Chapter 2
Digital image Fundamentals

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- Elements of Visual perception
- Image Sensing and Acquisition
- Image Sampling and Quantization
- Some basic relationships between pixels

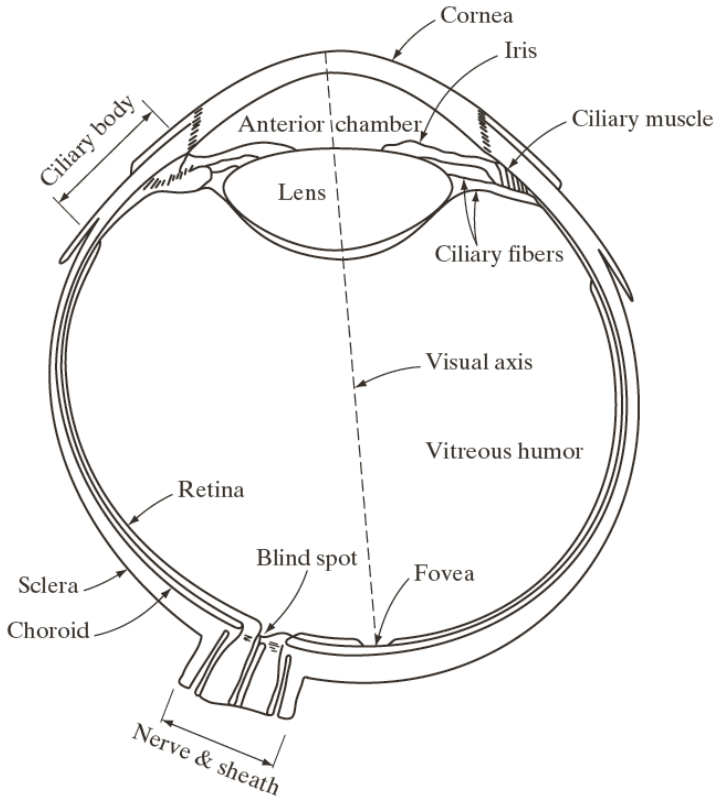

FIGURE 2.1
Simplified diagram of a cross section of the human eye.

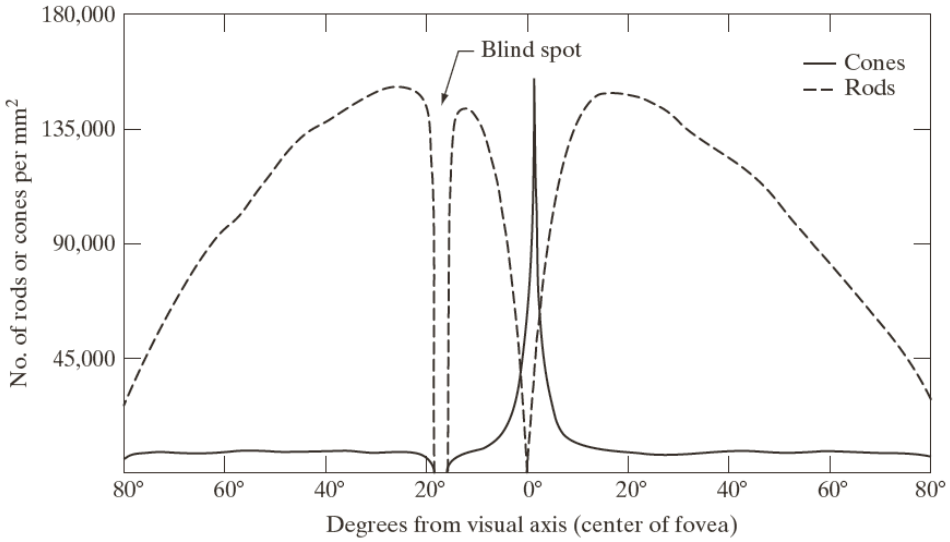

FIGURE 2.2
Distribution of rods and cones in the retina.

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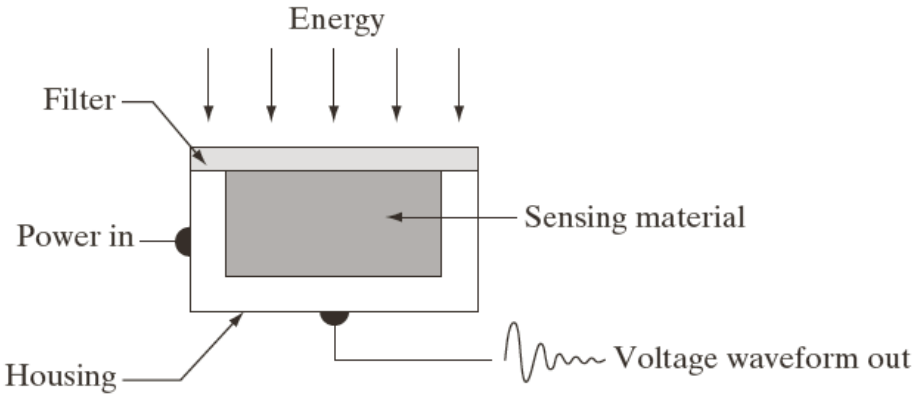


a
b
c

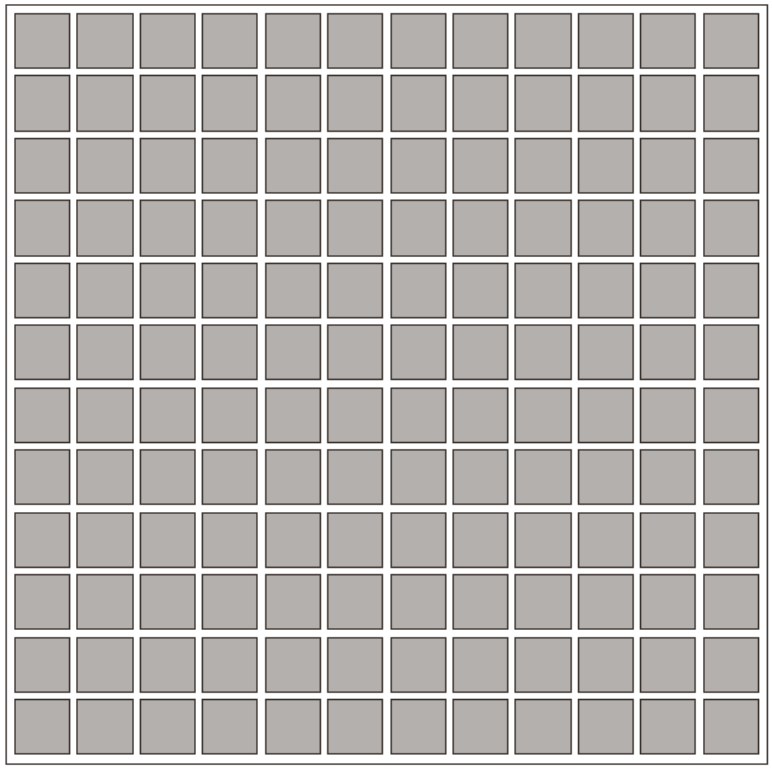


FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

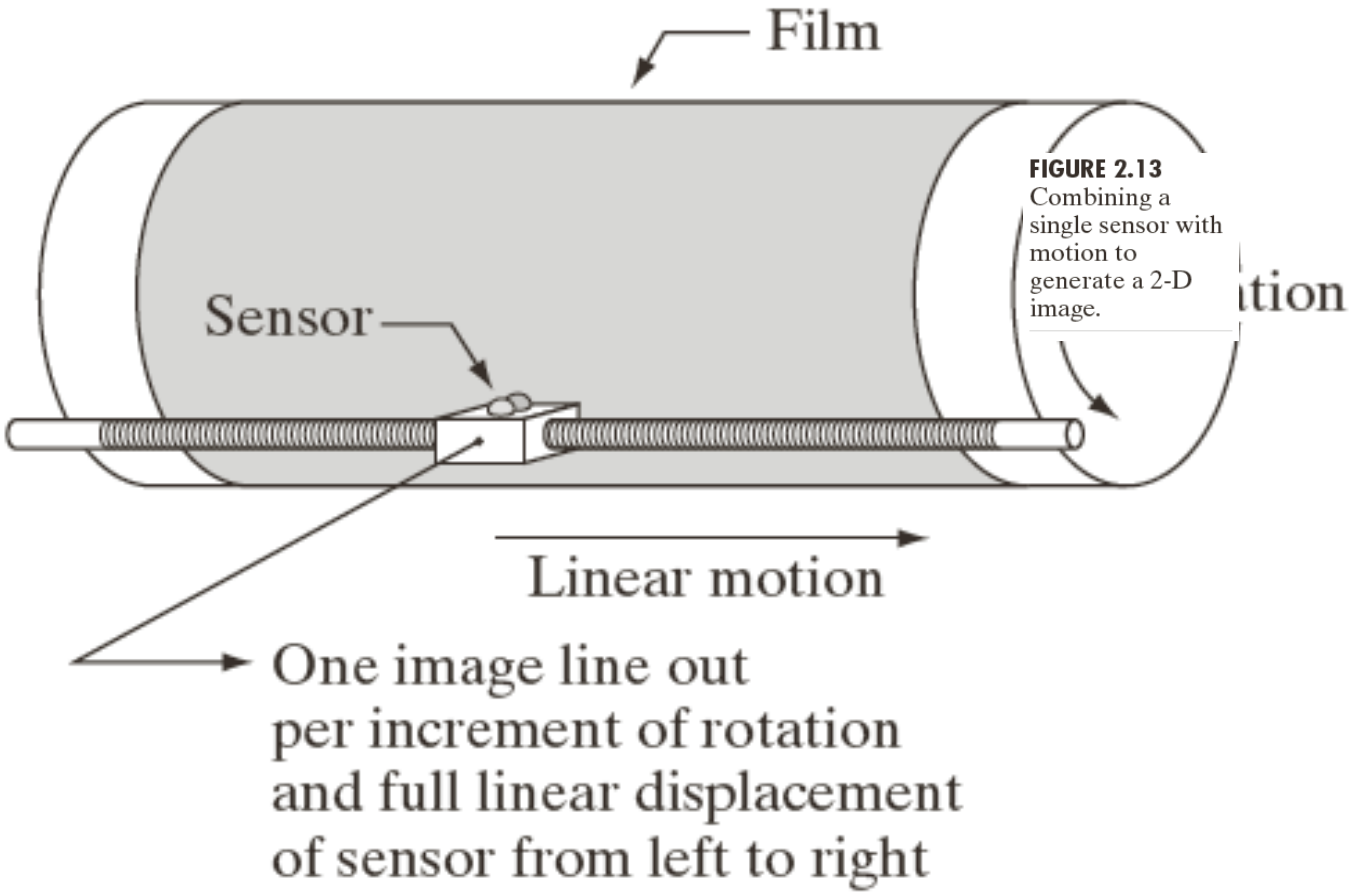
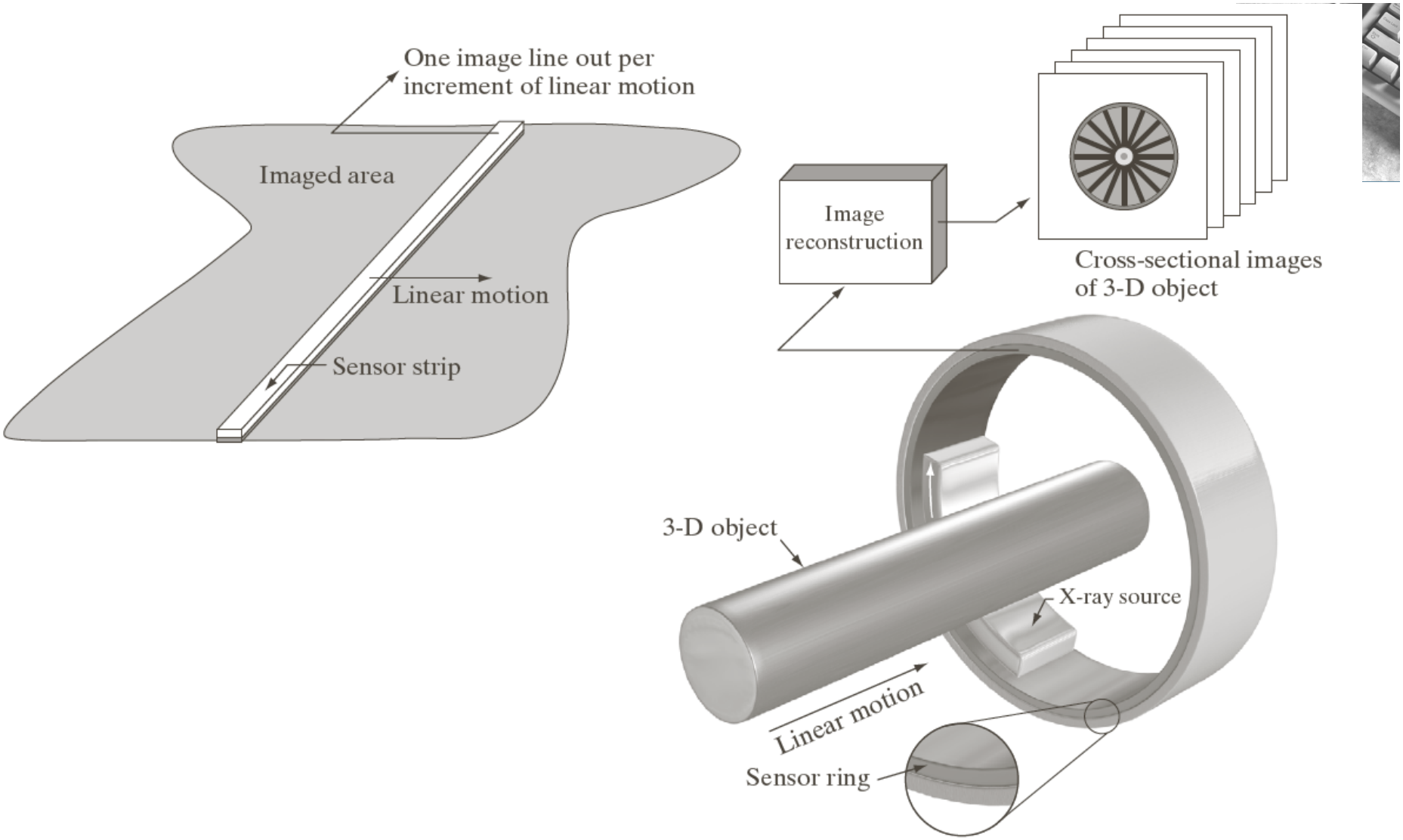
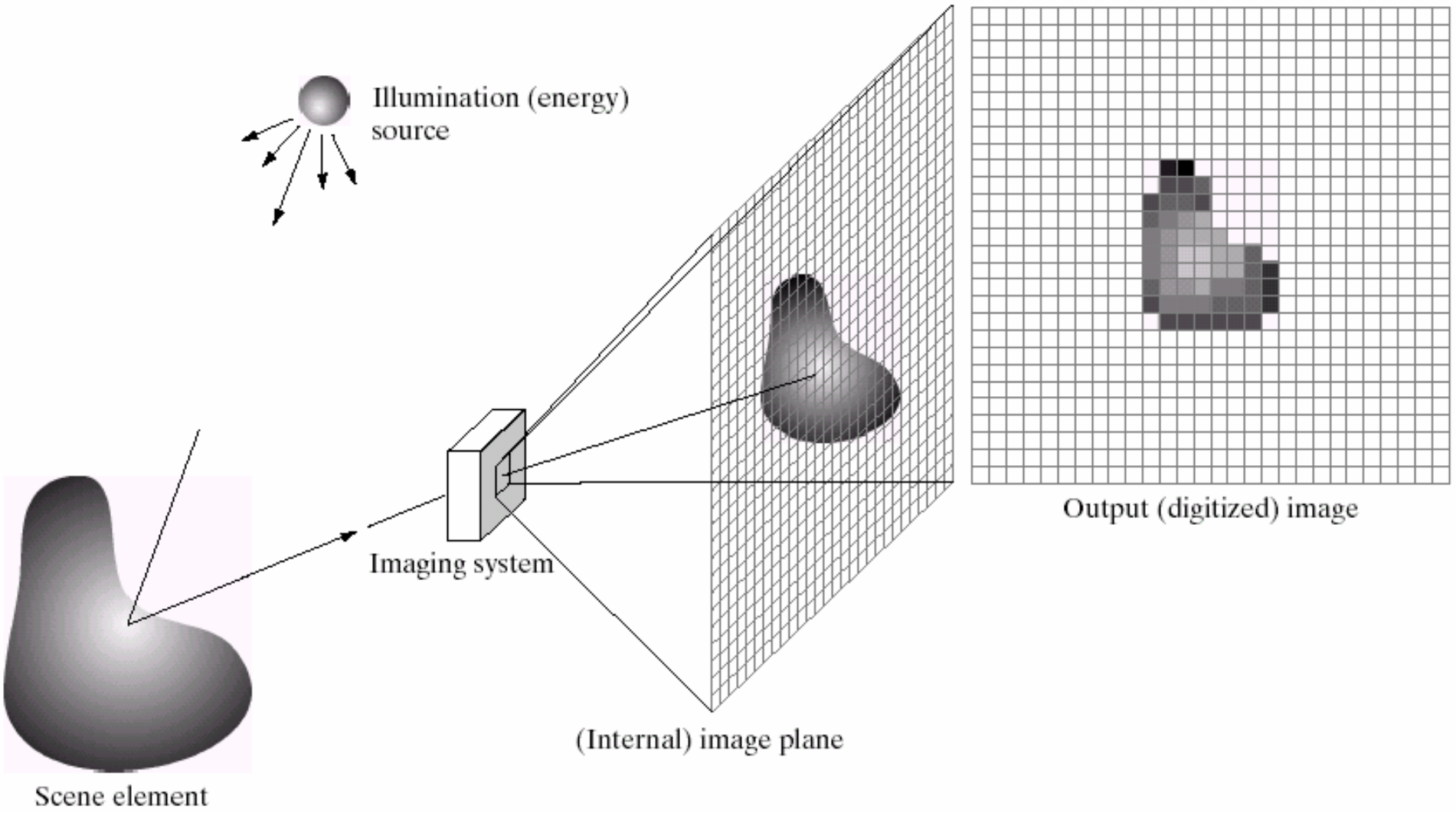


FIGURE 2.13
Combining a single sensor with motion to generate a 2-D image.



a b

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



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.

A simple Image Formation Model

- f(x,y)
  - The amount of source illumination incident on the scene being viewed
    - Illumination components: i(x,y)
  - The amount of illumination reflected by the objects in the scene
    - reflectance components: r(x,y)
- f(x,y)=i(x,y)r(x,y)

- Gray level (l)
- The interval[L_{min}, L_{max}] is called the gray scale.

  The intensity of a monochrome image at any coordinates (x_0,y_0) the gray level(l) of the image at that point.

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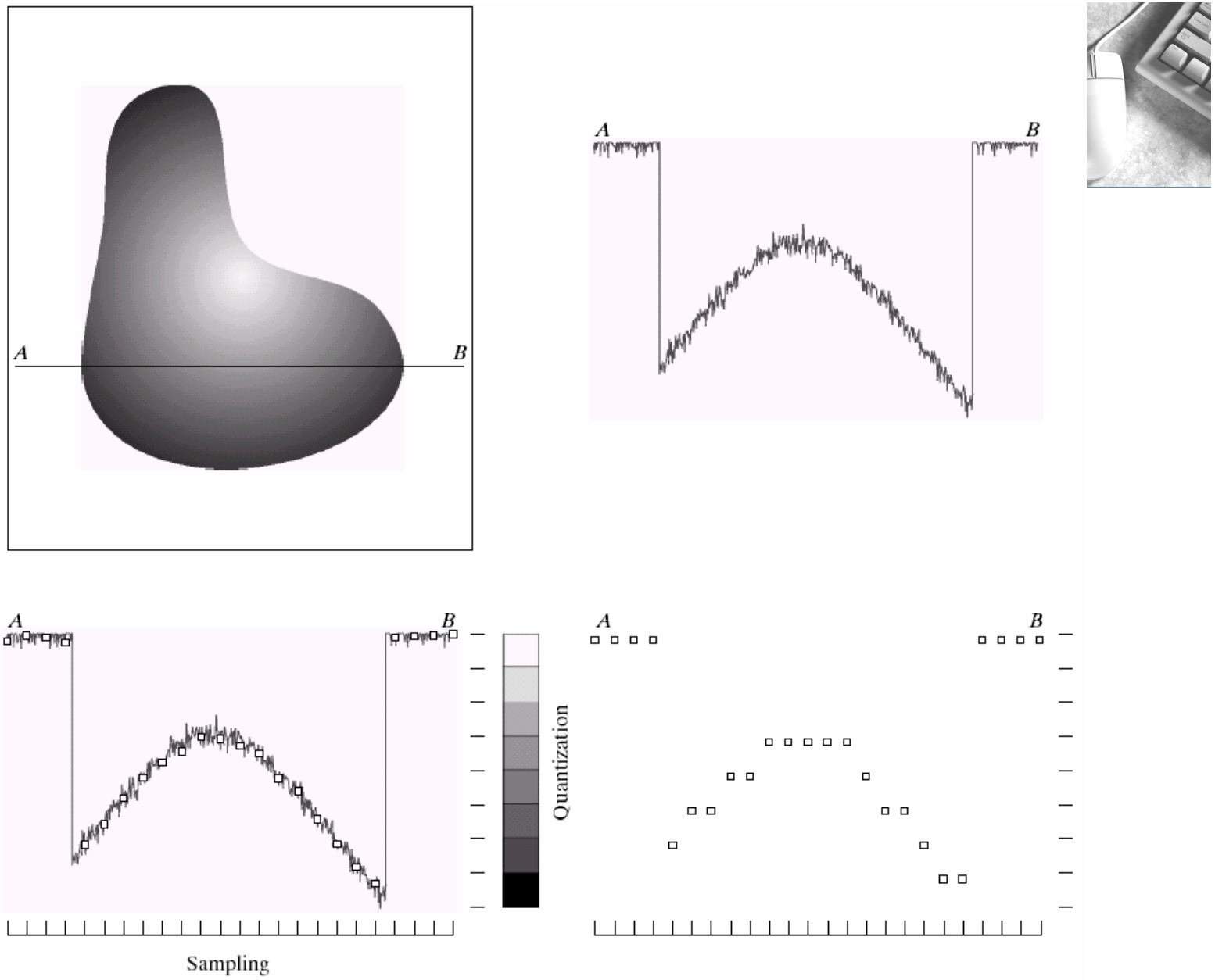
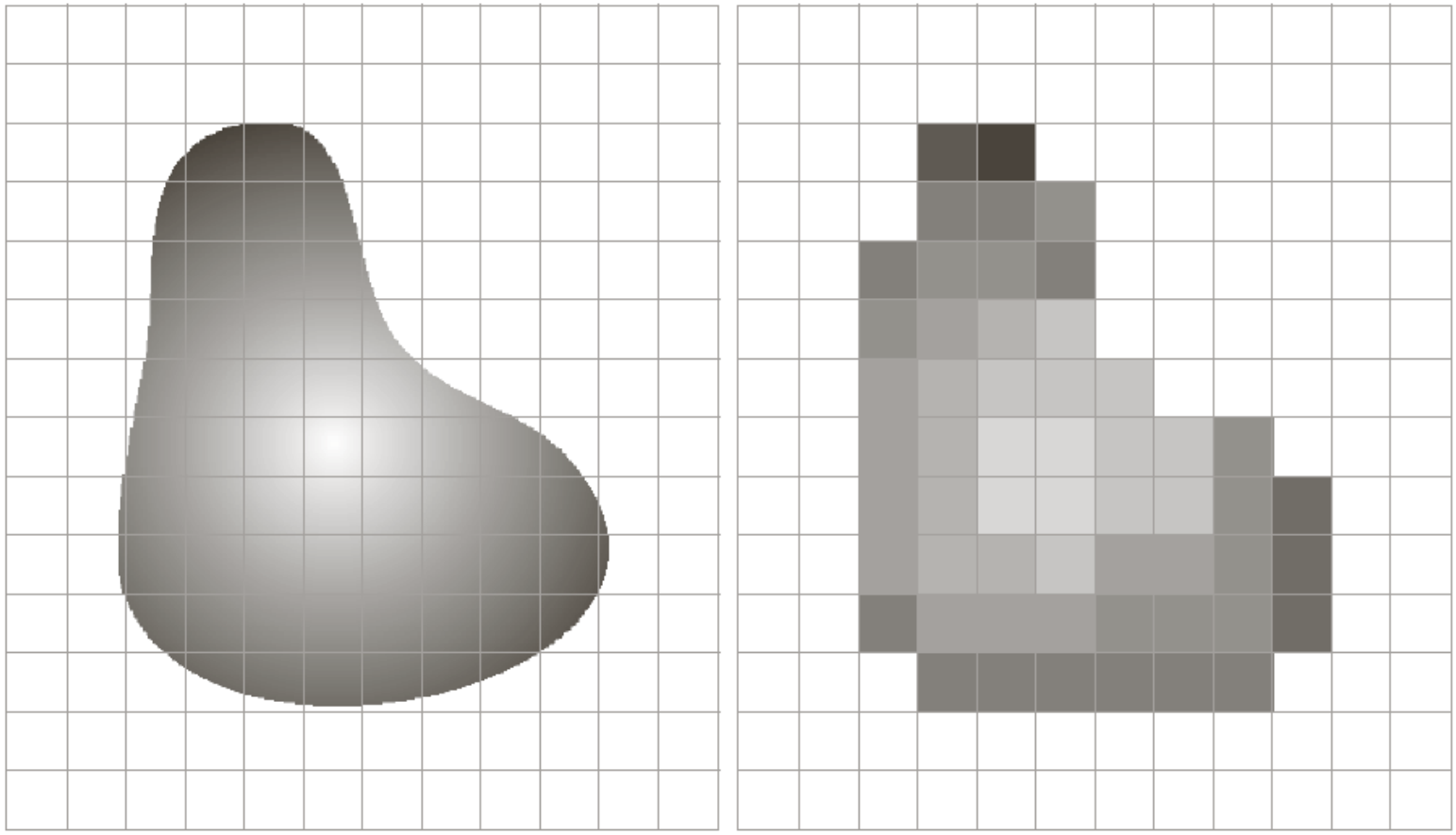
- Sampling:
  - Digitizing the coordinate values is called sampling.
- Quantization
  - Digitizing the amplitude values is called quantization.



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.



a b

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

Representing digital images

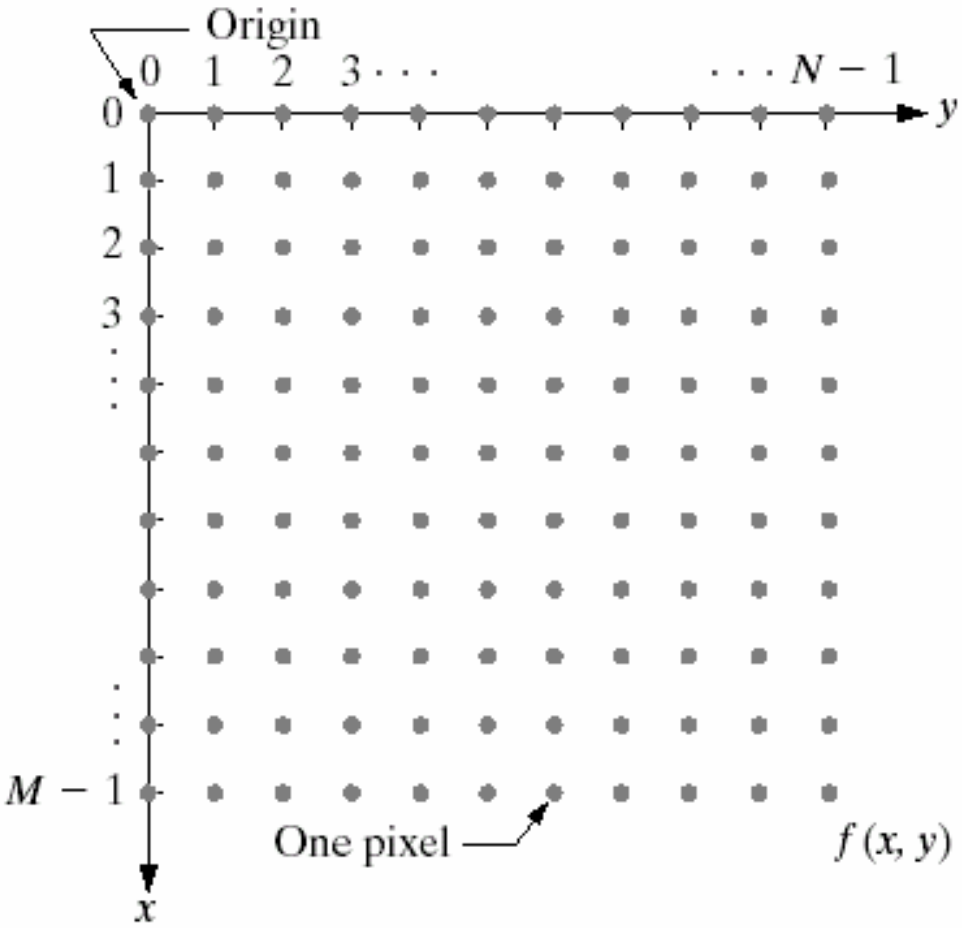


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

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

- The number of gray levels typically is an integer power of 2:

$$L=2^k$$

- The number,b, of bits required to store a digitized image is:

$$b=M*N*k$$

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

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- 4-neighbors of p, $N_4(p)$

  (x+1,y), (x-1,y), (x,y+1), (x,y-1)

- 8-neighbors of p, $N_8(p)$

  Add $N_D(p)$

  (x+1,y+1), (x+1,y-1), (x-1,y+1),(x-1,y-1)

Three types of adjacency

- 4-adjacency.

  Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.

- 8-adjacency.

  Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.

- m-adjacency(mixed adjacency).

  Two pixels p and q with values from V are m-adjacent if

  (i) q is in $N_4(p)$, or

  (ii) q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.

- A path from pixel p with coordinates (x,y) to pixel q with coordinates (s,t) is a sequence of distinct pixels with coordinates:

$$(x_0,y_0), (x_1,y_1), \ldots, (x_n,y_n)$$

- N is the length of the path.

- Region: We call R a region of the image if R is a connected set.
- Boundary: The boundary of a region R is the set of pixels in the region that have one or more neighbors that are not in R.

Distance Measures

- For pixels p,q, and z, with coordinates(x,y), (s,t), and (v,w), respectively, D is a distance function or metric if

  (a) D(p,q)>=0 (D(p,q)=0 iff p=q),

  (b) D(p,q)=D(q,p), and

  (c) D(p,z)<=D(p,q)+D(q,z).

- The Euclidean distance between p and q is defined as

$$D_e(p,q) = \left[(x-s)^2 + (y-t)^2\right]^{\frac{1}{2}}$$

- The D4 distance between p and q is defined as

$$D_4(p,q) = |x-s| + |y-t|$$

- The D8 distance between p and q is defined as

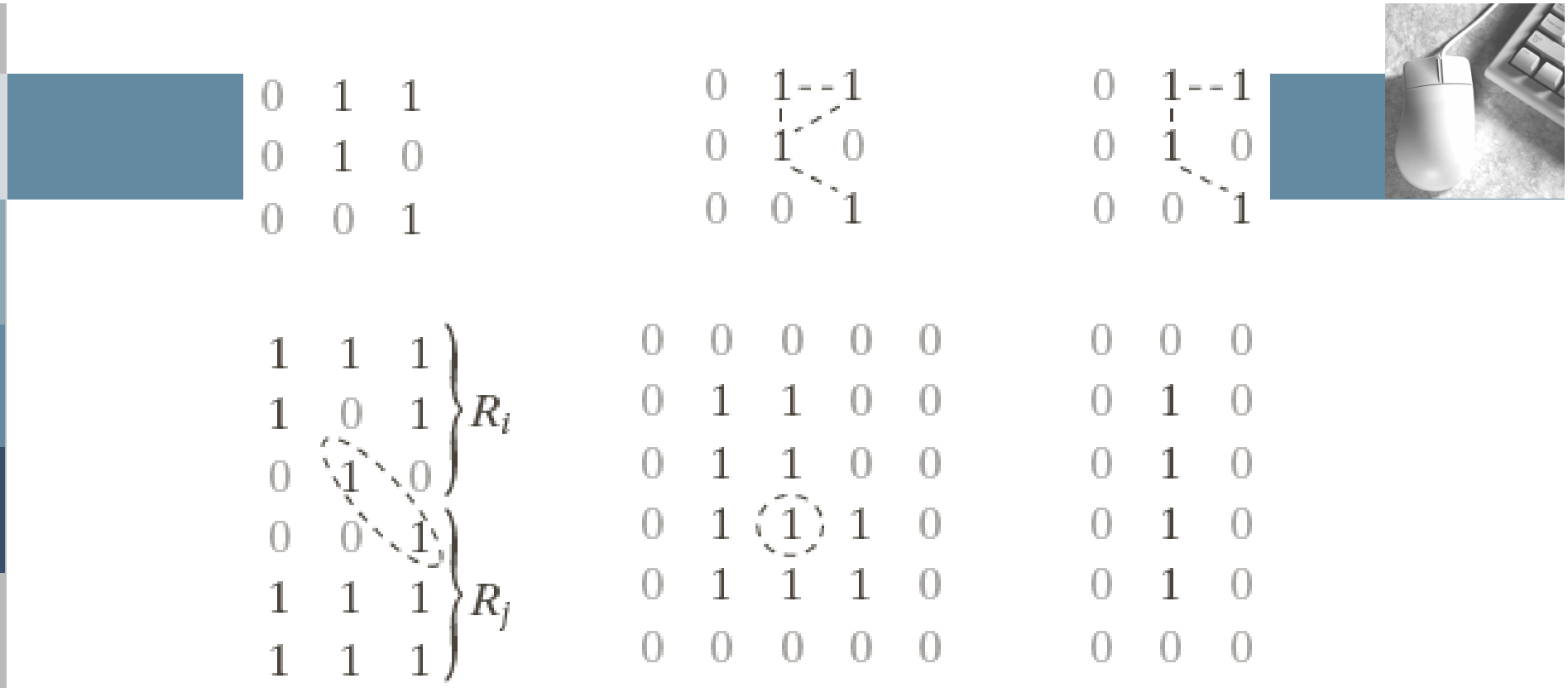
$$D_8(p,q) = \max(|x-s|, |y-t|)$$

- The pixels with D_4 distance <=2 from (x,y) from the following contours of constant distance:

```
        2
    2   1   2
2   1   0   1   2
    2   1   2
        2
```

- The pixels with D_8 distance <=2 from (x,y) from the following contours of constant distance:

2 2 2 2 2
2 1 1 1 2
2 1 0 1 2
2 1 1 1 2
2 2 2 2 2



a b c
d e f

FIGURE 2.25 (a) An arrangement of pixels. (b) Pixels that are 8-adjacent (adjacency is shown by dashed lines; note the ambiguity). (c) *m*-adjacency. (d) Two regions that are adjacent if 8-adjecency is used. (e) The circled point is part of the boundary of the 1-valued pixels only if 8-adjacency between the region and background is used. (f) The inner boundary of the 1-valued region does not form a closed path, but its outer boundary does.