Chapter 1 INTRODUCTION TO DIGITAL IMAGE PROCESSING

Digital Image

An image is defined as a two dimensional function *f(x,y) where (x,y)* are spatial coordinates. The amplitude of *f* at any pair of coordinates *(x,y)* is called intensity or gray level. When *(x ,y)* and the amplitude values of *f* are all finite and discrete quantities then the image is referred as Digital Image, where gray level indicates the brightness of a pixel, in case of black and white image gray level values can be either 0 and 1.

A digital image is composed of a finite number of elements, each of which has a particular location and values of these elements are referred to as picture elements, image elements and pixels. Digital image is also known numerical representation of two dimensional images.

Digital Image Processing

It refers to processing of digital images by means of digital computer. In a broader context, it implies digital processing of any two-dimensional data. Digital image processing encompasses processes whose inputs and outputs are images. It encompasses processes that extract attributes from images, up to and including the recognition of individual objects.

Digital image processing focuses on two major tasks:

– Improvement of pictorial information for human interpretation.

– Processing of image data for storage, transmission and representation for autonomous machine perception

It covers low, mid and high level processes

(1) Low Level Processes

– It involves primitive image operations such as contrast enhancement, image sharpening and image preprocessing to reduce noise.

(2) Mid-Level Processes

– It involves tasks such as segmentation (Partitioning an image into regions or objects) and classification (recognition) of individual objects.

(3) High Level Processes

– It involves “making sense” of an ensemble of recognized objects.

As an illustration to clarify these concepts, consider the area of automated analysis of text. The processes of acquiring an image of the area containing the text, preprocessing that image, extracting (segmenting) the individual characters, describing the characters in a form suitable for computer processing, and recognizing those individual characters are in the scope of what we call digital image processing

1.1 The Origins/History of Digital Image Processing

Early 1920s

One of the first applications of digital imaging was in the news-paper industry, through Bartlane cable picture transmission service. Images were transferred by submarine cable between London and New York. Pictures were coded for cable transfer and reconstructed at the receiving end on a telegraph printer shows in Figure 1.1.

Figure 1.1 a digital picture produced in 1921 from a coded tape by a telegraph printer. (McFarlane)

Mid to late 1920s:

Improvements to the Bartlane system resulted in higher quality images. New reproduction processes based on photographic techniques. Increased number of tones in reproduced images as shown in Figure 1.2(a),(b).

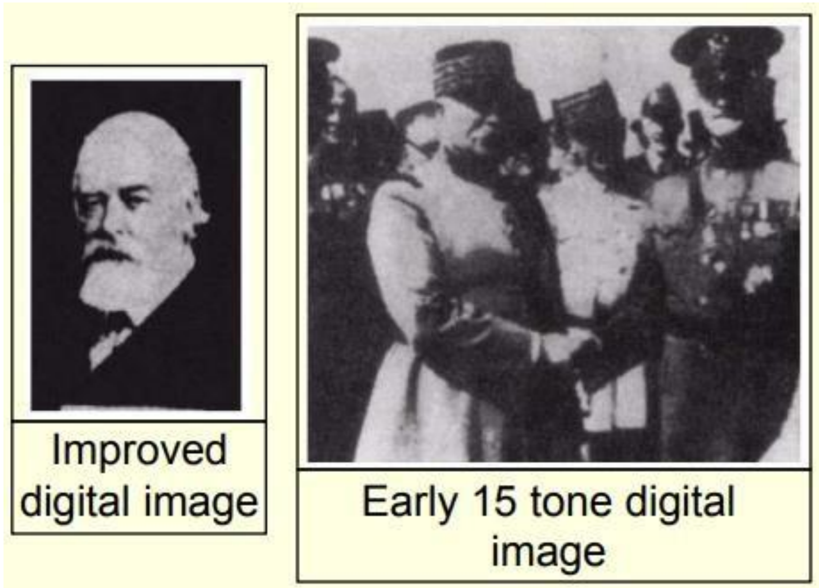


Figure 1.2 (a): a digital picture made in 1922 from a tape punched after the signal had crossed the Atlantic twice (McFarlane). Figure (b) un-retouched cable picture of Generals Pershing and Foch, transmitted in 1929 from London to New York by 15-tone equipment. (McFarlane)

1960s: Improvements in computing technology and the onset of the space race led to a surge of work in digital image processing. **1964:** Computers used to improve the quality of images of the moon taken by the Ranger 7 probe.**1970s**: Digital image processing begins to be used in medical applications.1979: Sir Godfrey N. Hounsfield & Prof. Allan M.Cormack share the Nobel Prize in medicine for the invention of tomography, the technology behind Computerized Axial Tomography (CAT) scans ,image of CAT scan is shown in Figure 1.3(b).

1980s - Today: The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas. Such techniques were used in other space missions including the Apollo landings, image taken before landing in shown in Figure 1.3(a).

Figure 1.3(a) Left: a picture of the moon taken by the Ranger 7 Probe minutes before landing (b) Typical head slice CAT image.

1.2 Examples of Fields that use Digital Image Processing

- Digital Image processing is not just limited to adjust the spatial resolution of the everyday images captured by the camera. It is not just limited to increase the brightness of the photo, e.t.c rather it is far more than that.
- Electromagnetic waves can be thought of as stream of particles, where each particle is moving with the speed of light. Each particle contains a bundle of energy. This bundle of energy is called a photon. The electromagnetic spectrum according to the energy of photon is shown below.

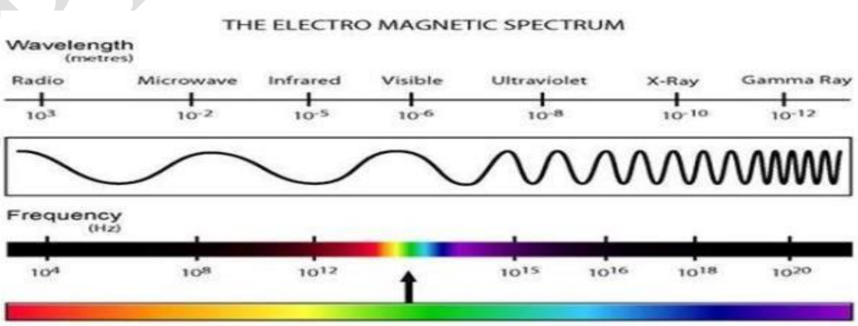


Figure 1.4 the Electro Magnetic Spectrum

- In this electromagnetic spectrum, we are only able to see the visible spectrum. Visible spectrum mainly includes seven different colors that are commonly term as (VIBGOYR). VIBGOYR stands for violet , indigo , blue , green , orange , yellow and Red.
- But that doesnot nullify the existence of other stuff in the spectrum. Our human eye can only see the visible portion, in which we saw all the objects. But a camera can see the other things that a naked eye is unable to see. For example: x rays , gamma rays , e.t.c. Hence the analysis of all that stuff too is done in digital image processing.

Digital image processing is widely used are mentioned below

a) Image sharpening and restoration
b) Medical field
c) Transmission and encoding
d) Machine/Robot vision
e) Color processing
f) Pattern recognition
g) Video processing
h) Others

a) 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 .This includes Zooming, blurring, sharpening, gray scale to color conversion, detecting edges and vice versa, Image retrieval and Image recognition.

b) Medical Field

The common applications of DIP in the field of medical is

Gamma-ray imaging

Major uses of imaging based on gamma rays include nuclear medicine and astronomical observations. In nuclear medicine, the approach is to inject a patient with a radioactive isotope that emits gamma rays as it decays. Images are produced from emissions collected by gamma ray detectors.

Positron emission tomography (PET)

The patient is given a radioactive isotope that emits positrons as it decays. When a positron meets a electron, both are annihilated and two gamma rays are given off. These are detected and a tomographic image is created using the basic principles of tomography.

X-ray Imaging (oldest source of EM radiation)

X-rays for medical and industrial imaging are generated using an x-ray tube, which is a vacuum tube with a cathode and anode. The cathode is heated, causing free electrons to be released. These electrons flow at high speed to the positively charged anode. When the electron strike a nucleus, energy is released in the form x-ray radiation. The energy(penetrating power) of the x-rays is controlled by a current applied to the filament in the cathode.

Angiography is another major application in an area called contrast enhancement radiography. The procedure is used to obtain images of blood vessels. A catheter (a small flexible hollow tube) is inserted, for example into an artery of vein in the groin. The catheter is threaded into the blood vessel and guided to the area to be studied. When the catheter reaches the site under investigation, an x-ray contrast medium is injected through the catheter. This enhances contrast of the blood vessles and enables the radiologist to see any irregularities or blockages.

c) 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. Now just imagine, that today we are able to see live video feed, or live cctv. footage from one continent to another with just a delay of seconds.

It means that a lot of work has been done in this field too. This field doesn't 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.

d) Machine/Robot vision

Apart from 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.

e) Color Processing

It 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

f) Pattern Recognition

It 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.

g) 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

h) Others

Imaging in the visible and infrared bands .Infrared band often is used in conjunction with visual imaging. The application ranges from light microscopy, astronomy, remote sensing industry and law enforcement.

Eg:

Microscopy- the applications ranges from enhancement to measurement

Remote sensing-weather observation from multispectral images from satellites

Industry-check up the bottle drink with less quantity

Law enforcement – biometrics

Imaging in the microwave band

Dominant application in microwave band is radar. The unique feature of imaging radar is its ability to collect data over virtually any region at any time, regardless of weather or ambient lighting conditions. Some radar waves can penetrate clouds and under certain conditions can also see through vegetation, ice and extremely dry sand. In many cases, radar is the only way to explore inaccessible regions of the earth’s surface. An imaging radar works like a flash camera in that it provides its own illumination (microwaves pulses) to illuminate an area on the ground and take a snapshot image.

Imaging in the radio band

Major applications of imaging in the radio band are in medicine and astronomy. In medicine radio waves are used in magnetic resonance imaging (MRI). This technique places a patient in a powerful magnet and passes radio waves through his or her body in short pulses. Each pulse causes a responding pulse of radio waves to be emitted by patient's tissues. The location from which these signals originate and their strength are determined by a computer which produces a two-dimensional picture of a section of the patient.

1.3 Fundamental Steps in Image Processing

Step 1: Image Acquisition

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

Step 2: Image Enhancement

Goal is to emphasize certain image features for subsequent analysis or for image display. Examples: Contrast and edge enhancement, noise filtering, magnifying, sharpening. It is useful in feature extraction, image analysis, and visual information display. An example is Histogram equalization method, where the input gray levels are mapped so that the output gray level distribution is uniform. This has been found to be powerful method of enhancement of low contrast images.

Step 3: Image Restoration

It refers to removal or minimization of known degradations in an image. It includes de-blurring of images degraded by the limitations of a sensor or its environment, noise filtering, and correction of geometric distortion or non-linarites due to sensors .For image restoration Wiener filter is used. This filter gives best linear mean square estimate of the object from the observations.

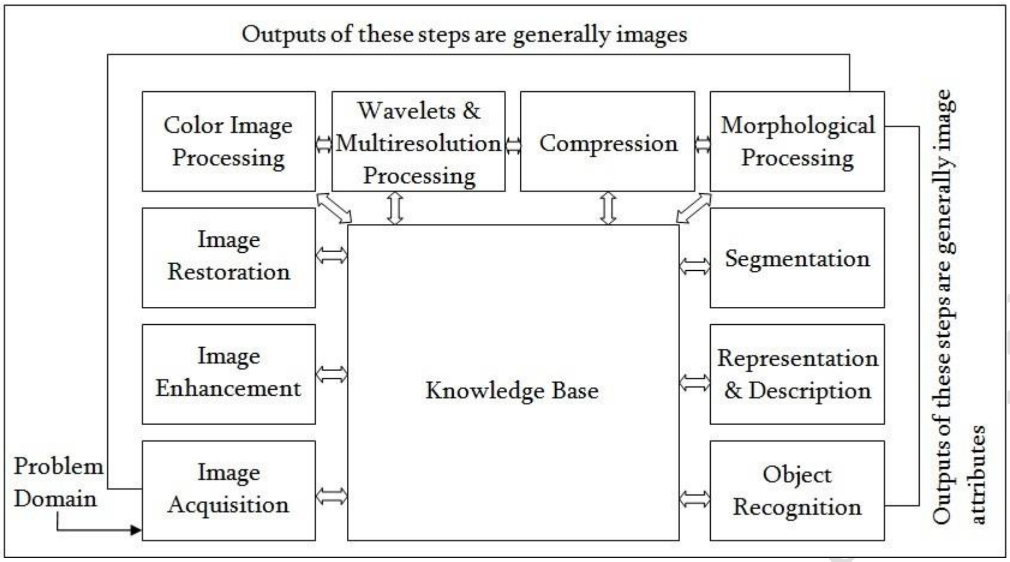


Figure 1.5: Fundamental Steps in Image

Step 4: Color Image Processing

Use the color of the image to extract features of interest in an image.

Step 5: Wavelets

It is 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. Image data compression techniques are concerned with reduction of number of bits required to store or transmit images without any loss of information. Examples: Image Compression for Ubiquitous Multimedia Services.

Step 7: Morphological Processing

Tools for extracting image components that is 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.

Step 8: Image Segmentation

Segmentation procedures partition an image into its constituent parts or objects. The more accurate the segmentation, the more likely recognition is to succeed.

Step 9: Representation and Description

Representation: Make a decision whether the data should be represented as a boundary or as a complete region. It is almost always follows the output of a segmentation stage. Boundary Representation: Focus on external shape characteristics, such as corners and inflections

Region Representation: Focus on internal properties, such as texture or skeleton shape. 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

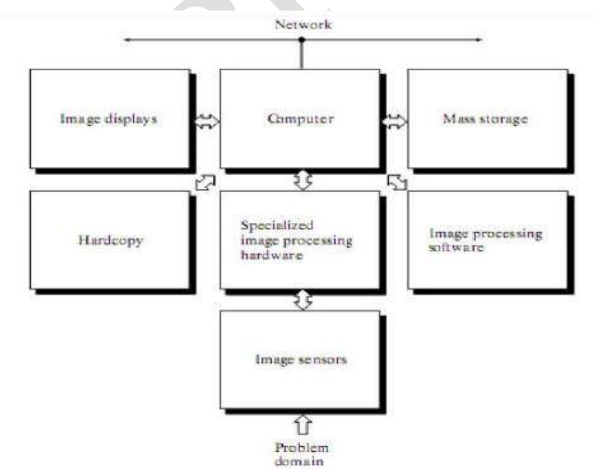
Recognition: the process that assigns label to an object based on the information provided by its description.

Step 10: Knowledge Base

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

1.4 Elements of Digital Processing System

The basic operations performed in a digital image processing systems include (1) acquisition, (2) storage, (3) processing, (4) communication and (5) display.



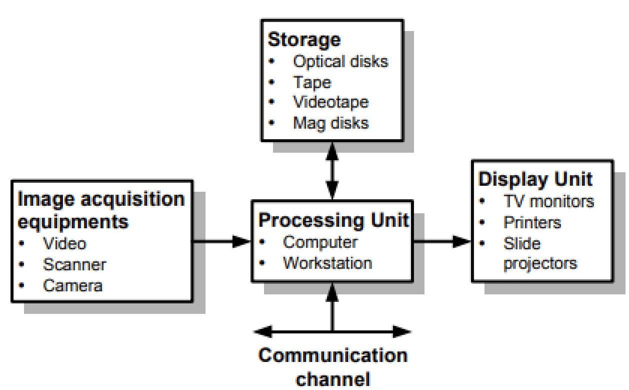


Figure 1.6 Elements of Digital image Processing

Different elements of Digital Image Processing are:

Image Sensors: With reference to sensing, two elements are required to acquire digital image. The first is a physical device that is sensitive to the energy radiated by the object we wish to image and second is specialized image processing hardware.

Specialize image processing hardware: It consists of the digitizer just mentioned, plus hardware that performs other primitive operations such as an arithmetic logic unit, which performs arithmetic such addition and subtraction and logical operations in parallel on images.

Computer: It is a general purpose computer and can range from a PC to a supercomputer depending on the application. In dedicated applications, sometimes specially designed computer are used to achieve a required level of performance Software: It consists of specialized modules that perform specific tasks a well-designed package also includes capability for the user to write code, as a minimum, utilizes the specialized module. More sophisticated software packages allow the integration of these modules.

Mass storage: This capability is a must in image processing applications. An image of size 1024 x1024 pixels, in which the intensity of each pixel is an 8- bit quantity requires one Megabytes of storage space if the image is not compressed .Image processing applications falls into three principal categories of storage i) Short term storage for use during processing ii) On line storage for relatively fast retrieval iii) Archival storage such as magnetic tapes and disks

Image display: Image displays in use today are mainly color TV monitors. These monitors are driven by the outputs of image and graphics displays cards that are an integral part of computer system.

Hardcopy devices: The devices for recording image includes laser printers, film cameras, heat sensitive devices inkjet units and digital units such as optical and CD ROM disk. Films provide the highest possible resolution, but paper is the obvious medium of choice for written applications.

Networking: It 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 bandwidth.

1.5 Image Sampling and Quantization

The output of most of the image sensors is an analog signal, and we cannot apply digital processing on it because we cannot store it. We cannot store it because it requires infinite memory to store a signal that can have infinite values. So we have to convert an analog signal into a digital signal. To create an image which is analog, we need to covert continuous data into digital form. There are two steps in which it is done. a)Sampling b) Quantization.

The basic idea behind converting an analog signal to its digital signal is

- To convert both of its axis (x,y) into a digital format.
- Since an image is continuous not just in its co-ordinates (x axis), but also in its amplitude (y axis), so the part that deals with the digitizing of co-ordinates is known as sampling. And the part that deals with digitizing the amplitude is known as quantization

- **Sampling:** digitizing the 2-dimensional spatial coordinate values
- **Quantization:** digitizing the amplitude values (brightness level)

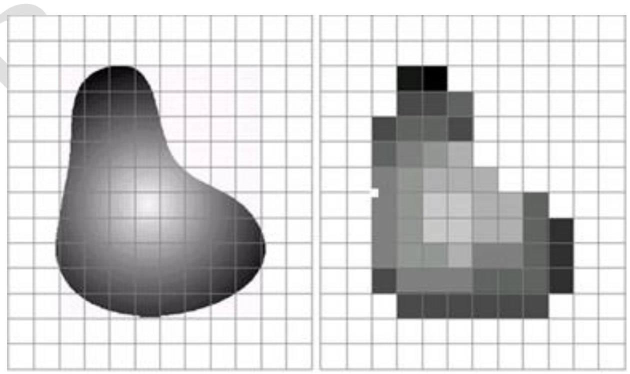


Figure 1.7 (a) Continuous image projected onto a sensor array (b) Result of image Sampling and Quantization.

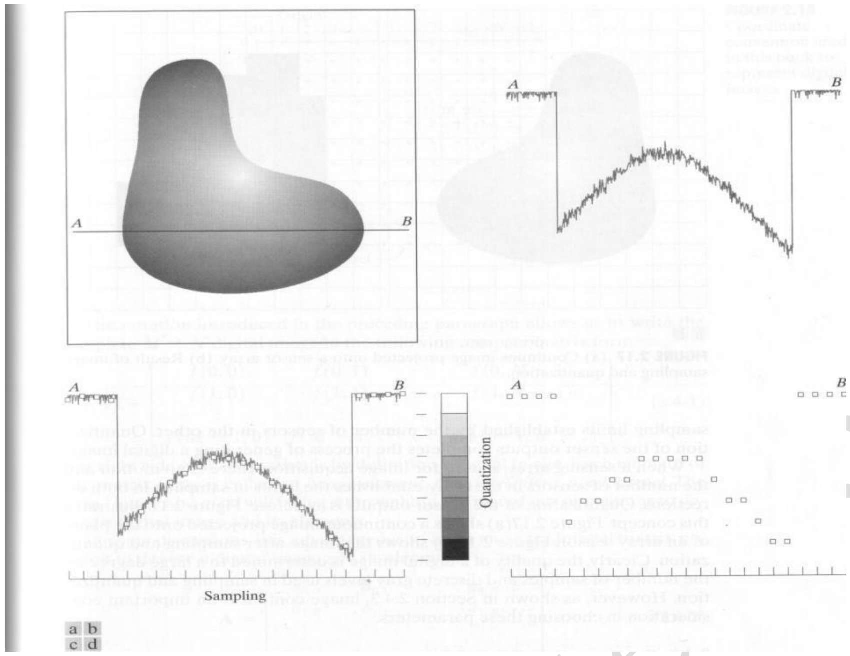


Figure 1.8**:** Generating a digital image (a) Continuous image. (b) A scan line from A to B in the continuous image. (c) Sampling & quantization. (d) Digital scan line

The one-dimensional function shown in Figure (b) is a plot of amplitude (gray level) values of the continuous image along the line segment AB in Figure (a). To sample this function, we take equally spaced samples along line AB, as shown in Figure (c).Location of each sample is given by a vertical tick mark in the bottom part of the figure.The samples are shown as small white squares superimposed on the function. The set of these discrete locations gives the sampled function. However, the values of the samples still span (vertically) a continuous range of gray-level values.

In order to form a digital function, the gray-level values also must be converted *(quantized)* into discrete quantities. The right side of Figure(c) shows the gray-level scale divided into eight discrete levels, ranging from black to white. The vertical tick marks indicate the specific value assigned to each of eight gray levels.

The continuous gray levels are quantized simply by assigning one of the eight discrete gray levels to each sample. The assignment is made depending on the vertical proximity of a sample to a vertical tick mark. The digital samples resulting from both sampling and quantization are shown in Figure (d) and Figure (b).

1.6. Some Basic Relationship like Neighbors, Connectivity, Distance Measures between Pixels

Representation of Digital Image

When we assume that an image *f(x, y)* is sampled and quantized so that digital image has M rows and N columns. The complete M x N digital image can be written as

( ) ( ) ( )
( ) [( ) ( ) ( )]
( ) ( ) ( )

- Each element of a matrix array is called an image element, picture element, pixel or pel.
- Assume gray level at each coordinate value for each pixel = L (Should be discrete).
- Due to processing, storage and sampling hardware consideration, the number of gray levels typically is an integer power of 2.

  $L = 2^K$ (Where K = no of bits per pixel)
- The discrete levels are equally spaced and that they are integer in the interval [0, L-1].
- The number of *b* bits required to store a digital image is

  $b = M \times N \times k$

  $b = N^2 K$ (When M= N)
- For image size of 1024 x 1024, if k = 3 then L = 8. Total bits required to store this image is 1024 x 1024 x 3 = 3145728 bits

Relationships between Pixels

1. Neighbors of a Pixel

- 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)*

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

Fig:- neighbors of p (all horizontal and vertical neighbors)

- This set of pixels is called the *4-neighbors of p* and is denoted by $N_4(p)$
- Each pixel is a unit distance from (x,y)
- The four diagonal neighbors of p have coordinates (x+1,y+1),(x+1,y-1),(x-1,y+1), (x-1,y-1).It is denoted by $N_D(p)$

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

Fig: Diagonal neighbors of p

- These points together with the 4-neighbors are called the *8-neighbors* of *p* and denoted by $N_8(p)$. $N_8(p) = N_4(p)\ N_D(p)$

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

Adjacency, Connectivity, Regions and Boundaries

- Connectivity between pixels => Regions and boundaries
- Two pixels are connected => if they are neighbors and if their gray levels satisfy a specified criterion of similarity (if their gray levels are equal).

Adjacency

- Adjacency : Let V be the set of gray level values used to define adjacency
- For Binary Image V= {1}
- For a Gray Scale Image V = {0,1,2,3,8,255} (V could be any subset of 256 values).
- Three types of adjacency = > 4-adjacency, 8-adjacency and m-adjacency.

- 4-adjacency => Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$ (4-neighbor of p).
- 8-adjacency=> Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$ (8-neighbor of p).

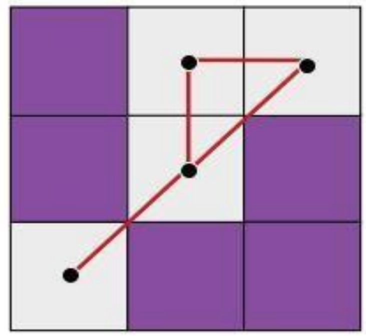


Fig: Pixels that are 8-adjacent to the center pixel

m-adjacency (mixed adjacency)

- 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 $N_4(p)$ $N_4(q)$ has no pixel whose values are from V.
- m-adjacency (mixed adjacency)
- 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 $N_4(p)$ $N_4(q)$ has no pixel whose values are from V.
- Mixed adjacency is a modification of 8-adjacency.
- It is introduced to eliminate the ambiguities that often arise when 8-adjacency is used.

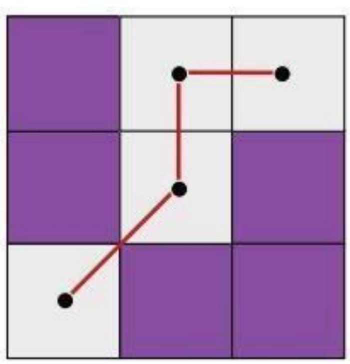


Fig: m-adjacency

Two Image subsets S1 and S2 are adjacent if at least one pixel from S1 and one pixel from S2 are adjacent.

Path

- A path (or curve) from pixel p with coordinates (x,y) to pixel q with coordinates (s,t) is a sequence of distinct pixels with coordinates (x_0,y_0), (x_1,y_1)… ....(x_n,y_n)
- Where $(x_0,y_0) = (x,y)$ and $(x_n,y_n=) = (s,t)$
- Pixels (x_i,y_i) and (x_{i-1},y_{i-1}) are adjacent for 1................(Where n = length of the path).
- If $(x_0,y_0) = (x_n,y_n)$ then path is a closed path.
- We can define 4-path, 8-path or m-path depending on the type of adjacency specified.

Connectivity

- Let *S* represents a subset of pixels in an image.
- Two pixels *p* and *q* in *S* are called connected if there exists a path between them whose pixels are all in *S*.
- For any pixel *p* in *S*, the set of pixels that are connected to it is called a *connected component* of *S*.
- If it only has one connected component, then set S is called a *connected set*.

Region of the Image

- Let R be a subset of pixels in an image.
- We call R as a region of image if R is a connected Set.

Boundary

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

Distance Measures

- Let pixels be p=p(x,y) , q=q(s,t) and z = z(u,v).
- Let *D* be the *Distance Function* or Metric if
    - *D(p,q) 0 (D(p,q) = 0 iif p=q)*
    - D(p,q) = D(q,p), and
    - D(p,z) D(p,q) + D(q,z)
- The *Euclidean Distance* between p and q is defined as

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

- The D_4 distance (also called *city-block distance*) between p and q is defined as
  $D_4(p,q) = |x-s|+|y-t|$
- The pixels having D_4 distance => form a diamond centered at (x,y).

$$\begin{array}{ccccc} & & 2 & & \\ & 2 & 1 & 2 & \\ 2 & 1 & 0 & 1 & 2 \\ & 2 & 1 & 2 & \\ & & 2 & & \end{array}$$

D_4 Distance

- The pixel with D_4=1 are the 4-neighbors of (x,y)
- The D8 distance (also called *chessboard distance*) between p and q is defined as
  $D8(p,q) = \max(|x-s|,|y-t|)$.
- The pixels with D8 distance => form a square

$$\begin{array}{ccccc} 2 & 2 & 2 & 2 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 1 & 0 & 1 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 2 \end{array}$$

D_8 Distance

- The pixel with D_8=1 are the 8-neighbors of (x,y)

1.7 Elements of Visual Perception

The field of digital image processing is built on the foundation of mathematical and probabilistic formulation, but human intuition and analysis play the main role to make the selection between various techniques, and the choice or selection is basically made on subjective, visual judgments.

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:

- Structure of Eye
- Image Formation in the Eye
- Brightness Adaptation and Discrimination

Structure of Human Eye

- The eye is nearly a sphere with an average diameter of approximately 20 mm.
- Three membranes enclose the eye: The *cornea* and *sclera* outer cover; the *choroid*; and the *retina*.

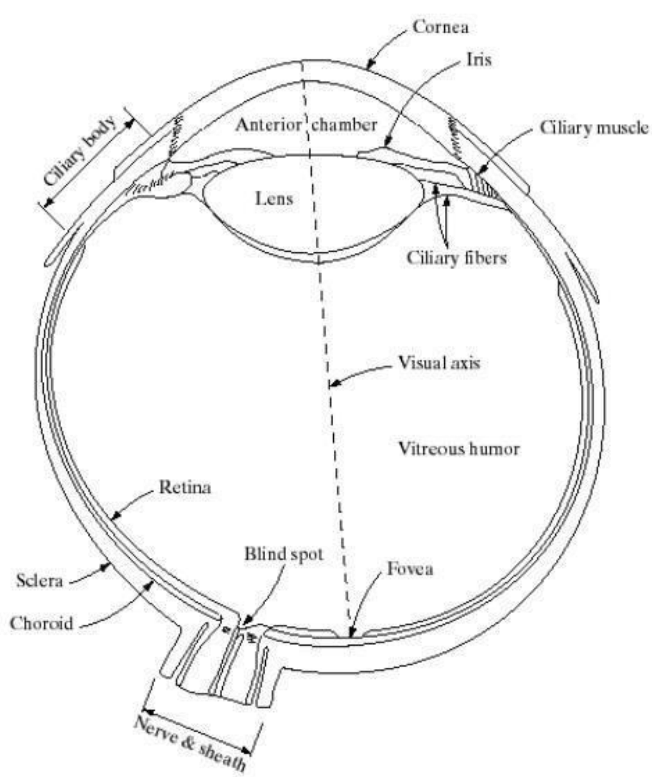


Figure 1.9: Cross Section of Human Eye

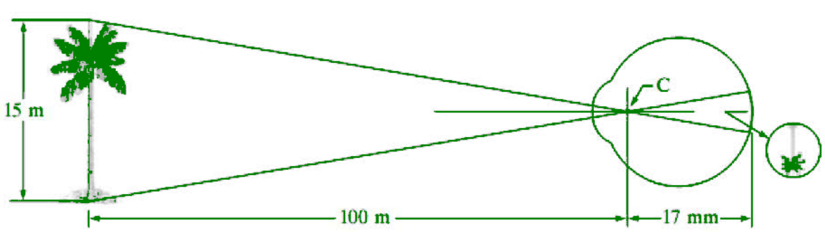
- The *retina* of human eye contains two types of photoreceptors called *rods* and *cones*.
- The *rods* are about 100 million in number are relatively long and thin.
- They provide *scotopi*c vision, which is the visual response at the lower several orders of magnitude of illuminations. (Dim light vision)
- The cones about 6.5 millions are shorter and thicker are less sensitive than the rods which provides *photopic* vision. (Bright light vision)
- It is active at higher orders of magnitude of illuminations (Bright sunlight, Well lighted room).
- In an intermediate region of illumination, both rods and cones are active and provide

mesopic vision.

- The cones are also responsible for color vision.
- They are densely packed in the center of the retina (called *fovea*) at a density about 120 cones per degree of arc.
- The pupil of the eye acts as an aperture. In bright light it is about 2 mm in diameter and acts as a low pass filter (green light).
- The cones are laterally connected by *horizontal cells* and have a forward connection with *bipolar cells.*
- The bipolar cells are connected to *ganglion cells*, which join to form the optic nerve that provides communication to the central of *nervous system.*

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.



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

Brightness Adaptation and Discrimination:

Digital images are displayed as a discrete set of intensities. The eyes ability to discriminate black and white at different intensity levels is an important consideration in presenting image processing result.