Components of an Image Processing System

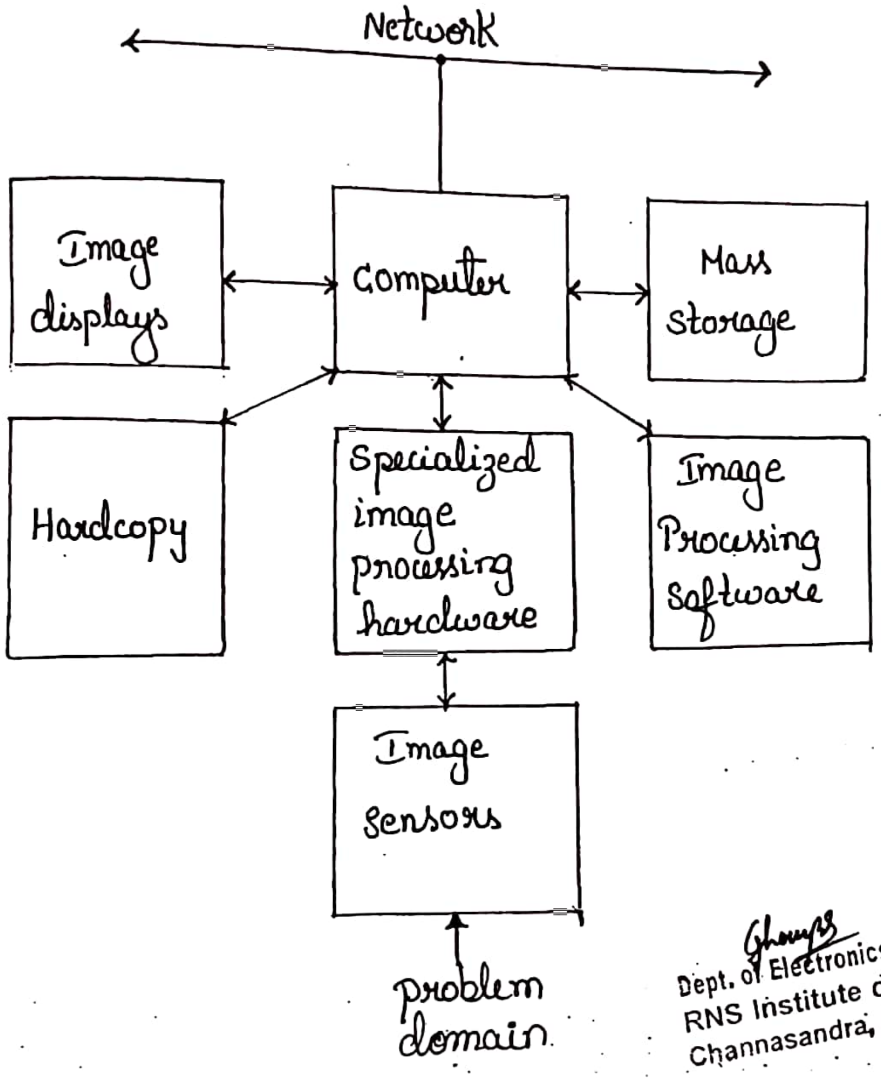


Fig2: Components of a general-purpose image processing system

1. Image sensors can vary from simple camera to multi-spectral scanners. CCDs or CMOS devices are used as sensors to convert light energy into electrical energy.
2. Specialized image processing hardware Consists of digitizer and hardware to perform operation [such as arithmetic/logical] on images at very high speed [real time].

A digitizer takes sensor input and produces a digital output composed of discrete intensity levels at discrete positions.

Specialized image processing hardware is used for noise reduction and other processing of digital image at very high speed.

3. Computer used for image processing system can range from personal computer to a super computer. In dedicated applications, some times custom computer are used to achieve a required level of performa

4. Image processing software consists of specialized modules to perform specific tasks. These tasks can be enhancem edge / corner detection, boundary / region extraction, object detection / recognition etc.

5. Mass storage facility has to be huge for image processing applications.
   Images are associated with huge amount of memory with one image requiring upto megabytes of storage space.
   Storage space can be short term storage, online storag or Mass storage facility.

6. Image displays in use today are mainly color TV monitors. Monitors are driven by the outputs of images and graphics display cards that are an integral part of the Computer system.
   A display devices produces a visual form of data stored in computer.

7. Hard Copy are printers ranging from line printers, dot matrix printers to laser printer.

8. Networking is almost a default function in any computer system in use today
Lot of information and images need to be shared between different people.
As large amount of data is associated with image processing applications, transmission bandwidth is the Key consideration.

Applications of Image processing

Digital Image processing and Analysis techniques are widely used in various fields today

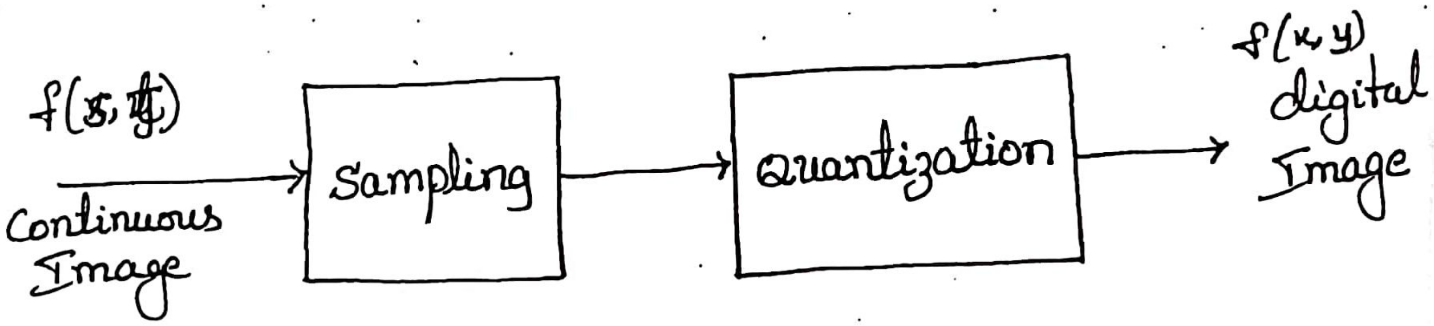
1. Medicine :
CT scan, X-ray imaging, ultrasound scanning, magnetic resonance imaging (MRI) etc are used in medical imaging.
Filtering, segmentation, pattern recognition techniques are used for identifying various abnormalities in human body.
Image processing in medicine has a vital role to play as the ratio of no of doctors to no of patients is very low.

2. Industrial Automation :
Examples are automatic inspection system, Non destructive testing (NDT), automatic assembly, process control etc.
The objective of industrial inspection is to find damaged or incorrectly manufactured products automatically before packaging.

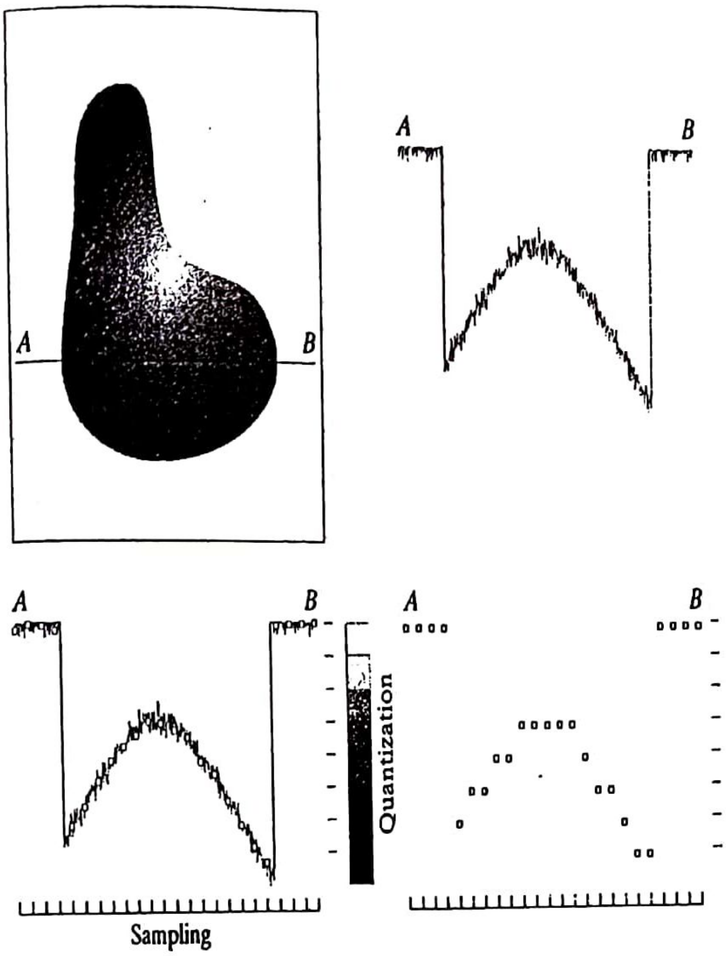
1 [Total reflectance].
Nature of $i(x,y)$ is determined by illumination source and $r(x,y)$ is determined by the characteristics of the imaged objects.

Image Sampling and quantization

The output of most sensors is a continuous voltage waveform, which has to be converted into digital form.
This involves two processes: 1. Sampling
2. and quantization



The basic idea behind Sampling and quantization is illustrated in Fig. Fig(a) shows a continuous image f that we want to convert to digital form. An image may be continuous with respect to the x- and y- coordinates, and also in amplitude.



a b
c d

FIGURE Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

To convert it to digital form, we have to sample the function in both coordinates and in amplitude.
Digitizing the coordinate values is called Sampling.
Digitizing the amplitude values is called quantization.

The one dimensional function in Fig(b) is a plot of amplitude (intensity level) values of the continuous image along the line segment AB in Fig(a).
The random variations are due to image noise.
To Sample this function, we take equally spaced samples along line AB, as shown in fig(c).

The spacial location of each sample is indicated by a vertical tick mark in the bottom part of Fig(c). The samples are shown as small squares superimposed on the function. The set of these discrete locations gives the sampled function.

In order to form a digital function, the intensity values also must be converted (quantized) into discrete quantities.

The right side of Fig (c) shows the intensity scale divided into eight discrete intervals, ranging from black to white. The vertical tick marks indicate the specific value assigned to each of the eight intensity intervals. The continuous intensity levels are quantized by assigning one of the eight values 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 Fig (d).

Fig (a) shows a continuous image projected onto the plane of an array sensor.

Fig (b) shows the image after sampling and quantization.

The quality of a digital image is determined to a large degree by the number of samples and discrete intensity levels used in sampling and quantization.

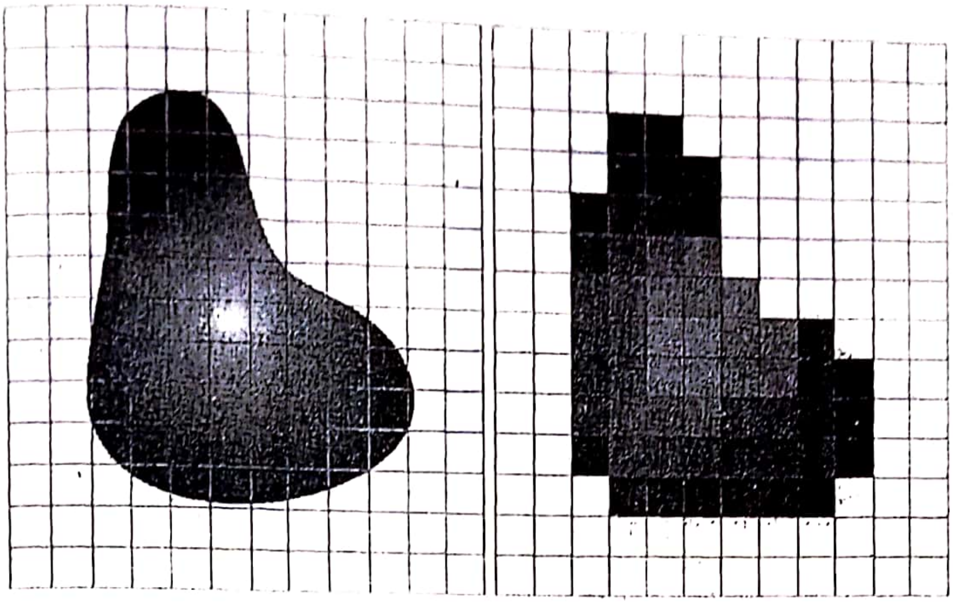


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Representing Digital Images

→ The result of sampling and quantization is a matrix of real numbers.

→ Let us say that an image $f(x,y)$ is sampled so that the resulting digital image has M rows and N columns.

→ The values of the coordinates (x,y) now become discrete quantities

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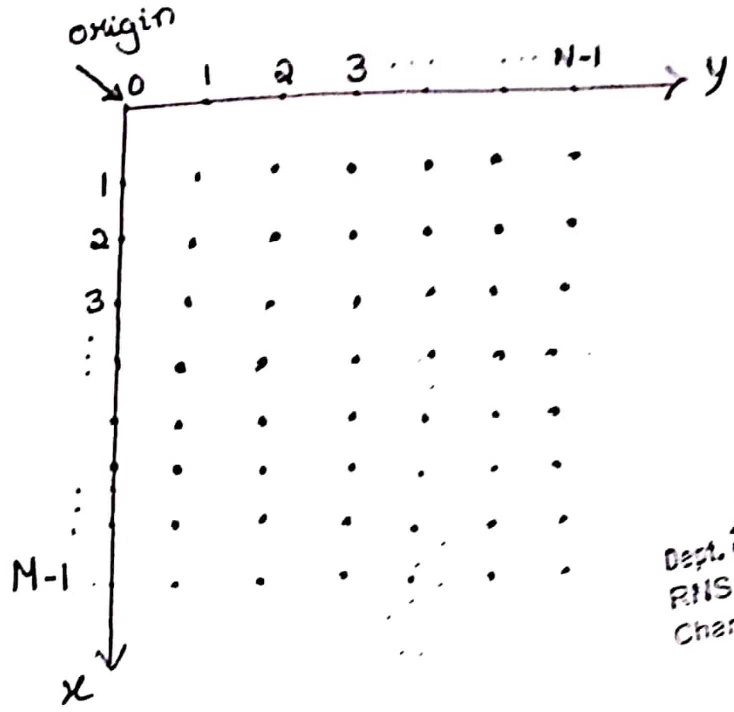
Fig shows the coordinate convention used.



The above notation allows us to write the complete M×N digital image in the following compact matrix form.

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

Each element in this matrix array is called a pixel.

The digitization process requires decisions about values of

$M \rightarrow$ no of rows

$N \rightarrow$ no of columns

$L \rightarrow$ no of discrete gray levels

$L = 2^k$ where k = no of bits required to represent amplitude values.

We assume that the discrete gray levels are equally spaced and that they are integers in the interval [0, L-1]

No of bits required to store a digital image

$$\boxed{b = M \times N \times K}$$

K=1, for binary image of size 512 x 512

$\therefore\ b = 512 \times 512 \times 1 = 262144$ bits

K=8, for Gray scale image of size 512 x 512

$b = 512 \times 512 \times 8 = 262.14$ Kb

K = 8 x 3, for a color image of size 512 x 512

$b = 512 \times 512 \times 8 \times 3 = 786.43$ Kb

Spatial Resolution

→ Spatial resolution determines the smallest noticable detail in an image.

→ Line pair / unit distance, dots (Pixels) / inch (dpi) are some common measures to define spatial resolution.

→ Spatial resolution can be expressed as total no. of pixels in an image. A 1.3 Mega pixel Camera has 1,310,720 pixels generating an image of size 1024 rows and 1280 columns.

→ As no. of pixels in an image increases, pixel size gets smaller, which requires high quality lens for focusing.

generally visible in images displayed using 16 gray levels (4 bit) or less.

Some Basic Relationships between Pixels

→ A image is denoted by $f(x,y)$.

→ When referring to a particular pixel, we use lowercase letters, such as p and q.

→ Image boundary and region are extracted for image analysis and understanding. To draw object boundary we need to know if pixels are related to each other or not.

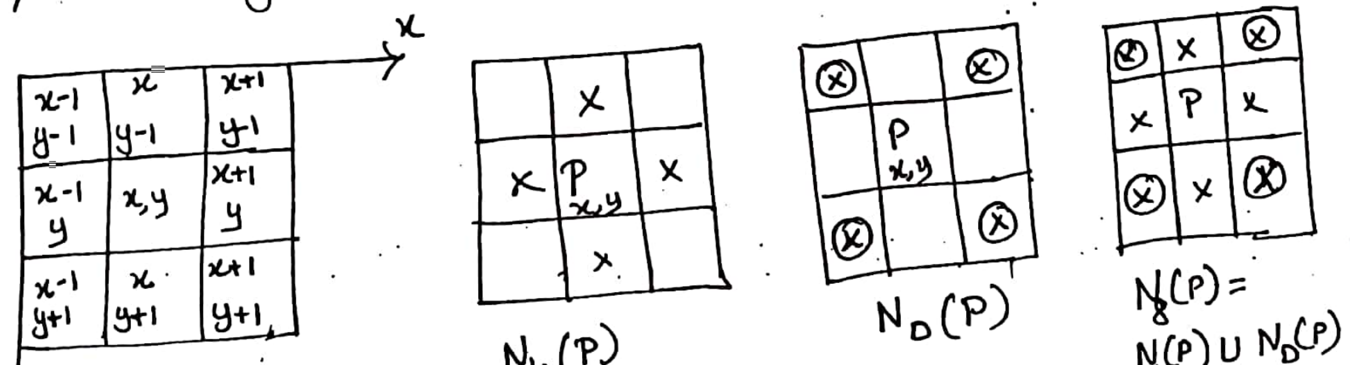
i) Neighbours of a Pixel

A pixel p at (x,y) has 3 types of neighbours.

a) 4-Neighbour of P $[N_4(P)]$

b) 8-Neighbour of P $[N_8(P)]$

c) D-Neighbour [diagonal Neighbour] of P $[N_D(P)]$



co-ordinate convention

$N_4(P)$

$N_D(P)$

$N_8(P) = N_4(P) \cup N_D(P)$

a) $N_4(P)$: Pixel P at (x,y) has 4 horizontal and vertical neighbours, $(x+1,y)$, $(x-1,y)$, $(x,y-1)$ $(x,y+1)$. This set of pixels are called $N_4(P)$. Each Pixel is a unit distance from (x,y).

Scanned with CamScanner

b) **$N_D(P)$** : Diagonal neighbours of P have coordinates $(x+1, y+1)$, $(x+1, y-1)$, $(x-1, y+1)$, $(x-1, y-1)$. this set of pixels are denoted by $N_D(P)$.

c) **$N_8(P)$** : Diagonal neighbours together with 4-neighbours are called 8-neighbours of P

$$N_8(P) = N_4(P) \cup N_D(P)$$

ii) **Adjacency**

To determine pixel adjacency, 2 conditions are there
a) two pixels should be neighbours.
b) their gray level should be similar

Let V be the set of intensity values used to define adjacency.
In a binary image, if we are referring to adjacency of pixels with value 1 then $V = \{1\}$.

There are 3 types of adjacency

i) **4-adjacency**

Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(P)$

Ex: $V = \{1\}$

0	0	0
0	1_P	1_{q_1}
0	0_{q_2}	0

→ P and q_1 are 4-adjacent as both are 1 and $q_1 \in N_4(P)$

→ p and q_2 are not 4 adjacent as $q_2 \in N_4(P)$ but $P=1, q_2=0 \notin V$

2) 8- adjacency :

Two pixels p and q with gray level values from $\bar{V}$ are 8 - adjacent if q is in the set $N_8(p)$.

$V = \{1\}$

q_1 1	0	0
0	1 p	1 q_2
0	0	0

→ P and q_1 are 8 adjacent as $q_1 \in N_8(P)$ and $(P, q_1) \in \bar{V}$

→ P and q_2 are 8 adjacent as $q_2 \in N_8(P)$ and $(P, q_2) \in \bar{V}$

→ P and q_3 are not 8 adjacent as $q_3 \in N_8(P)$ but $q_3 \notin \bar{V}$

3) m - adjacency

Two pixels p and q are called m - adjacent if both have values from set V and

i) q is in $N_4(P)$ or

ii) q is in $N_D(P)$ and set $N_4(P) \cap N_4(q) \notin V$

$V = \{1\}$

0	1 q_2	1 q_3
0	1 p	0
1 q_1	0	0

→ P, q_1 are m adjacent as $p = q_1 = 1$, $q_1 \in N_4(P)$ and $N_4(P) \cap N_4(q_1) \neq 1$

→ P, q_2 are m - adjacent as $p = q_2 = 1$ $q_2 \in N_4(P)$

→ P, q_3 are not m - adjacent as $p = q_3 = 1$ $q_3 \in N_D(P)$ and $N_4(P) \cap N_D(P) = 1 \in \bar{V}$

---

d whether 4, 8 and m adjacency occurs b/w P and q_1, nd q_2 , P and q_3 for the following image

0	4 q_1	1 q_3
p 0	20 q_2	
70	50	

	4	8	m
P and q_1	✓	✓	✓
P and q_2	× ($p, q_2 \notin V$)	×	✓
P and q_3	×	✓	×

Scanned with CamScanner

Path :-

A digital path or curve from pixel P with co-ordinates (x, y) to pixel Q with co-ordinates (s, t) is the sequence of distinct pixels with co-ordinates (x_0, y_0) (x_1, y_1) ..... (x_n, y_n), where,

$(x_0, y_0) = (x, y)$, $(x_n, y_n) = (s, t)$,

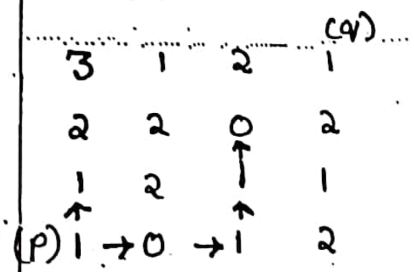
and the pixels (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \le i \le n$, where n is the length of the path.

If $(x_0, y_0) = (x_n, y_n)$, the path is a closed path.

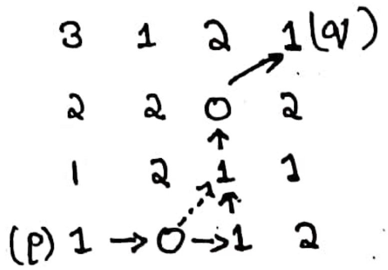
We define 4, 8 and or m path depending on the type of adjacency specified.

ex :- For $V = \{0, 1\}$, find the shortest 4, 8 and m path between P & Q. Repeat for $V = \{1, 2\}$.

$V = \{0, 1\}$

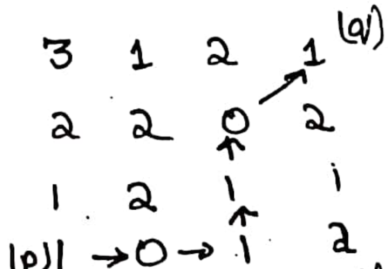


No 4 path



shortest length = 4

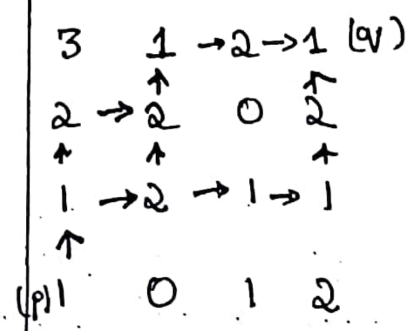
8 path



shortest length

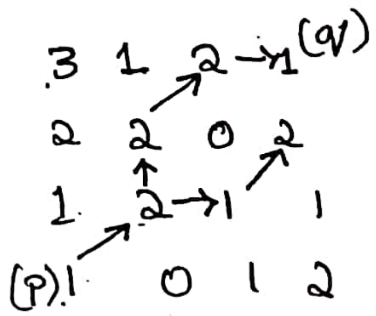
m path

$V = \{1, 2\}$



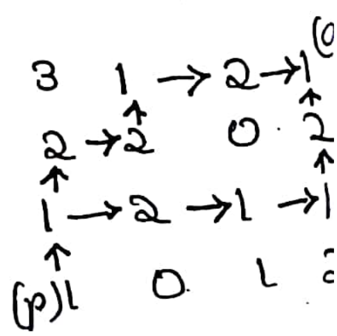
shortest length = 6

4 path



shortest length = 4

8 path



shortest length =

m - path

ex 2 :- For $V = \{2, 3, 4\}$, compute the length of shortest 4, 8, m paths between P & Q in the following image.

sol

	3	4	1	2	0
	0	1	0	4	2 (Q)
	2	2	3	1	4
(P)	3	0	4	2	1
	1	2	0	3	4

```
      3   4   1   2   0
      0   1   0   4   2(q)
      2 → 2 → 3   1   4
      ↑
  (P) 3   0   4   2   1
      1   2   0   3   4
```

NO. 4 - path

```
      3   4   1   2   0
      0   1   0   4 → 2(q)
      2   2 → 3 ↗ 1   4
        ↗
  (P) 3   0   4   2   1
      1   2   0   3   4
```

8 path length = 4

```
      3   4   1   2   0
      0   1   0   4 → 2 (q)
      2 → 2 → 3 ↗ 1   4
      ↑
  (P) 3   0   4   2   1
      1   2   0   3   4
```

shortest m-path length = 5

* Connected Set :-

Let S represent a subset of pixels in an image. 2 pix[els] P & Q are ~~set~~ said to be connected in S if there exists a path between them, consisting entirely of pi[xels] in 'S'.

* For any pixel 'p' in S, the set of pixels that are connected to it in S, is called a 'connected component'.
* If it only has 1 connected component, then set 'S' is cal[led] a 'Connected Set'.
* If there is a 4-path between pixels 'p' and 'q', they are said to be '4-connected'. (similarly 8-connected).
* A set of pixels that are connected to each other is called a component
* Pixels are 4-connected ⇒ 4-components.

Similarly pixels are 8-connected ⇒ 8-components

* Regions :-

Let R be a subset of pixels in an image. We call 'R' region of the image, if 'R' is a connected set.

* 2-Regions Ri and Rj are said to be adjacent if th[eir] union forms a connected set.
* The regions that are not adjacent are said to be disjoi[nt]
* We consider 4 and 8 adjacency when referring to regions

ex :- The 2 regions are adjacent only if 8-adjacency used.

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

Foreground & Background :-

* If an image contains 'K' disjoint regions R_k where $1 \leq k \leq K$, 'R_u' denotes the union of all the K regions $(R_u)^c$ denotes the complement.
* The points in R_u are the Foreground & all the points in the $(R_u)^c$ is the Background of the image.

Boundary :-

Boundary of region 'R' is the set of points that are adjacent to points in the complement of 'R'.

* The boundary of the region is the set of pixels in the region that are atleast one background neighbour

$$
\begin{matrix}
0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 0 & 0 \\
0 & 1 & 1 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 \\
0 & 1 & 1 & 1 & 0 \\
0 & 0 & 0 & 0 & 0
\end{matrix}
$$

* The point circled in the figure/image is not a member of the border of the 1-value region, if 4-connectivity is used between the region & its background
* Adjacency between points in a region & its background is defined in terms of 8-connectivity under situations like this.

The above defined is also called the Inner border. The corresponding border in the backgrour Outer border is the

Distance Measures

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

i) $D(p,q) \geq 0$ $\quad [D(p,q) = 0 \text{ iff } p = q]$

ii) $D(p,q) = D(q,p)$

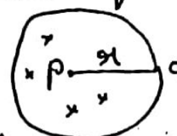
iii) $D(p,z) \leq D(p,q) + D(q,z)$

Based on above conditions, 3 distance measures are defined

1) Euclidean distance

Euclidean distance between p and q is defined as

$$\boxed{D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}}$$



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

2) City block distance (D_4)

D_4 distance b/w P and q is defined as

$$\boxed{D_4(p,q) = |x-s| + |y-t|}$$

The pixels having a D_4 Distance from (x, y) less than or equal to some value r, form a diamond centered at (x, y)

EX: the pixels with D_4 distance ≤ 2 from (x, y) (the center point) form the following contours of constant distance

	0	1	2	3	4
0			2 (0,2)		
1		2 (1,1)	1 (1,2)	2 (1,3)	
2	2 (2,0)	1 (2,1)	0 (2,2)	1 (2,3)	2 (2,4)
3		2 (3,1)	1 (3,2)	2 (3,3)	
4			2		

3. Chessboard distance (D_8)

The chessboard distance (D_8) between p and q is

$$\boxed{D_8(p,q) = \max(|x-s|, |y-t|)}$$

The pixels with D_8 distance from (x,y) less than or equal to some value r, from a square centered at (x,y)

Ex: The pixels with D_8 distance ≤ 2 from (x,y) (the center point) form the following contours of constant distance

The pixels with $D_8 = 1$ are the 8 neighbours of (x,y)

2	2	2	2	2
2	1	1	1	2
2	1	0 (2,2)	1 (2,3)	2 (2,4)
2	1	1	1	2
2	2	2	2	2

Let p and q be the pixels at coordinates (10,15) and (15, 25) respectively. Find out which distance measure gives the minimum distance between pixels

$$D_e(p,q) = \sqrt{(15-10)^2 + (25-15)^2} = \underline{11.18}$$

$p,q = 10, 15$
$s,t = 15, 25$

$$D_4(p,q) = (|15-10| + |25-15|) = \underline{15}$$

$$D_8(p,q) = \max(|15-10|, |25-15|) = \underline{10}$$

Minimum distance is given by chessboard distance D_8 which is 10

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Linear v/s Non-linear operation

One of the most important classifications of an image processing method is whether it is linear or non-linear. Consider a general operator 'H' that produces an output-image $g(x,y)$ for a given input-image $f(x,y)$. 'H' is said to be linear operator if

$$H[a_i f_i(x,y) + a_j f_j(x,y)] = a_i H[f_i(x,y)] + a_j H[f_j(x,y)]$$
$$= a_i g_i(x,y) + a_j g_j(x,y) \quad \text{--- (1)}$$

eq (1) indicates that the output of linear operation due to sum of 2 inputs is the same as performing operation on the inputs individually and then summing the result.

If 'H' is the sum operator 'Σ',

$$\Sigma[a_i f_i(x,y) + a_j f_j(x,y)] = \Sigma a_i f_i(x,y) + \Sigma a_j f_j(x,y)$$
$$= a_i \Sigma f_i(x,y) + a_j \Sigma f_j(x,y)$$
$$= a_i g_i(x,y) + a_j g_j(x,y)$$

$\therefore$ Sum is Linear.

* Consider Max operation.

ex:- $f_1 = \begin{bmatrix} 0 & 2 \\ 2 & 3 \end{bmatrix}$ and $f_2 = \begin{bmatrix} 6 & 5 \\ 4 & 7 \end{bmatrix}$

let $a_1 = 1$ and $a_2 = -1$

$$\max\left\{(1)\begin{bmatrix} 0 & 2 \\ 2 & 3 \end{bmatrix} + (-1)\begin{bmatrix} 6 & 5 \\ 4 & 7 \end{bmatrix}\right\} = \max\begin{bmatrix} -6 & -3 \\ -2 & -4 \end{bmatrix}$$
$$= -2$$

$$(1)\ \max\begin{bmatrix}0 & 2\\ 2 & 3\end{bmatrix} + (-1)\max\begin{bmatrix}6 & 5\\ 4 & 7\end{bmatrix} = 3 + (-1)7$$

$$= -4$$

$\therefore$ max operator is non-linear.

Problems:

Assume a camera is focused at a pillar of hieght 2m and is at a distance of 10m. If the focal length of camera is 10mm. what will be the height of the image in camera

$$\frac{2}{10} = \frac{h}{10} \Rightarrow h = \frac{2}{10} \times 10 = 2\,mm$$

calculate the no of bits required to store an image of size 1024×1024 with 128 gray levels

$128 = 2^k \Rightarrow k = 7$

$\therefore b = M \times N \times K = 1024 \times 1024 \times 7 = 7.34$ M bits

Find the time required to Tx a monochrome image of size $2.5'' \times 2''$ scanned at 150 dpI and to be sent at 28 Kbps speed.

soln

Size of image $= (2.5'' \times 150)$ rows $\times (2'' \times 150)$ columns
$= 112500$ pixels

for Gray scale images $K = 8$

$b = 112500 \times 8 = 0.1125$ M bytes

$$\text{Time} = \frac{112500 \times 8}{28 \times 1000} = 32.142 \text{ sec}$$