Unit 2
DIGITAL IMAGE FUNDAMENTALS

Image sensing and acquisition,
Basic concept of sampling and quantization,
representations of digital image,
spatial and grey level resolution,
zooming and shrinking of image,
Basic relationship between pixels.

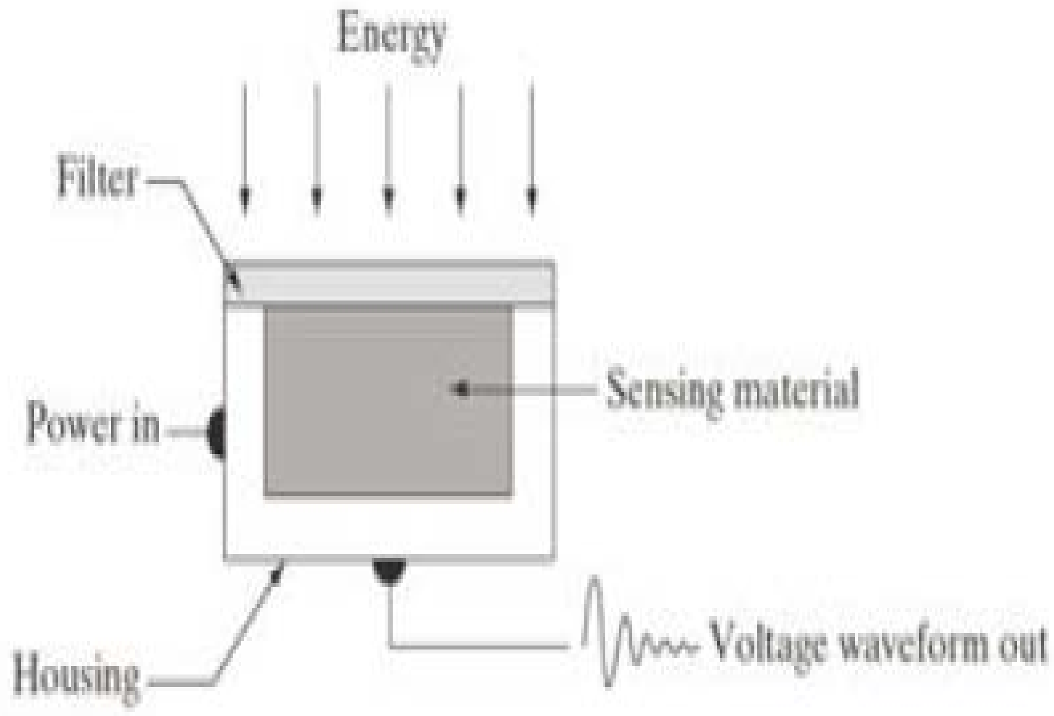
What is a Digital Image?

- Real Images
  - A real image can be represented as a two-dimensional continuous light intensity function $g(x,y)$; where x and y denote the spatial coordinates and the value of g is proportional to the brightness (or gray level) of the image at that point.

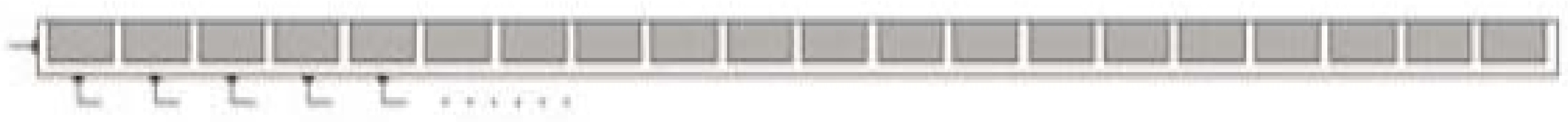
Image sensing and acquisition

1. Single imaging sensor
2. Line sensor
3. Array sensor image sensing and acquisition

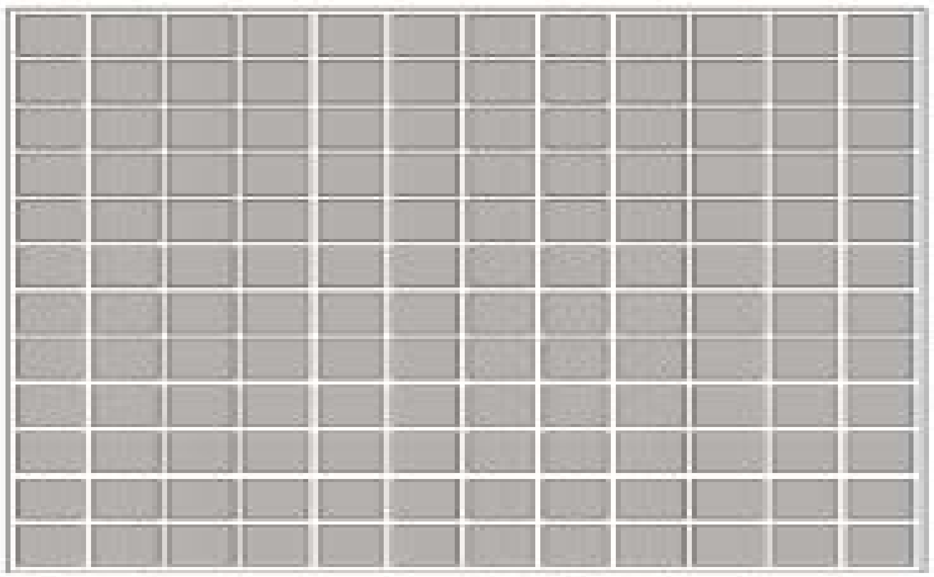
Single imaging sensor



Line sensor

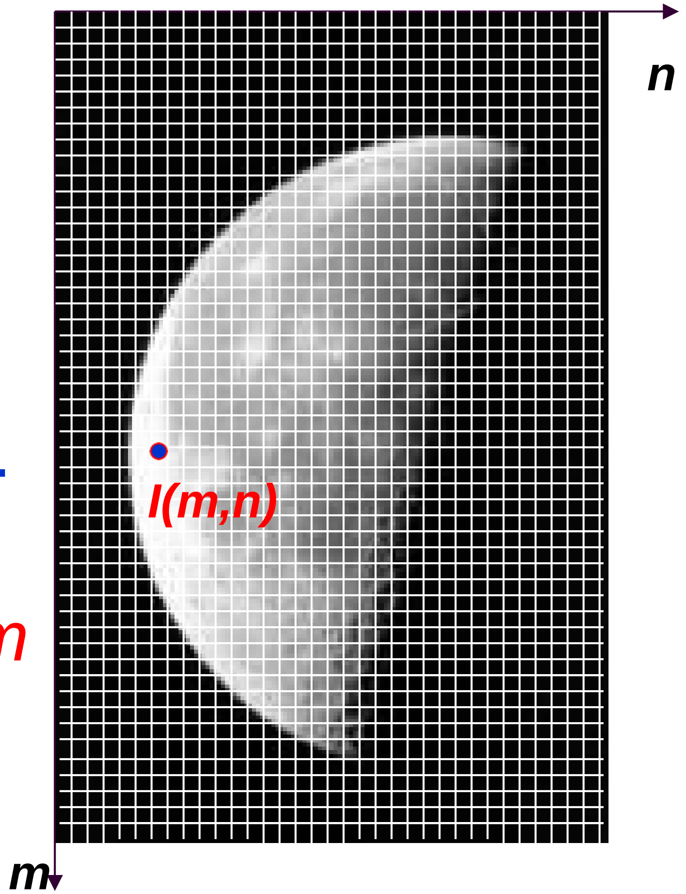


Array sensor mage sensing and acquisition



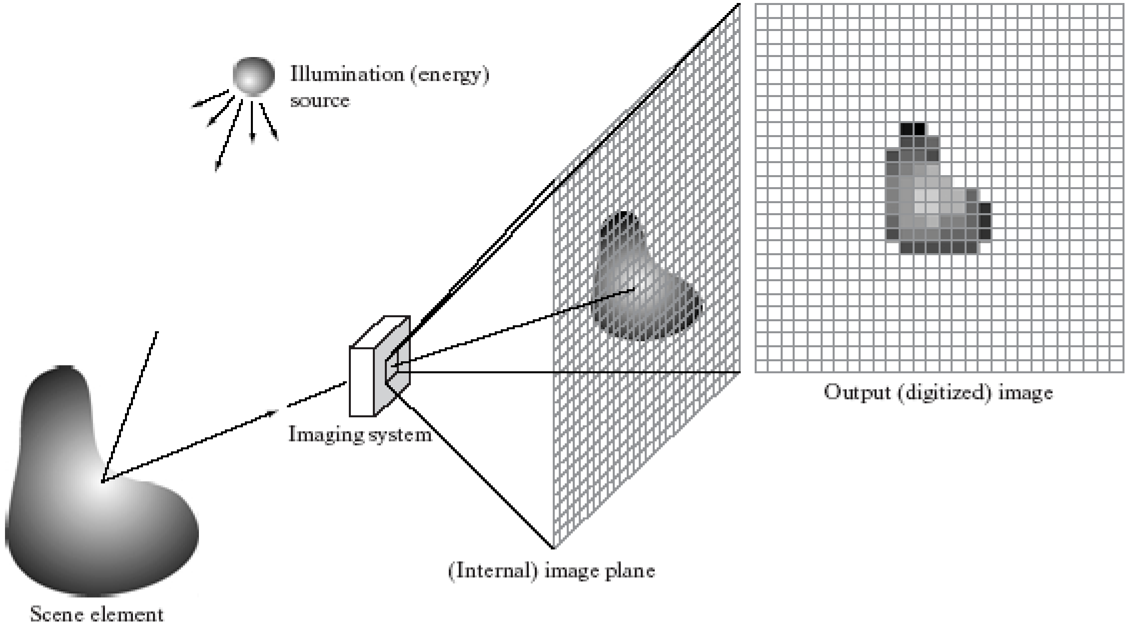
What is a Digital Image?

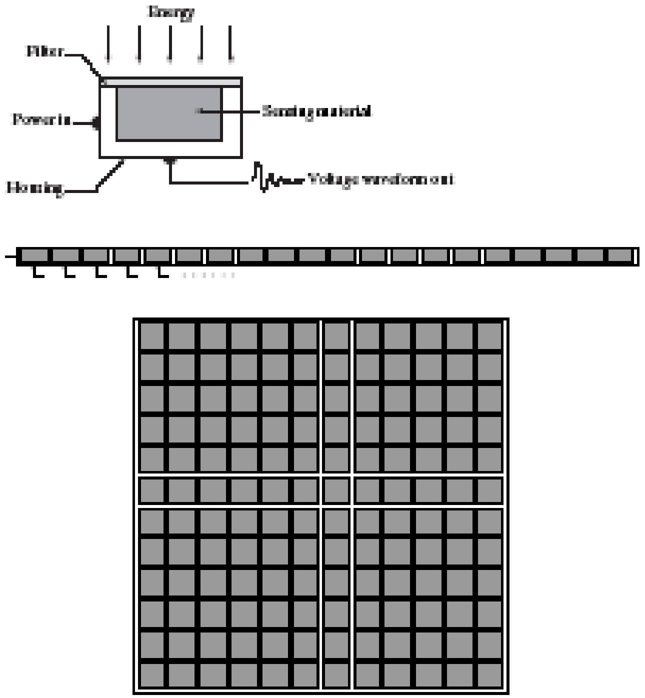
- Digital Images
  - A digital image is the *sampling* and *quantization* of a two-dimensional real image both in spatial coordinates and brightness.
  - A digital image *I(m,n)* = <u>*samples of*</u> *g(x,y)*;   where *m* and *n* are integers, and *I* is the intensity at *m* and *n* .



Digital Image Acquisition

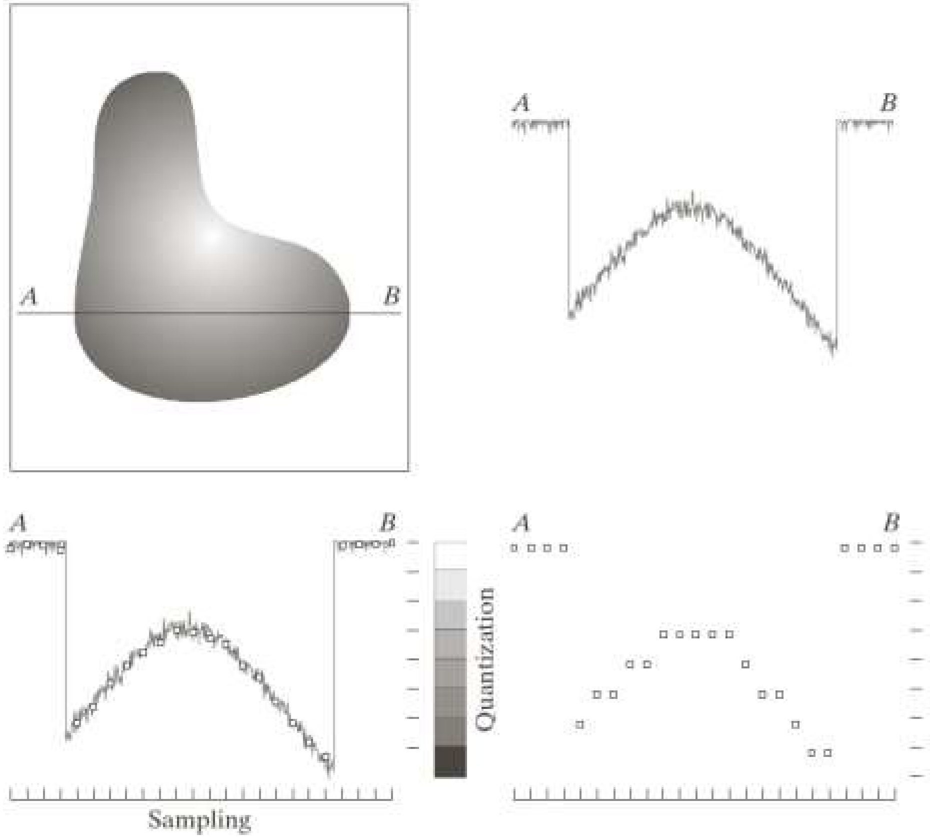
- A digital imaging system (digital camera).





Digital Image Acquisition

- **Sampling & Quantization**

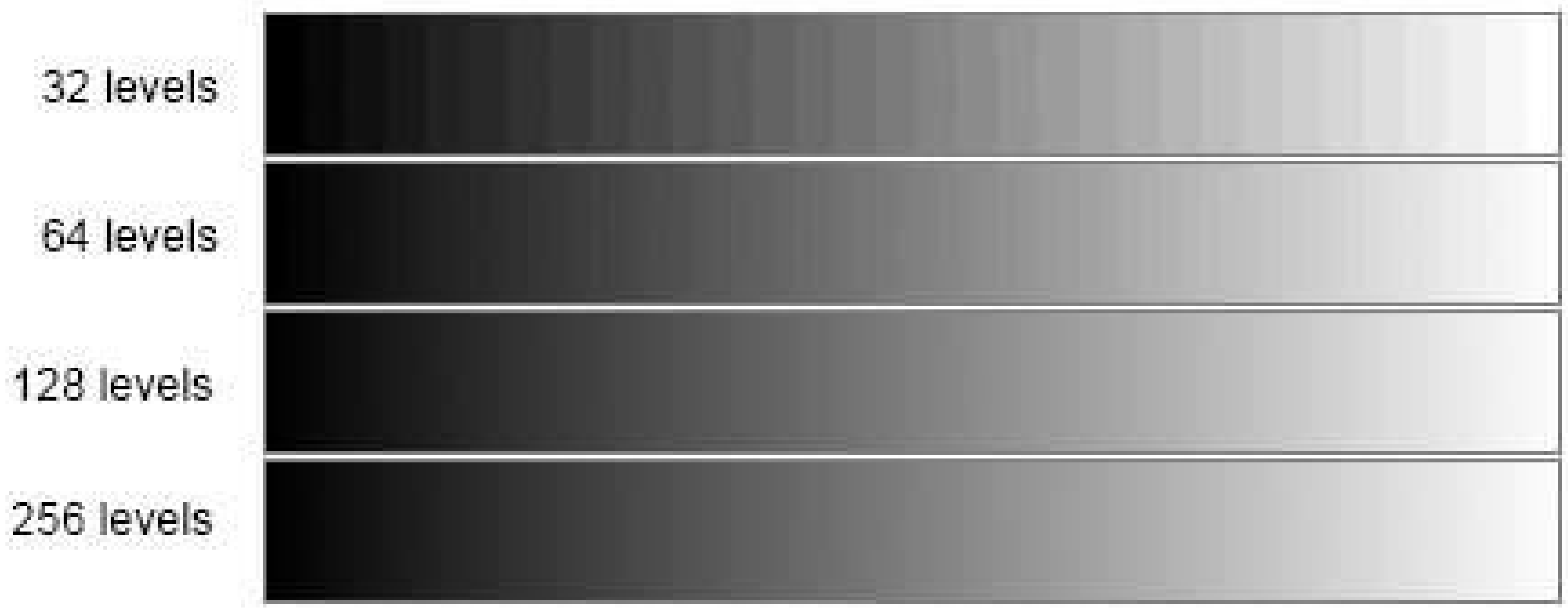


a b
c d

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.

Digital Image Acquisition

- What is the best *quantization* level ?



- Digital images are typically quantized to 256 gray levels.

Digital Image Acquisition

- **Sampling & Quantization**

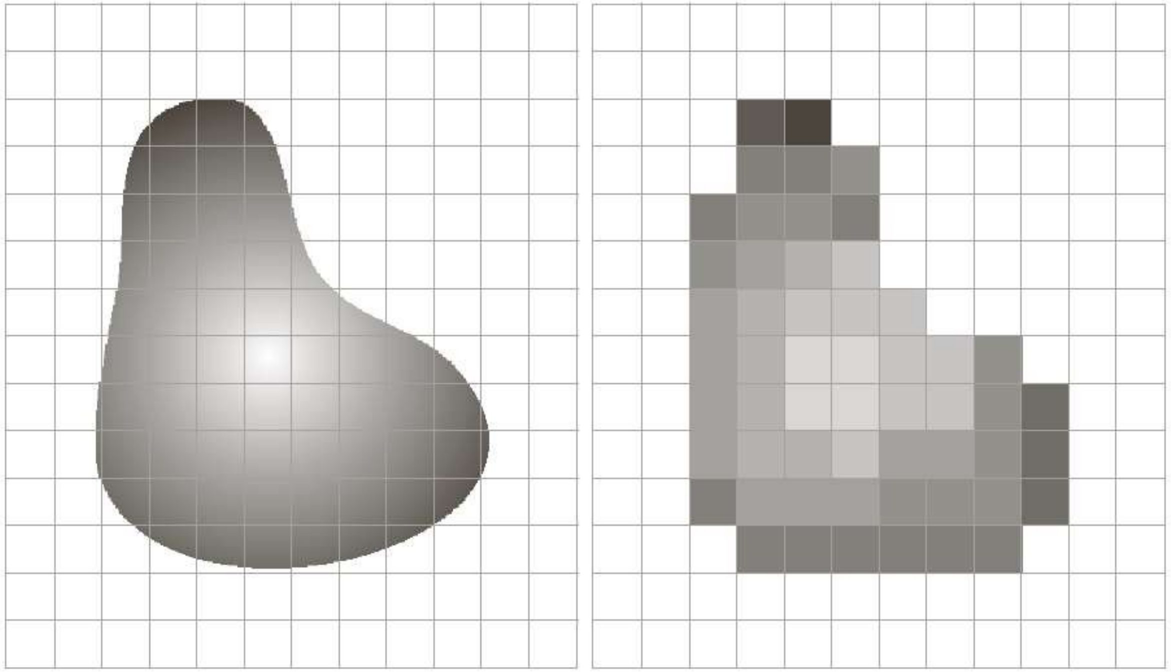
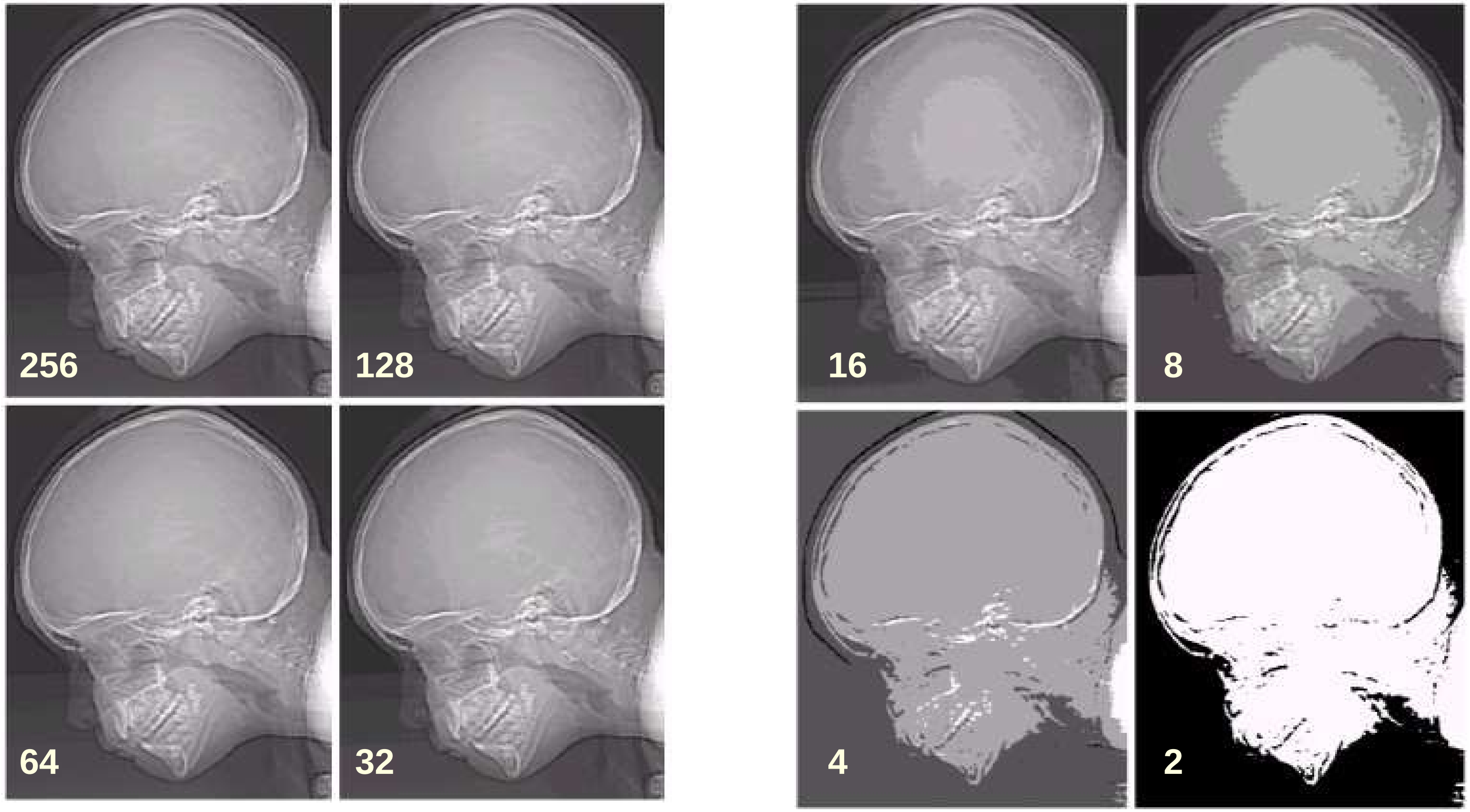


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Digital Image Acquisition

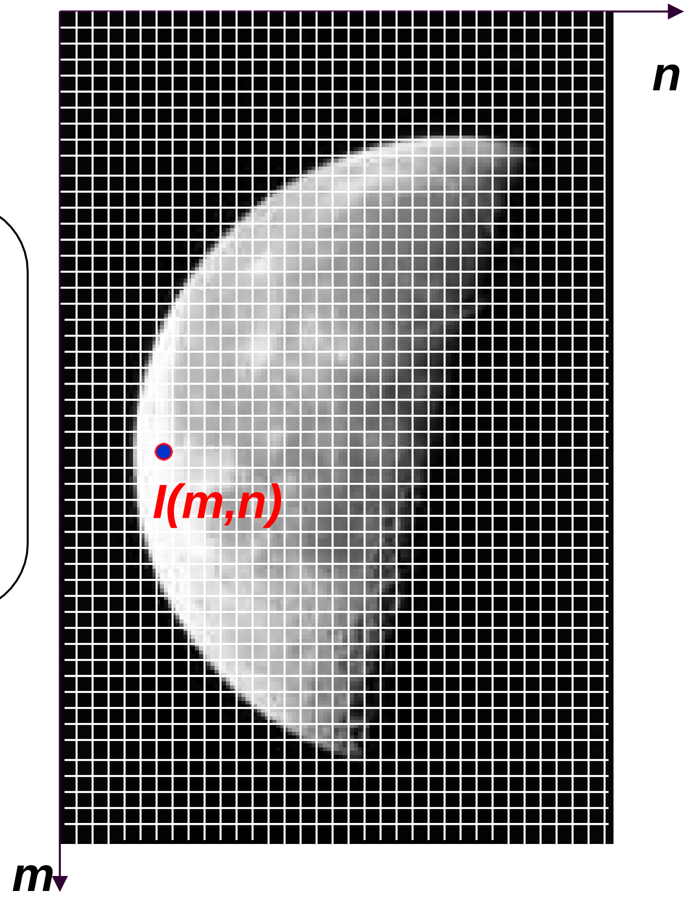
- **Effect of Quantization**



Digital Image Representation

- A digital image can be represented as a two-dimensional matrix.

$$
I(mn) = \begin{pmatrix}
i(1,1) & i(1,2) & \ldots\ldots. & i(1, n-1) \\
i(2,1) & i(2,2) & \ldots\ldots. & i(2, n-1) \\
. & & & . \\
. \;\; . & . \;\; . \;\; . \;\; . \;\; . \;\; . & . & . \, . \, . \\
. & & & . \\
i(m-1,1) & i(m-1,2) & \ldots & i(m-1, n-1)
\end{pmatrix}
$$



• Each element is called a *pixel* (picture element).

•A color (RGB) image is represented by a 3-dimensional matrix   I(mxnx3)

Digital Image Size

- The size of a digital image is determines by its dimensions ($M \times N$) multiplied by the number of bits b required to store the intensity levels ($L = 2^b$).

- image size = $M \times N \times b$ (bits)

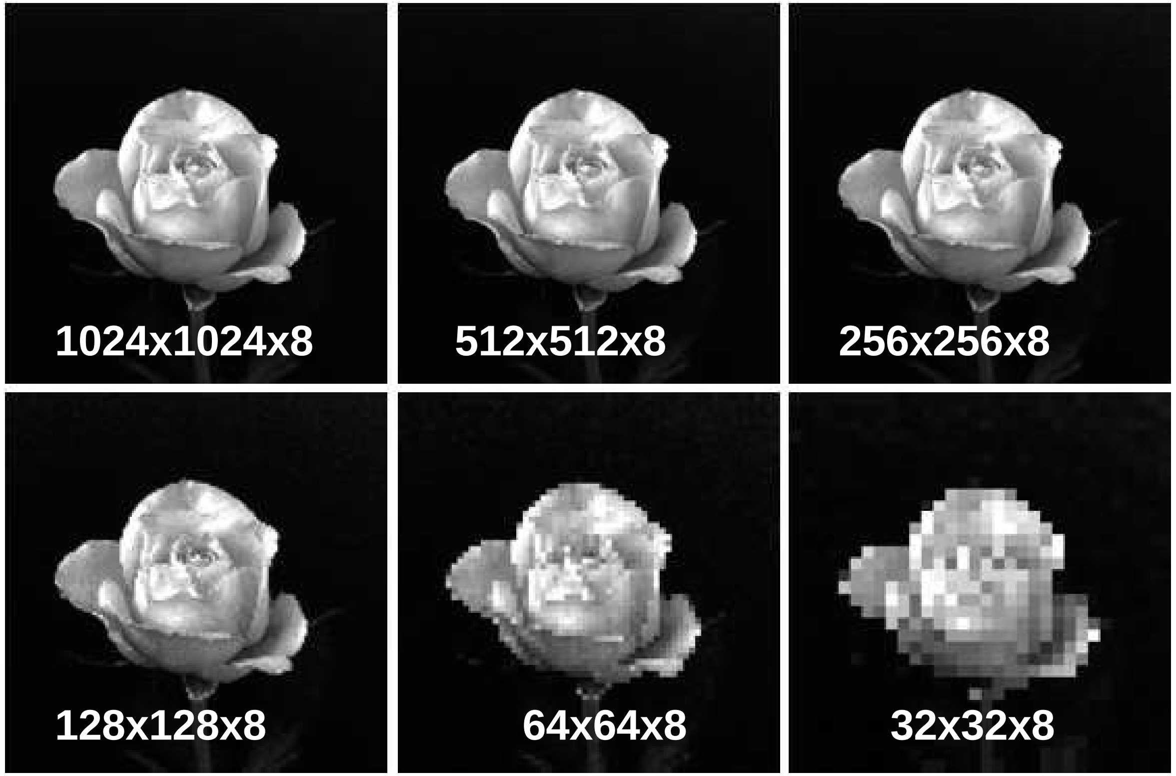
- Typical values of b are:
  - $b = 1$ black and white (binary) images.
  - $b = 8$ grayscale (256 gray levels), or indexed color images
  - $b = 24$ RGB color image.

Digital Image size

- Digital image resolution is determined by the number of pixels (samples) in the image.

Digital Image Resolution

- Digital image with low resolution has low quality.



Digital image Types

- RGB (Color) Images

Each pixel is a mixture of three values of Red, Geen, and Blue.

R,G,B = {0-255, 0-255, 0-255}

0 = Black

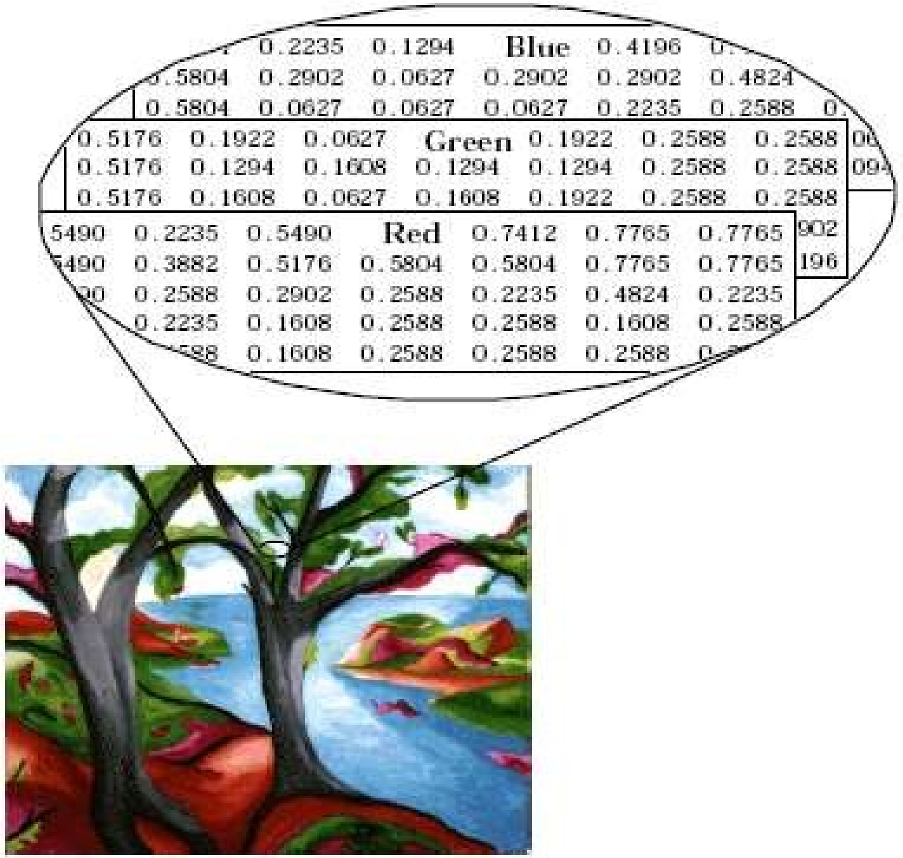
255 = White

In normalized values:

R,G,B = {0-1, 0-1, 0-1}

0 = Black

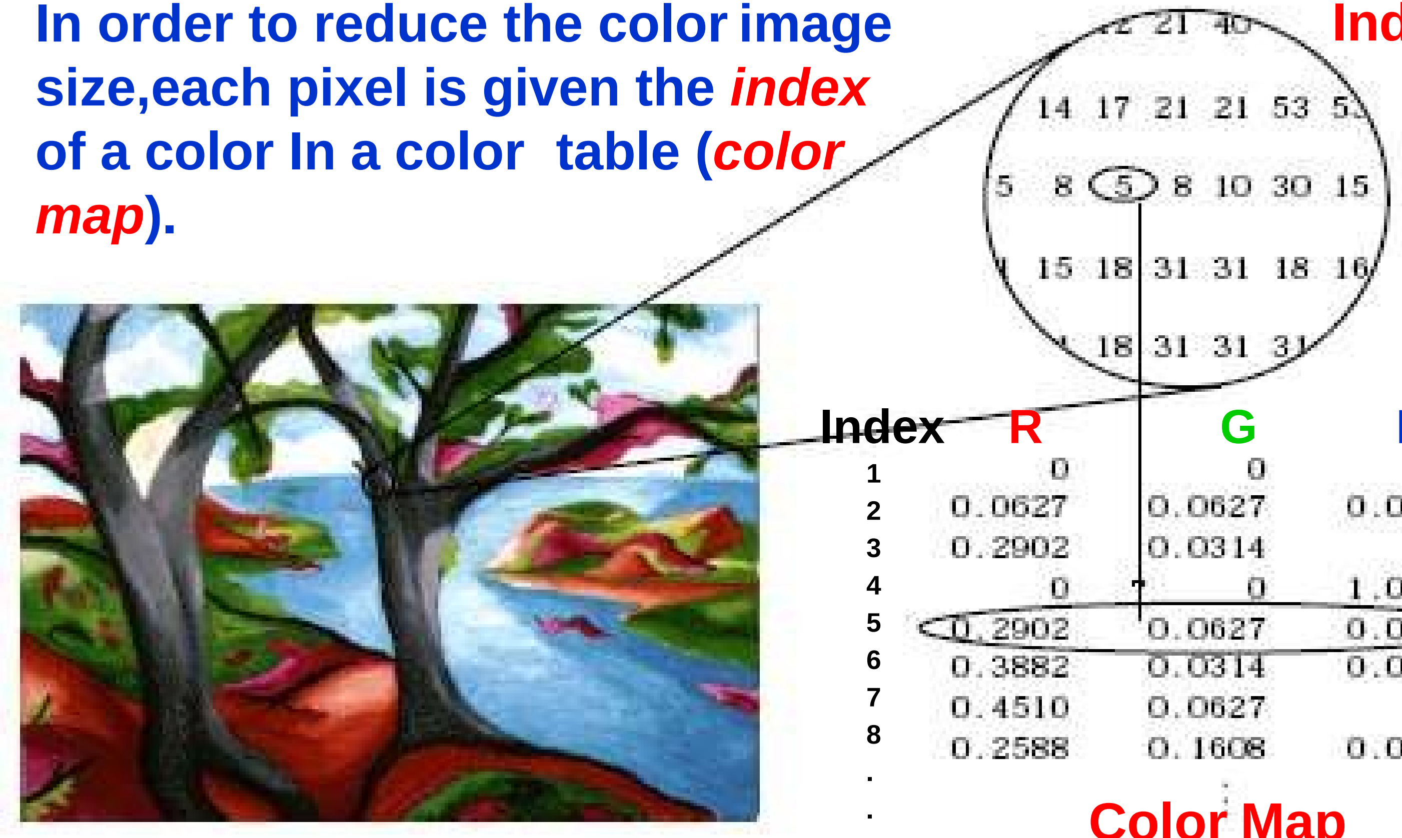
1 = White



Digital image Types

- Indexed (Color) Images

  In order to reduce the color image size,each pixel is given the *index* of a color In a color table (*color map*).



Index	R	G	B
1	0	0	0
2	0.0627	0.0627	0.0314
3	0.2902	0.0314	0
4	0	0	1.0000
5	0.2902	0.0627	0.0627
6	0.3882	0.0314	0.0941
7	0.4510	0.0627	0
8	0.2588	0.1608	0.0627
.			
.			

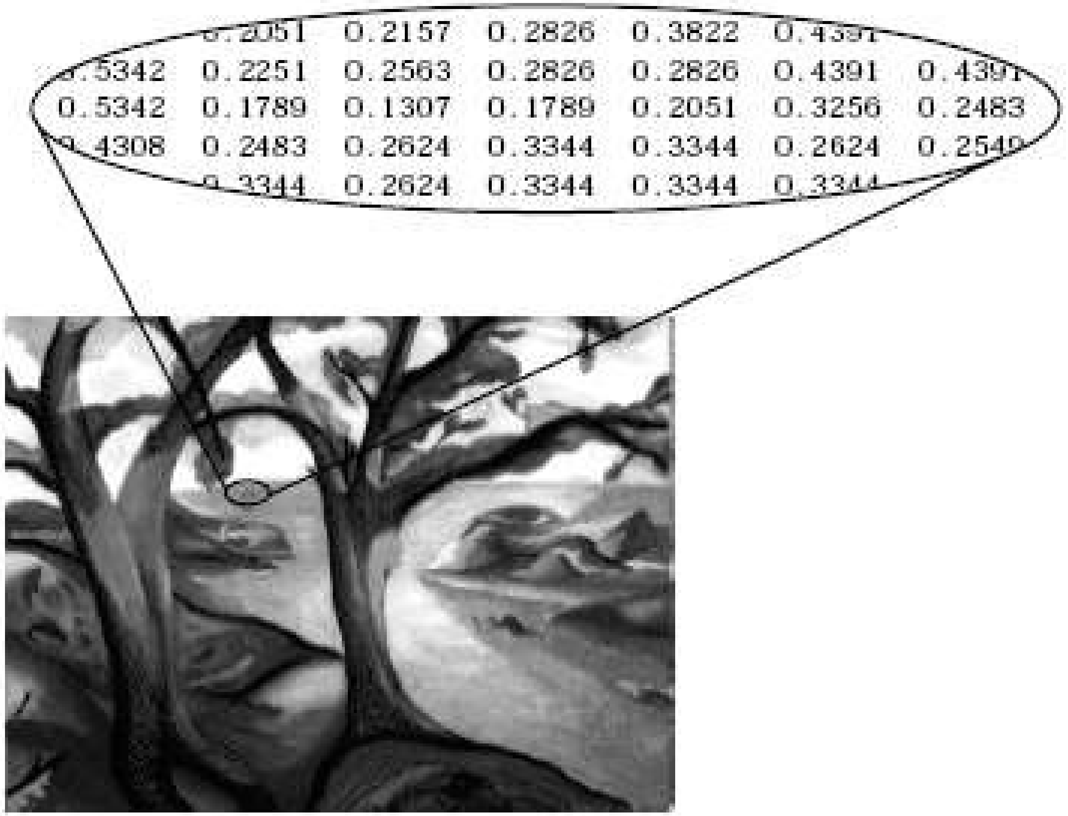
Color Map

Digital image Types

- Grayscale (Intensity) Images

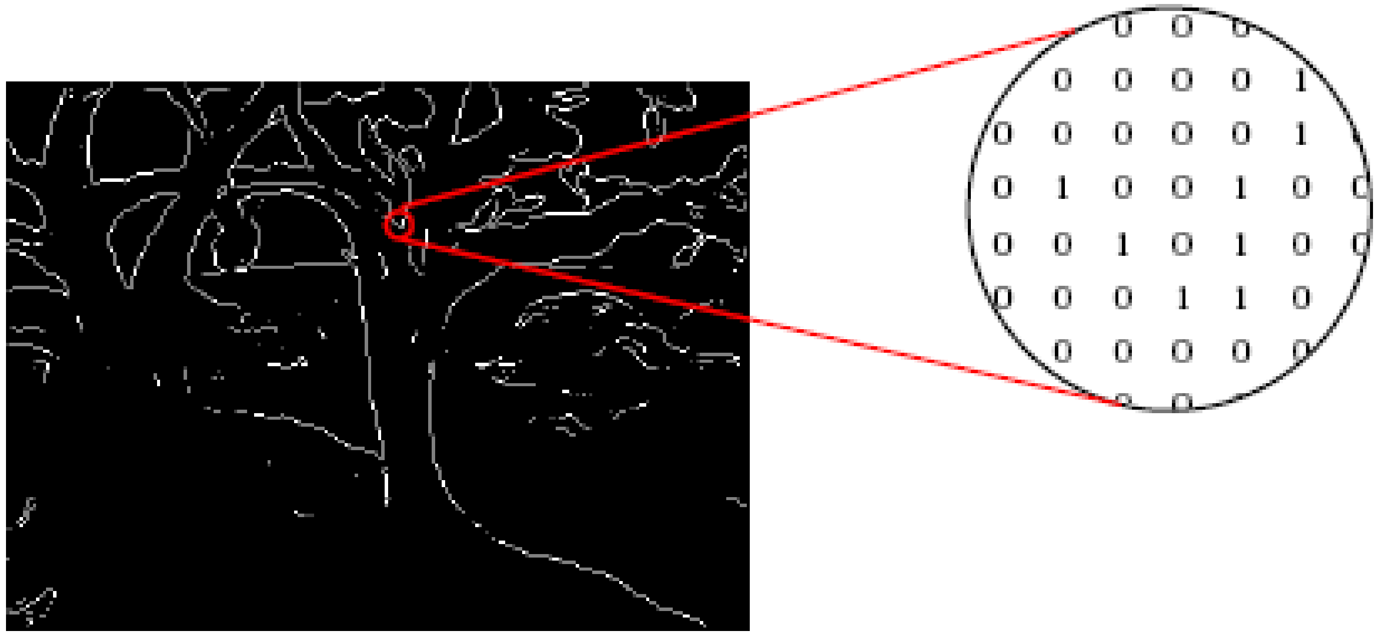
Each pixel is given a gray level value between 0 – 255 or between 0 – 1.

We need 8 bits to store a grayscale value.



Digital image Types

- Black and white (Binary) Images
  - **Each pixel has one of two gray levels either black (0) or white (1).**
  - **We need 8 bits to store a grayscale value.**

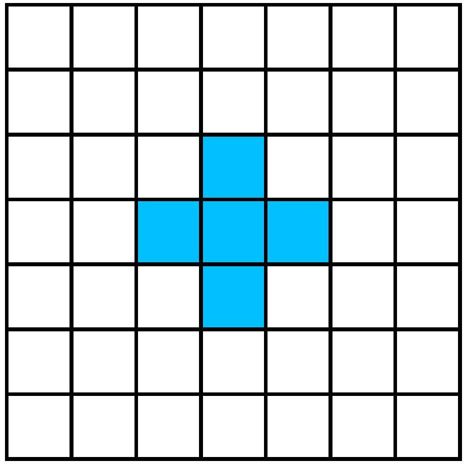


Types of Pixel Neighborhoods

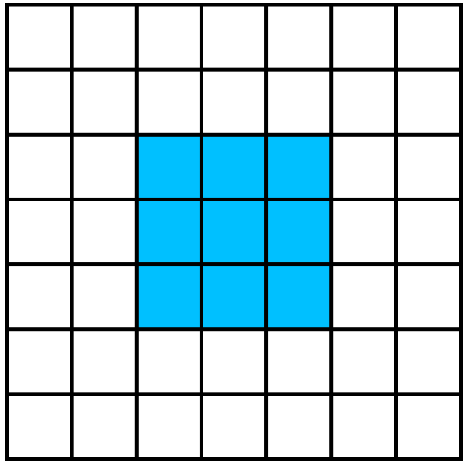
- ***Image sampling*:**
  - *Rectangular sampling* - In most cases, images are sampled by laying a rectangular grid over an image.
  - *Hexagonal sampling* - An alternative sampling scheme is shown.
- ***Pixel Neighborhoods*:**
  - *4-connected* and *8-connected* neighborhood (Rectangular sampling)
  - *6-connected* neighborhood (Hexagonal sampling)

Types of Pixel Neighborhoods

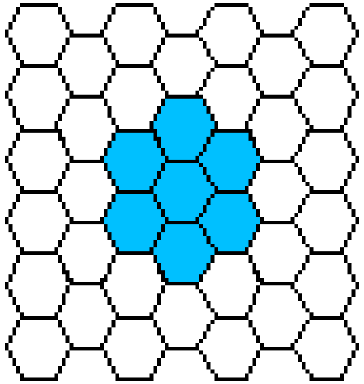
- **Basic Relationships Between Pixels**



4-connected



8-connected



6-connected

Distance Measures

- If pixels p and q have coordinates (x, y) and (s, t), respectively.
  - The *Euclidean distance* between p and q
    - $D_e(p, q) = [(x - s)^2 + (y - t)^2]^{1/2}$
  - The D_4 (*City-block*) *distance* between p and q
    - $D_4(p, q) = |x - s| + |y - t|$
  - The D_8 (*Chessboard*) *distance* between p and q
    - $D_8(p, q) = \max(|x - s| , |y - t|)$

Distance Measures

- Results of D_4 and D_8 distances

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

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

- The pixels with $D_4=1$ *are the 4-neighbors*
- The pixels with $D_8=1$ *are the 8-neighbors*

Adjacency, Connectivity, Regions, and Boundaries

- Adjacency:
  - 4-adjacency **:** Two pixels p and q are 4-adjacent if q is in the set $N_4(p)$.
  - 8-adjacency. Two pixels p and q are 8-adjacent if q is in the set $N_8(p)$.
- Connectivity: Let S represent a subset of pixels:
  - Two pixels p and q are said to be connected in S if there exists a path between them consisting entirely of pixels in S.
  - the set of pixels that are connected to each other in S is called a connected component of S.

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Adjacency, Connectivity, Regions, and Boundaries

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

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

    where $(x_0, y_0) = (x, y)$; $(x_n, y_n) = (s, t)$; and

    pixels (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 <= i <= n$.

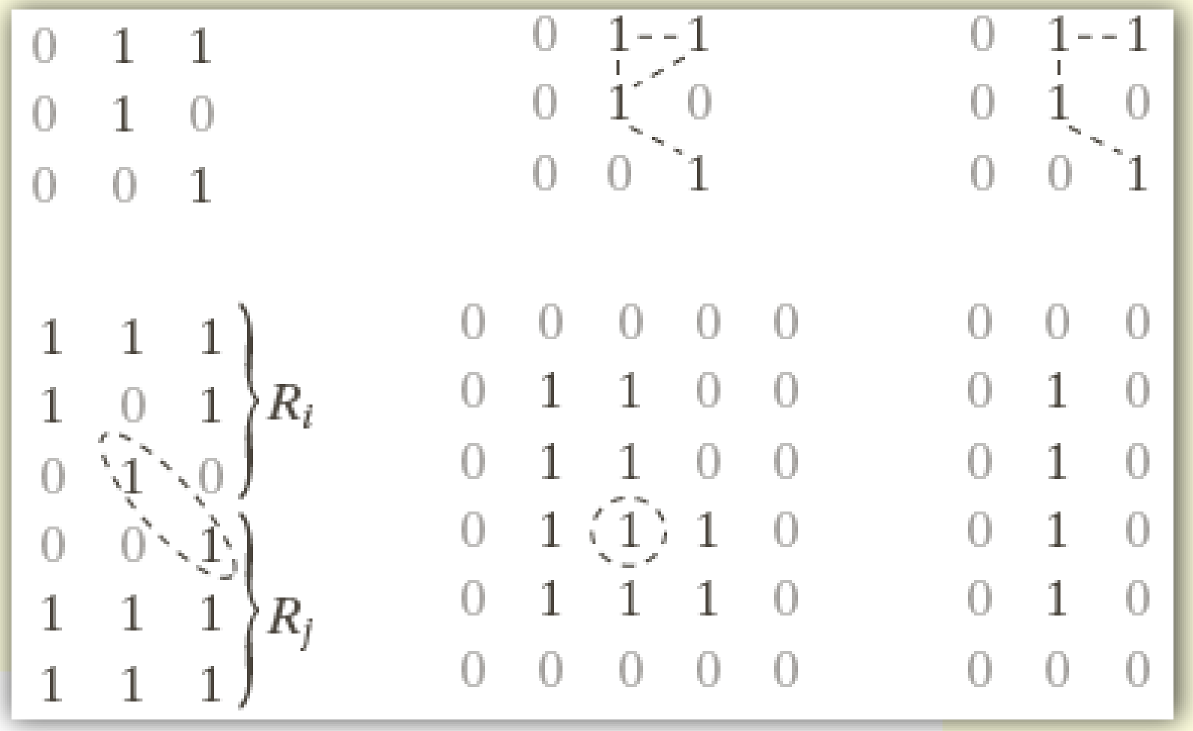
  - In this case, n is the length of the path. If $(x_0, y_0) = (s, t)$ the path is a closed path.
  - We can define 4- or 8-paths depending on the type of adjacency specified.

Adjacency, Connectivity, Regions, and Boundaries

- Region:
  - If R be a subset of pixels in an image, we call R a region of the image if R is a connected set.

- Boundary:
  - The *boundary* (also called *border* or *contour*) of a region R is *the set of pixels in the region that have one or more neighbors that are not in R*.

Adjacency, Connectivity, Regions, and Boundaries



a b c
d e f

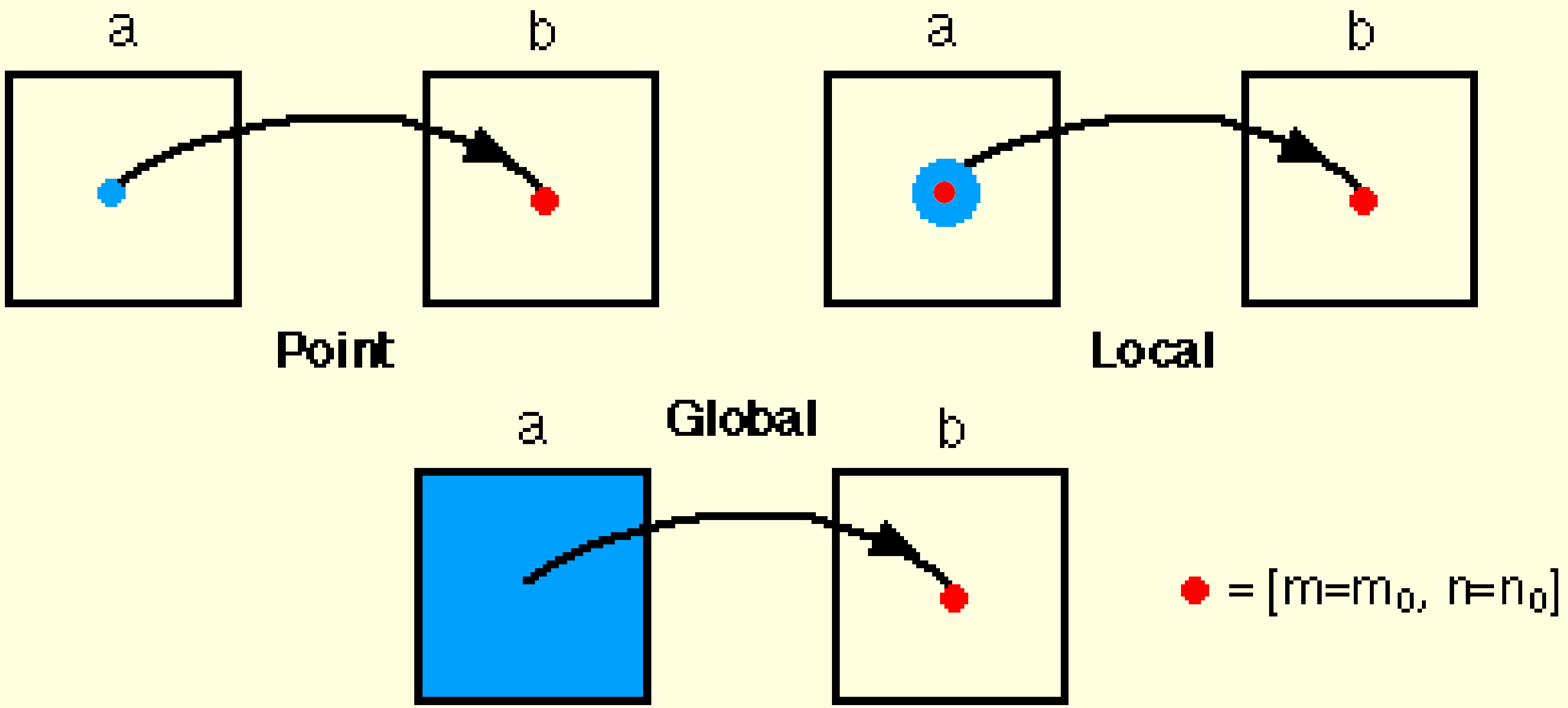
FIGURE 2.25 (a) An arrangement of pixels. (b) Pixels that are 8-adjacent (adjacency is shown by dashed lines; note the ambiguity). (c) m-adjacency. (d) Two regions that are adjacent if 8-adjecency is used. (e) The circled point is part of the boundary of the 1-valued pixels only if 8-adjacency between 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.

Types of image Operations

- Operation Domain

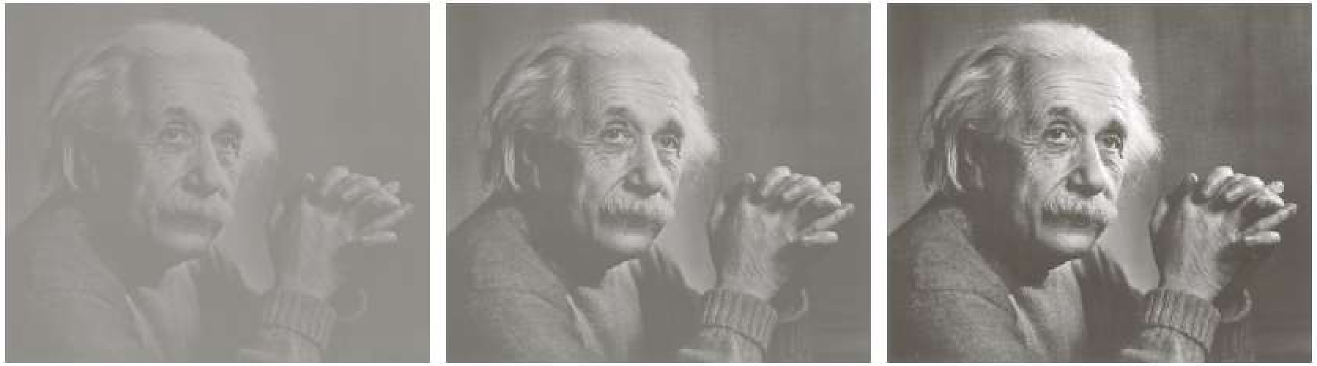
Operation	Characterization	Complexity/Pixel
Point	the output value at a specific coordinate is dependent only on the input value at that same coordinate.	constant
Local	the output value at a specific coordinate is dependent on the input values in the neighborhood of that same coordinate.	P^2
Global	the output value at a specific coordinate is dependent on all the values in the input image.	N^2

Types of image Operations



Types of image Operations

- Pixel Operations

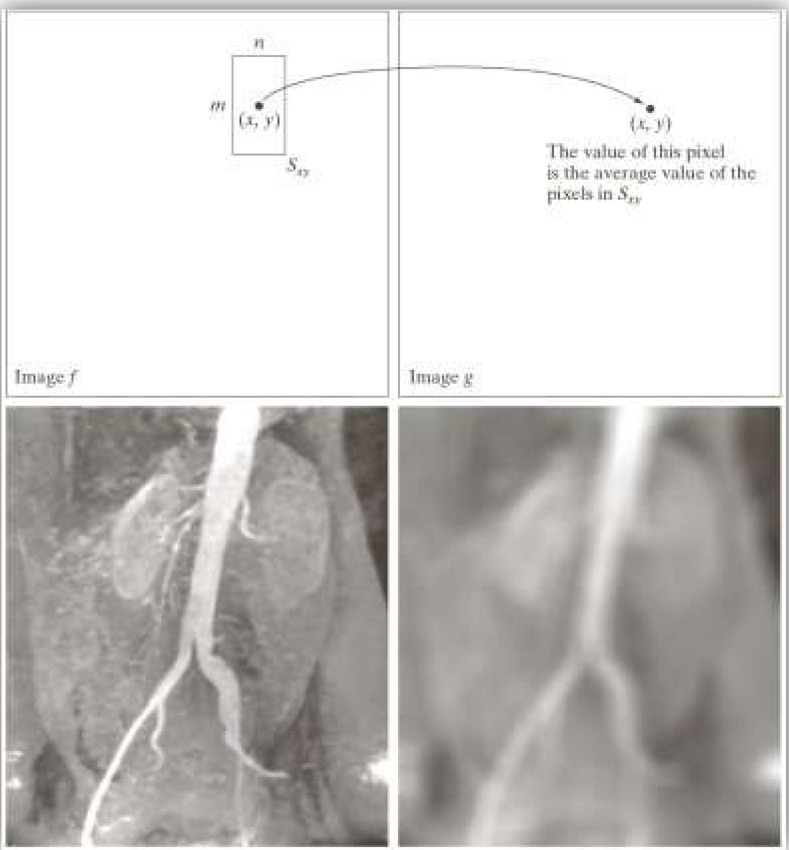


a b c

FIGURE 2.41 Images exhibiting (a) low contrast, (b) medium contrast, and (c) high contrast.

Types of image Operations

- Local Operations



a b
c d

FIGURE 2.35 Local averaging using neighborhood processing. The procedure is illustrated in (a) and (b) for a rectangular neighborhood. (c) The aortic angiogram discussed in Section 1.3.2. (d) The result of using Eq. (2.6-21) with $m = n = 41$. The images are of size 790×686 pixels.

Types of image Operations

- Local Operations

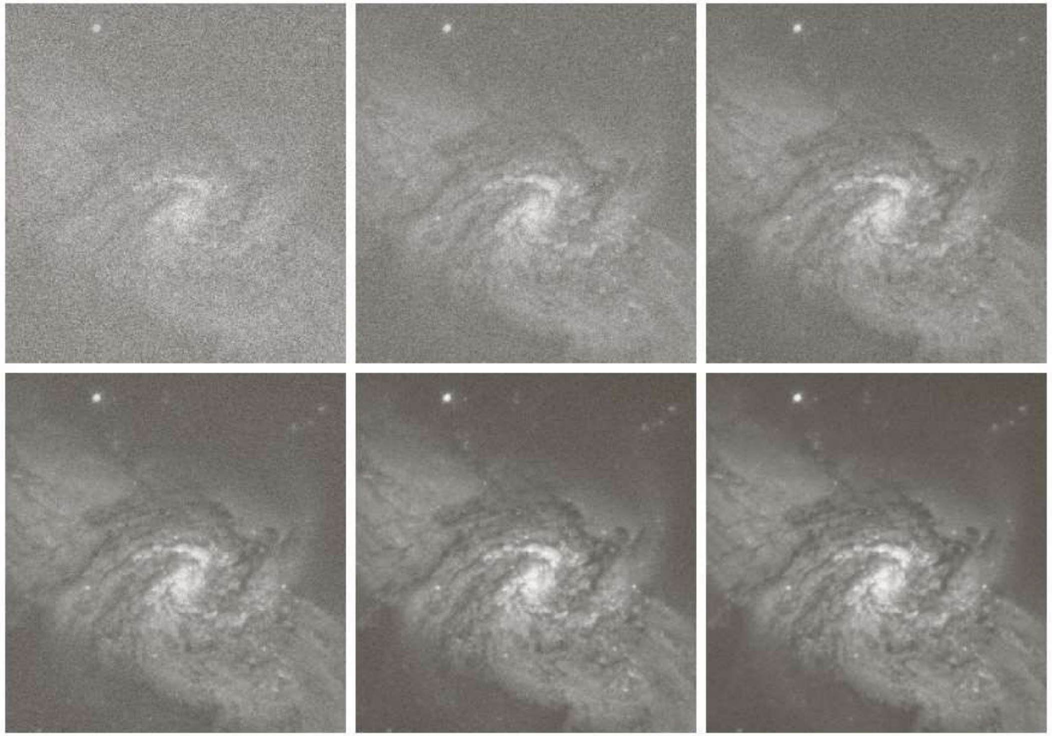
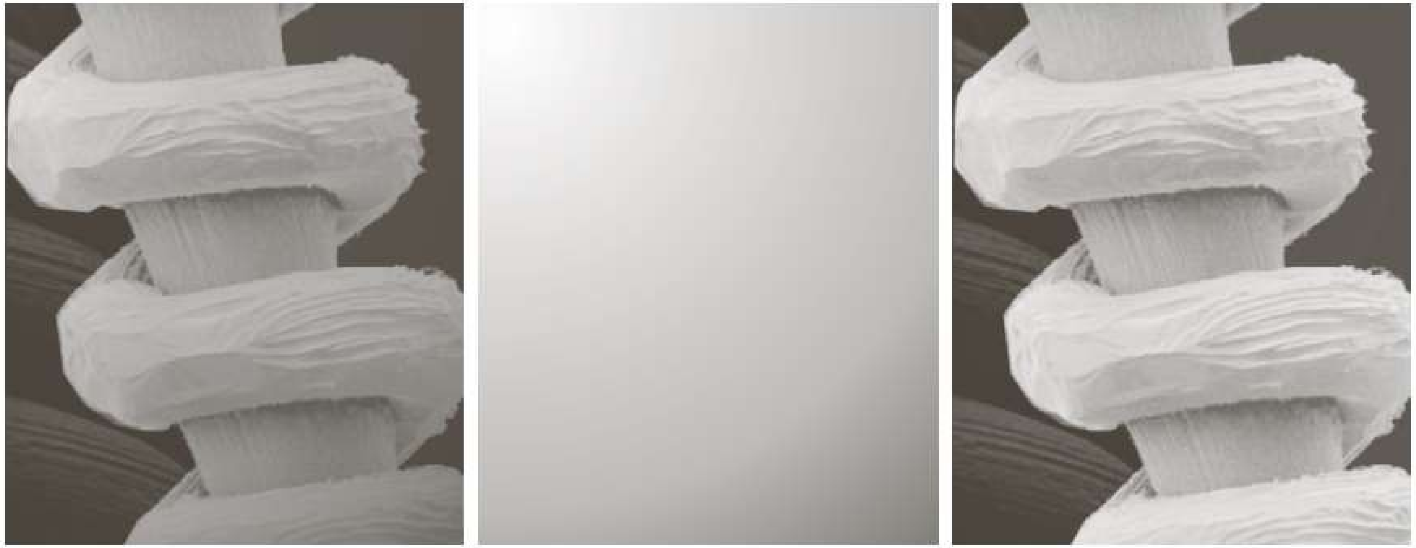


FIGURE 2.26 (a) Image of Galaxy Pair NGC 3314 corrupted by additive Gaussian noise. (b)–(f) Results of averaging 5, 10, 20, 50, and 100 noisy images, respectively. (Original image courtesy of NASA.)

Types of image Operations

- Arithmetic Operations

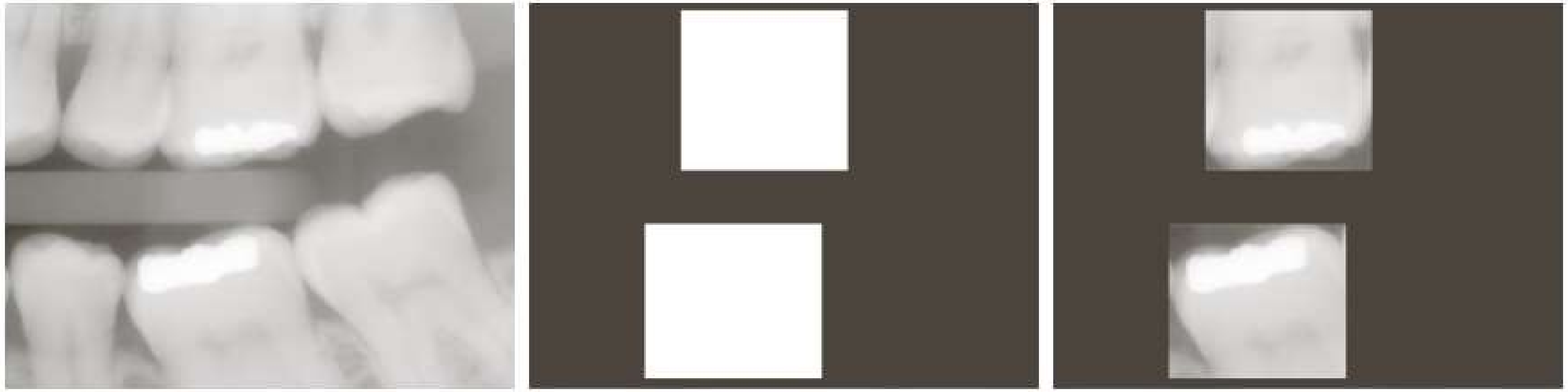


a b c

FIGURE 2.29 Shading correction. (a) Shaded SEM image of a tungsten filament and support, magnified approximately 130 times. (b) The shading pattern. (c) Product of (a) by the reciprocal of (b). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

Types of image Operations

- Arithmetic Operations



a b c

FIGURE 2.30 (a) Digital dental X-ray image. (b) ROI mask for isolating teeth with fillings (white corresponds to 1 and black corresponds to 0). (c) Product of (a) and (b).

Types of image Operations

- Logical Operations

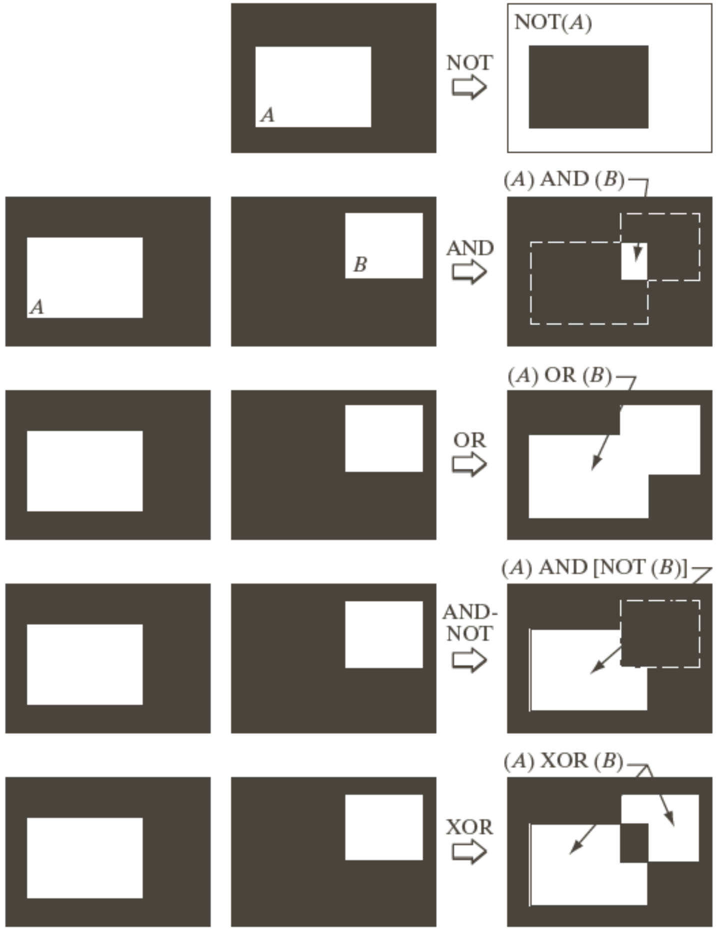


FIGURE 2.33 Illustration of logical operations involving foreground (white) pixels. Black represents binary 0s and white binary 1s. The dashed lines are shown for reference only. They are not part of the result.

Types of image Operations

- Sets Operations

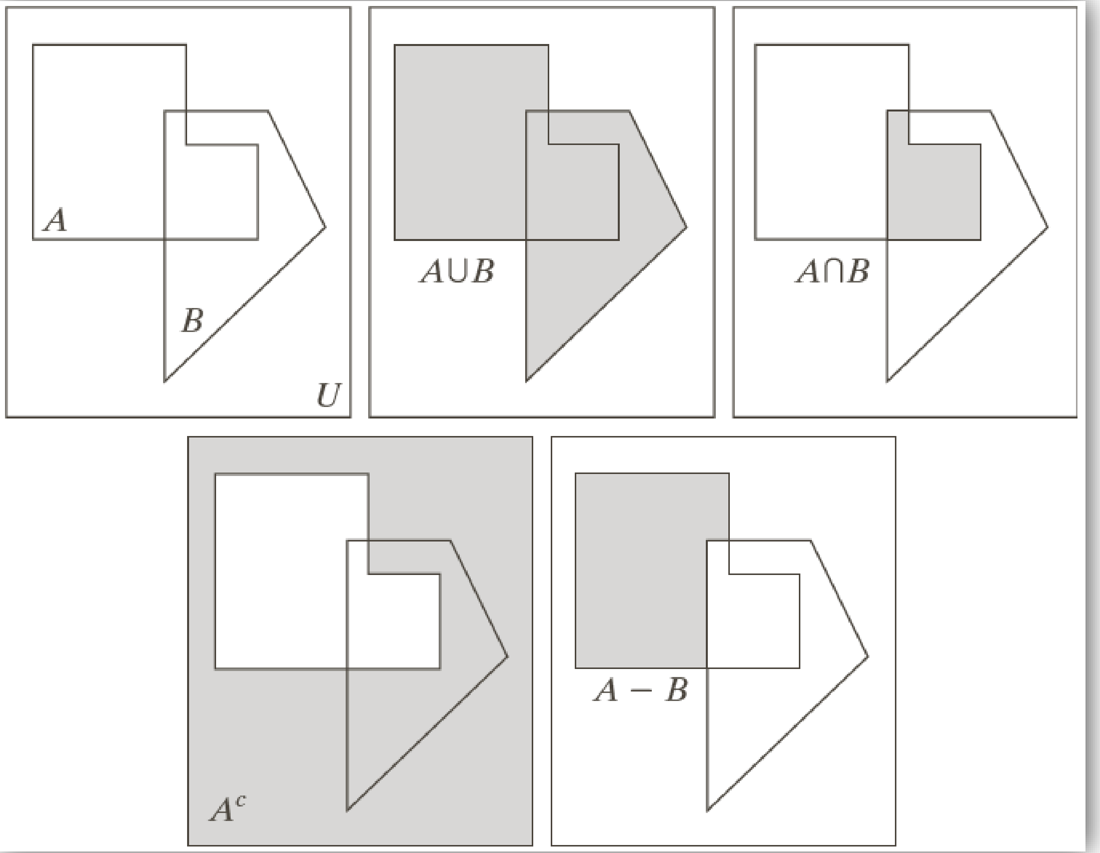
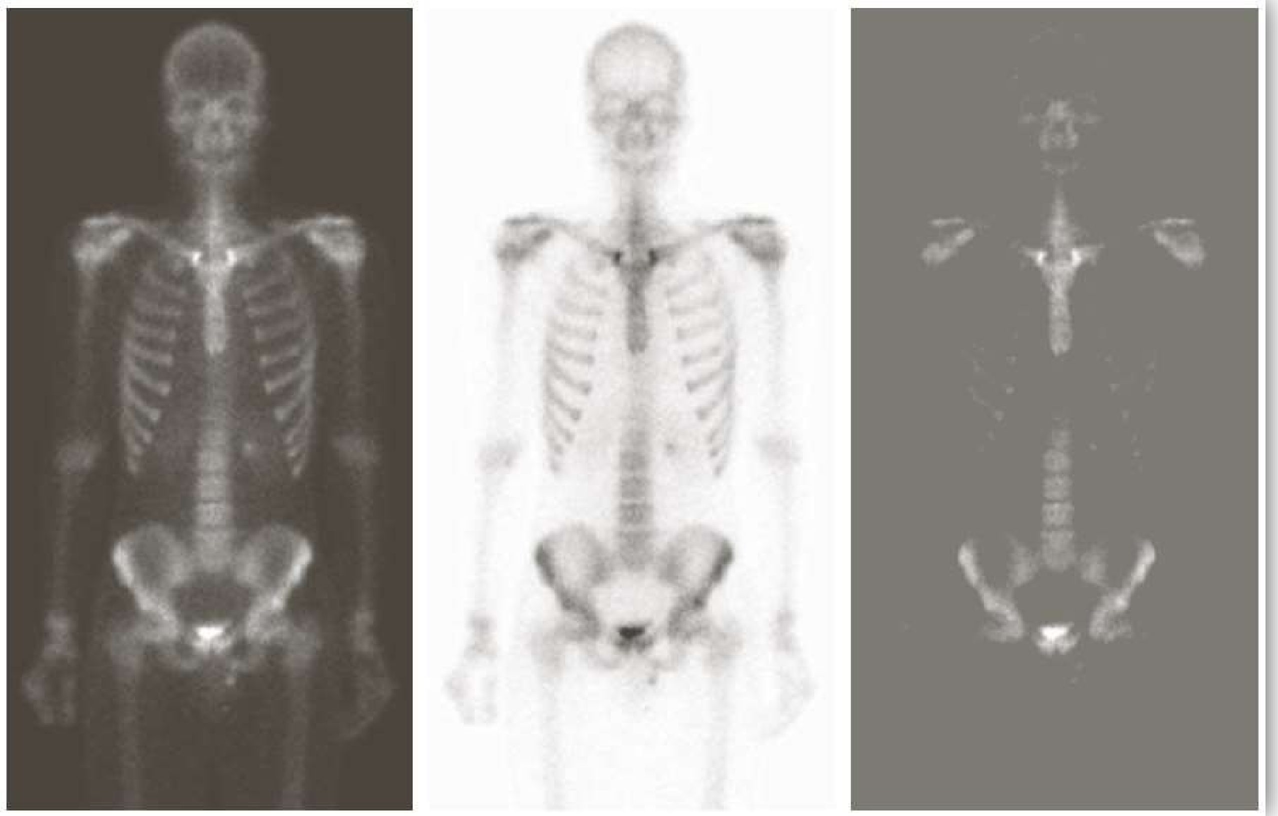


FIGURE 2.31 (a) Two sets of coordinates, A and B, in 2-D space. (b) The union of A and B. (c) The intersection of A and B. (d) The complement of A. (e) The difference between A and B. In (b)–(e) the shaded areas represent the member of the set operation indicated.

Types of image Operations

- Sets Operations



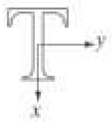
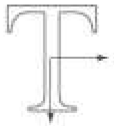
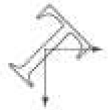
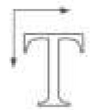
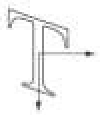
a b c

FIGURE 2.32 Set operations involving gray-scale images. (a) Original image. (b) Image negative obtained using set complementation. (c) The union of (a) and a constant image. (Original image courtesy of G.E. Medical Systems.)

Types of image Operations

- Geometric Operation (Transformation)

TABLE 2.2
Affine transformations based on Eq. (2.6.–23).

Transformation Name	Affine Matrix, T	Coordinate Equations	Example
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = w$	
Scaling	$\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = c_x v$ $y = c_y w$	
Rotation	$\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v\cos\theta - w\sin\theta$ $y = v\cos\theta + w\sin\theta$	
Translation	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{bmatrix}$	$x = v + t_x$ $y = w + t_y$	
Shear (vertical)	$\begin{bmatrix} 1 & 0 & 0 \\ s_v & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v + s_v w$ $y = w$	
Shear (horizontal)	$\begin{bmatrix} 1 & s_h & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = s_h v + w$	

Types of image Operations

- Space Transformations

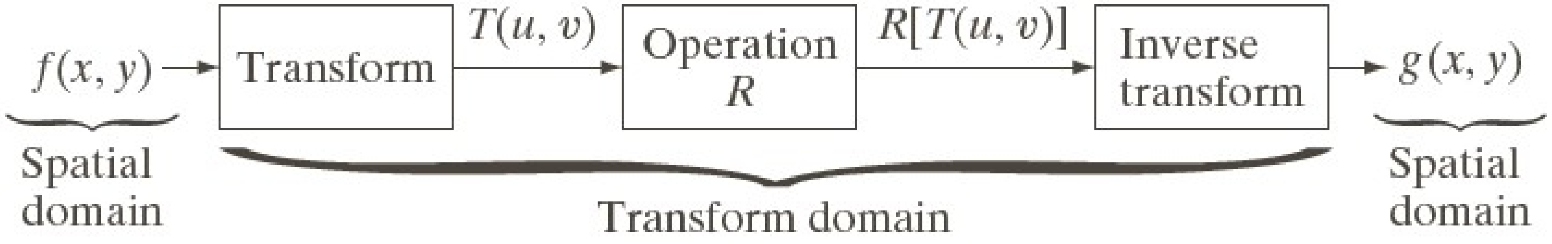


FIGURE 2.39
General approach for operating in the linear transform domain.

Types of image Operations

- Space Transformation

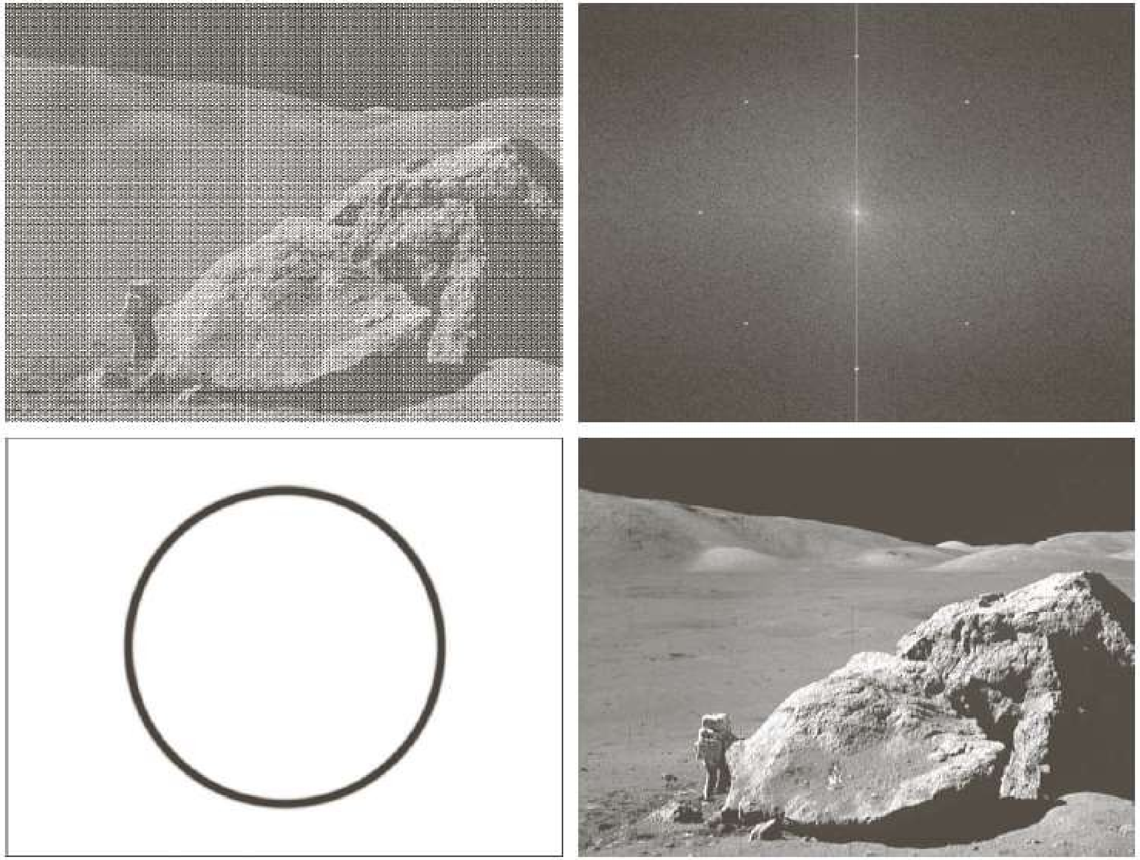


FIGURE 2.40 (a) Image corrupted by sinusoidal interference. (b) Magnitude of the Fourier transform showing the bursts of energy responsible for the interference. (c) Mask used to eliminate the energy bursts. (d) Result of computing the inverse of the modified Fourier transform. (Original image courtesy of NASA.)

Categories of Image Operations

- **Linear and Nonlinear Operations**
  - H is said to be a *linear* operator if, for any two images *f* and *g* and any two scalars a and b,

$$H(a f + b g) = a H(f) + b H(g)$$

  - Operations that do not satisfy this condition is called *nonlinear* operations

Homework 1

- Problems:
  - Page 72: 2.9, 2.10, 2.11
  - Page 73: 2.12, 2.14, 2.15, 2.20

Next time

Image Enhancement

In

The Spatial Domain