GLA UNIVERSITY

DIGITAL IMAGE PROCESSING

By:
Dr. Ankush Agarwal

Outline

- Introduction and Fundamentals:
  - Motivation and Perspective, Applications, Components of Image Processing System,
  - Element of Visual Perception, A Simple Image Model,
  - Sampling and Quantization, Some Basic Relationships between Pixels
- Intensity Transformations and Spatial Filtering:
  - Introduction, Some Basic Intensity Transformation Functions,
  - Histogram Processing, Histogram Equalization, Histogram Specification,
  - Local Enhancement, Enhancement using Arithmetic/Logic Operations
  - Basics of Spatial Filtering, Smoothing, Sharpening
- Filtering in the Frequency Domain:
  - Fourier Transform and the Frequency Domain,
  - Basis of Filtering in Frequency Domain

INTRODUCTION AND FUNDAMENTALS

Image

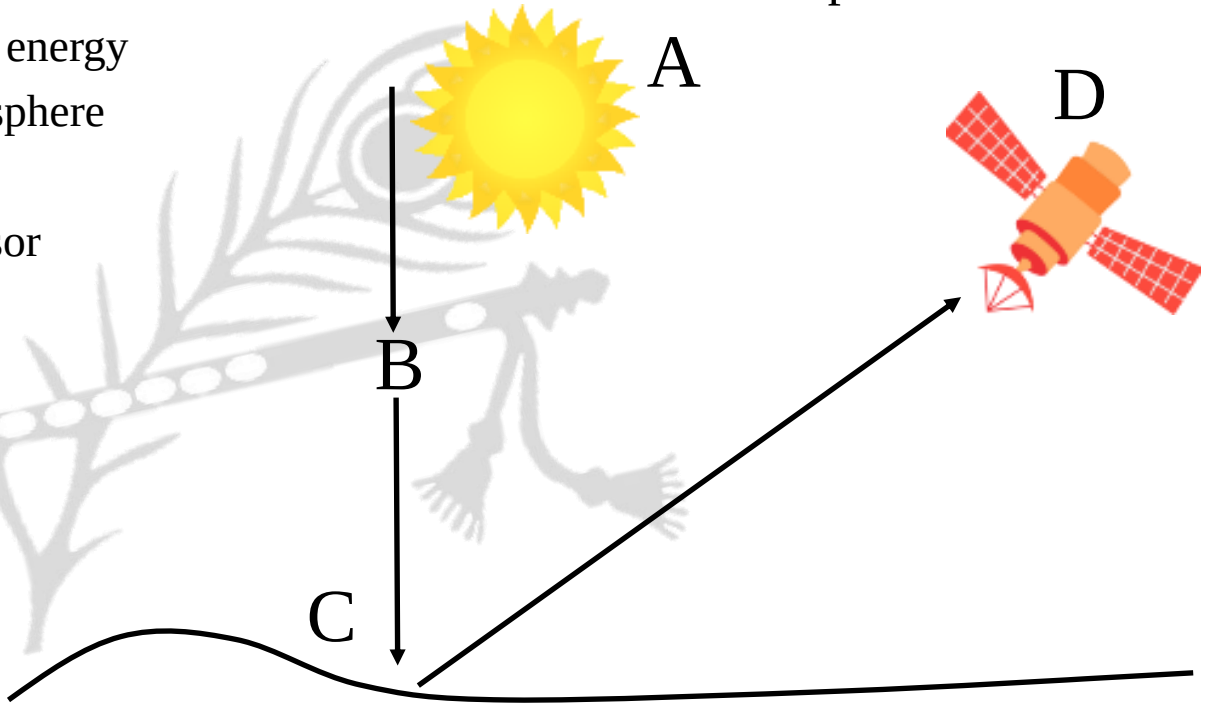
- An image is a visual representation of scene
- An image is an item that depicts visual perception such as a photograph or other two-dimensional picture, which resembles a subject, usually a physical object
- In the context of signal processing, an image is a distributed amplitude of color(s)
- An image is a representation of visual information, such as drawings, pictures, graphs, logos, or individual video frames

Digital Image

- A digital image is a binary representation of visual information
- A digital image is a representation in a two dimensional space as a finite set of digital values, called picture elements or pixels

Image Acquisition

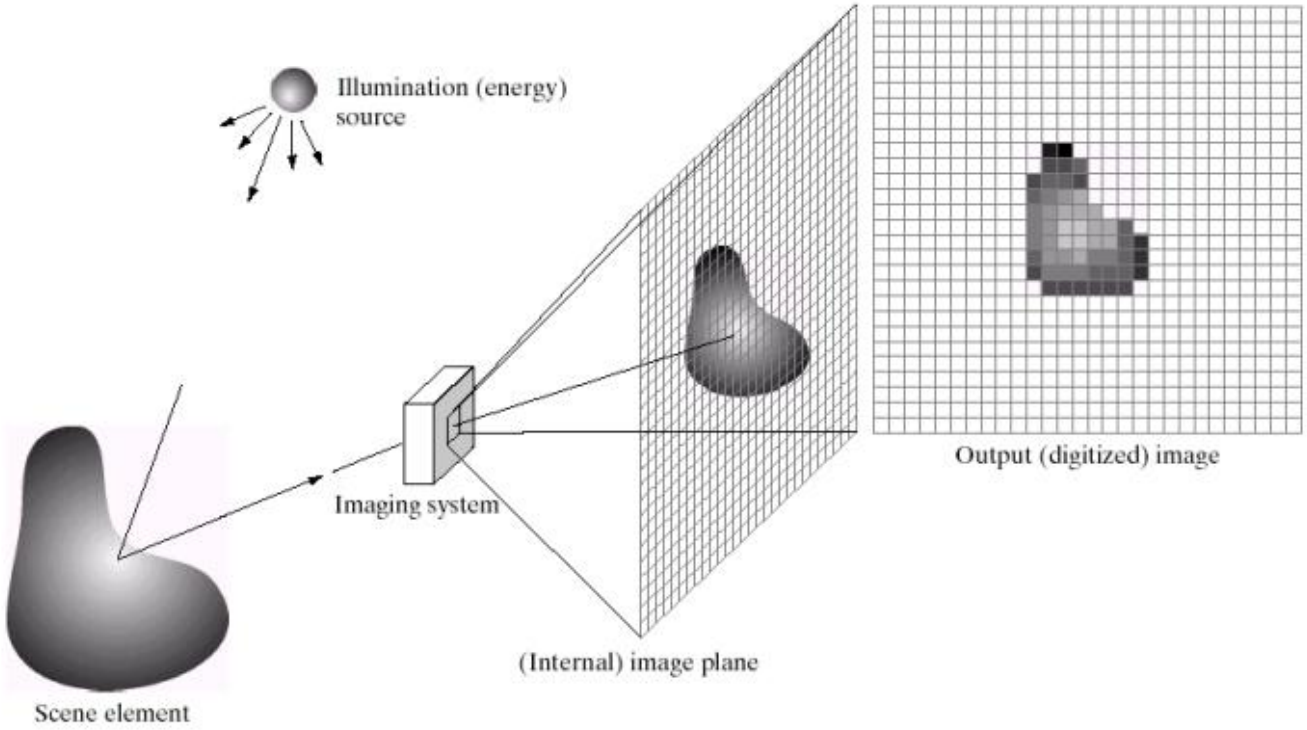
- Images captured by sensors have an involvement of various components
  - Source of electromagnetic energy
  - Interaction with the Atmosphere
  - Interaction with the Target
  - Energy Recording by Sensor



Process involved in Digital Image

- Output of most sensors is a continuous voltage waveform whose amplitude & spatial behavior are related to the physical phenomenon (e.g. brightness) being sensed
- For an image to be processed by a computer, it must be represented by an appropriate discrete data structure (e.g. Matrix)
- Two important processes to convert continuous analog image into digital image
  - Sampling
  - Quantization

Process involved in Digital Image

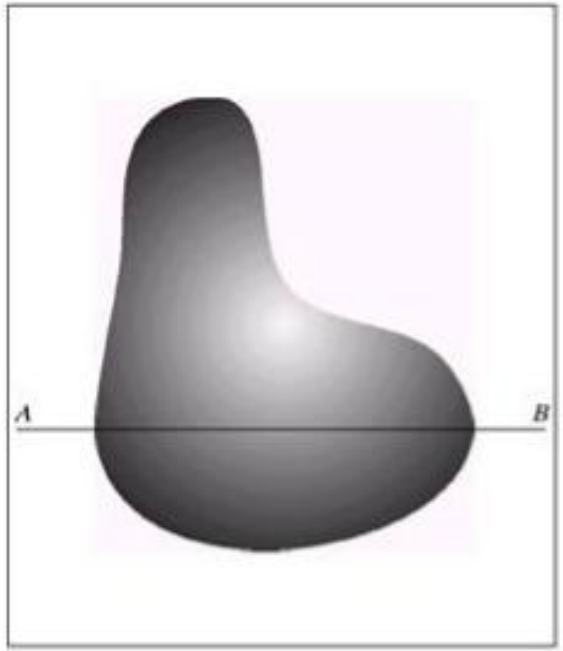


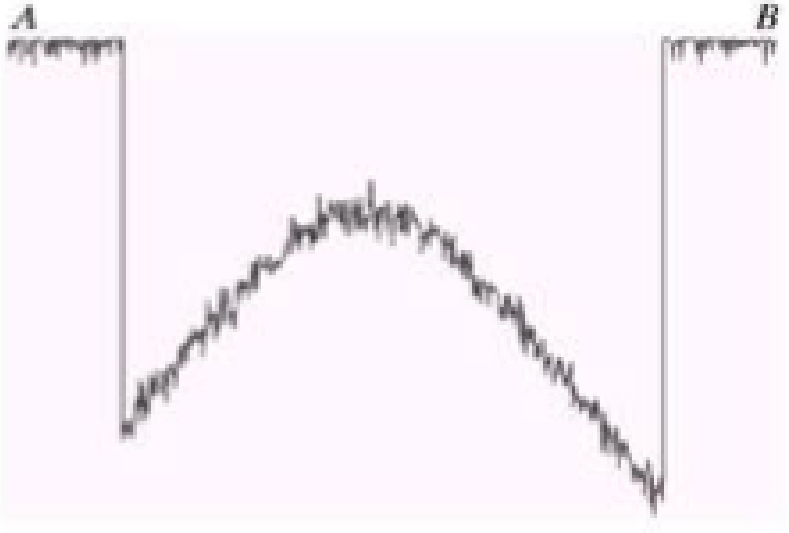
Process involved in Digital Image

- To convert an image to digital form, we have to sample the image in both coordinates (spatial domain) and in amplitude

- Discretization
  - Process in which signals or data samples are considered at regular intervals
- Sampling
  - It is the discretization of image data in spatial coordinates or defining finite discrete coordinate to every part of an image
  - Digitizing the coordinate (spatial domain) values is called sampling
- Quantization
  - It is the discretization of image intensity (gray level) values or defining finite value to every discrete interval
  - Digitizing the amplitude values is called quantization

Sampling and Quantization





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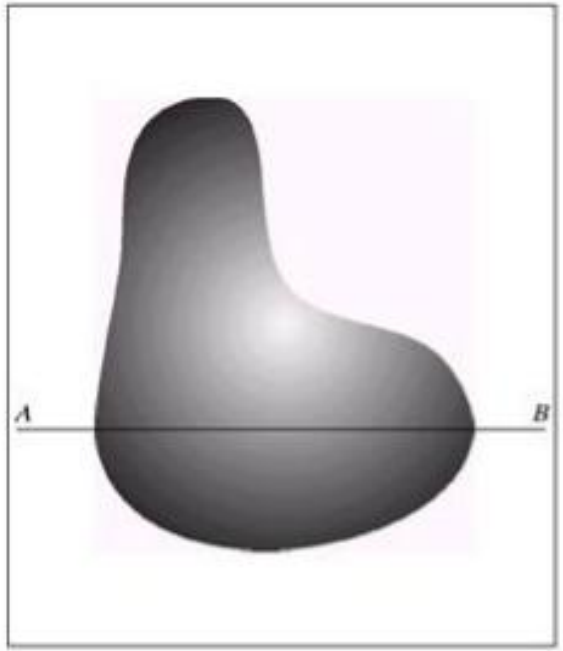

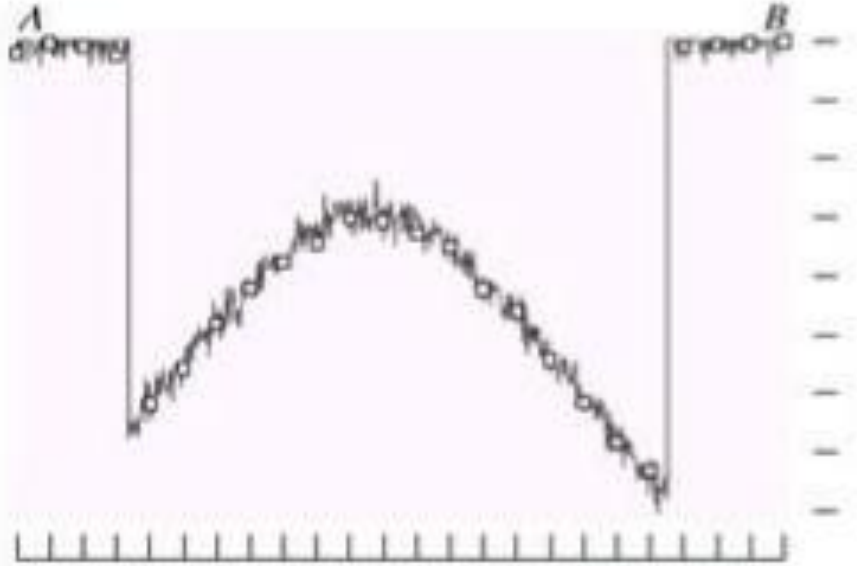

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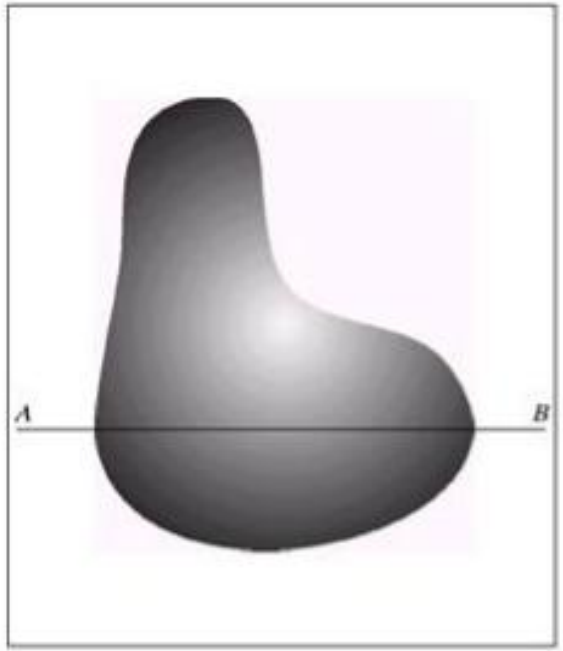

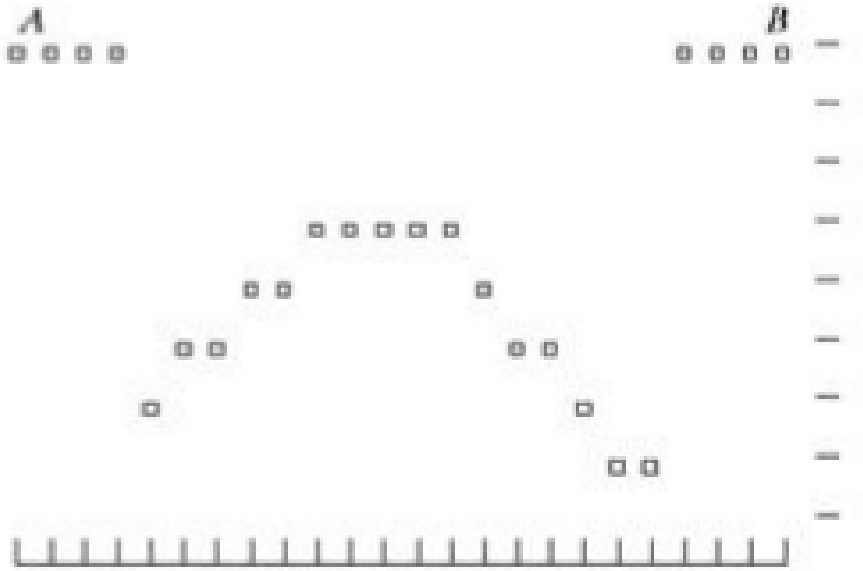

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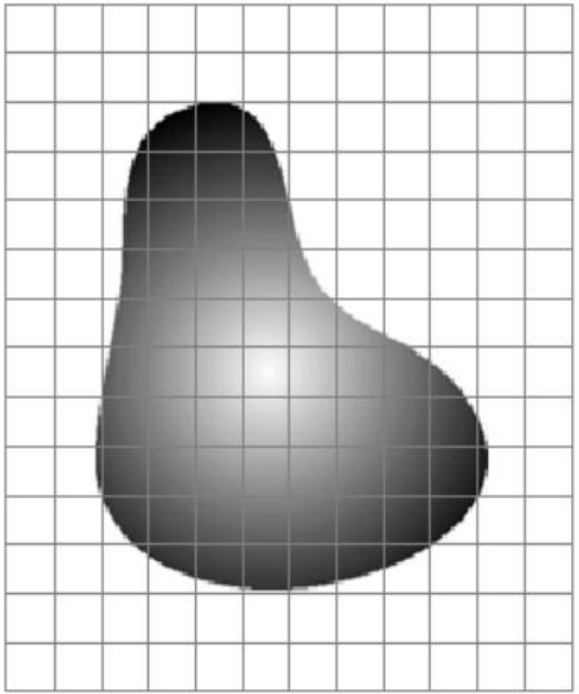
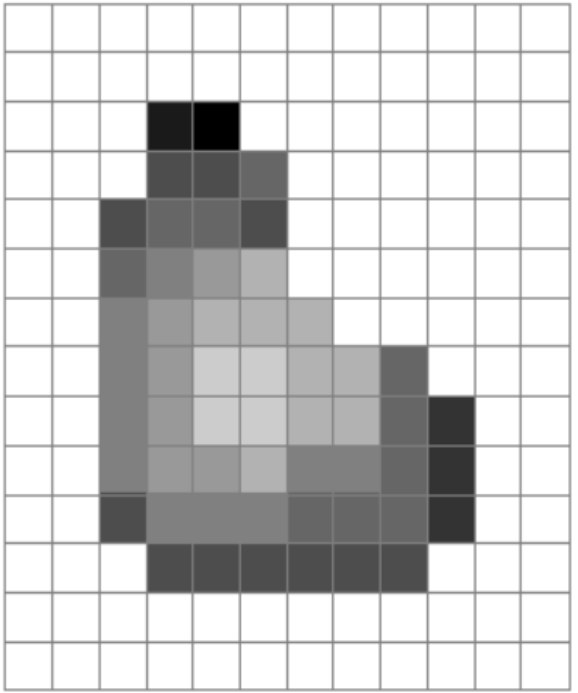


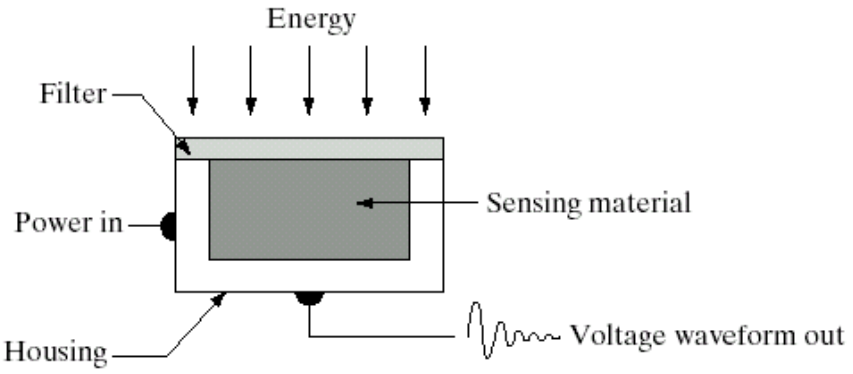
before



after

Sensor Arrangement

- Single imaging sensor

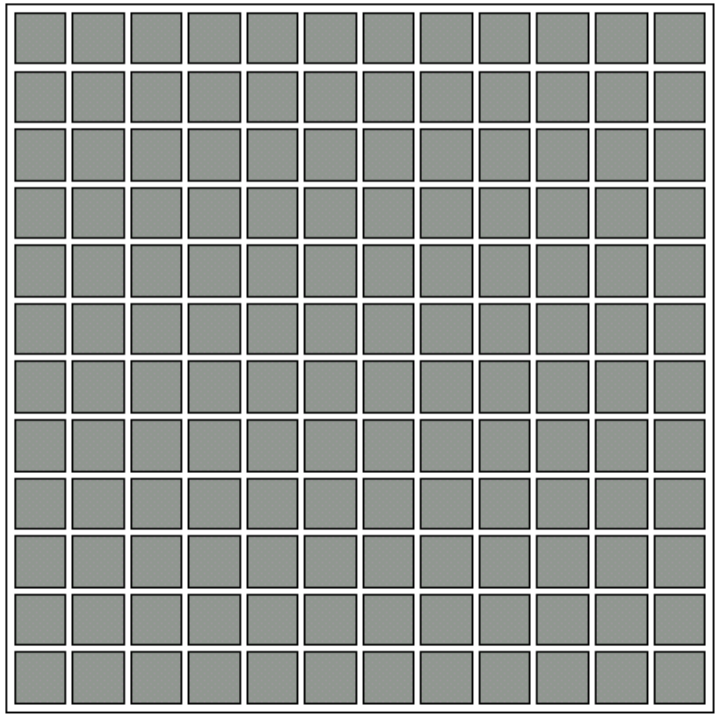


Sensor Arrangement

- Single imaging sensor
- Line sensor

Sensor Arrangement

- Single imaging sensor
- Line sensor
- Array sensor



Digital Image Representation

- Monochrome image can be represented as a two dimensional light intensity function f(x, y)
- where x & y are spatial coordinates and the value of f at point (x, y) is the gray level or the brightness of the image at that point
- For computer storage, an array with the number of gray levels being a power of 2 is selected
- A typical gray level image contains 256 shades of gray (8 bit)
- Values are stored between 0 - 255

Digital Image Representation

- The intensity of a monochrome image at any coordinate (x_i, y_i) is called the gray level (i_i) of the image at that point that is given by
  - $i_i = f(x_i, y_i)$
  - $L_{min} \leq i \leq L_{max}$
  - $i = 0$ is considered black
  - $i = L_{max} - 1$ is considered white on the gray scale

Image Samples

- Generally, image is of size m x n
  - where, m = number of rows and
  - n = number of columns
- The no. of gray level values (L), is also usually taken as power of 2
- $L = 2^k$
  - where, k = number of bits used for representation

Image Size

- For an image of size m x n, if k are the number of bits for representation, then

Image size = m x n x k

Image Size

- Eg:
  - For an image of 512 by 512 pixels, with 8 bits per pixel

Solution

$$\text{Size} = 512 * 512 * 8 \text{ bits}$$
$$= 2^9 * 2^9 * 2^3 \text{ bits}$$
$$= 2^{21}/2^3 \text{ bytes}$$
$$= 2^{18}/2^{10} \text{ K bytes}$$
$$= 256 \text{ KB}$$

Motivation

- The human brain is unequalled in 2D image analysis and image understanding

- Limitations of the human visual system
  - Quantification
  - Reconstruction of 3D scenes from images
  - High dimensional image spaces

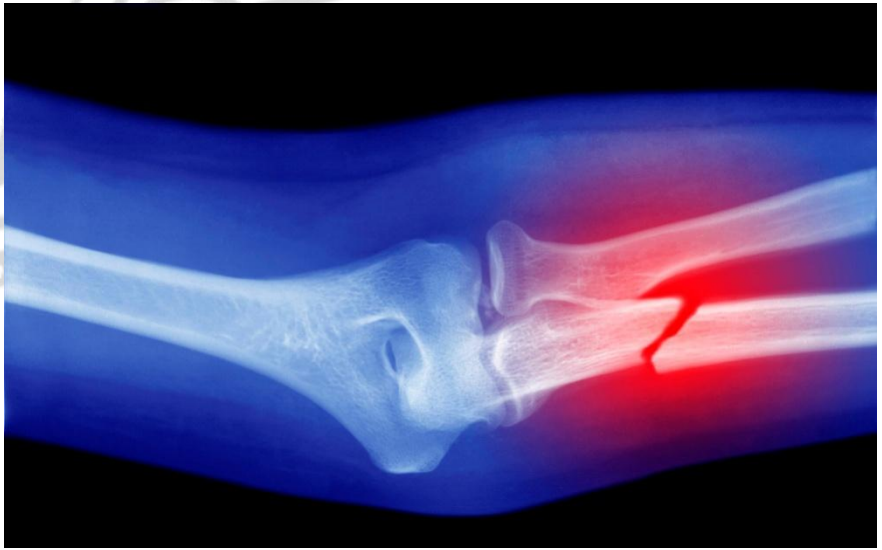
- Practical applications
  - Quantitative measurements
  - Automatic analysis of images

Perspective

- Digital image processing deals with manipulation of digital images through a digital computer
- It is a subfield of signals and systems but focus particularly on images
- DIP focuses on developing a computer system that is able to perform processing on an image
- The input of that system is a digital image and the system process that image using efficient algorithms, and gives an image as an output

Applications

- Some of the major fields in which digital image processing is widely used are
  - Medical field



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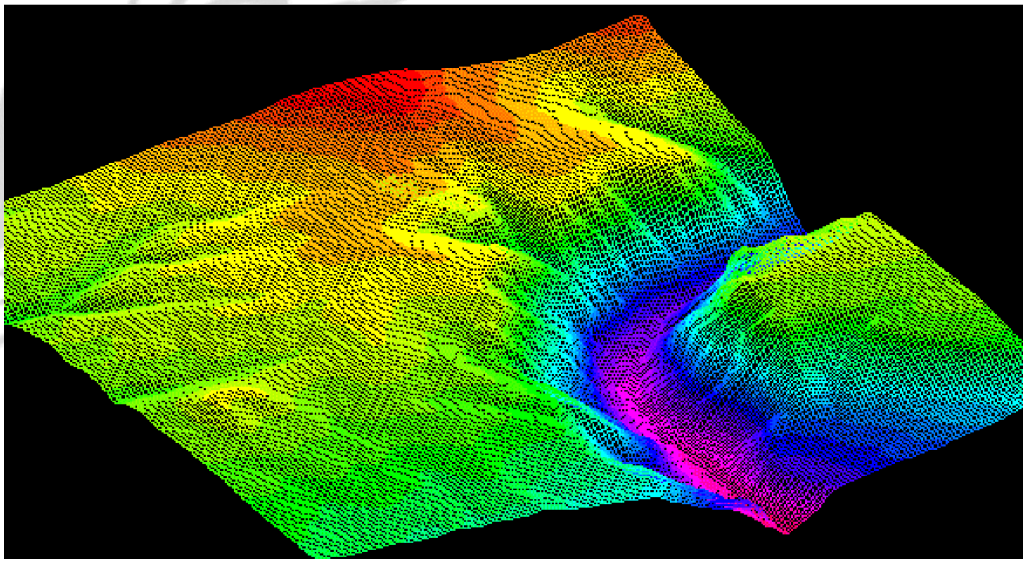

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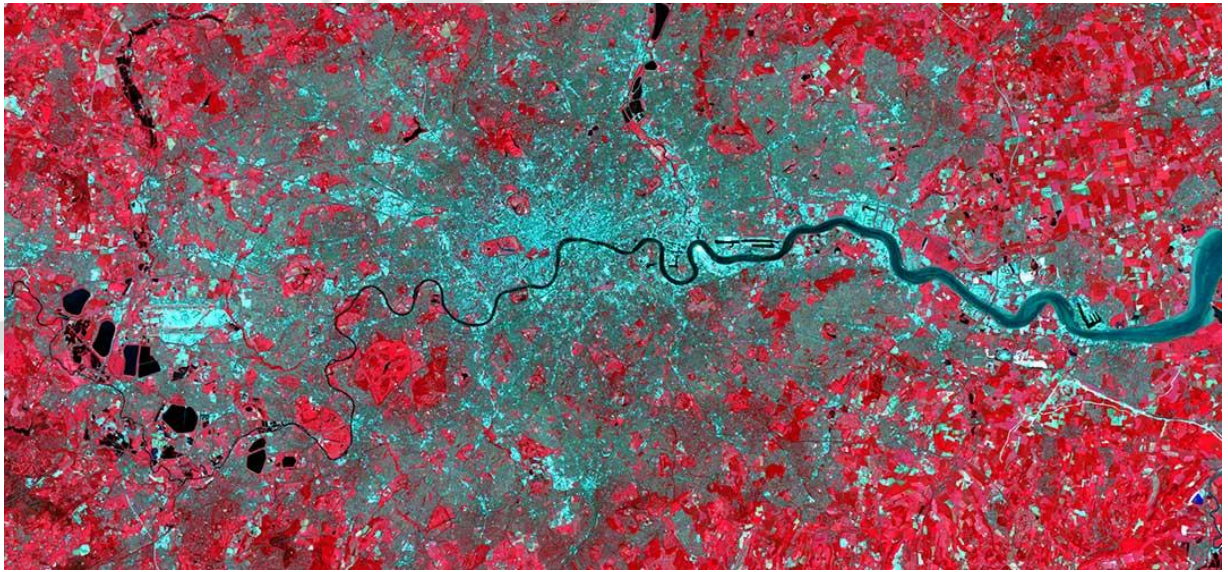
  - GIS
  - Remote sensing



Applications

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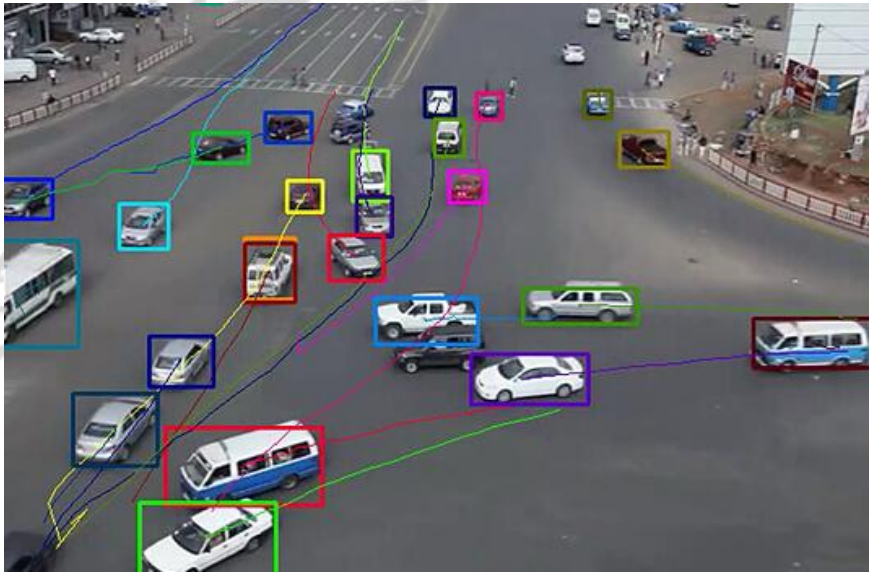
  - GIS
  - Remote sensing
  - Object tracking



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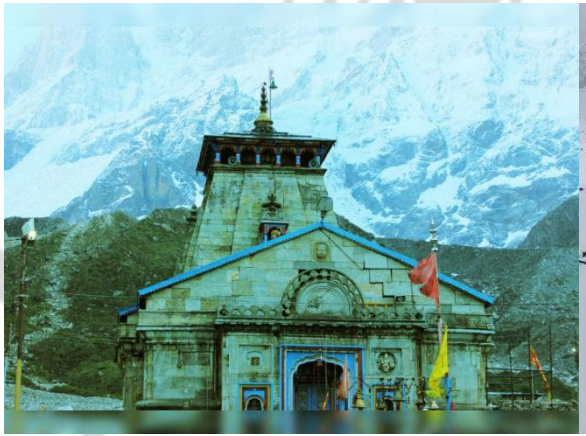
  - Object tracking
  - Classification

Applications

- Some of the major fields in which digital image processing is widely used are
  - Medical field
  - GIS
  - Remote sensing
  - Object tracking
  - Classification
  - Change detection



Applications

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  - GIS
  - Remote sensing
  - Object tracking
  - Classification
  - Change detection
  - Disaster monitoring

Applications

- Some of the major fields in which digital image processing is widely used are
  - Medical field
  - GIS
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  - Object tracking
  - Classification
  - Change detection
  - Disaster monitoring
  - etc

Image Sensing

- Sensing operates in various region of Electro Magnetic Spectrum

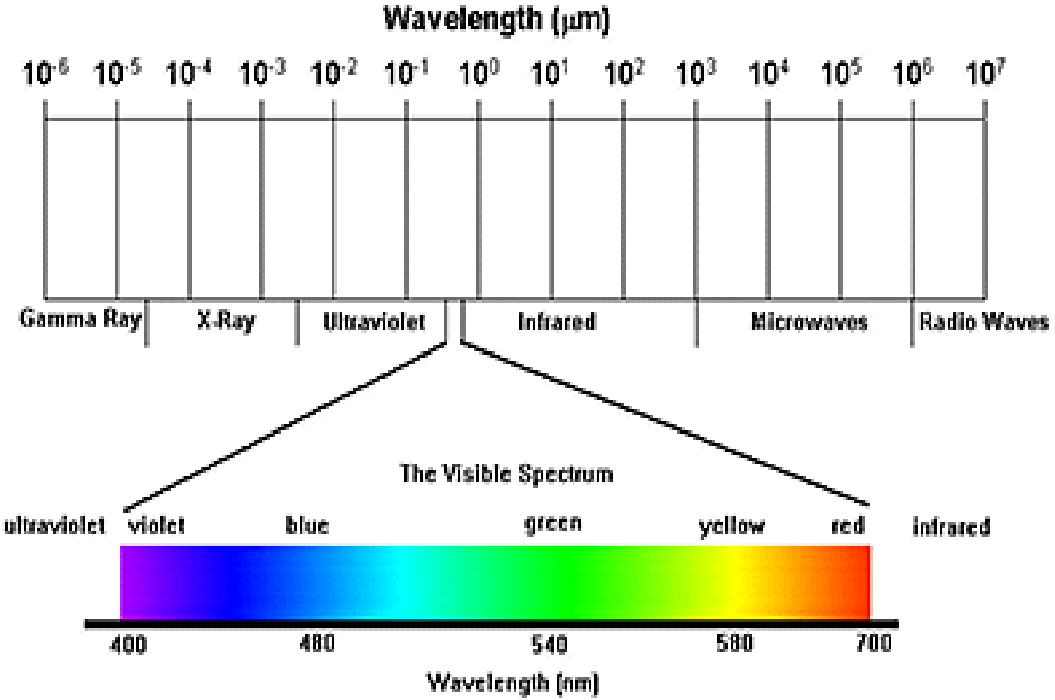


Image Resolutions

- There are four types of resolution
  - Spatial resolution
  - Spectral resolution
  - Temporal resolution
  - Radiometric resolution

Spatial Resolution

- The smallest possible feature that can be detected in an image OR
- The size of single pixel or area covered by a single pixel (GSD)

Spatial Resolution

← 512 x 512

← 256 x 256

← 128 x 128

← 64 x 64

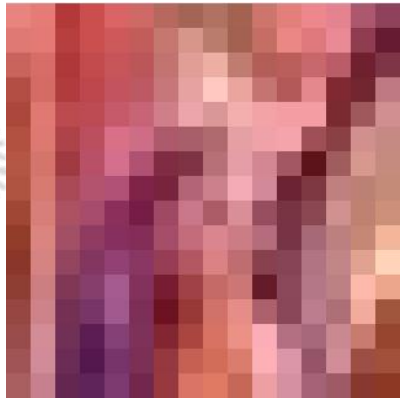
← 32 x 32

← 16 x 16

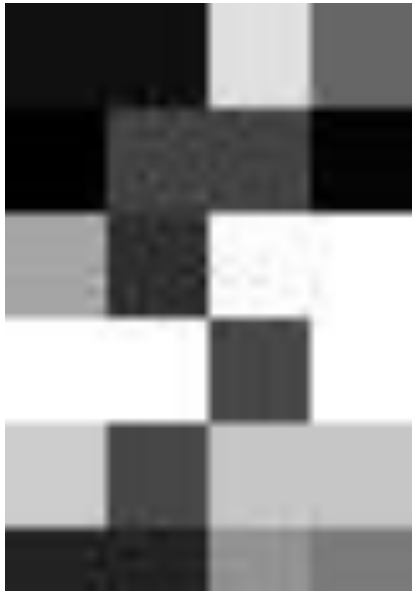
Spatial Resolution





Various sensors image



MODIS (250 m)

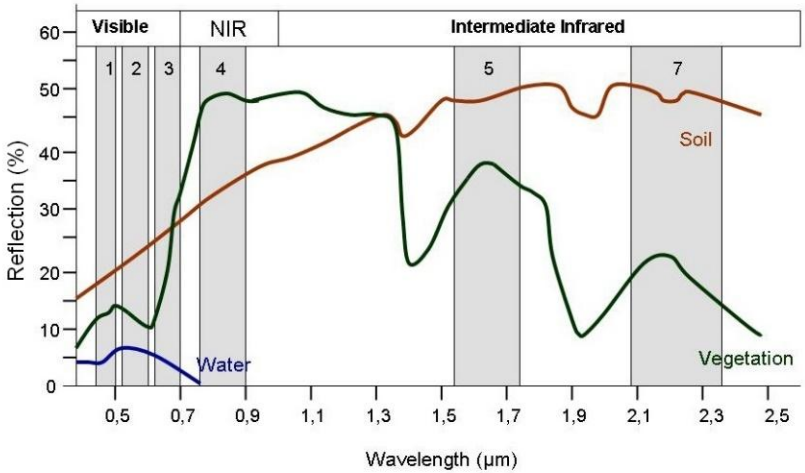
LANDSAT 8 (30 m)

SENTINEL 2 (10 m)

DRONE (0.05 m)

Spectral Resolution

- It describes the capability of a sensor to capture information in various bands which have fine wavelength intervals
- Information recorded by the sensor in various bands are referred as multi-spectral sensors



Spectral Resolution

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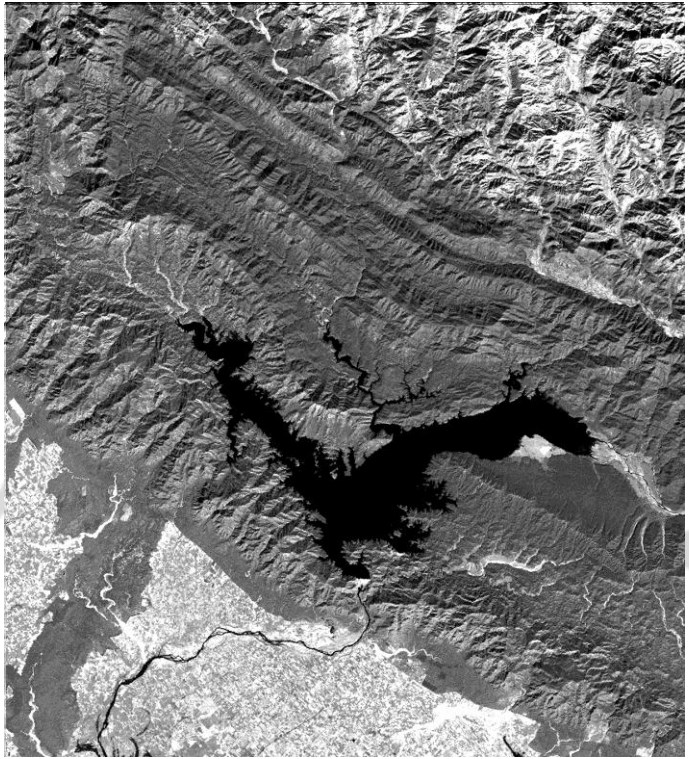
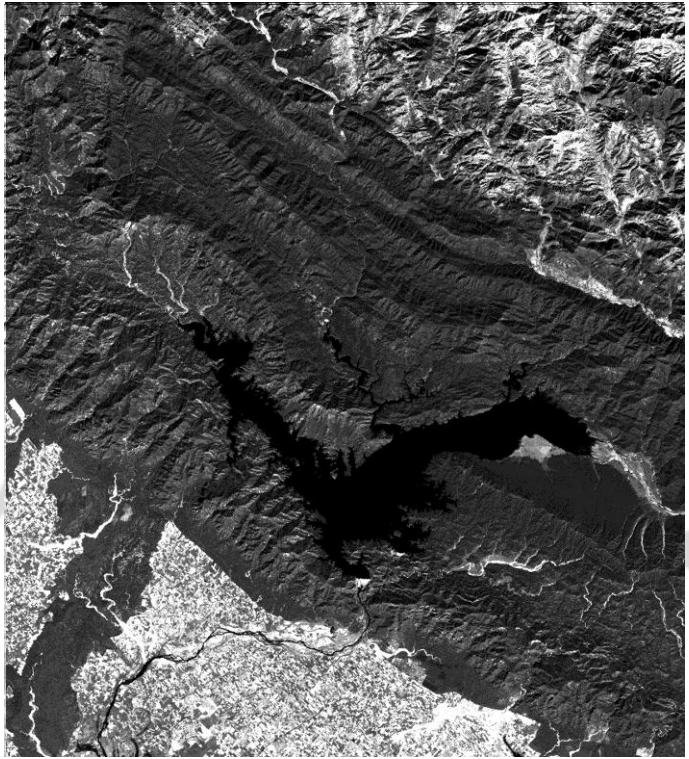


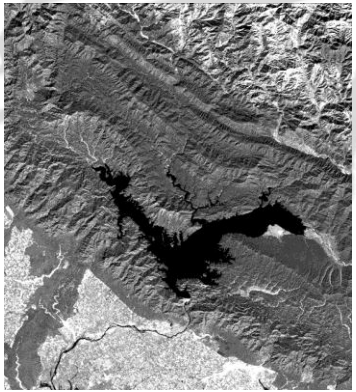
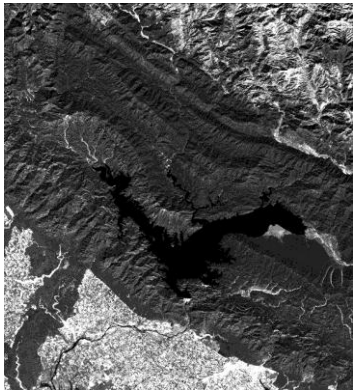
Spectral Resolution



Spectral Resolution





Temporal Resolution

- The concept of revisit period is important for monitoring which help us to identify the changes over a period of time
- Time taken by a sensor to locate exact same area second time at same interval time is considered as temporal resolution

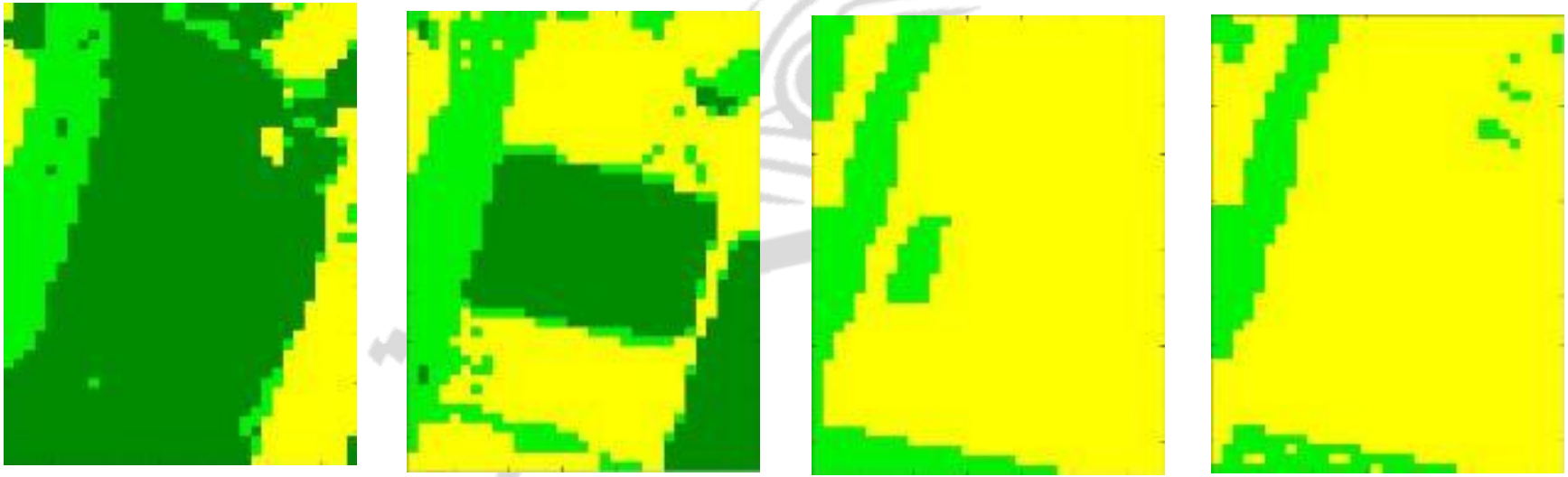
Temporal Resolution

Sentinel-2
RGB




Temporal Resolution

Sentinel-2
Classified



Bare Land | Dense Vegetation | Sparse Vegetation

Radiometric Resolution

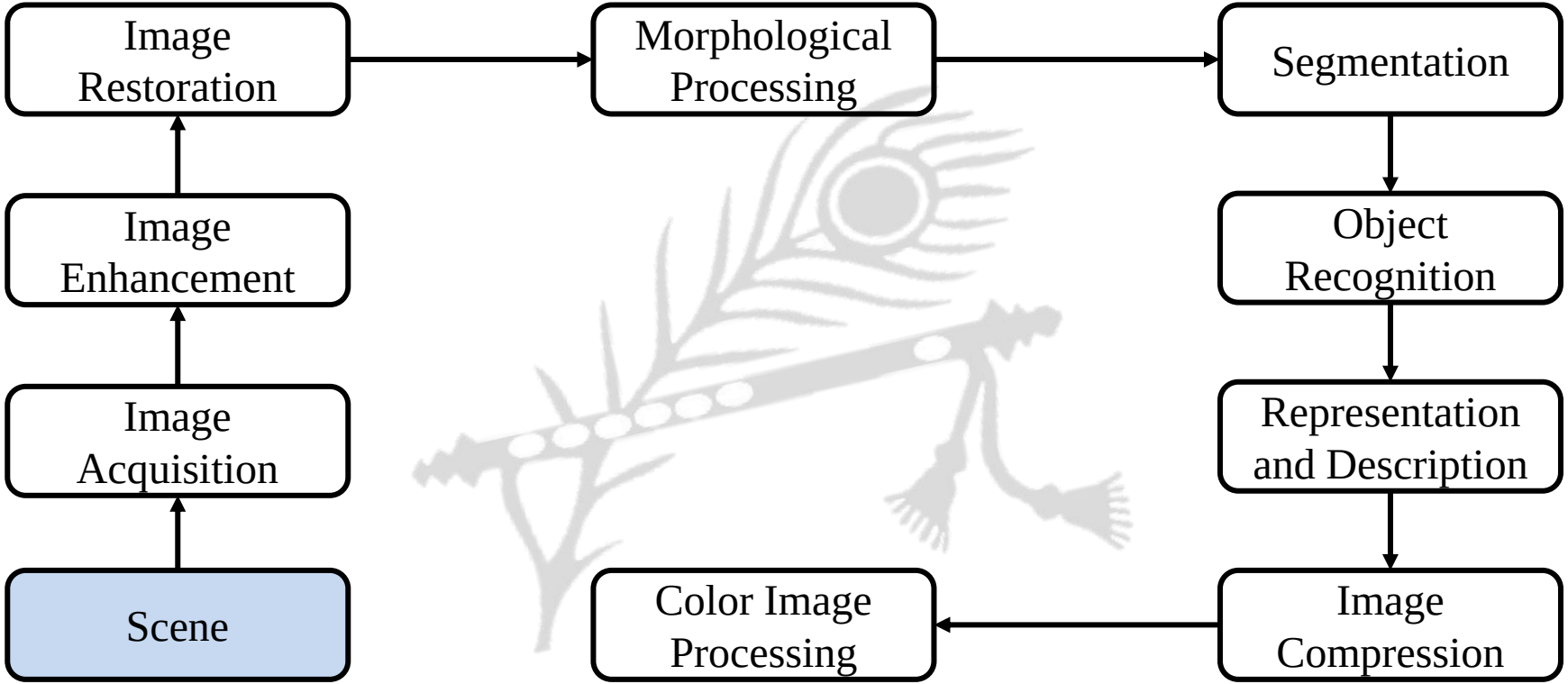
- Image captured by sensor have certain characteristics which can be improved later
- This is a part of radiometric resolution which helps to enhance the pixel characteristics which ultimately help to identify very slight difference in an image
- It depends on the ability of sensor
- Sensor having greater radiometric property is more sensitive to detect changes
- It is the smallest visible change in the gray level of an image

Radiometric Resolution

Type of effects

- There are two type of effects
  - Checkerboard effect
    - When the no. of pixels in an image is reduced by keeping the no. of gray levels in the image constant, fine checkerboard patterns are found at the edges of the image
  - False contouring effect
    - When the no. of gray-levels in the image is low, the foreground details of the image merge with the background details of the image, causing ridge like structures. This degradation phenomenon is known as false contouring

Key Stages in Digital Image Processing



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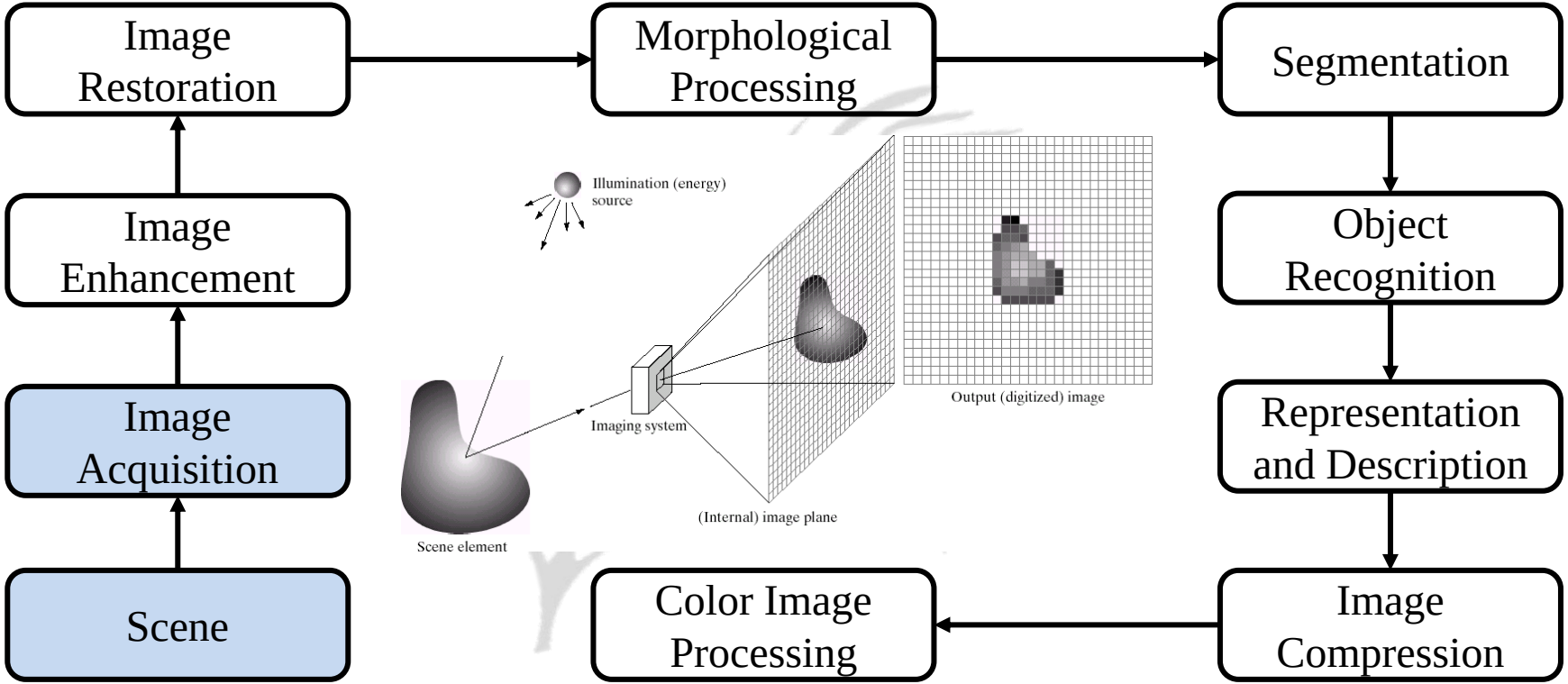

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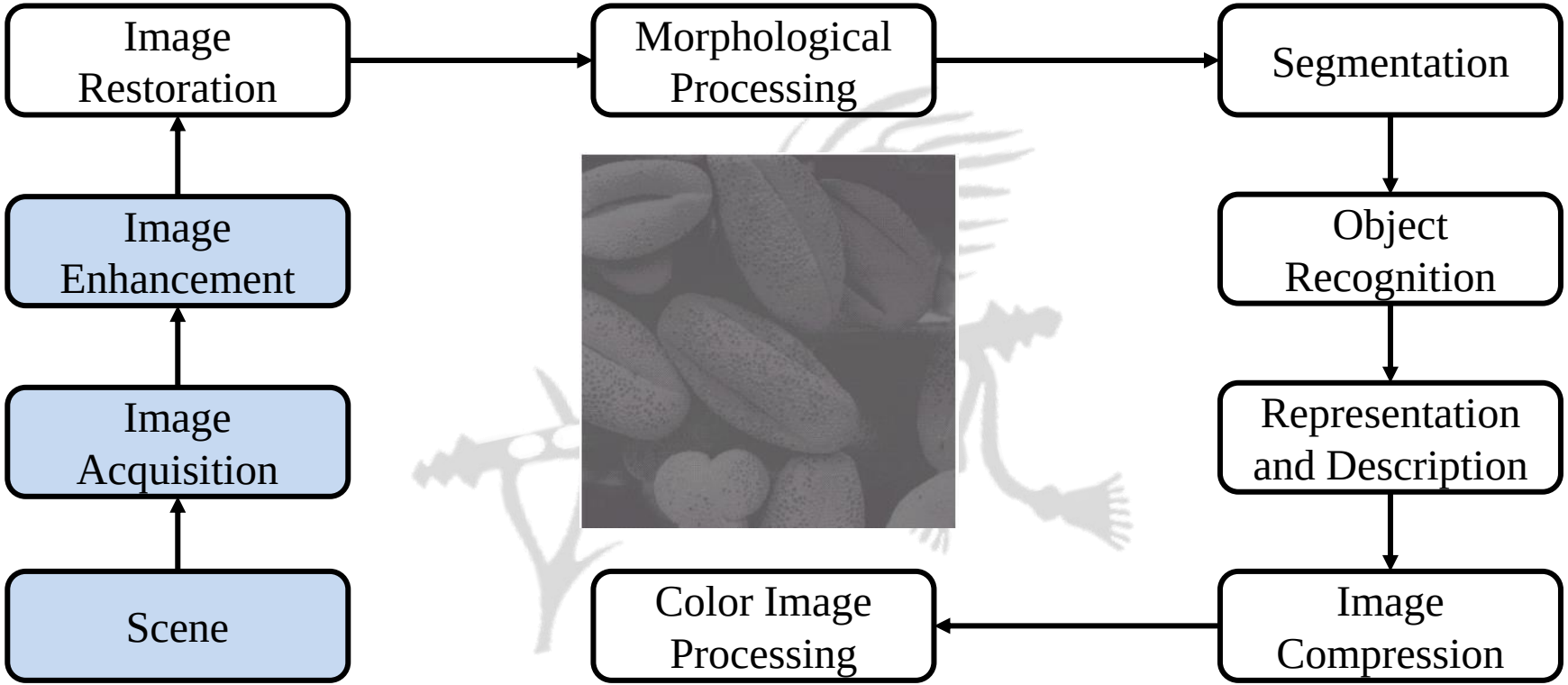

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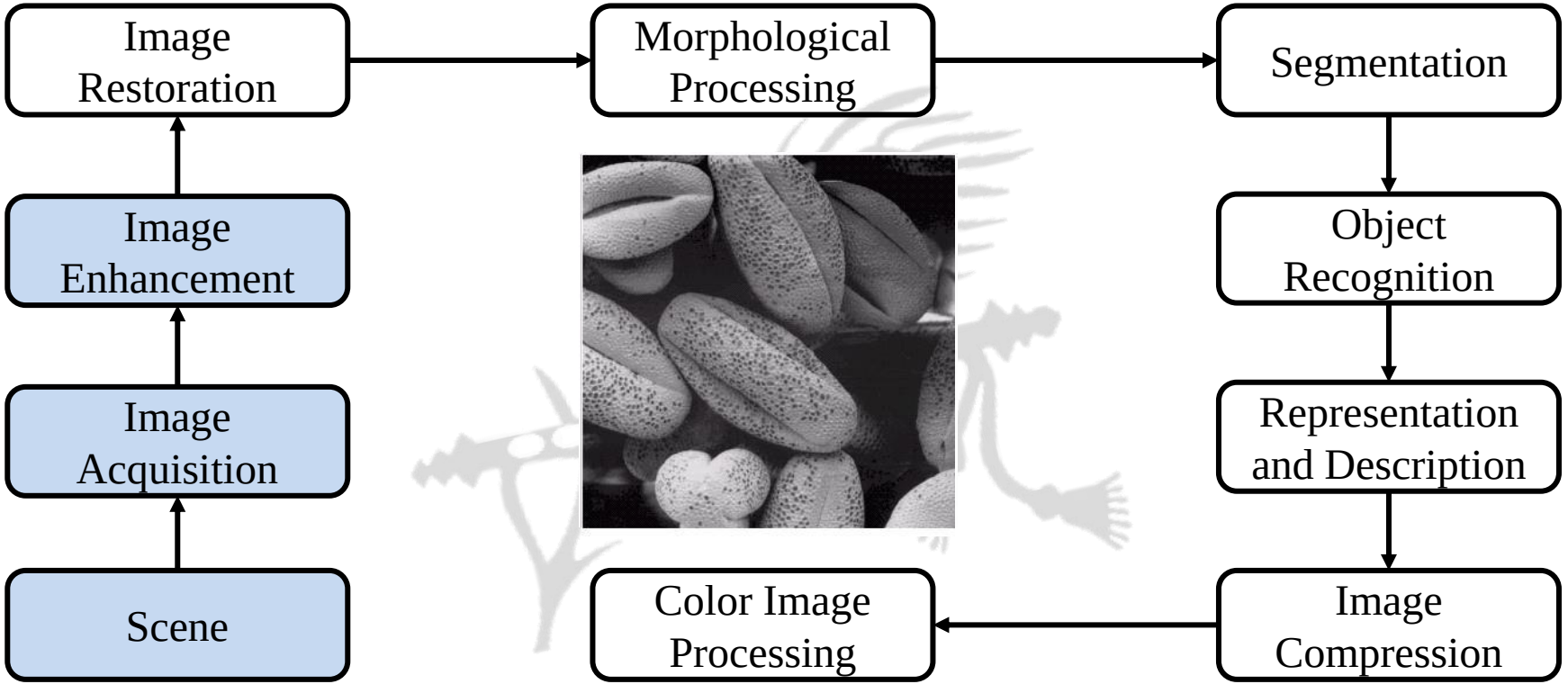

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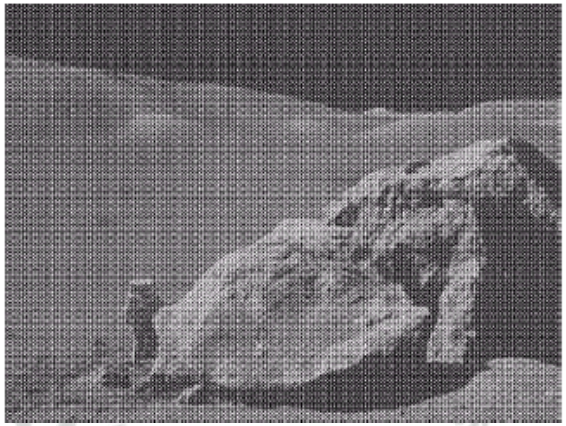
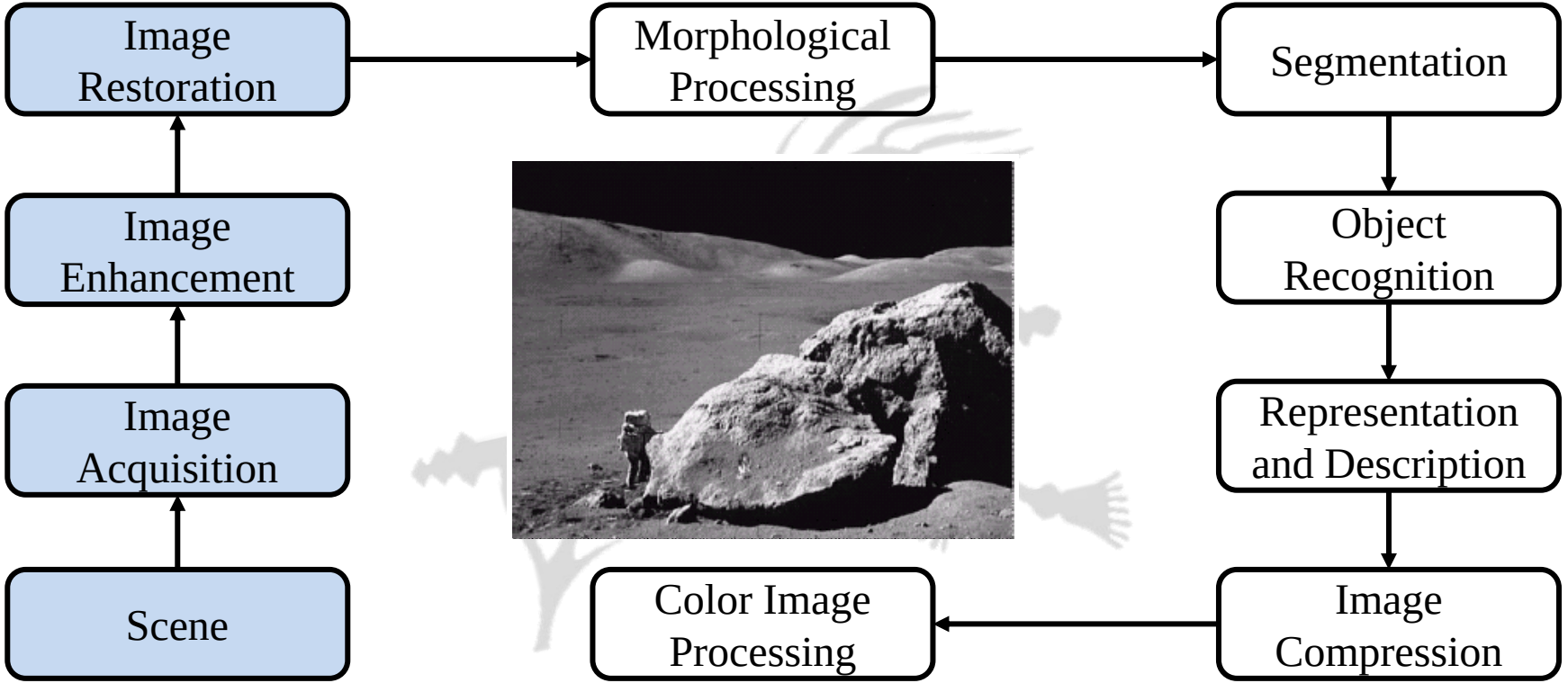


Image Restoration → Morphological Processing → Segmentation → Object Recognition → Representation and Description → Image Compression → Color Image Processing → Scene → Image Acquisition → Image Enhancement → Image Restoration

Key Stages in Digital Image Processing



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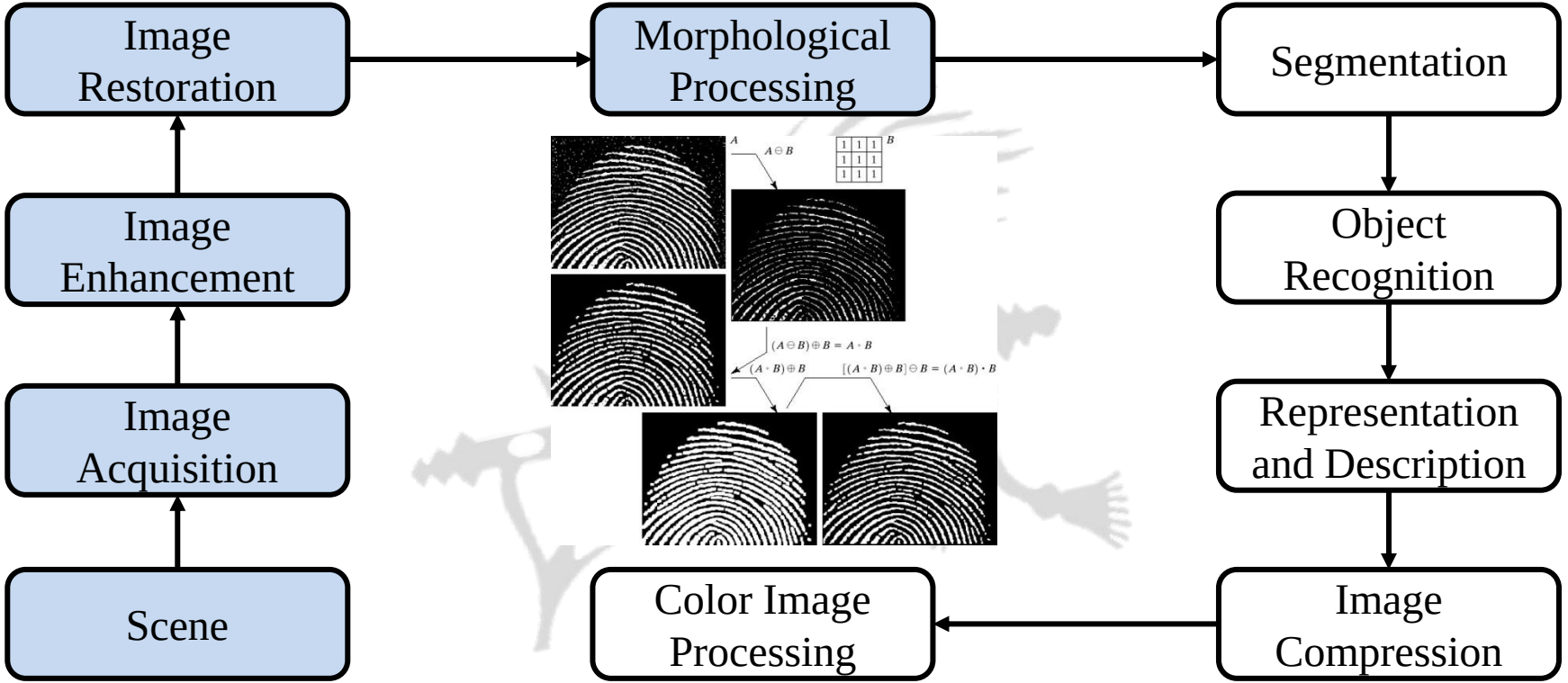

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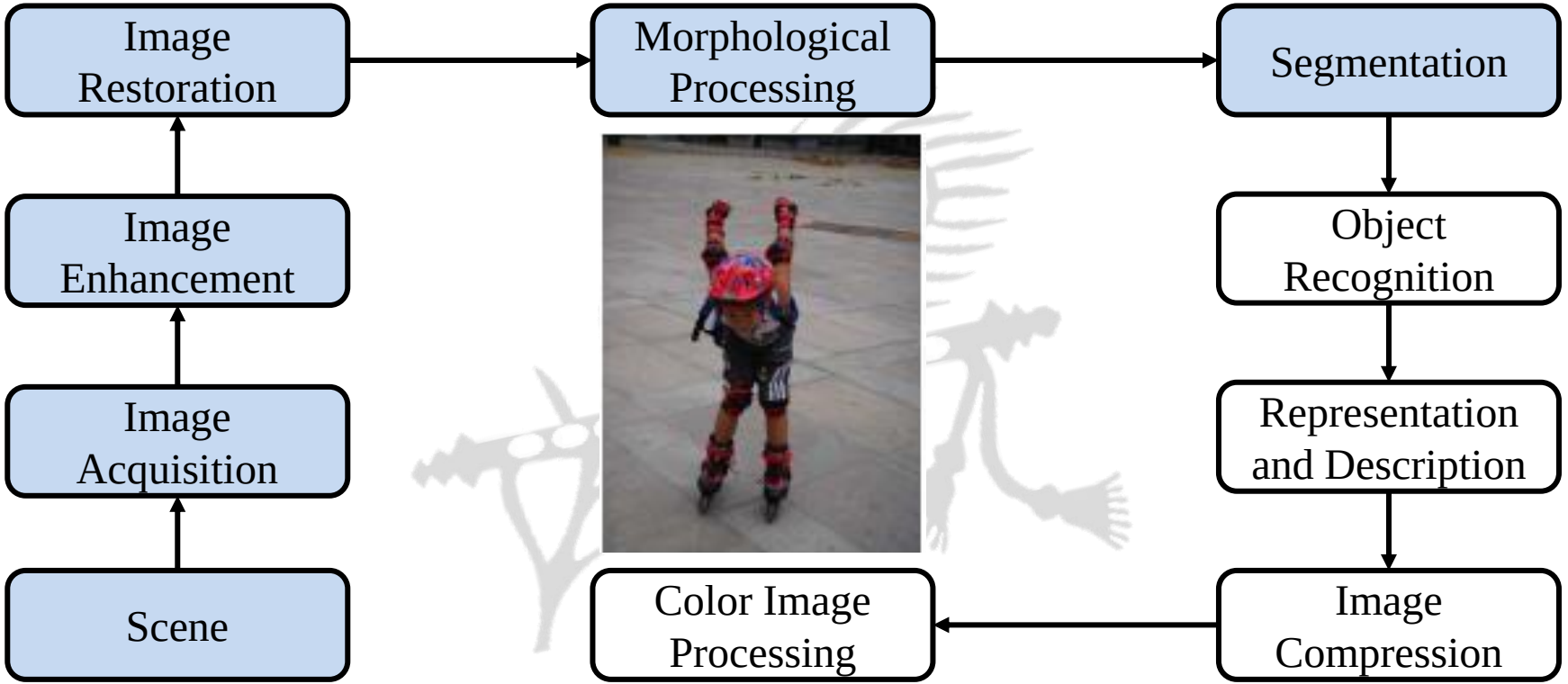

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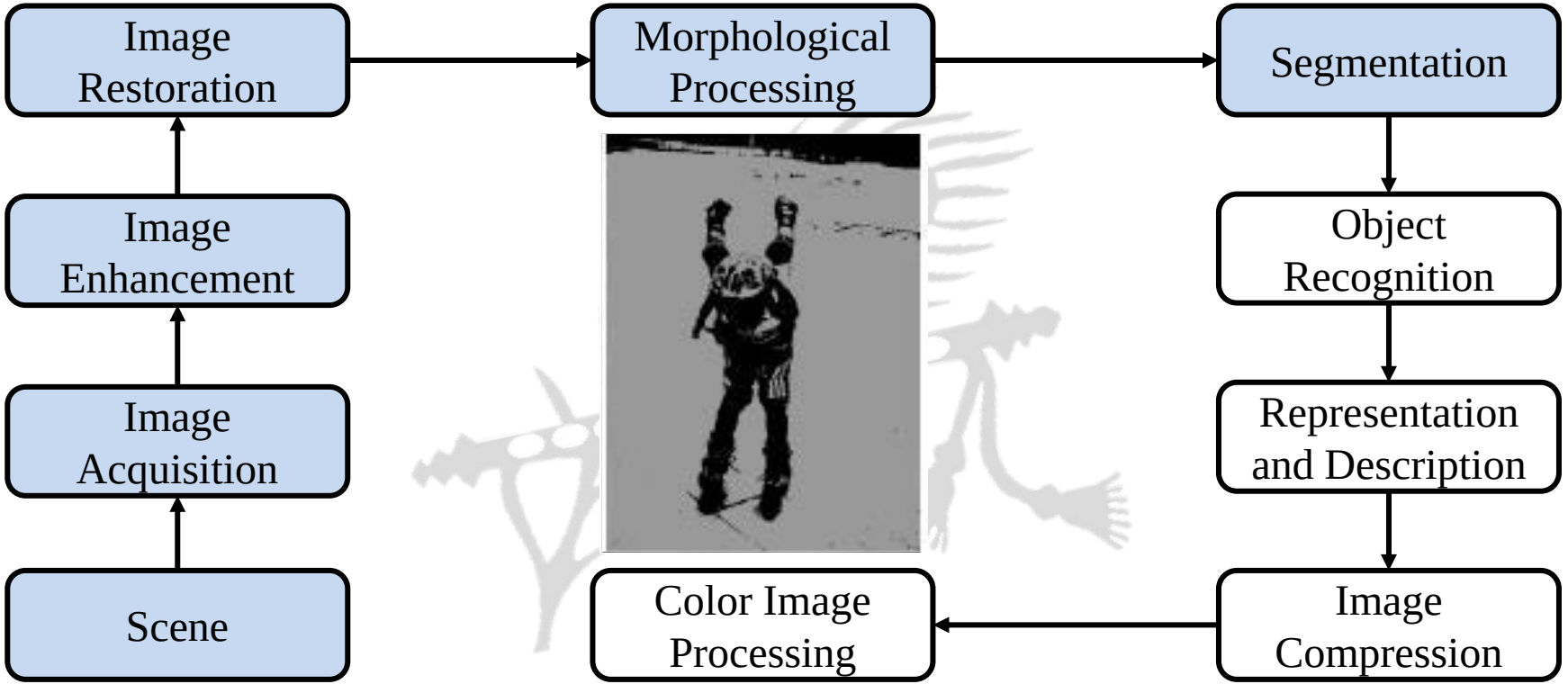

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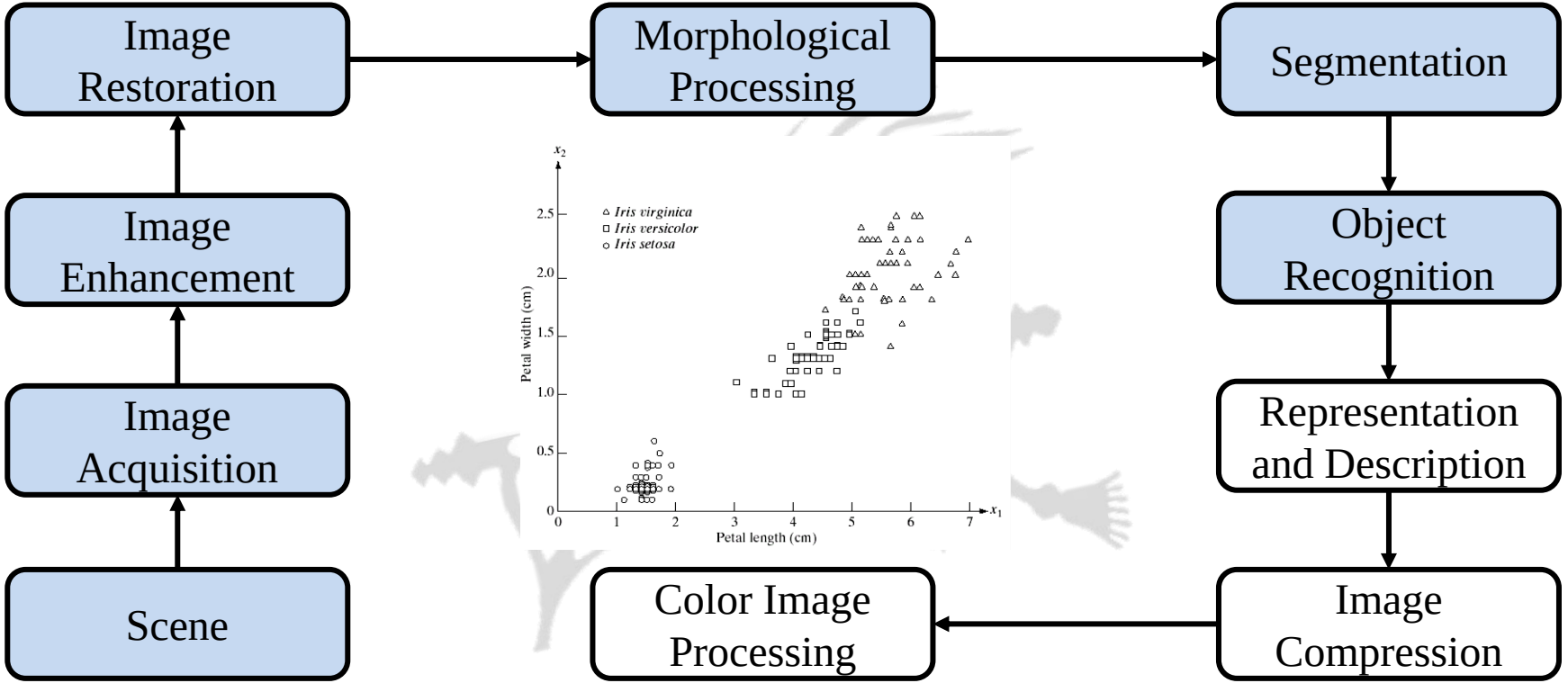

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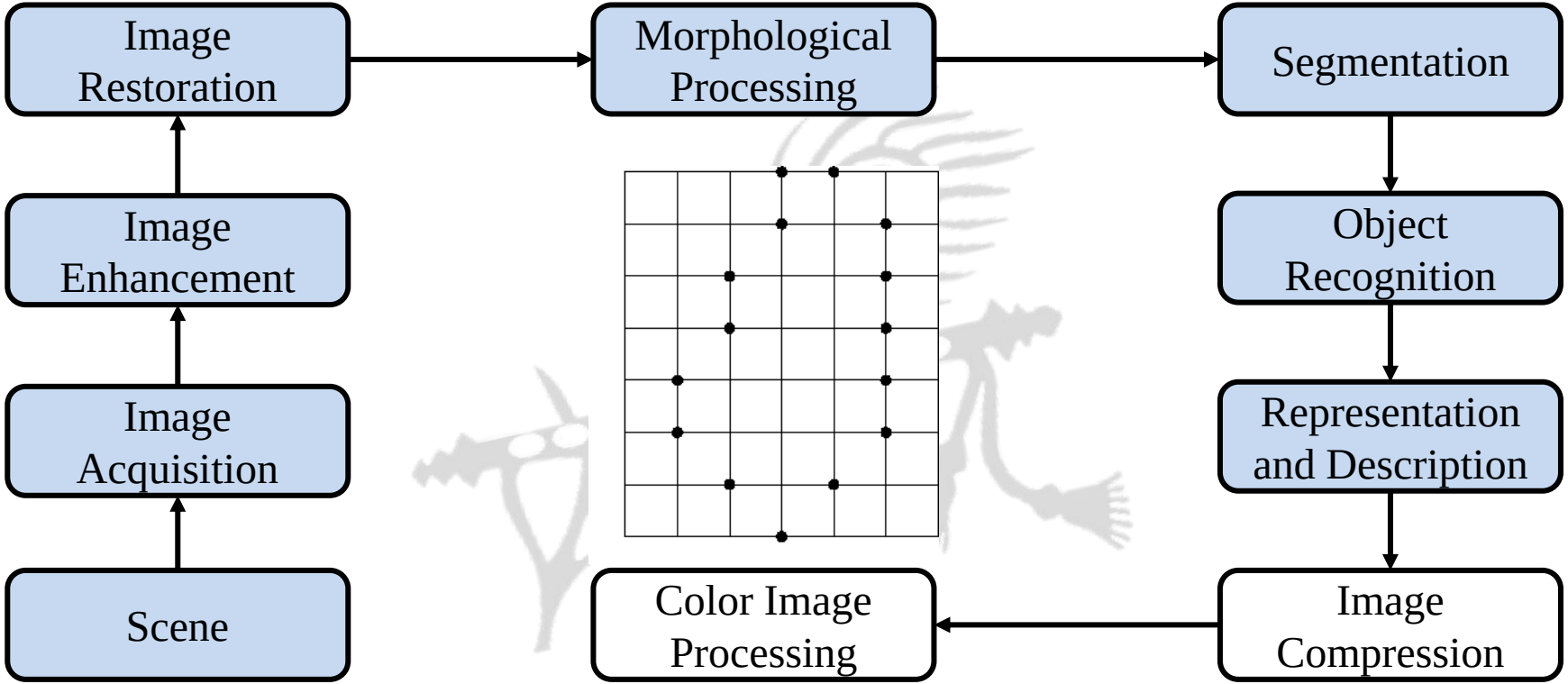

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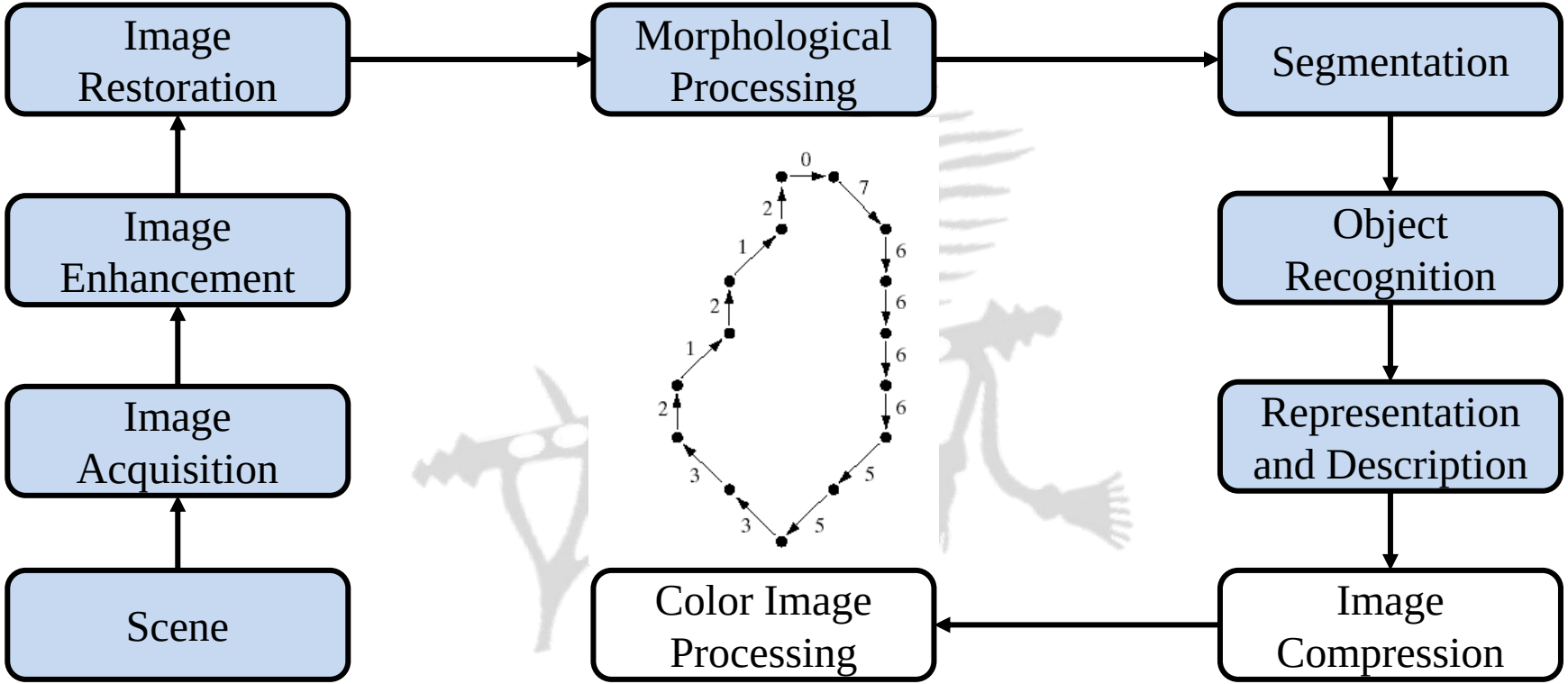

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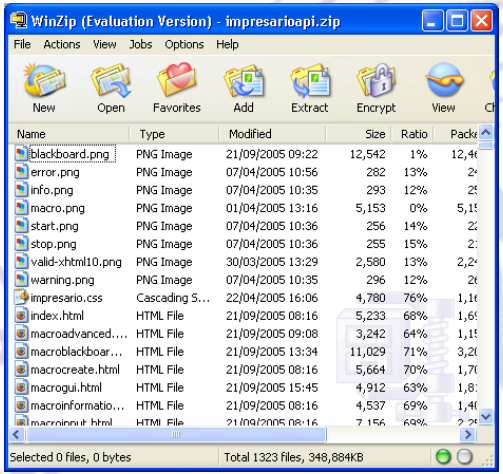

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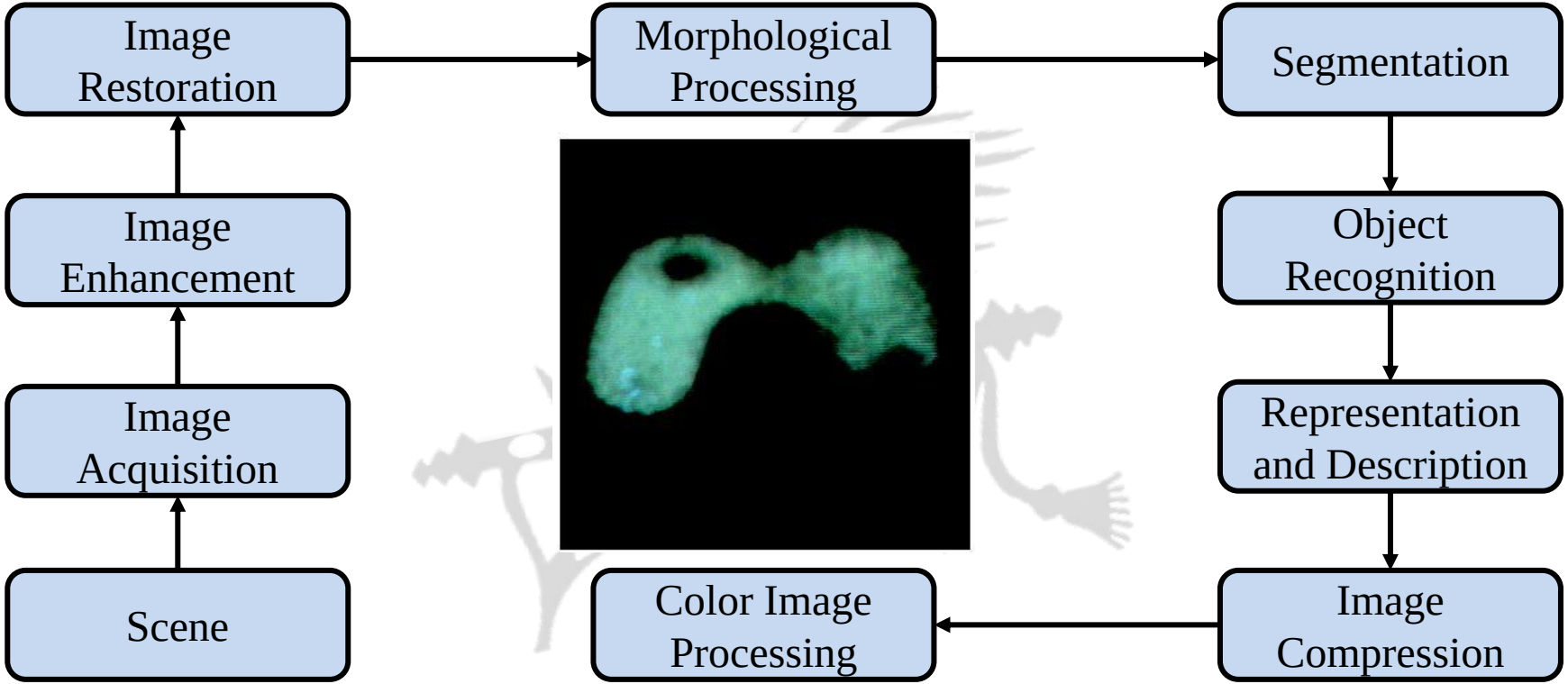

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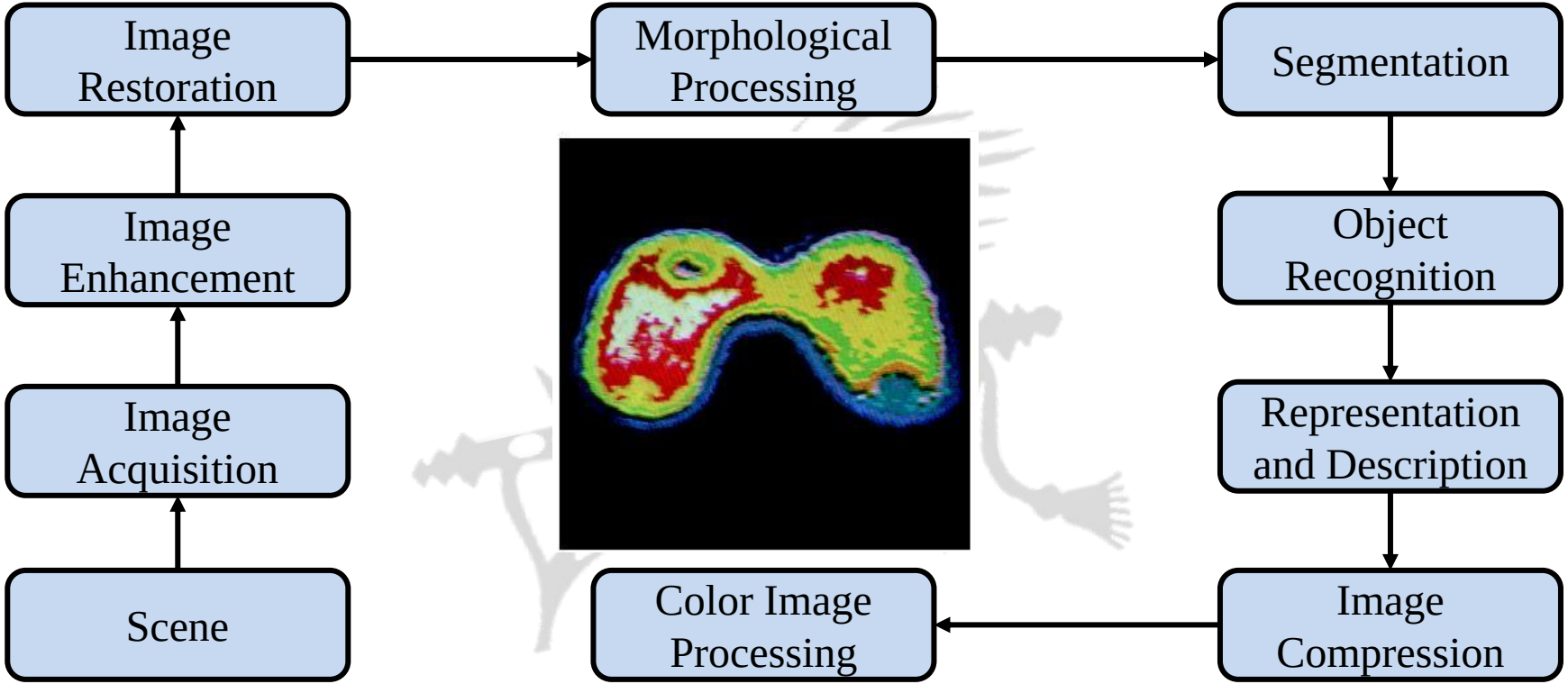

Various operations on Image

- Image Restoration
  - Image Restoration is the process of recovering the native dataset undistorted and uncorrupted by noise

Original

Restored

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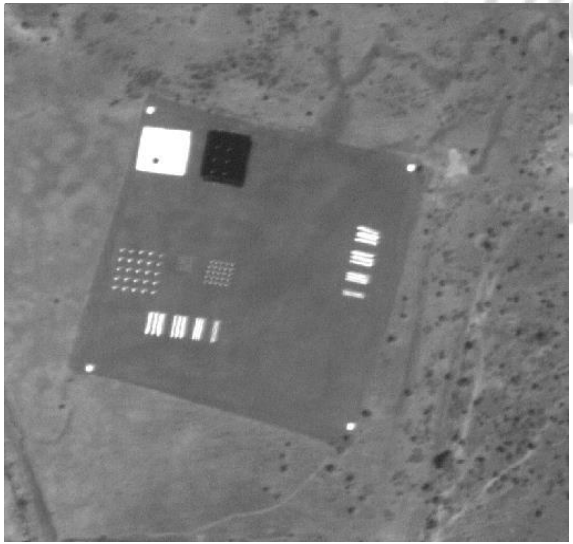
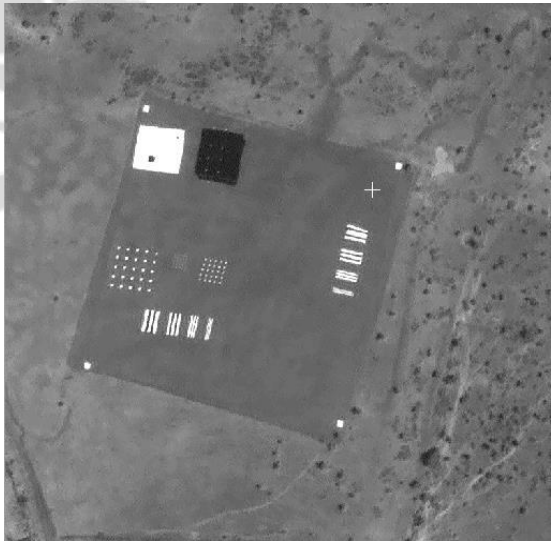


Original

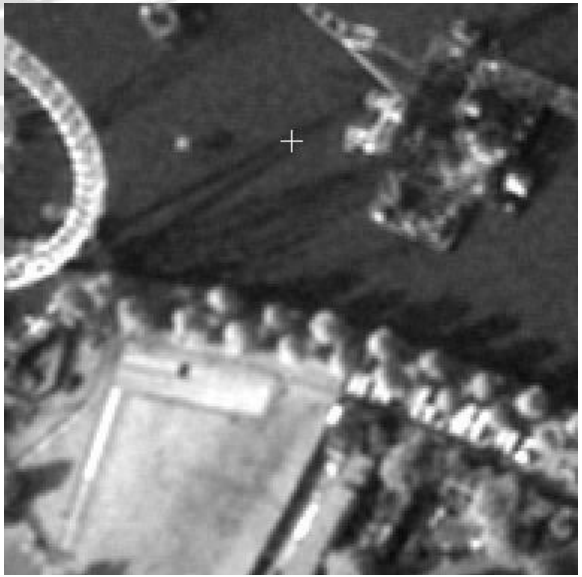


Restored

Various operations on Image

- Noise Removal
  - Various types of noise is induced in the data that needs to be corrected

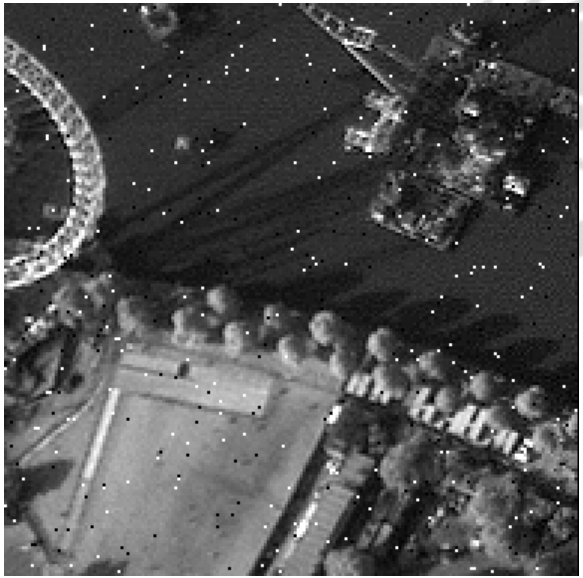
Original



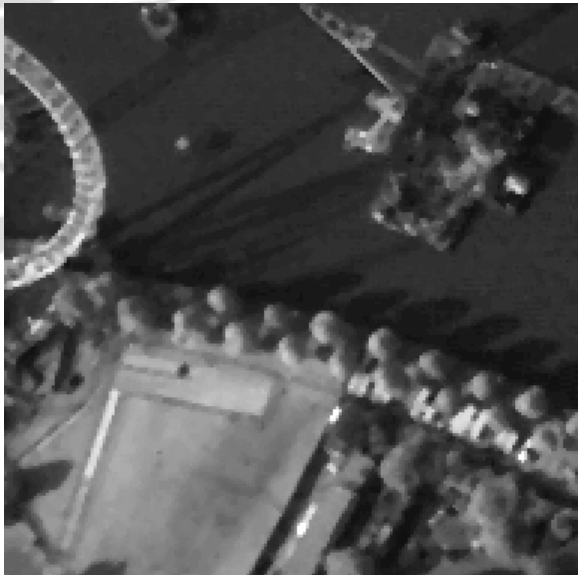
Corrected

Various operations on Image

- Noise Removal
  - Various types of noise is induced in the data that needs to be corrected



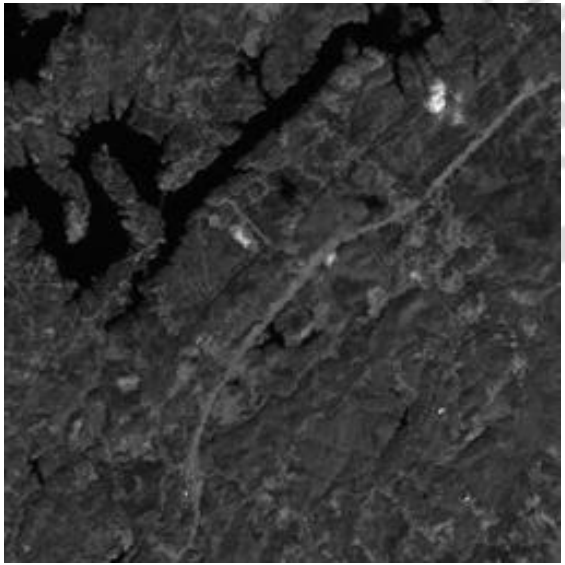
Original



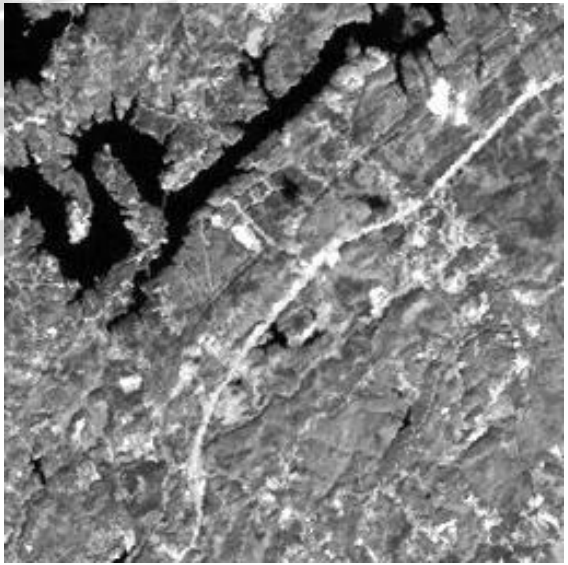
Corrected

Various operations on Image

- Image Enhancement (Min-Max stretching)
  - It is required to enhance the feature so that they can be extracted



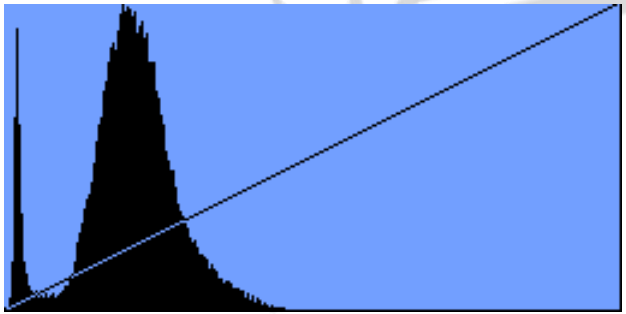
Original



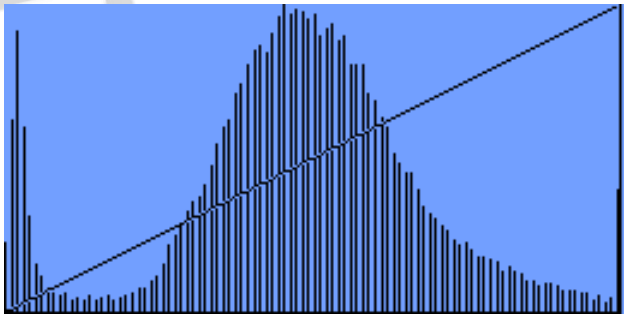
Enhanced

Various operations on Image

- Image Enhancement (Min-Max stretching)
  - It is required to enhance the feature so that they can be extracted



Original



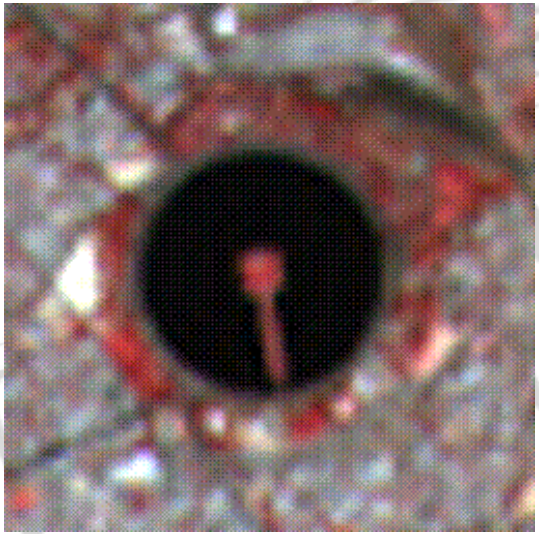
Enhanced

Various operations on Image

- Image Enhancement (data fusion)

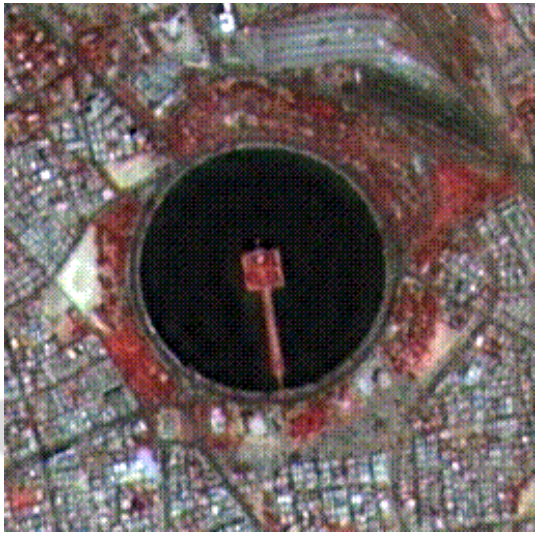
PAN (5.8 m)

+



L3 (23.5 m)

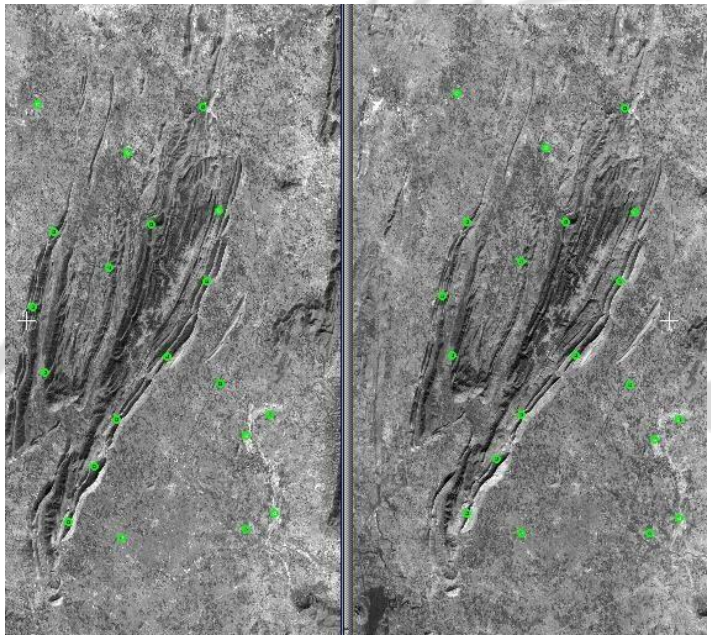
→



P+L3

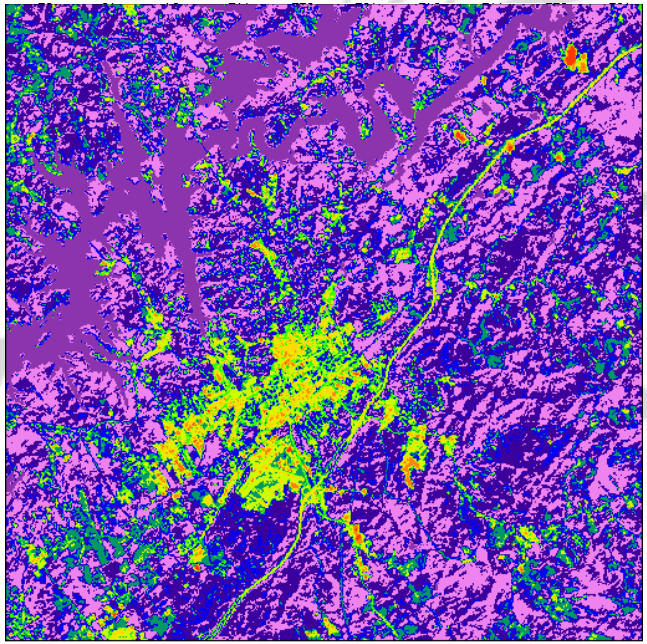
Various operations on Image

- Image Matching
  - It is used to geo-register the image by matching the features



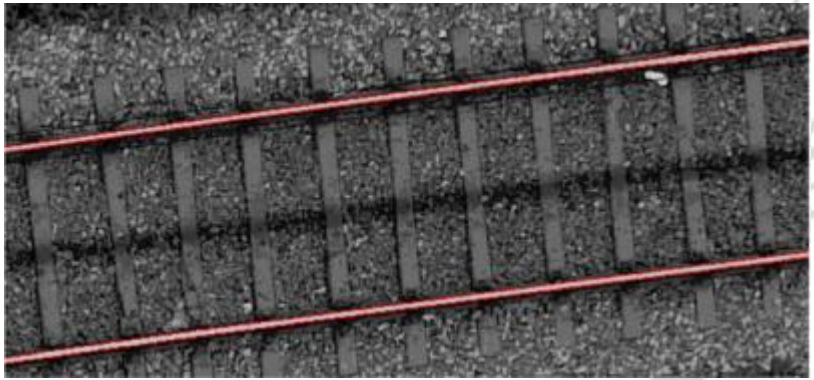
Various operations on Image

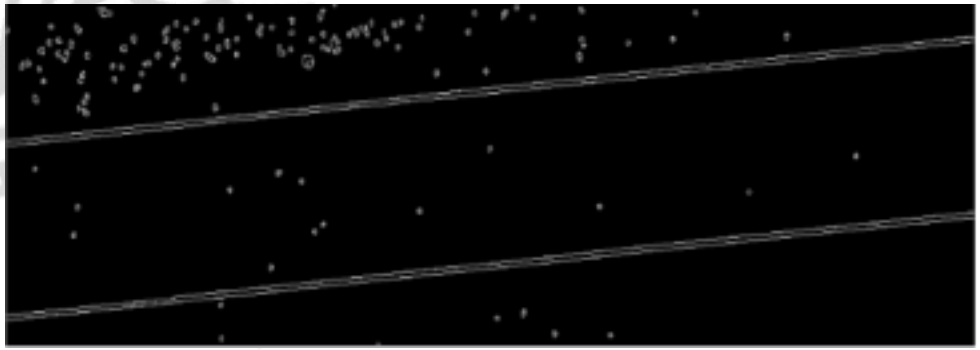
- Image Classification
  - To classify the images into different classes



Various operations on Image

- Object Extraction
  - To extract the object by using morphological operators





Various operations on Image

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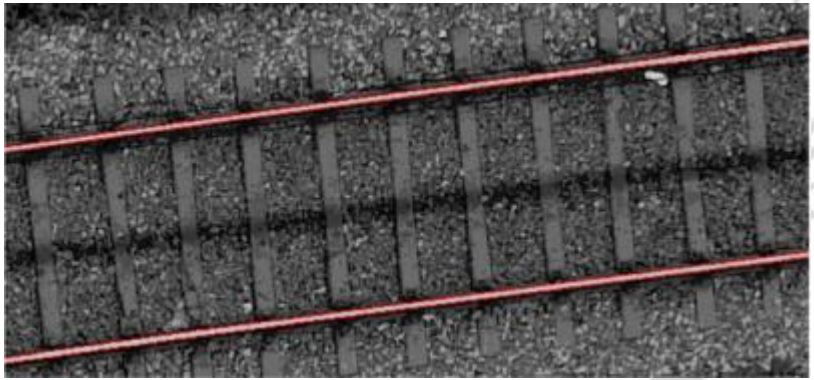
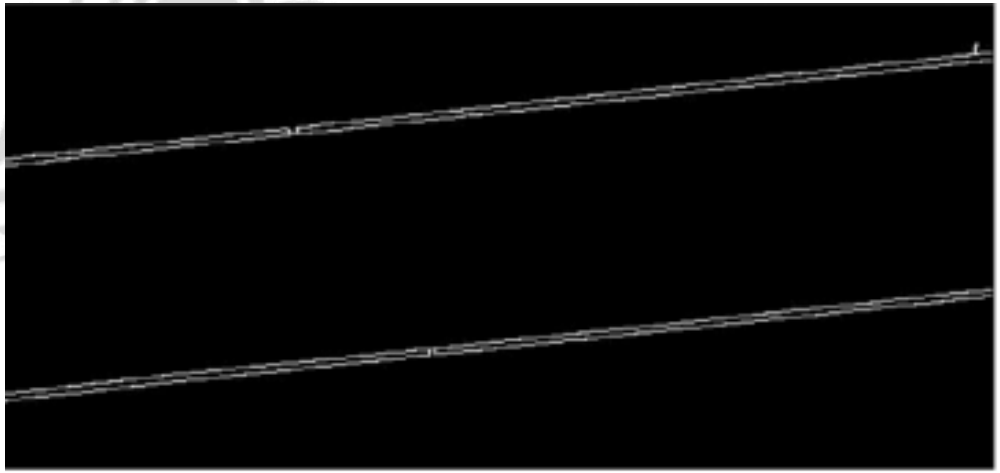
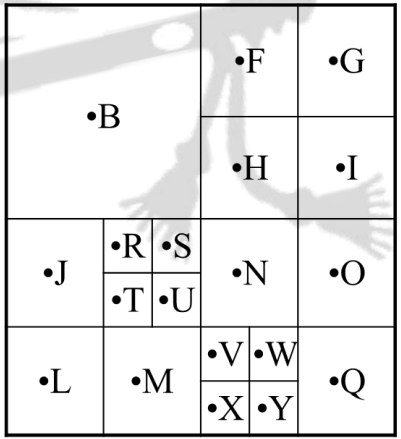




Various operations on Image

- Image Representation
  - Successive divisions of image into quadrants and recursively into sub quadrants
  - Recursion is stopped when all pixels in a sub image is found to have the same colour or gray value
  - Suitable for binary and segmented/classified images

•0	•0	•0	•0	•0	•0	•0	•0
•0	•0	•0	•0	•0	•0	•0	•0
•0	•0	•0	•0	•1	•1	•1	•1
•0	•0	•0	•0	•1	•1	•1	•1
•0	•0	•0	•1	•1	•1	•1	•1
•0	•0	•1	•1	•1	•1	•1	•1
•0	•0	•1	•1	•1	•1	•1	•1
•0	•0	•1	•1	•1	•1	•1	•1



Various operations on Image

- Image Morphology
  - It is used to extract boundary, skeleton, CCA, etc

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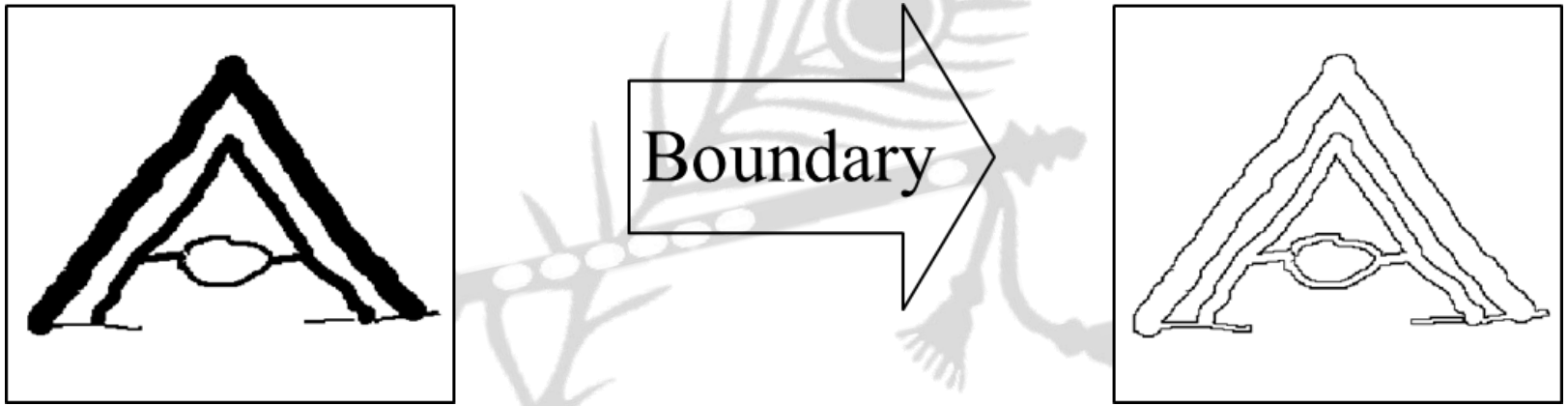

Various operations on Image

- Image Morphology
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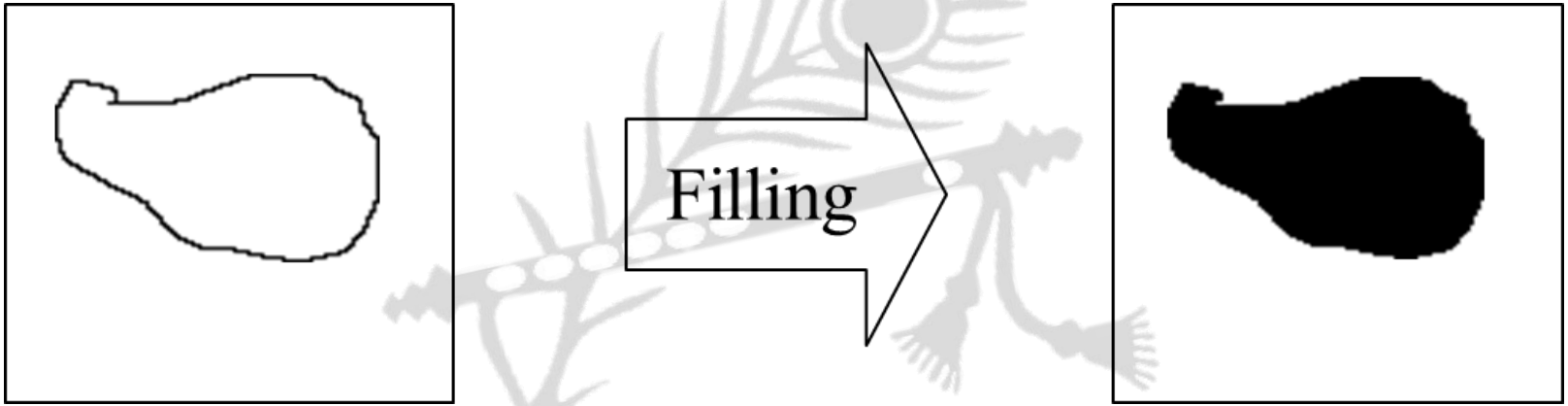


Image types

Image Examples

- X-ray Image
- Ultrasound Images
- CT Scan Images
- MR Images
- Satellite Images
- Thermal Images
- Radar Images
- Etc…

Image Formats

- RAW
- BMP
- GIF
- JPG
- TIFF
- HDF
- Etc…

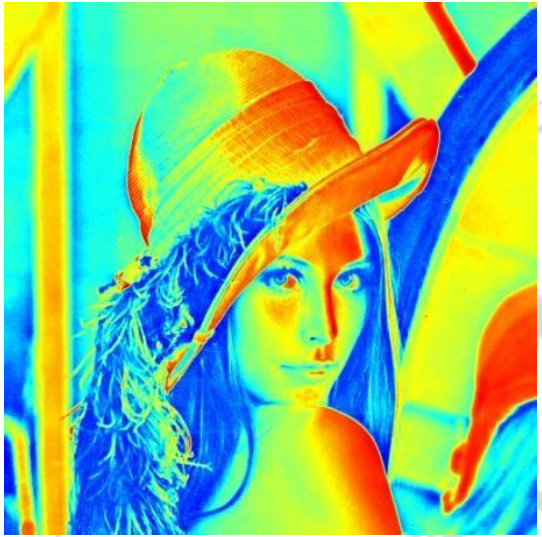
Image Types

- Bilevel
- GrayScale
- True Color
- False Color
- MultiSpectral
- HyperSpectral
- Etc…

Types of Images

Types of Images

Original Images



Pseudo Color

Binary Image

Aspect Ratio

- Eg:
  - If we want to resize a 1024x768 image to one that is 600 pixels wide with the same aspect ratio as the original image, what should be the height of the resized image?

Solution

$$\text{Aspect Ratio} = \text{width/height}$$
$$= 1024/768$$
$$= 1.33$$
$$\text{Height} = 600/1.33$$
$$= 451$$

Baud Rate

- A common measure of transmission for digital data
- It is the no. of bits transmitted per second
- Generally transmission is accomplished in packets consisting of a start bit, a byte of information & a stop bit

Baud Rate

- Eg:
  - How many minutes would it take to transmit a 1024 x 1024 image with 256 gray levels using a 56K baud rate?

Solution

Total no. of bits needed to represent the image: 1024 x 1024 x 8

No. of packets required: 1024 x 1024

Total no. of bits that need to be transferred: 1024 x 1024 x [8 + 2]

Total time required: 1024 x 1024 x [8 + 2]/56000

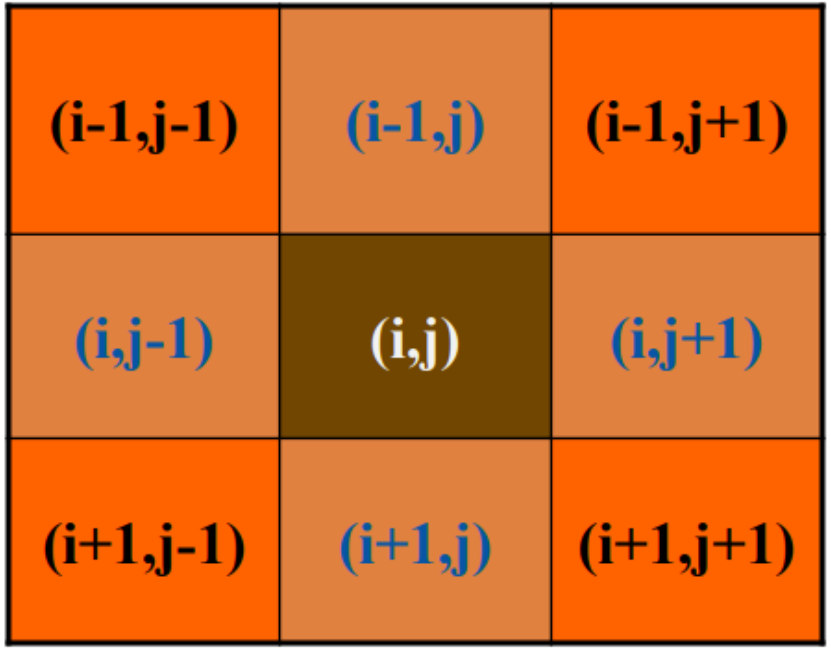
= 187.25 sec or 3.1 min

Basic relationship between pixels

- An image is denoted by a function f(x, y)
- Each element f(x, y) at location (x, y) is called a pixel
- There exist some basic but important relationships between pixels

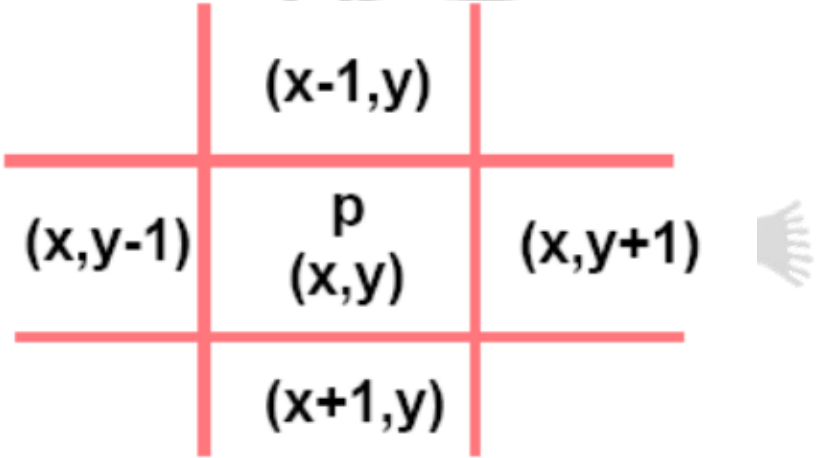
Basic relationship between pixels

- Neighborhood
- Adjacency
- Connectivity
- Paths
- Regions and boundaries



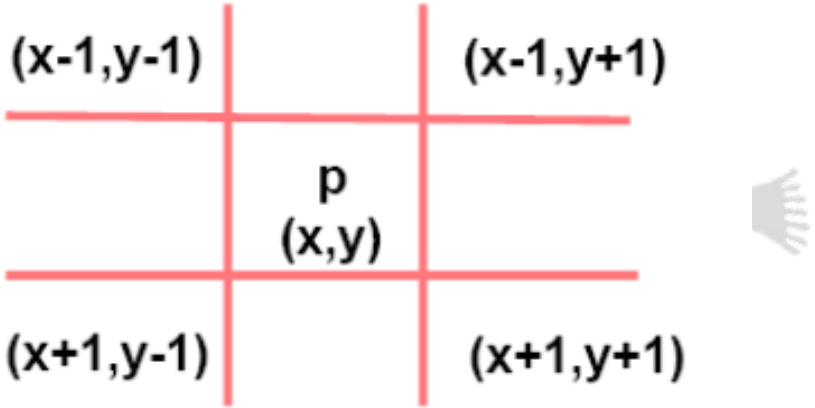
Basic relationship between pixels (Neighbours)

- A pixel p at location (x, y) has two horizontal and two vertical neighbours
- This set of four pixels is called 4-neighbors of p = $N_4(p)$
- Each of these neighbours is at a unit distance from p
- If p is a boundary pixel then it will have less number of neighbours



Basic relationship between pixels (Neighbours)

- A pixel p has four diagonal neighbours $N_D(p)$
- The points of $N_4(p)$ and $N_D(p)$ together are called 8-neighbors of p
- $N_8(p) = N_4(p) \cup N_D(p)$
- If p is a boundary pixel then both $N_D(p)$ and $N_8(p)$ will have less number of pixels



Basic relationship between pixels (Adjacency)

- Two pixels are said to be connected if they are adjacent in some sense
  - They are neighbours (N_4, N_D or N_8) and
  - Their intensity values (gray levels) are similar

Basic relationship between pixels (Adjacency)

- Two pixels are adjacent if they are neighbour and their intensity level ‘V’ satisfy some specific criteria of similarity
- Let V be the set of intensity values

Basic relationship between pixels (Adjacency)

- 4-adjacency: Two pixels p and q with values from set ‘V’ are 4-adjacent if q is in the set $N_4(p)$
- Eg:
  - V = {0, 1}

1	1	0
1	1	0
1	0	1

Basic relationship between pixels (Adjacency)

- 8-adjacency: Two pixels p and q with values from set ‘V’ are 8-adjacent if q is in the set $N_8(p)$
- Eg:
  - V = {1, 2}

0	1	1
0	2	0
0	0	1

Basic relationship between pixels (Adjacency)

- m-adjacency: Two pixels p and q with values from V are m-adjacent if
  - (i) q is in the set $N_4(p)$, Eg: V = {1} OR
  - (ii) q is in the set $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ is empty

0	1	1
0	1	0
0	0	1

Basic relationship between pixels (Adjacency)

- m-adjacency: Two pixels p and q with values from V are m-adjacent if
  - (i) q is in the set $N_4(p)$, Eg: V = {1} OR
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0	1	1
0	1	0
0	0	1

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0	1	1
0	1	0
0	0	1

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0	1	1
0	1	0
0	0	1

Basic relationship between pixels (Adjacency)

- Eg:
  - Find 4-adjacency and 8-adjacency of the center pixel
  - Note: V = {1}

Solution

- 4-adjacency

0	1	1
0	1	0
0	0	1

Basic relationship between pixels (Adjacency)

- Eg:
  - Find 4-adjacency and 8-adjacency of the center pixel
  - Note: V = {1}

Solution

  - 8-adjacency

0	1	1
0	1	0
0	0	1

Basic relationship between pixels (Connectivity)

- Let S represent a subset of pixels in an image
- Two pixels p with coordinates (x_0, y_0) and q with coordinates (x_n, y_n) are said to be connected in S if there exists a path

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

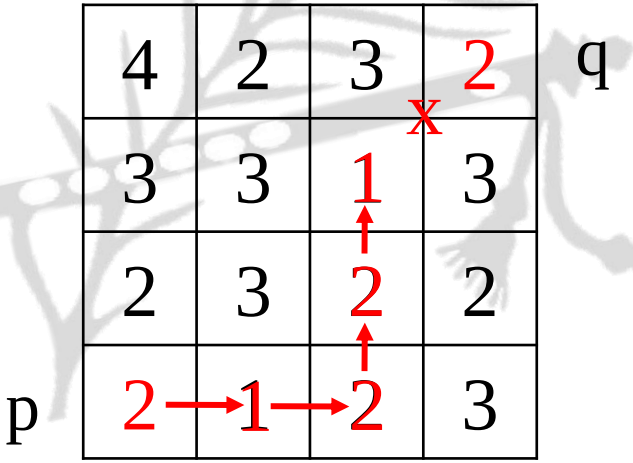
Basic relationship between pixels (Path)

- A path from pixel p with coordinates (x_0, y_0) to pixel q with coordinates (x_n, y_n) is a sequence of distinct pixels with coordinates (x_0, y_0), (x_1, y_1), …, (x_n, y_n)
  - where (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \leq i \leq n$
- Here n is the length of the path
- If $(x_0, y_0) = (x_n, y_n)$, the path is closed path
- We can define 4-, 8-, and m-paths based on the type of adjacency used

Basic relationship between pixels (Path)

- Eg:
  - Compute the length of shortest-4 path between pixels p and q, where V = {1, 2}

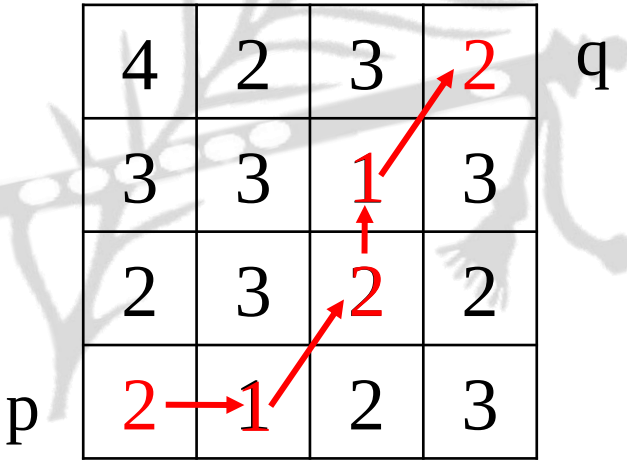
Solution



Basic relationship between pixels (Path)

- Eg:
  - Compute the length of shortest-8 path between pixels p and q, where V = {1, 2}

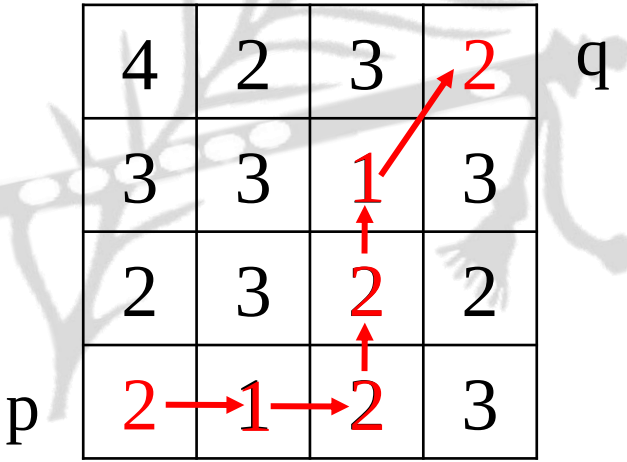
Solution



Basic relationship between pixels (Path)

- Eg:
  - Compute the length of shortest-m path between pixels p and q, where V = {1, 2}

Solution



Basic relationship between pixels (Region)

- Let R be a subset of pixels in an image, two regions R_i and R_j are said to be adjacent if their union form a connected set
- Regions that are not connected are said to be disjoint
- We consider 4- and 8- adjacency when referring to the regions
- Eg:

R_i

1	1	0
1	0	1
1	1	0

R_j

0	1	1
0	1	1
1	1	1

- Regions are adjacent only if 8-adjacency is used

Basic relationship between pixels (Boundary)

- The boundary of a region R is the set of pixels in the region that have one or more neighbours that are not in R

OR

- The boundary of a region R is the set of points that are adjacent to point in the compliment of R
- Boundary = $A - (A \ominus B)$

Basic relationship between pixels (Boundary)

- Eg:
  - Given A, find the boundary using structuring element B

A

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

B

1	1	1
1	1	1
1	1	1

Basic relationship between pixels (Boundary)

A

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

B

1	1	1
1	1	1
1	1	1

Basic relationship between pixels (Boundary)

A

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

B

1	1	1
1	1	1
1	1	1

Basic relationship between pixels (Boundary)

A

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

B

1	1	1
1	1	1
1	1	1

Basic relationship between pixels (Boundary)

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

Basic relationship between pixels (Boundary)

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