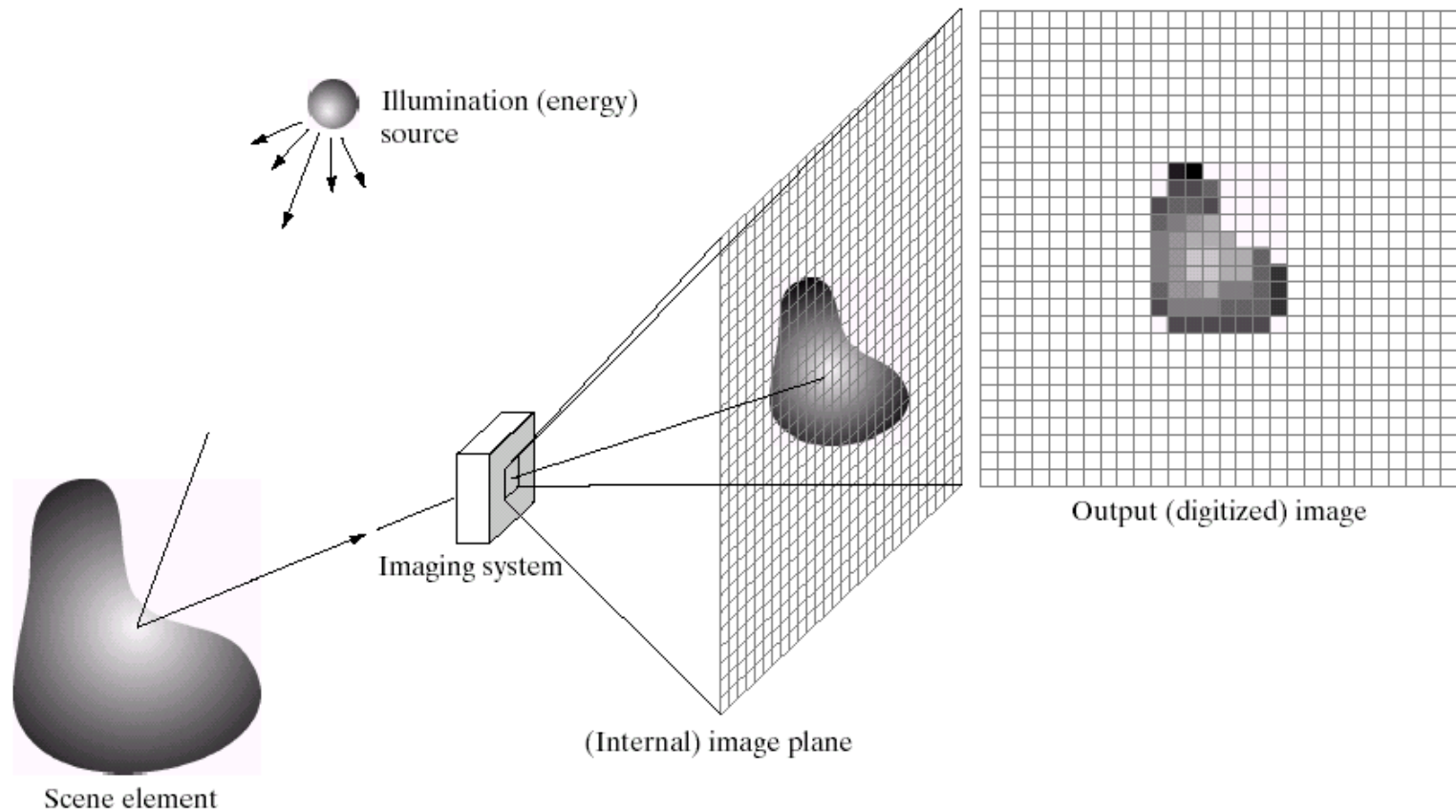Ultraviolet Violet   Blue   Green   Yellow   Orange   Red   Infrared

Figure 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation (The visible light represents *a very small portion* of the electromagnetic spectrum)

What is color ?

- Everybody knows what time is - until you ask him to explain it. It is same with the color.

- **Color:** Color or colour (see spelling differences) is the *visual perceptual property* corresponding in humans to the categories called red, yellow, blue, and others.

- Color derives from the spectrum of light interacting in the eye with the spectral sensitivities of the light receptors.

Digital image

• An image may be defined as a two dimensional function, *f(x, y),* where x and y are *spatial (plane) coordinates* and the *amplitude* of *f* at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point

• When *x, y,* and the amplitude values of *f* are all finite, discrete quantities, we call the image a *digital image*

Illumination (energy) source

Imaging system

Scene element

(Internal) image plane

Output (digitized) image

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.
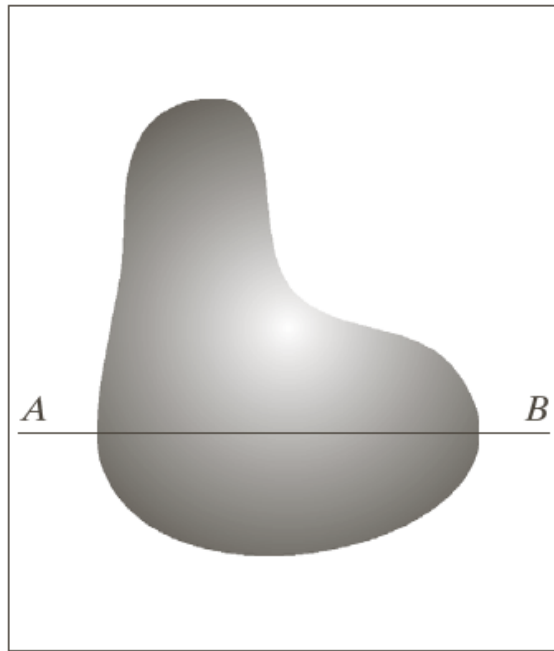
$f(x, y) = i(x, y)r(x, y)$, illumination & reflectance

Image sampling and quantization

There are numerous ways to acquire images but our objective to *generate digital images from sensed data*. To create digital image, we need to convert the continuous sensed data into digital form. This involves two processes: **sampling** and **quantization**.
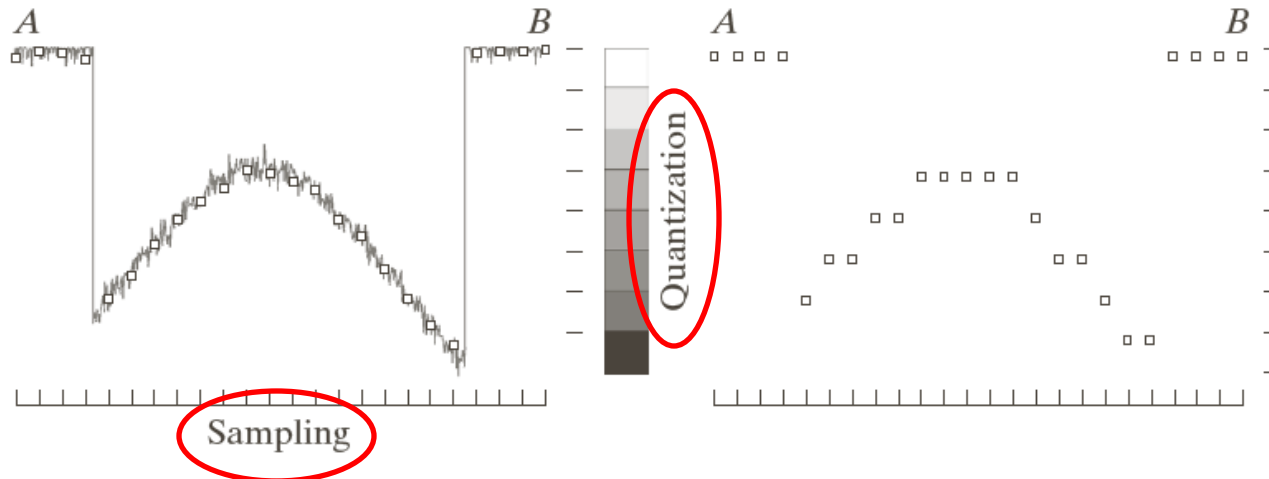
• The basic idea behind sampling and quantization is illustrated in Fig. 2.16. Fig. 2.16 (a) shows a continuous image, f(x, y), that we want to convert digital form. *An image may be continuous* with respect to *the x- and y-coordinates and also in amplitude*. To convert it to digital form, we have to sample the function in both coordinates and in amplitude.

• Digitizing the coordinate values is called **sampling**.

• Digitizing the amplitude values is called the **quantization.**

2.3 Image Sampling & Quantization

a b
c d

FIGURE 2.16
Generating a digital image.
(a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization.
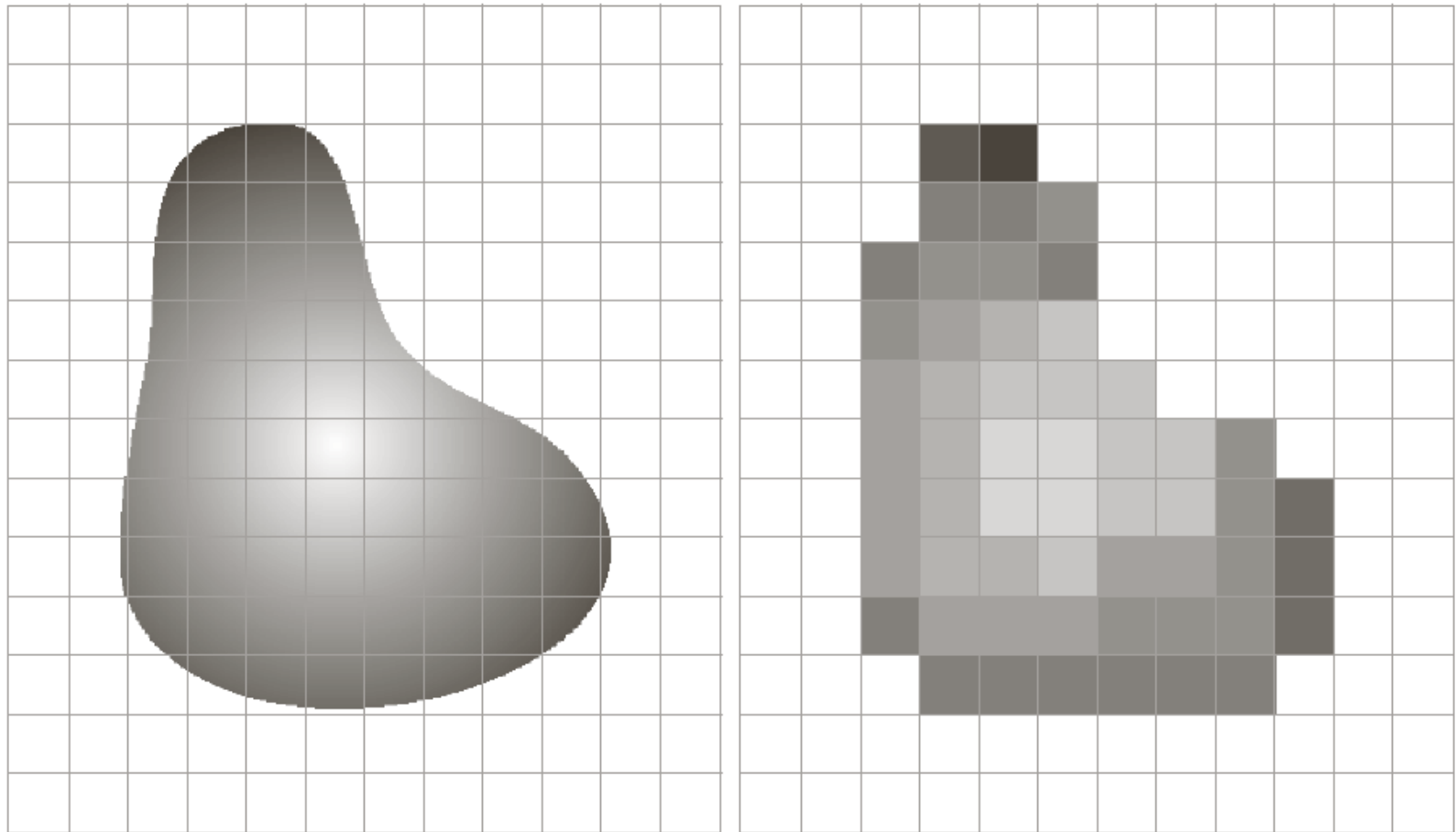(c) Sampling and quantization.
(d) Digital scan line.

Cont.

The one dimensional function shown in 2.16 (b) is a plot of amplitude (gray level) values of the continuous image along the line segment AB in fig. 2.16 (a).

To sample this function, we take equally spaced samples along line AB, as shown in fig. 2.16 (c). The samples are shown as small white squares superimposed on the function. The set of these discrete locations gives the sampled function.

The right side of the fig. 2.16 (c) shows the gray level scale divided into eight discrete levels, ranging from black to white. The continuous gray levels are quantized simply by assigning one if the eight discrete gray levels to each sample. *The digital samples resulting from both sampling and quantization are shown in 2.16(d).*

a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization
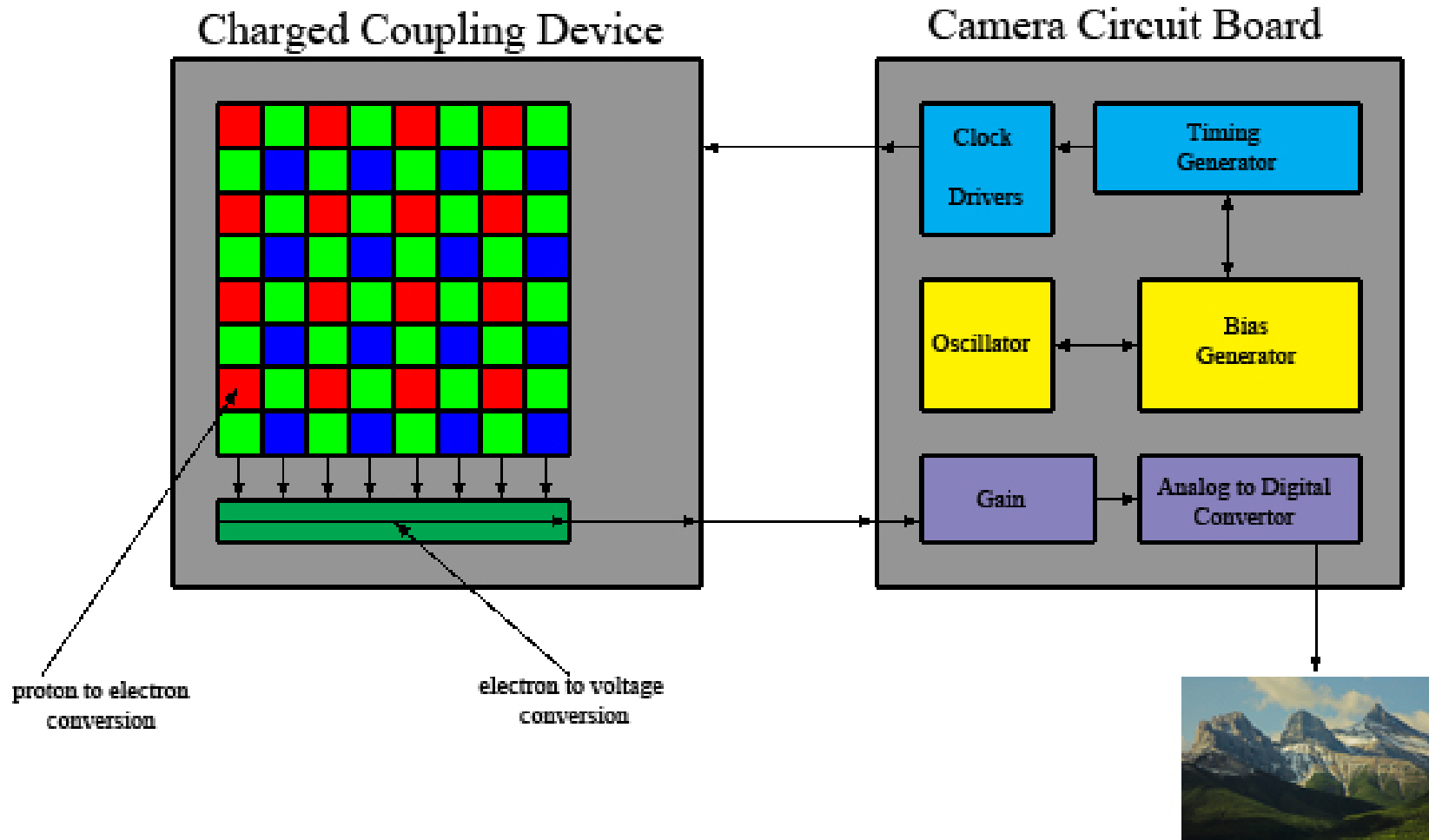
CCD vs. CMOS

CCD : Charge Coupled Device

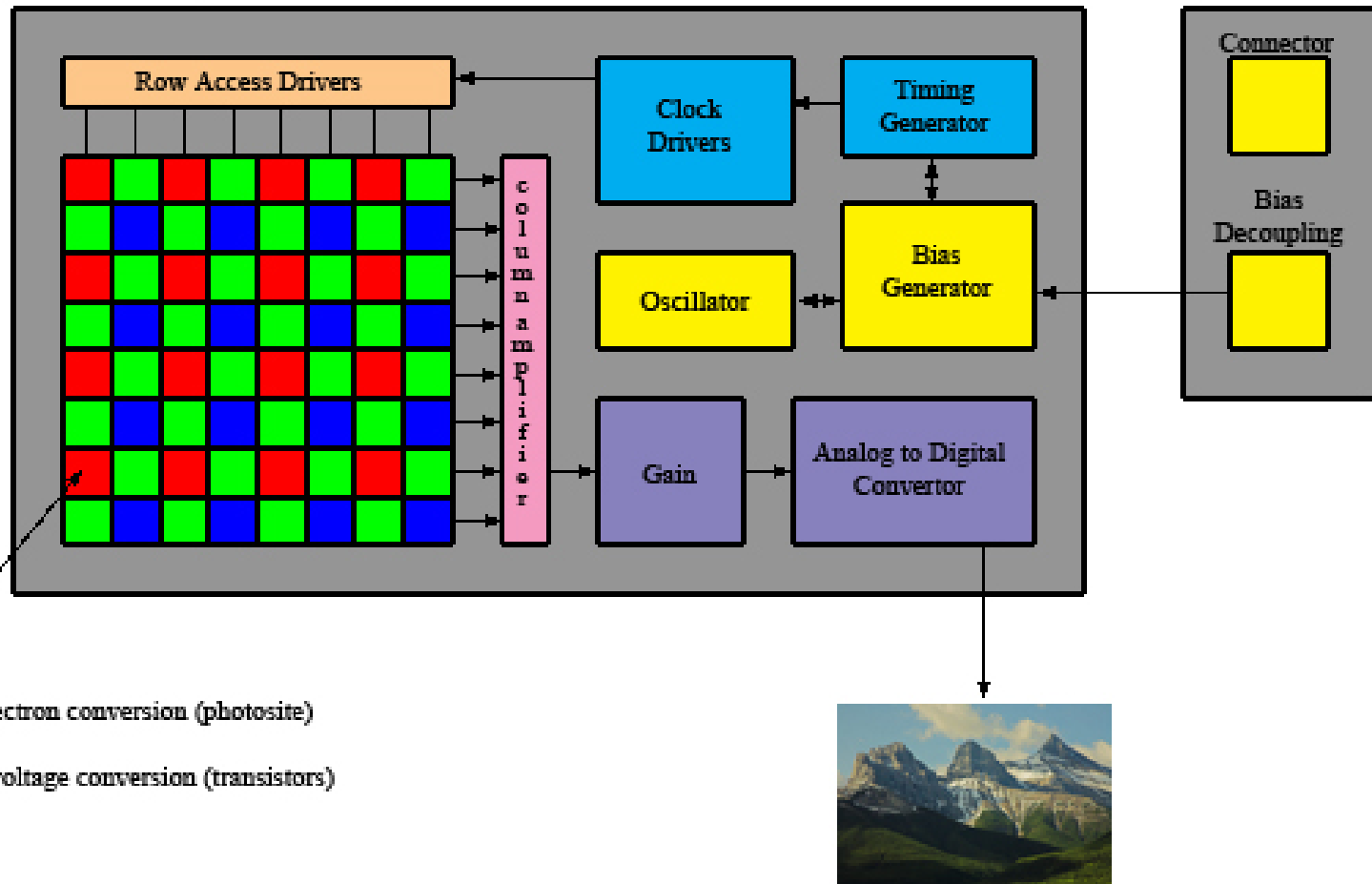CMOS : Complementary Metal Oxide Semiconductor

CCD

- A CCD, or a Charged-Coupled Device, is a photosensitive analog device that records light as a **small electrical charge in each of its pixels** or cells. In essence a CCD is an collection of CCD cells.

- The signal captured by the CCD requires **additional circuitry to convert the analog light data** into a readable digital signal.

Charged Coupling Device

Camera Circuit Board

Clock Drivers

Timing Generator

Oscillator

Bias Generator

Gain

Analog to Digital Convertor

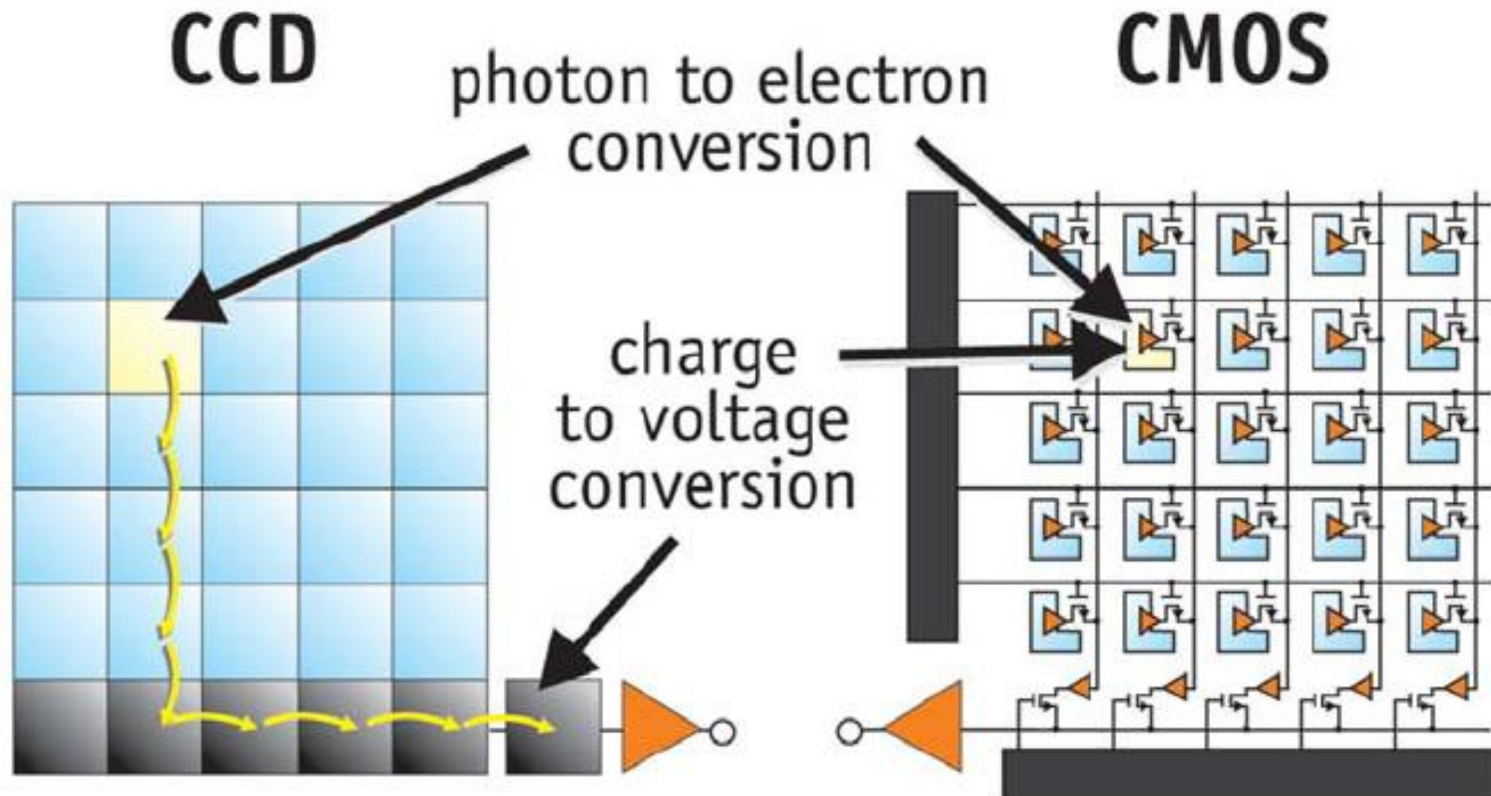proton to electron conversion

electron to voltage conversion

CMOS

- A CMOS, or Complementary Metal Oxide Semiconductor, each pixel has neighboring transistors which locally perform the analog to digital conversion.
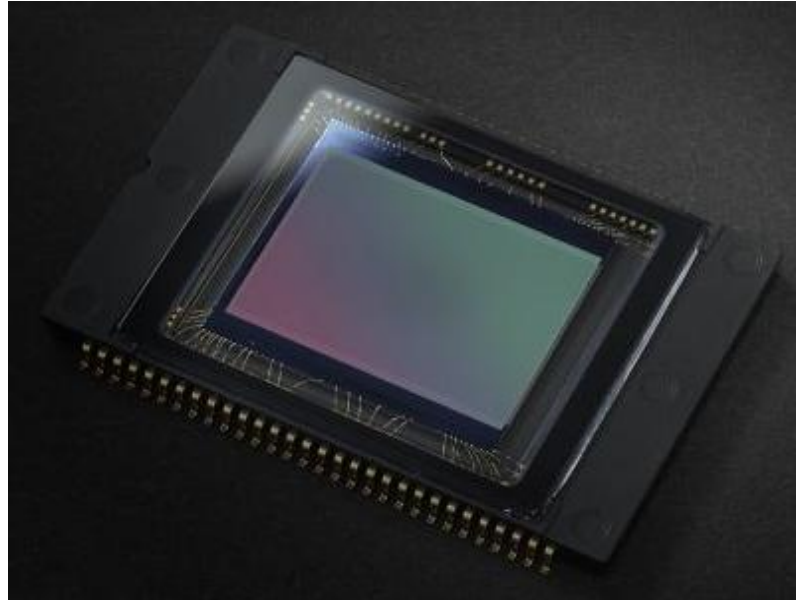
Camera Circuit Board

Complementary Metal Oxide Semiconductor

Row Access Drivers

column amplifier

Clock Drivers

Timing Generator

Oscillator

Bias Generator

Gain

Analog to Digital Convertor

Connector

Bias Decoupling

proton to electron conversion (photosite)

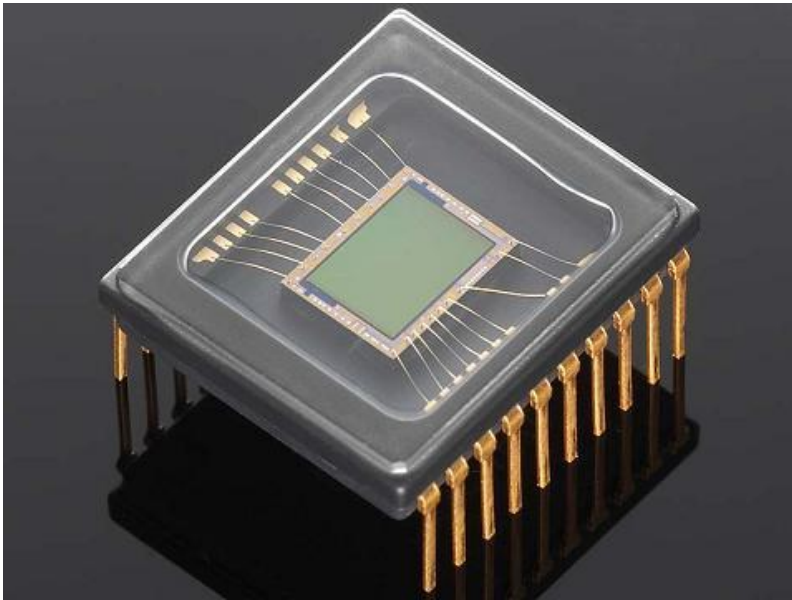electron to voltage conversion (transistors)
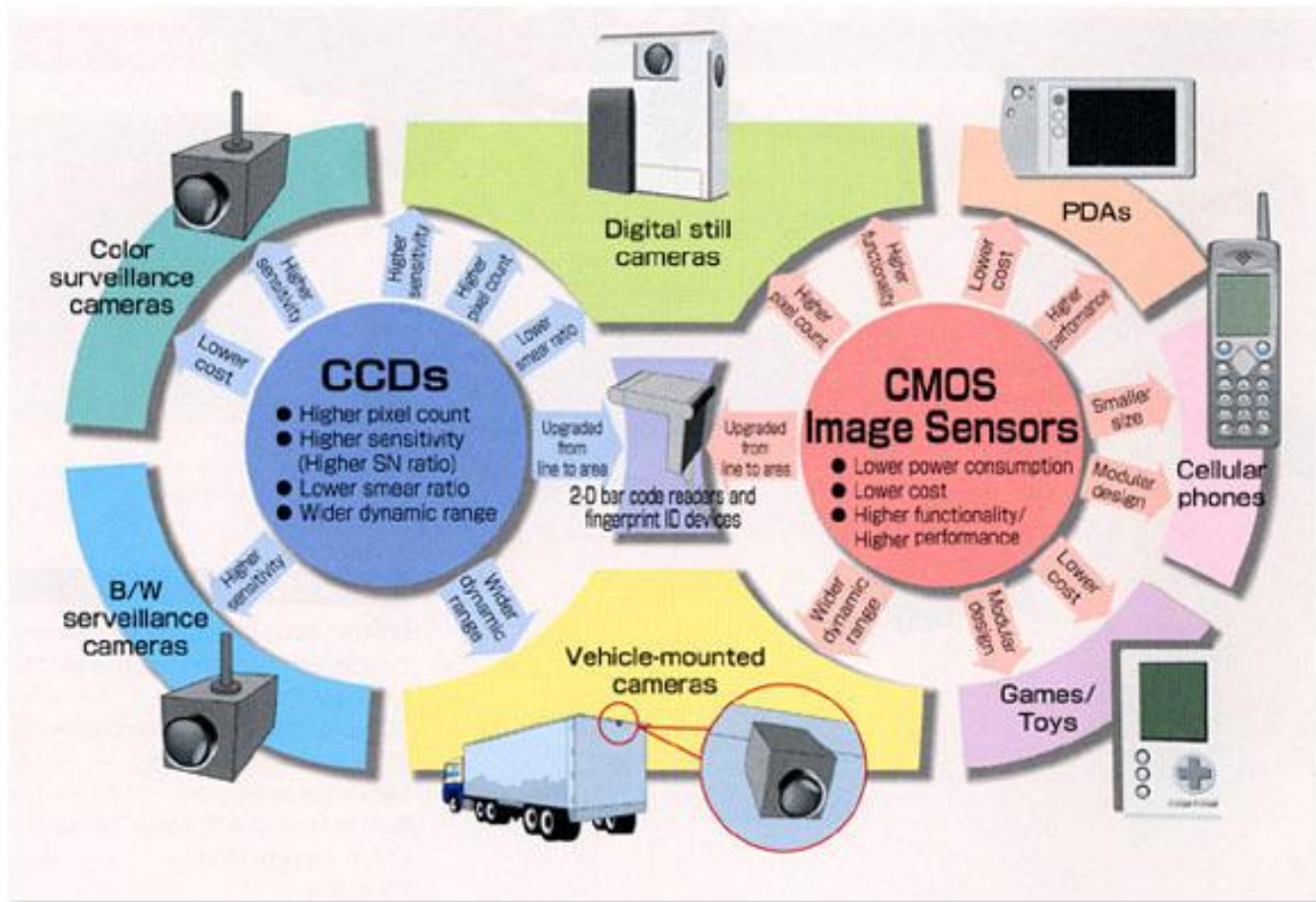
CCD and CMOS inside

CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

How Image Sensors Work,,,

- **Both CCD and CMOS sensors work by employing photosensitive circuitry that reacts to light and stores the analog signals as digital data, namely an image.**

CCD and CMOS Uses

CCD   vs   CMOS

- Create high-quality, low-noise images.
- Light sensitivity is higher
- 100 times more power
- Needs extra circuitry to convert to digital signal

- More susceptible to noise

- Light sensitivity is lower
- Consume little power
- On-chip analog-to-digital conversion

A CMOS Sensor