CST 304
Computer Graphics & Image Processing
Module - 4 Part-1
Fundamentals of Digital Image Processing

- Introduction to Image Processing and applications.
- Image as 2D data. Image representation in Gray scale, Binary and Colour images.
- Fundamental steps in Image Processing. Components of image processing system. Coordinate conventions. Sampling and quantization. Spatial and Gray Level Resolution.
- Basic relationship between pixels– Neighbourhood, Adjacency, Connectivity.
- Fundamentals of spatial domain- Convolution operation.

IMAGE PROCESSING – Fundamentals

- Image processing involves processing or altering an existing image in a desired manner.
- **Digital Image Processing - Two major tasks :**
  - Improvement of pictorial information for human interpretation
  - Processing of image data for storage, transmission and representation for autonomous machine perception
- **Need of image processing:-**
  - Since the digital image is “invisible” it must be prepared for viewing on one or more output device (laser printer, monitor, etc)
  - The digital image can be optimized for the application by enhancing or altering the appearance of structures within it (based on: body part, diagnostic task, viewing preferences, etc)
  - It might be possible to analyze the image in the computer and provide cues to the radiologists to help detect important/suspicious structures (e.g.:Computed Aided Diagnosis, CAD)

Image Processing Fields

- Computer Graphics: Creation of images
- Image Processing: Enhancement or other manipulation of the image
- Computer Vision: Analysis of the image content

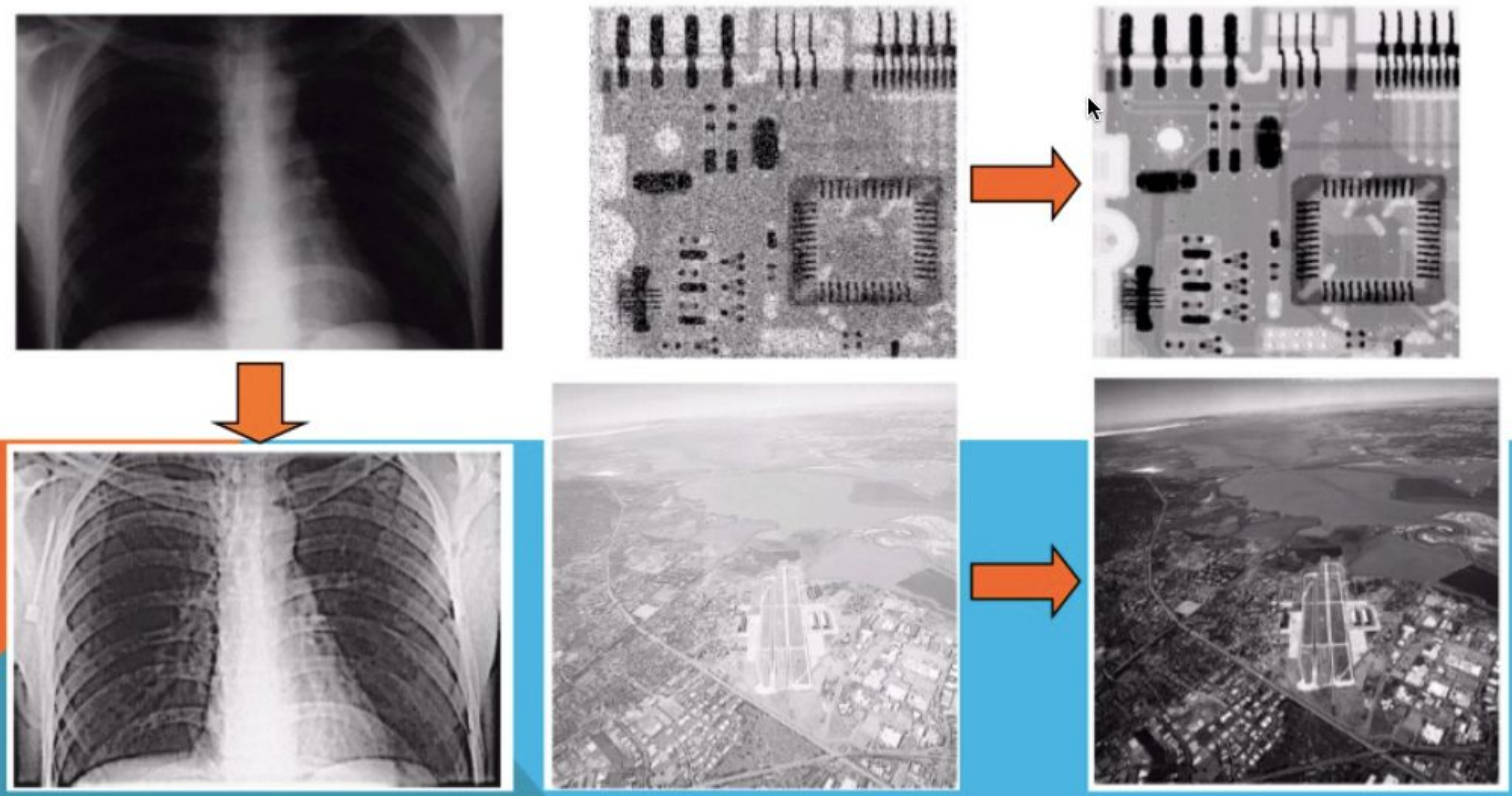
The continuum from image processing to computer vision can be broken up into low, mid and high-level processes.s

Low Level Process	Mid Level Process	High Level Process
Input: Image Output: Image Examples: Noise removal, image sharpening	Input: Image Output: Attributes Examples: Object recognition, segmentation	Input: Attributes Output: Understanding Examples: Scene understanding, autonomous navigation

EXAMPLE

Image Enhancement

One of the most common uses of DIP techniques: improve quality, remove noise etc



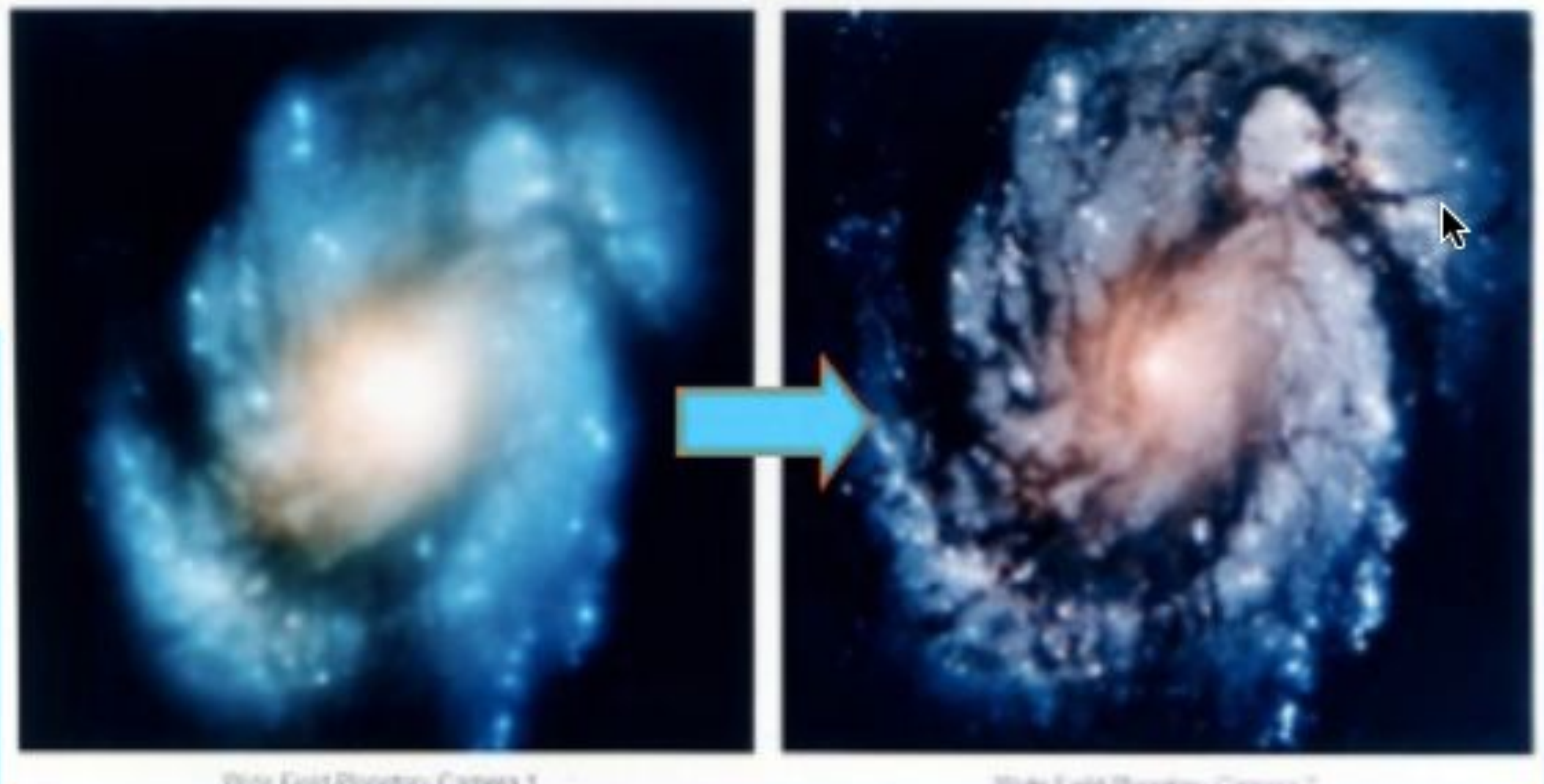
EXAMPLE

The Hubble Telescope

Launched in 1990 the Hubble telescope can take images of very distant objects

However, an incorrect mirror made many of Hubble's images useless

Image processing techniques were used to fix this



EXAMPLE

Artistic Effect

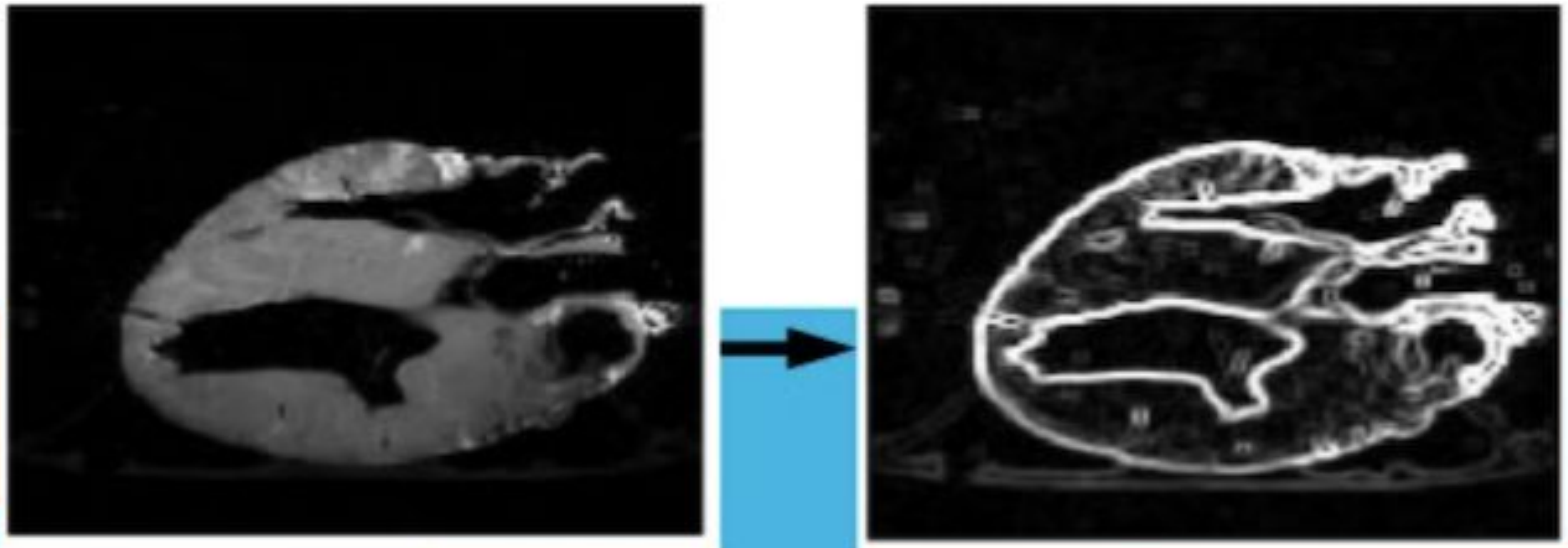
Artistic effects are used to make images more visually appealing, to add special effects and to make composite images

EXAMPLE

Medicine

Take slice from MRI scan of canine heart, and find boundaries between types of tissue

- Image with gray levels representing tissue density
- Use a suitable filter to highlight edges



Original MRI Image of a Dog Heart

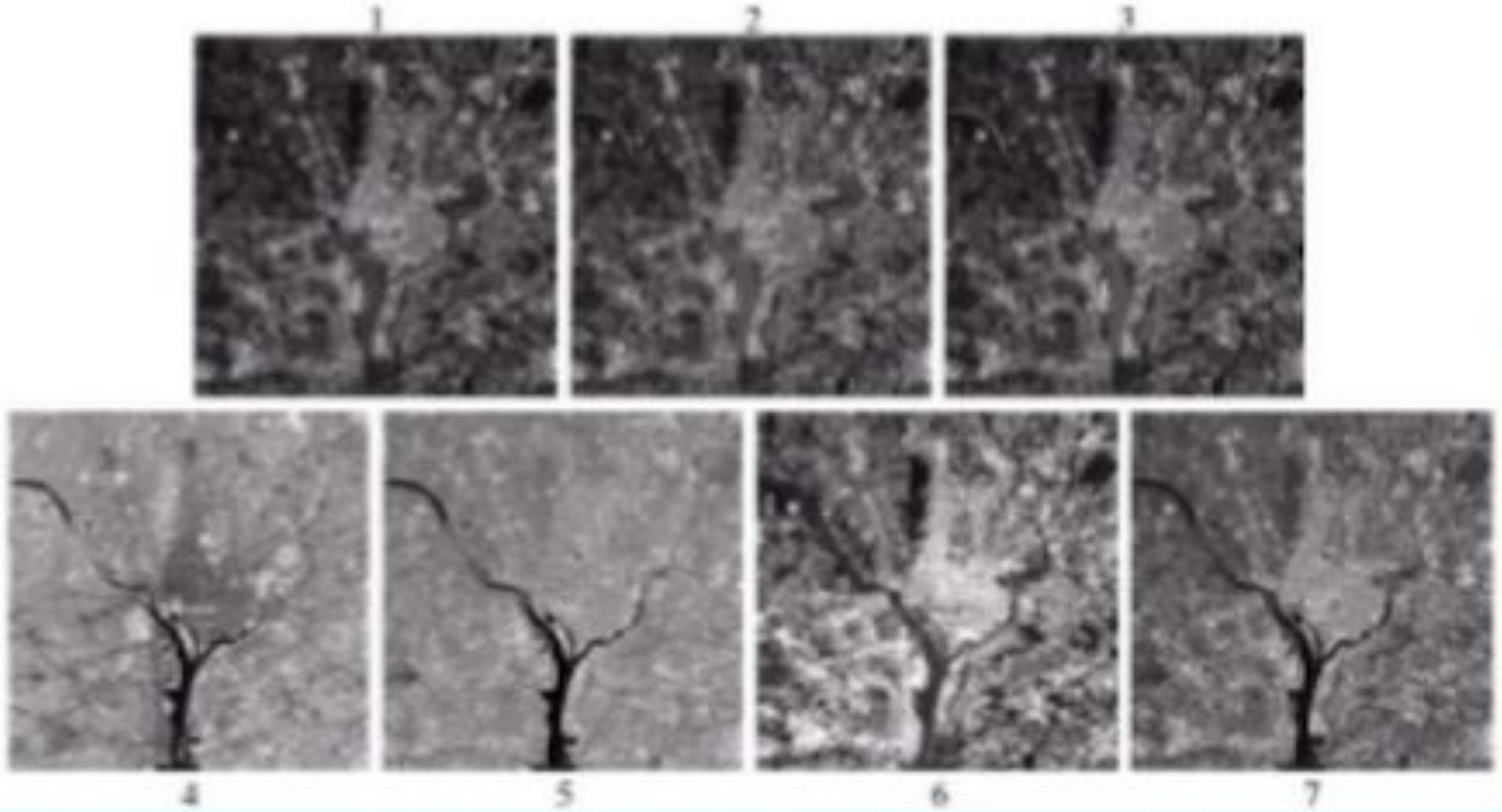
Edge Detection Image

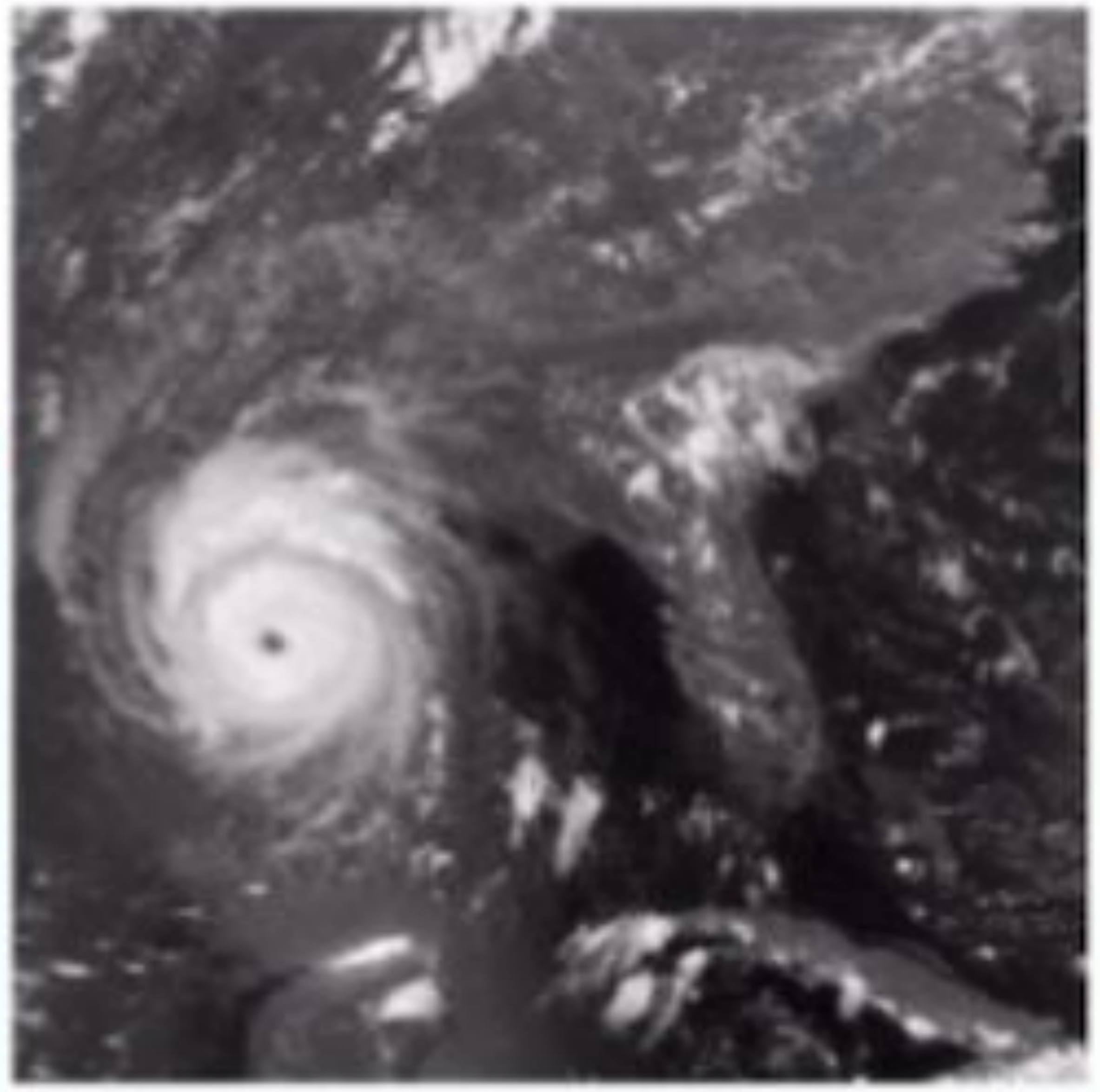
EXAMPLE

GIS

Geographic Information Systems

- Digital image processing techniques are used extensively to manipulate satellite imagery
- Terrain classification
- Meteorology





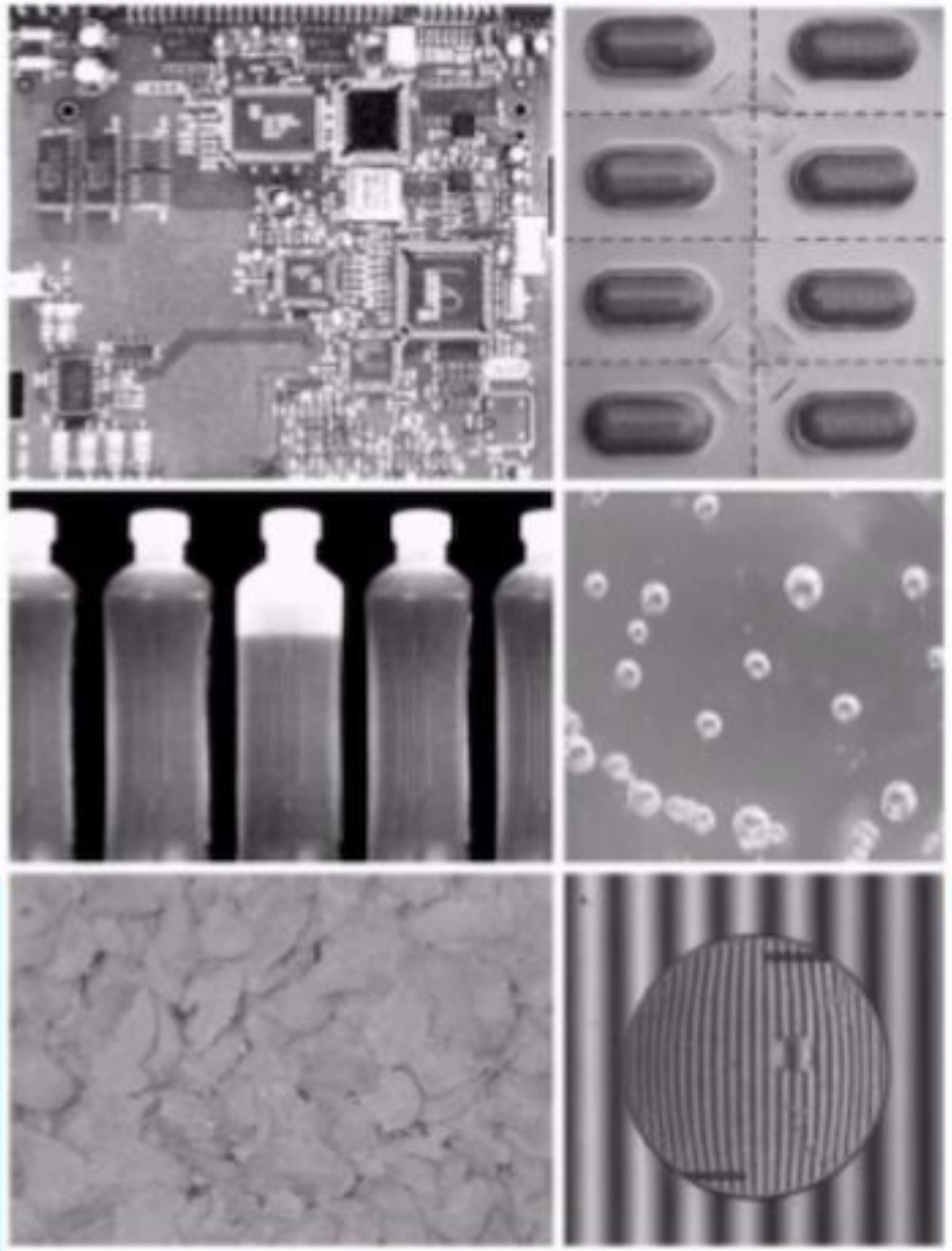
EXAMPLE

Industrial Inspection

Human operators are expensive, slow and unreliable

Make machines do the job instead

Industrial vision systems are used in all kinds of industries

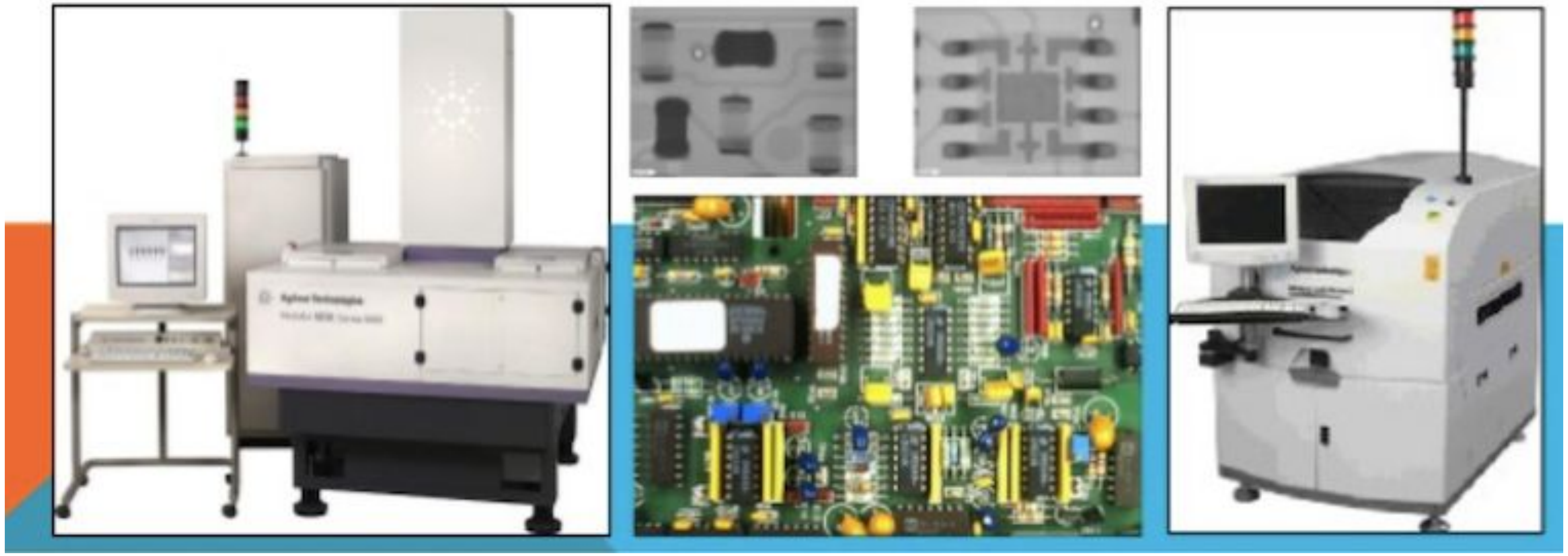


EXAMPLE

PCB Inspection

Printed Circuit Board (PCB) inspection

- Machine inspection is used to determine that all components are present and that all solder joints are acceptable
- Both conventional imaging and x-ray imaging are used



EXAMPLE

Law Enforcement

Image processing techniques are used extensively by law enforcers

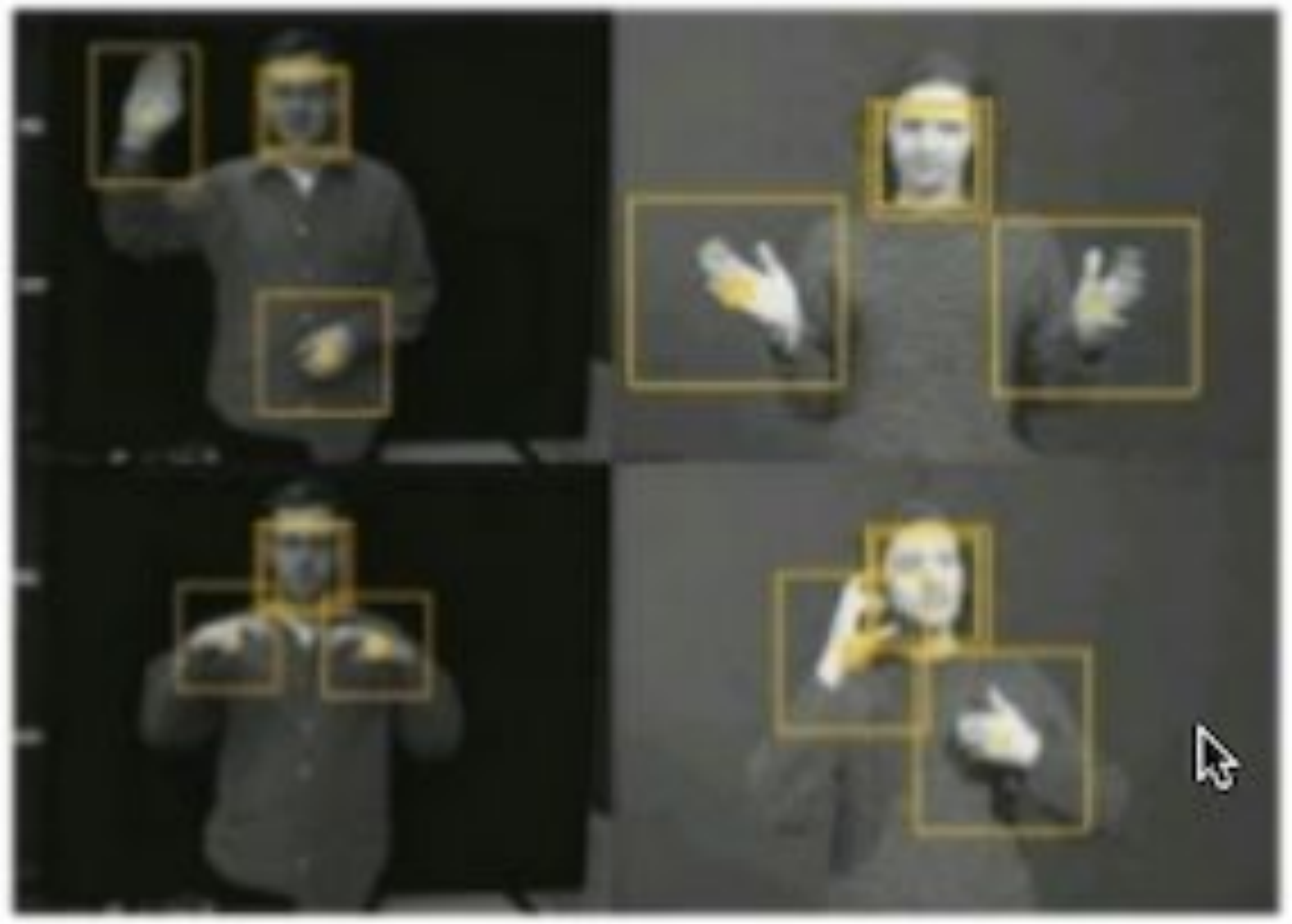
- Number plate recognition for speed cameras/automated toll systems
- Fingerprint recognition
- Enhancement of CCTV images

EXAMPLE

HCI

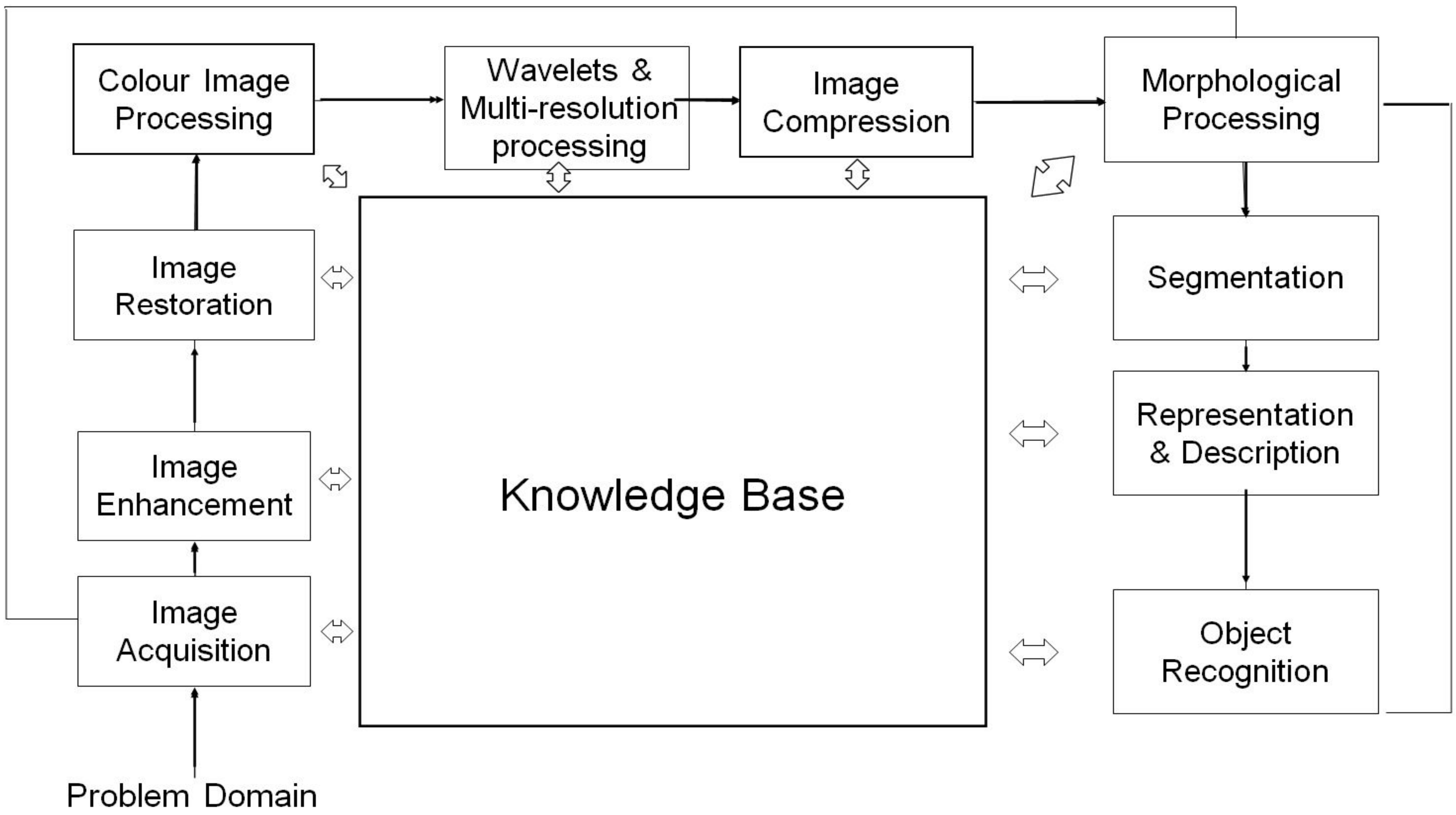
Try to make human computer interfaces more natural

- Face recognition
- Gesture recognition



Fundamental Steps in Digital Image Processing

Outputs of these processes generally are images



Outputs of these processes generally are image attributes

Fundamental Steps in Digital Image Processing

Step 1 : Image Acquisition

- The image is captured by a sensor (eg. Camera), and digitized if the output of the camera or sensor is not already in digital form, using analogue-to-digital convertor.

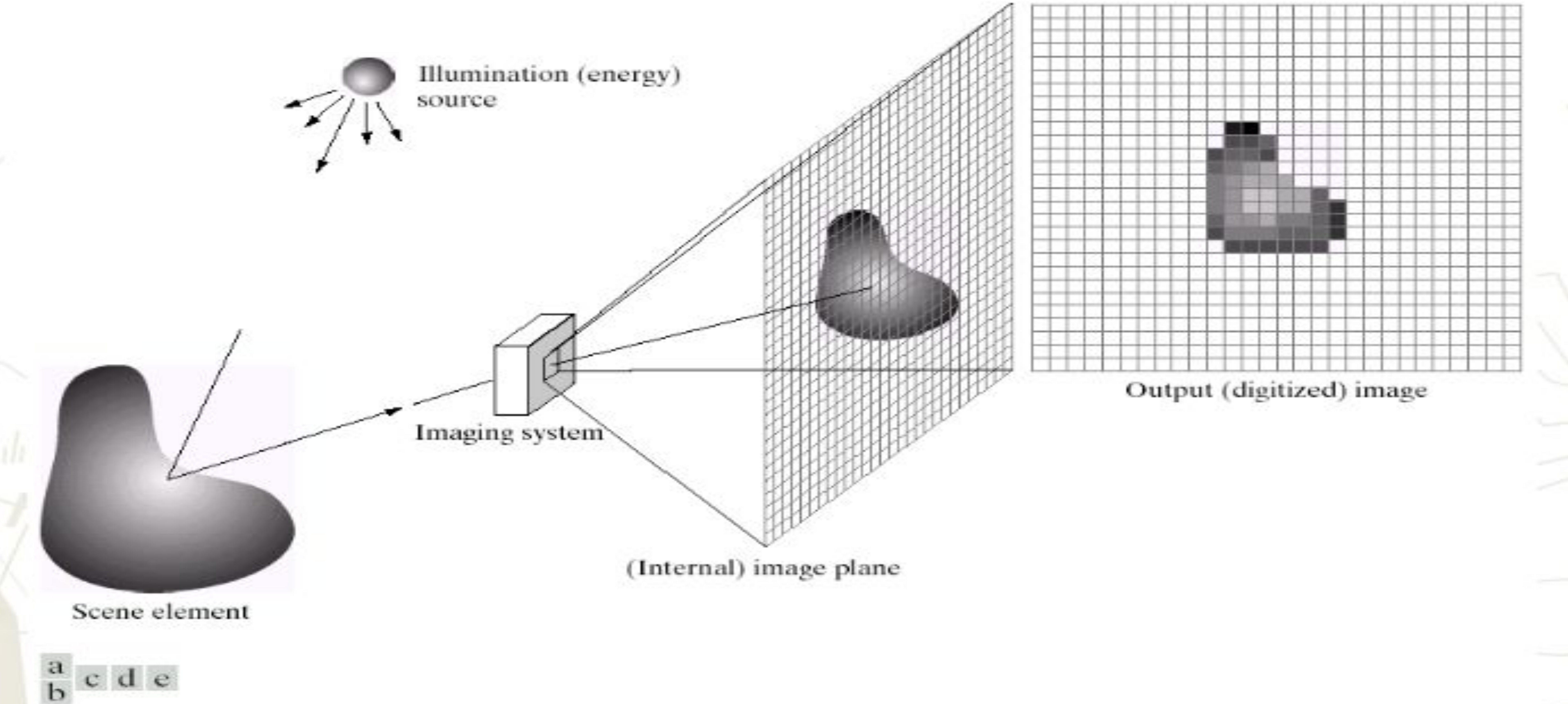
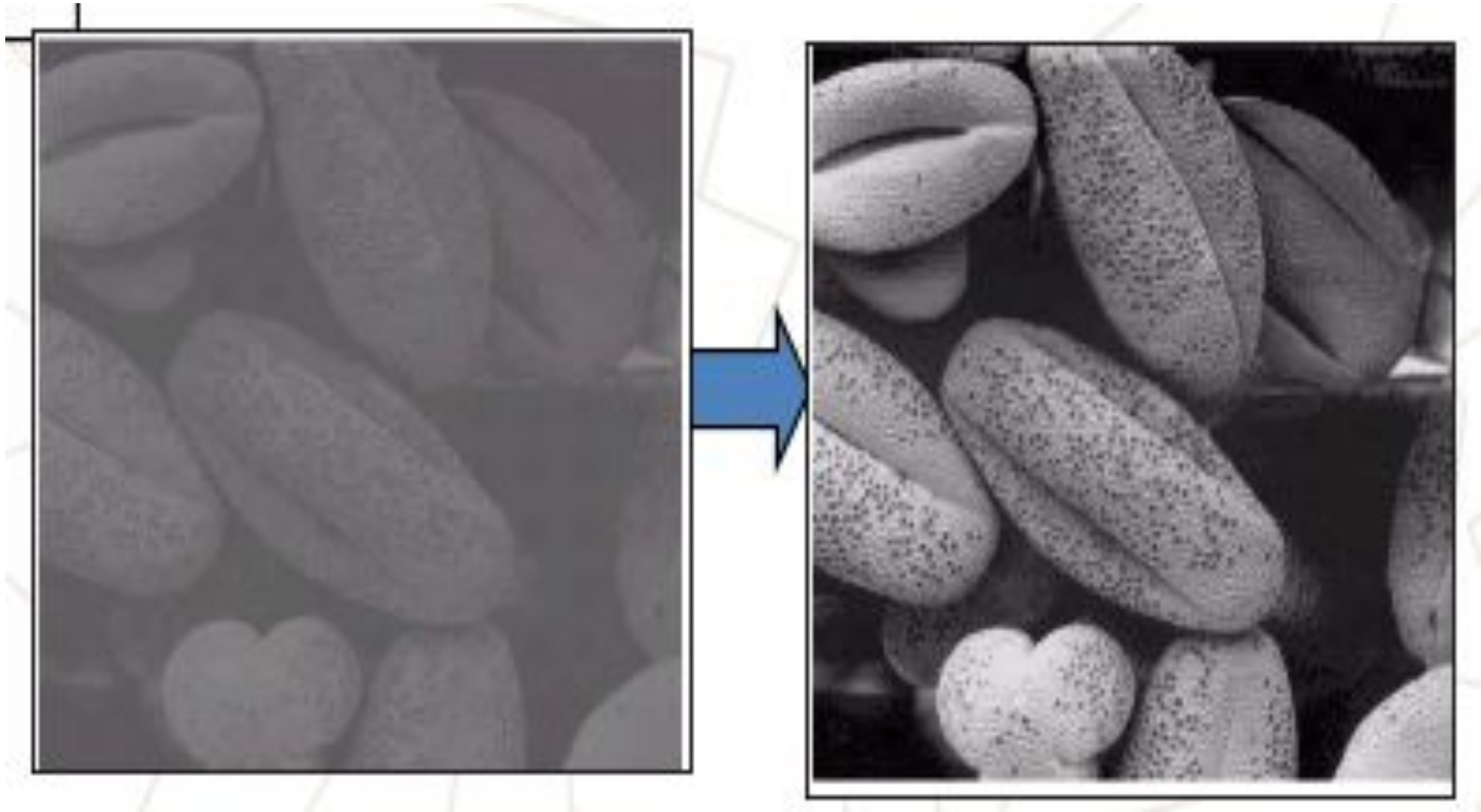


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Fundamental Steps in Digital Image Processing

Step 2 : Image Enhancement

- The process of manipulating an image so that the result is more suitable than the original for specific applications.
- The idea behind enhancement techniques is to bring out details that are hidden, or simply to highlight certain features of interest in an image.

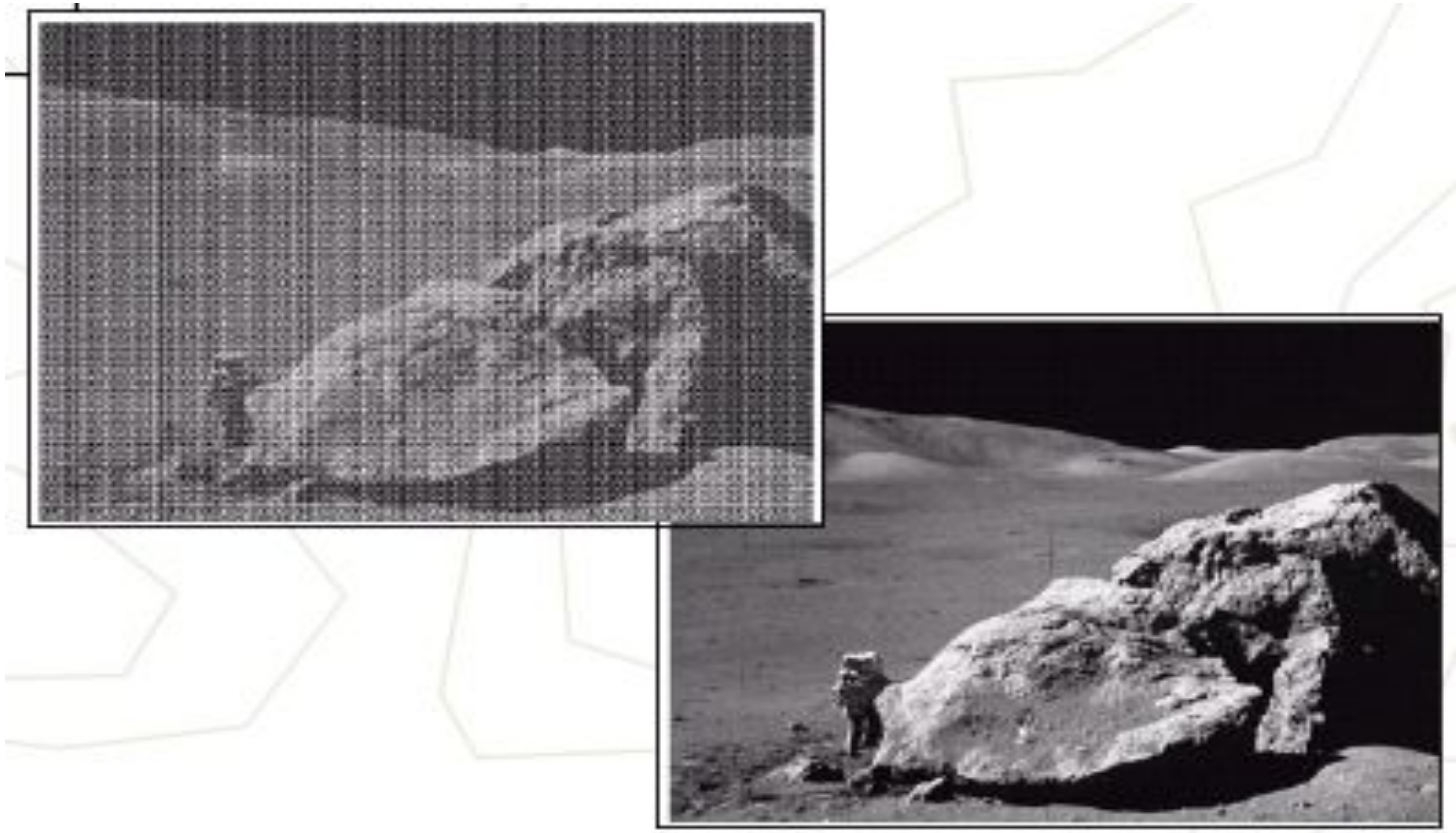


Fundamental Steps in Digital Image Processing

Step 3 : Image Restoration

- Restoration - Improving the appearance of an image. Tend to be mathematical or probabilistic models.

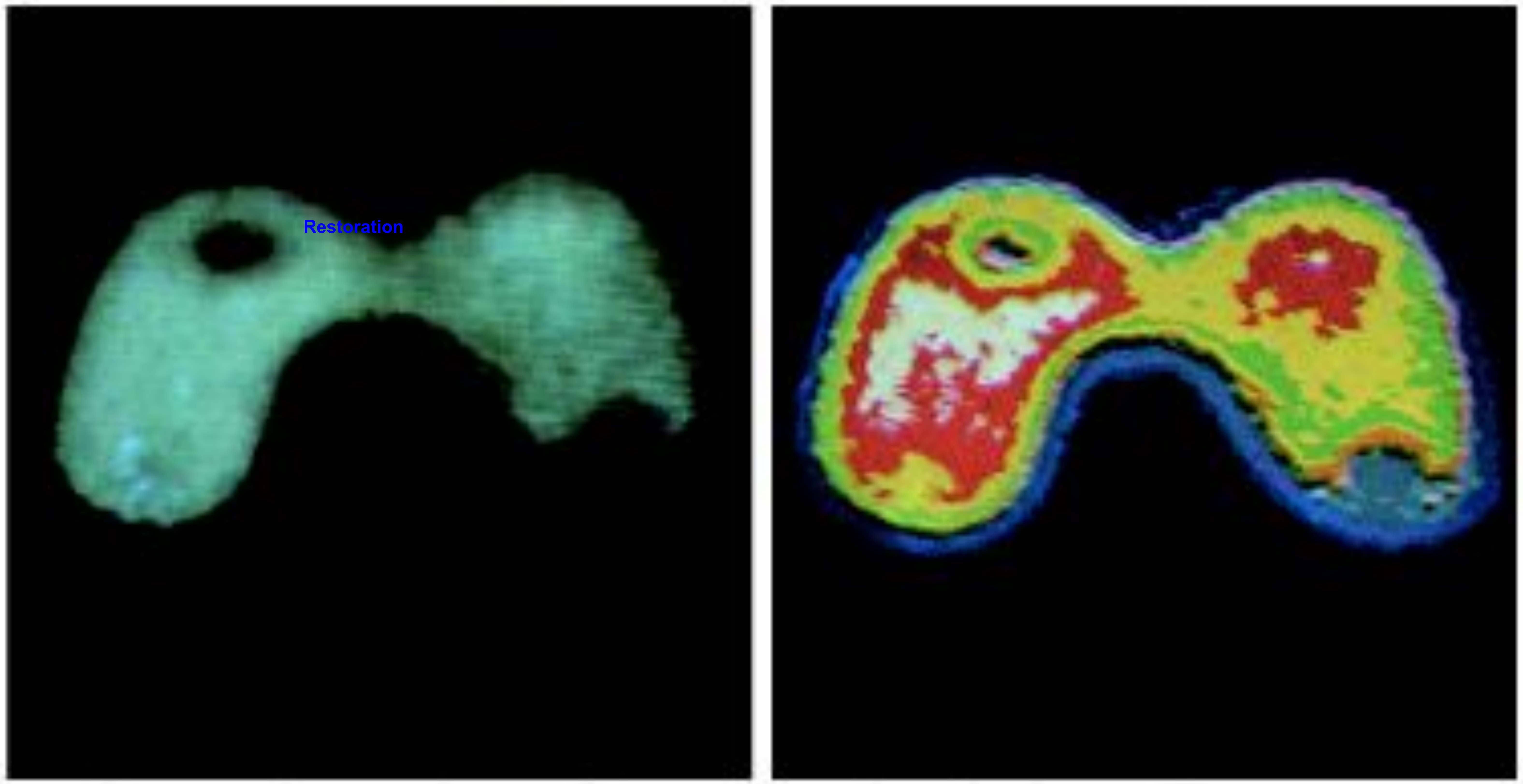
- Enhancement, on the other hand, is based on human subjective preferences regarding what constitutes a "good" enhancement result.



Fundamental Steps in Digital Image Processing

Step 4 : Colour Image Processing

- Use the colour of the image to extract features of interest in an image



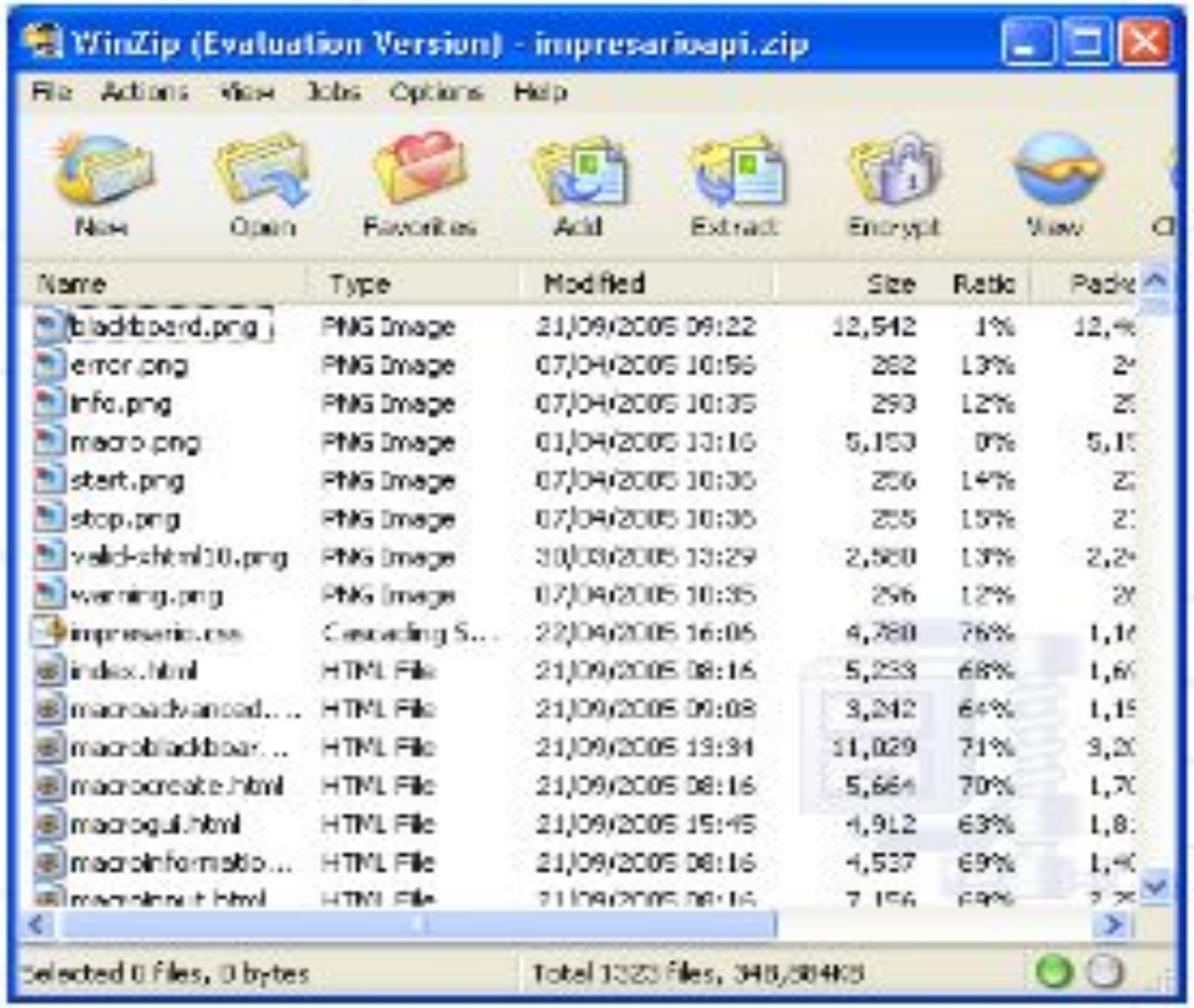
Fundamental Steps in Digital Image Processing

Step 5 : Wavelets

- Are the foundation of representing images in various degrees of resolution.
- It is used for image data compression.

Step 6 : Compression

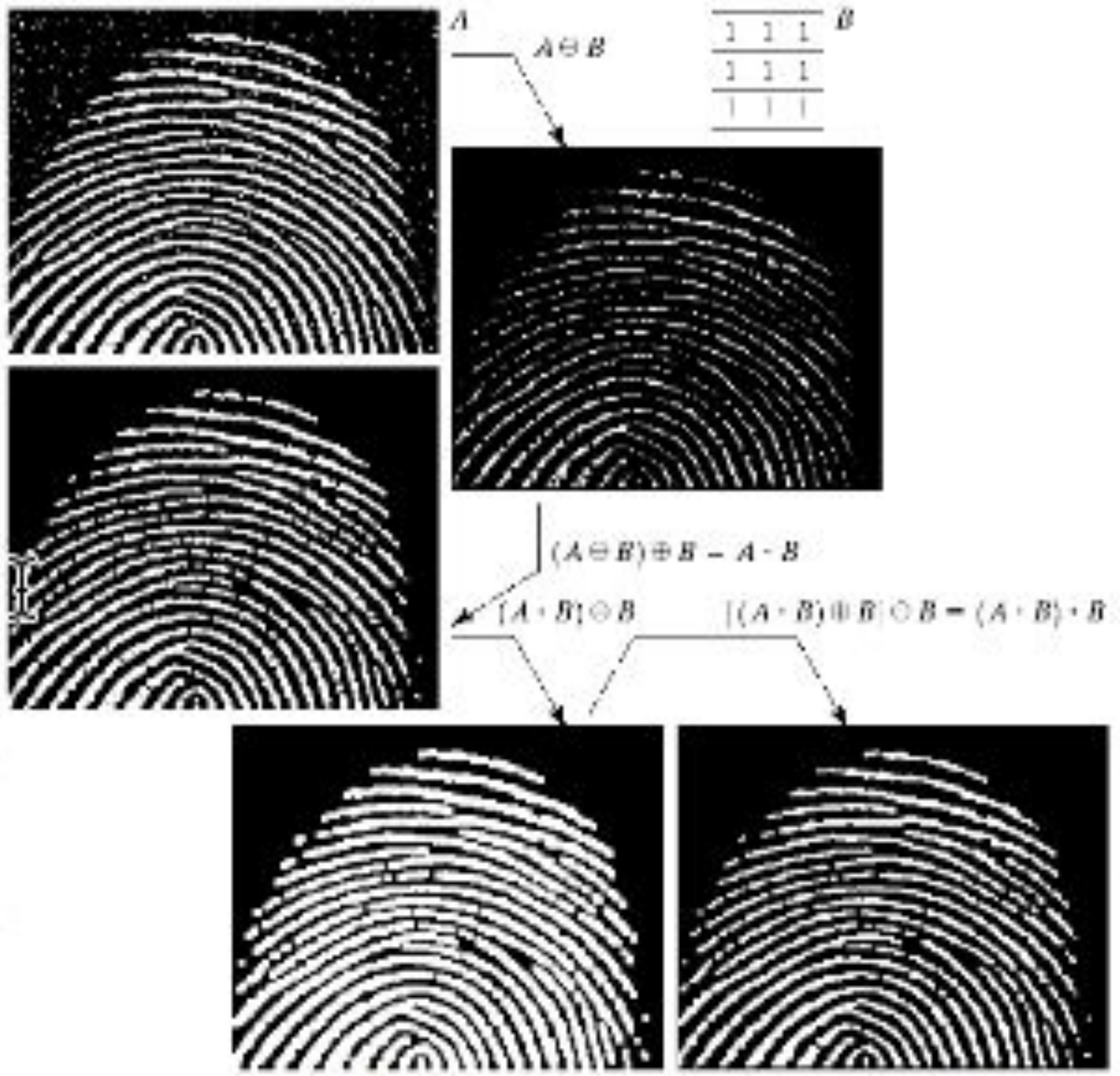
- Techniques for reducing the storage required to save an image or the bandwidth required to transmit it.



Fundamental Steps in Digital Image Processing

Step 7 : Morphological Processing

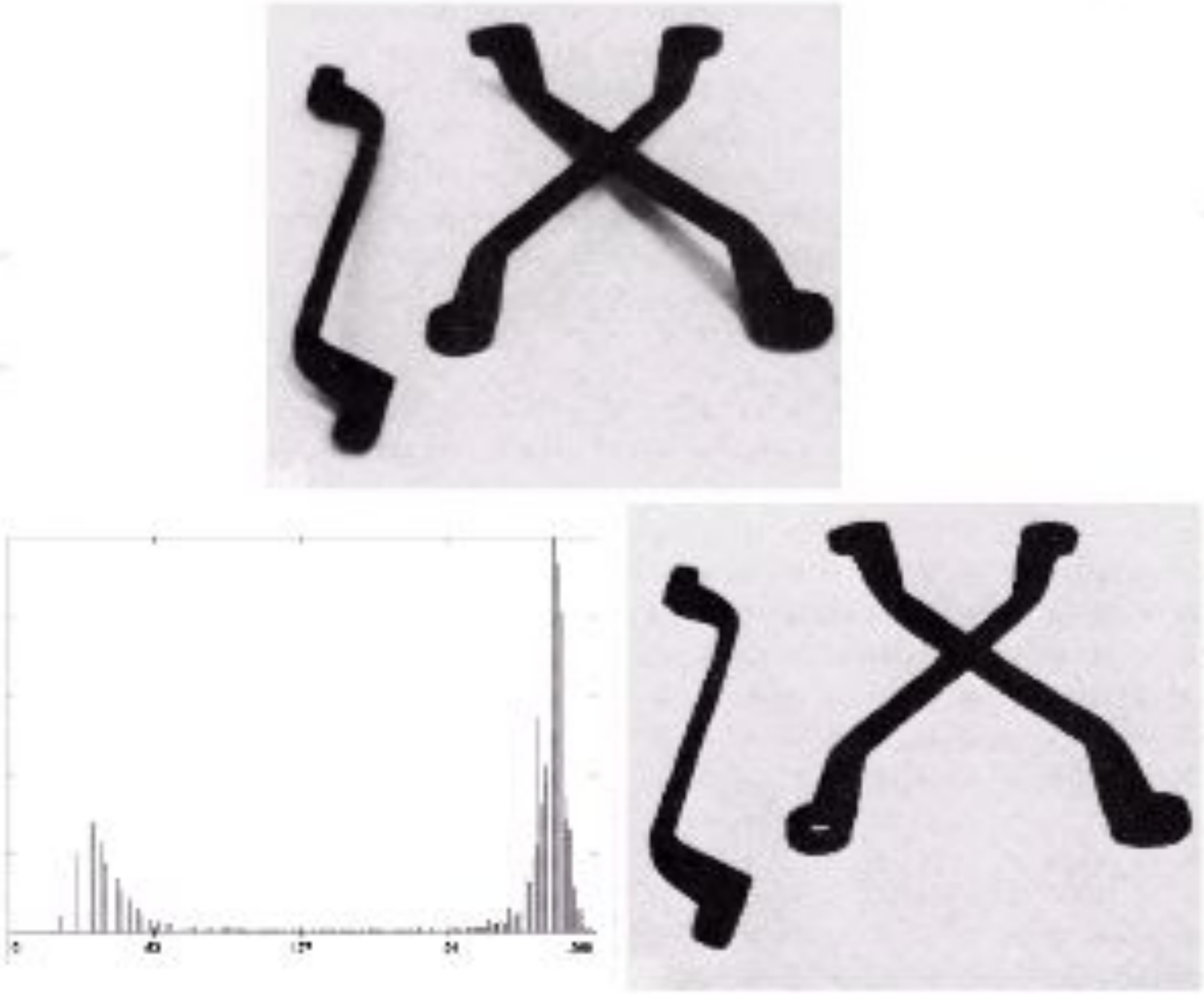
- Tools for extracting image components that are useful in the representation and description of shape.
- In this step, there would be a transition from processes that output images, to processes that output image attributes.



Fundamental Steps in Digital Image Processing

Step 8 : Image Segmentation

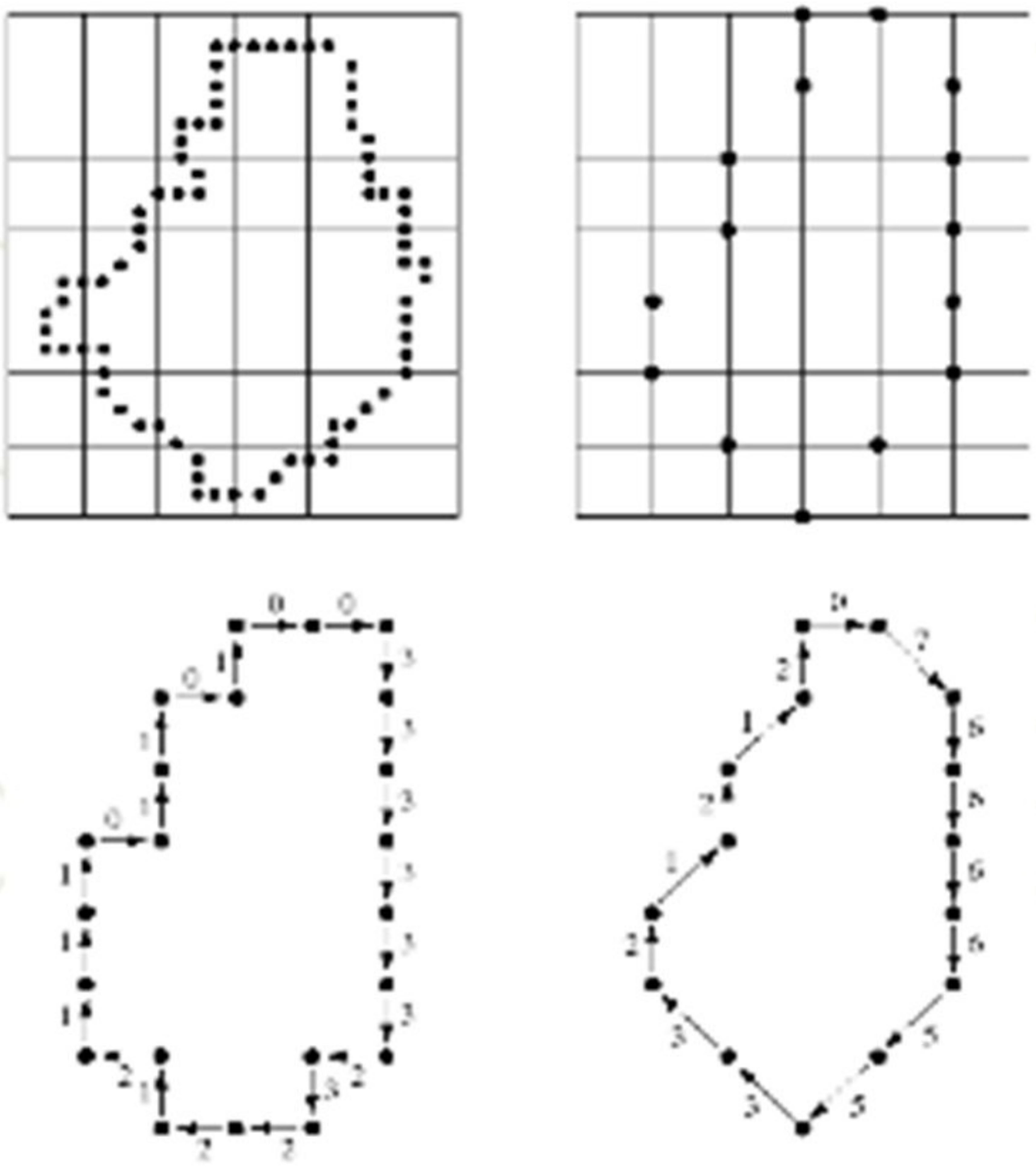
- Segmentation procedures partition an image into its constituent parts or objects.



Fundamental Steps in Digital Image Processing

Step 9 : Representation and Description

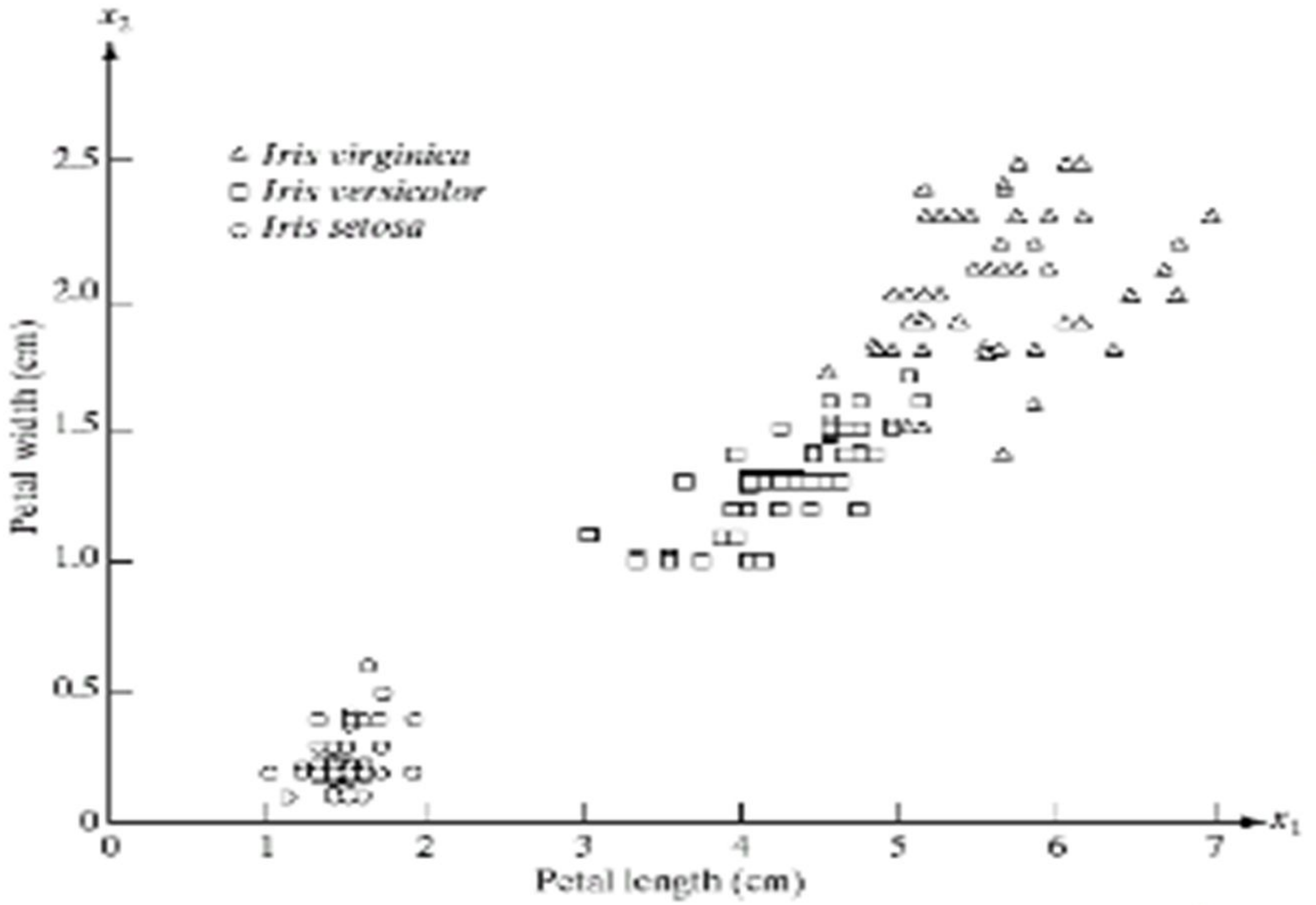
- **Representation:** Make a decision whether the data should be represented as a boundary or as a complete region. It almost always follows the output of a segmentation stage.
  - Boundary Representation: Focus on external shape characteristics, such as corners
  - Region Representation: Focus on internal properties, such as texture
- Choosing a representation is only part of the solution for transforming raw data into a form suitable for subsequent computer processing (mainly recognition).
- **Description:** also called, feature selection, deals with extracting attributes that result in some information of interest.



Fundamental Steps in Digital Image Processing

Step 10: Object Recognition

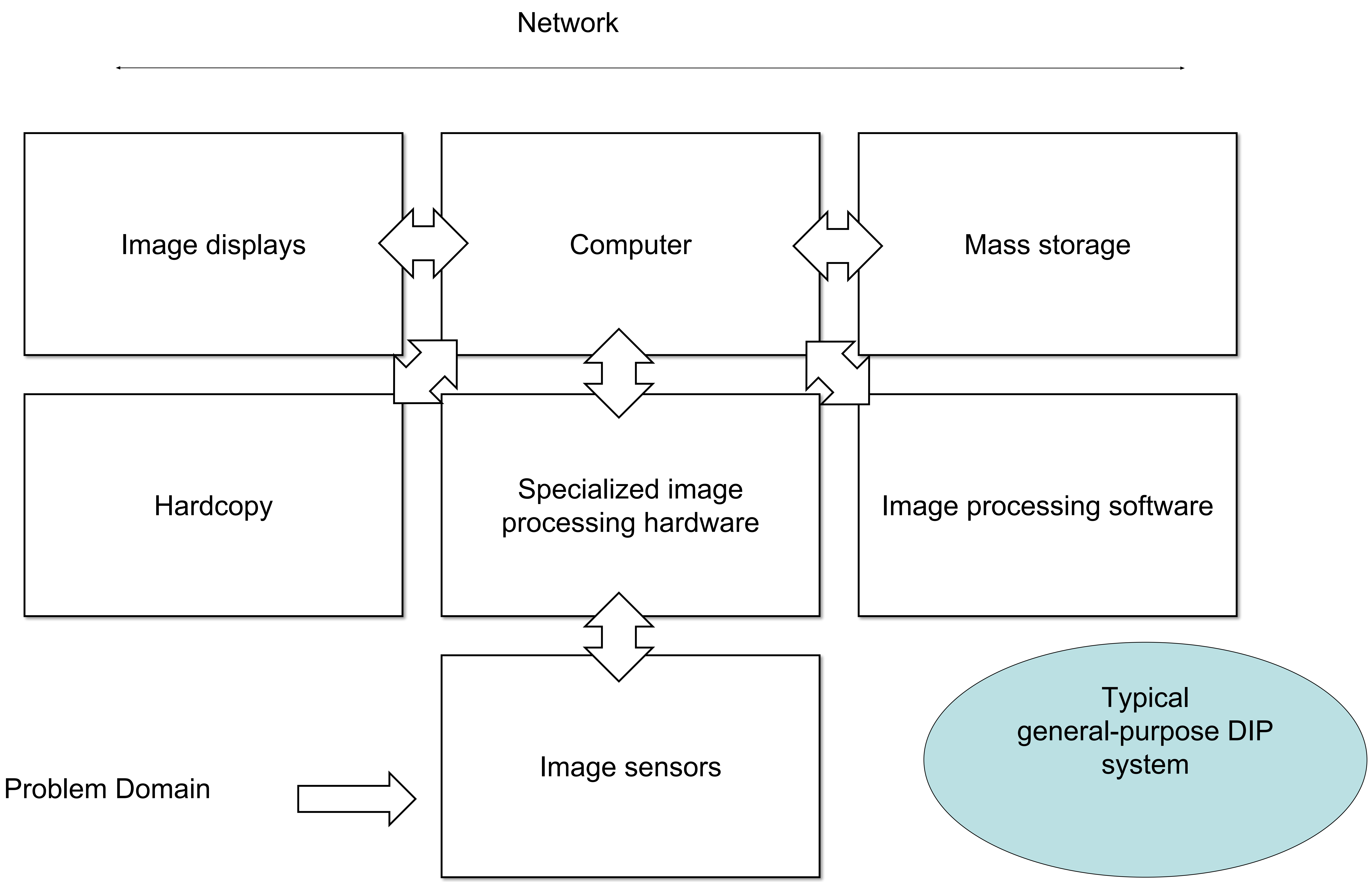
- Recognition: the process that assigns label to an object based on the information provided by its description.



Step 11 : Knowledge Base

- Knowledge about a problem domain is coded into an image processing system in the form of a knowledge database.

Components of an Image Processing System



Components of an Image Processing System

1. **Image Sensors -** Two elements are required to acquire digital images. The first is the physical device that is sensitive to the energy radiated by the object we wish to image (*Sensor*). The second, called a *digitizer*, is a device for converting the output of the physical sensing device into digital form.
2. **Specialized Image Processing Hardware -** Usually consists of the digitizer, mentioned before, plus hardware that performs other primitive operations, such as an arithmetic logic unit (ALU), which performs arithmetic and logical operations in parallel on entire images.

   This type of hardware sometimes is called a front-end subsystem, and its most distinguishing characteristic is speed. In other words, this unit performs functions that require fast data throughputs that the typical main computer cannot handle.
3. **Computer -** The computer in an image processing system is a general-purpose computer and can range from a PC to a supercomputer. In dedicated applications, sometimes specially designed computers are used to achieve a required level of performance.

Components of an Image Processing System

4. Image Processing Software - Software for image processing consists of specialized modules that perform specific tasks. A well-designed package also includes the capability for the user to write code that, as a minimum, utilizes the specialized modules.

5. Mass Storage Capability - Mass storage capability is a must in a image processing applications. And image of sized 1024 * 1024 pixels requires one megabyte of storage space if the image is not compressed.

- Digital storage for image processing applications falls into three principal categories:
  - ✔ Short-term storage for use during processing
  - ✔ Online storage for relatively fast recall
  - ✔ Archival storage, characterized by infrequent access

One method of providing short-term storage is computer memory. Another is by specialized boards, called frame buffers, that store one or more images and can be accessed rapidly.

The on-line storage method, allows virtually instantaneous image zoom, as well as scroll (vertical shifts) and pan (horizontal shifts). On-line storage generally takes the form of magnetic disks and optical-media storage. The key factor of on-line storage is frequent access to the stored data.

Finally, archival storage is characterized by massive storage requirements but infrequent need for access.

Components of an Image Processing System

6. Image Displays

The displays in use today are mainly colour (preferably flat screen) TV monitors. Monitors are driven by the outputs of the image and graphics display cards that are an integral part of a computer system.

7. Hardcopy devices

Used for recording images, include laser printers, film cameras, heat-sensitive devices, inkjet units and digital units, such as optical and CD-Rom disks.

8. Networking

Is almost a default function in any computer system, in use today. Because of the large amount of data inherent in image processing applications the key consideration in image transmission is bandwidth.

In dedicated networks, this typically is not a problem, but communications with remote sites via the internet are not always as efficient.

DIGITAL IMAGE REPRESENTATION

- An image can be defined as a two-dimensional function f(x,y)
  - x,y : Spatial coordinate
  - f : the amplitude of any pair of coordinate x,y, which is called the intensity or gray level of the image at that point.
  - x,y and f, are all finite and discrete quantities.
- An image can be defined by a two-dimensional array specifically arranged in rows and columns.
- Digital Image is composed of a finite number of elements, each of which elements have a particular value at a particular location. These elements are referred to as picture elements, image elements, and pixels.
- A Pixel is most widely used to denote the elements of a Digital Image.

DIGITAL IMAGE REPRESENTATION

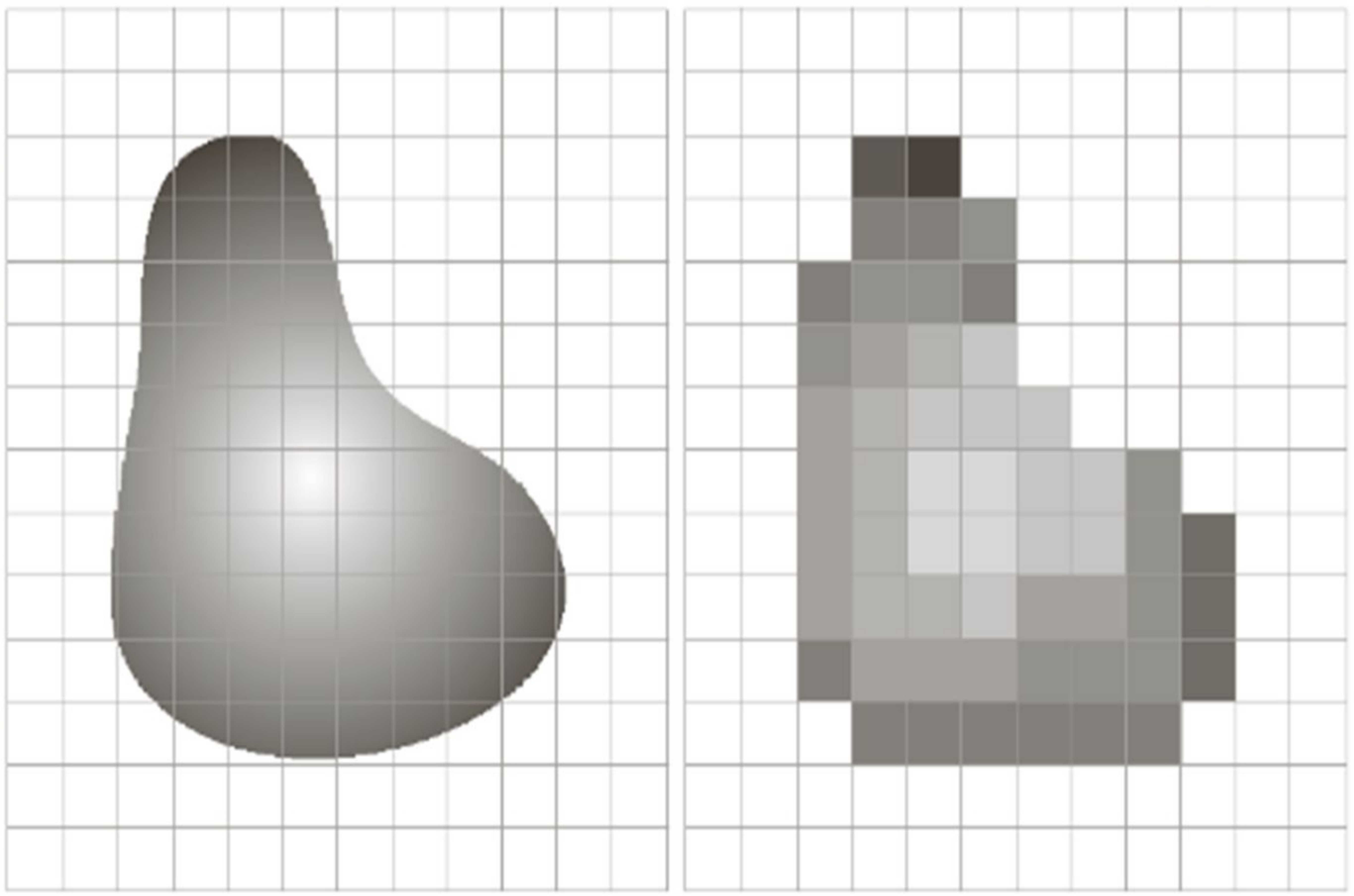
Types of an image

- BINARY IMAGE
  - The binary image as its name suggests, contain only two pixel elements i.e 0 & 1, where 0 refers to black and 1 refers to white. This image is also known as Monochrome.
- BLACK AND WHITE IMAGE
  - The image which consist of only black and white color is called BLACK AND WHITE IMAGE.
- 8 bit COLOR FORMAT
  - It is the most famous image format. It has 256 different shades of colors in it and commonly known as Grayscale Image. In this format, 0 stands for Black, and 255 stands for white, and 127 stands for gray.
- 16 bit COLOR FORMAT
  - It is a color image format. It has 65,536 different colors in it. It is also known as High Color Format. In this format the distribution of color is not as same as Grayscale image.
  - It is actually divided into three further formats which are Red, Green and Blue (RGB format).

DIGITAL IMAGE REPRESENTATION

Image Sampling and Quantization

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

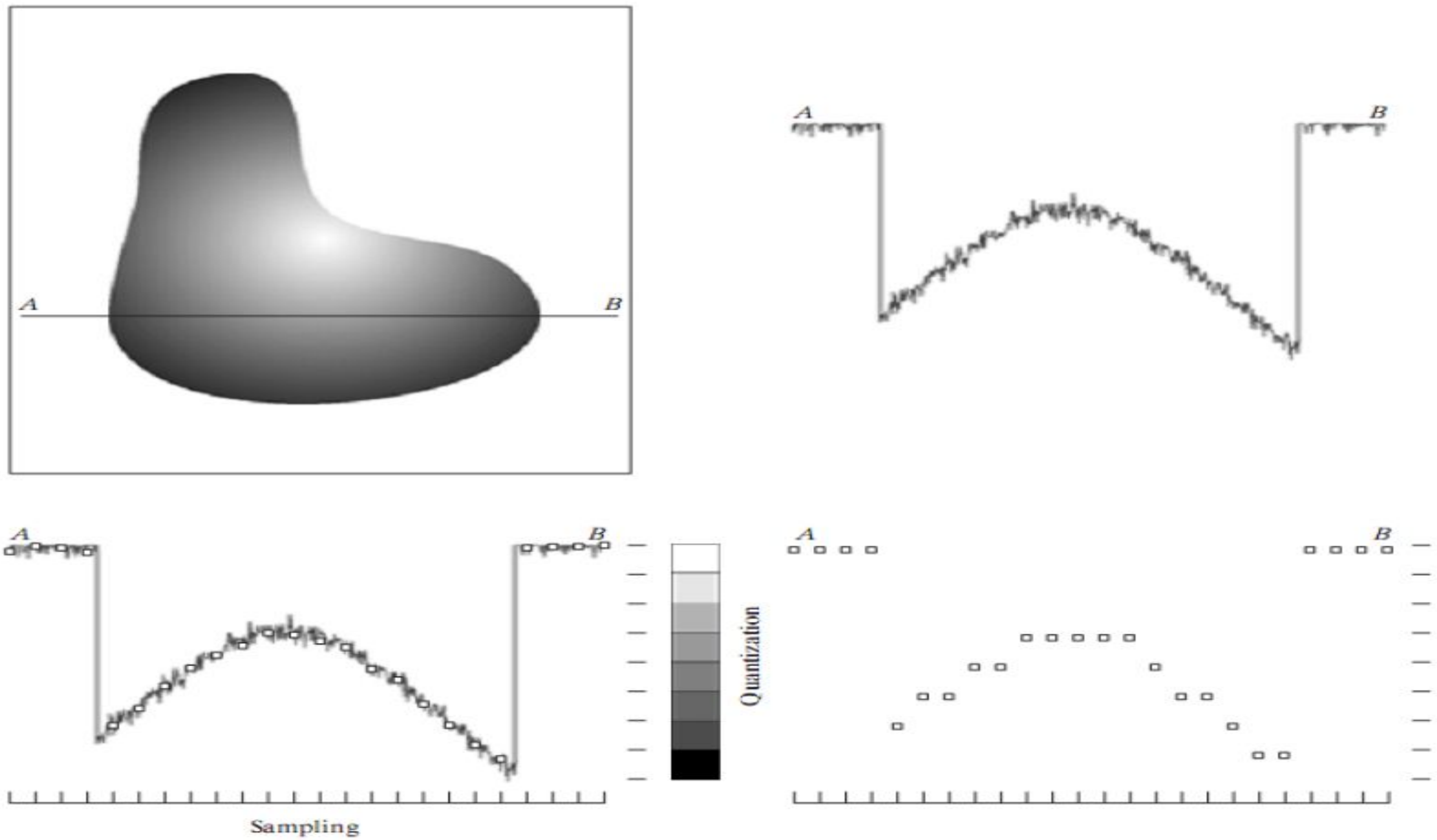


a b

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

DIGITAL IMAGE REPRESENTATION

Image Sampling and Quantization



DIGITAL IMAGE REPRESENTATION

Image as a Matrix

- Images are represented in rows and columns, we have the following syntax in which images are represented

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & f(0,2) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & f(1,2) & \dots & f(1,N-1) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ f(M-1,0) & f(M-1,1) & f(M-1,2) & \dots & f(M-1,N-1) \end{bmatrix}$$

- Every element of this matrix is called image element , picture element , or pixel.
- M and N are positive integers and no restriction is placed on this
- No. of intensity levels L is typically an integer power of 2 : **$L=2^k$**
- We assume that discrete levels are equally spaced and they are integers in the range [0,L-1].

DIGITAL IMAGE REPRESENTATION

Image as a Matrix

- The number of bits(b) required to store a digitized image is

  b = M*N*k

- k bit image: An image with 2^k intensity levels

- Eg: 8 bit image: 256 possible discrete intensity values
- Dynamic range of an imaging system is the ratio of maximum measurable intensity to minimum detectable intensity level in the system
- Contrast: defined as the difference in intensity between the highest and lowest intensity levels in an image

Image as a Matrix

- An image processing operation typically defines a new image in terms of an existing image .
- We can transform either the **range of f**

$$g(x,y) = t(f(x,y))$$

- or the **domain of f**

$$g(x,y) = f(t_x(x,y), t_y(x,y))$$

Relationship between Pixels

Neighbours of a Pixel

x-1,y-1	x-1,y	x-1,y+1
x,y-1	x,y	x,y+1
x+1,y-1	x+1,y	x+1,y+1

- A pixel p at coordinates (x,y) has four horizontal and vertical neighbors whose coordinates are given by:

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

- This set of pixels, called the 4-neighbors of p, is denoted by N4(p).
- Each pixel is one unit distance from (x,y) and some of the neighbors of p lie outside the digital image if (x,y) is on the border of the image.

Relationship between Pixels

Neighbours of a Pixel

x-1,y-1	x-1,y	x-1,y+1
x,y-1	x,y	x,y+1
x+1,y-1	x+1,y	x+1,y+1

- The four diagonal neighbors of p denoted by $N_D(p)$, have coordinates:

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

- These points, together with the 4-neighbors, are called the 8-neighbors of p, denoted by $N_8(p)$.
- As before, some of the points in $N_D(p)$ and $N_8(p)$ fall outside the image if (x,y) is on the border of the image.

Relationship between Pixels
Adjacency and Connectivity

- Let V: a set of intensity values used to define adjacency and connectivity.
  - In a binary image, V = {1}, if we are referring to adjacency of pixels with value 1.
  - In a gray-scale image, the idea is the same, but V typically contains more elements, for example, V = {180, 181, 182, …, 200}
- If the possible intensity values are 0 – 255, V set can be any subset of these 256 values.

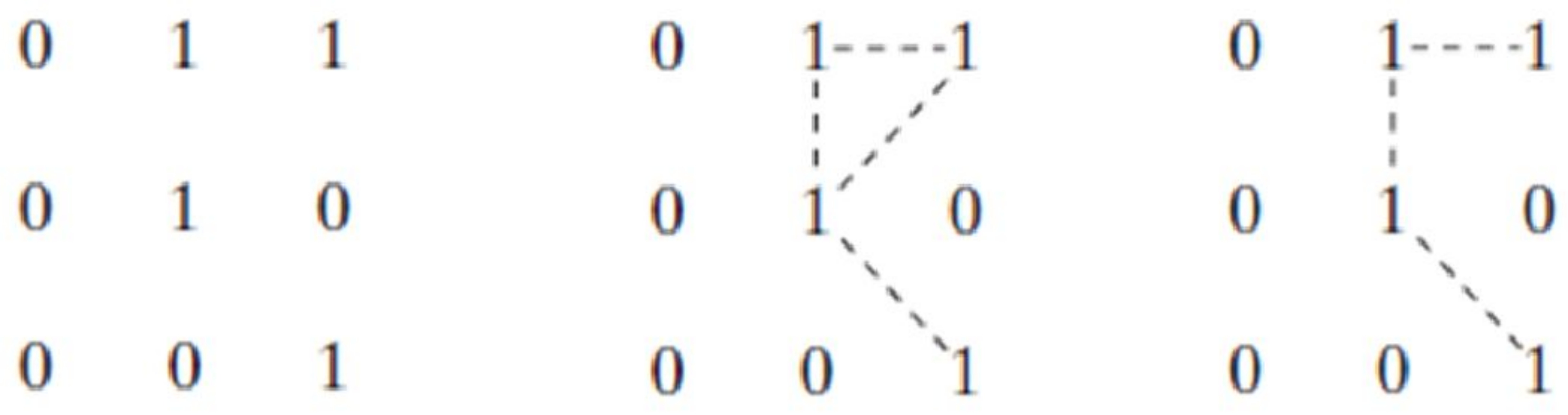
Relationship between Pixels
Types of Adjacency

- **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)**
  - Two pixels p and q with values from V are m-adjacent if :
    - q is in $N_4(p)$ or
    - q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixel whose values are from V

    (no intersection)

Relationship between Pixels

Types of Adjacency



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

- Mixed adjacency is a modification of 8-adjacency. It is introduced to eliminate the ambiguities that often arise when 8-adjacency is used.
- In 8-adjacency way, can find multiple paths between two pixels. While, in m-adjacency, can find only one path between two pixels.
- So, m-adjacency has eliminated the multiple path connection that has been generated by the 8-adjacency.

Relationship between Pixels

A DIGITAL PATH

- A digital path (or curve) from pixel p with coordinate (x,y) to pixel q with coordinate (s,t) is a sequence of distinct pixels with coordinates (x0,y0), (x1,y1), …, (xn,yn)
  - where (x0,y0) =(x,y) and (xn,yn) = (s,t) and
  - pixels (xi,yi) and (xi-1,yi-1) are adjacent for $1 \le i \le n$ is the length of the path
  - If (x0,y0)=(xn,yn), the path is closed.
- We can specify 4-, 8- or m-paths depending on the type of adjacency specified.

Relationship between Pixels

CONNECTIVITY

- Let S represent a subset of pixels in an image, 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.

- For any pixel p in S, the set of pixels that are connected to it in S is called a connected component of S.

- If it only has one connected component, then set S is called a connected set.

Relationship between Pixels
REGION AND BOUNDARY

- **Region**
  - Let R be a subset of pixels in an image, we call R a region of the image if R is a connected set.
  - Two regions Ri and Rj are said to be adjacent if their union forms a connected set.
  - Regions that are not adjacent→ disjoint
- **Boundary**
  - The boundary (also called border or contour) of a region R is the set of points that are adjacent to points in the complement of R
  - Or, border of a region is the set of pixels in the region that have atleast one background neighbour

Relationship between Pixels

REGION AND BOUNDARY

$$
\left.\begin{array}{ccc}1 & 1 & 1\\ 1 & 0 & 1\\ 0 & 1 & 0\end{array}\right\} R_i
$$
$$
\left.\begin{array}{ccc}0 & 0 & 1\\ 1 & 1 & 1\\ 1 & 1 & 1\end{array}\right\} R_j
$$

$$
\begin{array}{ccccc}
0 & 0 & 0 & 0 & 0\\
0 & 1 & 1 & 0 & 0\\
0 & 1 & 1 & 0 & 0\\
0 & 1 & 1 & 1 & 0\\
0 & 1 & 1 & 1 & 0\\
0 & 0 & 0 & 0 & 0
\end{array}
$$

$$
\begin{array}{ccc}
0 & 0 & 0\\
0 & 1 & 0\\
0 & 1 & 0\\
0 & 1 & 0\\
0 & 1 & 0\\
0 & 0 & 0
\end{array}
$$

The circled pixel is NOT a member of boundary if 4-connectivity is used between region and background. It is if 8-connectivity is used.

$$
\begin{array}{ccccc}
0 & 0 & 0 & 0 & 0\\
0 & 1 & 1 & 0 & 0\\
0 & 1 & 1 & 0 & 0\\
0 & 1 & 1 & 1 & 0\\
0 & 1 & 1 & 1 & 0\\
0 & 0 & 0 & 0 & 0
\end{array}
$$

Relationship between Pixels
REGION AND BOUNDARY

- If R happens to be an entire image, then its boundary is defined as the set of pixels in the first and last rows and columns in the image.
- This extra definition is required because an image has no neighbors beyond its borders
- Normally, when we refer to a region, we are referring to subset of an image, and any pixels in the boundary of the region that happen to coincide with the border of the image are included implicitly as part of the region boundary.

Relationship between Pixels
DISTANCE MEASURES

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

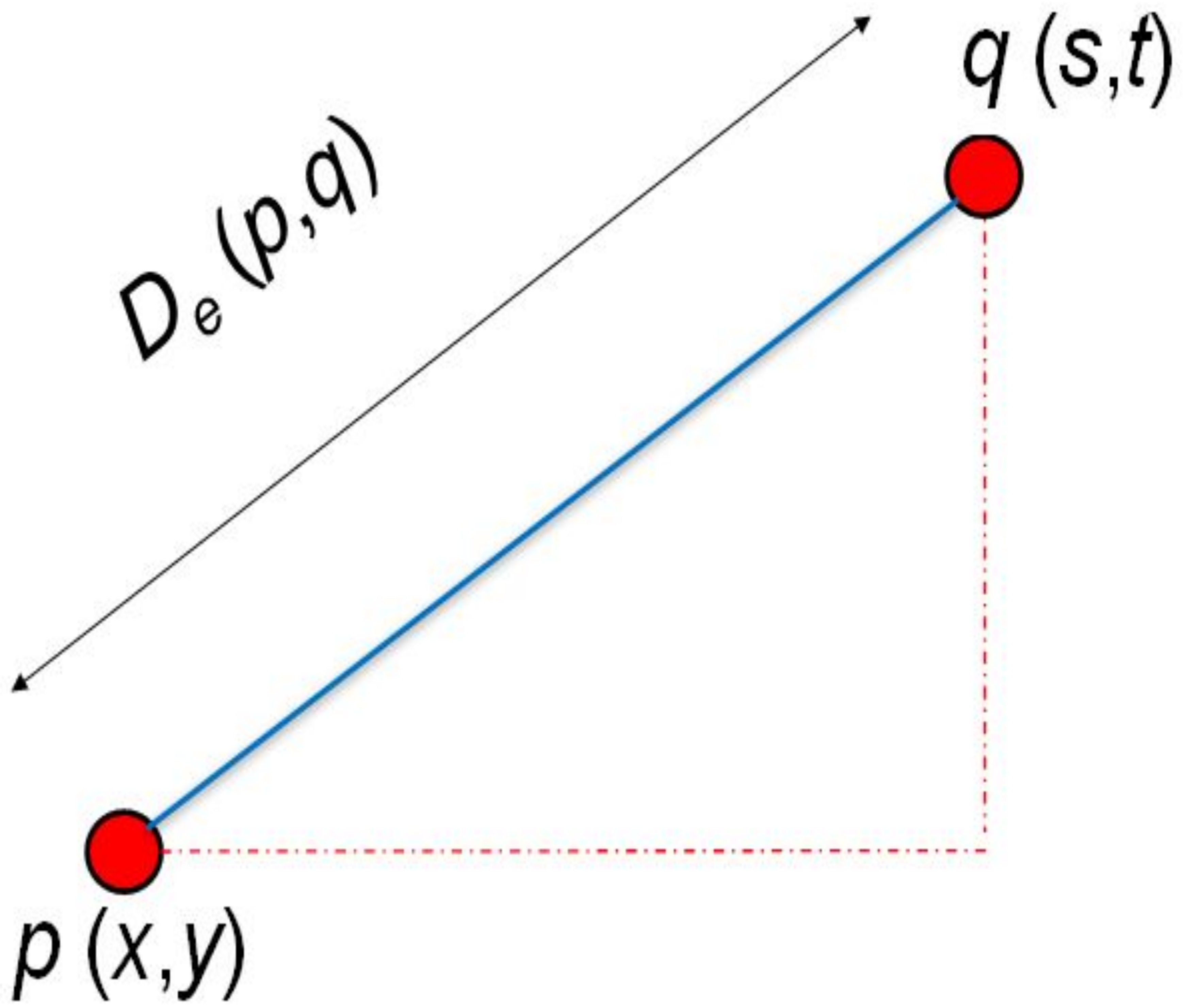
  (a) D (p,q) ≥ 0   (D(p,q) = 0 iff p = q),

  (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:

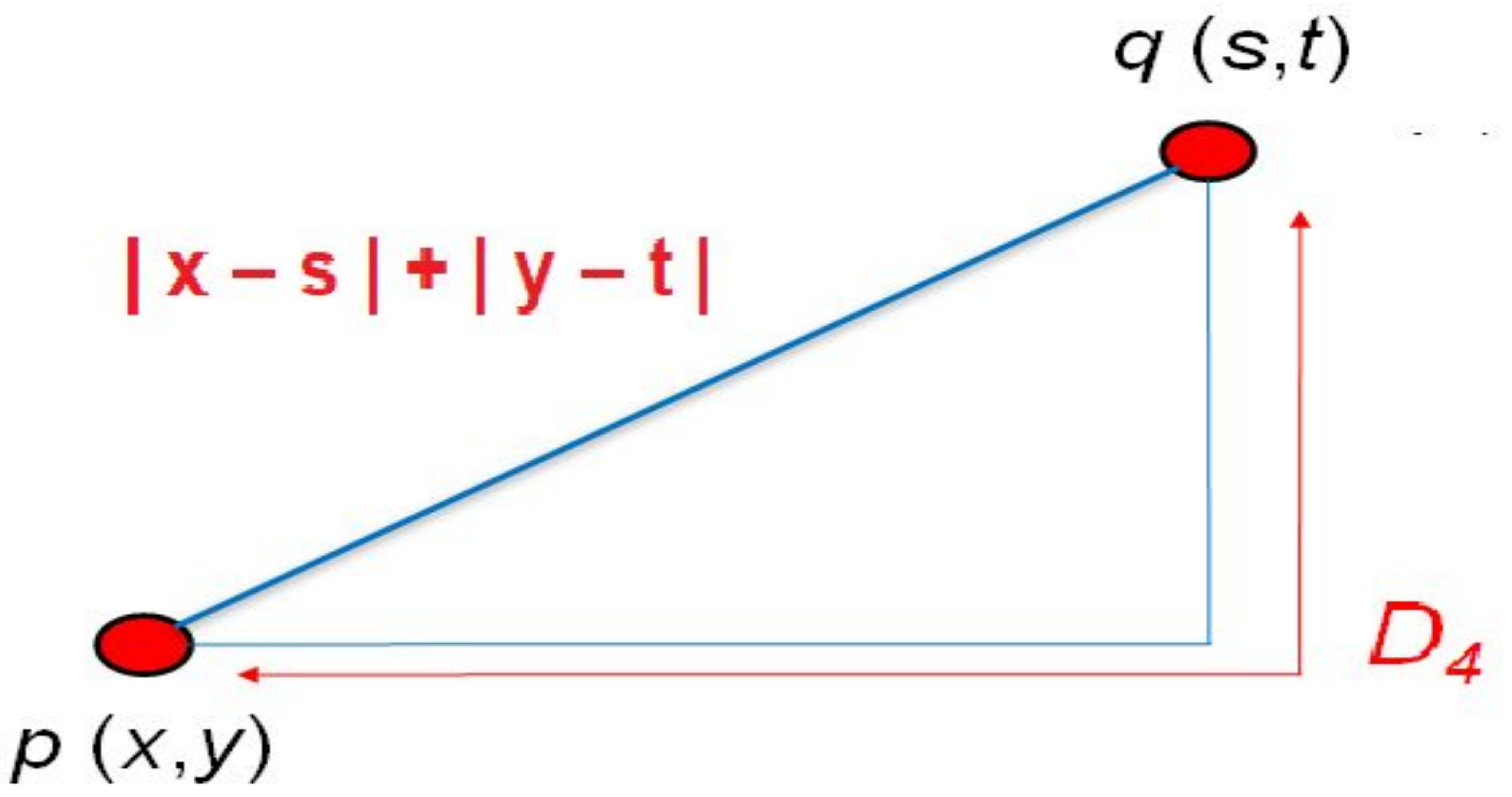
$$D_e(p,q) = [(x-s)^2 + (y-t)^2]^{1/2}$$



- Pixels having a distance less than or equal to some value r from (x,y) are the points contained in a disk of radius r centered at (x,y)

Relationship between Pixels

DISTANCE MEASURES



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

- The D4 distance (also called city-block distance) between p and q is defined as:

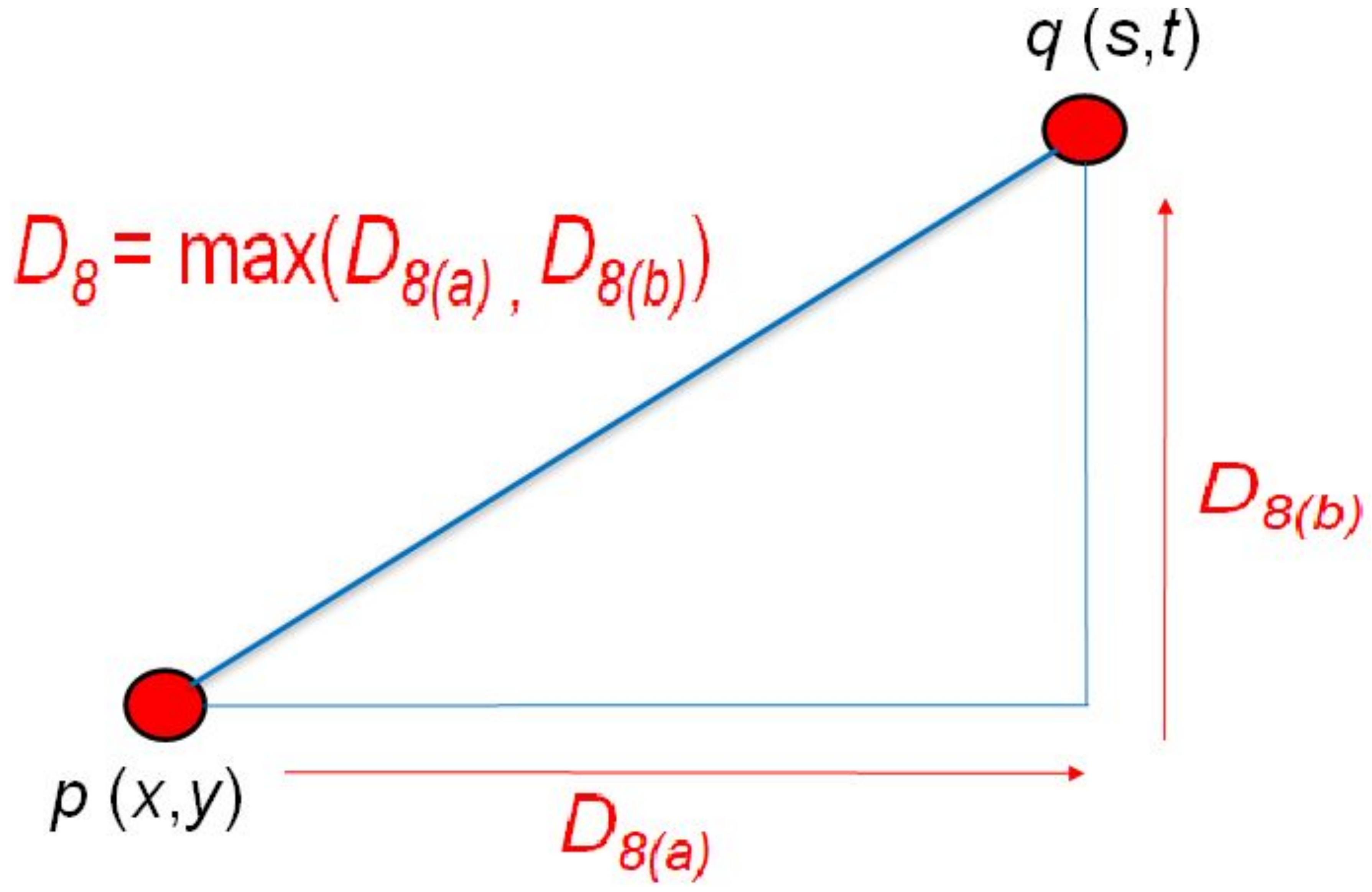
  $(p,q) = | x - s | + | y - t |$

- Pixels having a D4 distance from (x,y), less than or equal to some value r form a Diamond centered at (x,y)
- The pixels with distance D4 ≤ 2 from (x,y) form the following contours of constant distance.
- The pixels with D4 = 1 are the 4-neighbors of (x,y)

Relationship between Pixels
DISTANCE MEASURES

- **The D8 distance (also called chessboard distance) between p and q is defined as:**

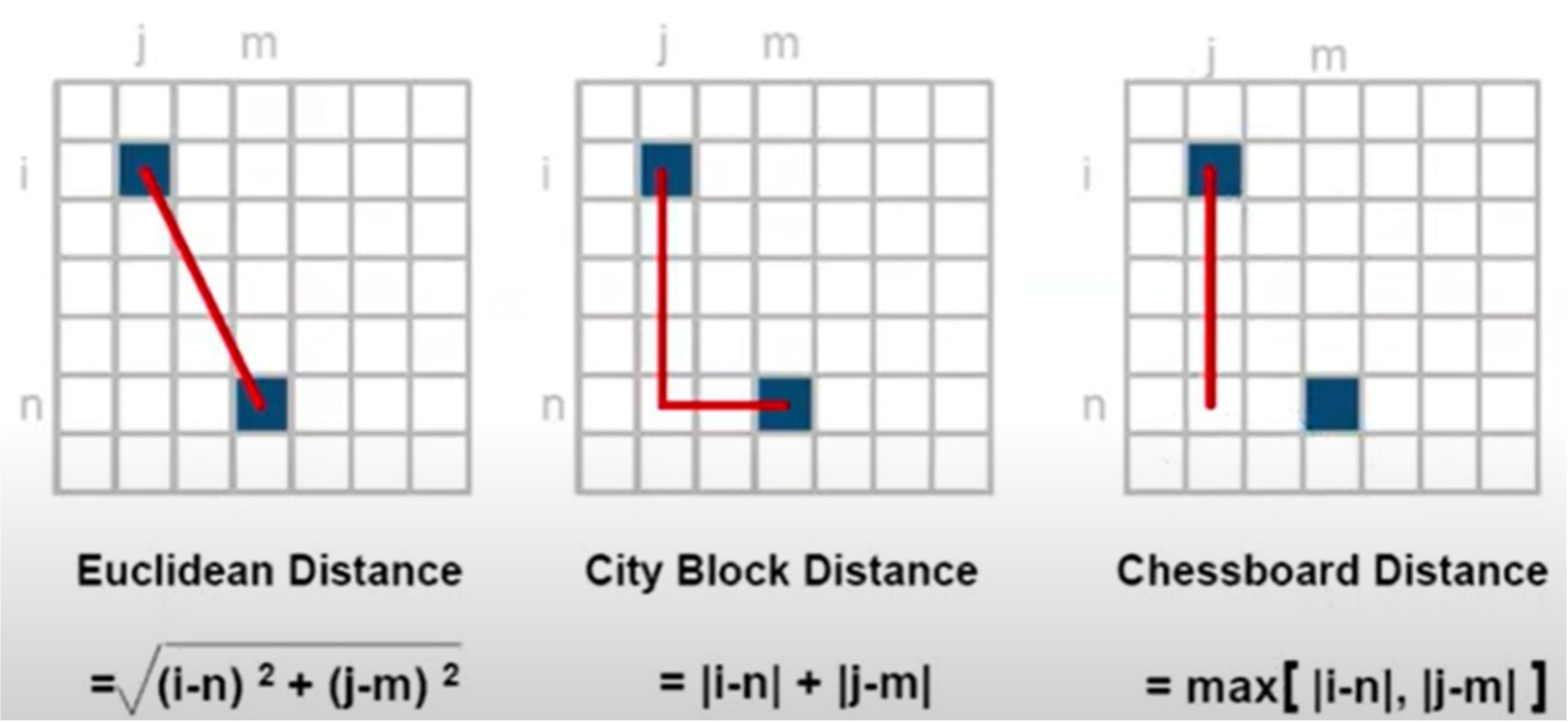
$$(p,q) = \max(| x - s |,| y - t |)$$



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

- **Pixels having a distance from (x,y), less than or equal to some value r form a square centered at (x,y)**
- **Example:**
  - D8 distance ≤ 2 from (x,y) form the following contours of constant distance.

Relationship between Pixels
DISTANCE MEASURES



Relationship between Pixels
DISTANCE MEASURES

- Dm distance is defined as the shortest m-path between the points.
- In this case, the distance between two pixels will depend on the values of the pixels along the path, as well as the values of their neighbors.

SOLVED EXAMPLE OF PATH LENG

Que Find the shortest 4-, 8-, m- path between p and q. ∀

(i) V = {0, 1}

(ii) V = {1, 2}

Given image -

$$\begin{array}{cccc} 3 & 1 & 2 & 1^{(q)} \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ {}^{(p)}1 & 0 & 1 & 1 \end{array}$$

(ii) V = {1, 2}

4-path

$$\begin{array}{cccc} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 0 & 1 & 1 \end{array}$$

8-path

$$\begin{array}{cccc} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 0 & 1 & 1 \end{array}$$

m-path

$$\begin{array}{cccc} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 0 & 1 & 1 \end{array}$$

Relationship between Pixels
DISTANCE MEASURES

- Consider the following arrangement of pixels and assume that p, p2, and p4 have value 1 and that p1 and p3 can have a value of 0 or 1. Suppose that we consider the adjacency of pixels values 1 (i.e. **V = {1}**)

	p_3	p_4
p_1	p_2	
p		

Relationship between Pixels
DISTANCE MEASURES

- Now, to compute the **Dm between points p and p4**,

  Here we have **4 cases**:

- **Case1: If p1 =0 and p3 = 0**

  The length of the shortest m-path (Dm distance) is 2 = (p, p2, p4)

	0	1
0	1	
1		

- **Case 2: If p1 =1 and p3 = 0**

  now, p1 and p will no longer be adjacent .Then, the length of the shortest m-path will be 3 = (p, p1, p2, p4)

	0	1
1	1	
1		

- **Case 3: If p1 =0 and p3 = 1**

  The same applies here, and the length of the shortest m-path will be 3 = (p, p2, p3, p4)

	1	1
0	1	
1		

- **Case 4: If p1 =1 and p3 = 1**

  The length of the shortest m-path will be 4 = (p, p1, p2, p3, p4)

	1	1
1	1	
1		