# Introduction

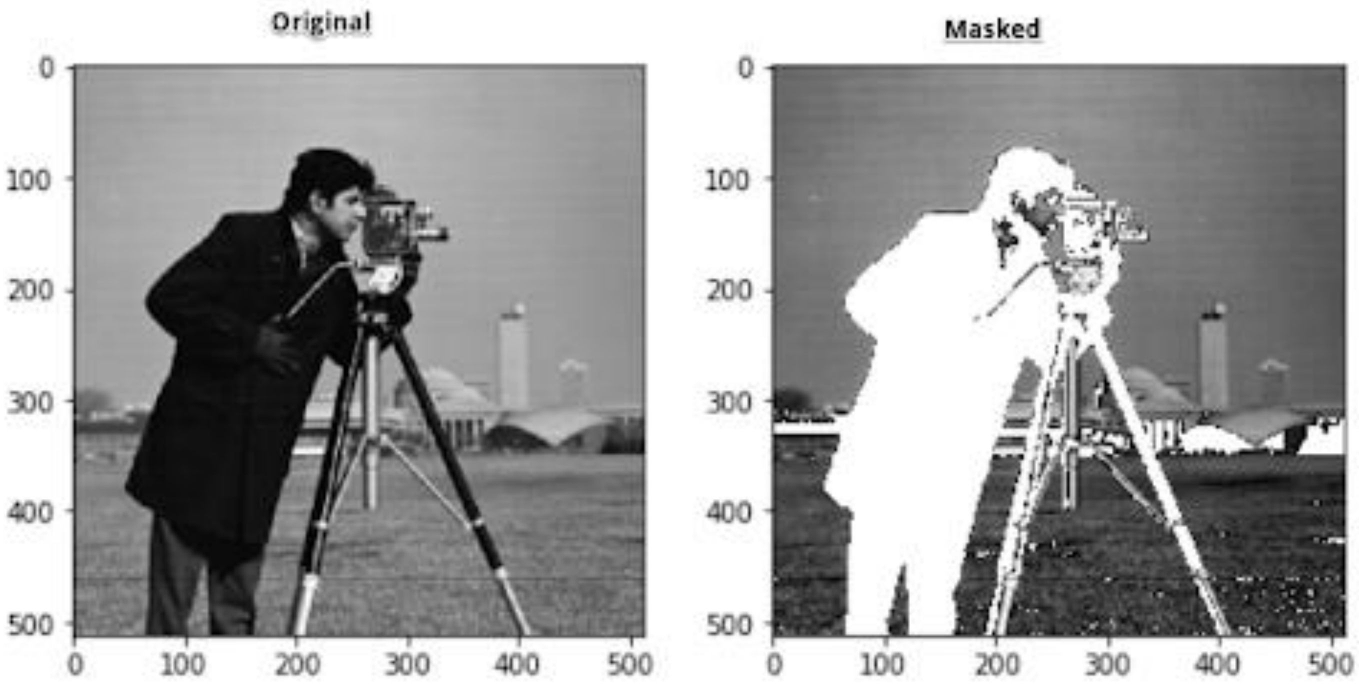
UNIT 1 | Yuba Raj Devkota

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 Basics

- Digital Image Processing means processing digital image by means of a digital computer. We can also say that it is a use of computer algorithms, in order to get enhanced image either to extract some useful information.
- Digital image processing is the use of algorithms and mathematical models to process and analyze digital images.
- The goal of digital image processing is to enhance the quality of images, extract meaningful information from images, and automate image-based tasks.



- 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.

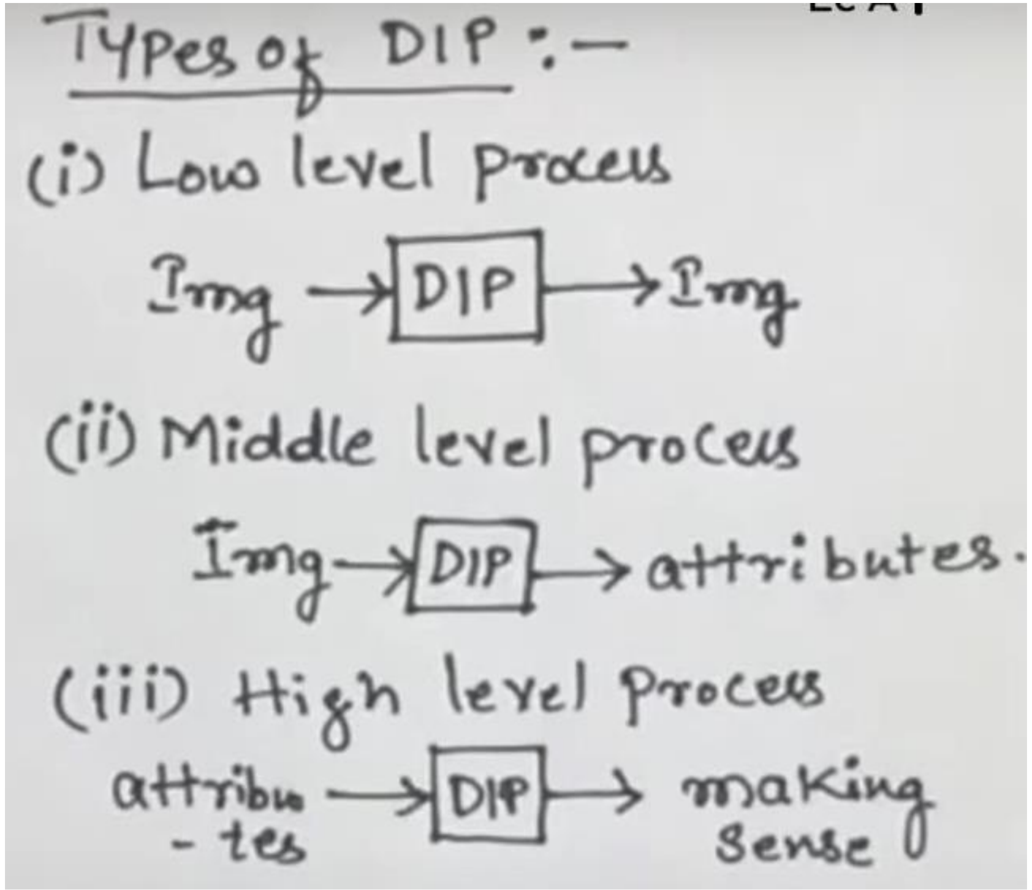
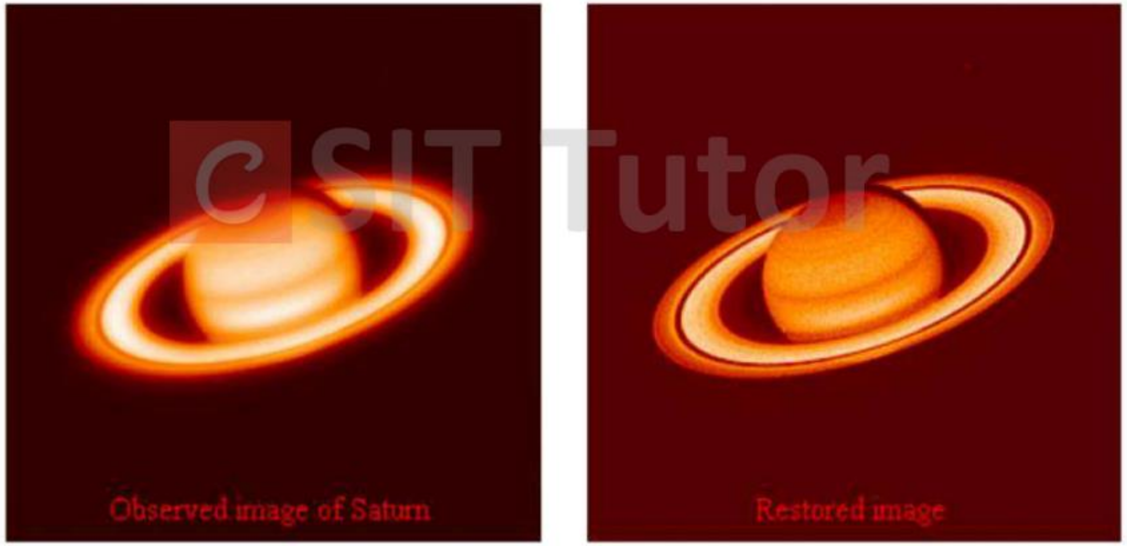


**Image processing mainly include the following steps:**

1. Importing the image via image acquisition tools;
2. Analysing and manipulating the image;
3. Output in which result can be altered image or a report which is based on analyzing that image.

## Image Processing Examples

Restoration of image from Hubble Space Telescope




Color photo enhancement

Original

Enhanced photo

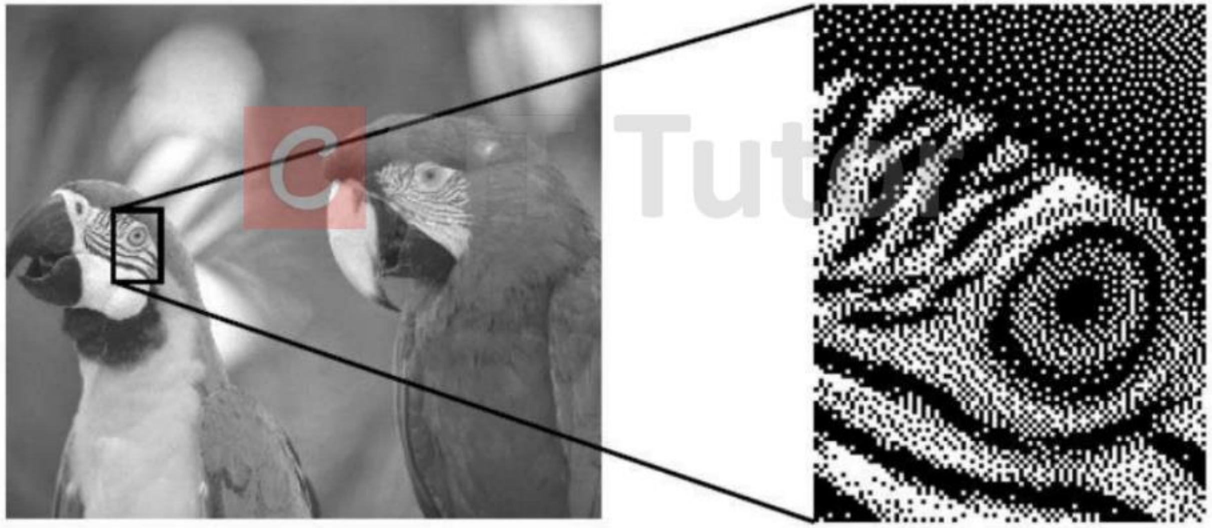

(a) The original image (b) After removing the blur

(a) The original image (b) After removing noise

(a) The original image (b) Its edge image

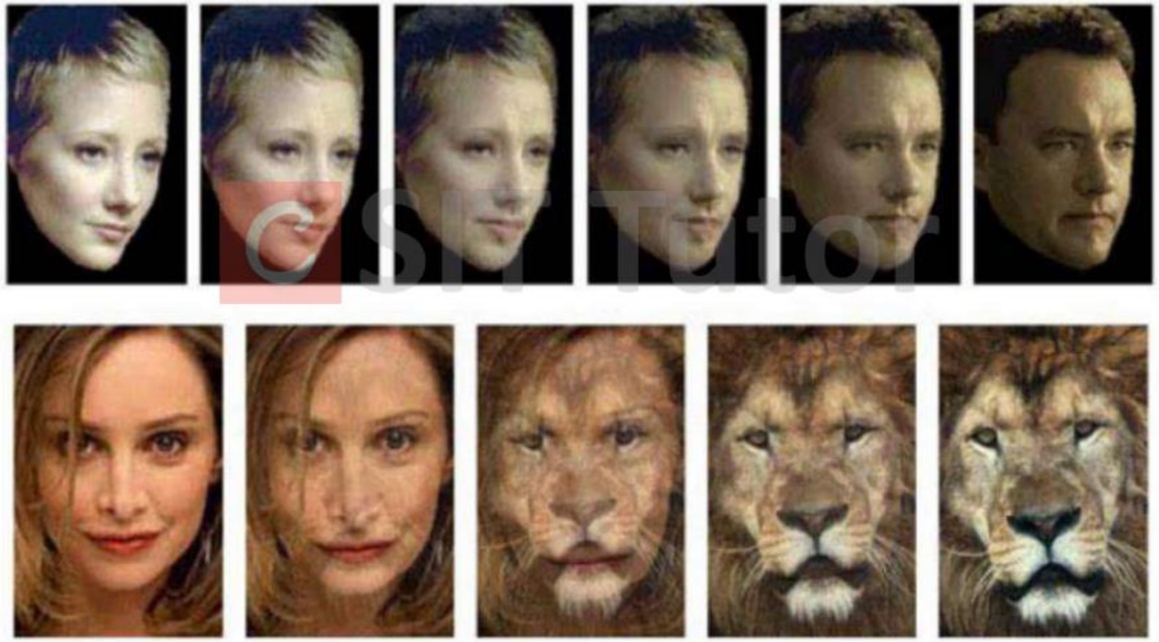
(a) The original image (b) Blurring to remove detail

## Halftoning

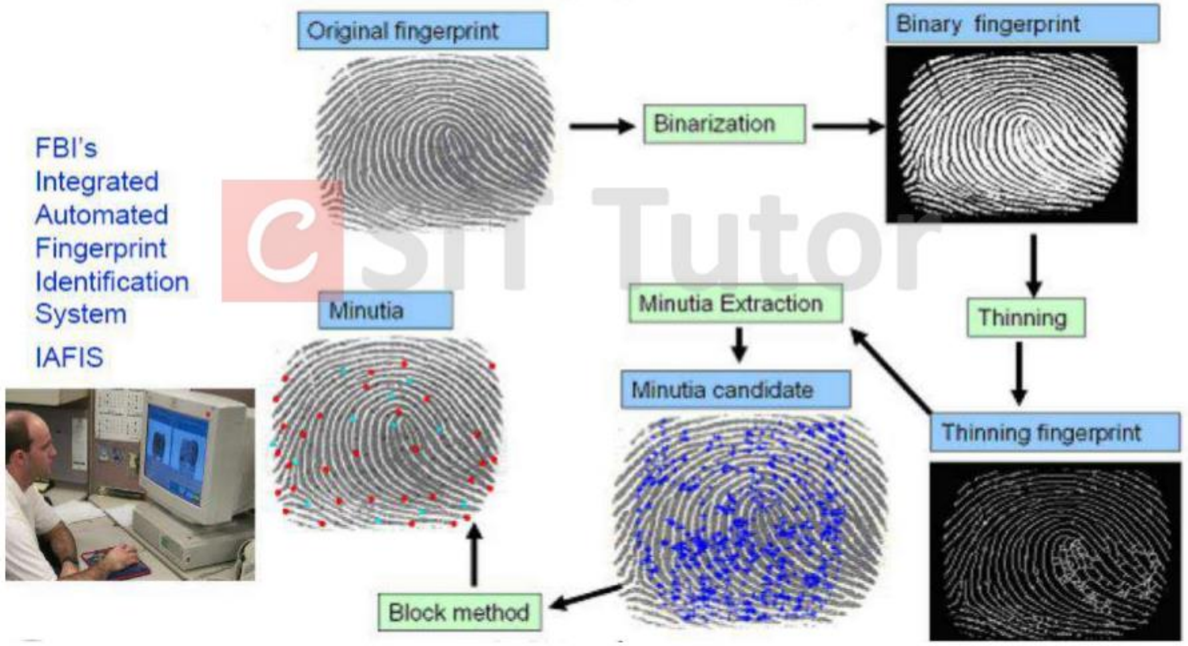


## Face Detection

## Face morphing



## Biometrics: Fingerprint recognition

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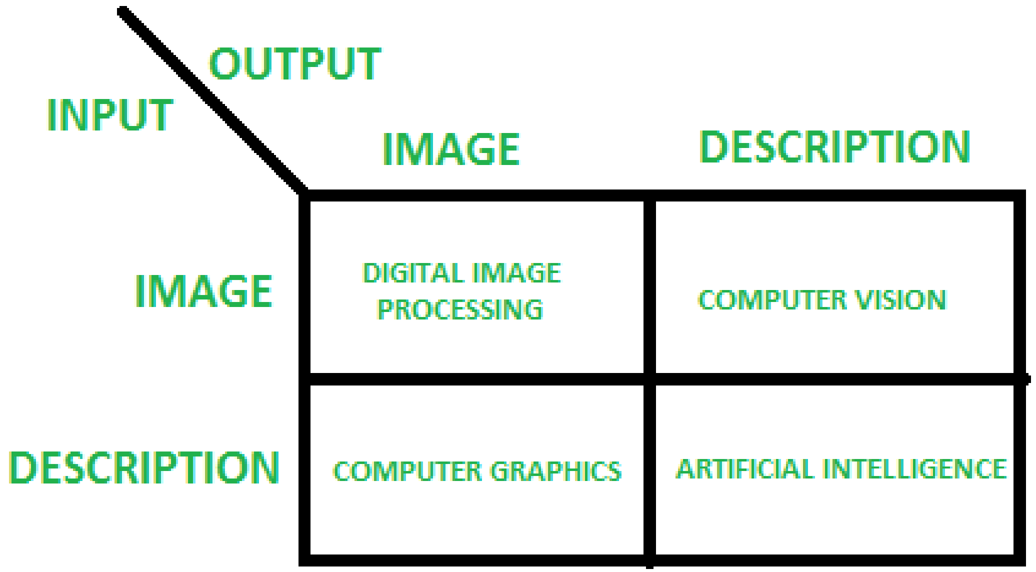
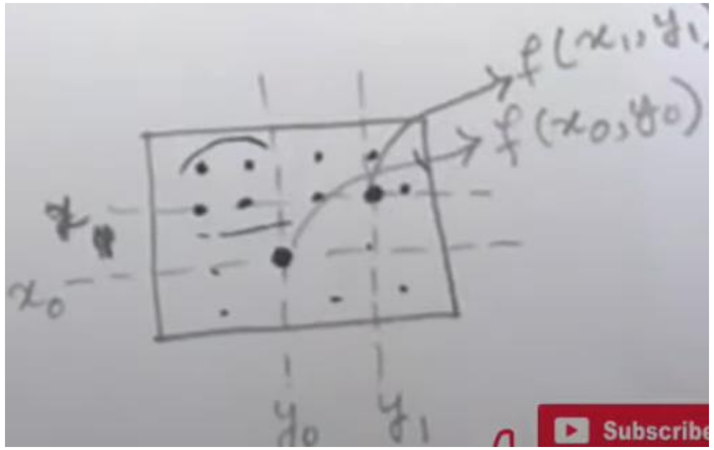
# OVERLAPPING FIELDS WITH IMAGE PROCESSING

- **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 defined as a two-dimensional function, **F(x,y)**, where x and y are spatial coordinates, and the amplitude of **F** at any pair of coordinates (x,y) is called the **intensity** of that image at that point. When x,y, and amplitude values of **F** are finite, we call it a **digital image**.
- In other words, 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.
- Processing of Digital Image with digital computers is called digital image processing.



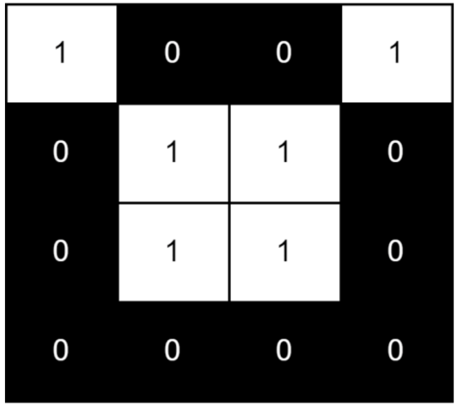
# Types of image?

1. **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.

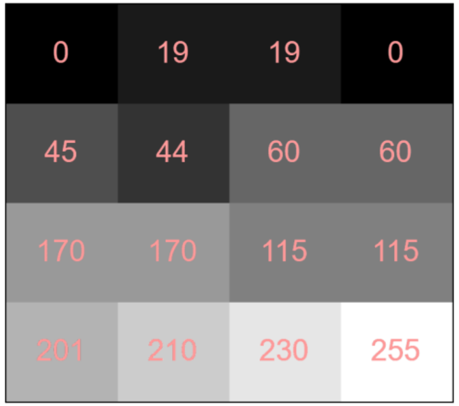
2. **BLACK AND WHITE IMAGE**– The image which consist of only black and white color is called BLACK AND WHITE IMAGE.

3. **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.

4. **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. A 16 bit format is actually divided into three further formats which are Red, Green and Blue. That famous RGB format.




Binary image




Grayscale image


RGB image

# Image as a Matrix

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

images are represented in rows and columns we have the following syntax in which images are represented:

The right side of this equation is digital image by definition. Every element of this matrix is called image element , picture element , or pixel.

In MATLAB the start index is from 1 instead of 0. Therefore, f(1,1) = f(0,0). henceforth the two representation of image are identical, except for the shift in origin. In MATLAB, matrices are stored in a variable i.e X,x,input_image , and so on. The variables must be a letter as same as other programming languages.

$$f = \begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,N) \\ f(2,1) & f(2,2) & \cdots & f(2,N) \\ \vdots & \vdots & & \vdots \\ f(M,1) & f(M,2) & \cdots & f(M,N) \end{bmatrix}$$

# PHASES OF IMAGE PROCESSING

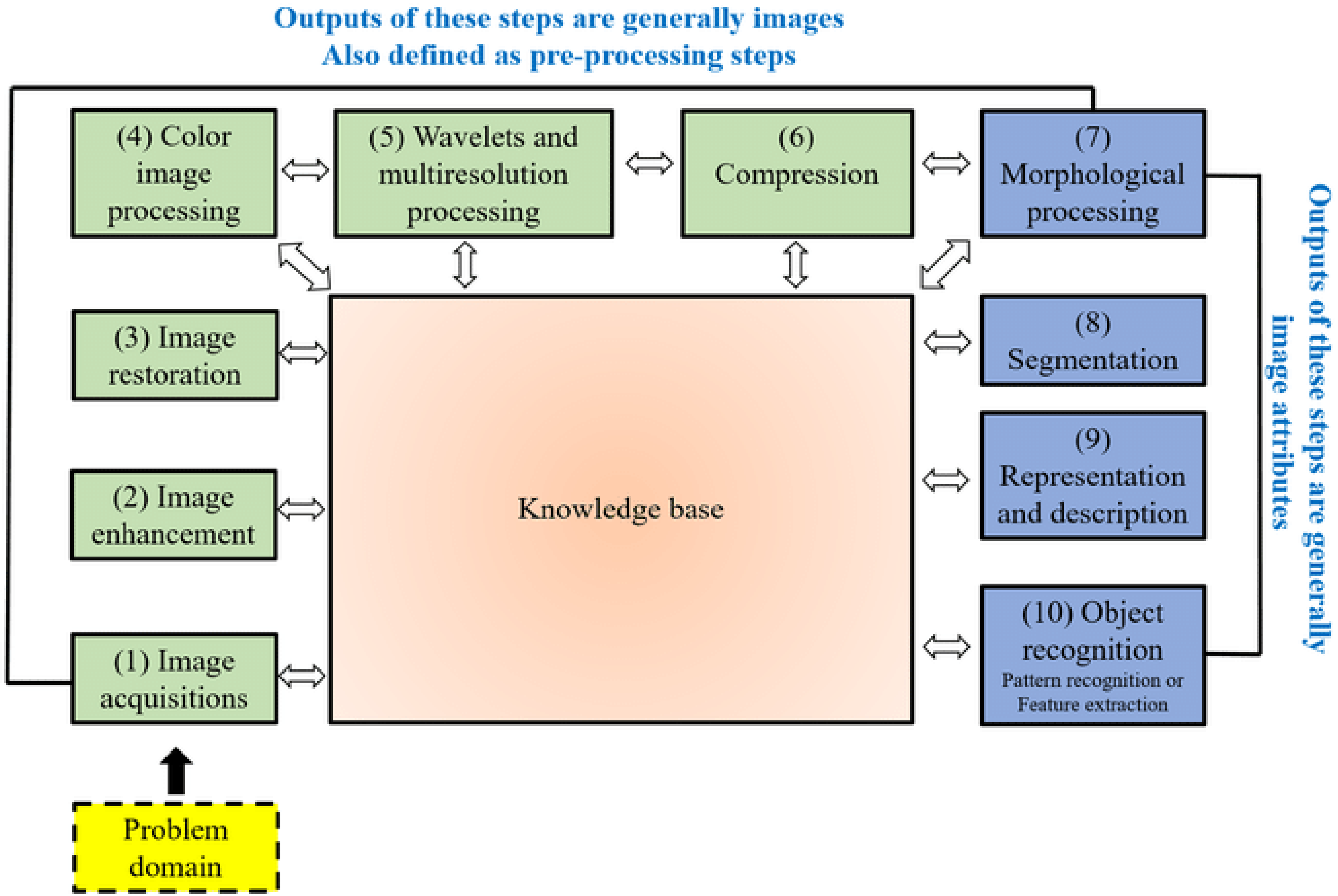



Fig: Fundamental steps in digital image processing

1. **Image Acquisition:**
   - In image processing, it is defined as the action of retrieving an image from some source, usually a hardware-based source for processing.
   - It is the first step in the workflow sequence because, without an image, no processing is possible. The image that is acquired is completely unprocessed. In image acquisition using pre-processing such as scaling is done.
2. **Image Enhancement:**
   - It is the process of adjusting digital images so that the results are more suitable for display or further image analysis. Usually in includes sharpening of images, brightness & contrast adjustment, removal of noise, etc. In image enhancement, we generally try to modify the image, so as to make it more pleasing to the eyes.
   - It is subjective in nature as for example some people like high saturation images and some people like natural color. That's why it is subjective in nature as it differs from person to person.
3. **Image Restoration:**
   - It is the process of recovering an image that has been degraded by some knowledge of degraded function H and the additive noise term. Unlike image enhancement, image restoration is completely objective in nature.
4. **Color Image Processing:**
   - This part handles the image processing of colored images either as indexed images or RGB images.
5. **Wavelets and multiresolution processing:**
   - Wavelets are small waves of limited duration which are used to calculate wavelet transform which provides time-frequency information.
   - Wavelets lead to multiresolution processing in which images are represented in various degrees of resolution.

## 6. Compression:

- Compression deals with the techniques for reducing the storage space required to save an image or the bandwidth required to transmit it.
- This is particularly useful for displaying images on the internet as if the size of the image is large, then it uses more bandwidth (data) to display the image from the server and also increases the loading speed of the website.

## 7. Morphological Processing:

- It deals with extracting image components that are useful in representation and description of shape.
- It includes basic morphological operations like erosion and dilation. As seen from the block diagram above that the outputs of morphological processing generally are image attributes.

## 8. Segmentation:

- It is the process of partitioning a digital image into multiple segments. It is generally used to locate objects and boundaries in objects.

## 9. Representation and Description:

- Representation deals with converting the data into a suitable form for computer processing.
    - Boundary representation: it is used when the focus is on external shape characteristics e.g. corners
    - Regional representation: it is used when the focus in on internal properties e.g. texture
- Description deals with extracting attributes that
    - results in some quantitative information of interest
    - is used for differentiating one class of objects from others

**10. Recognition:** It is the process that assigns a label (e.g. car) to an object based on its description.

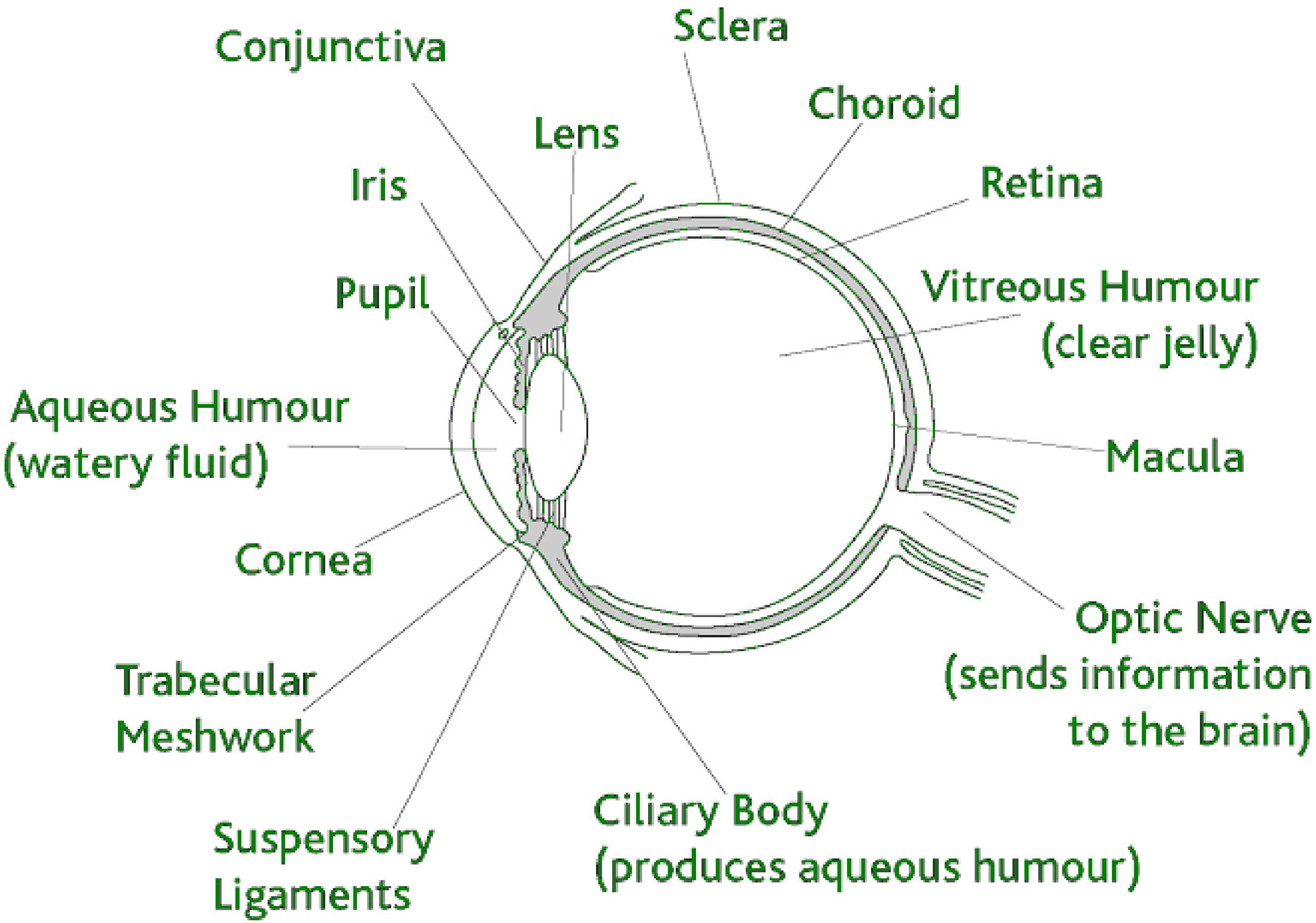
# Elements of Visual Perception

- In human visual perception, the eyes act as the sensor or camera, neurons act as the connecting cable and the brain acts as the processor. The basic elements of visual perceptions are:
    1. Structure of Eye
    2. Image Formation in the Eye
    3. Brightness Adaptation and Discrimination

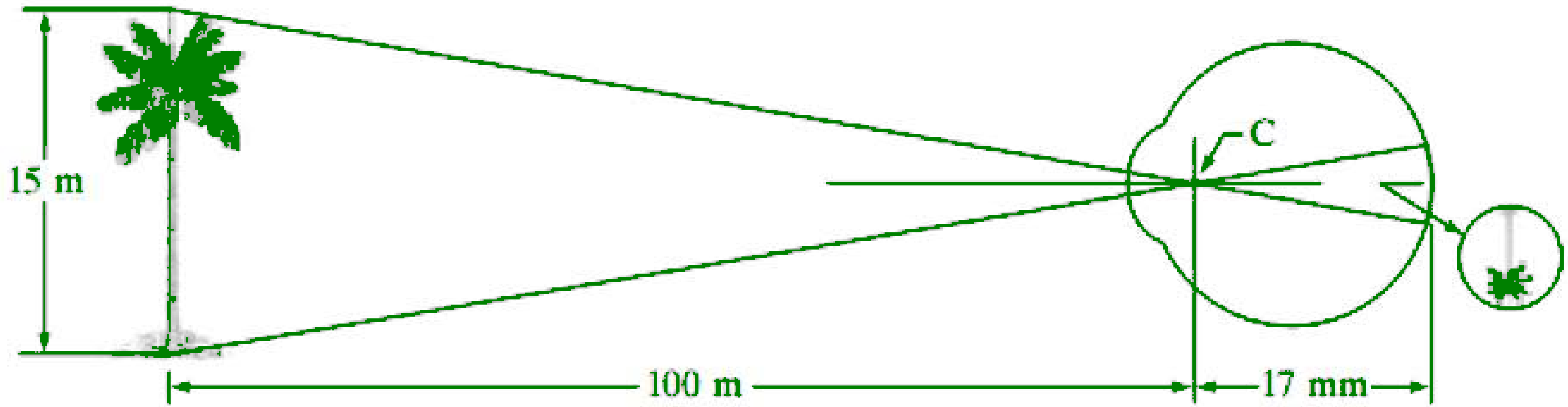
Light enters the eye through a small hole called the pupil, a black looking aperture having the quality of contraction of eye when exposed to bright light and is focused on the retina which is like a camera film.

Cones in eye number between 6 to 7 million which are highly sensitive to colors. Human visualizes the colored image in daylight due to these cones. The cone vision is also called as photopic or bright-light vision.

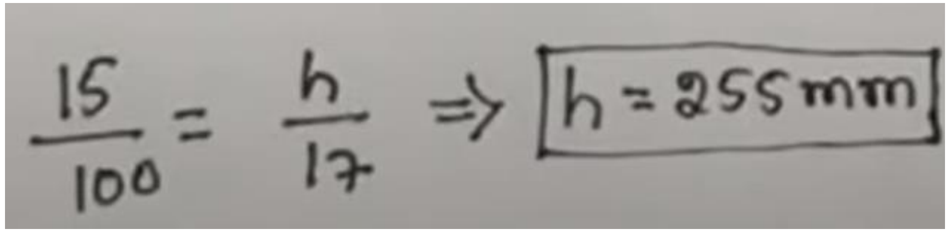
Rods in the eye are much larger between 75 to 150 million and are distributed over the retinal surface. Rods are not involved in the color vision and are sensitive to low levels of illumination.



## 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.



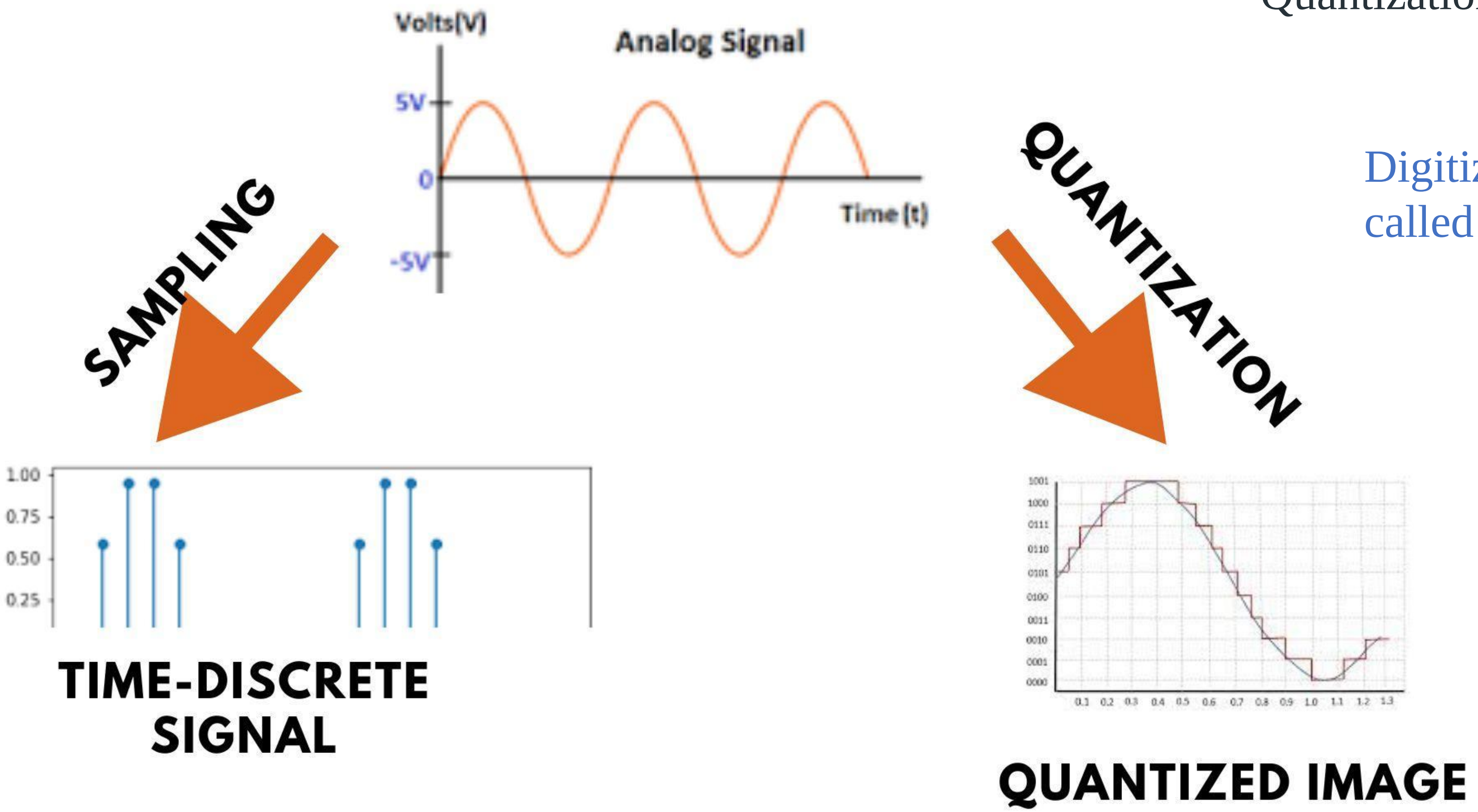

**h = 2.55 mm**

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

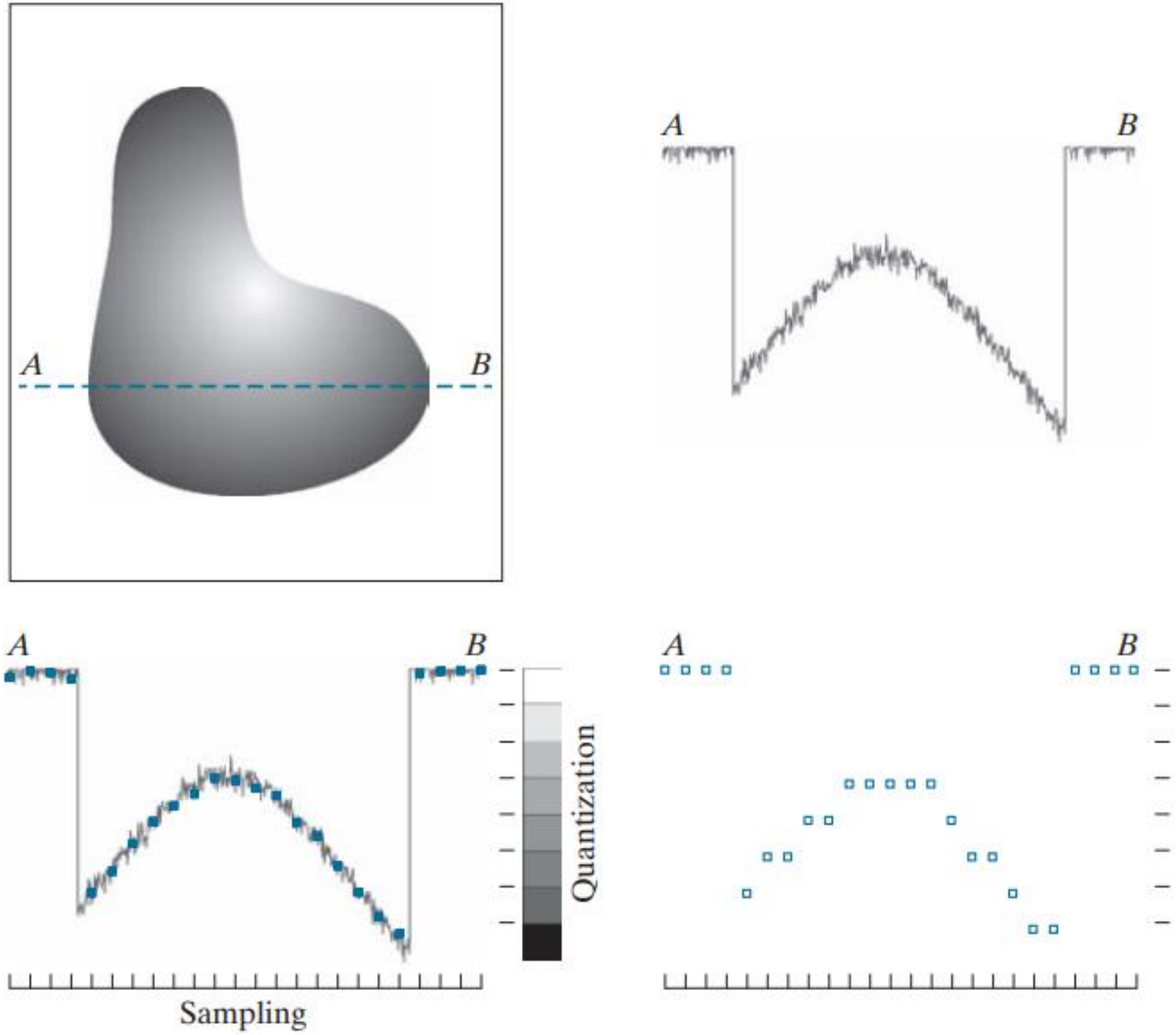
The output of sensor is continuous voltage. We need to convert that continuous sensed data to digital form. For that we can use Sampling and Quantization.




Digitizing x and y co-ordinate value is called sampling

Digitizing amplitude value is called Quantization

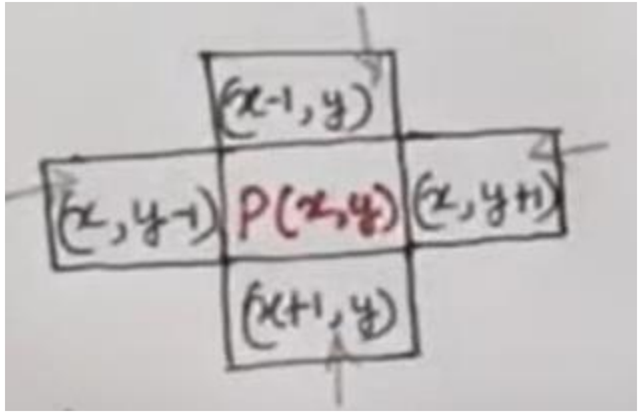
| Sampling | Quantization |
| --- | --- |
| Digitization of co-ordinate values. | Digitization of amplitude values. |
| x-axis(time) – discretized. | x-axis(time) – continuous. |
| y-axis(amplitude) – continuous. | y-axis(amplitude) – discretized. |
| Sampling is done prior to the quantization process. | Quantizatin is done after the sampling process. |
| It determines the spatial resolution of the digitized images. | It determines the number of grey levels in the digitized images. |
| It reduces c.c. to a series of tent poles over a time. | It reduces c.c. to a continuous series of stair steps. |
| A single amplitude value is selected from different values of the time interval to represent it. | Values representing the time intervals are rounded off to create a defined set of possible amplitude values. |




(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.

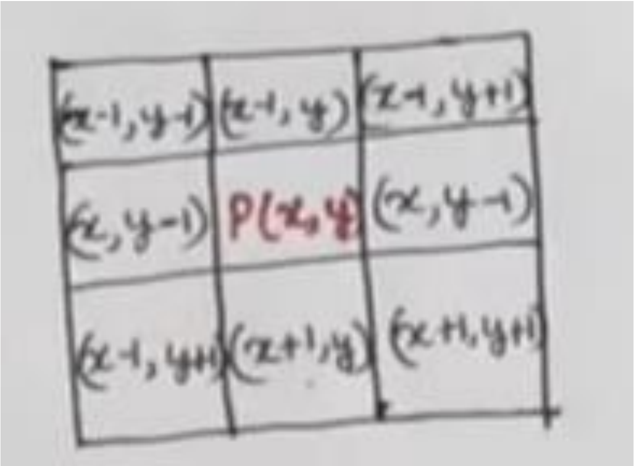
# Relationships between pixels

An image is denoted by f(x,y) and p,q are used to represent individual pixels of the image.



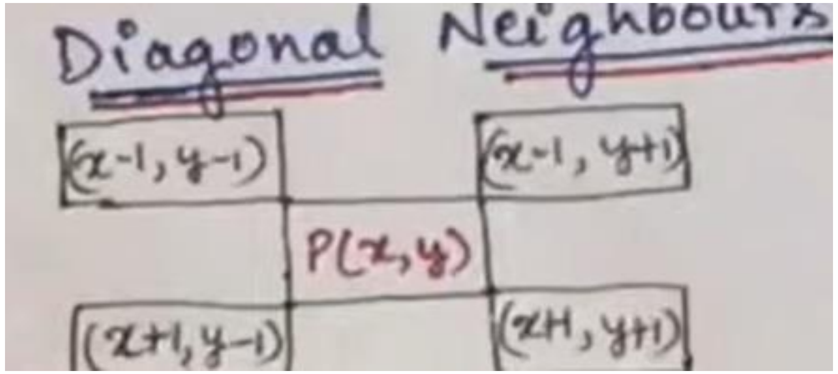

## Neighbours of a pixel

- A pixel p at (x,y) has 4-horizontal/vertical neighbours at (x+1,y), (x-1,y), (x,y+1) and (x,y-1). These are called the **4-neighbours of p : N4(p)**.
- A pixel p at (x,y) has 4 diagonal neighbours at (x+1,y+1), (x+1,y-1), (x-1,y+1) and (x-1,y-1). These are called the **diagonal-neighbours of p : ND(p).**
- The 4-neighbours and the diagonal neighbours of p are called **8-neighbours of p : N8(p).**




## Adjacency between pixels

- Let **V** be the set of intensity values used to define adjacency.
- In a binary image, V ={1} if we are referring to adjacency of pixels with value 1. In a gray-scale image, the idea is the same, but set V typically contains more elements.
- For example, in the adjacency of pixels with a range of possible intensity values 0 to 255, set V could be any subset of these 256 values.



- We consider three types of adjacency:
- **a) 4-adjacency:** Two pixels p and q with values from V are 4-adjacent if q is in the set N4(p).
- **b) 8-adjacency:** Two pixels p and q with values from V are 8-adjacent if q is in the set N8(p).
- **c) m-adjacency(mixed adjacency):** Two pixels p and q with values from V are m-adjacent if

1. q is in N4(p), or
2. 2) q is in ND(p) and the set N4(p)∩N4(q) has no pixels whose values are from V.

## Connectivity between pixels

- It is an important concept in digital image processing.
- It is used for establishing boundaries of objects and components of regions in an image.
- Two pixels are said to be connected:
- if they are adjacent in some sense(neighbour pixels,4/8/m-adjacency)
- if their gray levels satisfy a specified criterion of similarity(equal intensity level)

- There are three types of connectivity on the basis of adjacency. They are:
  - **4-connectivity:** Two or more pixels are said to be 4-connected if they are 4-adjacent with each others.
  - **8-connectivity:** Two or more pixels are said to be 8-connected if they are 8-adjacent with each others.
  - **m-connectivity:** Two or more pixels are said to be m-connected if they are m-adjacent with each others.

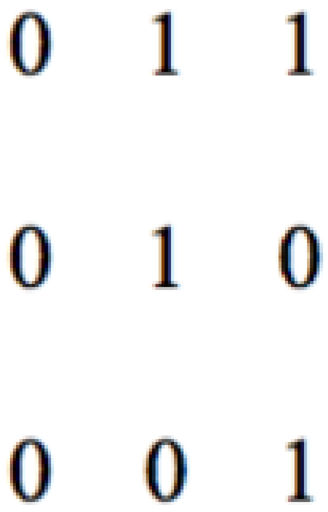



**Fig: An arrangement of pixels**

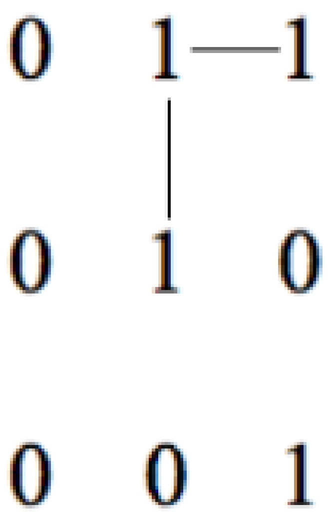



**Fig: 4-connectivity of pixels**

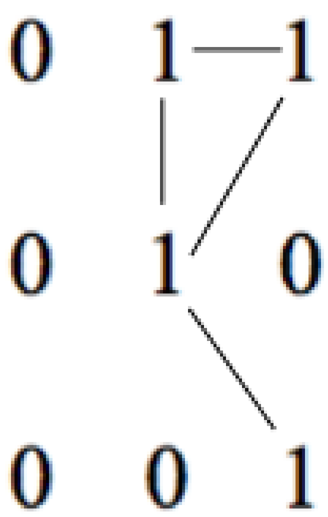



**Fig: 8-connectivity of pixels**

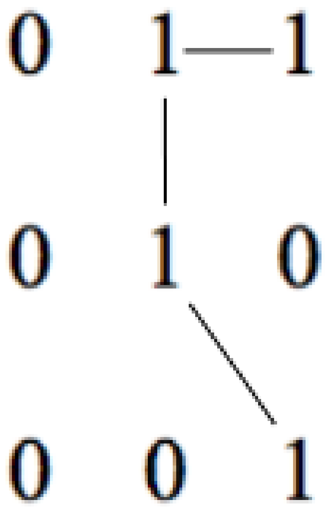
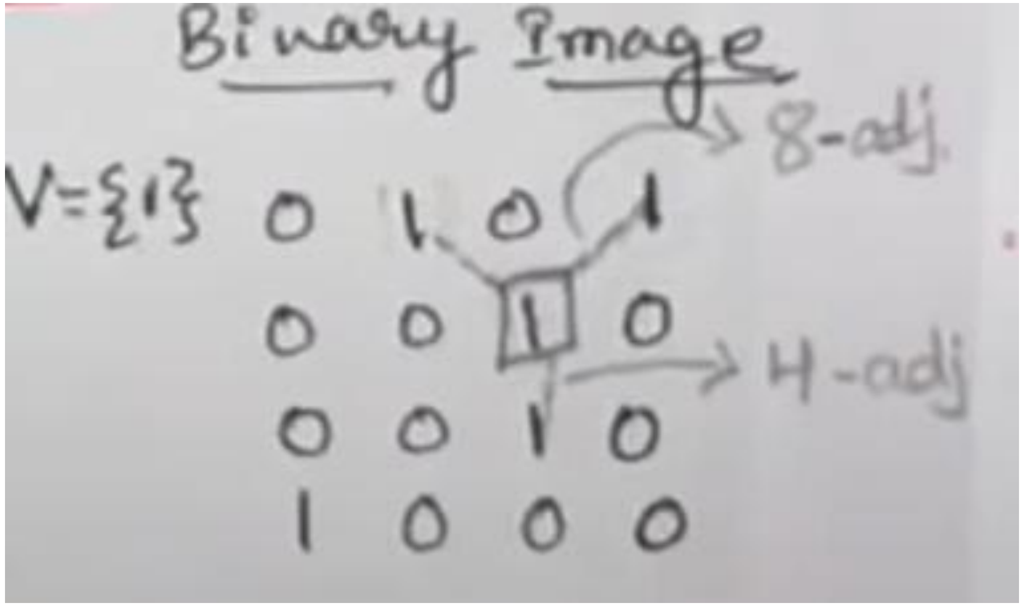
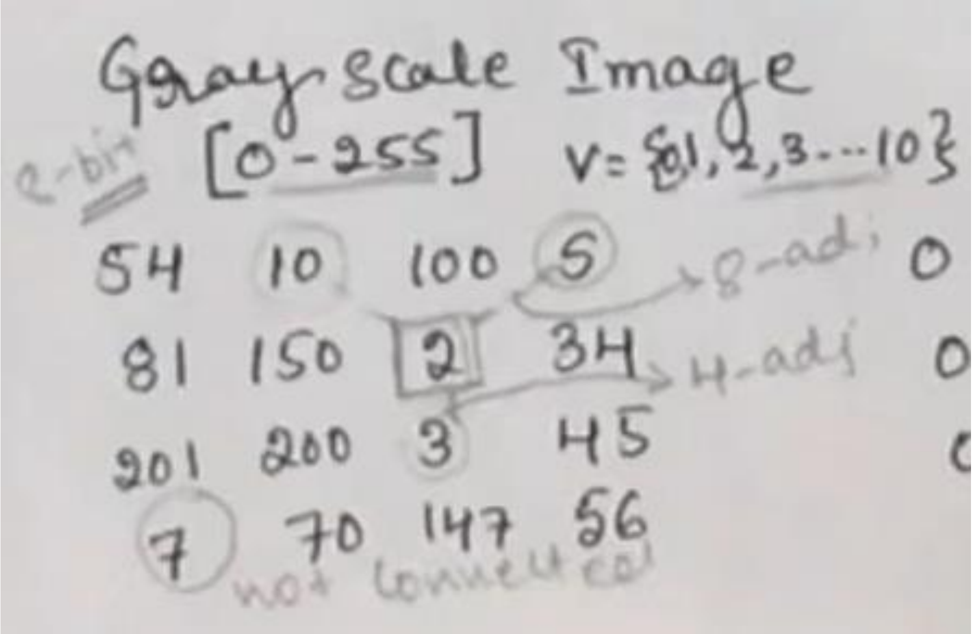



**Fig: m-connectivity of pixels**

Note: M connectivity is introduced to solve the ambiguity problem of 8 connectivity. It says, if straight line is connected, then we shouldn't connect the diagonal co-ordinates. So in last images, 3 and 6 is not connected but 6 and 9 is connected.



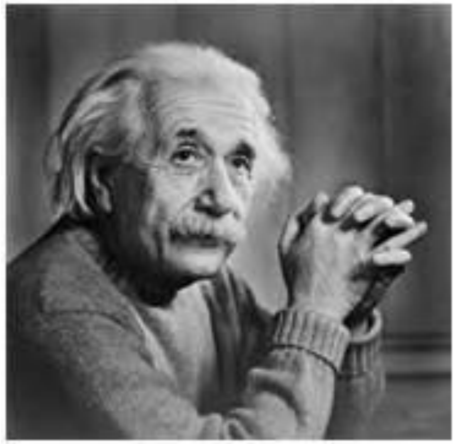




In Gray Scale image, values from 0 to 10 are connected to each other. It forms 4 connectivity and 8 connectivity. 7 cannot be connected to 2 because no any adjacent co-ordinates with them.

# Applications of Digital Image Processing

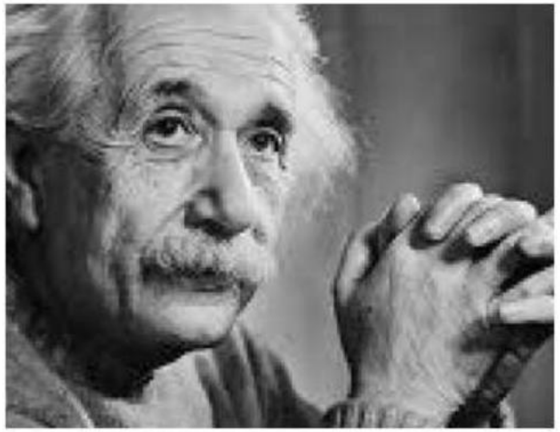
**1. Image sharpening and restoration**

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.

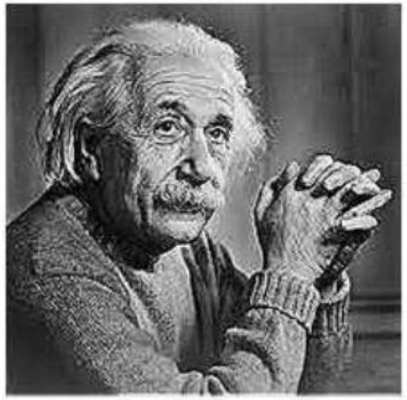


The original image

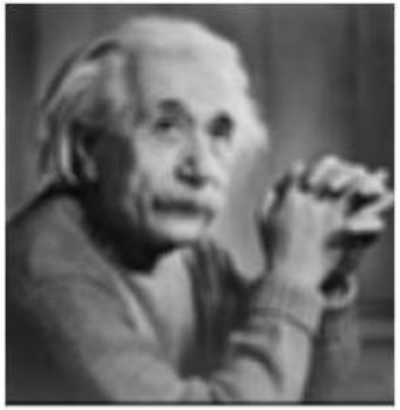
The zoomed image



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. **Complexity**: The algorithms involved in DSP can be extremely complex, requiring a deep understanding of mathematics, signal theory, and software engineering. This complexity can make DSP systems difficult to design, implement, and debug.
2. **Real-time Processing Requirements**: Many DSP applications, such as voice recognition, streaming video, and radar systems, require real-time processing. Meeting these time constraints can be challenging, especially as the complexity of the processing increases.
3. **Power Consumption**: DSP operations can be power-intensive, which is a significant concern for battery-powered devices like smartphones and portable medical devices. Balancing performance and power consumption requires careful design and optimization.
4. **Precision and Accuracy**: DSP algorithms often involve operations that can introduce errors, such as rounding errors in floating-point calculations. Ensuring the precision and accuracy of these calculations is crucial, especially in applications like medical imaging or scientific research where the integrity of the data is paramount.
5. **Hardware Limitations**: The performance of DSP systems is closely tied to the capabilities of the underlying hardware. Limitations in processing power, memory, and bandwidth can constrain the performance of DSP applications, leading to trade-offs between complexity, accuracy, and speed.

# 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:

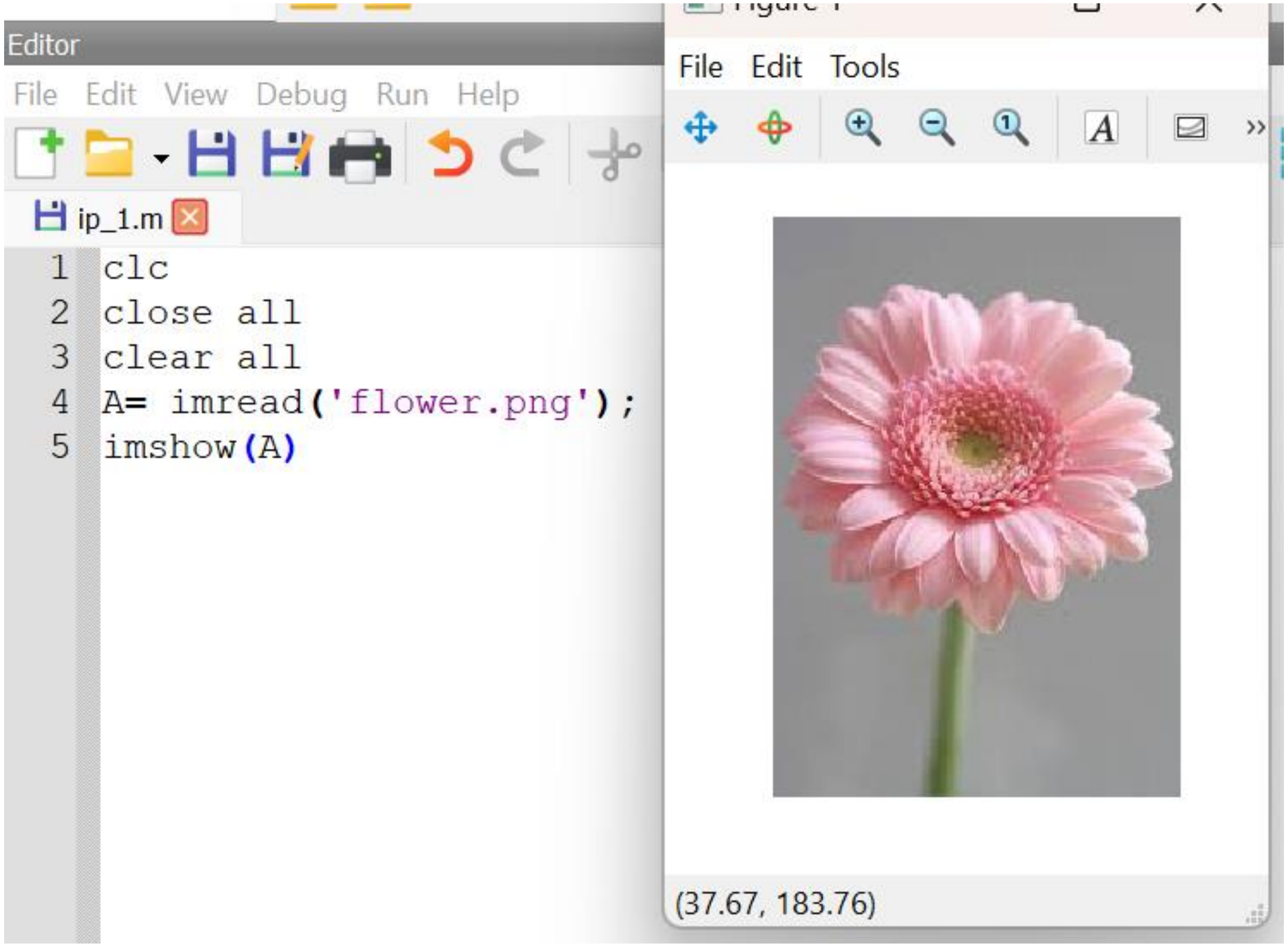
$$\text{Number of images} = \frac{\text{Storage space}}{\text{Image size}}$$

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

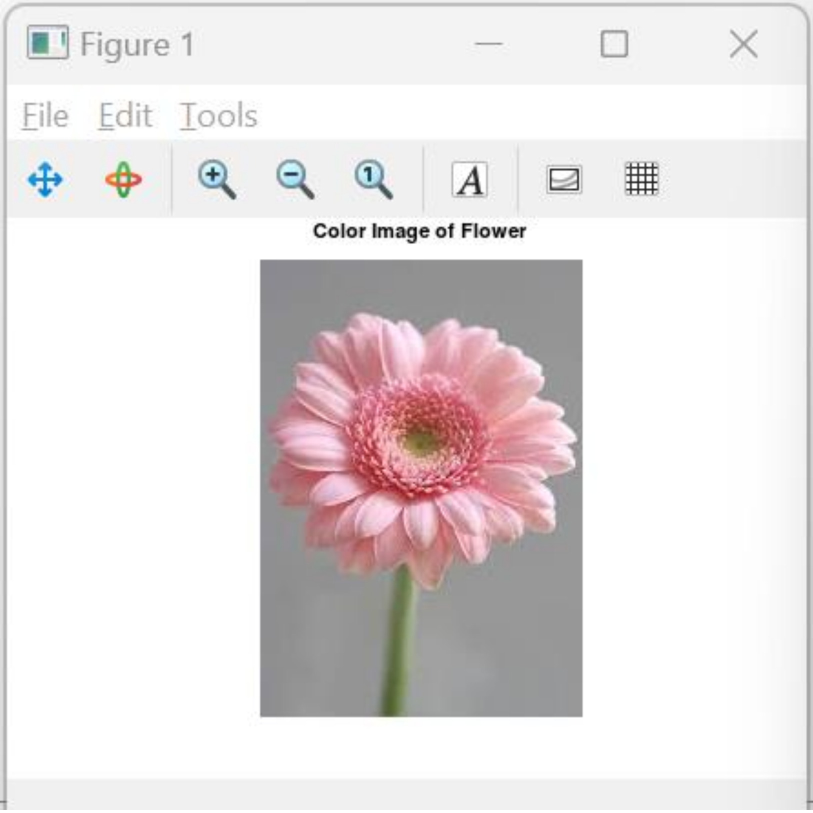
$$\text{Number of images} \approx 2730.67$$

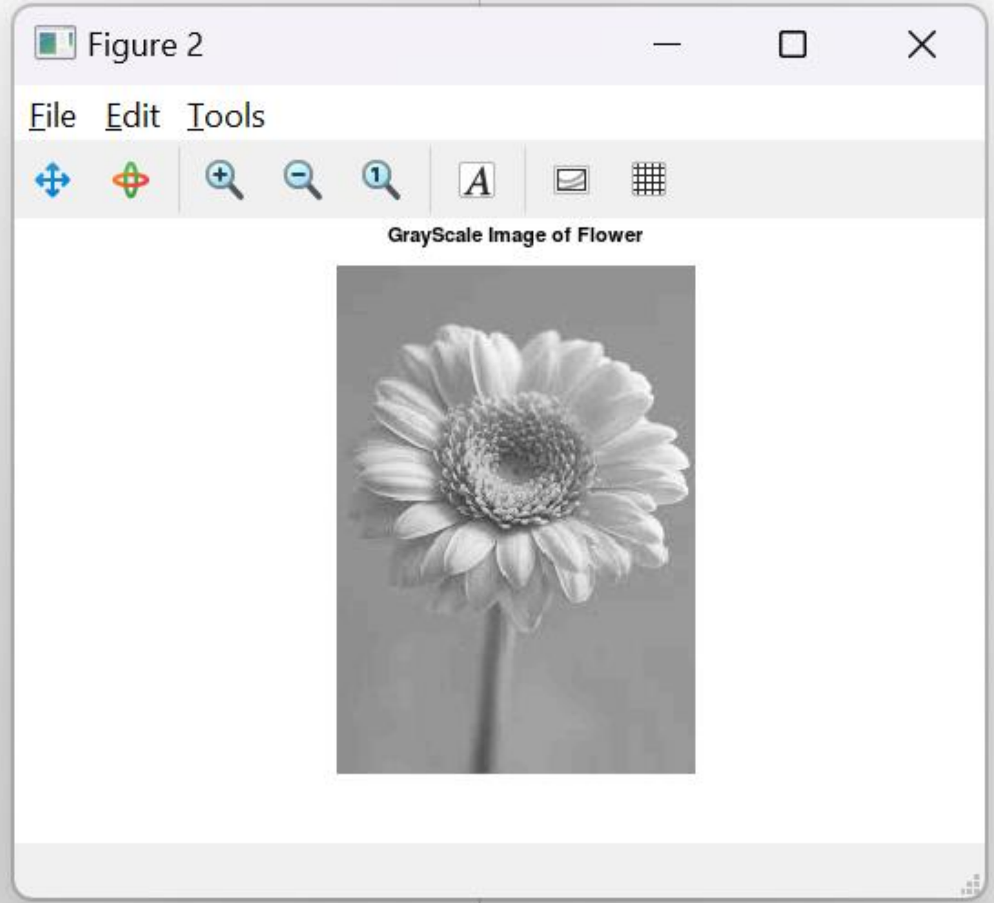
So, approximately 2730 images of size 1024×768 with 256 gray levels can be stored in a 2048 MB storage space. However, since we can't have a fraction of an image, we would round down to the nearest whole number, meaning you can store 2730 images in this space.

# Lab 01: Convert to Grayscale Image

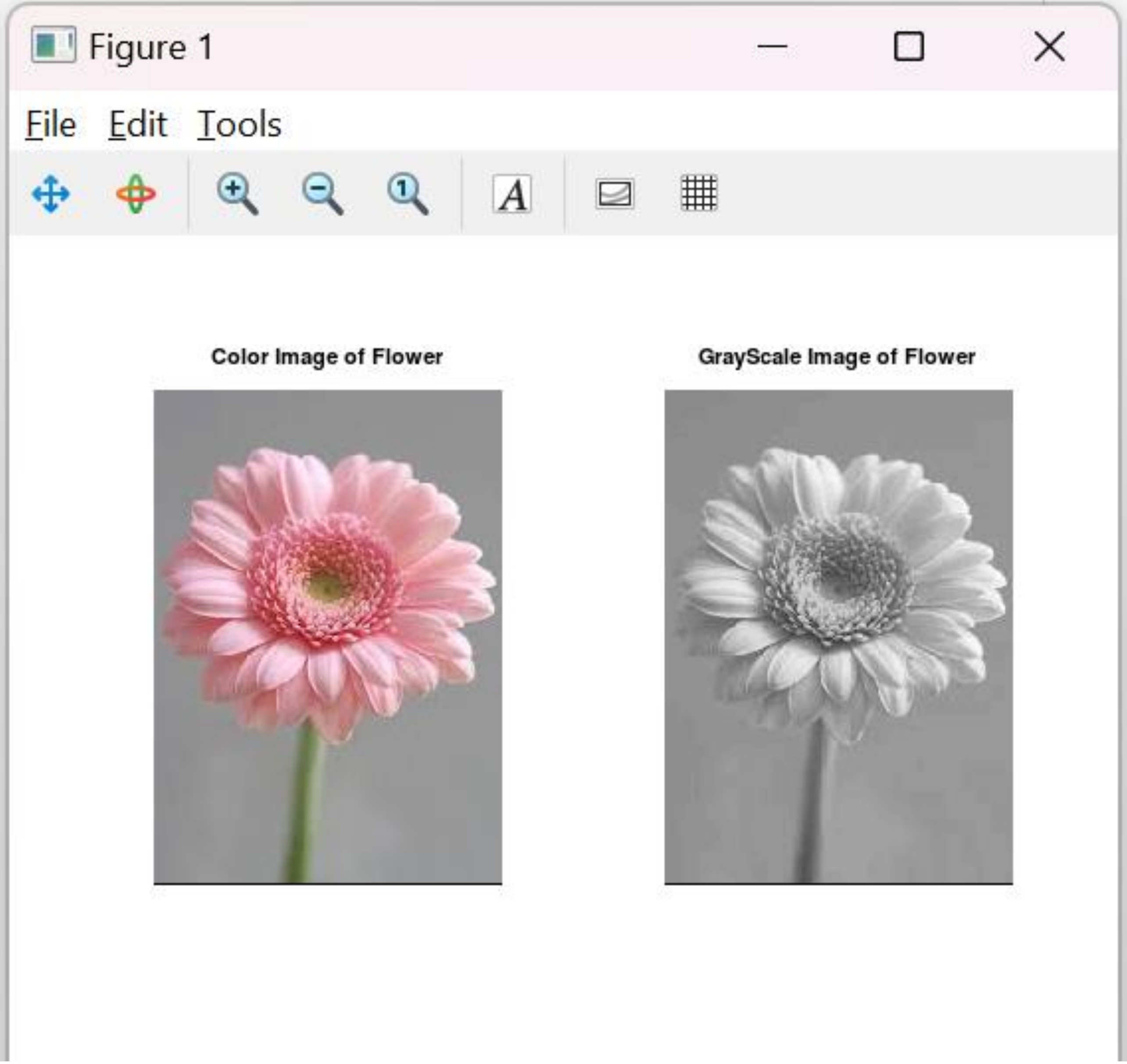


```
clc
close all
clear all
A= imread('flower.png');
imshow(A)
title('Color Image of Flower')
B=rgb2gray(A);
figure
imshow(B)
title('GrayScale Image of Flower')
```



```
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]