Introduction

UNIT 1 | Yuba Raj Devkota

5 hrs | NCCS

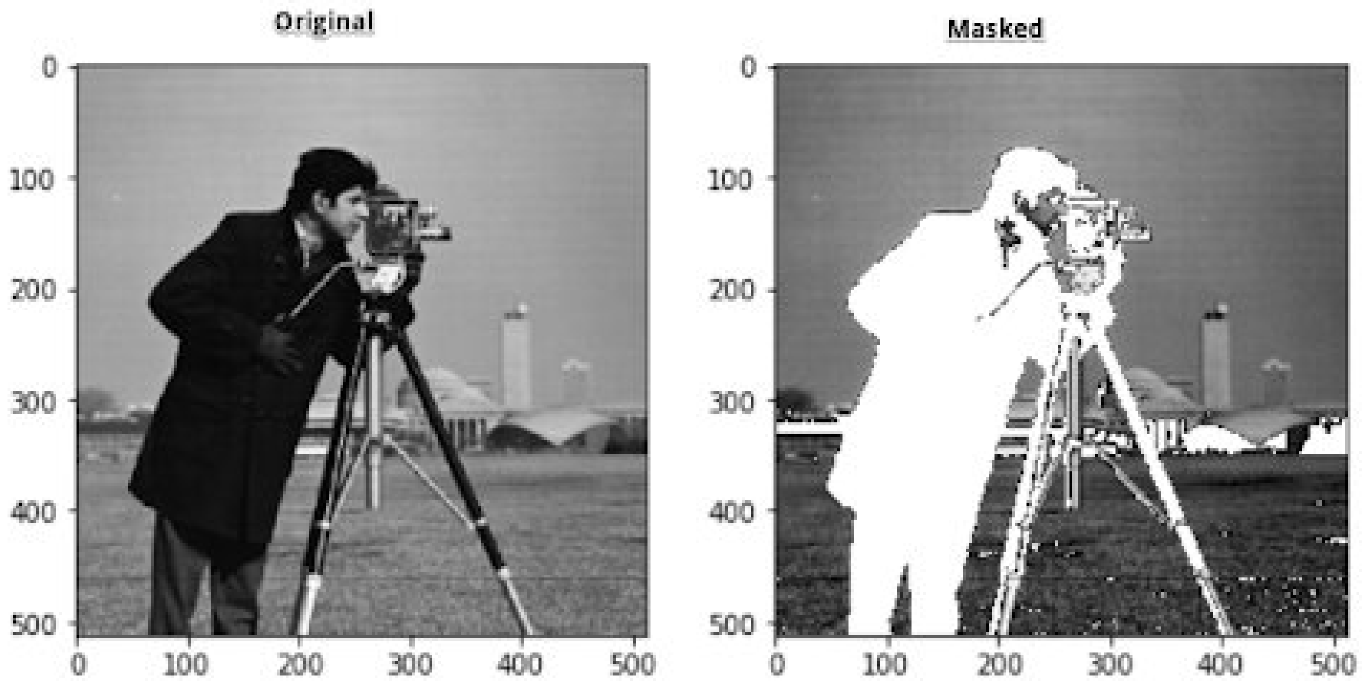
Unit 1	**Introduction**	**Teaching Hours (5)**
Digital Image, A Simple Image Model	Definition of digital image, pixels, representation of digital image in spatial domain as well as in matrix form.	1 hr
Fundamental steps in Image Processing	Block diagram of fundamentals steps in digital image processing, application of digital image processing system, Elements of Digital Image Processing systems	1 hr
Element of visual perception	Structure of the Human, Image Formation in the Eye, Brightness Adaptation and Discrimination	1 hr
Sampling and Quantization	Basic Concepts in Sampling and Quantization, Representing Digital Images, Spatial and Gray-Level Resolution	1 hr
Some basic relationships like Neighbors	Neighbors of a Pixel, Adjacency, Connectivity, Regions, and Boundaries, Distance Measures between pixels	1 hr

Digital Image Processing

Digital Image Processing (DIP) is the process of performing operations on an image using a **computer** to improve its quality or to extract useful information from it.

It involves:

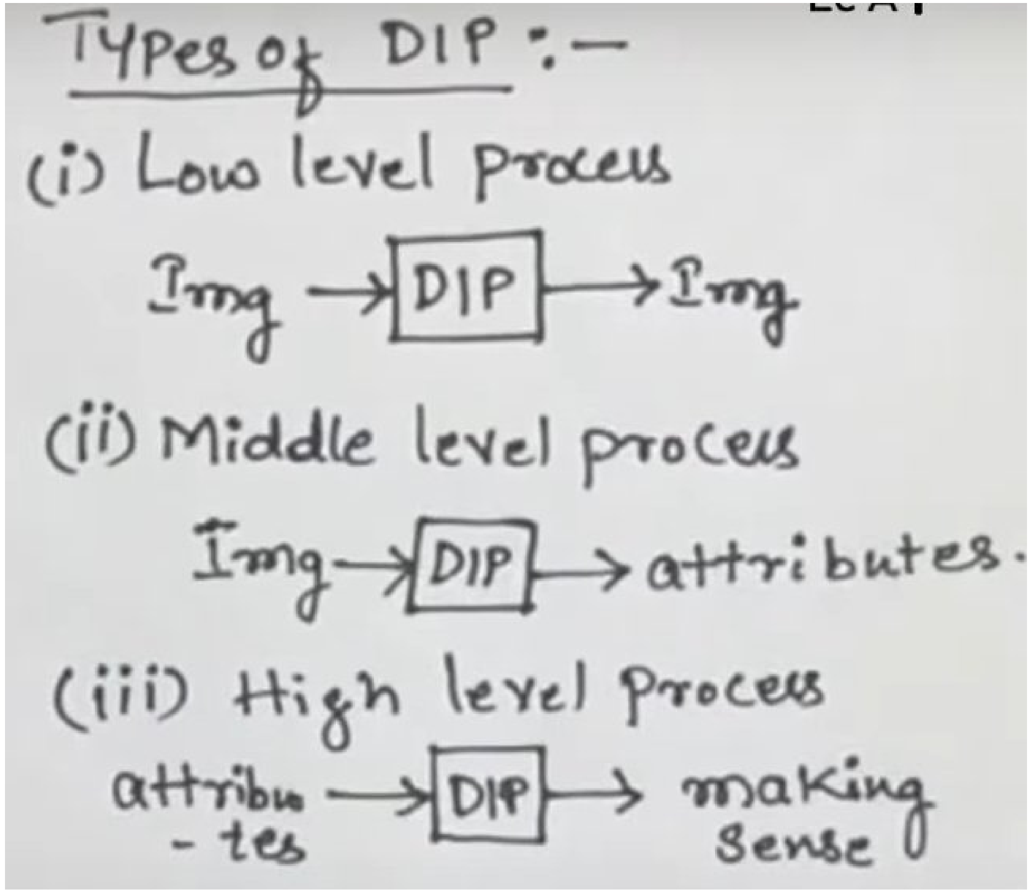
- Converting images into numerical form (pixels)
- Applying algorithms to enhance, restore, compress, analyze, and understand images



Examples:

- ***Improving brightness & contrast***
- ***Removing noise***
- ***Face detection***
- ***Medical image analysis (X-ray, MRI)***

- Vision is the most advance senses that we humans have. But it is limited only to “Visual bands” of EM Spectrum. DIP is needed because it covers wide and varied fields of applications.
- Electromagnetic Spectrum (EM Spectrum) consists of different bands as
    - Gamma Rays
    - X Rays
    - Ultra Violet Rays
    - Visible Bands
    - Infra Rays
    - Microwaves
    - Radio Waves



Examples:

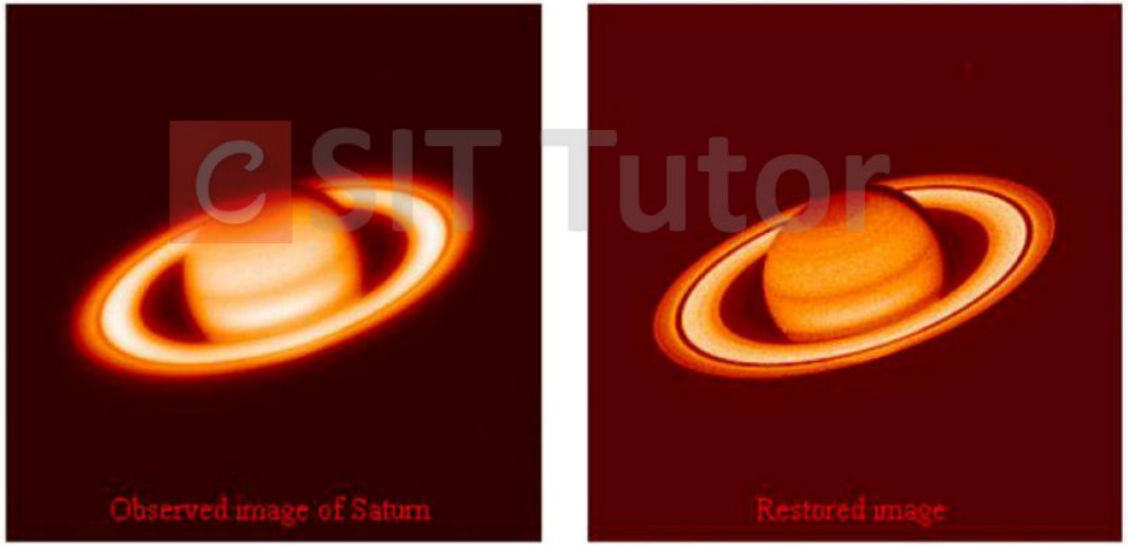
i) Low Level Process: Noisy image is given input and clear image with less noise will be output.

ii) In Middle Level Processing, attributes are the values extracted from the images. The images are sampled and its values are taken as output.

iii) In High level Processing, if attributes of ball image is given as input, the output must be identified as Ball.

Image Processing Examples

Restoration of image from Hubble Space Telescope



Color photo enhancement

Original

Enhanced photo

(a) The original image

(b) After removing the blur

(a) The original image

(b) After removing noise

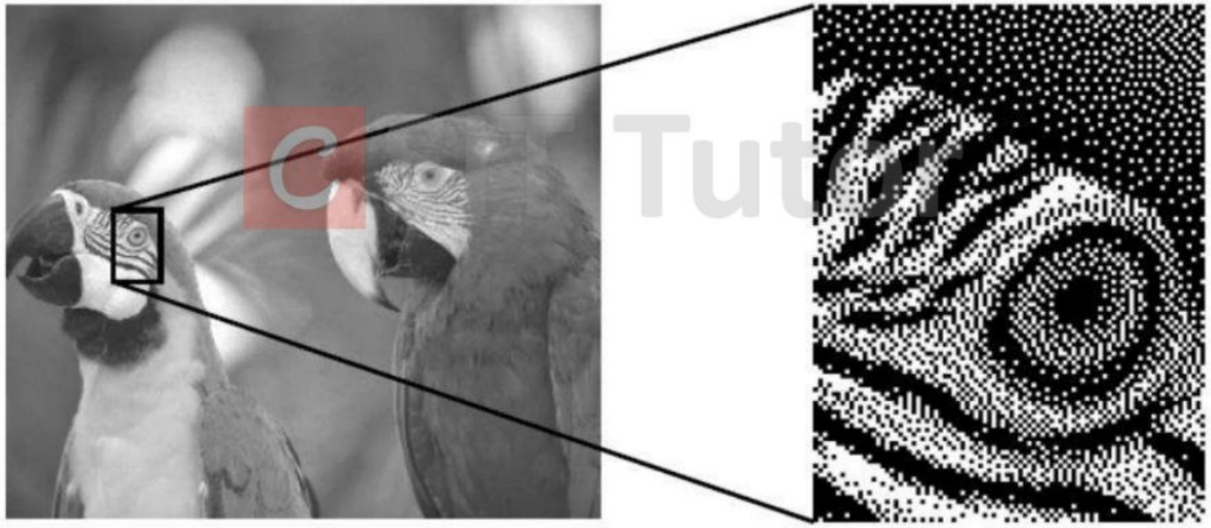
(a) The original image

(b) Its edge image

(a) The original image

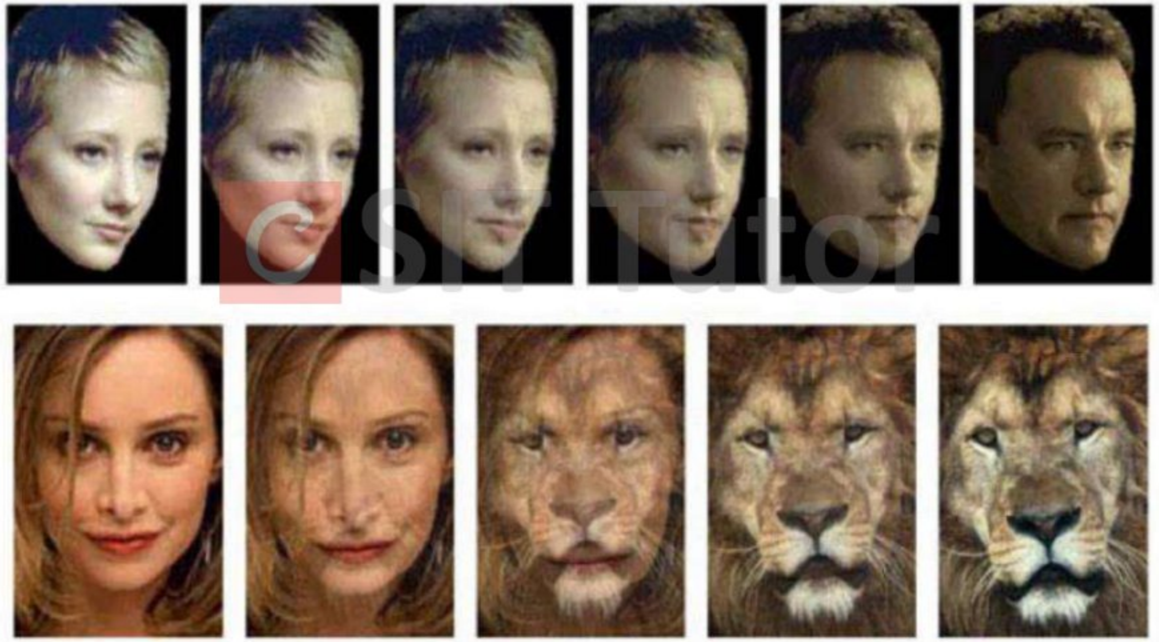
(b) Blurring to remove detail

Halftoning

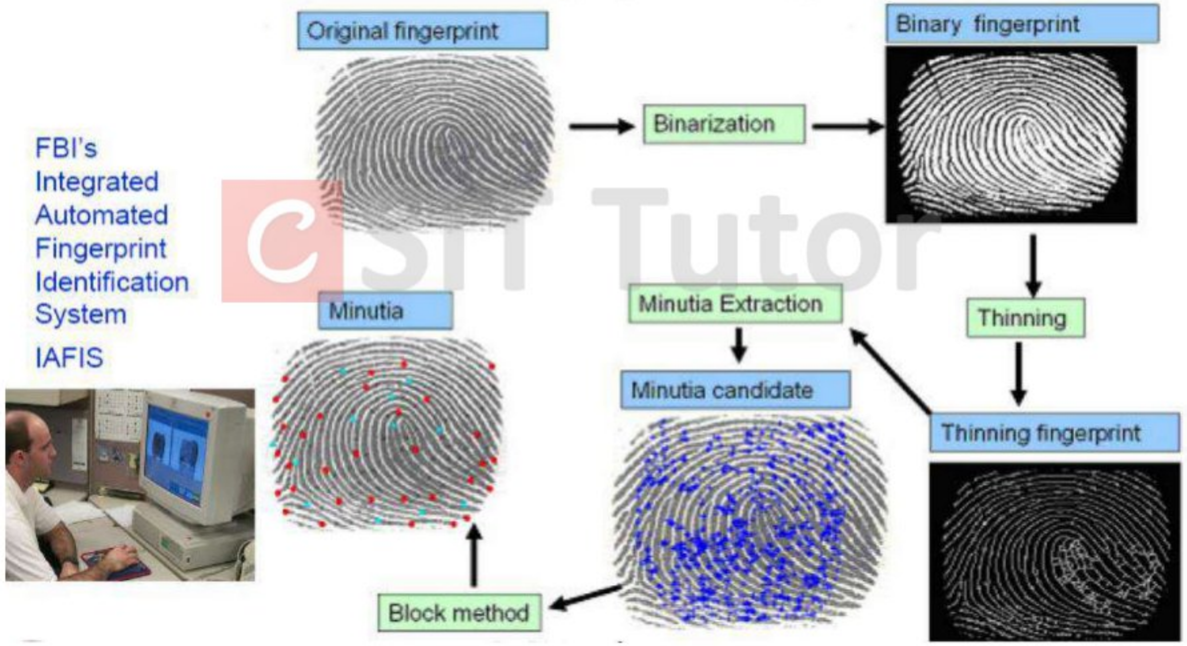


Face Detection

Face morphing

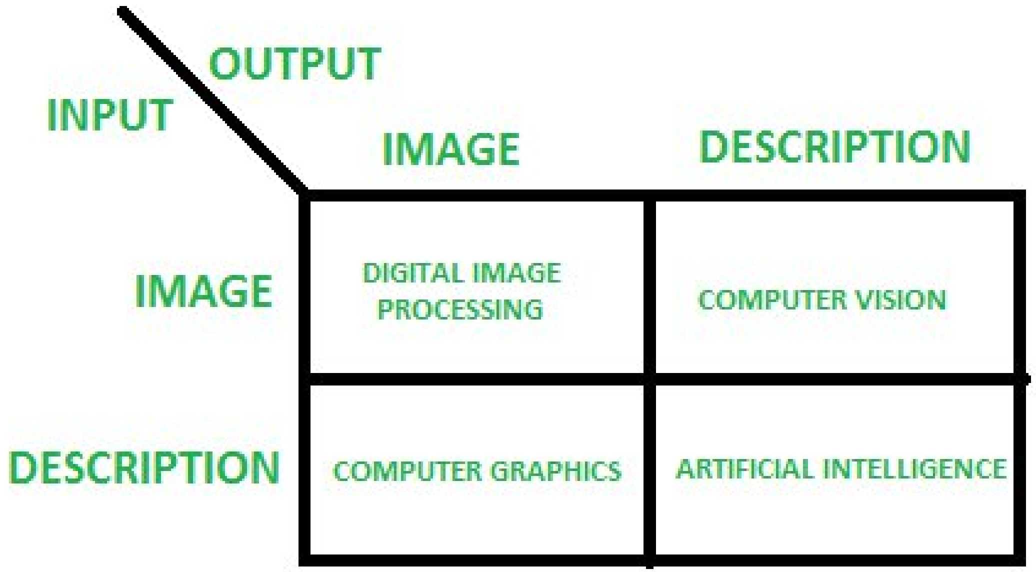


Biometrics: Fingerprint recognition



OVERLAPPING FIELDS WITH IMAGE PROCESSING

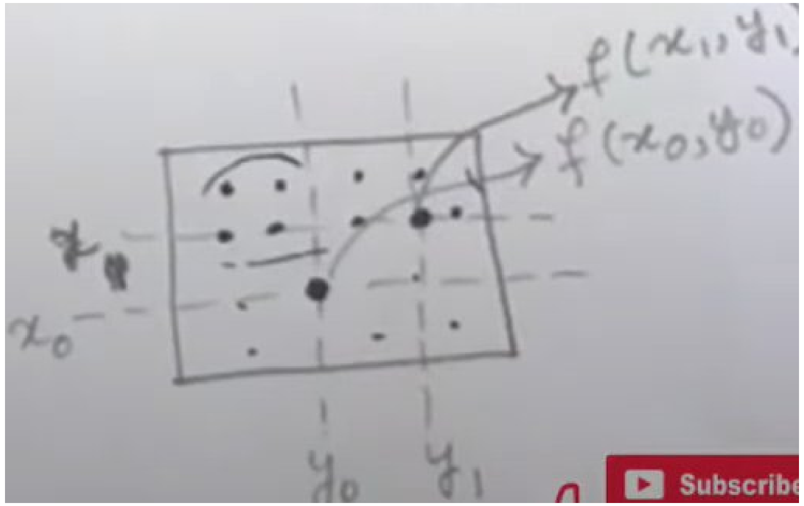
- **According to block 1**,if input is an image and we get out image as a output, then it is termed as Digital Image Processing.
- **According to block 2**,if input is an image and we get some kind of information or description as a output, then it is termed as Computer Vision.
- **According to block 3**,if input is some description or code and we get image as an output, then it is termed as Computer Graphics.
- **According to block 4**,if input is description or some keywords or some code and we get description or some keywords as a output, then it is termed as Artificial Intelligence



What is an image?

An **image** is a 2-dimensional representation of an object or scene.

In digital form, an image is made of small square elements called **pixels**.



Each pixel contains:

- **Intensity** (brightness)
- **Color information** (for color images)

Mathematically:

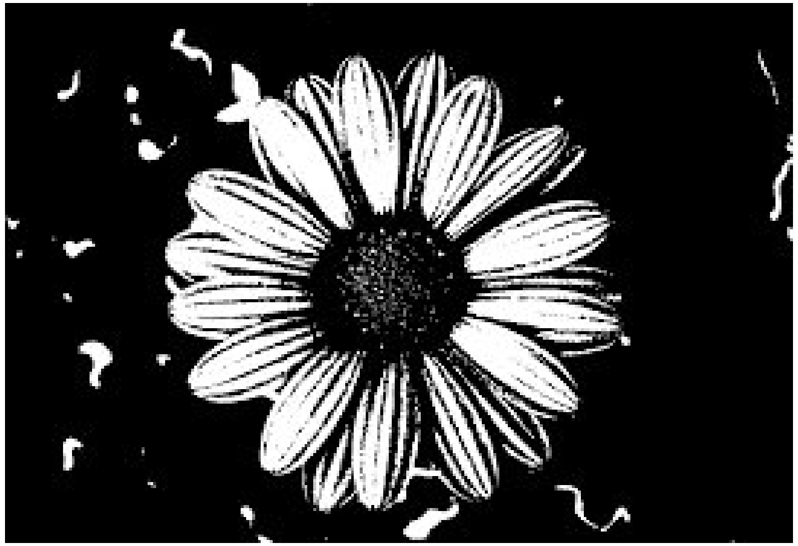
An image can be represented as a function:

$$f(x, y)$$

where

- **x, y** = spatial coordinates
- **f(x, y)** = intensity value at that point

Types of image



1. Binary Image

- Each pixel is **0 or 1** (Black or White)
- Example: Scanned signature, thresholded images

2. Grayscale Image

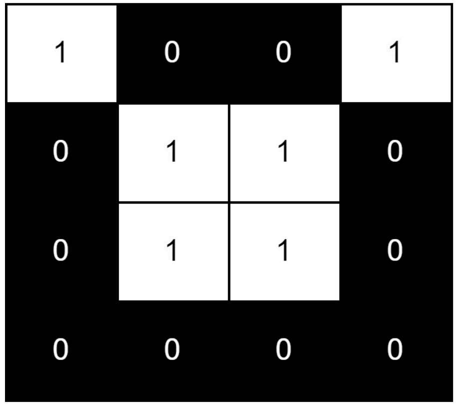
- Pixel values range from **0 to 255**
- 0 = black
- 255 = white
- Intermediate values = shades of gray

Greyscale Image

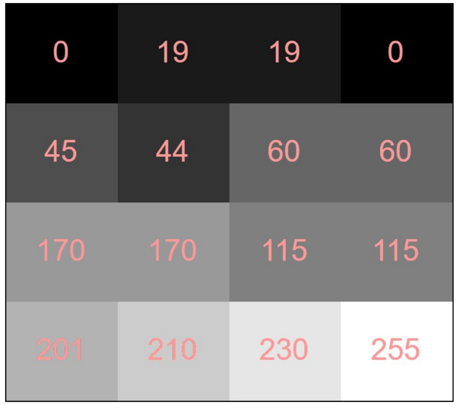
3. Color Image

- Contains color information
- Represented using **RGB model**
    - R = Red
    - G = Green
    - B = Blue
- Each channel is an 8-bit image → total **24 bits**

Color Image



Binary image



Grayscale image

RGB image

PHASES OF IMAGE PROCESSING

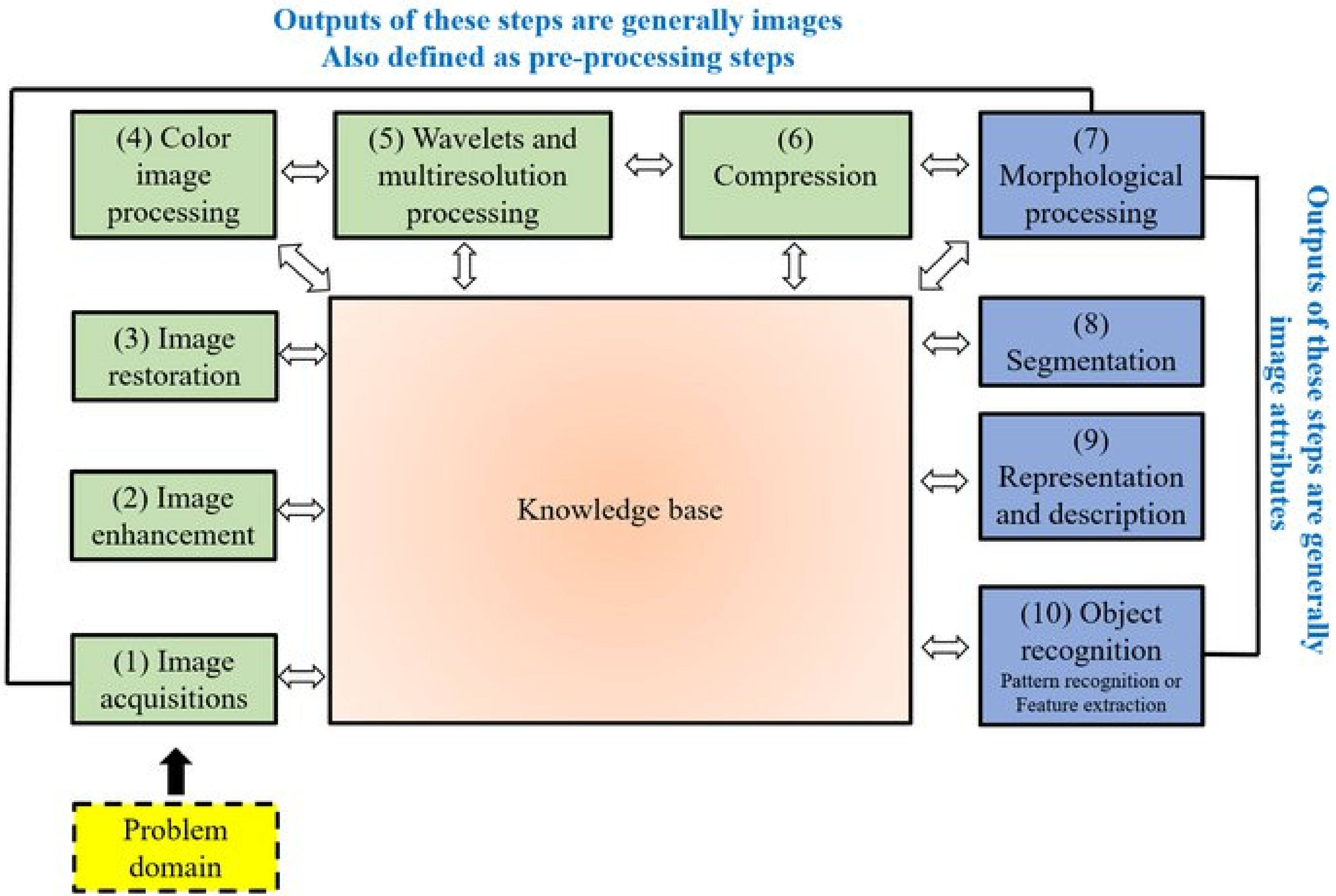


Fig: Fundamental steps in digital image processing

1. Image Acquisition

This is the **first step** where an image is captured by a camera or sensor and converted into a digital form.

What happens here?

- Capturing the image
- Converting analog signal → digital image
- Preprocessing like noise removal may start here

Example:
Taking a photo of a handwritten page using a mobile camera.

2. Image Enhancement

Improving the visual quality of an image to make it more useful for humans or machines.

What happens?

- Adjust brightness, contrast
- Remove noise
- Sharpen edges

Example:
Increasing brightness of a dark CCTV image to see faces clearly.

3. Image Restoration

Restores a **degraded** (blurred/noisy) image using mathematical models.

What happens?

- Deblurring
- Removing unwanted distortions
- Reconstructing damaged images

Example:

Restoring a blurred photograph taken from a shaking camera.

4. Color Image Processing

Deals with color models and manipulation of color images.

What happens?

- RGB to Gray conversion
- Color enhancement
- Color level adjustments

Example:

Correcting color tone in a portrait photo.

5. Wavelets and Multiresolution Processing

Represents images at multiple scales (resolutions).
Used for compression and feature extraction.

What happens?

- Decomposes image into multiple levels
- Useful for zooming and compression

Example:
JPEG2000 image compression uses wavelet transform.

6. Image Compression

Reduces image file size for storage/transmission.

What happens?

- Lossless compression (PNG)
- Lossy compression (JPEG)
- Removing redundant pixels

Example:

Compressing an image from 5 MB to 1 MB for faster upload.

7. Morphological Processing

Shape-based processing mainly applied to **binary images**.

What happens?

- Dilation
- Erosion
- Opening & closing

Example:

Removing small black dots (noise) from a scanned signature.

8. Image Segmentation

Divides an image into meaningful regions or objects.

What happens?

- Detect object boundaries
- Separate foreground & background
- Region-based segmentation

Example:
Separating a human face from the background in a photo.

9. Representation and Description

After segmentation, representing the object using **boundaries or regions** and describing its features.

What happens?

- Boundary representation
- Feature extraction
- Shape analysis

Example:

Extracting the shape and size of a tumor from an MRI scan.

10. Object Recognition

Identifying objects or patterns using extracted features.

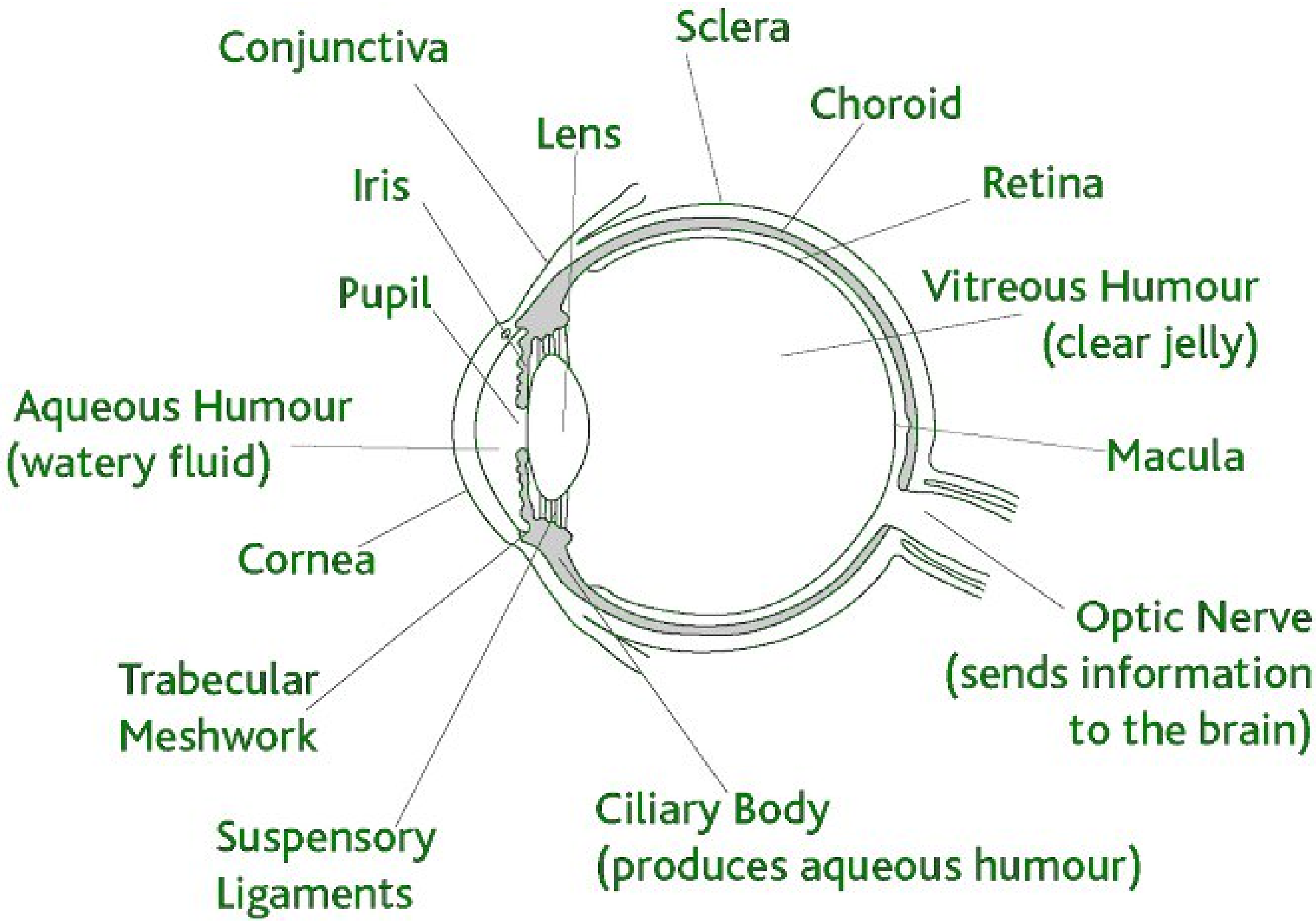
What happens?

- Pattern recognition
- Feature matching
- Machine learning may be used

Example:

Face recognition system detecting a person's face.

Elements of Visual Perception



The human eye works like a **camera**.

Light from an object enters through the **cornea**, passes through the **lens**, and forms an **inverted image** on the **retina**.

- Retina contains **photoreceptors**:
  - **Rods** → detect brightness (low-light vision)
  - **Cones** → detect color (RGB perception)

Example:

You see a red flower because your cone cells detect red wavelengths.

The eye can adapt to a wide range of light intensities.

This is called **luminance adaptation**.

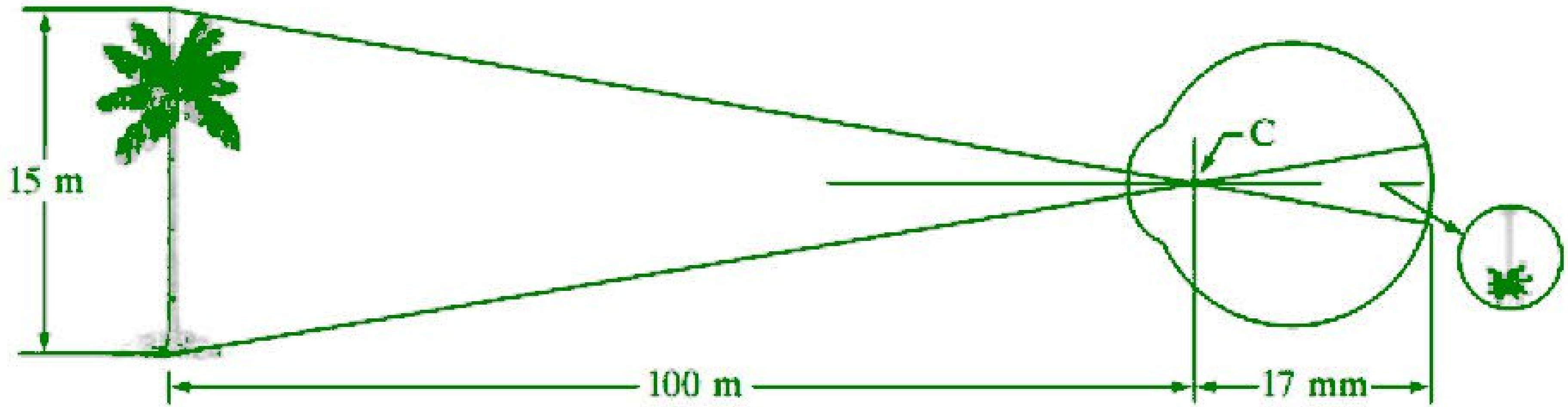
- In bright light → pupils shrink
- In dark areas → pupils expand

This allows us to see in different lighting conditions.

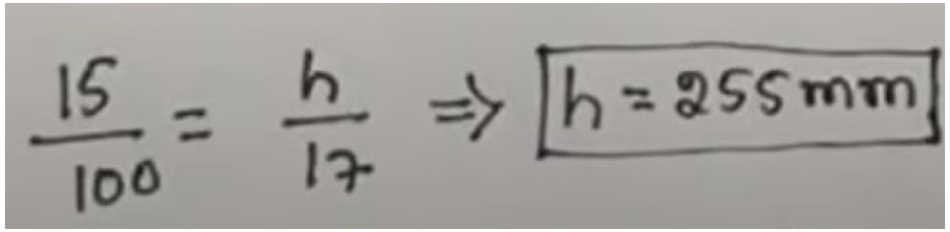
Example:

Walking into a dark room from sunlight—your eyes take time to adjust.

Image Formation in the Eye:



When the lens of the eye focus an image of the outside world onto a light-sensitive membrane in the back of the eye, called retina the image is formed. The lens of the eye focuses light on the photoreceptive cells of the retina which detects the photons of light and responds by producing neural impulses.



h = 2.55 mm

The distance between the lens and the retina is about 17mm and the focal length is approximately 14mm to 17mm.

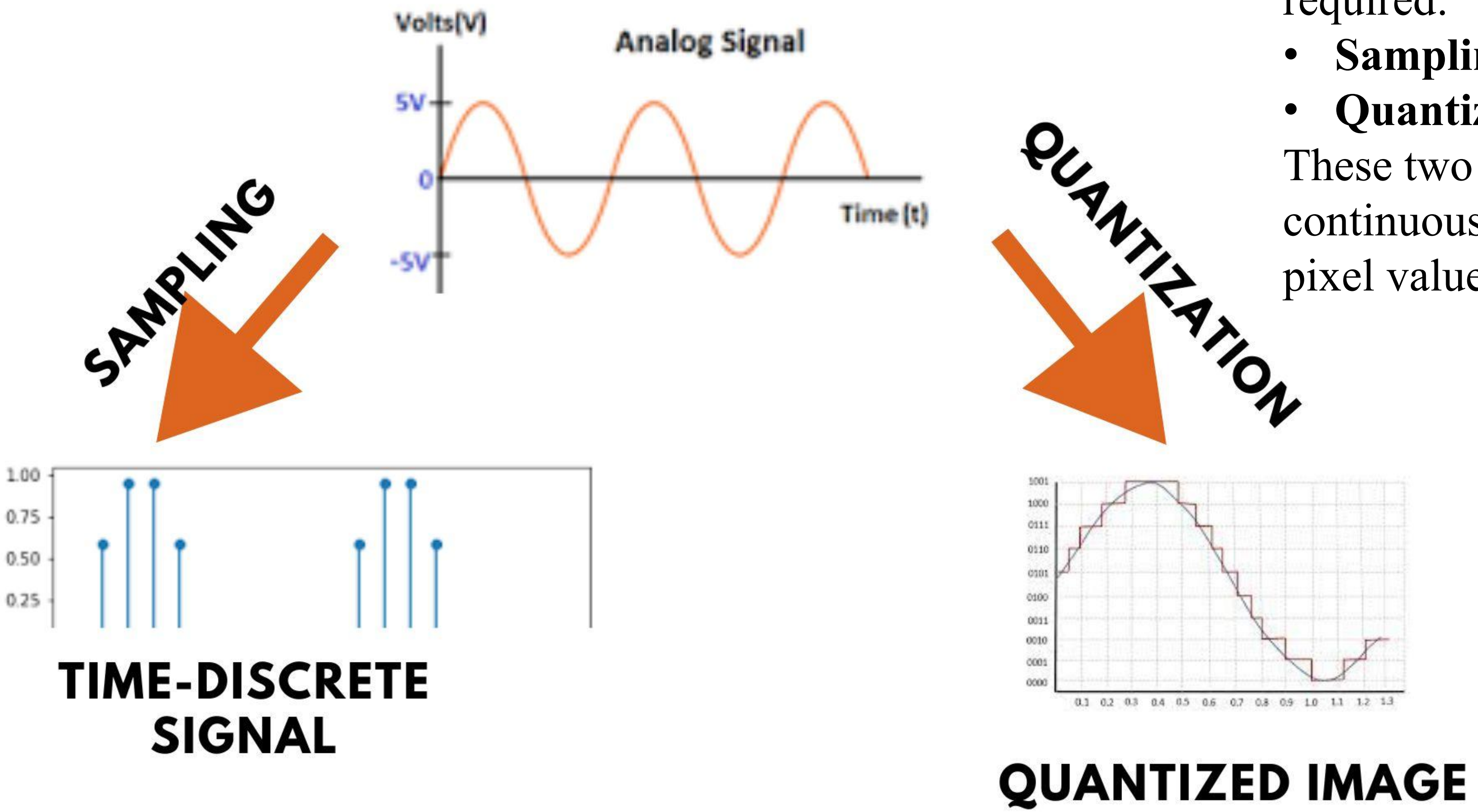
Once the images is refracted in retina, the light receptors will transform the radiant energy to electrical impulses and it will be decoded by brain…..after that we can visualize the image.

Sampling vs Quantization

To convert an analog (real-world) image into a digital image, two main processes are required:

- **Sampling**
- **Quantization**

These two steps together convert a continuous image into a matrix of digital pixel values.



1. Sampling (Spatial Sampling)

Sampling means **selecting the number of pixels** used to represent an image.

- It determines the **spatial resolution** of an image.
- Higher sampling → more pixels → better detail
- Lower sampling → fewer pixels → poor quality

In simple terms:

Sampling = How many dots (pixels) are taken from the image.

Example:

A 4×4 image has 16 samples.

A 1024×1024 image has over 1 million samples and looks much clearer.

2. Quantization (Intensity Quantization)

Quantization means **assigning a specific intensity value** to each sampled pixel.

- It controls the **number of gray levels** in the image.
- Using 8 bits → 256 gray levels
- Using 1 bit → only 2 levels (black & white)

In simple terms:

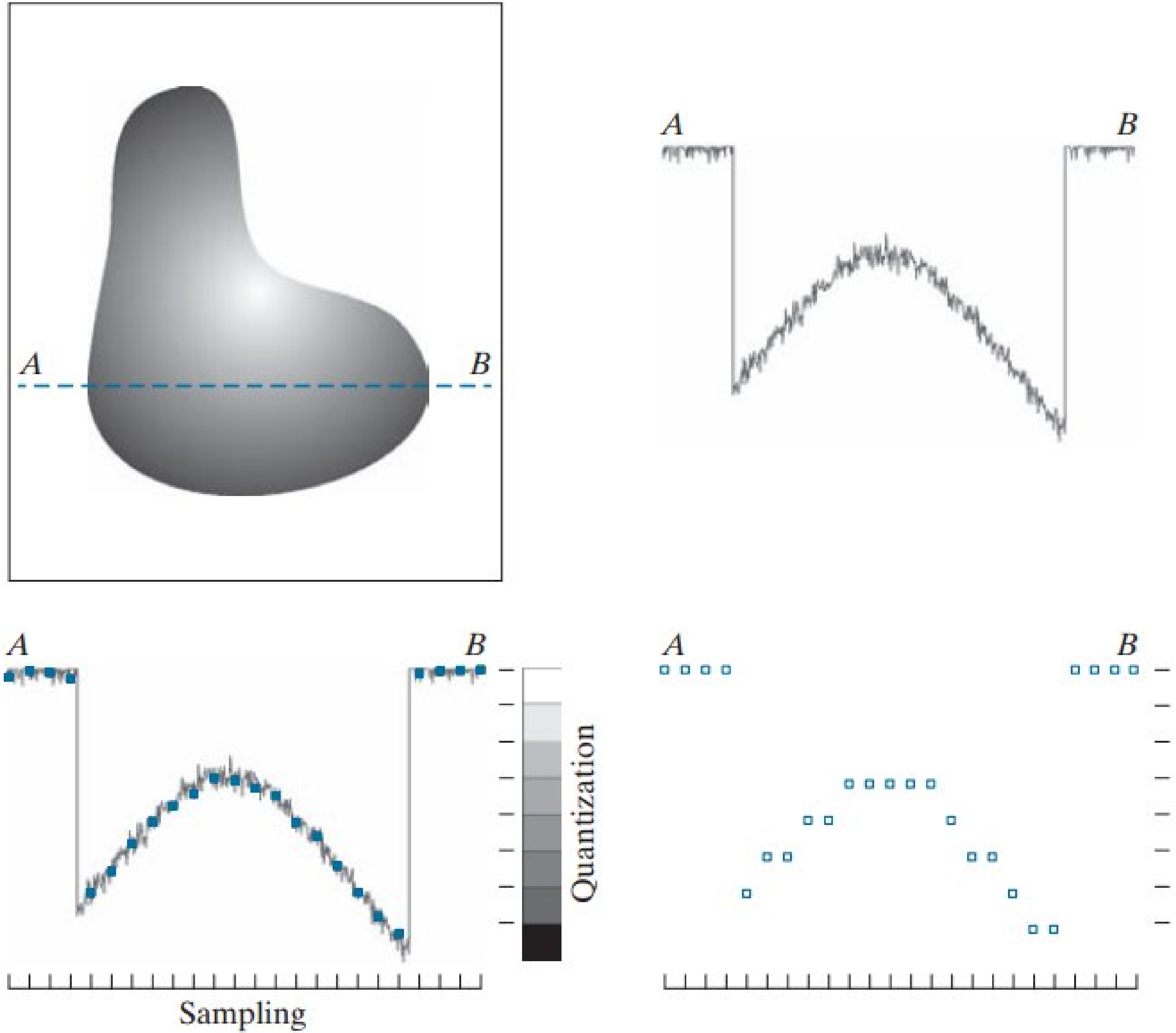
Quantization = How many brightness levels are available.

Example:

- 8-bit image → 256 shades of gray
- 4-bit image → 16 shades
- 1-bit image → black or white only

Higher quantization → smoother image

Lower quantization → visible banding/noise



(a) Continuous image in x & y axis and amplitude.

(b) Amplitude of a line AB in gray format. In A and B, image is white. Inside the figure, line in the middle of image is a bit brighter while in sides its darker.

(c) Equal size samples are taken for sampling.

(d) In order to form a digital function, the gray level values must be converted into digital quantity called quantization. Values of each square is obtained from 8 gray levels ranging from black to white.

Relationships between pixels

In a digital image, **pixels are related** based on how they are **neighbors** to each other.

Pixel relationships help in **segmentation, edge detection, region growing**, etc.

Two pixels are considered neighbors if they are adjacent based on a type of **connectivity**.

The three main types:

1. **4-connectivity**
2. **8-connectivity**
3. **m-connectivity (mixed connectivity)**

```
0 1 0
1 P 1
0 1 0
```

⭐ 1. 4-Connectivity (4-neighbors)

A pixel is connected to its **four** immediate neighbors:

- Left
- Right
- Up
- Down

```
    N4(P):
      (x-1, y)
(x, y-1) P (x, y+1)
      (x+1, y)
```

Here, P is connected to four pixels (up, down, left, right).

⭐ 2. 8-Connectivity (8-neighbors)

A pixel is connected to **all eight** surrounding pixels:

- 4-connectivity neighbors
- - 4 diagonal neighbors

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

Example (8-neighbors of pixel P):

```
1 1 1
1 P 1
1 1 1
```

P is connected to all eight surrounding pixels.

⭐ 3. m-Connectivity (Mixed Connectivity)

m-connectivity is used to **avoid diagonal ambiguity** that occurs in 8-connectivity.

It combines:

- **4-connectivity**
- **diagonal neighbors (D)**
- But allows a diagonal connection **only if the diagonal does NOT connect two foreground pixels through a common 4-neighbor**.

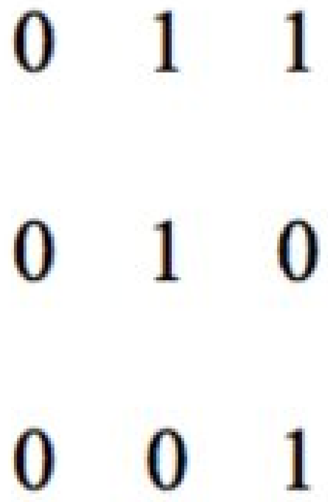


Fig: An arrangement of pixels

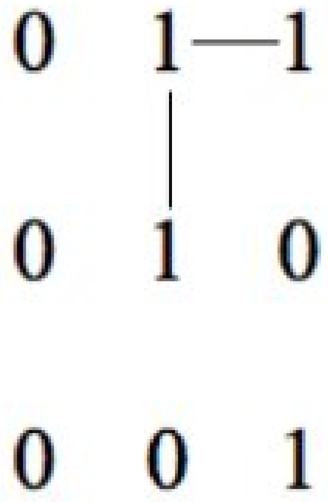


Fig: 4-connectivity of pixels

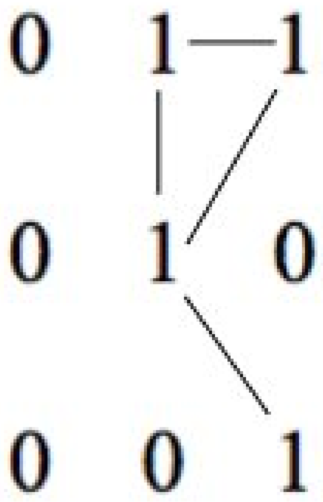


Fig: 8-connectivity of pixels

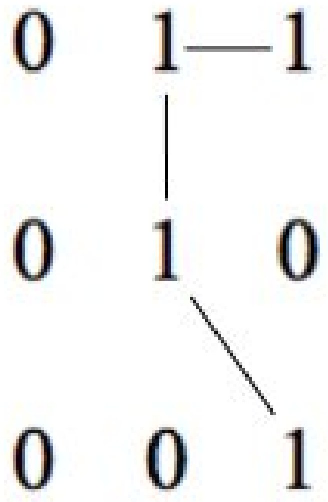


Fig: m-connectivity of pixels

⭐ Why m-connectivity is needed?

It removes false connections that occur in 8-connectivity.

It ensures:

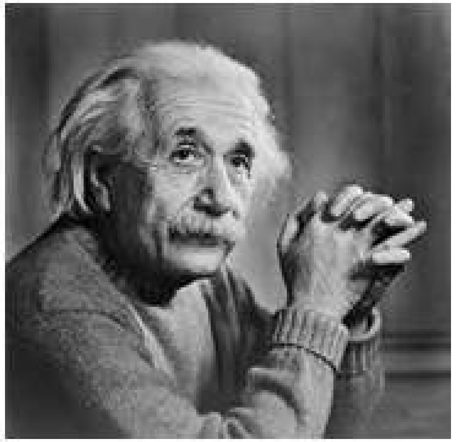
- No unwanted diagonal merging
- Regions are correctly separated

Useful in **boundary detection, segmentation, connected component labeling**, etc.

Applications of Digital Image Processing

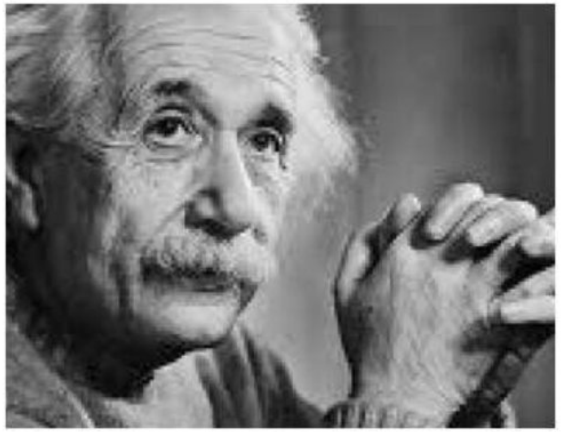
1. Image sharpening and restoration

Image sharpening and restoration refers here to process images that have been captured from the modern camera to make them a better image or to manipulate those images in way to achieve desired result. It refers to do what Photoshop usually does.

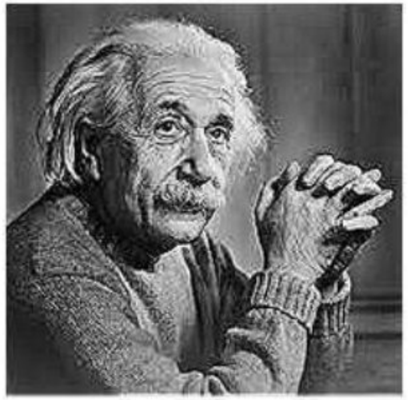


The original image

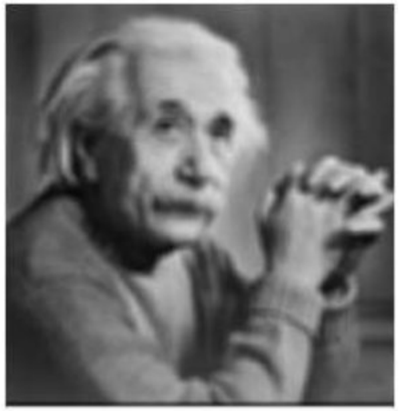
The zoomed image



Sharp image



Blurr image



Edges

2. Medical field

- Gamma ray imaging
- PET scan
- X Ray Imaging
- Medical CT
- UV imaging

An image of the effected area is captured from the above ground and then it is analyzed to detect the various types of damage done by the earthquake.

3. Transmission and encoding:

- The very first image that has been transmitted over the wire was from London to New York via a submarine cable.
- The picture that was sent took three hours to reach from one place to another.
- today we are able to see live video feed , or live cctv footage from one continent to another with just a delay of seconds.
- This field does not only focus on transmission , but also on encoding. Many different formats have been developed for high or low bandwidth to encode photos and then stream it over the internet or e.t.c.

4. Machine/Robot vision

Apart form the many challenges that a robot face today , one of the biggest challenge still is to increase the vision of the robot. Make robot able to see things , identify them , identify the hurdles e.t.c. Much work has been contributed by this field and a complete other field of computer vision has been introduced to work on it.

5. Hurdle detection

Hurdle detection is one of the common task that has been done through image processing, by identifying different type of objects in the image and then calculating the distance between robot and hurdles.

6. Line follower robot

Most of the robots today work by following the line and thus are called line follower robots. This help a robot to move on its path and perform some tasks. This has also been achieved through image processing.

7. Color processing

- Color processing includes processing of colored images and different color spaces that are used. For example RGB color model , YCbCr, HSV. It also involves studying transmission , storage , and encoding of these color images.

8. Pattern recognition

- Pattern recognition involves study from image processing and from various other fields that includes machine learning (a branch of artificial intelligence). In pattern recognition , image processing is used for identifying the objects in an images and then machine learning is used to train the system for the change in pattern. Pattern recognition is used in computer aided diagnosis , recognition of handwriting , recognition of images e.t.c

9. Video processing

- A video is nothing but just the very fast movement of pictures. The quality of the video depends on the number of frames/pictures per minute and the quality of each frame being used. Video processing involves noise reduction , detail enhancement , motion detection , frame rate conversion , aspect ratio conversion , color space conversion e.t.c.

Problems associated with DIP

1. Noise in Images

Digital images often contain **unwanted random variations** (noise) due to sensors, transmission, or environment.

Example:

- Low-light photographs contain **salt-and-pepper noise** (random white/black dots).
- MRI or X-Ray images have **Gaussian noise**.

2. Image Blur and Distortion

Blurring can occur during **image capture**, **camera motion**, or **focus errors**.

Example:

- A moving car captured by a phone camera becomes blurry (motion blur).
- Out-of-focus passport photo.

3. Limited Resolution

Digital images have finite pixels. Low resolution causes **loss of detail**.

Example:

- Zooming into a low-resolution CCTV frame makes faces unrecognizable (pixelation).

4. Quantization Errors

When converting a continuous image to digital form, the intensity values are rounded → **loss of accuracy**.

Example:

- A smooth sky becomes "banded" due to low grey levels (posterization effect).

5. Sampling Problems (Aliasing)

Improper sampling creates **distortion or false patterns**.

Example:

- A striped shirt appears wavy or creates moiré patterns in digital photos.
- Wheel spokes in video appear to move backward.

6. High Computational Cost

Some DIP tasks require heavy computation and memory, especially for large images.

Example:

- Processing a 4K image for object recognition takes significant CPU/GPU time.
- Real-time video enhancement is computationally expensive.

7. Sensitivity to Lighting and Environment

Images vary greatly with illumination, angle, shadows, and background.

Example:

- Face recognition systems fail in poor lighting.
- Barcode scanning fails under glare.

8. Storage and Transmission Issues

High-resolution images and videos require large storage and bandwidth.

Example:

- RAW images from DSLR are ~30–50 MB each.
- 4K videos need compression, which reduces quality.

9. Difficulty in Segmentation

Separating objects from background is often challenging.

Example:

- Separating a person from a complex background.
- Medical images where tumors blend with surrounding tissues.

10. Loss of Information During Compression

Compressed images (JPEG) lose data permanently.

Example:

- JPEG artifacts (blocky patches) in WhatsApp images.

11. Occlusion and Missing Data

Objects may be partially hidden in the image.

Example:

- A face covered with a mask or hair → recognition becomes difficult.

12. Variability in Object Appearance

Objects change shape, size, and orientation.

Example:

- A car looks different from front, side, back.
- A handwritten number varies from person to person.

13. Difficulty in Real-Time Processing

Real-time DIP for robotics, drones, or medical imaging must be fast and accurate.

Example:

- A drone cannot avoid obstacles if processing is slow.

1. Noise in images → reduces quality.
2. Blur due to motion or focus issues.
3. Limited resolution → pixelation.
4. Quantization errors → loss of grey-scale detail.
5. Aliasing due to poor sampling.
6. High computational requirement.
7. Lighting and environmental sensitivity.
8. Large storage and bandwidth needs.
9. Difficult object segmentation.
10. Lossy compression artifacts.
11. Occlusion or missing data.
12. Variation in object appearance.
13. Real-time processing challenges.

How many images of size 1024×768 with 256 gray levels can be stored in a 2048 MB storage space?

- To determine how many images of size 1024×768 with 256 gray levels can be stored in a 2048 MB storage space, we first need to calculate the size of one image.
- Each pixel in the image requires 1 byte to store its grayscale value because there are 256 gray levels (which can be represented using 8 bits or 1 byte).

So, the size of one image in bytes can be calculated as:

$$\text{Image size} = \text{width} \times \text{height} \times \text{bytes per pixel}$$

Substituting the values:

$$\text{Image size} = 1024 \times 768 \times 1$$

$$\text{Image size} = 1024 \times 768 \times 1$$

$$\text{Image size} = 786{,}432 \text{ bytes}$$

$$\text{Image size} = 786{,}432 \text{ bytes}$$

Now, to find out how many images can be stored in a 2048 MB (or 2048 * 1024 * 1024 bytes) storage space, we'll divide the total storage space by the size of one image:

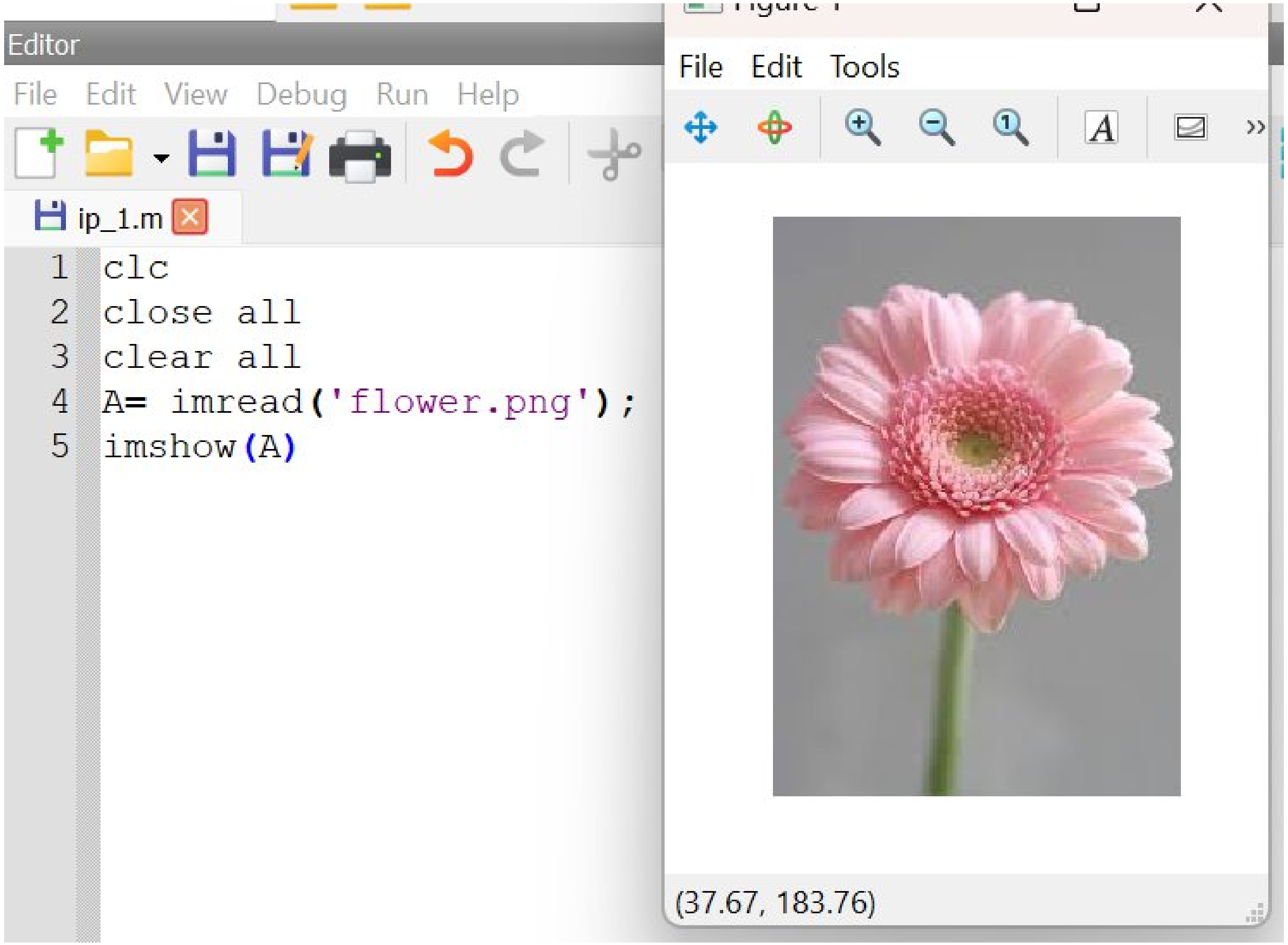
$$\text{Number of images} = \frac{\text{Storage space}}{\text{Image size}}$$

$$\text{Number of images} = \frac{2048 \times 1024 \times 1024}{786{,}432}$$

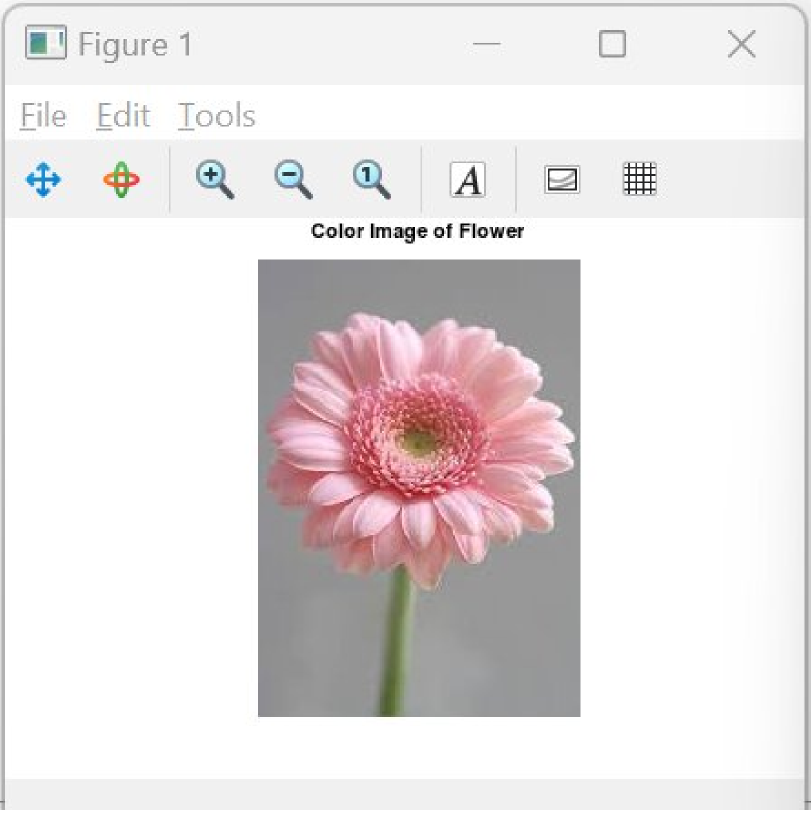
$$\text{Number of images} \approx 2730.67$$

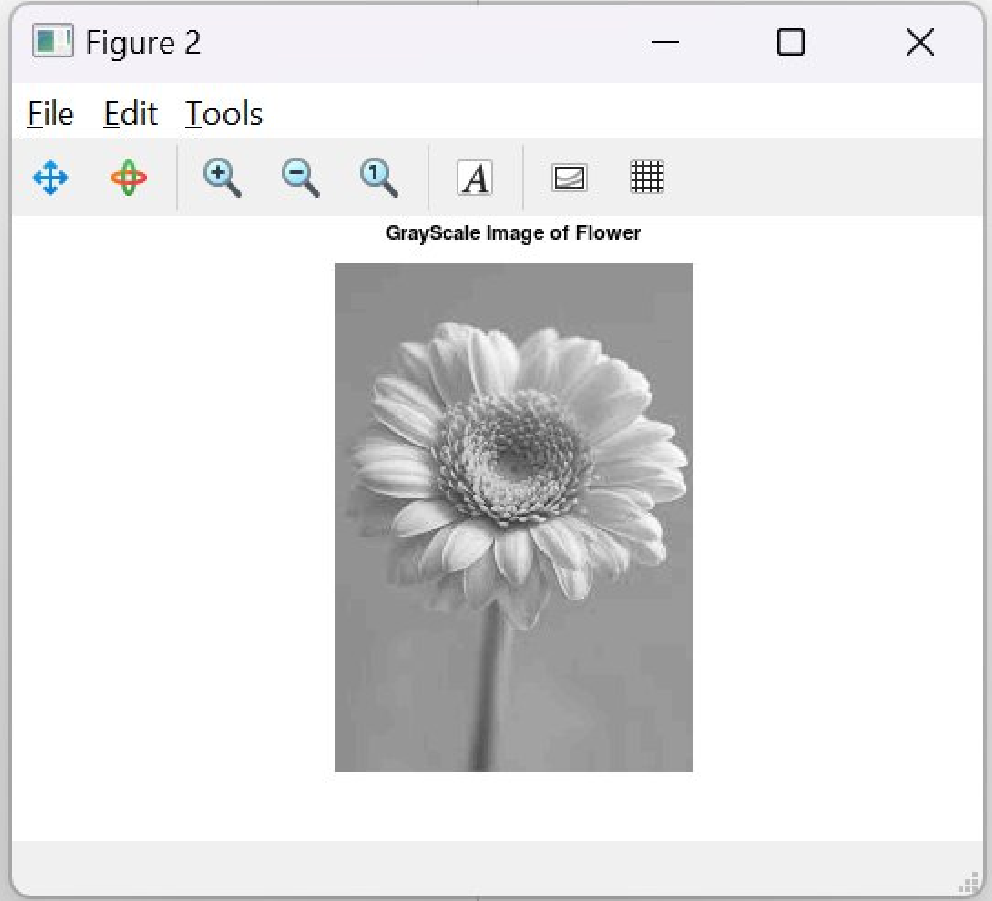
So, approximately 2730 images of size 1024×768 with 256 gray levels can be stored in a 2048 MB storage space. However, since we can't have a fraction of an image, we would round down to the nearest whole number, meaning you can store 2730 images in this space.

Lab 01: Convert to Grayscale Image



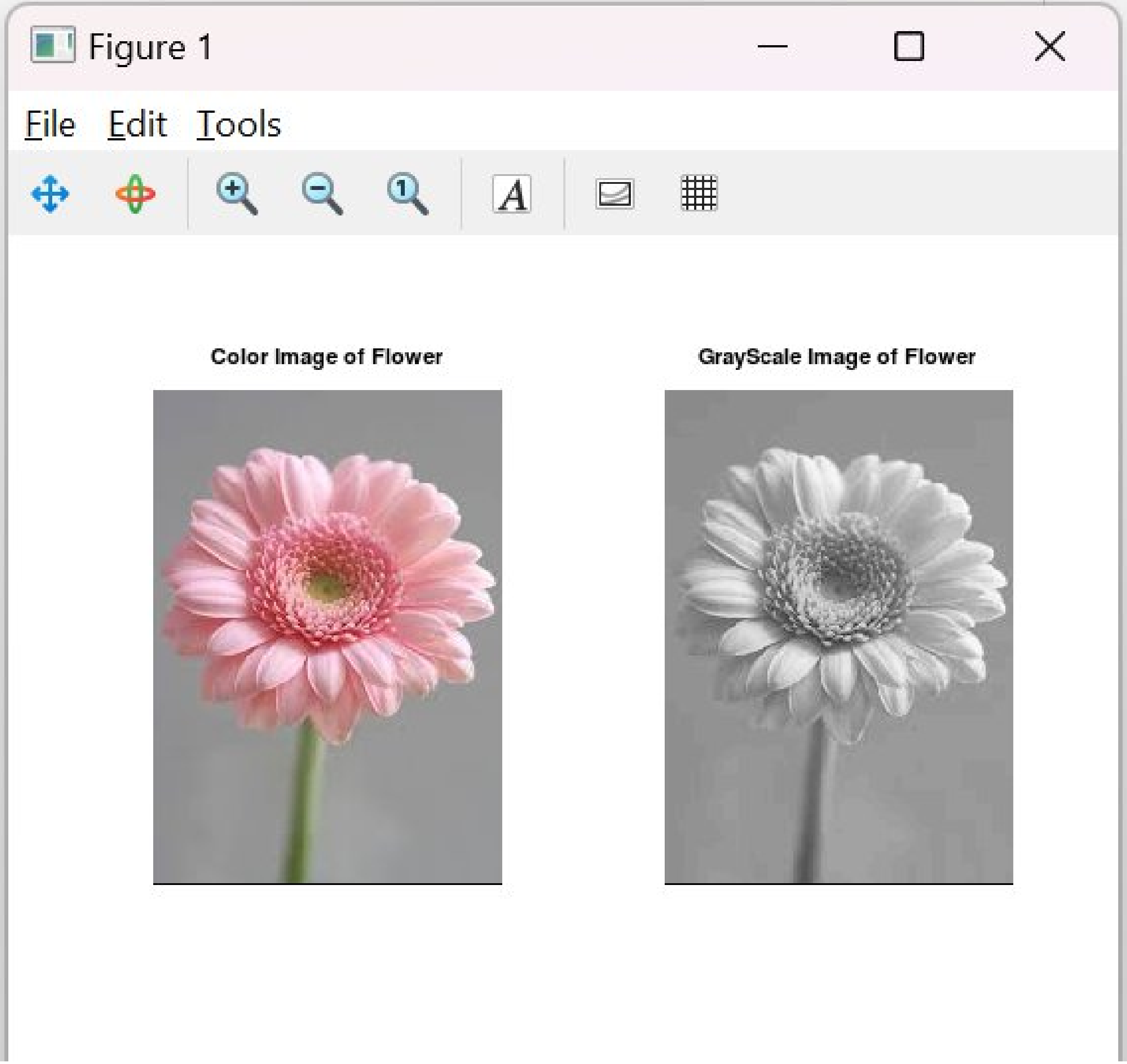
```
clc
close all
clear all
A= imread('flower.png');
imshow(A)
title('Color Image of Flower')
B=rgb2gray(A);
figure
imshow(B)
title('GrayScale Image of Flower')
```





```
clc
close all
clear all
A= imread('flower.png');
subplot(1,2,1);
imshow(A)
title('Color Image of Flower')
B=rgb2gray(A);
#figure
subplot(1,2,2);
imshow(B)
title('GrayScale Image of Flower')

```



What is a digital image? Draw and explain the block diagram of a typical image processing system in brief.(1+5) [2075]

How many images of size 1024×768 with 256 gray levels can be stored in a 2048 MB storage space? (5) [Model Q]

Discuss the various applications and problems associated with the digital image processing in brief. (5) [2076]