

Image Formation

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Introduction

Digital Image

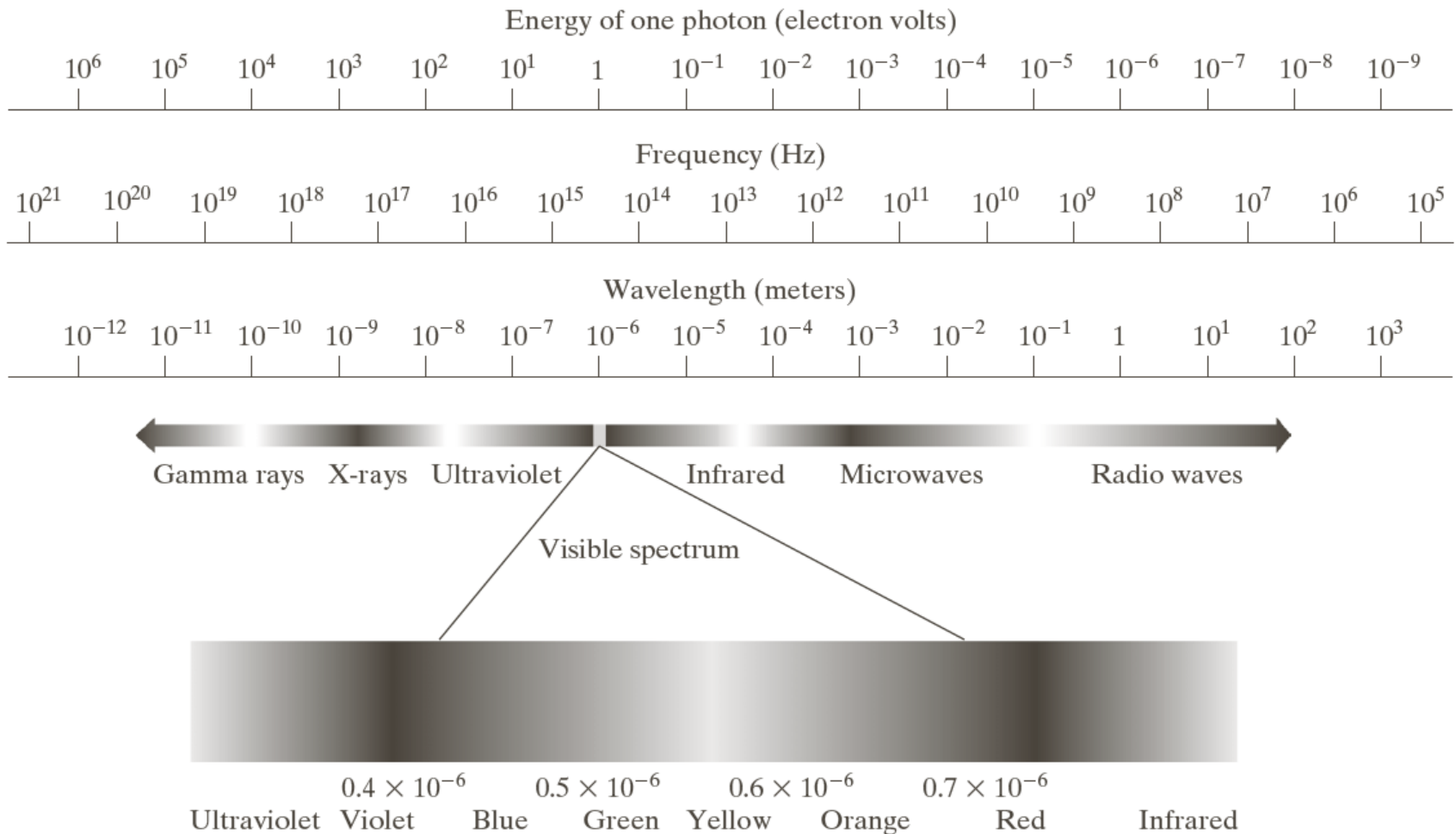
is a two-dimensional function

$$f(x, y)$$

where x and y are spatial coordinates, and

amplitude of f is called **intensity** or **gray level** at the point (x, y)

Light and EM Spectrum



Light and EM Spectrum

The colors that humans perceive in an object are determined by the nature of the light reflected from the object.

e.g. green objects reflect light with wavelengths primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelength

..Light and EM Spectrum

- ▶ Monochromatic light: void of color

Intensity is the only attribute, from black to white

Monochromatic images are referred to as **gray-scale** images

- ▶ Chromatic light bands: 0.43 to 0.79 μm

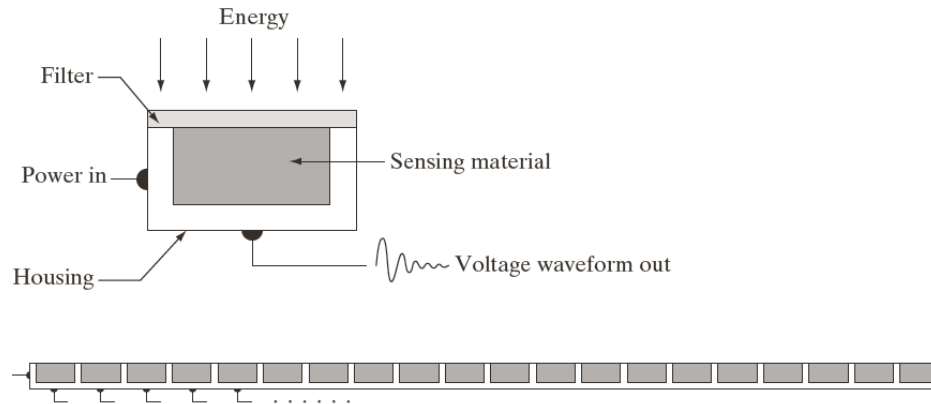
The quality of a chromatic light source:

Radiance: total amount of energy

Luminance (Im): the amount of energy an observer perceives from a light source

Brightness: a subjective descriptor of light perception that is impossible to measure. It embodies the achromatic notion of intensity and one of the key factors in describing color sensation.

Image Acquisition



a
b
c

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

Transform
illumination
energy into
digital images

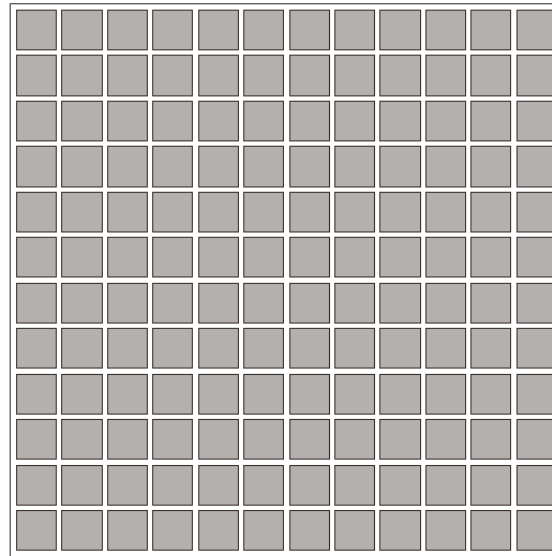


Image Acquisition Using a Single Sensor

FIGURE 2.13

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

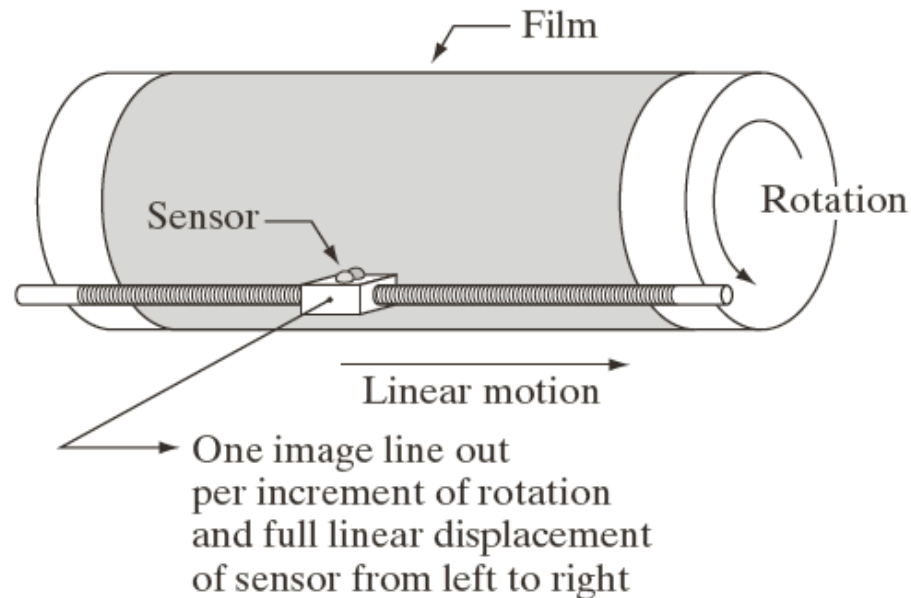
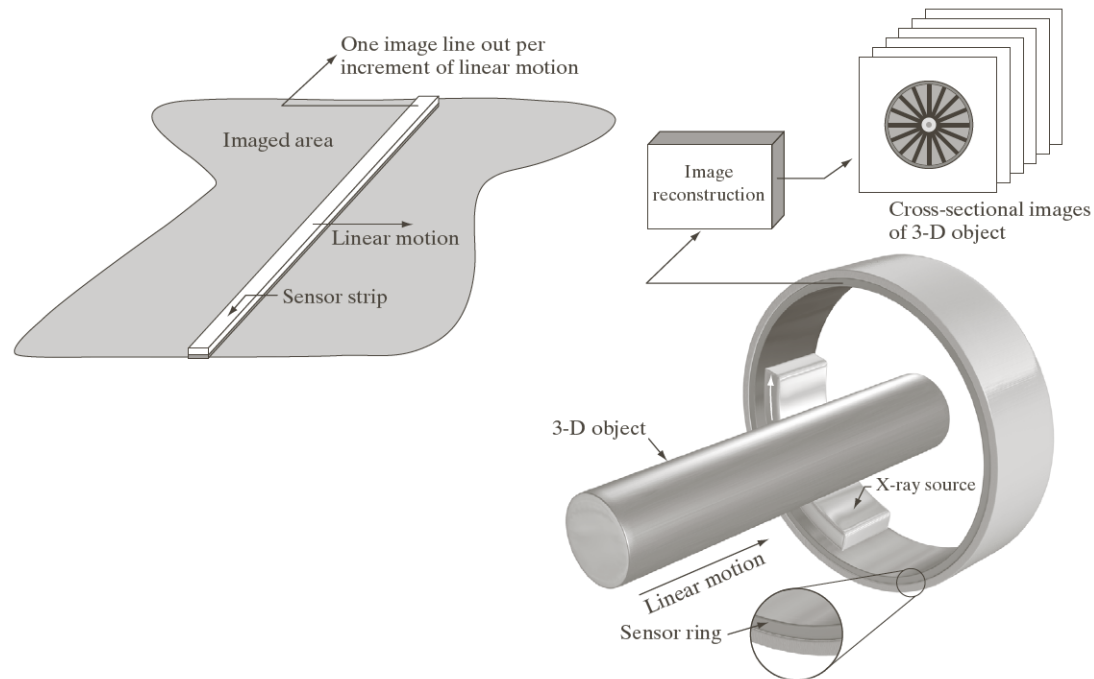


Image Acquisition Using Sensor Strips



a b

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

Image Acquisition Process

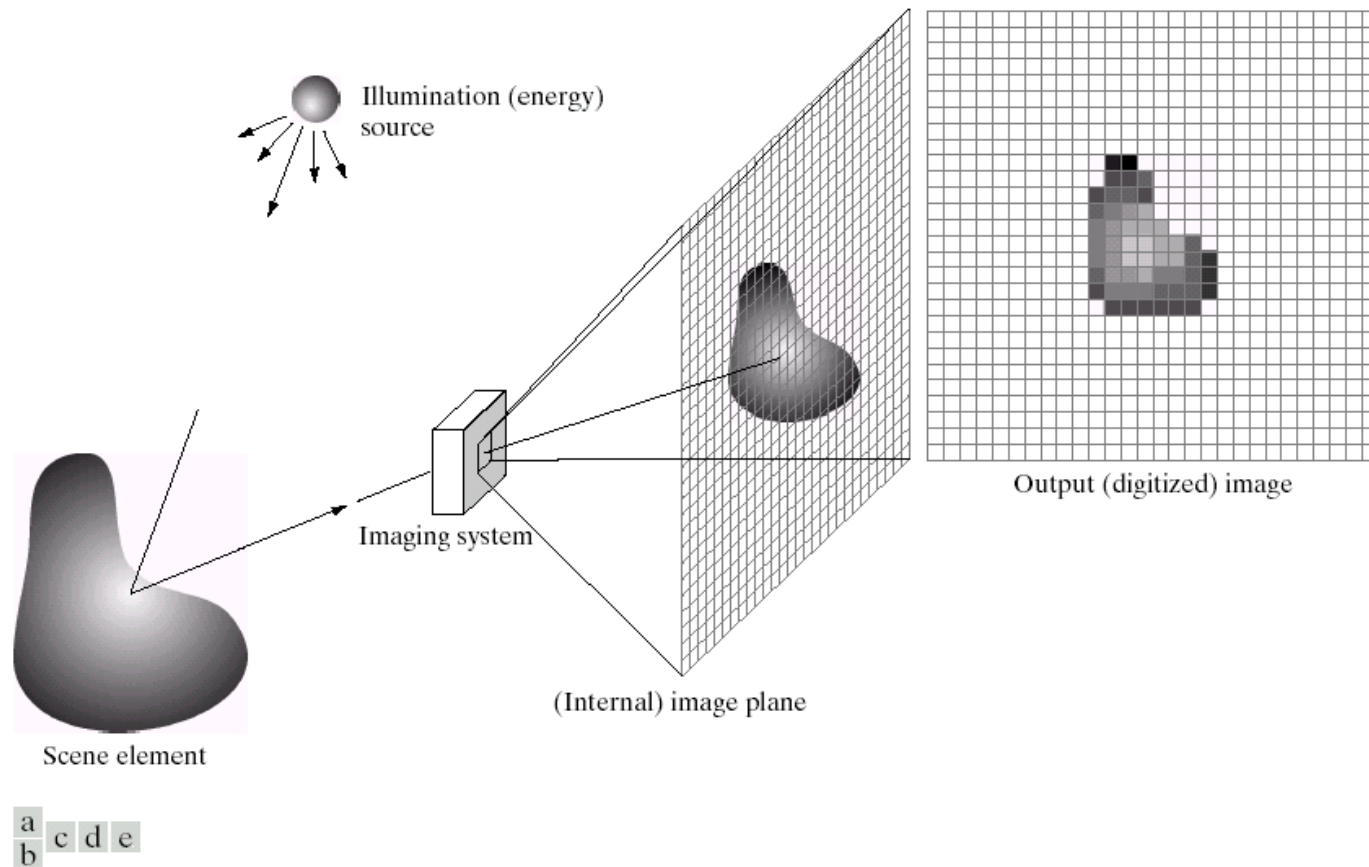
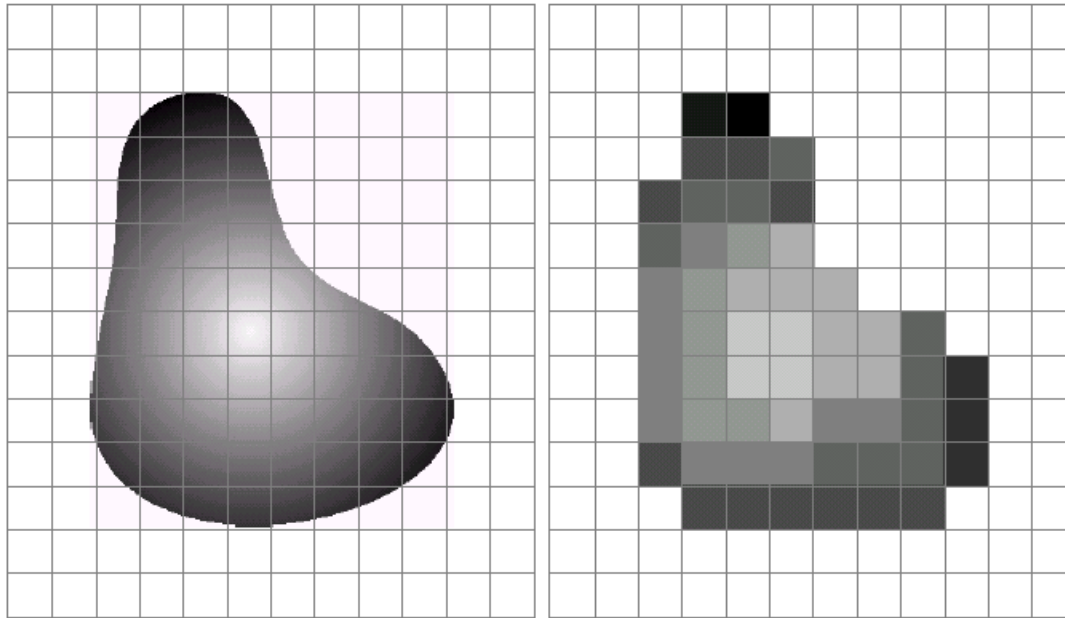


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy (“illumination”) source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Sensor Array



a b

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



CMOS sensor

A Simple Image Formation Model

$$f(x, y) = i(x, y) * r(x, y)$$

$f(x, y)$: intensity at the point (x, y)

$i(x, y)$: illumination at the point (x, y)

(the amount of source illumination incident on the scene)

$r(x, y)$: reflectance/transmissivity at the point (x, y)

(the amount of illumination reflected/transmitted by the object)

where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$

Some Typical Ranges of illumination

- **Illumination**

Lumen — A unit of light flow or luminous flux

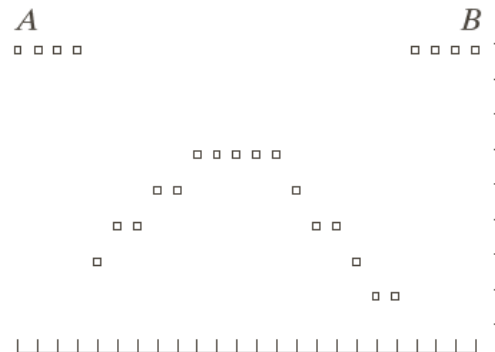
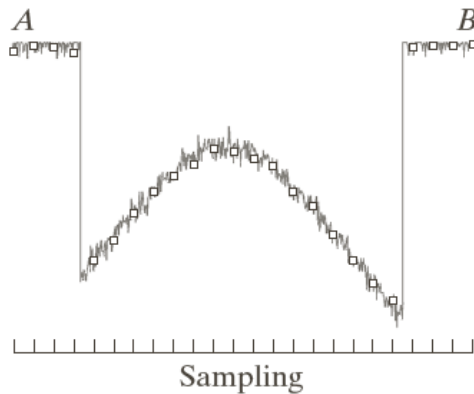
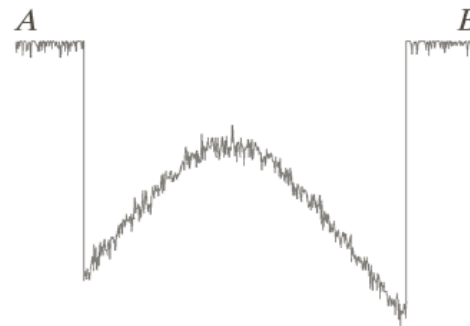
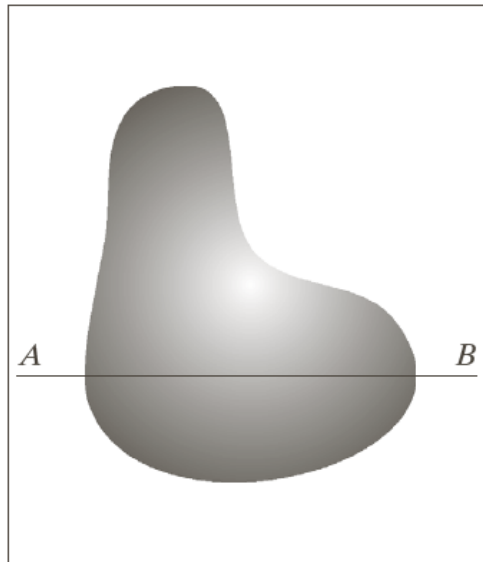
Lumen per square meter (lm/m^2) — The metric unit of measure for illuminance of a surface

- On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth
- On a cloudy day, the sun may produce less than 10,000 lm/m^2 of illumination on the surface of the Earth
- On a clear evening, the moon yields about 0.1 lm/m^2 of illumination
- The typical illumination level in a commercial office is about 1000 lm/m^2

Some Typical Ranges of Reflectance

- Reflectance
 - 0.01 for black velvet
 - 0.65 for stainless steel
 - 0.80 for flat-white wall paint
 - 0.90 for silver-plated metal
 - 0.93 for snow

Image Sampling and 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.

Image Sampling and Quantization

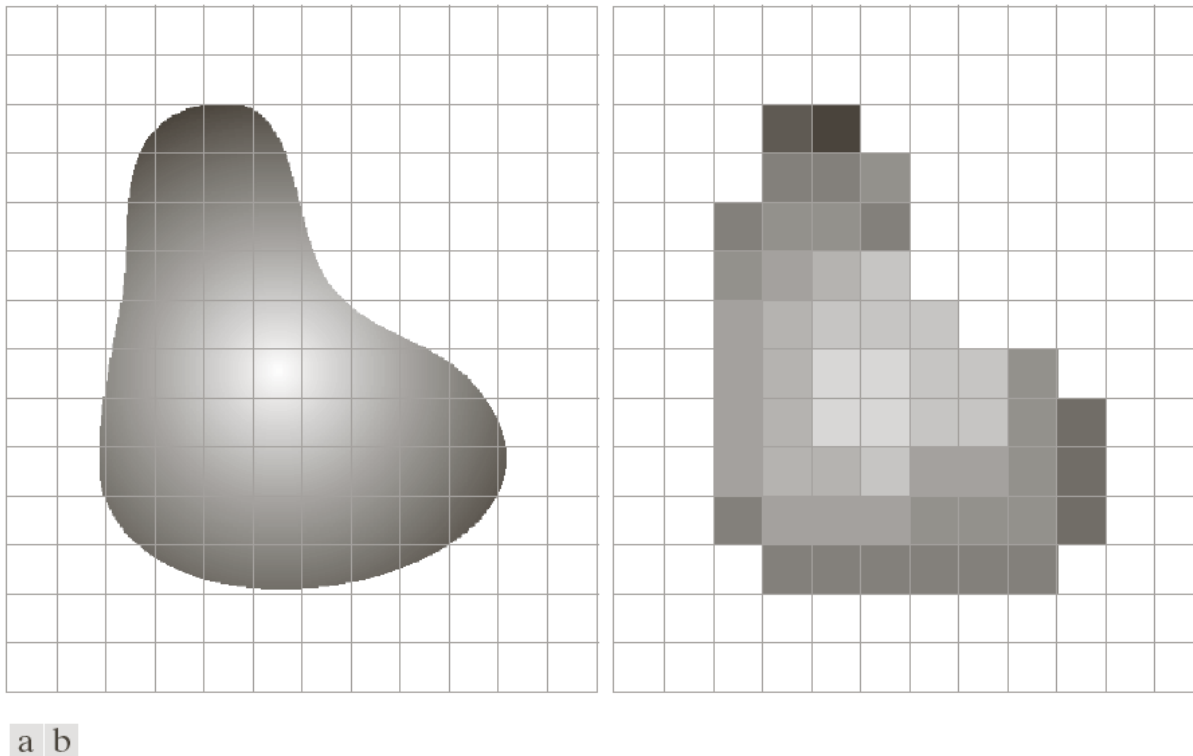
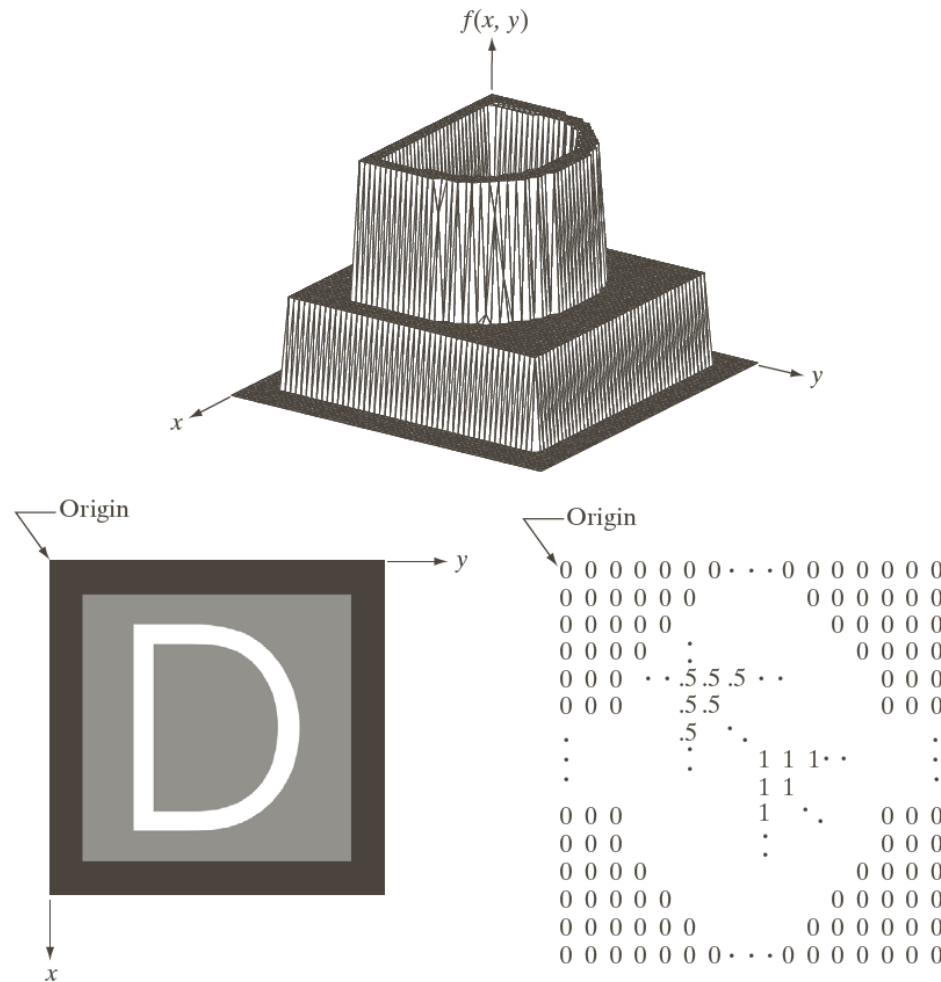


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Representing Digital Images



a
b c

FIGURE 2.18

(a) Image plotted as a surface.

(b) Image displayed as a visual intensity array.

(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).

Representing Digital Images

The representation of an $M \times N$ numerical array as

$$f(x, y) = \begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Representing Digital Images

The representation of an $M \times N$ numerical array as

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \cdots & \cdots & \cdots & \cdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Representing Digital Images

The representation of an $M \times N$ numerical array in MATLAB

$$f(x, y) = \begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \dots & \dots & \dots & \dots \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{bmatrix}$$

Representing Digital Images

- Discrete intensity interval $[0, L-1]$, $L=2^k$

The number b of bits required to store a $M \times N$ digitized image

$$b = M \times N \times k$$

Representing Digital Images

TABLE 2.1

Number of storage bits for various values of N and k .

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Spatial and Intensity Resolution

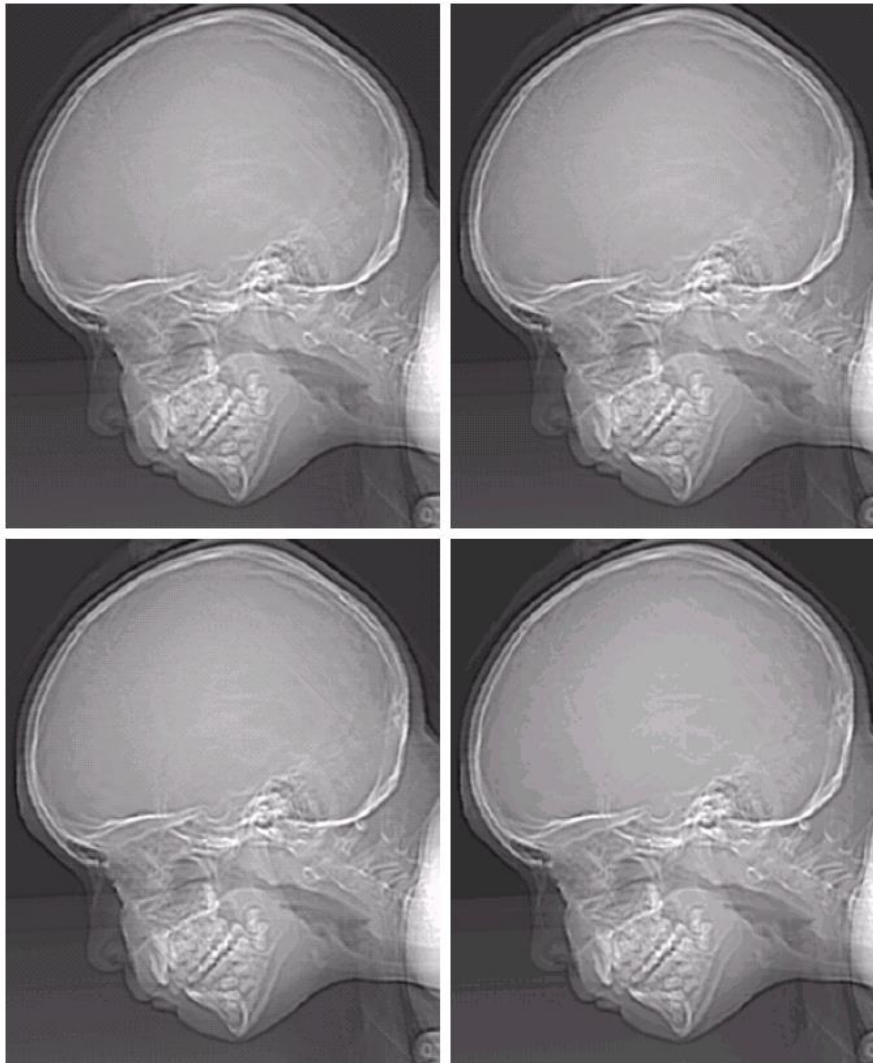
- Spatial resolution
 - A measure of the smallest discernible detail in an image
 - stated with *line pairs per unit distance*, *dots (pixels) per unit distance*, *dots per inch (dpi)*
- Intensity resolution
 - The smallest discernible change in intensity level
 - stated with *8 bits*, *12 bits*, *16 bits*, *etc.*

Spatial and Intensity Resolution



FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Spatial and Intensity Resolution



a b
c d

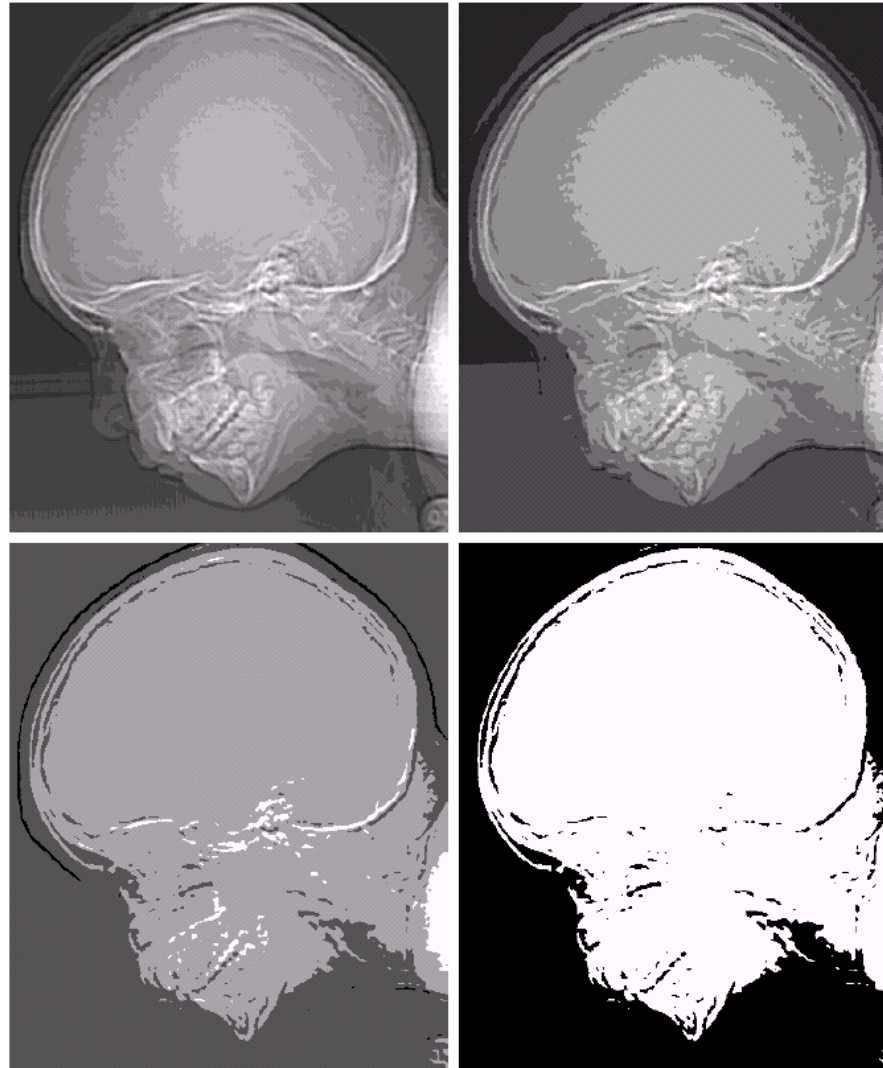
FIGURE 2.21

(a) 452×374 , 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Spatial and Intensity Resolution

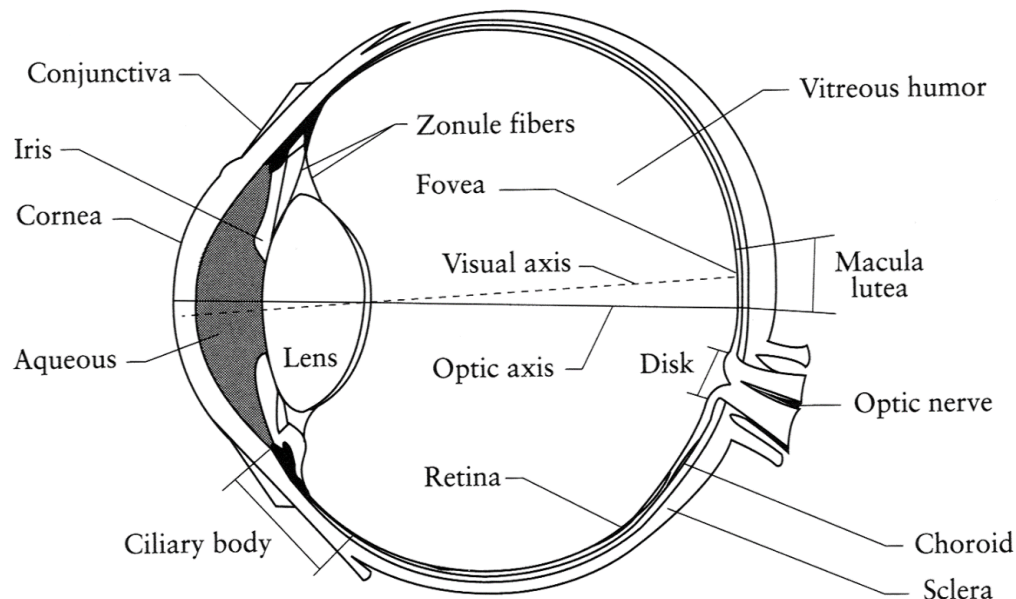
e f
g h

FIGURE 2.21
(Continued)
(e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

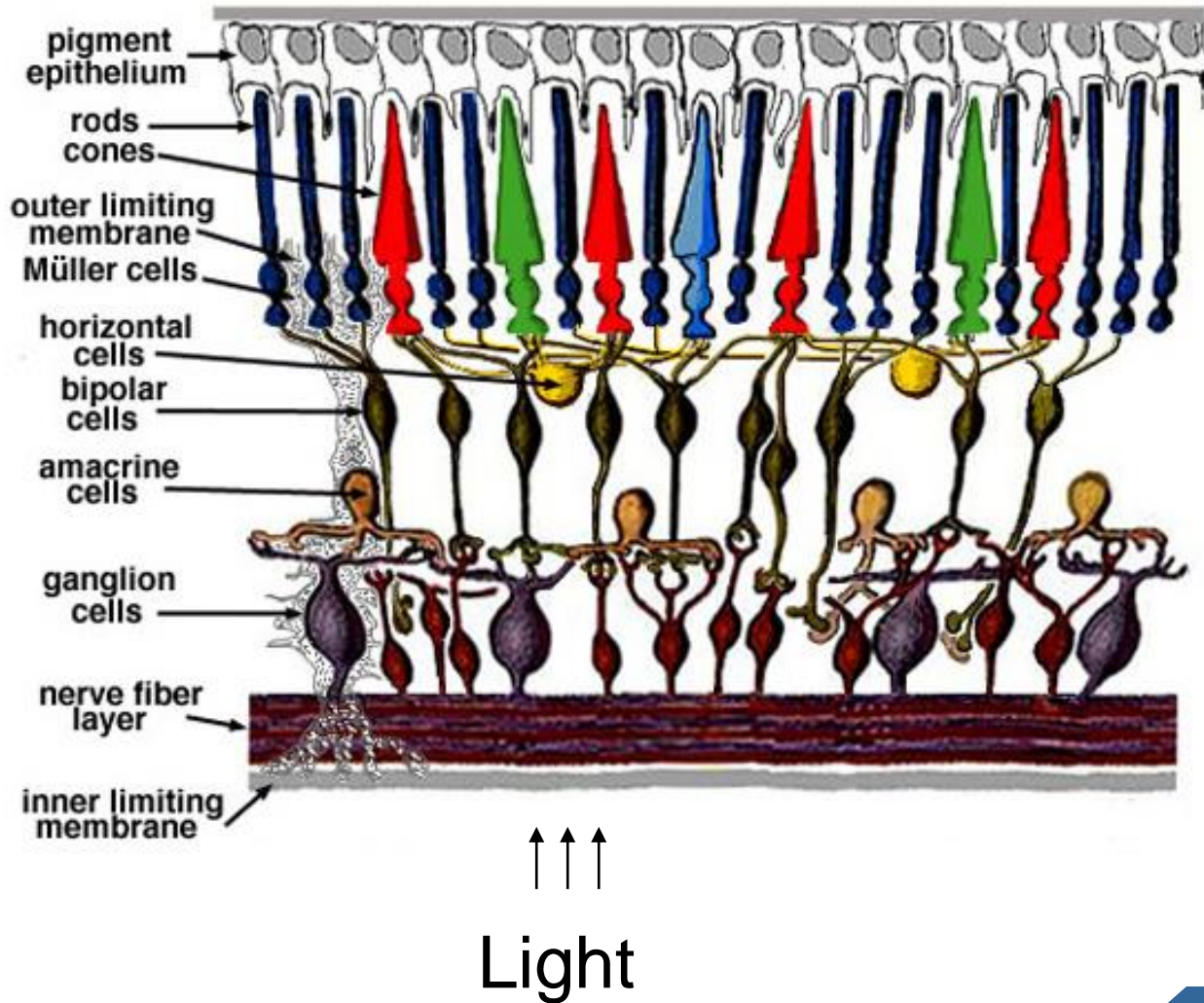


The Eye

- The human eye is a camera!
 - **Iris** - colored annulus with radial muscles
 - **Pupil** - the hole (aperture) whose size is controlled by the iris
 - What's the “film”? photoreceptor cells (rods and cones) in the **retina**



Retina up-close



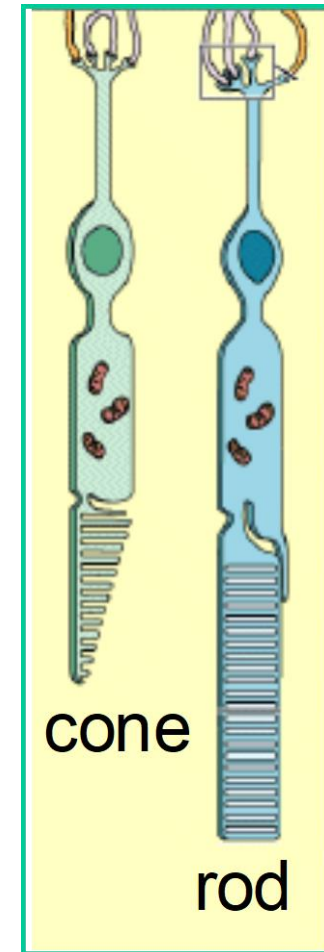
Two types of light-sensitive receptors

Cones

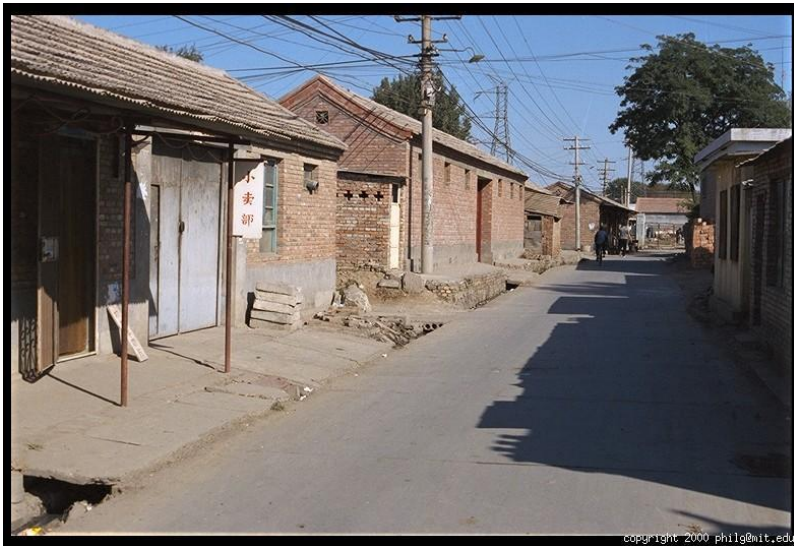
- cone-shaped
- less sensitive
- operate in high light color vision

Rods

- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision
- slower to respond



Color Image



Thank You