Digital Image Processing

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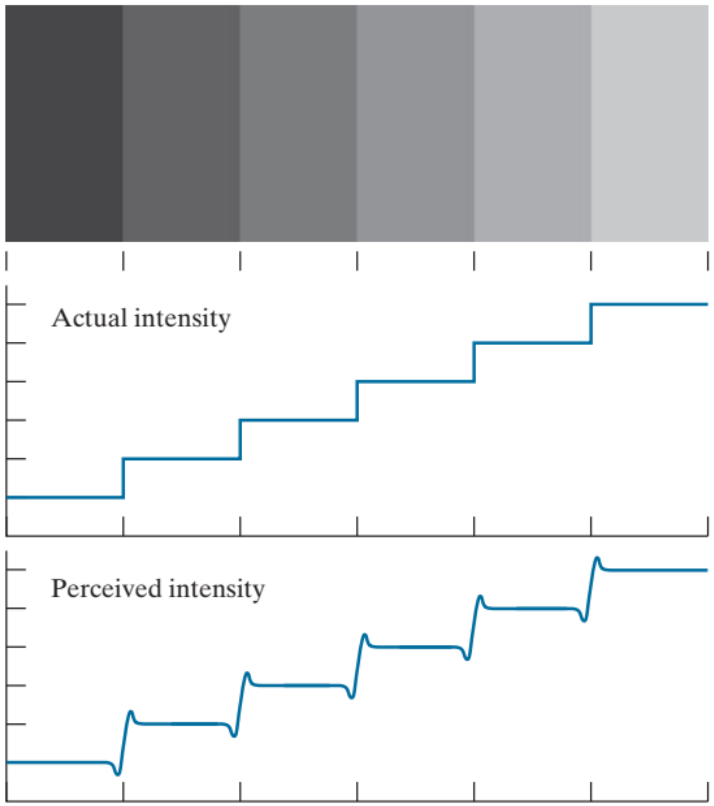
- BRIGHTNESS ADAPTATION AND DISCRIMINATION
- we actually perceive a brightness pattern that is strongly scalloped near the boundaries, as Fig. 2.7(c) shows. These perceived scalloped bands are called *Mach bands* after Ernst Mach, who first described the phenomenon in 1865.

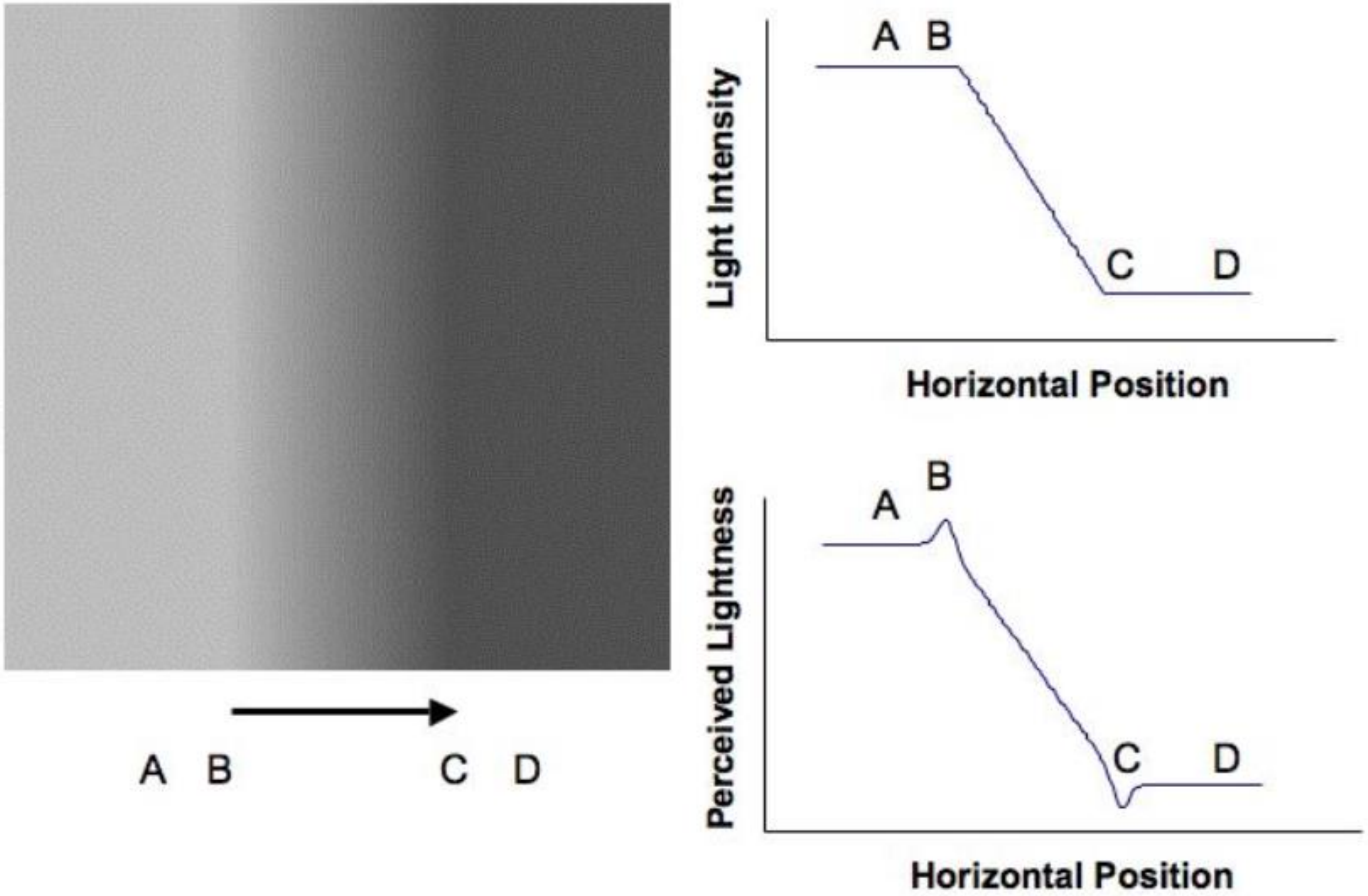
Near the boundaries where the brightness changes

a
b
c

FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.



Mach bands



A B
C D
Light Intensity
Horizontal Position
Perceived Lightness
Horizontal Position

- BRIGHTNESS ADAPTATION AND DISCRIMINATION
- *simultaneous contrast*, is that a region's perceived brightness does not depend only on its intensity, as Fig. 2.8 demonstrates. All the center squares have exactly the same intensity, but each appears to the eye to become darker as the background gets lighter. A more familiar example is a piece of paper that looks white when lying on a desk, but can appear totally black when used to shield the eyes while lookir

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.

A SIMPLE IMAGE FORMATION MODEL

- we denote images by two-dimensional functions of the form $f(x, y)$. The value of f at spatial coordinates (x, y) is a scalar quantity whose physical meaning is determined by the source of the image, and whose values are proportional to energy radiated by a physical source (e.g., electromagnetic waves).
- As a consequence, $f(x, y)$ must be nonnegative† and finite; that is,
- $0 \leq f(x, y) < \infty$

A SIMPLE IMAGE FORMATION MODEL

- Function $f(x, y)$ is characterized by two components: (1) the amount of source illumination incident on the scene being viewed, and (2) the amount of illumination reflected by the objects in the scene. Appropriately, these are called the *illumination* and *reflectance* components, and are denoted by $i(x, y)$ and $r(x, y)$, respectively. The two functions combine as a product to form $f(x, y)$:

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

- $0 \leq i(x, y) < \infty$
- $0 \leq r(x, y) \leq 1$
- Thus, reflectance is bounded by 0 (total absorption) and 1 (total reflectance). The nature of $i(x, y)$ is determined by the illumination source, and $r(x, y)$ is determined by the characteristics of the imaged objects.

- **The objects which shine due the light of other objects** are called illuminated objects. Example: Earth's moon, receives light from the sun and reflects it.
-

A SIMPLE IMAGE FORMATION MODEL

- The following numerical quantities illustrate some typical values of illumination and reflectance for visible light. On a clear day, the sun may produce in excess of 90 000, lm/m^2 of illumination on the surface of the earth. This value decreases to less than 10 000, lm/m^2 on a cloudy day. On a clear evening, a full moon yields about 0 .1 lm/m^2 of illumination. The typical illumination level in a commercial office is about 1 000, lm/m^2. Similarly, the following are typical values of $r(x, y)$: 0.01 for black velvet, 0.65 for stainless steel, 0.80 for flat-white wall paint, 0.90 for silver-plated metal, and 0.93 for snow.

A SIMPLE IMAGE FORMATION MODEL

- Let the intensity (gray level) of a monochrome image at any coordinates (*x, y*) be denoted by $\ell = f(x, y)$
- From Eqs. (2-4) through (2-6) it is evident that ℓ lies in the range

$$L_{\min} \leq \ell \leq L_{\max}$$

A SIMPLE IMAGE FORMATION MODEL

In theory, the requirement on $L_{\min}$ is that it be nonnegative, and on $L_{\max}$ that it be finite. In practice, $L_{\min} = i_{\min} r_{\min}$ and $L_{\max} = i_{\max} r_{\max}$. From Example 2.1, using average office illumination and reflectance values as guidelines, we may expect $L_{\min} \approx 10$ and $L_{\max} \approx 1000$ to be typical indoor values in the absence of additional illumination. The units of these quantities are lum/m^2. However, actual units seldom are of interest, except in cases where photometric measurements are being performed.

The interval $[L_{\min}, L_{\max}]$ is called the *intensity* (or *gray*) *scale*. Common practice is to shift this interval numerically to the interval $[0, 1]$, or $[0, C]$, where $\ell = 0$ is considered black and $\ell = 1$ (or C) is considered white on the scale. All intermediate values are shades of gray varying from black to white.

SAMPLING AND QUANTIZATION

To convert the continuous function f(x,y) to digital form we need to sample the continuous sensed data in both coordinates and in amplitude using finite and discrete sets of values.

- Digitizing the coordinate values is called ***sampling***.
- Digitizing the amplitude values is called ***quantization***.

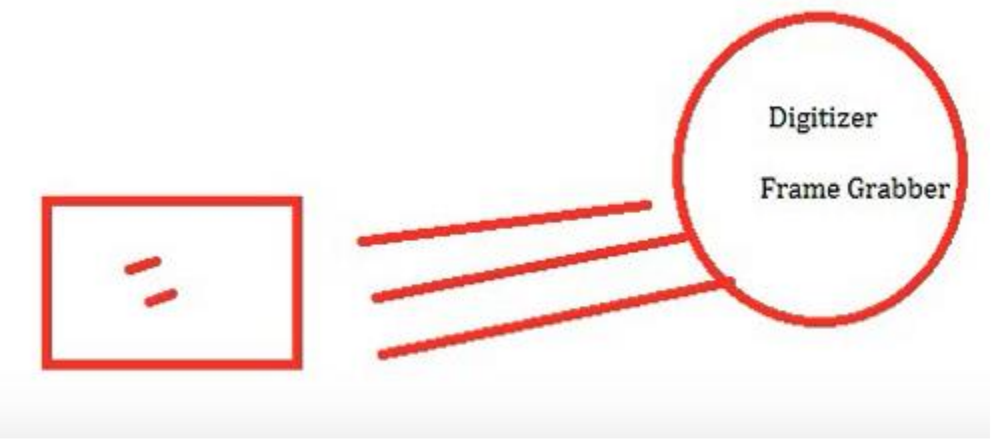
The number of selected values in the sampling process is known as the image spatial resolution. This is simply the number of pixels relative to the given image area

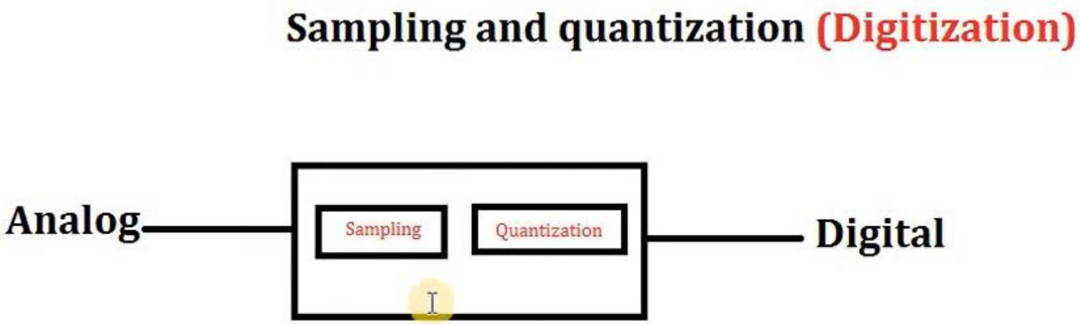
The number of selected values in the quantization process is called the grey-level (color level) resolution. This is expressed in terms of the number of bits allocated to the color levels.

The quality of a digitized image depends on the resolution parameters of both processes.

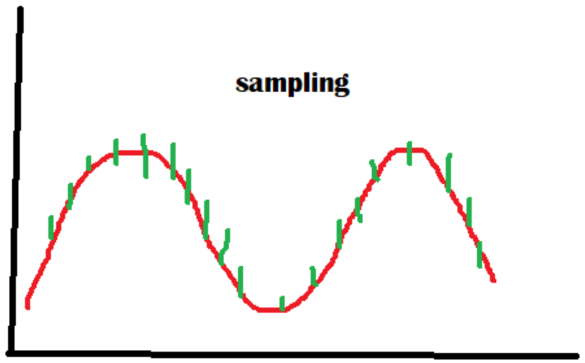
SAMPLING AND QUANTIZATION

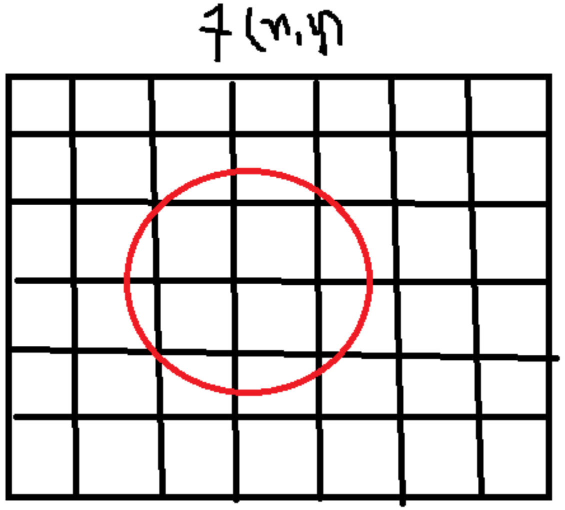
- Digitizer in camera do sampling and quantization.
- An image have coordinates and intensity (color).

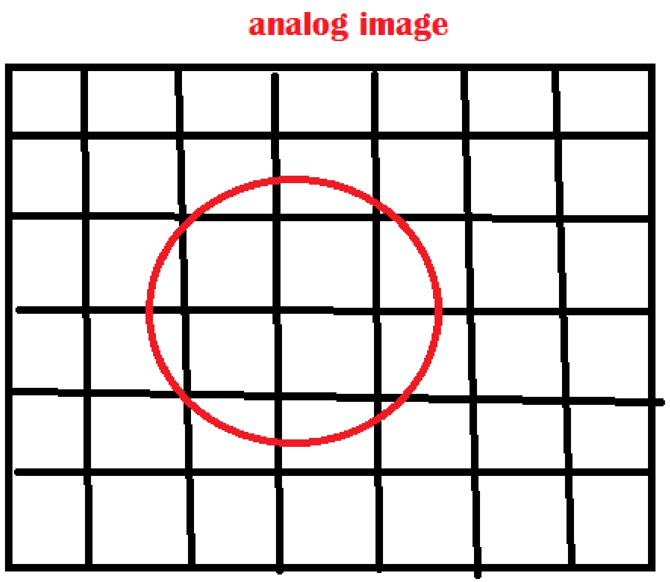


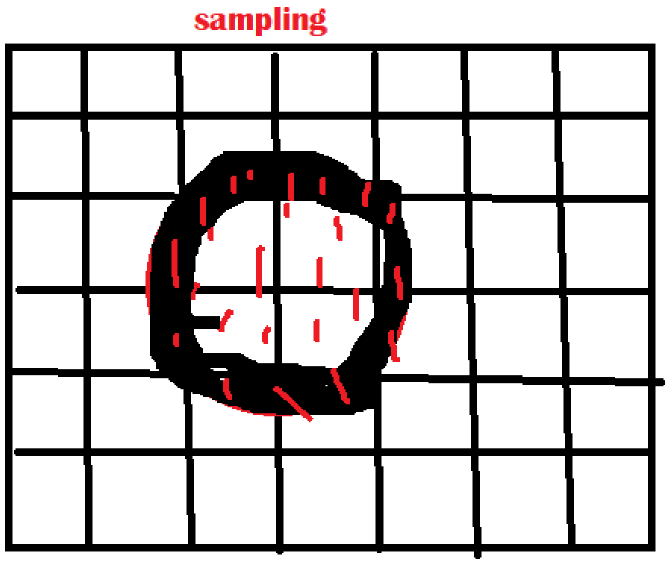


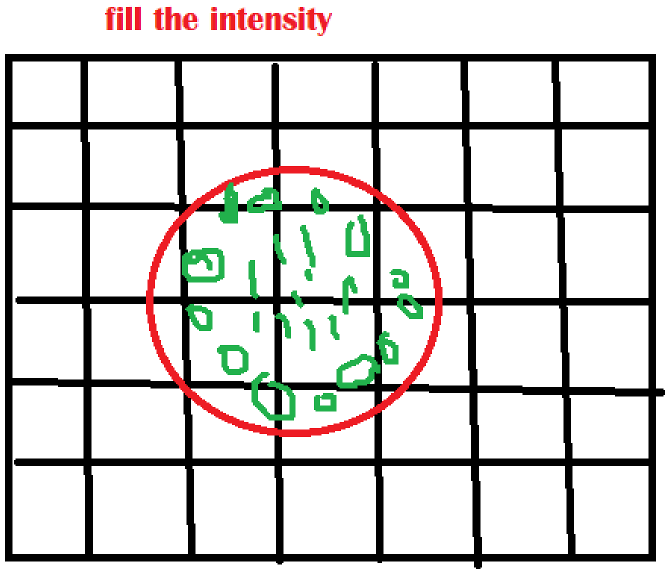
Sampling and quantization



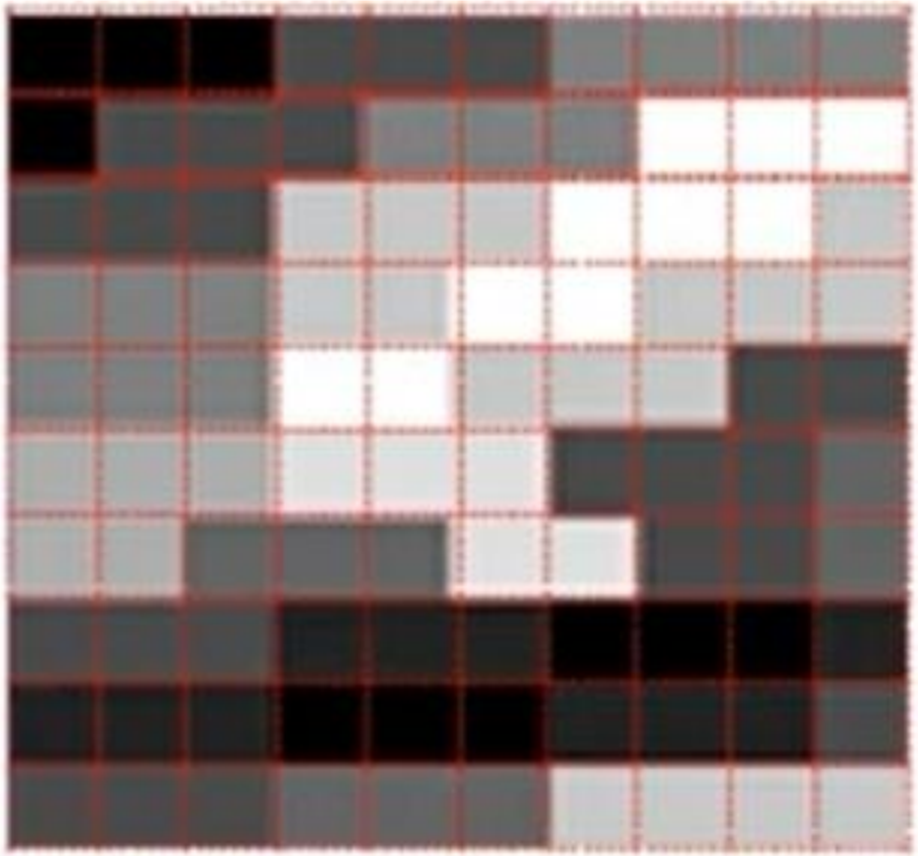








Sampling and quantization



0	0	0	75	75	75	128	128	128	128
0	75	75	75	128	128	128	255	255	255
75	75	75	200	200	200	255	255	255	200
128	128	128	200	200	255	255	200	200	200
128	128	128	255	255	200	200	200	75	75
128	128	128	225	225	225	75	75	75	100
128	128	128	100	100	225	225	75	75	100
75	75	75	35	35	35	0	0	0	35
35	35	35	0	0	0	35	35	35	75
75	75	75	100	100	100	200	200	200	200

SAMPLING AND QUANTIZATION

- We can capture a picture using the sensors in imaging tools, such as a camera. The sensors produce an image in the form of an analog signal, which is then digitized to produce a digital image.

- A digital image is a two-dimensional function f(x,y) where x and y indicate the position in an image. The f(x,y) function holds a discrete value called the intensity value.

SAMPLING AND QUANTIZATION

- A digital image f(x,y) consists of coordinates x and y. Additionally, it contains the function's amplitude. Quantization refers to digitizing the amplitudes, while sampling refers to digitizing the coordinate values.

- The sensors placed in the image acquisition device capture the projected continuous image. Later, this digitizes to form a digital image suitable for real-time applications. For example, let's see the difference between a continuous and digital image:

SAMPLING AND QUANTIZATION

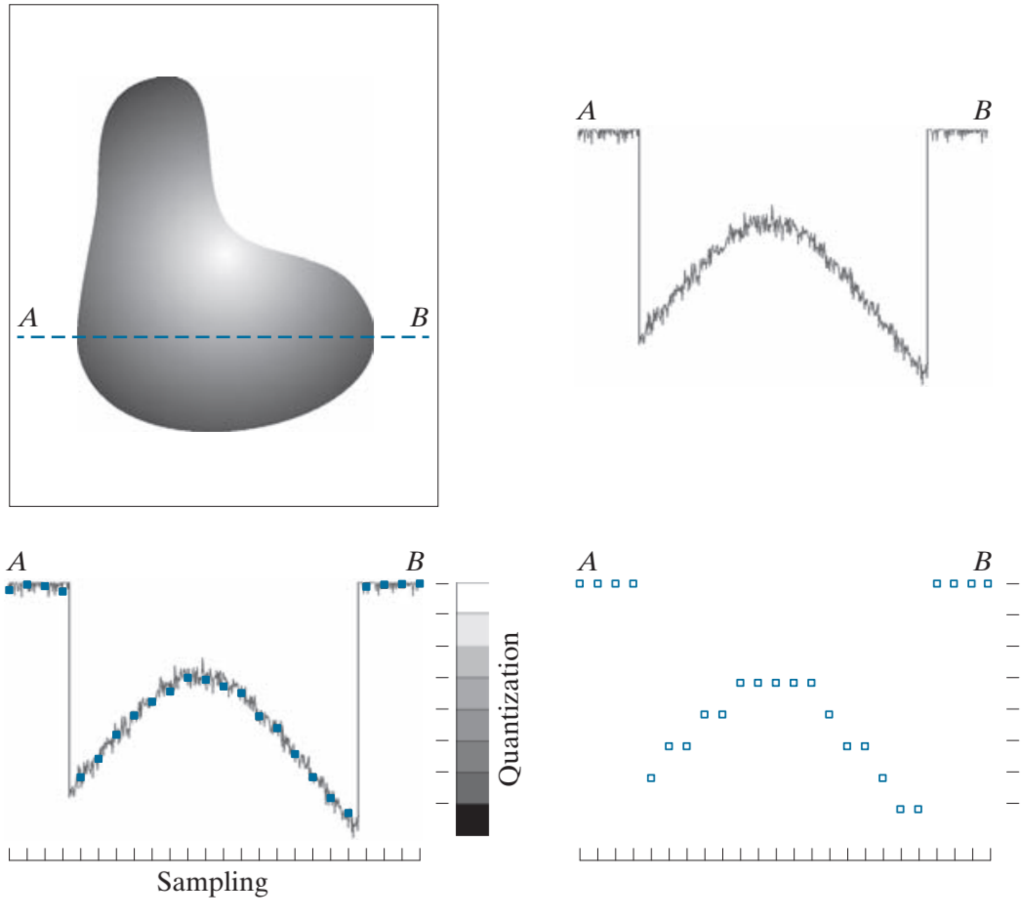
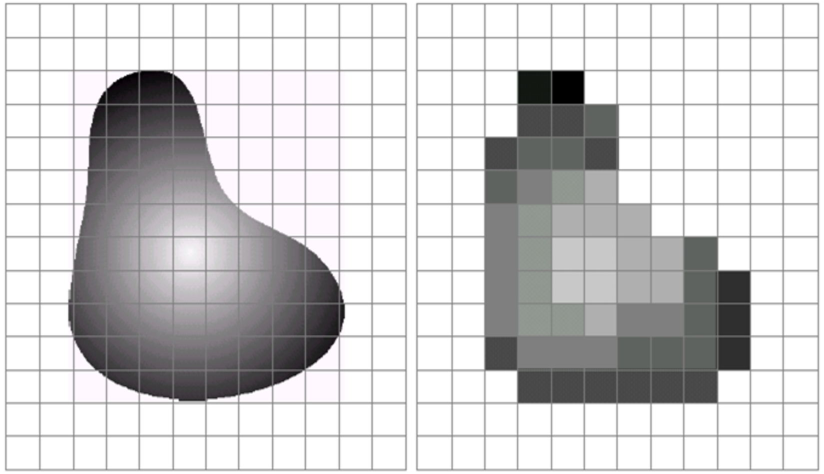


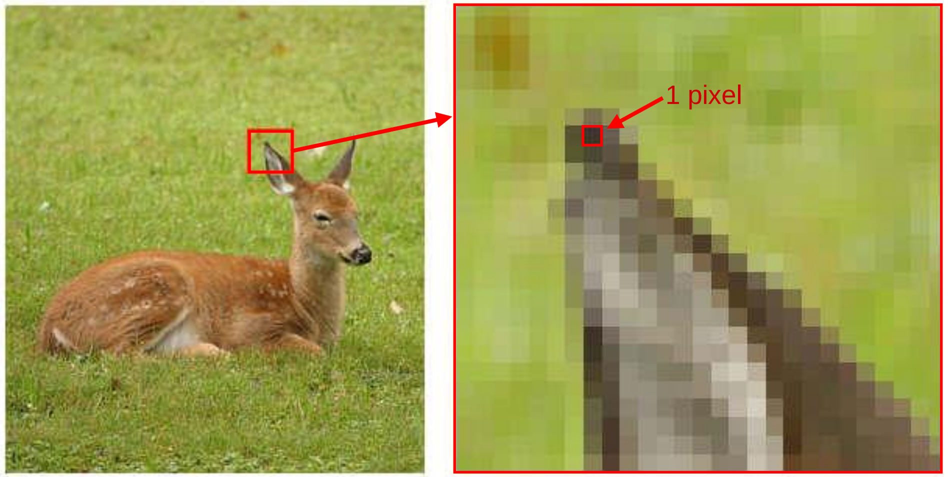
FIGURE 2.16
(a) Continuous image. (b) A scan line showing intensity variations along line *AB* in the continuous image. (c) Sampling and quantization. (d) Digital scan line. (The black border in (a) is included for clarity. It is not part of the image).

SAMPLING AND QUANTIZATION

Pixel values typically represent gray levels, colors, heights, etc

Remember *digitization* implies that a digital image is an *approximation* of a real scene





Digital image Representation – Revised

A monochrome digital image is a 2-dimensional light intensity function f (x,y) whose independent variables (x,y) are digitized through spatial sampling, and whose intensity values are quantized by a finite uniformly spread grey-levels. i.e. an image f can be represented as a 2-dimensional array:

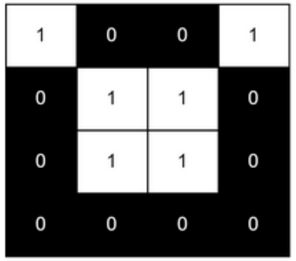
$$
f = \begin{pmatrix}
f(1,1) & f(1,2) & f(1,3) & \dots & f(1,n) \\
f(2,1) & f(2,2) & f(2,3) & \dots & f(2,n) \\
f(3,1) & f(3,2) & f(3,3) & \dots & f(3,n) \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
f(m,1) & f(m,2) & f(m,3) & \dots & f(m,n)
\end{pmatrix}
$$

Usually, m=n and the number of gray levels are $g=2^k$ for some k. The spatial resolution is mn and g is the grey level resolution.

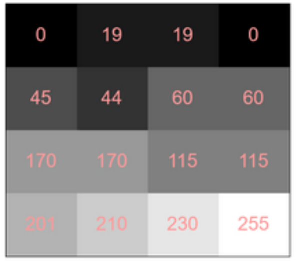
RGB-based color images are represented similarly except that *f*(i,j) is a 3D vector representing intensity of the three primary colors at the (i,j) pixel position,

Digital Images

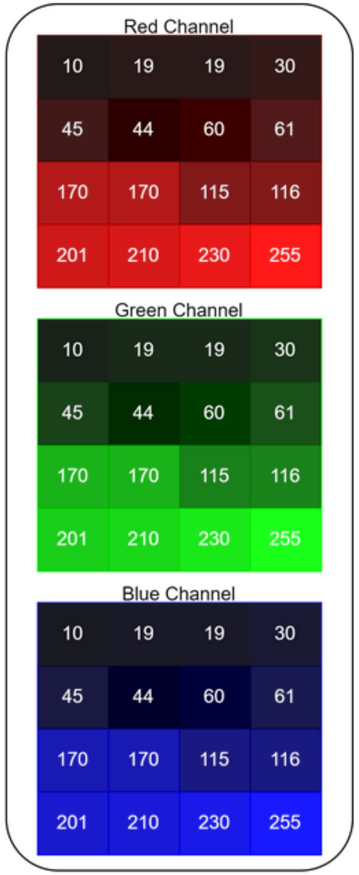
- **Digital images are basically of three types: monochrome or binary images, grayscale images, and color images.**
- The pixel value of a binary image at a specific location (x,y) usually holds the value 0 for black or 1 for white. Grayscale images have intensity values ranging from 0 to 255, where 0 is black, gradually fading to 255, which is white. Additionally, color images like RGB images contain three channels red, green, and blue channels. Each channel in an RGB image has intensity values ranging from 0-255.



Binary image



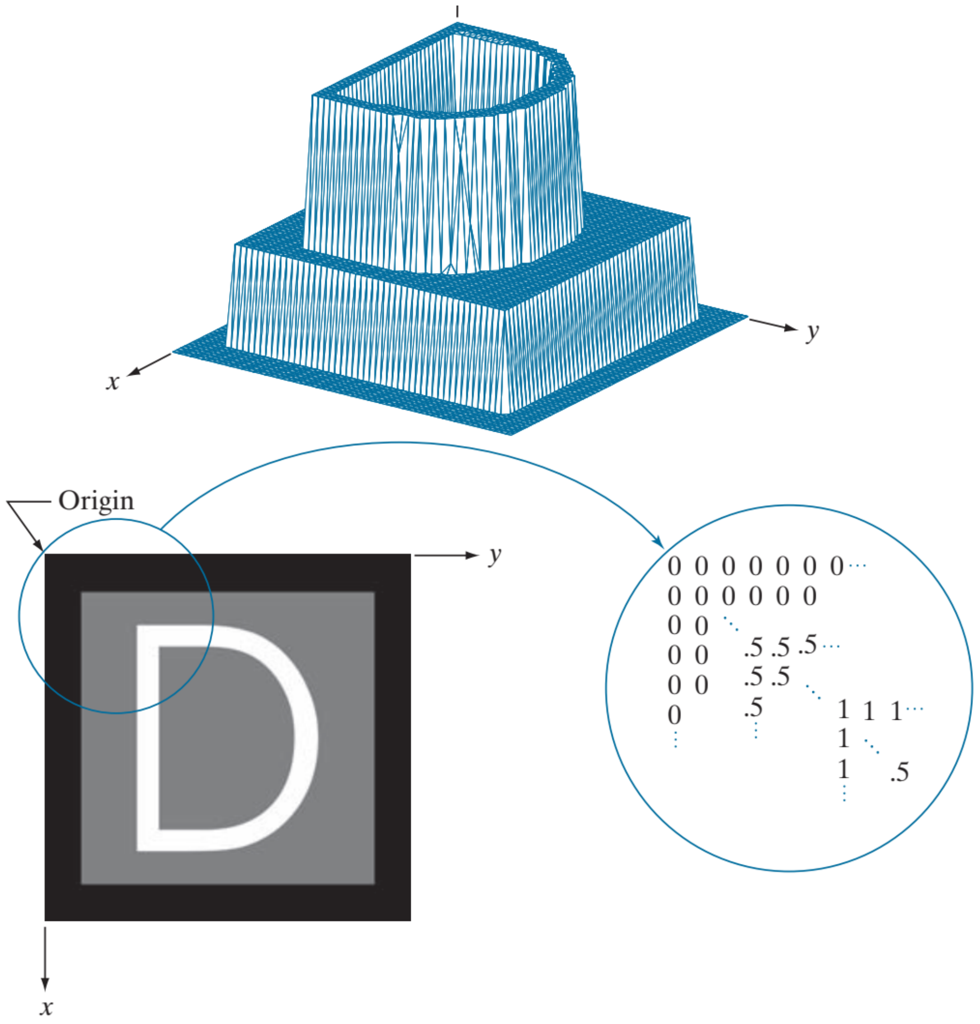
Grayscale image



RGB image

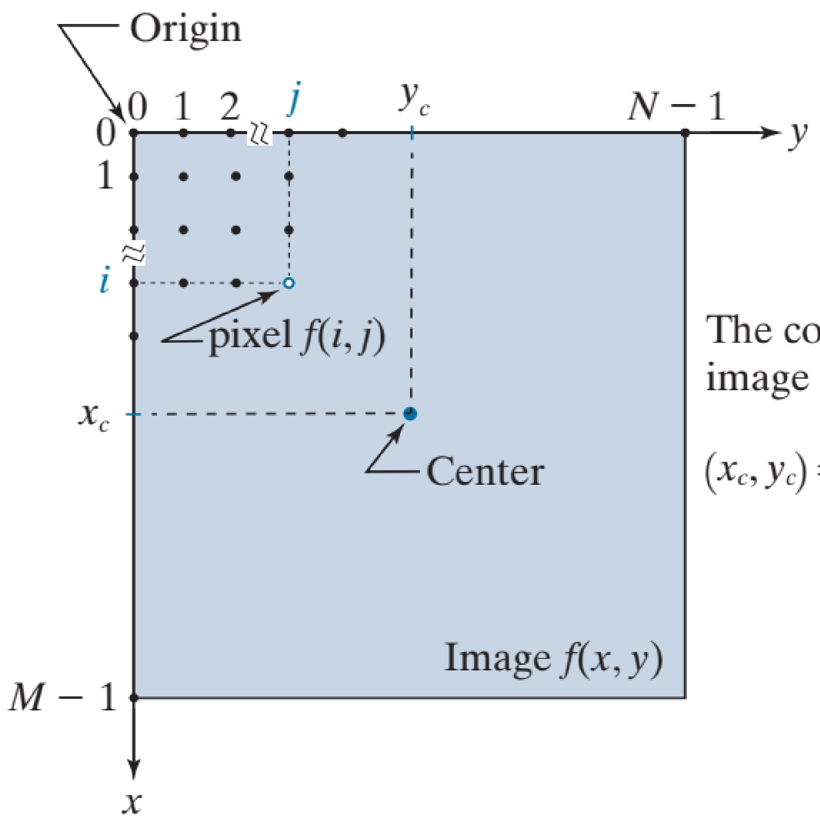
REPRESENTING DIGITAL IMAGES

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. (The numbers 0, .5, and 1 represent black, gray, and white, respectively.)



REPRESENTING DIGITAL IMAGES

FIGURE 2.19 Coordinate convention used to represent digital images. Because coordinate values are integers, there is a one-to-one correspondence between x and y and the rows (r) and columns (c) of a matrix.



The coordinates of the image center are

$$(x_c, y_c) = \left(\text{floor}\left(\frac{M}{2}\right), \text{floor}\left(\frac{N}{2}\right)\right)$$

REPRESENTING DIGITAL IMAGES

The *center* of an $M \times N$ digital image with origin at $(0,0)$ and range to $(M-1, N-1)$ is obtained by dividing M and N by 2 and rounding *down* to the nearest integer. This operation sometimes is denoted using the floor operator, $\lfloor \bullet \rfloor$, as shown in Fig. 2.19. This holds true for M and N even *or* odd. For example, the center of an image of size 1023×1024 is at $(511, 512)$. Some programming languages (e.g., MATLAB) start indexing at 1 instead of at 0. The center of an image in that case is found at $(x_c, y_c) = \left(\text{floor}(M/2) + 1, \text{floor}(N/2) + 1\right)$.

Spatial Resolution

The spatial resolution of a digital image reflects the amount of details that one can see in the image (i.e. the ratio of pixel “area” to the area of the image display).

If an image is spatially sampled at mxn pixels, then the larger mn the finer the observed details.

For a fixed image area, the noticeable image quality is directly proportional to the value of mn results.

Reduced spatial resolution, within the same area, may result in what is known as Checkerboard pattern.

However beyond a certain fine spatial resolution, the human eye may not be able to notice improved quality.

Spatial Resolution Vs Image Quality

Decreasing spatial resolution reduces image quality proportionally - Checkerboard pattern.

† Images extracted from DIP, 2nd Edition, Gonzalez & Woods, PH.

Spatial Resolution Vs Image Quality - continued

The checkerboard effect is not visible if a lower–resolution image is displayed in a proportionately small window.

Effect of grey level resolution

Image f =

123	162	200	147	93
137	157	165	232	189
151	155	152	141	130
205	101	100	193	115
250	50	75	88	100

8 bits

$f(i,j) \leftarrow int(f(i,j)/2)$

61	80	100	73	46
68	78	82	116	94
75	77	76	70	65
102	50	50	96	57
125	25	37	43	50

7 bits

30	40	50	36	23
34	39	41	58	47
37	38	38	35	32
51	25	25	48	28
62	12	18	21	25

6 bits

15	20	25	18	11
17	19	20	29	23
18	19	19	17	16
25	12	12	24	14
31	6	9	10	12

5 bits

7	10	12	9	5
8	9	10	14	11
9	9	9	8	8
12	6	6	12	7
15	3	4	5	6

4 bits

3	5	6	4	2
4	4	5	7	5
4	4	4	4	4
6	3	3	6	3
7	1	2	2	3

3 bits

1	2	3	2	1
2	2	2	3	2
2	2	2	2	2
3	1	1	3	1
3	0	1	1	1

2 bits

0	1	1	1	0
1	1	1	1	1
1	1	1	1	1
1	0	0	1	0
1	0	0	0	0

1 bits

Original image f is reasonably bright, but gradually the pixels get darker as the Grey-level resolution decreases.

Effect of grey level resolution

8 bits

7 bits

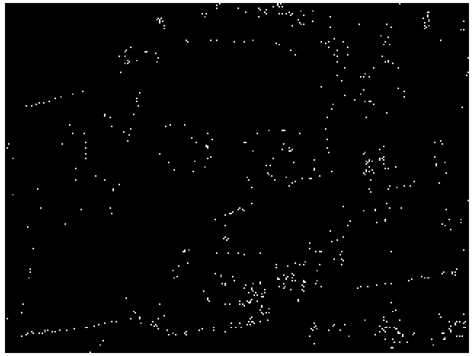
6 bits

5 bits

4 bits

3 bits

2 bits



1 bit

0 bits !!!

Sometimes, the range of values spanned by the grayscale is referred to as the *dynamic range*, a term used in different ways in different fields. Here, we define the dynamic range of an imaging system to be the ratio of the maximum measurable intensity to the minimum detectable intensity level in the system. As a rule, the upper limit is determined by *saturation* and the lower limit by *noise*, although noise can be present also in lighter intensities.

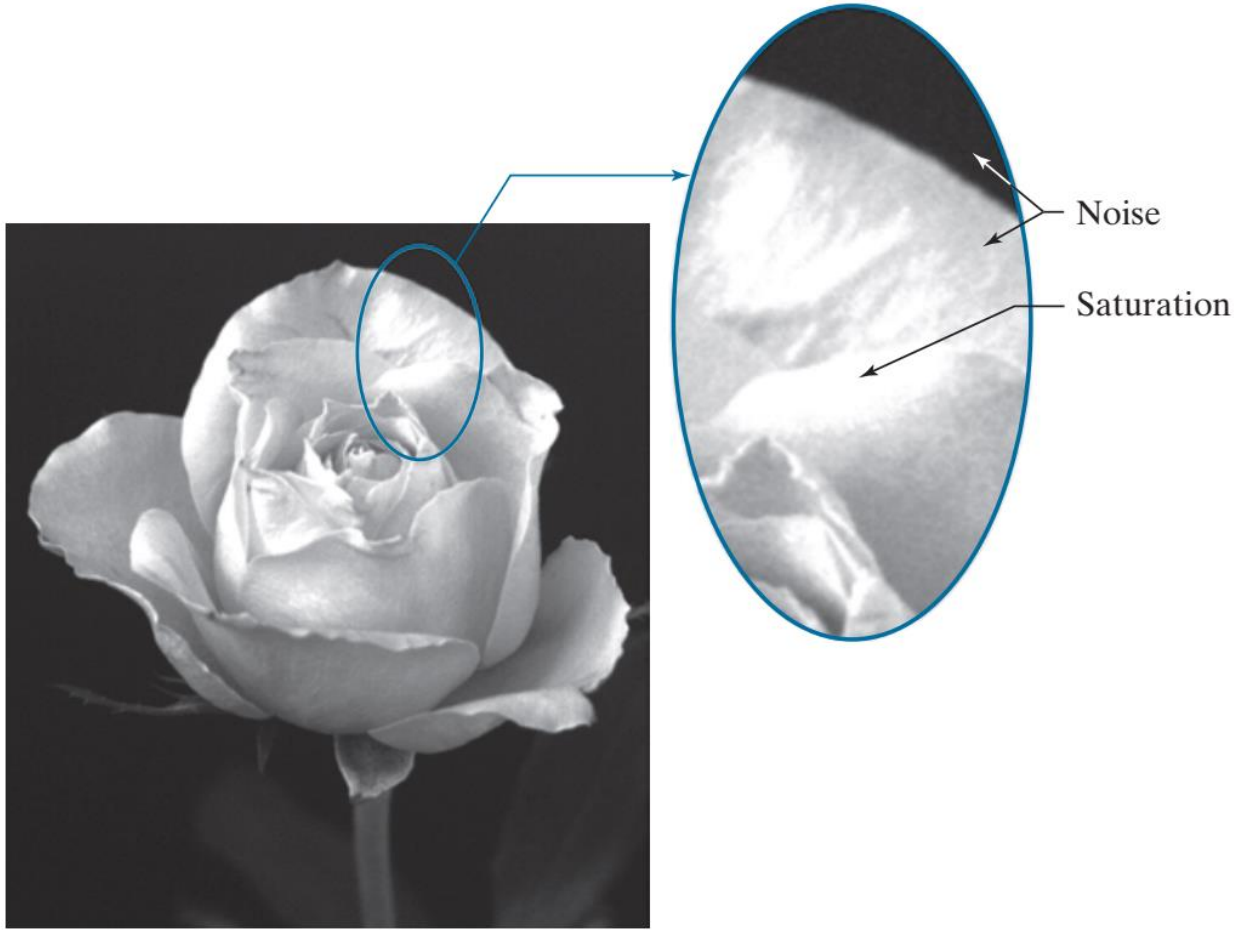


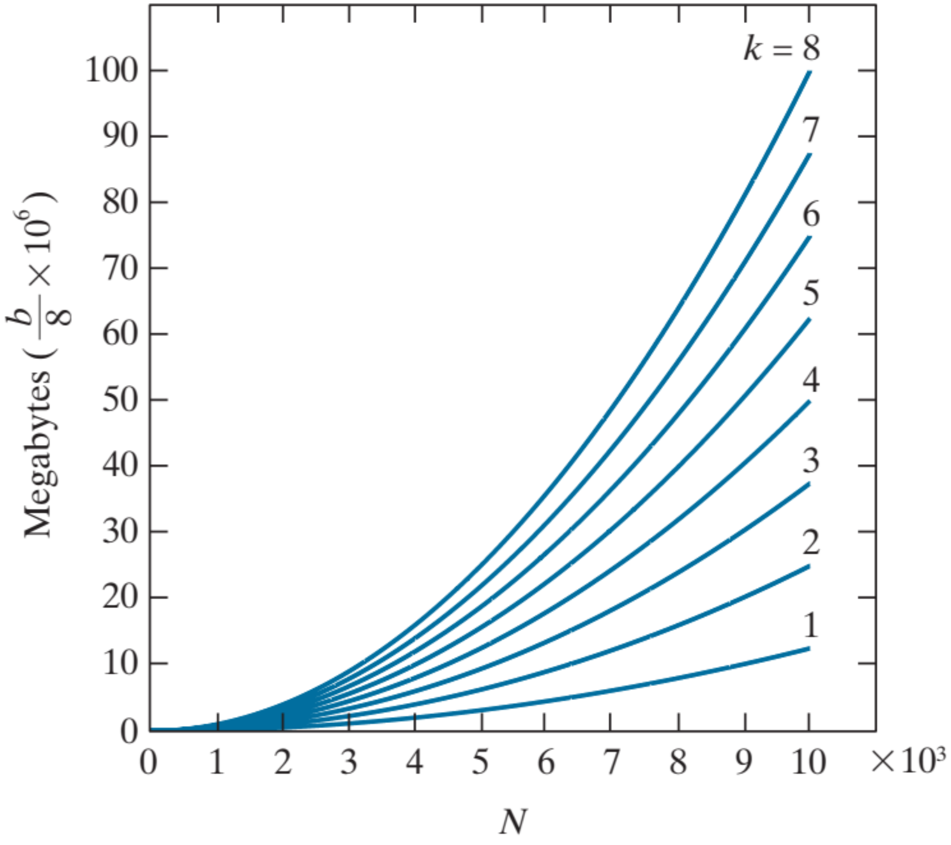
FIGURE 2.20 An image exhibiting saturation and noise. Saturation is the highest value beyond which all intensity values are clipped (note how the entire saturated area has a high, constant intensity level). Visible noise in this case appears as a grainy texture pattern. The dark background is noisier, but the noise is difficult to see.

REPRESENTING DIGITAL IMAGES

- The number, *b*, of bits required to store a digital image is
- b = M * N * K
- When M = N
- B = N^2 * k

Image storage

FIGURE 2.21
Number of megabytes required to store images for various values of N and k.



- The size of a digital image file depends on its resolution, color depth, and file format.
- Given that the image has a resolution of m = 1000 x n = 1000 pixels and a color depth of k = 8 bits per pixel (bpp), we can calculate the size of the image as follows:
- Number of pixels = m x n = 1000 x 1000 = 1,000,000 pixels
- Size per pixel = k/8 bytes per pixel = 8/8 = 1 byte per pixel
- Therefore, the size of the image file in bytes is:
- Size in bytes = Number of pixels x Size per pixel = 1,000,000 x 1 = 1,000,000 bytes
- To convert this to kilobytes (KB) and megabytes (MB), we can use the following conversion factors:
- 1 KB = 1024 bytes
- 1 MB = 1024 KB
- So, the size of the image file in kilobytes and megabytes is:
- Size in KB = Size in bytes / 1024 = 1,000,000 / 1024 = 976.5625 KB (approx.)
- Size in MB = Size in KB / 1024 = 976.5625 / 1024 = 0.95367 MB (approx.)
- Therefore, to store this digital image, we would need approximately 1,000,000 bytes, 976.5625 KB or 0.95367 MB of storage space.

SPATIAL AND INTENSITY RESOLUTION

- Intuitively, *spatial resolution* is a measure of the smallest discernible detail in an image. Quantitatively, spatial resolution can be stated in several ways, with *line pairs per unit distance*, and *dots (pixels) per unit distance* being common measures. Suppose that we construct a chart with alternating black and white vertical lines, each of width *W* units (*W* can be less than 1). The width of a *line pair* is thus 2*W*, and there are *W* 2 line pairs per unit distance. For example, if the width of a line is 0.1 mm, there are 5 line pairs per unit distance (i.e., per mm). A widely used definition of image resolution is the largest number of *discernible* line pairs per unit distance (e.g., 100 line pairs per mm). Dots per unit distance is a measure of image resolution used in the printing and publishing industry. In the U.S., this measure usually is expressed as *dots per inch* (dpi).

SPATIAL AND INTENSITY RESOLUTION

- DPI stands for **Dots per Inch**, referring to the number of ink droplets a printer will produce per inch while printing an image. The more dots of ink per inch the picture has, the more detail you will see when printed.

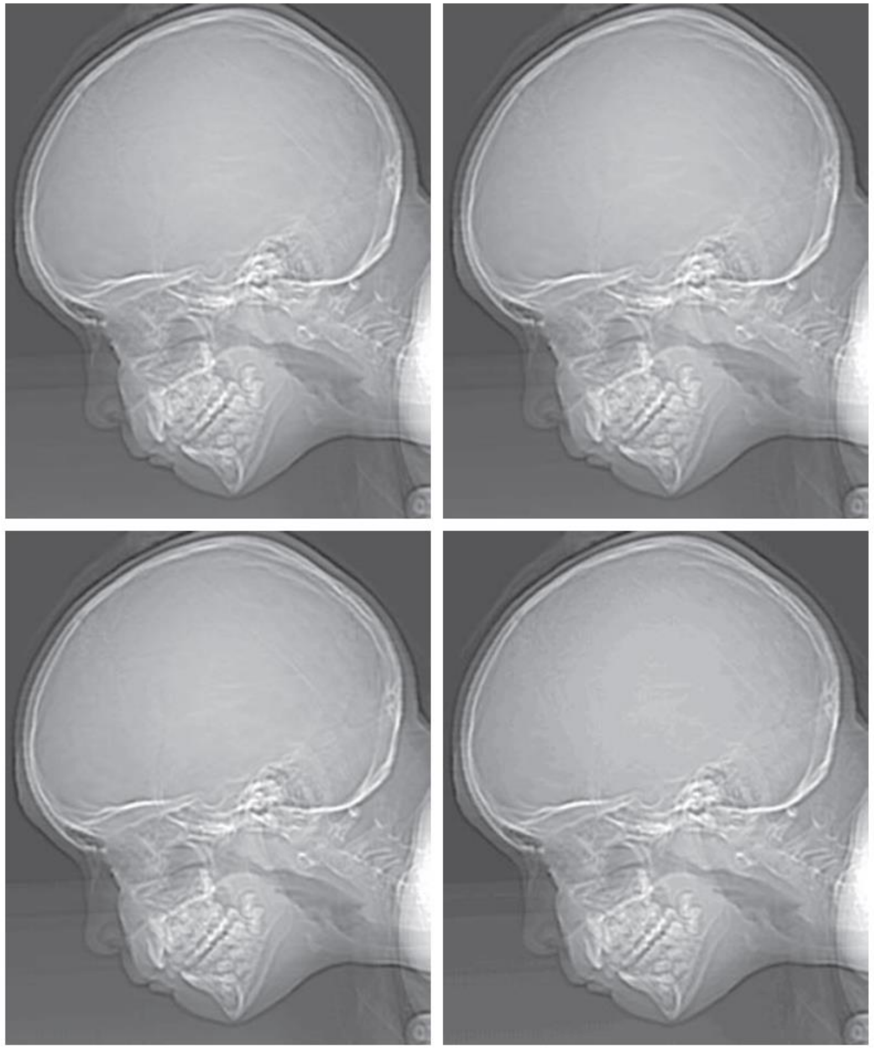
a b
c d

FIGURE 2.23 Effects of reducing spatial resolution. The images shown are at: (a) 930 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi.

SPATIAL AND INTENSITY RESOLUTION

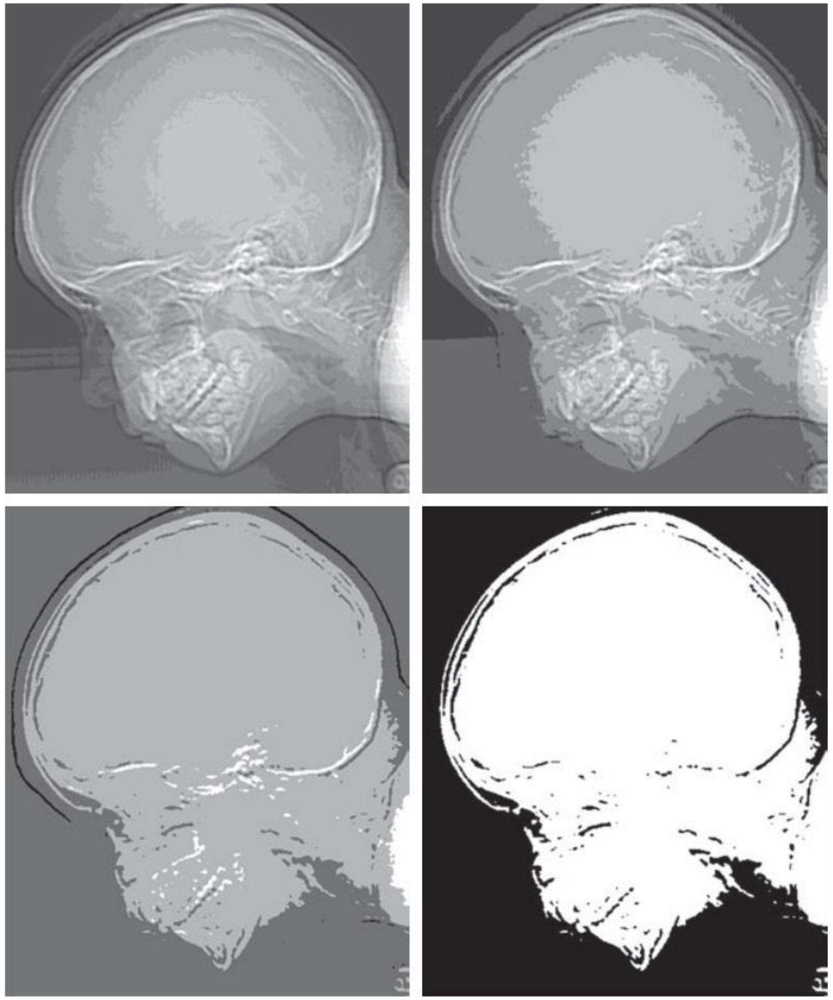
a b
c d

FIGURE 2.24
(a) 774 × 640, 256-level image. (b)-(d) Image displayed in 128, 64, and 32 intensity levels, while keeping the spatial resolution constant. (Original image courtesy of the Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



e f
g h

FIGURE 2.24
(*Continued*)
(e)-(h) Image displayed in 16, 8, 4, and 2 intensity levels.



SOME BASIC RELATIONSHIPS BETWEEN PIXELS

- A pixel *p* at coordinates (*x, y*) has two horizontal and two vertical neighbors with coordinates.

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

- This set of pixels, called the 4-*neighbors* of *p*, is denoted *N* 4(*p*). The four *diagonal* neighbors of *p* have coordinates
- $(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)$
- and are denoted *N D*(*p*). These neighbors, together with the 4-neighbors, are called the 8-*neighbors* of *p*, denoted by *N* 8(*p*). The set of image locations of the neighbors of a point *p* is called the *neighborhood* of *p*. The neighborhood is said to be *closed* if it contains *p*. Otherwise, the neighborhood is said to be *open*.

ADJACENCY, CONNECTIVITY, REGIONS, AND BOUNDARIES

- Let V be the set of intensity values used to define adjacency. In a binary image, $V = \{1\}$ if we are referring to adjacency of pixels with value 1. In a grayscale image, the idea is the same, but set V typically contains more elements. For example, if we are dealing with the adjacency of pixels whose values are in the range 0 to 255, set V could be any subset of these 256 values. We consider three types of adjacency:
- **1.** 4-*adjacency*. Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.
  2. 8-*adjacency*. Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.
  3. *m-adjacency* (also called *mixed adjacency*). Two pixels p and q with values from V are m-adjacent if
- **(a)** q is in $N_4(p)$, *or*
  (b) q is in $N_D(p)$ *and* the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.