Chapter 1 Digital Image Fundamentals

- A digital image is a matrix, and is composed of an array of elements.
- The element that forms an image is called ***pixel*** (= picture element).
- A matrix can be visualized as an image by converting the value of each pixel into brightness or intensity.
- The number of intensity levels is usually 8 bits, i.e., 256 gray levels.

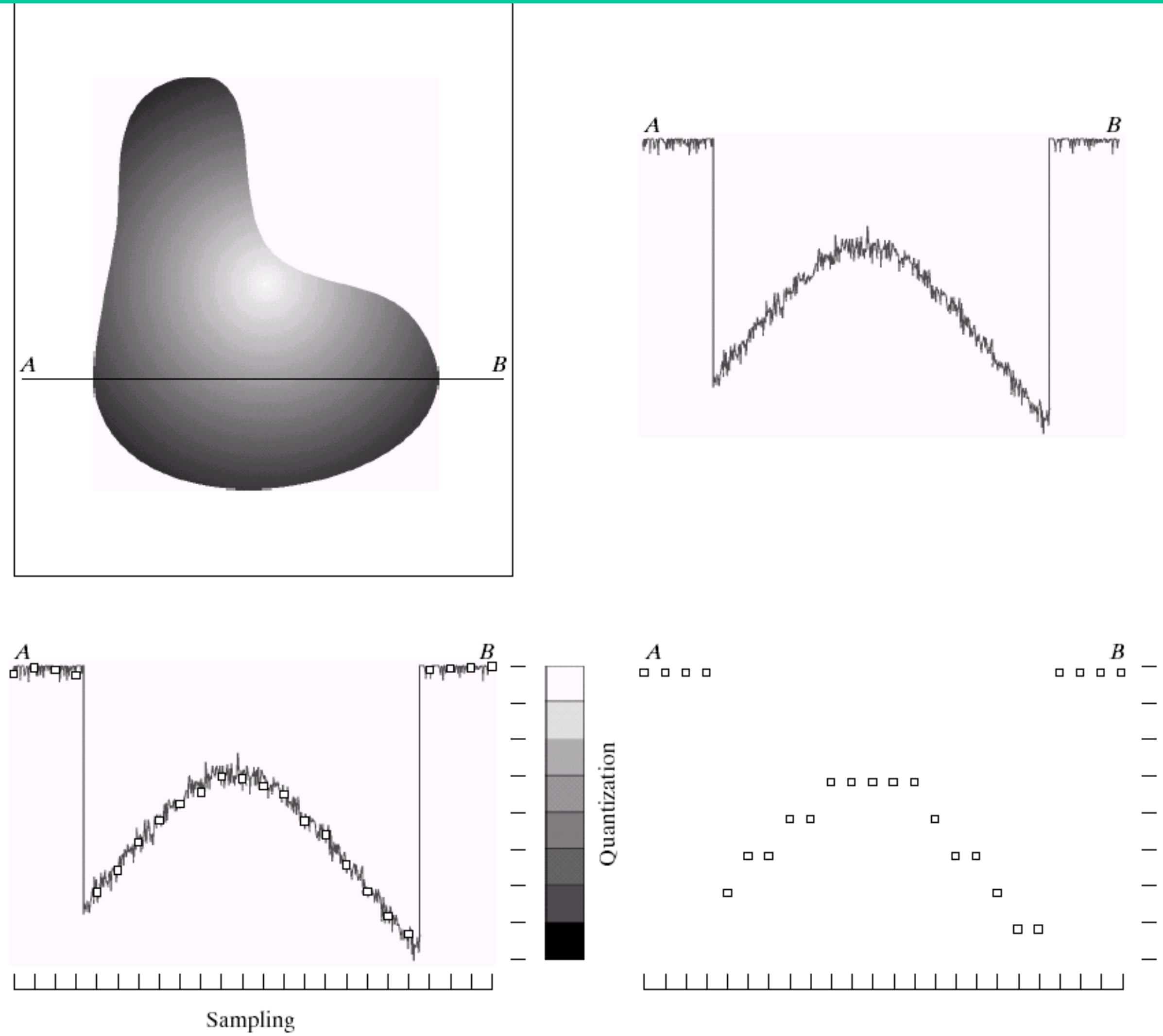
What Is Digital Image Processing?

- The field of digital image processing refers to processing digital images by means of a digital computer.
- Applications include enhancement, analysis (diagnosis, inspection, etc.), compression, object recognition, depth estimation, motion detection.

How Do We Obtain A Digital Image?

- A digital image is obtained through two types of digitization steps.
- One is called *sampling* that is the digitization of space or time (abscissa).
- The other is called *quantization* that is the digitization of intensity or amplitude (ordinate).

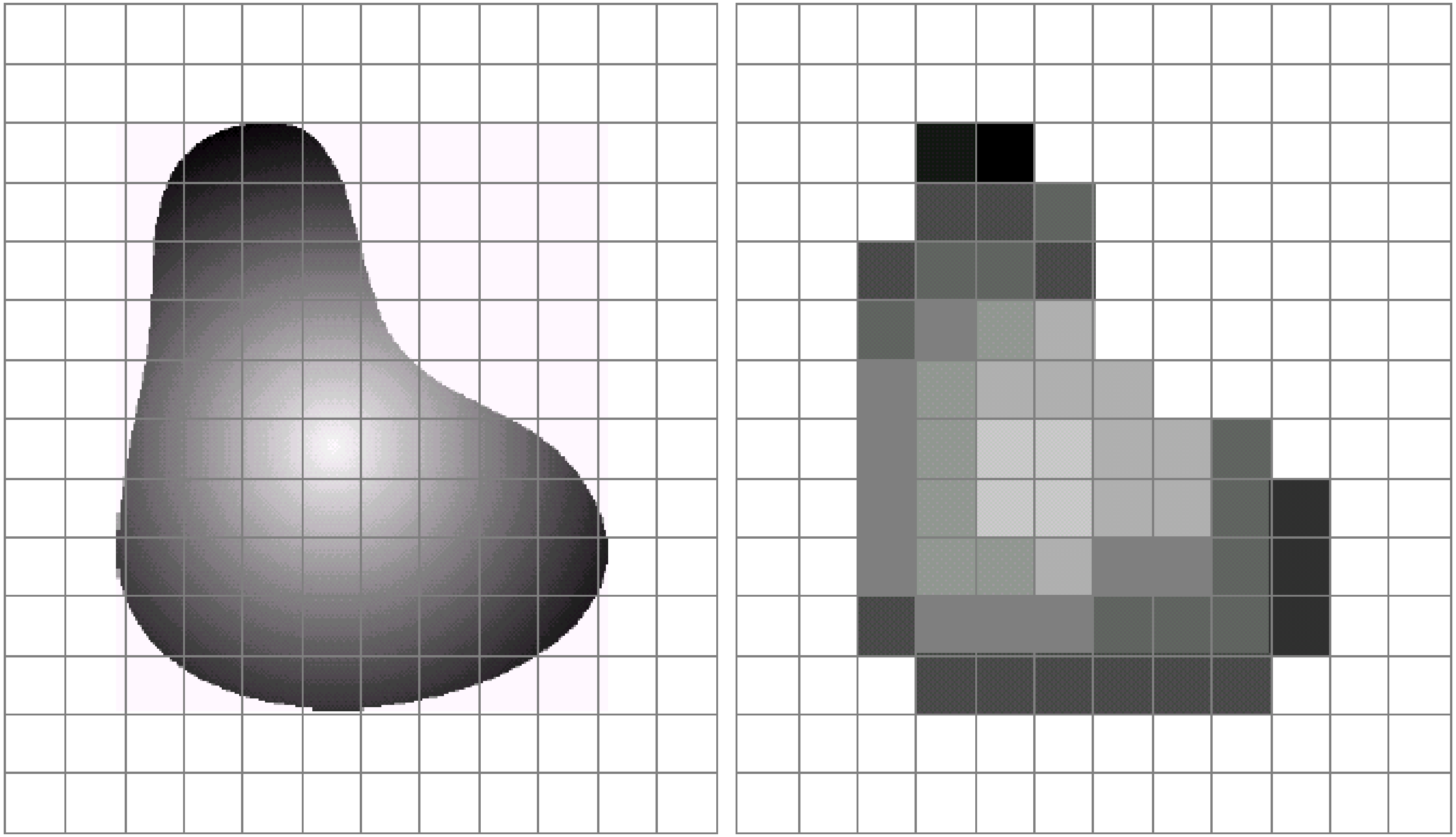
Sampling and Quantization



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.

Generation of A Digital Image



a b

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

Various Spatial Resolutions

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Spatial resolution is determined by the number of sampling points.

Block Artifacts

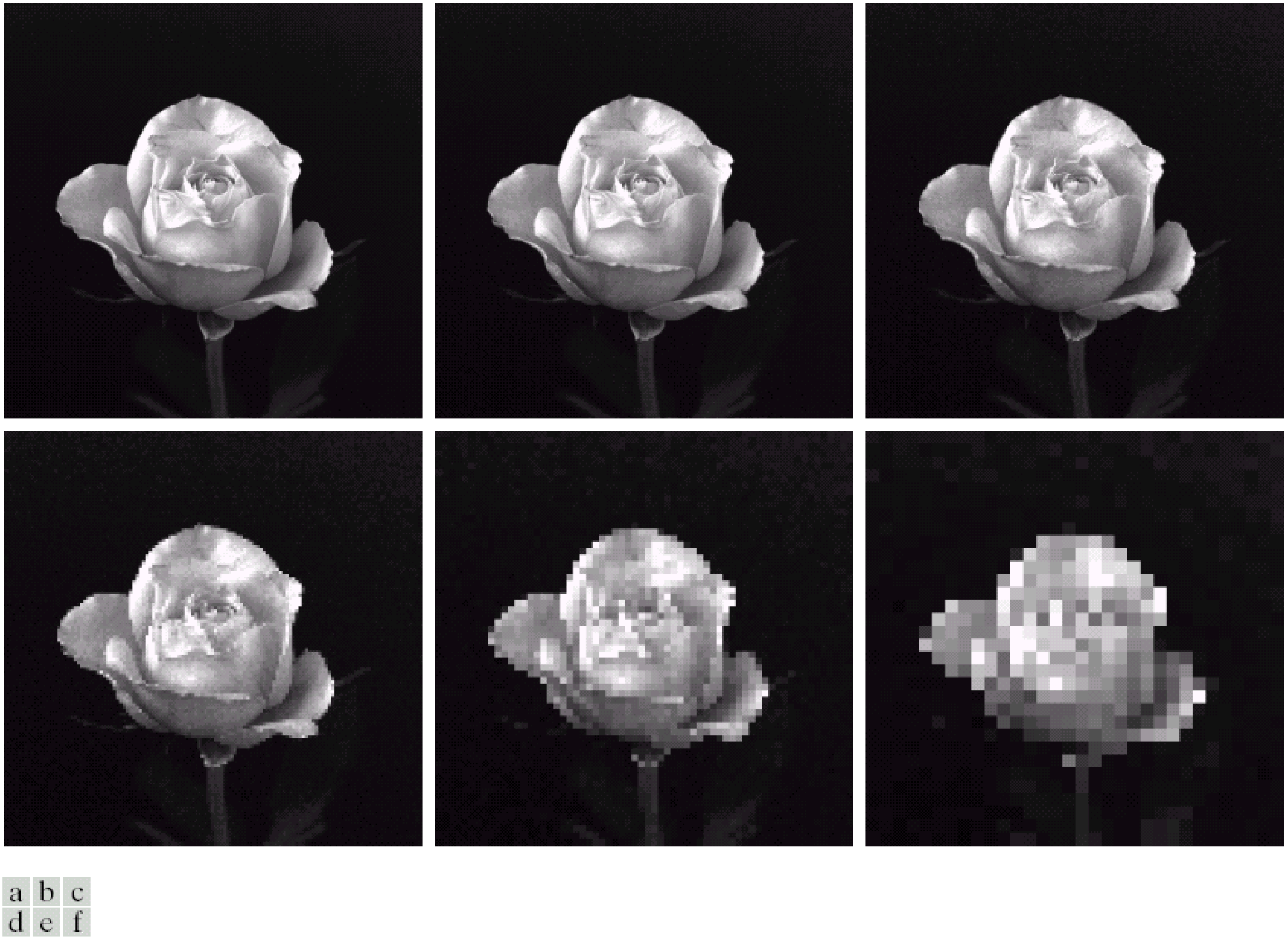
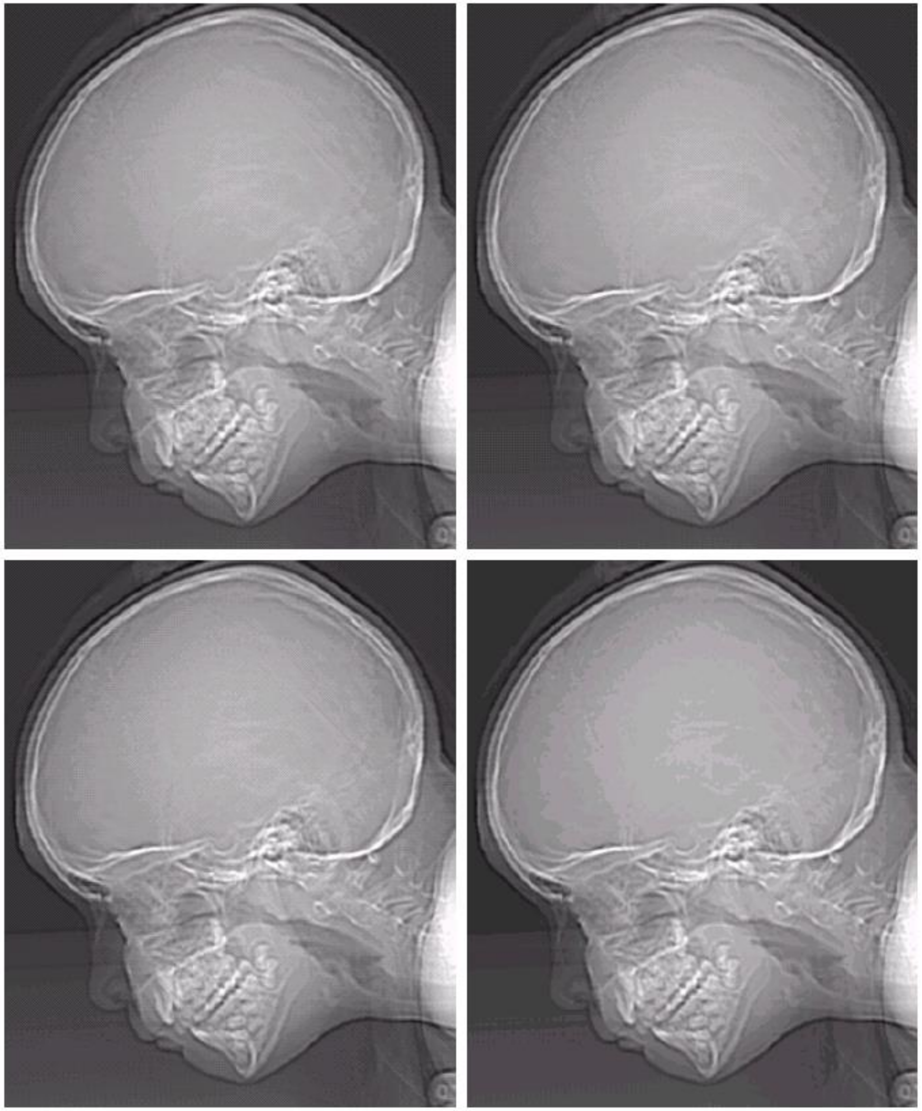


FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

A small number of sampling points makes *block artifacts* conspicuous.

Various Quantization Levels



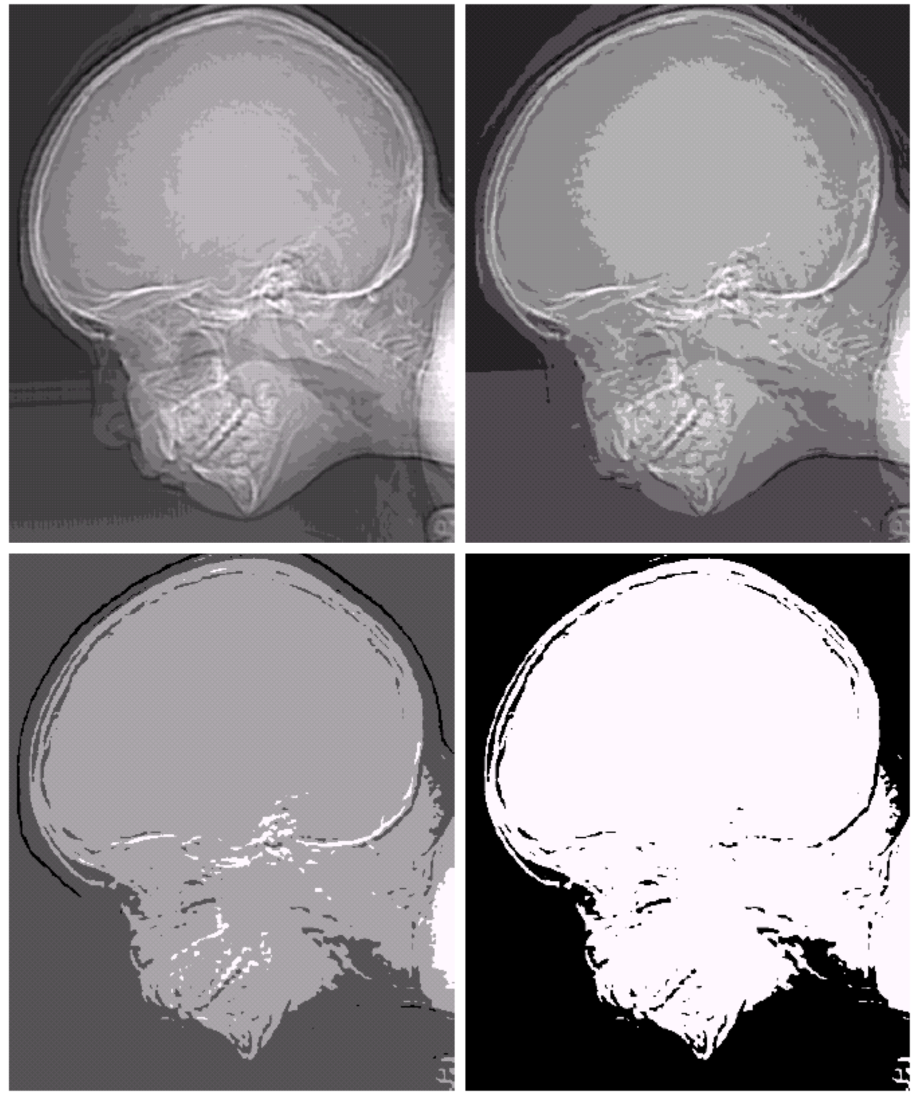
a b
c d

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.

False Contours

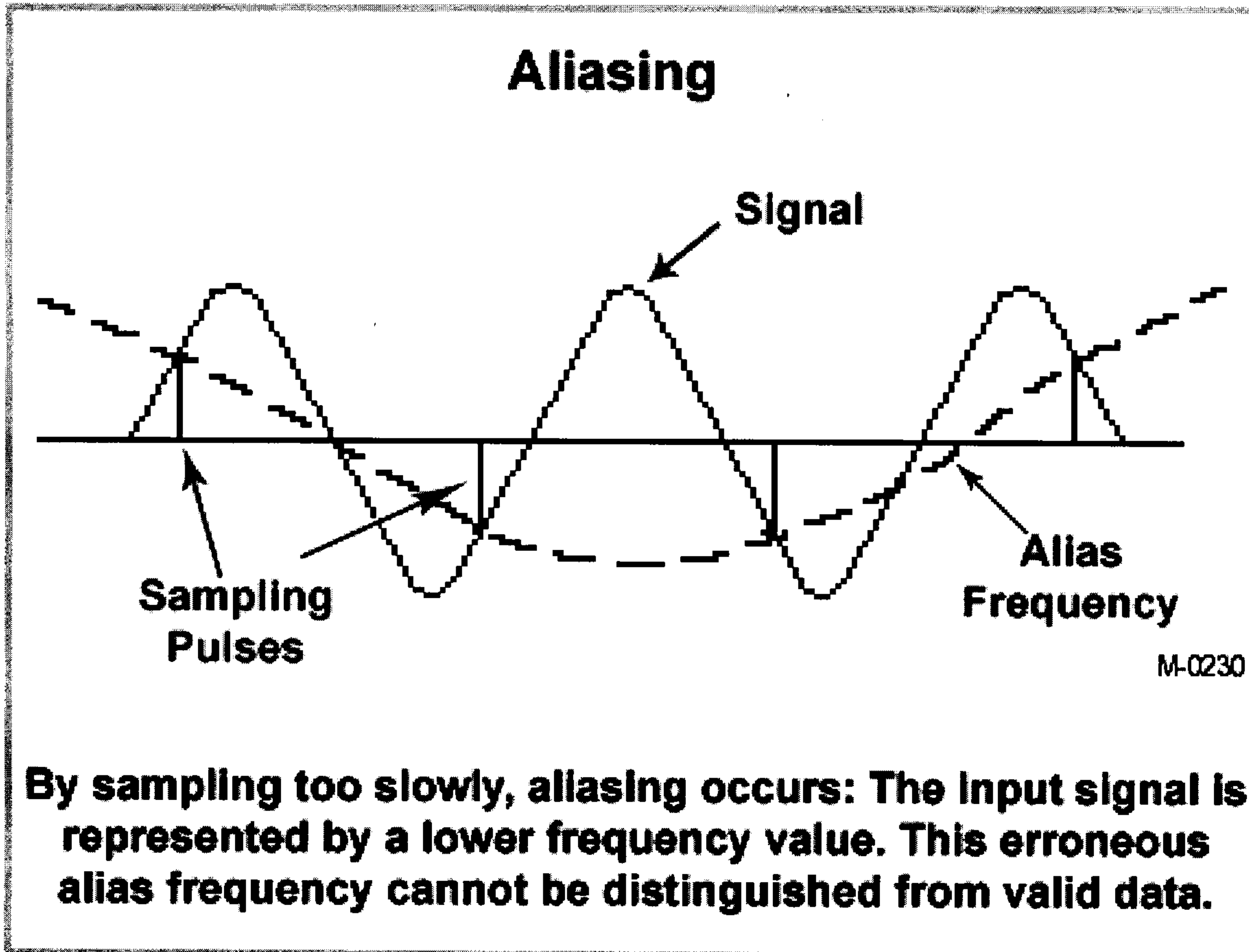
e f
g h

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.)



A small number of quantization levels (gray levels) makes *false contours* conspicuous.

Aliasing Error



Another serious problem owing to a small number of sampling points is *aliasing error*.

Aliasing Error

A small number of sampling points may bring about *aliasing error*.

Coordinate Systems

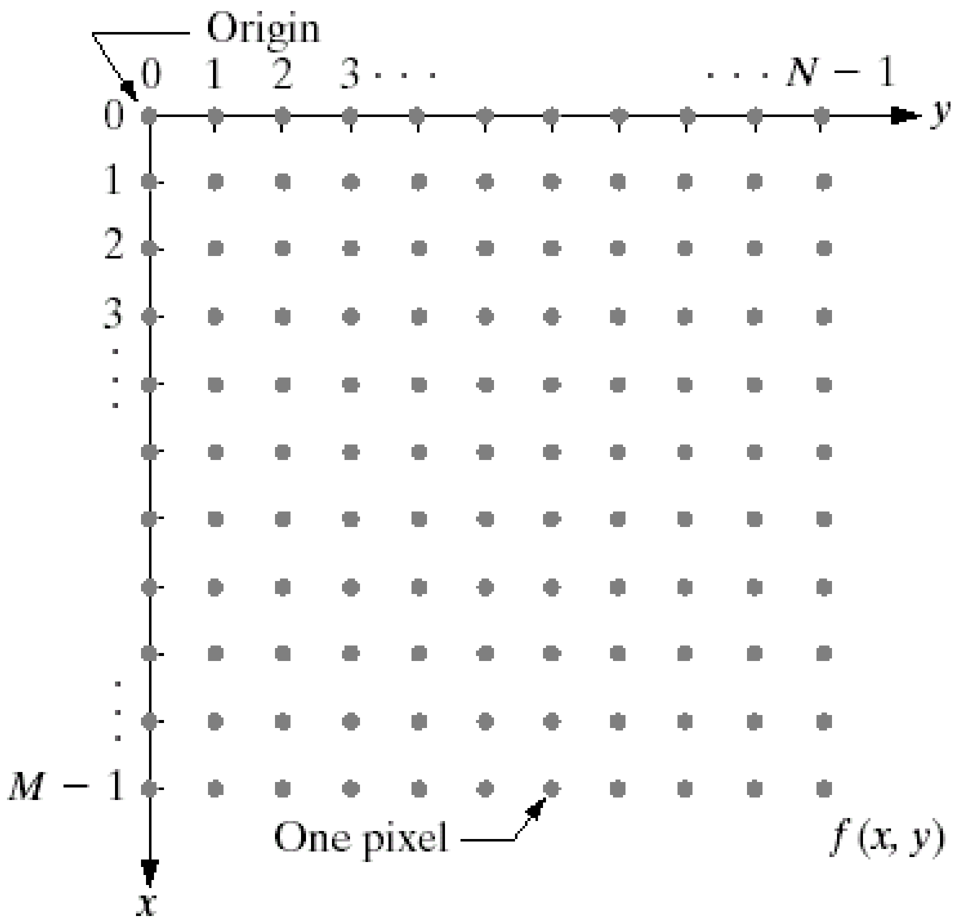


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Column

Row

Matrix notation

$$M = \begin{pmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{pmatrix}$$

Neighbors of A Pixel

4 neighbors, 8 neighbors and diagonal neighbors of a pixel p

	x	
x	p	x
	x	

$N_4(p)$

x	x	x
x	p	x
x	x	x

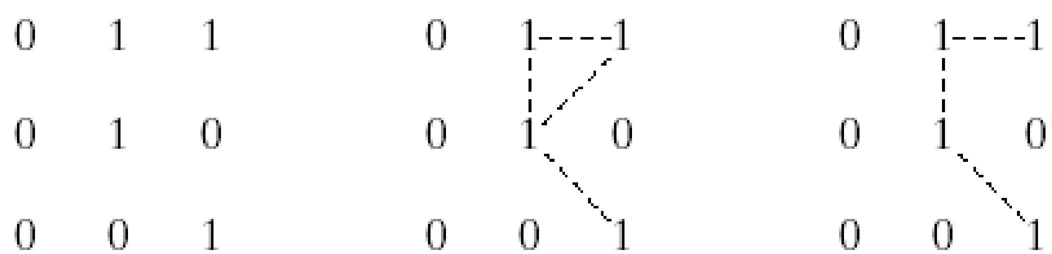
$N_8(p)$

x		x
	p	
x		x

$N_D(p)$

Three Types of Connectivity

- If q is in $N_4(p)$, p and q are 4-adjacent.
- If q is in $N_8(p)$, p and q are 8-adjacent.
- If q is in $N_4(p)$, or $N_D(p)$ and $N_4(p) \cap N_4(q)$ is empty, p and q are m-adjacent.



a b c

FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

Distance Measures

The distance between $p(x,y)$ and $q(s,t)$ is expressed as follows:

- Euclidean distance $$D_e(p,q) = [(x-s)^2 + (y-t)^2]^{1/2}$$

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

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

Sampling Theorem

The sampling theorem states that to avoid aliasing error, the sampling frequency has to be at least two times faster than the highest frequency of an input analog signal.

$$f_{sample} \geq 2 f_{input}$$

To satisfy this condition, a low-pass filter (anti-aliasing filter) is applied to the input signal.

Exercise 1

Plot three 7 by 7 matrices by letting each element denote the distance from the element in the center. Three matrices are obtained based on the Euclidean distance, D_4 distance, and D_8 distance, respectively.

Assignment from Chapter 1

1. Obtain a digital image of your face.
2. Change the spatial resolution of it, and comment on the results. (See Chap1_1.m)
3. Change the number of gray levels, and comment on the results. (See Chap1_2.m)
4. Obtain a digital image that shows aliasing error, and comment on it.

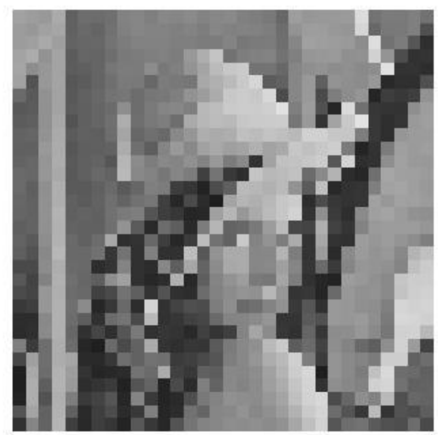
Various Spatial Resolutions

256 by 256

128 by 128

64 by 64

32 by 32



MATLAB Sample Code 1

```
function Chap1_1
img1=imread('Lena.gif');
%Various spatial resolutions.
img2=img1(1:2:256,1:2:256); %Output image of size 128 by 128
img3=img1(1:4:256,1:4:256); %Output image of size 64 by 64
img4=img1(1:8:256,1:8:256); %Output image of size 32 by 32

subplot(2,2,1), imshow(img1)
subplot(2,2,2), imshow(img2)
subplot(2,2,3), imshow(img3)
subplot(2,2,4), imshow(img4)
return
```

Various Gray-Level Resolutions

Original

32 gray levels

16 gray levels

8 gray levels

4 gray levels

2 gray levels

MATLAB Sample Code 2

```
%2-bit (4 gray levels) image.

buf2=zeros(256,256);

step=256/4; %Quantization step width

ic=-1;

for l=1:4

    ic=ic+1;

    index=find((step*(ic))<=img1&img1<step*(ic+1));

    buf5(index)=ic;

end

buf5=mat2gray(buf5);

subplot(2,3,5), imshow(buf5), title('4 gray levels')
```