Image Processing:

Image Processing is a method to convert an image into digital form and perform some ~~image or~~ operation on it, in order to get an enhanced image or to extract some useful information from it.

~~→A two~~

Digital Image Processing:

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.

→A 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 intensity of that image at that point.

*When x,y and amplitude values of F are finite, we call it a digital image.

$$\boxed{f(x,y) = i(x,y) * r(x,y)}$$

f→ intensity
i → illumination
r→ reflectance

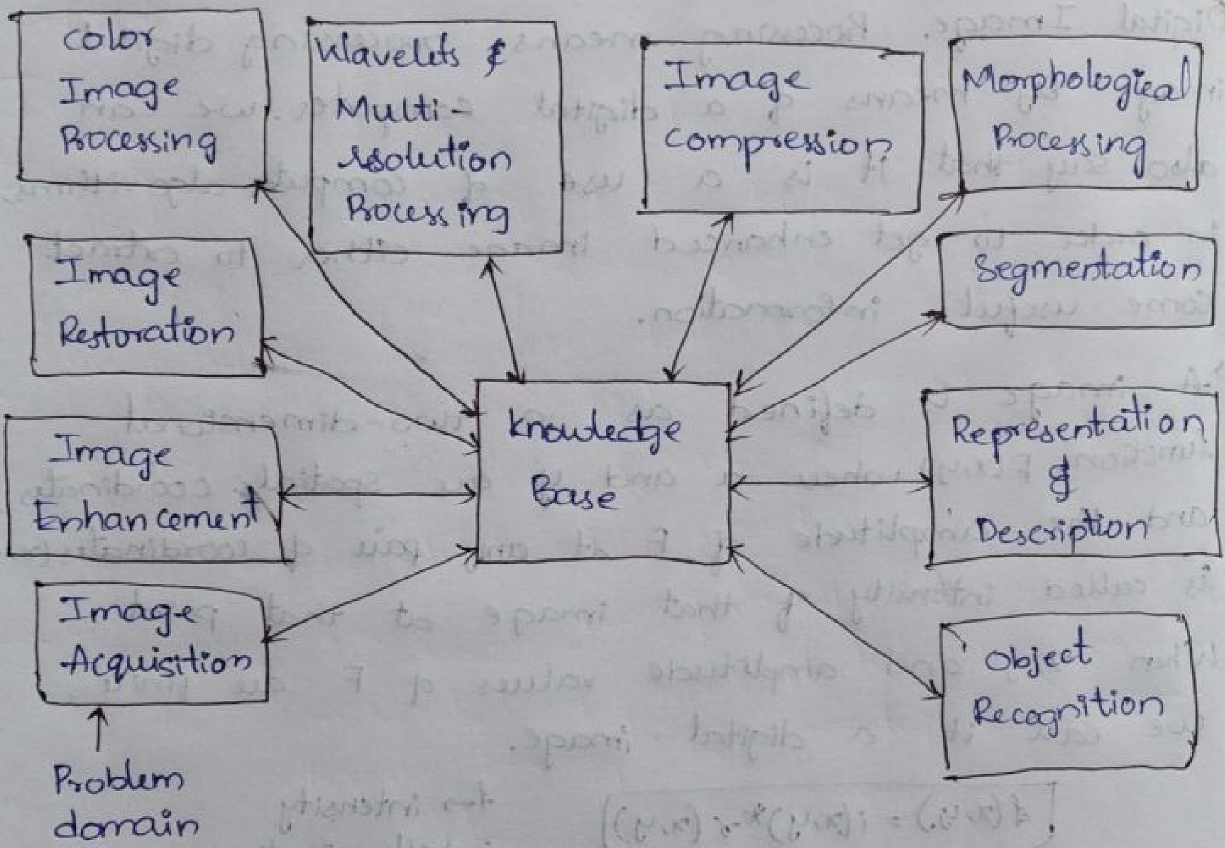
→ In general, there are three levels of processing.
* low level
* mid level
* high level

low level processing: It involves primitive operation such as image preprocessing to reduce noise, constrast enhancement, image sharpening etc... In the low-level process, both input and output are images.

Mid-level Processing: involves tasks such as image segmentation, description of images, object recognition etc... Here, inputs are generally images but its outputs are generally image attributes.

High-level Processing: involves "making sense" from a group of recognized objects. This process is normally associated with computer vision.

## Fundamentals steps of Image Processing.




① Image Acquisition: It is the first step of fundamental steps of DIP. In this stage, an image is given in the digital form. Generally, in this stage, pre-processing such as scaling is done.

② Image Enhancement: It is simplest and attractive area. In this stage, we can say that intresting features of an image is highlighted. Such as brightness, contrast etc...

③ Image Restoration: It is the stage in which the appearance of an image is improved.

④ Color Image Processing: color image processing is famous area because it has increased the use of digital images on the internet. This includes color modeling, processing in a digital domain etc...

⑤ Wavelets and Multi-Resolution Processing:
In this stage, an image is represented in various degrees of resolution. Image is divided into smaller regions for data compression and for the pyramidal representation.

⑥ Image Compression: Compression is a technique which is used for reducing the requirement of storing an image.

⑦ Morphological Processing: This stage deals with tools which are used for extracting the components of the image, which is useful in the representation and description of shape.

⑧ Segmentation: In this stage, an image is Partitioned into its objects. Segmentation is the most difficult tasks in DIP. It is a process which takes a lot of time for sucessful solution of imaging Problems which requires object to identify individually.

⑨ Representation and Description: It follows the output of segmentation stage. The output is a raw pixel data which has all points of the region itself. To transform raw data, representation is the only Solution. where as description is used for extracting information's to differentiate one class

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of objects from another.

(10) object Recognition: In this stage, the label is assigned to the object, which is based on descriptors.

(11) knowledge Base: This is the last stage. Here, important information of image is located, which limits the searching processes. The knowledge base is very complex when the image database has a high-resolution satellite.

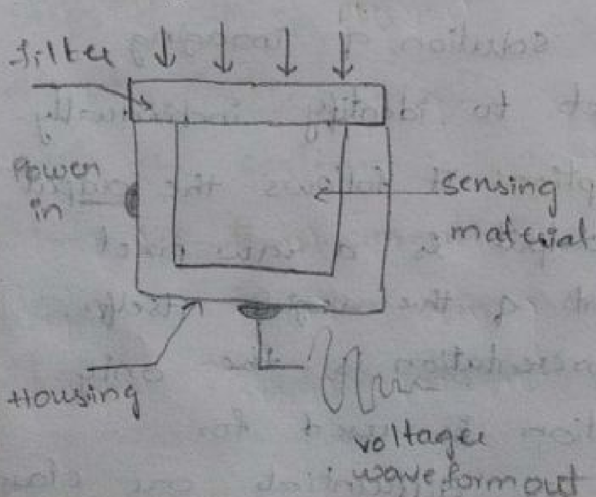
## Image Sensing and Acquisition

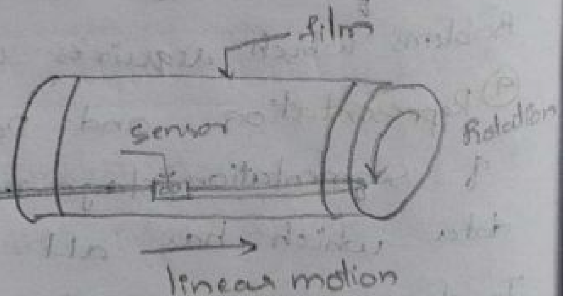
In Image processing it is defined as the action of retriving an image from some source, usually a hardware-based source for processing. It is the first step of workflow sequence because, without an image, no processing is possible. The image that is required is completely unprocessed.

→ Incoming energy is transformed into a voltage by the combination of input electrical power and sensor material energy being detected.

There are three types of sensors

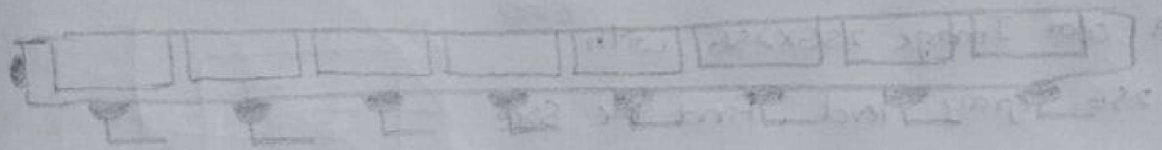
(1) Image Acquisition using single sensor




sensor of this type is photodiode.

② Image Acquisition using sensor strips (linear)

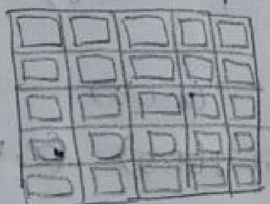


In linear arrangement of sensors in the form of a sensor strip. strip provides imaging elements in one direction.

→ Motion perpendicular to strip provides imaging in the other direction.

→ Sensor strip mounted in a ring configuration are used in medical and industrial imaging to obtain cross-sectional image of 3-D objects.

③ Image Acquisition using a Array Sensor



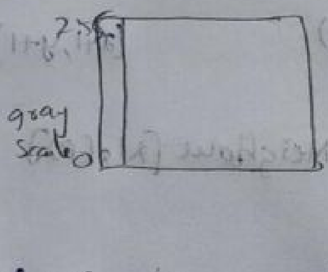
Array Sensor

Motion is not required for Array sensor

→ It covers huge area of an object and senses the energy without motion.

Date: 16/8/21

A image of 256×256 with $\frac{256}{8}$ gray levels. Then, find the size DI?




bits ⇒ $256 \times 256 \times 8 = 2^8 \times 2^8 \times 2^3$

$= 2^{19}$ bits

$= 512$ k bits

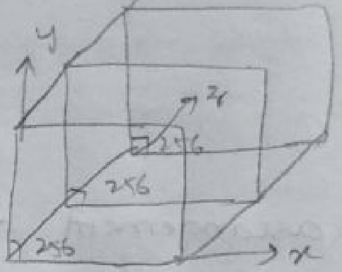
bytes ⇒ $256 \times 256 \times 1B = 2^8 \times 2^8 \times 1B = 2^{16}$ byte

$= 64$ kB

$\boxed{KB = 2^{10} B}$

## Color Image Model

A color Image 256X256 with 256 gray level. Find the Size?




bits $\Rightarrow 2^8 \times 2^8 \times 24 = 2^{16} \times 24$

$= 64 \times 24$ Kbits

byte $\Rightarrow 2^8 \times 2^8 \times 3 = 2^{16} \times 3 = 64 \times 3$ KB $= 192$ KB

## Relationship between pixels

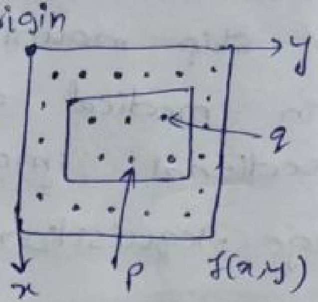



Image $\rightarrow f(x,y)$

S $\rightarrow$ subset of pixels

q, P $\rightarrow$ particular pixels

4 - Neighbours $[N_4(P)]$

2 Horizontal : $(x, y-1), (x, y+1)$

2 Vertical : $(x-1, y), (x+1, y)$

$\therefore N_4(P) = (x, y-1), (x, y+1), (x-1, y), (x+1, y)$

| | | |
|---|---|---|
| | $(x-1, y)$ | |
| $(x, y-1)$ | $P(x,y)$ | $(x, y+1)$ |
| | $(x+1, y)$ | |

· Diagonal neighbours

$N_D(P) = (x+1, y-1), (x-1, y-1)$
$(x-1, y+1), (x+1, y+1)$

| | | |
|---|---|---|
| $(x-1, y-1)$ | | $(x-1, y+1)$ |
| | $P(x,y)$ | |
| $(x+1, y-1)$ | | $(x+1, y+1)$ |

· 8 - Neighbour $[N_8(P)]$

$$\boxed{N_8(P) = N_4(P) + N_D(P)}$$

| | | |
|---|---|---|
| $(x-1, y-1)$ | $(x-1, y)$ | $(x-1, y+1)$ |
| $(x, y-1)$ | $P(x,y)$ | $(x, y+1)$ |
| $(x+1, y-1)$ | $(x+1, y)$ | $(x+1, y+1)$ |

# Connectivity / Adjacent

① 4-adjacency
② 8-adjacency
③ m-adjacency (mixed-adjacency)

$V = \{1\}$ Binary Image

| | | | | |
|---|---|---|---|---|
| 0 | 1 | 0 | 1 | → 8-adj |
| 0 | 0 | $\boxed{1}$ | 0 | |
| | | | | → 4 adjacency |
| 0 | 0 | 1 | 0 | |
| 1 | 0 | 0 | 0 | |

## Gray Scale Image

[0 - 255] $V = \{0, 1, 2, \ldots, 10\}$

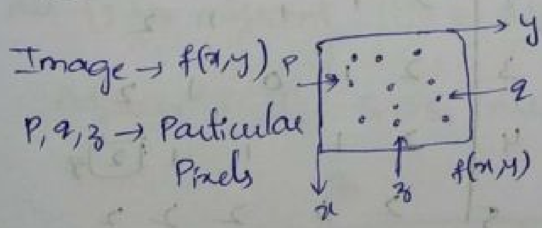
| | | | | |
|---|---|---|---|---|
| 54 | 10 | 100 | 5 | → 8-adj |
| 81 | 150 | $\boxed{2}$ | 34 | |
| | | | | → 4 adj |
| 201 | 200 | 3 | 45 | |
| 9 | 70 | 147 | 56 | |

9 not connected

| | | |
|---|---|---|
| 0 | $\boxed{1}$ | 1 |
| 0 | $\boxed{1}$ | 0 |
| 0 | 0 | 1 |

| | | |
|---|---|---|
| 0 | 1 | 1 |
| 0 | $\boxed{1}$ | 0 |
| 0 | 0 | 1 |

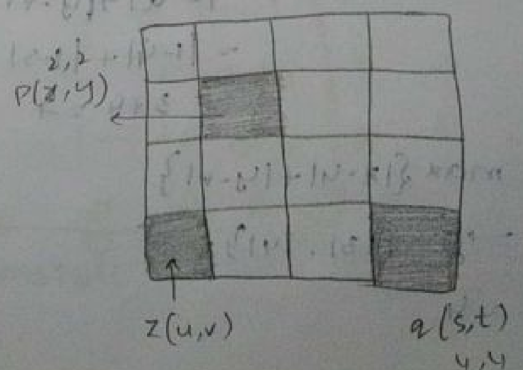
## Distance Measure




## Distance function D

**Properties**

1) $D(P,q) \geq 0$
2) $D(P,q) = 0$ if $P = q$
3) $D(P,q) = D(q,P)$
4) $D(P,z) \leq D(P,q) + D(q,z)$



## Distance Measure

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

(ii) City Block : $D_4(p,q) = |x-s| + |y-t|$

(iii) Chess board : $D_8(p,q) = \max\{|x-s|, |y-t|\}$

(a) $D_E(p,q) = [(2-4)^2 + (2-4)^2]^{1/2}$

$= [8]^{1/2}$

(b) $D_4(p,q) = |2-4| + |2-4| = 2+2 = 4$

(c) $D_8(p,q) = \max\{|2-4|, |2-4|\}$

$= \max\{2,2\}$

$= 2$

23/8/21 **Problems of Distance Measure**

(1) The pixel with distance $D_8$ from $(x,y)$ less than or equal to some value of form a square centered at $(x,y)$.

For example with $D_8$ distance $\leq 2$ from the following contours of constant distance

(i) Euclidean : $D_E(p,q) = [(4-1)^2 + (5-1)^2]^{1/2}$

$= [(3)^2 + (4)^2]^{1/2}$

$= [9+16]^{1/2} = (25)^{1/2}$

$= 5$

(ii) City Block distance : $D_4$

$= |x-u| + |y-v|$

$= |1-4| + |1-5|$

$= 3+4 = 7$

(iii) $D_8 = \max\{|x-u| + |y-v|\}$

$= \max\{|3|, |4|\}$

$= 4$

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | p $\boxed{2}$ | 2 | 2 | 2 | 2 |
| 2 | 2 | 1 | 1 | 1 | 2 |
| 3 | 2 | 1 | 0 | 1 | 2 |
| 4 | 2 | 1 | 1 | 1 | $\boxed{2}$ q |
| 5 | 2 | 2 | 2 | 2 | 2 |

$(x,y)$ $(u,v)$

1,1 4,5

(2) A common measure of transmission for digital data is the baudrate, defined at the number of bits transmitted per second. Generally transmission is accomplished in packets consisting of a start bit, a byte of information and a stop bit.

(a) How many minutes would it take to transmit a 1024×1024 image with 256 gray level using 56k baudrate

$$\text{Time} = \frac{\text{Size}}{\text{DTR}} \Rightarrow \frac{2^{10} \times 2^{10} \times 10}{56 \times 2^{10}} = \frac{2^7 \times 10}{7} = 182.85 \text{ sec}$$

$2^8$ (gray level)

2 extra bits (both sides)

1 min = 60sec

? = 182.85 ⇒ 3.0475 min

(b) What would be the time be at 750k baudrate, a representative speed of a phone (digital subscribe) connection?

$\text{Time} = \frac{\text{Size}}{\text{DTR}}$ 0.2275 min

As baudrate ↑ time ↓

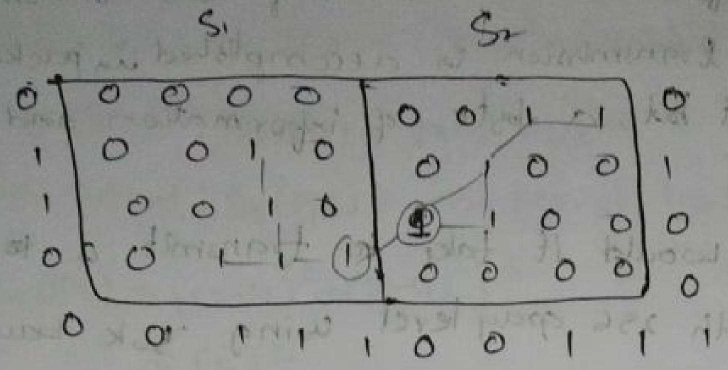
(3) Consider the two image subsets $S_1$ and $S_2$, shown in the following figure for $V=\{1\}$. determine whether two subsets are (i) 4 adjacent (ii) 8-adjacent (iii) m-adjacent

Adjacent: If $S_1 \cup S_2$ are adjacent (connected)

| $S_1$ | | | | | $S_2$ | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |

4-adjacent, not possible

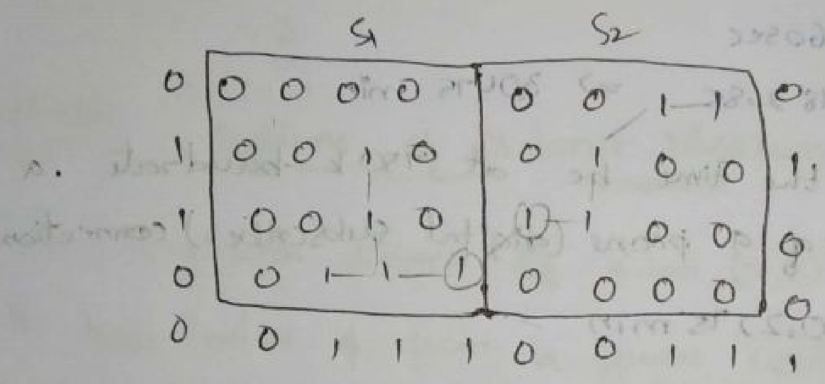
ⓑ 8-adjacent




Here S1, S2 are a region

S1 ∪ S2 are adjacent

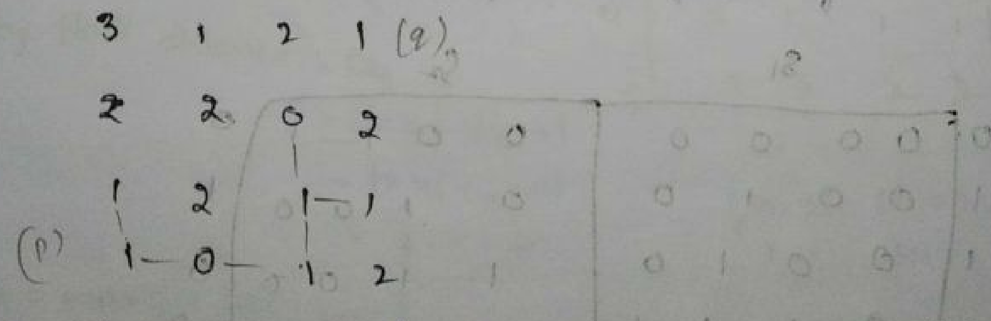
ⓒ m-adjacency




Here S1, S2 are region, S1 ∪ S2 are adjacent

④ Consider the image segment shown:

ⓐ Let V={0,1} and compute the length of the shortest 4, 8 and m path b/n p & q. If a particular path does not exist b/n two points. Explain Why?




(i) p and q are not in same connected component using 4-adjacency.

(ii) 8-adjacency

| | | | |
|---|---|---|---|
| 3 | 1 | 2 | 1 (q) |
| 2 | 2 | 0 | 2 |
| 1 | 2 | 1 | 1 |
| (p) 1 | 0 | 1 | 2 |

$D_8 = \max\{|4-1|, |1-4|\}$
$= \max\{3,3\}$
$= 3$

4 - shortest distance

$D_8 \le$ 8 adjacency

$3 \le 4$

(iii) m-adjacency

| | | | |
|---|---|---|---|
| 3 | 1 | 2 | 1 |
| 2 | 2 | 0 | 2 |
| 1 | 2 | 1 | 1 |
| 1 | 0 | 1 | 2 |

shortest path: 5

(b) Repeat for $V = \{1,2\}$

(i) 4-adjacency

| | | | |
|---|---|---|---|
| 3 | 1 | 2 | 1 |
| 2 | 2 | 0 | 2 |
| 1 | 2 | 1 | 1 |
| 1 | 0 | 1 | 2 |

shortest distance = 6

(ii) 8-adjacency

| | | | |
|---|---|---|---|
| 3 | 1 | 2 | 1 |
| 2 | 2 | 0 | 2 |
| 1 | 2 | 1 | 1 |
| 1 | 0 | 1 | 2 |

shortest path = 4

$(4,4) \to (3,2) \to (1,3) \to (1,4)$

$D_8 = 3$

$D_8 \le$ 8-adjacency

(iii) m-adjacency

| | | | |
|---|---|---|---|
| 3 | 1 | 2 | 1 |
| 2 | 2 | 0 | 2 |
| 1 | 2 | 1 | 1 |
| 1 | 0 | 1 | 2 |

Shortest distance = 6

$(4,1) \to (3,1) \to (2,2) \to (1,2)$

$(1,4) \leftarrow (1,3) \leftarrow$

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(b) Give the condition under which the $D_4$ distance b/n two points p and q is equal to the shortest 4 path between these points.

(i) p, q is in same row, but direct path is not there in same row

$$\begin{matrix} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & \boxed{1} & 1 \\ \boxed{1} & 0 & 1 & 2 \end{matrix}$$

$\therefore 2 \neq 4$

(ii) p, q is in same column, but direct path is not there

(iii) $V=\{1,2\}$ are not in same row/column

8 - path

$$\begin{matrix} 3 & 1 & 2 & 1\ q(1,4) \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 0 & 1 & 2 \end{matrix}$$

p (4,1)

$V=\{1,2\}$

$D_8 \Rightarrow \max\{|x_2-x_1|, |y_2-y_1|\}$

$= \max\{|3|, |-3|\}$

$= 3$

$D_8 \leq 8$ path

here, shortestpath = 4

* Now, let q be (4,3), p (4,1)

$$\begin{matrix} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ \boxed{1} & 0 & \boxed{1} & 2 \end{matrix}$$

p(4,1) q(4,3)

shortest path = 2

$p(4,1) \rightarrow p(3,2) \rightarrow p(4,3)$

$D_8 = \max\{|0|, |2|\}$

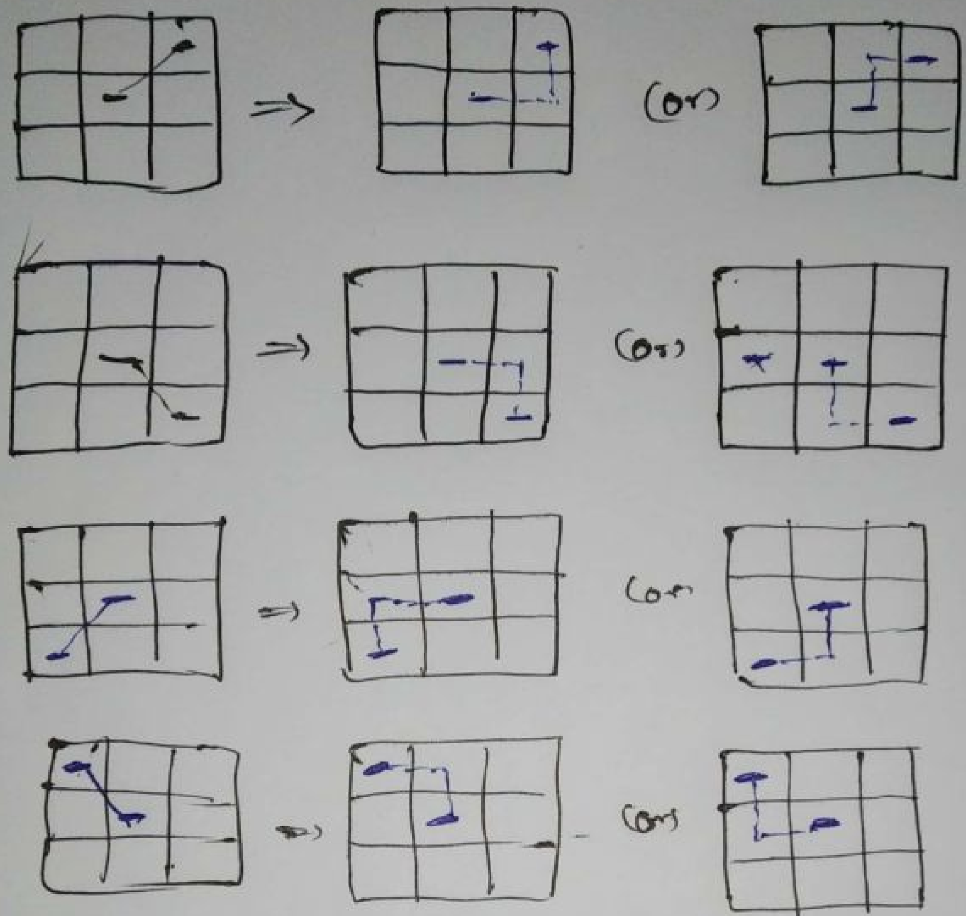
$= 2$

$\therefore$ wherever in the matrix we place q, the shortest path and $D_8$ distance are same

→ No, there are multiple paths.

Date: 24/8/21

Develop a algorithm for converting a one-pixel there 8 path to 4 path



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YouTube Channel: Muni Sekhar Velpuru


# Fundamentals of Image Processing

By
Dr. Muni Sekhar Velpuru,
Associate Professor & HOD
Department of Information Technology

# Content

- Fundamentals
- Image acquisition,
- Image model
- Sampling and Quantization
- Relationship between pixels,
- Distance  measures
- Connectivity
- Image  geometry



Dr. V Muni Sekhar, Associate Professor & Head, Department of Information Technology

# Fundamentals of Image Processing

- **What is Digital Image Processing?**

**Digital Image:**

— a two-dimensional function

x and y are spatial coordinates

The amplitude of $f$ is called intensity or gray level at the point (x, y)

$$f(x, y) = i(x, y) * r(x, y)$$

*f-> intensity*

*i-> illumination*

*r-> reflectance*

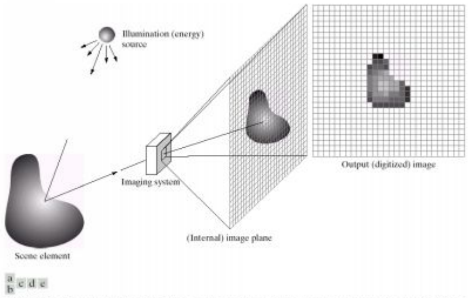


**FIGURE 2.15** An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

## Digital Image Processing:

— process digital images by means of computer, it covers low-, mid-, and high-level processes

low-level: inputs and outputs are images **(Enhancement)**

mid-level: outputs are attributes extracted from input images **(Feature extraction)**

high-level: an ensemble of recognition of individual objects **(Face recognition)**

**Reflectance**

0.01 for black velvet
0.65 for stainless steel
0.80 for flat-white wall paint
0.90 for silver-plated metal
0.93 for snow



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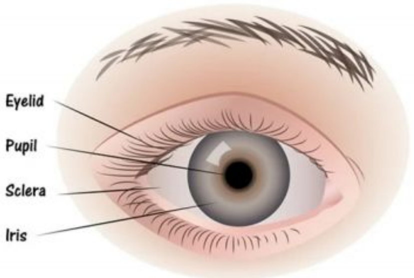
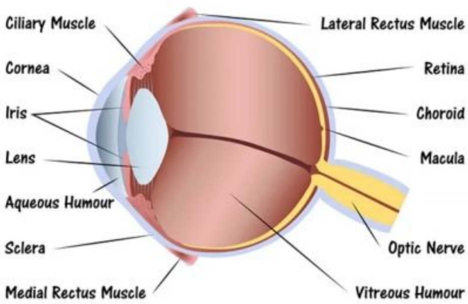
# Image Formation in Human Visual System



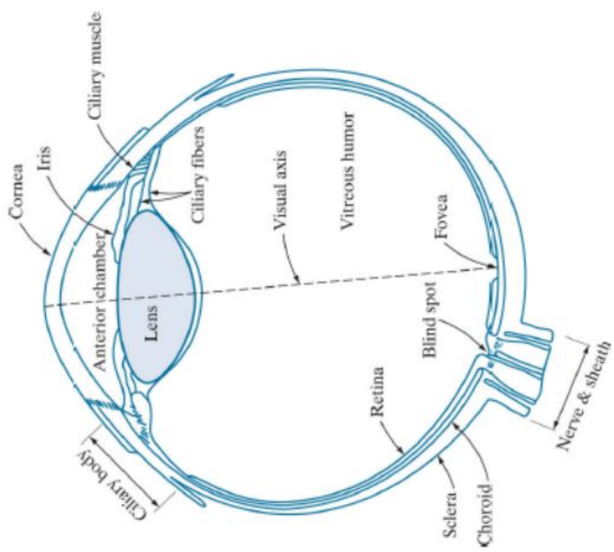




FIGURE 2.1
Simplified diagram of a cross section of the human eye.



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# The Origins of Digital Image Processing

One of the earliest applications of digital images was in the newspaper industry, when pictures were first sent by submarine cable between London and New York.

**Transmission Tech:** Bartlane cable
**Printing Tech:** telegraph printer fitted with typefaces simulating a halftone pattern
**Year:** 1921
**Gray level:** 5

**Transmission Tech:** Bartlane cable
**Printing Tech:** photographic reproduction made from tapes perforated at the telegraph receiving terminal
**Year:** 1922

**Transmission Tech:** Bartlane cable
**Printing Tech:** film plate via light beams that were modulated by the coded picture tape
**Year:** 1929
**Gray level:** 15



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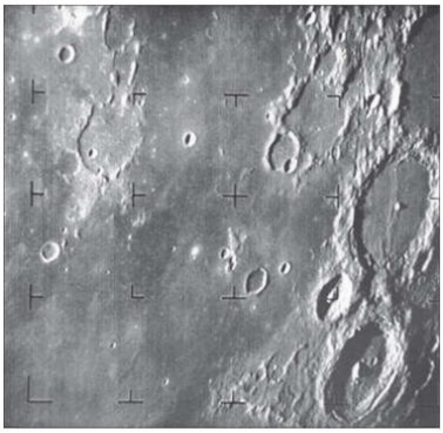
# Initial Digital Image Processing- Applications



•Early 1970s to be used in medical imaging, remote Earth resources observations, and astronomy.

Today, there is almost no area of technical endeavor that is not impacted in some way by digital image processing.

**Application:** space applications
**Technique:** Jet Propulsion Laboratory (Pasadena, California) in 1964
**Date:** July 31, 1964 at 9:09 AM.
**Gray level:** 5



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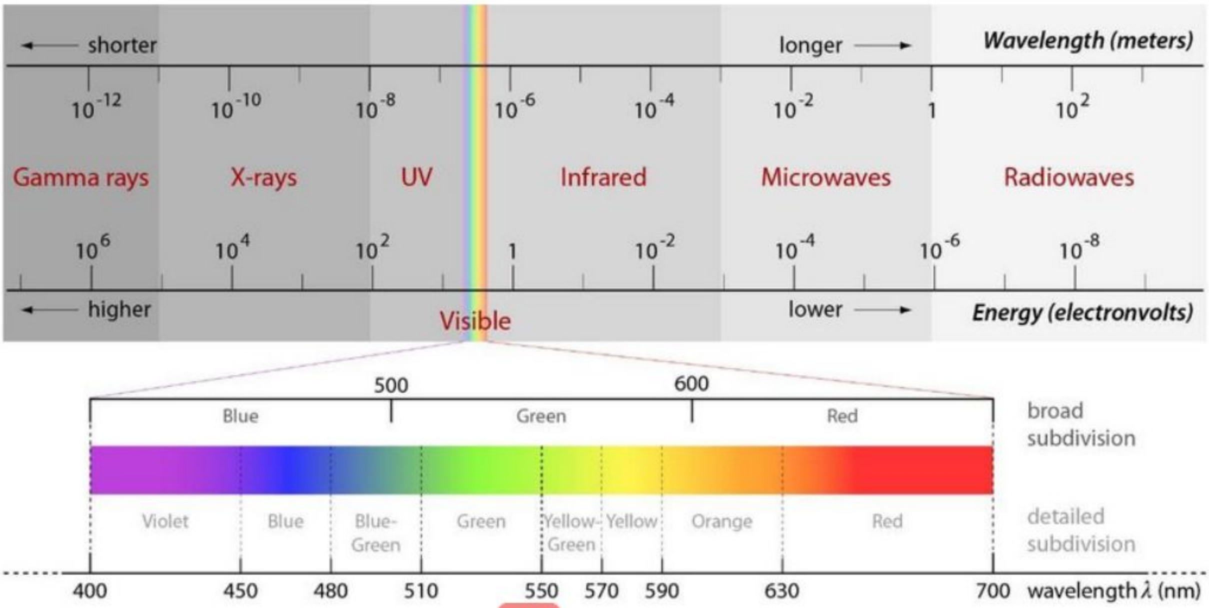
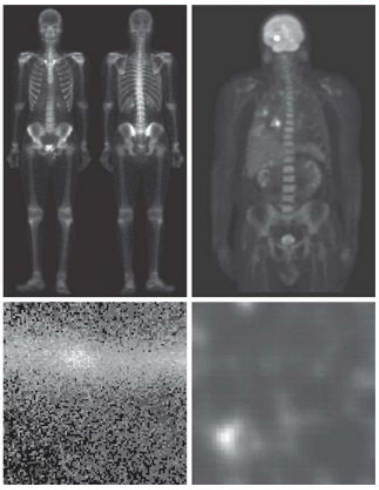
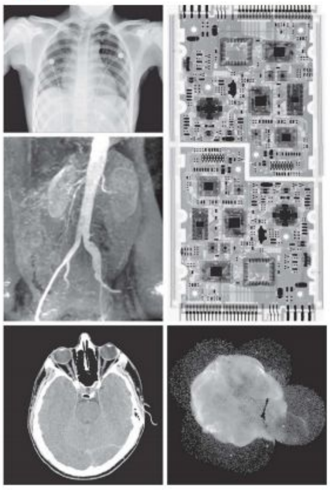
# Electromagnetic spectrum



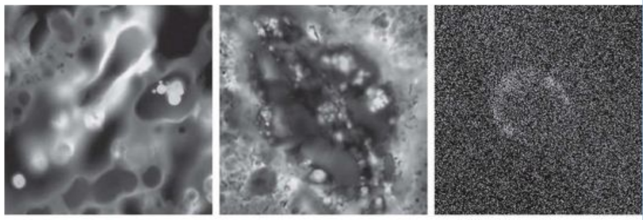
# Examples of Fields that Use Digital Image Processing



Gamma- Ray and PET



X-Ray



a b c

Ultra Violet

a b c
d e f

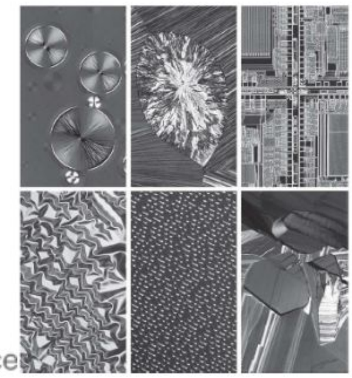




**FIGURE 1.9**
Examples of light microscopy images. (a) Taxol (anticancer agent), magnified $250\times$. (b) Cholesterol—$40\times$. (c) Microprocessor—$60\times$. (d) Nickel oxide thin film—$600\times$. (e) Surface of audio CD—$1750\times$. (f) Organic super-conductor—$450\times$. (Images courtesy of Dr. Michael W. Davidson, Florida State University.)

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# Examples of Fields that Use Digital Image Processing

a b
c
d


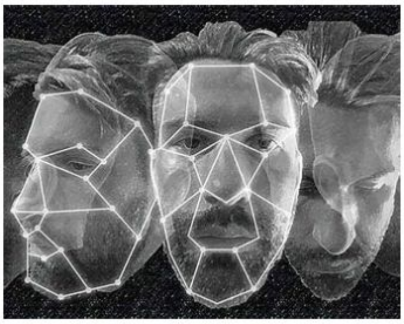

FIGURE 1.15
Some additional examples of imaging in the visible spectrum. (a) Thumb print. (b) Paper currency. (c) and (d) Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)



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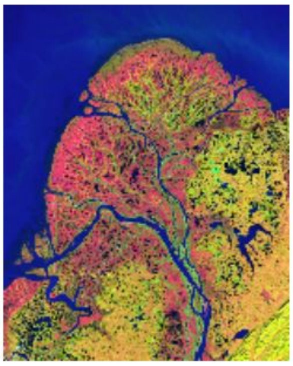
# Examples of Fields that Use Digital Image Processing

**TABLE 1.1**
Thematic bands of NASA's LANDSAT satellite.

| Band No. | Name | Wavelength ($\mu m$) | Characteristics and Uses |
|---|---|---|---|
| 1 | Visible blue | 0.45– 0.52 | Maximum water penetration |
| 2 | Visible green | 0.53– 0.61 | Measures plant vigor |
| 3 | Visible red | 0.63– 0.69 | Vegetation discrimination |
| 4 | Near infrared | 0.78– 0.90 | Biomass and shoreline mapping |
| 5 | Middle infrared | 1.55–1.75 | Moisture content: soil/vegetation |
| 6 | Thermal infrared | 10.4–12.5 | Soil moisture; thermal mapping |
| 7 | Short-wave infrared | 2.09–2.35 | Mineral mapping |





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# Examples of Fields that Use Digital Image Processing

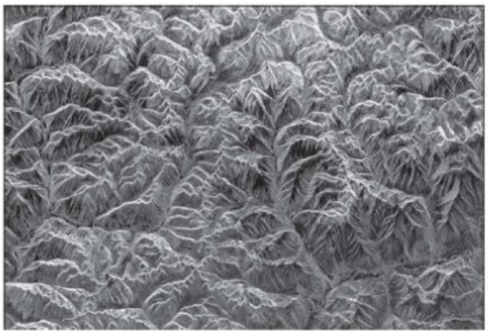
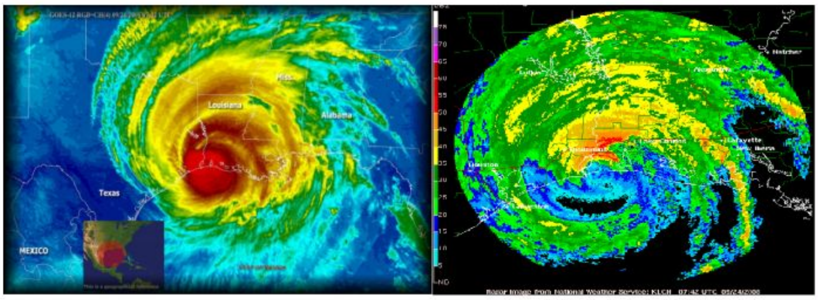


FIGURE 1.16
Spaceborne radar image of mountainous region in southeast Tibet. (Courtesy of NASA.)

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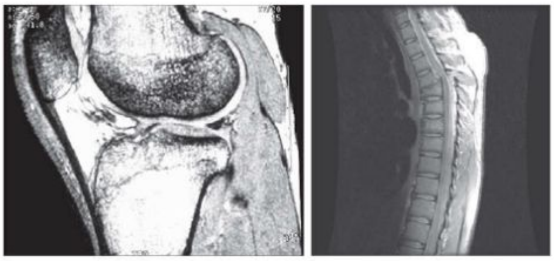
# Examples of Fields that Use Digital Image Processing



a b

**FIGURE 1.17**
MRI images of a human (a) knee, and (b) spine. (Figure (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Scien
Vanderbilt University Medical Center.)


**FIGURE 1.18**
Images of the Crab Pulsar (in the center of each image) covering the electromagnetic spectrum. (Courtesy of NASA.)

a b
c d

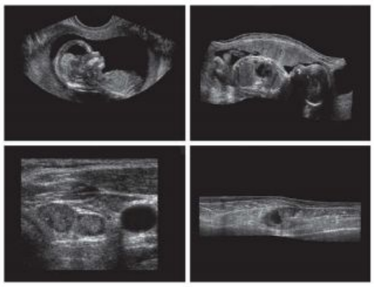


**FIGURE 1.20**
Examples of ultrasound imaging. (a) A fetus. (b) Another view of the fetus. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

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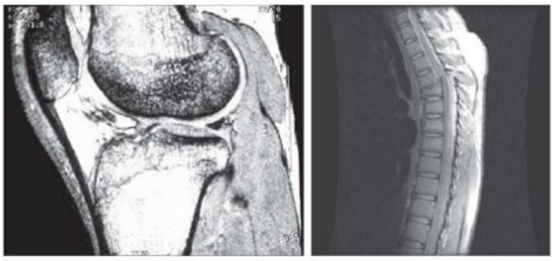
# Examples of Fields that Use Digital Image Processing



a b

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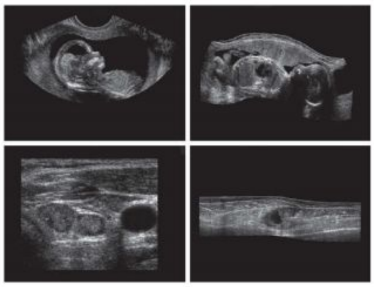
a b
c d



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Examples of ultrasound imaging. (a) A fetus. (b) Another view of the fetus. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)



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# What is DIP? (cont…)

- The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes

| Low Level Process | Mid Level Process | High Level Process |
|---|---|---|
| **Input:** Image<br>**Output:** Image | **Input:** Image<br>**Output:** Attributes | **Input:** Attributes **Output:** Understanding |
| **Examples:** Noise removal, image sharpening | **Examples:** Object recognition, segmentation | **Examples:** Scene understanding, autonomous navigation |

In this course we will stop here



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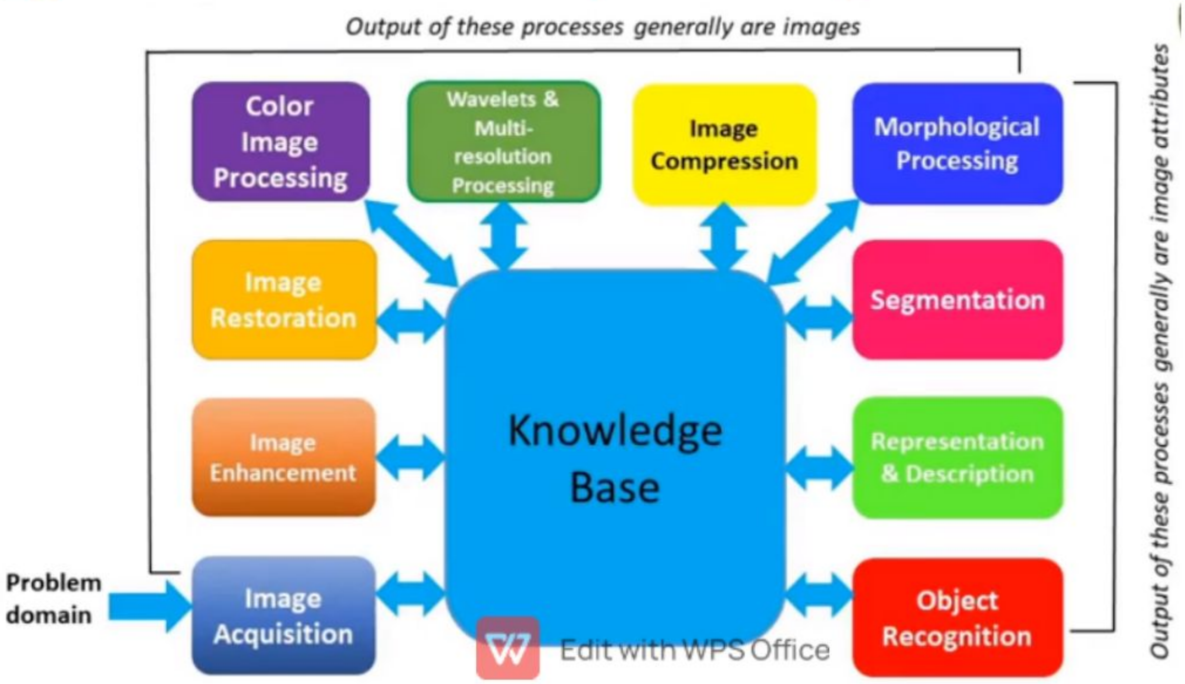
# Fundamental Steps in Image Processing



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# Fundamental Steps in Image Processing





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# Fundamental Steps in Image Processing






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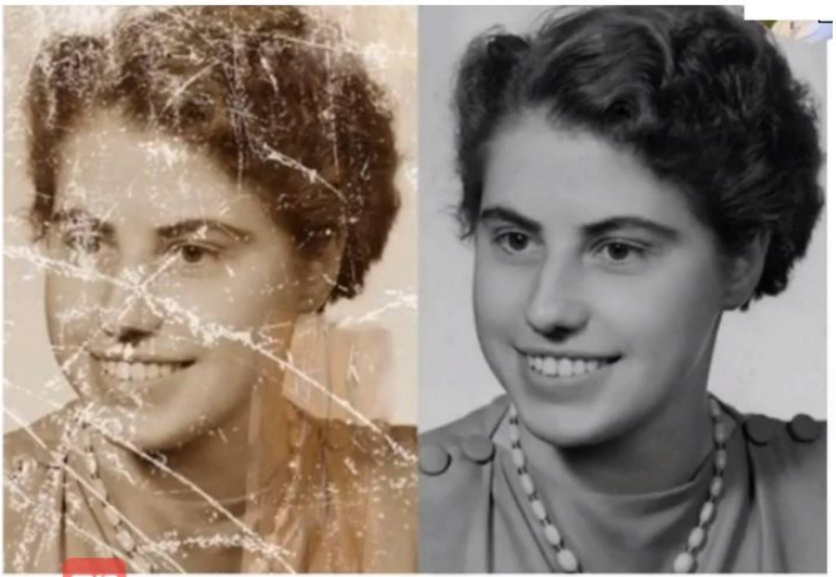
# Fundamental Steps in Image Processing

Source: https://towardsdatascience.com



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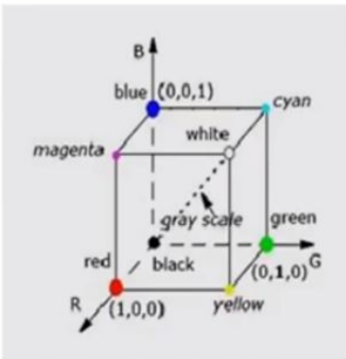
# Fundamental Steps in Image Processing

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# Fundamental Steps in Image Processing




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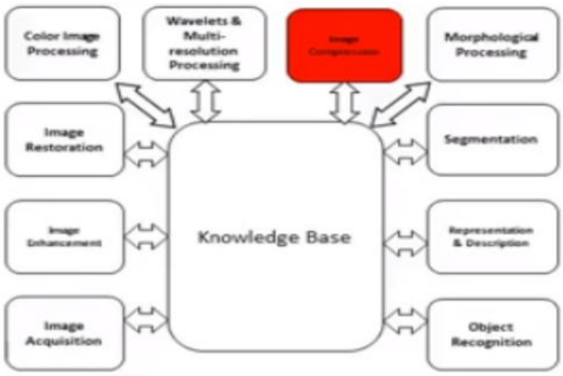
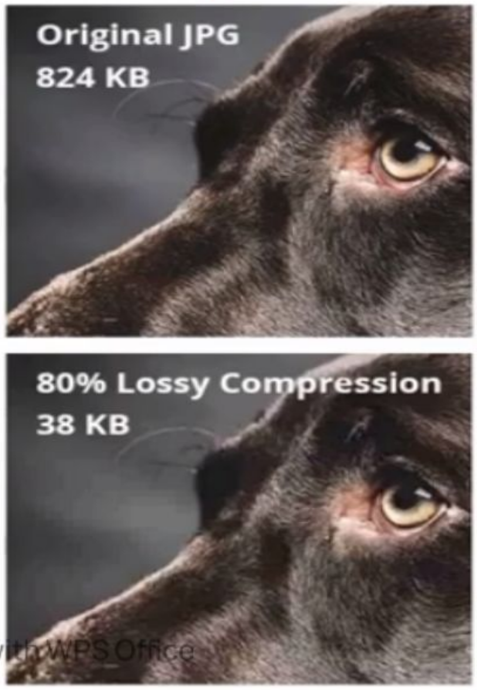
# Fundamental Steps in Image Processing



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# Fundamental Steps in Image Processing



FIGURE 25-11
Binary skeletonization. The binary image of a fingerprint, (a), contains ridges that are many pixels wide. The skeletonized version, (b), contains ridges only a single pixel wide.



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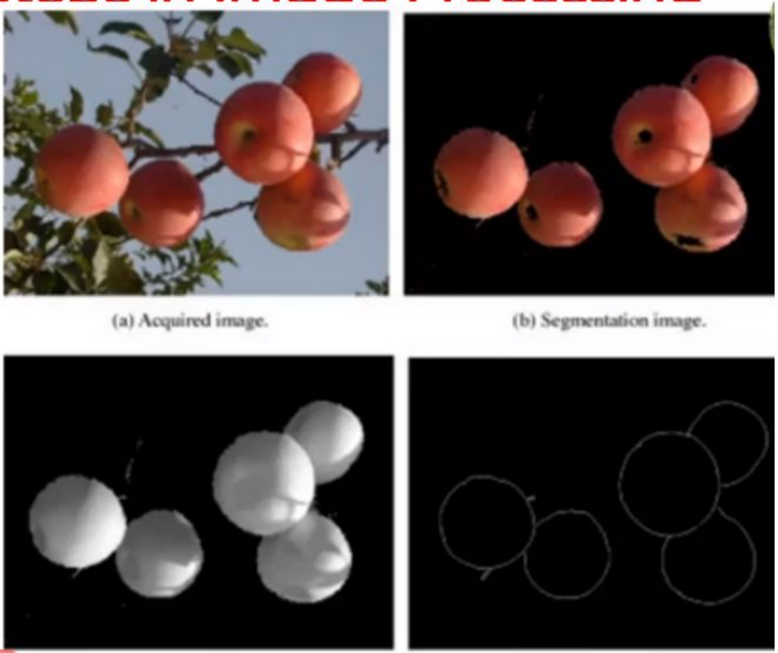
# Fundamental Steps in Image Processing

(a) Acquired image. (b) Segmentation image.

(c) Gray image. (d) Edge image.



Source: http://www.sciencedirect.com/science/article/pii/S003040261

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# Fundamental Steps in Image Processing


a b
c d

**FIGURE 11.21** (a) Infrared image of the Washington, D.C. area. (b) Thresholded image. (c) The largest connected component of (b). Skeleton of (c).

# Fundamental Steps in Image Processing


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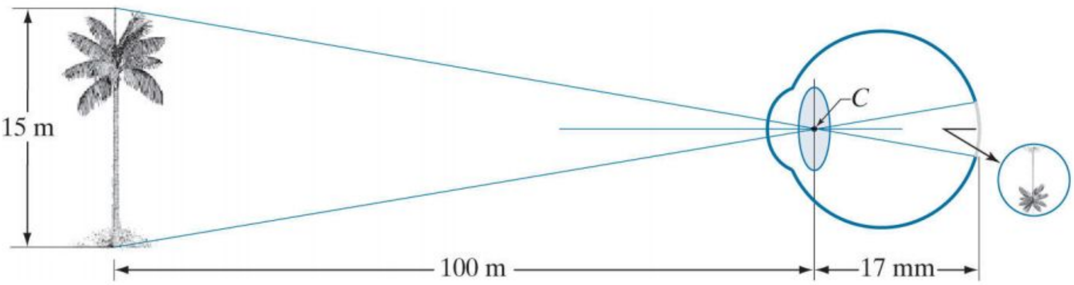
# Image Formation in the Eye

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# A Simple Image Formation Model

$f(x, y) = i(x, y) \bullet r(x, y)$

$f(x, y)$ : intensity at the point $(x, y)$

$i(x, y)$ : illumination at the point $(x, y)$

(the amount of source illumination incident on the scene)

$r(x, y)$ : reflectance/transmissivity at the point $(x, y)$

(the amount of illumination reflected/transmitted by the object)

where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$



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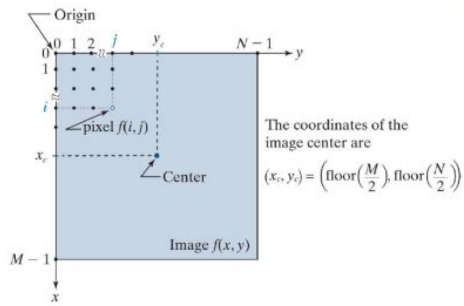
# Representing Digital Images

- The representation of an M×N numerical array as

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



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# Representing Digital Images

Discrete intensity interval [0, L-1], $L=2^k$

The number b of bits required to store a M × N digitized image

$b = M \times N \times k$

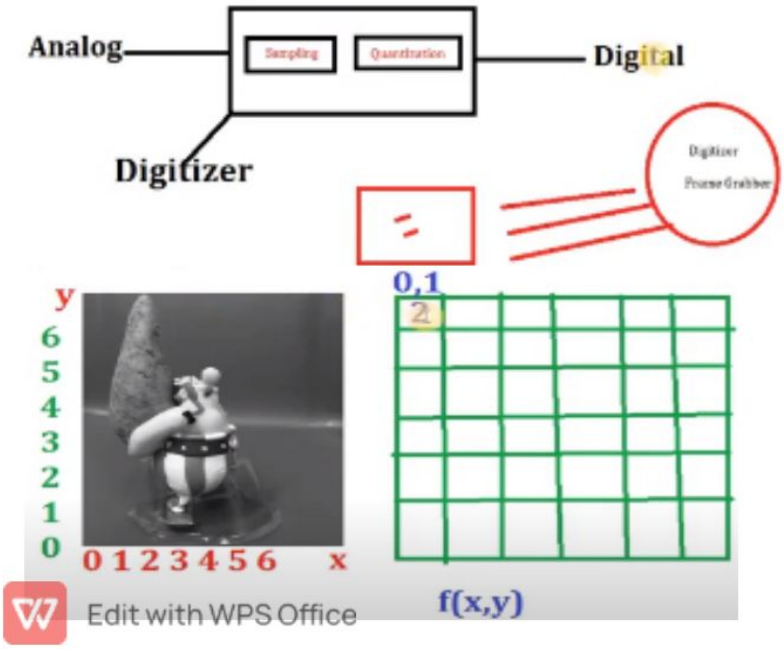
**TABLE 2.1**
Number of storage bits for various values of $N$ and $k$.

| $N/k$ | 1 ($L = 2$) | 2 ($L = 4$) | 3 ($L = 8$) | 4 ($L = 16$) | 5 ($L = 32$) | 6 ($L = 64$) | 7 ($L = 128$) | 8 ($L = 256$) |
|---|---|---|---|---|---|---|---|---|
| 32 | 1,024 | 2,048 | 3,072 | 4,096 | 5,120 | 6,144 | 7,168 | 8,192 |
| 64 | 4,096 | 8,192 | 12,288 | 16,384 | 20,480 | 24,576 | 28,672 | 32,768 |
| 128 | 16,384 | 32,768 | 49,152 | 65,536 | 81,920 | 98,304 | 114,688 | 131,072 |
| 256 | 65,536 | 131,072 | 196,608 | 262,144 | 327,680 | 393,216 | 458,752 | 524,288 |
| 512 | 262,144 | 524,288 | 786,432 | 1,048,576 | 1,310,720 | 1,572,864 | 1,835,008 | 2,097,152 |
| 1024 | 1,048,576 | 2,097,152 | 3,145,728 | 4,194,304 | 5,242,880 | 6,291,456 | 7,340,032 | 8,388,608 |
| 2048 | 4,194,304 | 8,388,608 | 12,582,912 | 16,777,216 | 20,971,520 | 25,165,824 | 29,369,128 | 33,554,432 |
| 4096 | 16,777,216 | 33,554,432 | 50,331,648 | 67,108,864 | 83,886,080 | 100,663,296 | 117,440,512 | 134,217,728 |
| 8192 | 67,108,864 | 134,217,728 | 201,326,592 | 268,435,456 | 335,544,320 | 402,653,184 | 469,762,048 | 536,870,912 |

How to Install Anaconda (Python) and Jupyter Notebook on Windows 10 - YouTube

# Sampling and Quantization

Sampling: Converting Coordinates
Quantization: Converting intensities

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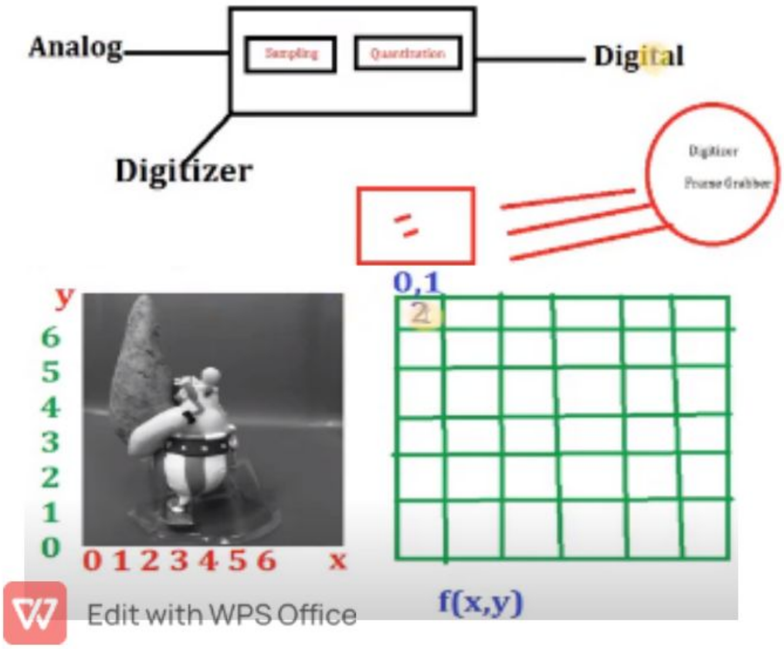
# Image Formation in the Eye

Sampling: Converting Coordinates
Quantization: Converting intensities

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# Relationship between pixels- Neighbors

## Neighbors of a Pixel

A pixel $p$ at coordinates $(x, y)$ has two horizontal and two vertical neighbors with coordinates

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

This set of pixels, called the 4-*neighbors* of $p$, is denoted $N_4(p)$.

The four *diagonal* neighbors of $p$ have coordinates

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

and are denoted $N_D(p)$. These neighbors, together with the 4-neighbors, are called the 8-*neighbors* of $p$, denoted by $N_8(p)$. The set of image locations of the neighbors of a point $p$ is called the *neighborhood* of $p$. The neighborhood is said to be *closed* if it contains $p$. Otherwise, the neighborhood is said to be *open*.



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# Relationship between pixels-Adjacency

## Adjacency, Connectivity, Regions, and Boundaries

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 grayscale image, the idea is the same, but set *V* typically contains more elements. For example, if we are dealing with the adjacency of pixels whose values are in the range 0 to 255, set *V* could be any subset of these 256 values. We consider three types of adjacency:

1. 4-*adjacency*. Two pixels *p* and *q* with values from *V* are 4-adjacent if *q* is in the set $N_4(p)$.
2. 8-*adjacency*. Two pixels *p* and *q* with values from *V* are 8-adjacent if *q* is in the set $N_8(p)$.
3. **m-adjacency** (also called *mixed adjacency*). Two pixels *p* and *q* with values from *V* are *m*-adjacent if
   a. *q* is in $N_4(p)$, *or*
   b. *q* is in $N_D(p)$ *and* the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from *V*.



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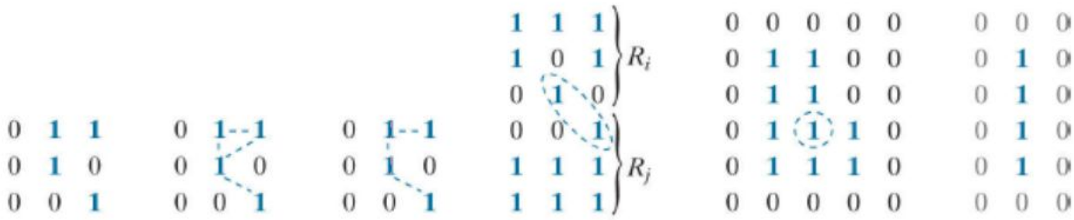
# Relationship between pixels- Adjacency Relationship

Mixed adjacency is a modification of 8-adjacency, and is introduced to eliminate the ambiguities that may result from using 8-adjacency. For example, consider the pixel arrangement in Fig. 2.28(a) and let $V = \{1\}$. The three pixels at the top of Fig. 2.28(b) show multiple (ambiguous) 8-adjacency, as indicated by the dashed lines. This ambiguity is removed by using $m$-adjacency, as in Fig. 2.28(c). In other words, the center and upper-right diagonal pixels are not $m$-adjacent because they do not satisfy condition (b).




a b c d e f

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# Relationship between pixels- Connected Set

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

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



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# Relationship between pixels- Region

Let *R* represent a subset of pixels in an image. We call *R* a *region* of the image if *R* is a connected set. Two regions, $R_i$ and $R_j$ are said to be *adjacent* if their union forms a connected set. Regions that are not adjacent are said to be *disjoint*. We consider 4- and 8-adjacency when referring to regions. For our definition to make sense, the type of adjacency used must be specified. For example, the two regions of 1's in Fig. 2.28(d) are adjacent only if 8-adjacency is used (according to the definition in the previous paragraph, a 4-path between the two regions does not exist, so their union is not a connected set).

Suppose an image contains *K* disjoint regions, $R_k, k = 1, 2, ..., K,$ none of which touches the image border.† Let $R_u$ denote the union of all the *K* regions, and let $(R_u)^c$ denote its complement (recall that the *complement* of a set *A* is the set of points that are not in *A*). We call all the points in $R_u$ the *foreground*, and all the points in $(R_u)^c$ the *background* of the image.

# Relationship between pixels- Boundary

**Definition of Boundary (also called border or contour) :**

- The boundary of a region R is the set of pixels in R that are adjacent to pixels in the complement of R.

Note: Only 8-adjacency or m-adjacency

| | | | | |
|---|---|---|---|---|
| 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 |

| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 |



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# Relationship between pixels- Path

**Definition of Path:** Number of pixels from pixel p with coordinates (x, y) to pixel q with coordinates (s, t).

| | | |
|---|---|---|
| 0 | 1 | 1 |
| 0 | 1 | 0 |
| 0 | 0 | 1 |



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# Distance Measures

For pixels $p$, $q$, and $s$, with coordinates $(x, y)$, $(u, v)$, and $(w, z)$, respectively, $D$ is a *distance function* or *metric* if

a. $D(p,q) \geq 0 \quad (D(p,q) = 0 \quad \text{iff} \quad p = q)$,
b. $D(p,q) = D(q,p)$, and
c. $D(p,s) \leq D(p,q) + D(q,s)$.

1. Euclidean Distance
2. City Block Distance or $D_4$
3. Chessboard Distance or $D_8$

The *Euclidean distance* between $p$ and $q$ is defined as

$$D_e(p,q) = [(x-u)^2 + (y-v)^2]^{\frac{1}{2}}$$

The $D_4$ *distance*, (called the *city-block distance*) between $p$ and $q$ is defined as

$$D_4(p,q) = |x-u| + |y-v|$$

The $D_8$ *distance* (called the *chessboard distance*) between $p$ and $q$ is defined as

$$D_8(p,q) = \max(|x-u|, |y-v|)$$

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



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# Distance Measures

In this case, the pixels with $D_8$ distance from (x, y) less than or equal to some value d form a square centered at (x, y). For example, the pixels with $D_8$ distance $\leq 2$ form the following contours of constant distance:

$$\begin{matrix} 2 & 2 & 2 & 2 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 1 & 0 & 1 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 2 \end{matrix}$$

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

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# Problems

A common measure of transmission for digital data is the *baud rate*, defined as the number of bits transmitted per second. Generally, transmission is accomplished in packets consisting of a start bit, a byte (8 bits) of information, and a stop bit. Using these facts, answer the following:

**(a)** How many minutes would it take to transmit a $1024 \times 1024$ image with 256 gray levels using a 56K baud modem?

**(b)** What would the time be at 750K baud, a representative speed of a phone DSL (digital subscriber line) connection?



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# Problems

Consider the two image subsets, $S_1$ and $S_2$, shown in the following figure. For $V = \{1\}$, determine whether these two subsets are (a) 4-adjacent, (b) 8-adjacent, or (c) $m$-adjacent.

| | | $S_1$ | | | | $S_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |



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# Problems

Develop an algorithm for converting a one-pixel-thick 8-path to a 4-path.

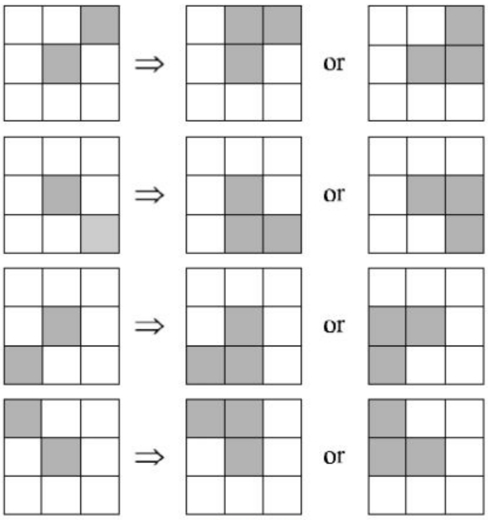

**Figure P2.12**



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# Problems

Develop an algorithm for converting a one-pixel-thick 8-path to a 4-path.

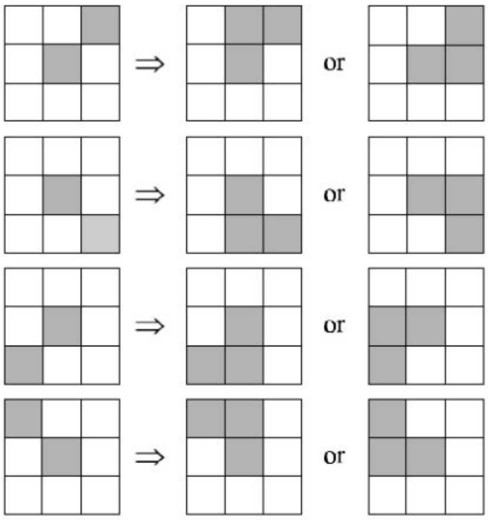


**Figure P2.12**



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# Problems

Show that the boundary of the region, as defined in Section 2.5.2, is a closed path.

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# Problems

Consider the image segment shown.

**(a)** Let $V = \{0, 1\}$ and compute the lengths of the shortest 4-, 8-, and $m$-path between $p$ and $q$. If a particular path does not exist between these two points, explain why.

**(b)** Repeat for $V = \{1, 2\}$.

| | | | | |
|---|---|---|---|---|
| | 3 | 1 | 2 | 1 $(q)$ |
| | 2 | 2 | 0 | 2 |
| | 1 | 2 | 1 | 1 |
| $(p)$ | 1 | 0 | 1 | 2 |

**(a)** Give the condition(s) under which the $D_4$ distance between two points $p$ and $q$ is equal to the shortest 4-path between these points.

**(b)** Is this path unique?

Repeat Problem 2.16 for the $D_8$ distance.



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# Question 1

- In the following arrangement of pixels, are the two regions (of 1s) adjacent? (if 8-adjacency is used)

| | | |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 0 | 1 |
| 0 | 1 | 0 |
| 0 | 0 | 1 |
| 1 | 1 | 1 |
| 1 | 1 | 1 |

Region 1

Region 2

## Question 2

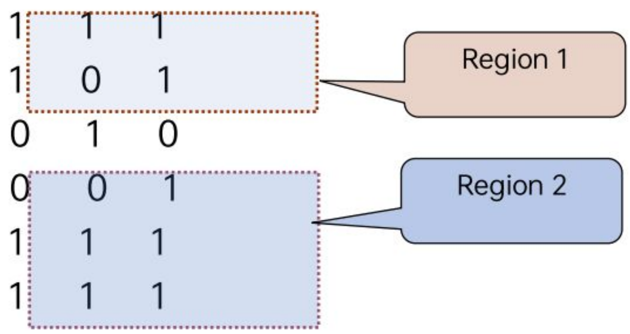
- **In the following arrangement of pixels, are the two parts (of 1s) adjacent? (if 4-adjacency is used)**

| | | |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 0 | 1 |
| 0 | 1 | 0 |
| 0 | 0 | 1 |
| 1 | 1 | 1 |
| 1 | 1 | 1 |

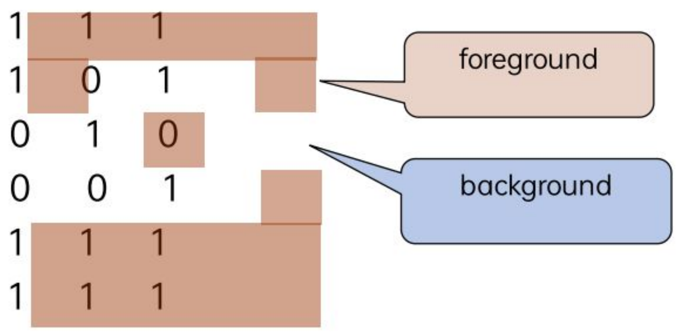
Part 1

Part 2

- In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)



- In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)

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## Question 3

- **In the following arrangement of pixels, the circled point is part of the boundary of the 1-valued pixels if 8-adjacency is used, true or false?**

| | | | | |
|---|---|---|---|---|
| 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 |

## Question 4

- In the following arrangement of pixels, the circled point is part of the boundary of the 1-valued pixels if 4-adjacency is used, true or false?

| | | | | |
|---|---|---|---|---|
| 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 |

## Distance Measures

- Given pixels *p, q* and *z* with coordinates (x, y), (s, t), (u, v) respectively, the distance function D has following properties:

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

b. $D(p, q) = D(q, p)$

c. $D(p, z) \leq D(p, q) + D(q, z)$

# Distance Measures

The following are the different Distance measures:

a. Euclidean Distance :

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

b. City Block Distance:

$D_4(p, q) = |x-s| + |y-t|$

| | | | | |
|---|---|---|---|---|
| | | 2 | | |
| | 2 | 1 | 2 | |
| 2 | 1 | 0 | 1 | 2 |
| | 2 | 1 | 2 | |
| | | 2 | | |

c. Chess Board Distance:

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

| | | | | |
|---|---|---|---|---|
| 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 |

## Question 5

- In the following arrangement of pixels, what's the value of the chessboard distance between the circled two points?

| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |

# Question 6

- In the following arrangement of pixels, what's the value of the city-block distance between the circled two points?

| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |

# Introduction to Mathematical Operations in DIP

- **Array vs. Matrix Operation**

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \qquad B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

Array product operator

$$A \;.*\; B = \begin{bmatrix} a_{11}b_{11} & a_{12}b_{12} \\ a_{21}b_{21} & a_{22}b_{22} \end{bmatrix}$$

Array product

Matrix product operator

$$A * B = \begin{bmatrix} a_{11}b_{11} + a_{12}b_{21} & a_{11}b_{12} + a_{12}b_{22} \\ a_{21}b_{11} + a_{22}b_{21} & a_{21}b_{12} + a_{22}b_{22} \end{bmatrix}$$

Matrix product

# Introduction to Mathematical Operations in DIP

- **Linear vs. Nonlinear Operation**

$$H\left[f(x,y)\right] = g(x,y)$$

$$\begin{aligned}
&H\left[a_i f_i(x,y) + a_j f_j(x,y)\right] \\
&= H\left[a_i f_i(x,y)\right] + H\left[a_j f_j(x,y)\right] \quad \text{Additivity} \\
&= a_i H\left[f_i(x,y)\right] + a_j H\left[f_j(x,y)\right] \quad \text{Homogeneity} \\
&= a_i g_i(x,y) + a_j g_j(x,y)
\end{aligned}$$

H is said to be a **linear operator;**

H is said to be a **nonlinear operator** if it does not meet the above qualification.

## Arithmetic Operations

- Arithmetic operations between images are array operations. The four arithmetic operations are denoted as

$$s(x,y) = f(x,y) + g(x,y)$$
$$d(x,y) = f(x,y) - g(x,y)$$
$$p(x,y) = f(x,y) \times g(x,y)$$
$$v(x,y) = f(x,y) \div g(x,y)$$

## Example: Addition of Noisy Images for Noise Reduction

Noiseless image: f(x,y)

Noise: n(x,y) (at every pair of coordinates (x,y), the noise is uncorrelated and has zero average value)

Corrupted image: g(x,y)

$$g(x,y) = f(x,y) + n(x,y)$$

Reducing the noise by adding a set of noisy images, $\{g_i(x,y)\}$

$$\overline{g}(x, y) = \frac{1}{K}\sum_{i=1}^{K} g_i(x, y)$$

Example: Addition of Noisy Images for Noise Reduction

$$\overline{g}(x, y) = \frac{1}{K}\sum_{i=1}^{K} g_i(x, y)$$

$$E\{\overline{g}(x, y)\} = E\left\{\frac{1}{K}\sum_{i=1}^{K} g_i(x, y)\right\}$$

$$= E\left\{\frac{1}{K}\sum_{i=1}^{K}[f(x, y) + n_i(x, y)]\right\}$$

$$= f(x, y) + E\left\{\frac{1}{K}\sum_{i=1}^{K} n_i(x, y)\right\}$$

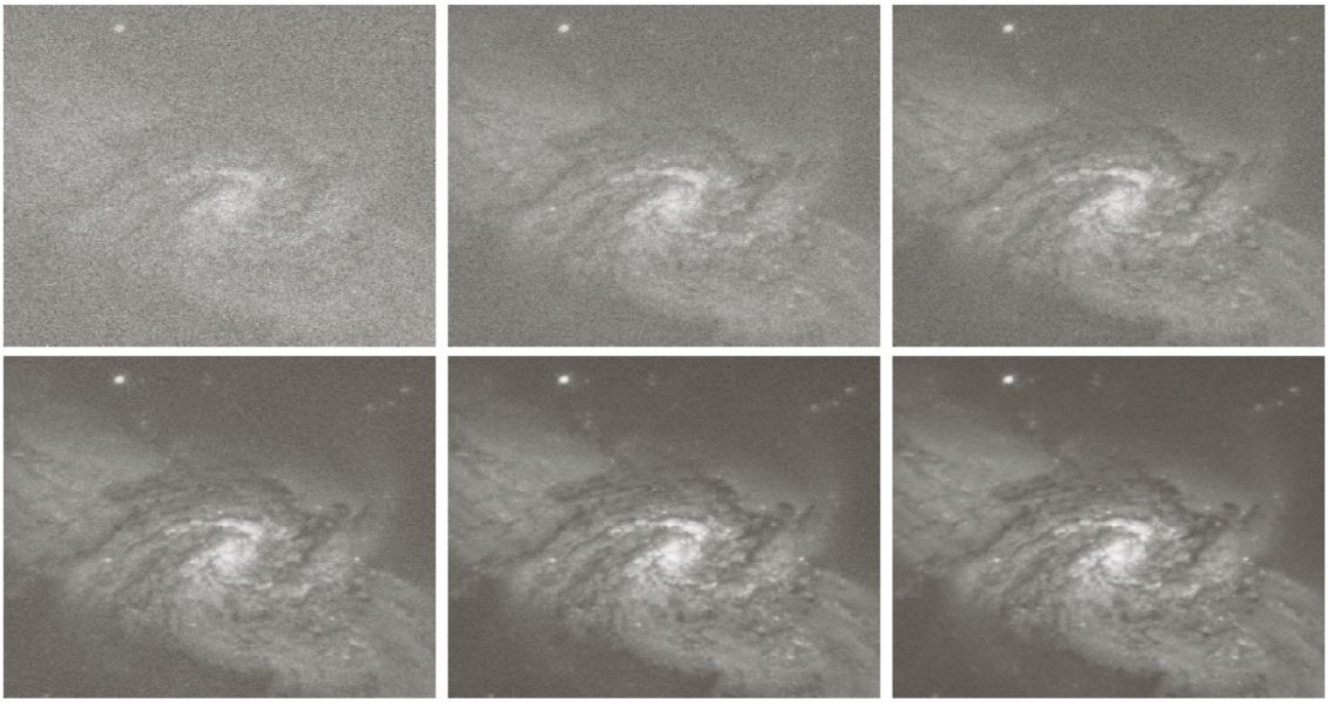
$$= f(x, y)$$

$$\sigma^2_{\overline{g}(x,y)} = \sigma^2_{\frac{1}{K}\sum_{i=1}^{K} g_i(x,y)}$$

$$= \sigma^2_{\frac{1}{K}\sum_{i=1}^{K} n_i(x,y)} = \frac{1}{K}\sigma^2_{n(x,y)}$$

## Example: Addition of Noisy Images for Noise Reduction

- In astronomy, imaging under very low light levels frequently causes sensor noise to render single images virtually useless for analysis.
- In astronomical observations, similar sensors for noise reduction by observing the same scene over long periods of time. Image averaging is then used to reduce the noise.



a b c
d e f



**FIGURE 2.26** (a) Image of Galaxy Pair NGC 3314 corrupted by additive Gaussian noise. (b)–(f) Results of averaging 5, 10, 20, 50, and 100 noisy images, respectively. (Original image courtesy of NASA.)

## An Example of Image Subtraction: Mask Mode Radiography

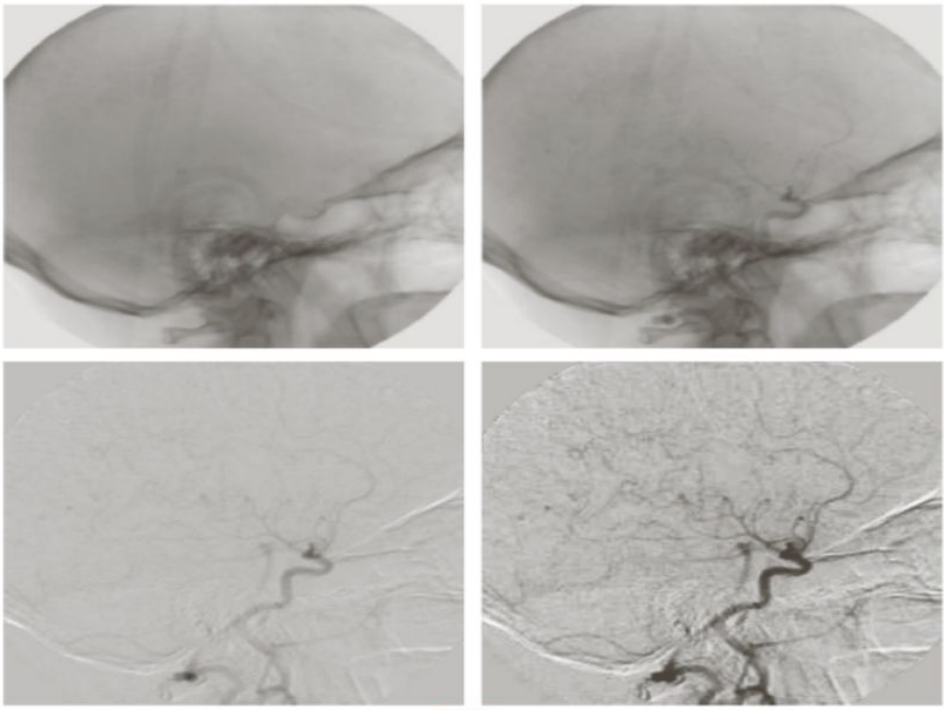
**Mask h(x,y):** an X-ray image of a region of a patient's body

**Live images f(x,y):** X-ray images captured at TV rates after injection of the contrast medium

**Enhanced detail g(x,y)**

$$g(x,y) = f(x,y) - h(x,y)$$

The procedure gives a movie showing how the contrast medium propagates through the various arteries in the area being observed.



a b
c d

**FIGURE 2.28** Digital subtraction angiography. (a) Mask image. (b) A live image. (c) Difference between (a) and (b). (d) Enhanced difference image. (Figures (a) and (b) courtesy of The Image Sciences Institute, University Medical Center, Utrecht, The Netherlands.)

An Example of Image Multiplication

a b c

**FIGURE 2.29** Shading correction. (a) Shaded SEM image of a tungsten filament and support, magnified approximately 130 times. (b) The shading pattern. (c) Product of (a) by the reciprocal of (b). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

# Set and Logical Operations

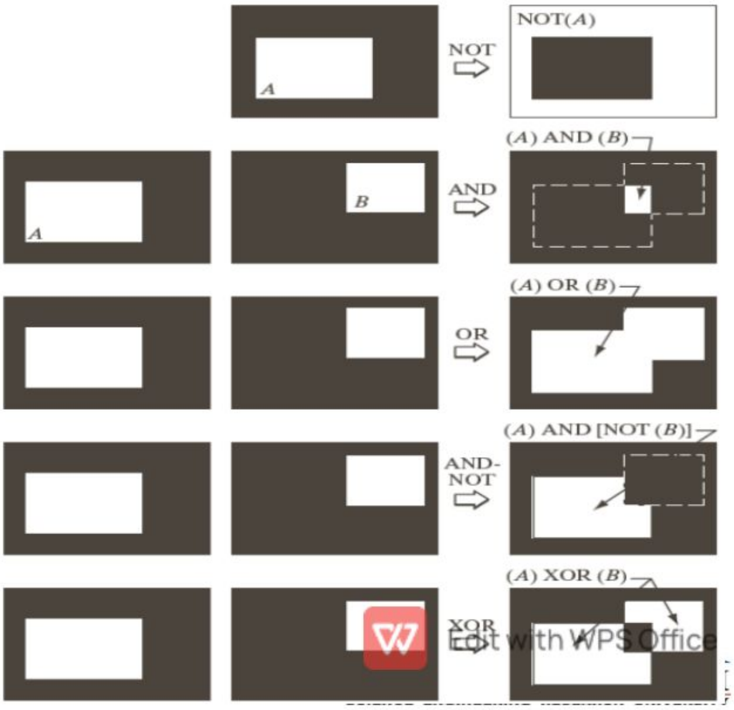



**FIGURE 2.33** Illustration of logical operations involving foreground (white) pixels. Black represents binary 0s and white binary 1s. The dashed lines are shown for reference only. They are not part of the result.

## Spatial Operations

- Single-pixel operations

  Alter the values of an image's pixels based on the intensity.

$$s = T(z)$$

e.g.,

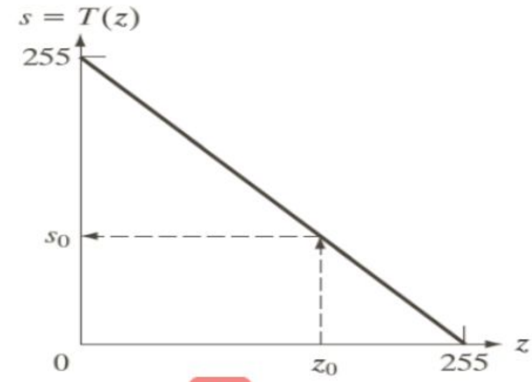
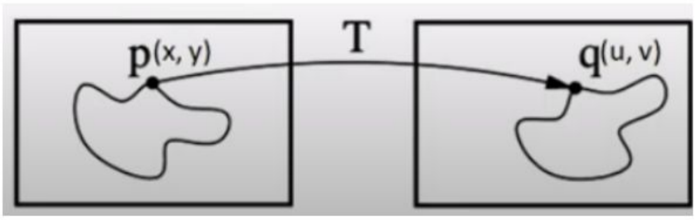



**FIGURE 2.34** Intensity transformation function used to obtain the negative of an 8-bit image. The dashed arrows show transformation of an arbitrary input intensity value $z_0$ into its corresponding output value $s_0$.

# Geometric/Spatial Transform

**Def:** Spatial/Geometric transformation of an Image is a geometric transformation of the image coordinate system.

**Note:** Image coordinates of each point (x, y) is mapped to a point (u, v) in a new coordinate system.




## Why it is used?

**Image Registration:** The process of transforming different set of images into same coordinate system.

- ***For example***, some person is clicking pictures of the same place at different times of the day and year to visualize the changes. Every time he clicks the picture, it's not necessary that he clicks the picture at the exact same angle. So for better visualization, he can align all the images at the same angle using geometric transformation.

## Applications of Image Geometry

➢ In many applications it is necessary to combine multiple images of the same scene acquired by different sensors or same sensors, from same or different viewpoint

Ex- Fusion of medical images like PET –MRI, CT-PET, CT-MRI etc. for diagnosis.

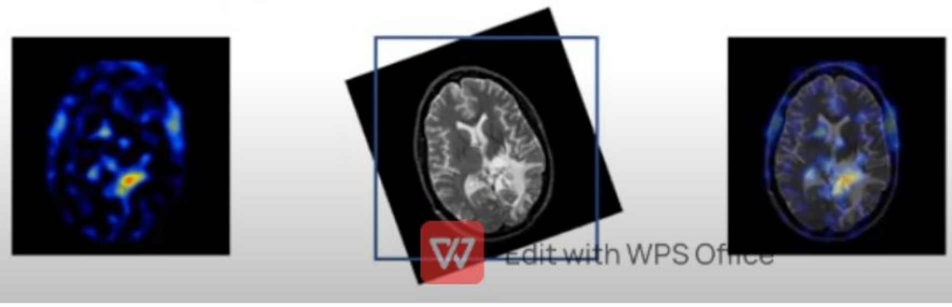
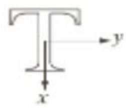
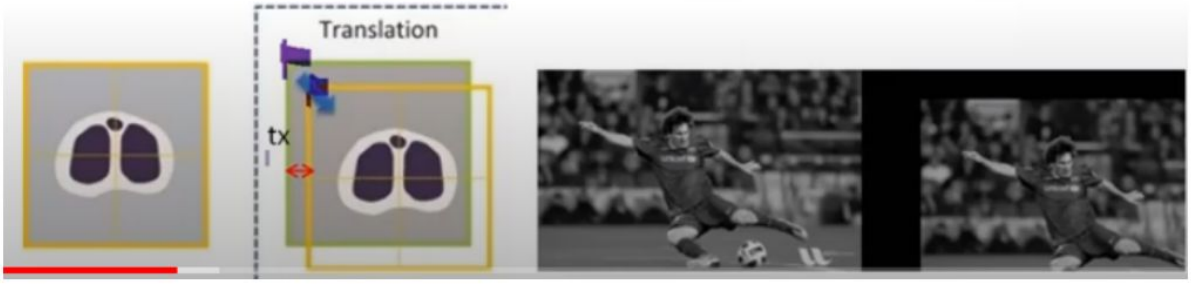


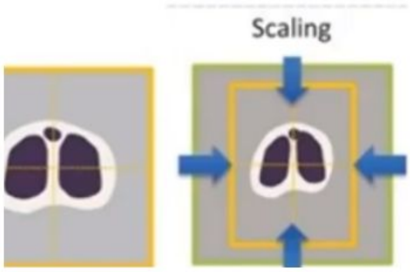
**TABLE 2.2**
Affine transformations based on Eq. (2.6.–23).

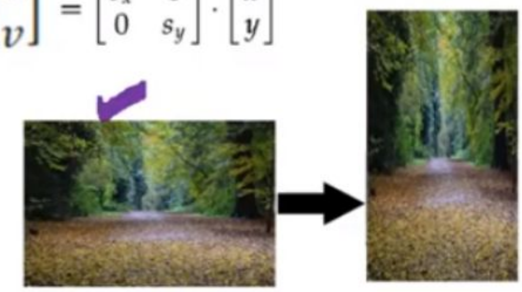
| Transformation Name | Affine Matrix, T | Coordinate Equations | Example |
|---|---|---|---|
| Identity | $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ | $x = v$<br>$y = w$ |   |
| Scaling | $\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$ | $x = c_x v$<br>$y = c_y w$ |  |
| Rotation | $\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$ | $x = v\cos\theta - w\sin\theta$<br>$y = v\cos\theta + w\sin\theta$ |  |
| Translation | $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{bmatrix}$ | $x = v + t_x$<br>$y = w + t_y$ |  |
| Shear (vertical) | $\begin{bmatrix} 1 & 0 & 0 \\ s_v & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ | $x = v + s_v w$<br>$y = w$ |  |
| Shear (horizontal) | $\begin{bmatrix} 1 & s_h & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ | $x = v$<br>$y = s_h v + w$ |  |

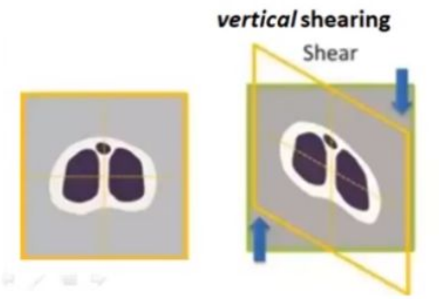

Translation
tx

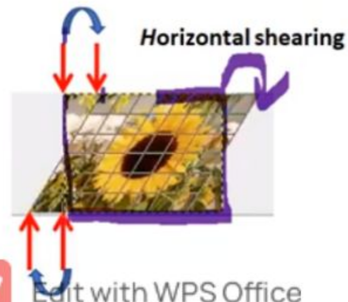

Rotation
Rotation angle =θ
(20,40)

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix}$$



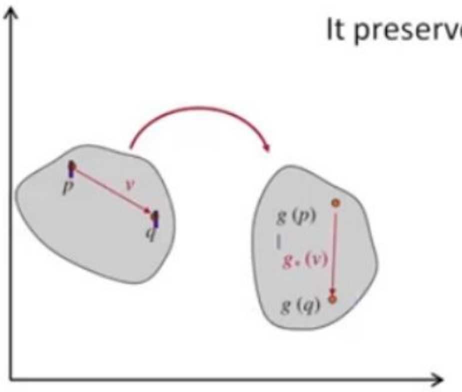





**Rigid transformation** : **It** is combination of translations and rotations

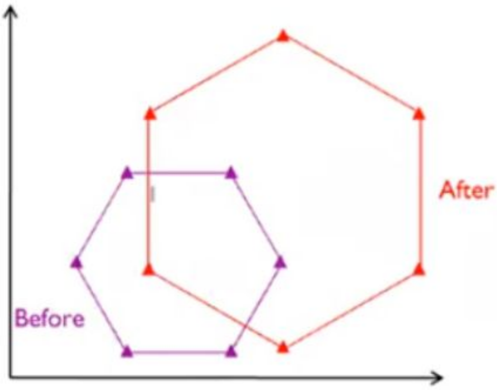
It preserves length




$$T = \begin{pmatrix} \cos\theta & -\sin\theta & x_t \\ \sin\theta & \cos\theta & y_t \\ 0 & 0 & 1 \end{pmatrix},$$

**Similarity transform:** It is combination of translations ,rotations and scale

- It preserves shape





$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{bmatrix} s\cos\theta & -s\sin\theta & t_x \\ s\sin\theta & s\cos\theta & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

where $s$ = scaling

## Affine Transformations

**It is combination of translations ,rotations , scale and shear**

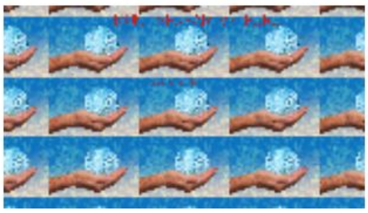
- An affine transformation is a transformation that preserves co-linearity and the ratio of distances (for example – the midpoint of a line segment is still the midpoint even after the transformation))
- **The parallel lines in an original image will be parallel in the output image.**

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} a_0 & a_1 & a_2 \\ b_0 & b_1 & b_2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

Affine

THANK YOU ALL

Dr. Muni Sekhar Velpuru



YouTube Channel: Muni Sekhar Velpuru


# Image Transforms

By
Dr. Muni Sekhar Velpuru,
Associate Professor & HOD
Department of Information Technology

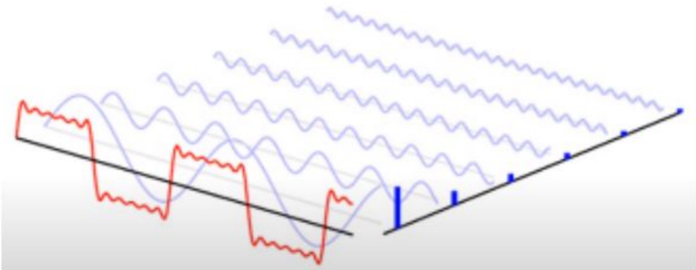
# Content

- Introduction to Image transforms
- Fourier Transform
- DFT- 1D and 2D DFT
- DFT properties
- FFT
- Walsh Transform and Hadamard Transforms
- DCT and Compaction property of DCT

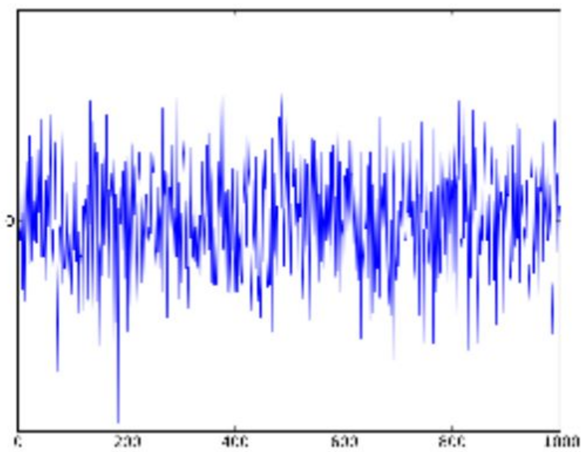


Dr. V Muni Sekhar, Associate Professor & Head, Department of Information Technology

# Fourier Transform



Periodic Signal




Noise Images



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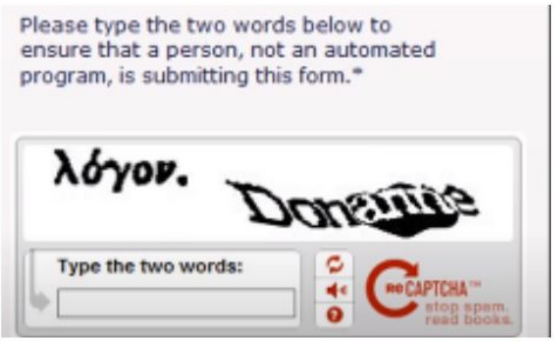
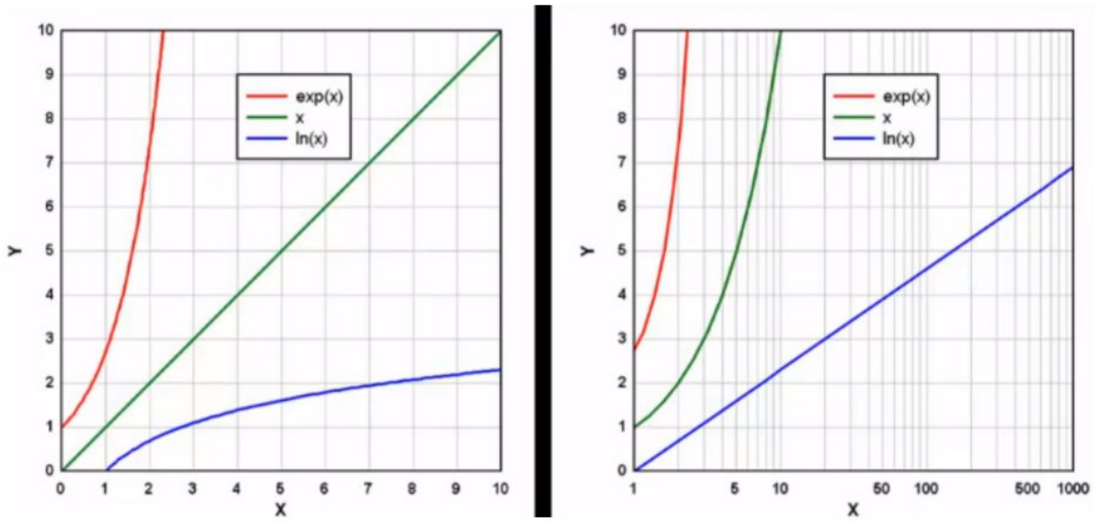
# Why Fourier Transform- Applications




# Why Fourier Transform- Functionality



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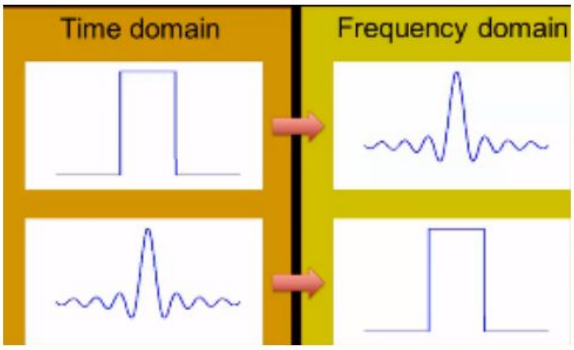
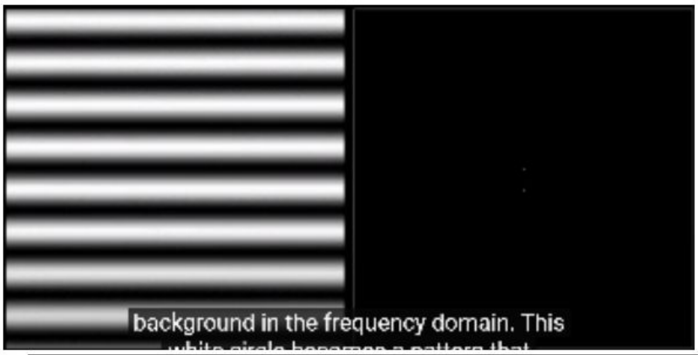
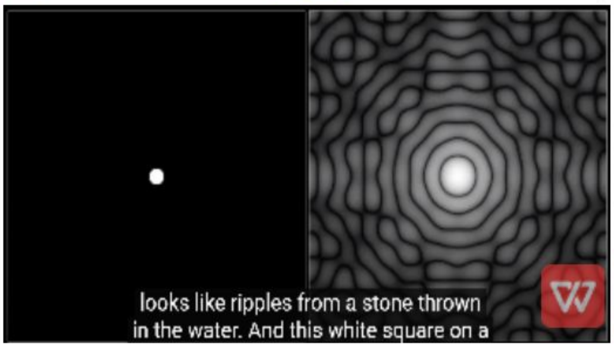
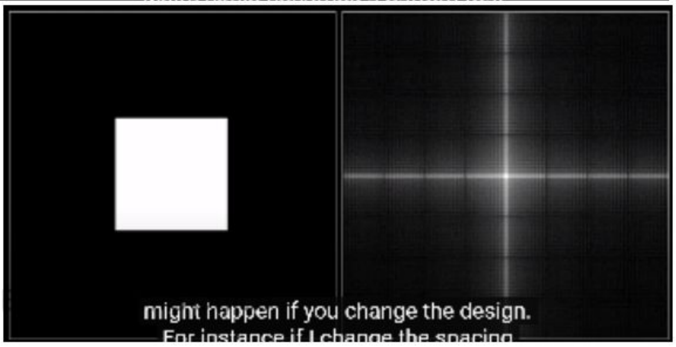
# Why Fourier Transform- Functionality

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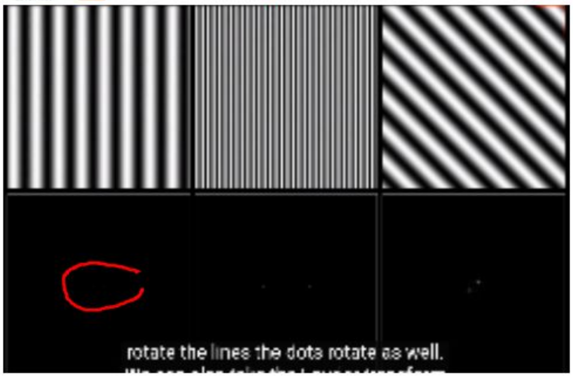
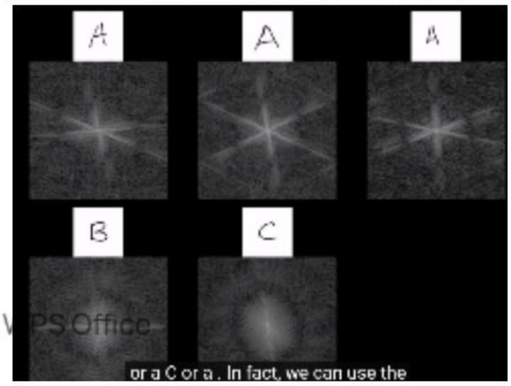
# Why Fourier Transform- Functionality







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# What is Fourier Transform?

- Fourier Transform is a mathematical tool used for frequency analysis of a signal. (ES, PS & Impulse Related signals)
- In Digital Image Processing, Fourier transform express relationship between Spatial and Frequency domain.
- It is also used for Image Enhancement in Frequency domain, OCR, Watermarking.

**Properties of DFT:**

1.Separability
2.Transform
3.Periodicity & Conjugate
4.Distributive and Scaling
5.Convolution and Correlation

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# Fourier Transform- Separability

**Example1.** A two dimensional DFT can be obtained using 1- dimensional –DFT algorithm twice, explain.
OR
Find 2–D DFT using separability property

For 4X4 image Kernel= $\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix}$

Lets Understand this with following example

| | | | |
|---|---|---|---|
| 0 | 1 | 2 | 1 |
| 1 | 2 | 3 | 2 |
| 2 | 3 | 4 | 3 |
| 1 | 2 | 3 | 4 |

| | | | |
|---|---|---|---|
| 0 | 1 | 2 | 1 |
| 1 | 2 | 3 | 2 |
| 2 | 3 | 4 | 3 |
| 1 | 2 | 3 | 4 |

Calculate 1–D DFT along rows.

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 2 \\ 1 \end{bmatrix} = \begin{bmatrix} 4 \\ -2 \\ 0 \\ -2 \end{bmatrix} \rightarrow \boxed{\text{DFT of } 1^{st} \text{ Row}}$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 3 \\ 2 \end{bmatrix} = \begin{bmatrix} 8 \\ -2 \\ 0 \\ -2 \end{bmatrix} \text{DFT of 2nd Row}$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 2 \\ 3 \\ 4 \\ 3 \end{bmatrix} = \begin{bmatrix} 12 \\ -2 \\ 0 \\ -2 \end{bmatrix} \text{DFT of 3rd Row}$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 3 \\ 2 \end{bmatrix} = \begin{bmatrix} 8 \\ -2 \\ 0 \\ -2 \end{bmatrix} \text{DFT of 4th Row}$$



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$$\begin{bmatrix} 4 & -2 & 0 & -2 \\ 8 & -2 & 0 & -2 \\ 12 & -2 & 0 & -2 \\ 8 & -2 & 0 & -2 \end{bmatrix}$$

Calculate 1–D DFT along columns.

$$DFT\ of\ 1st\ Column = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 4 \\ 8 \\ 12 \\ 8 \end{bmatrix} = \begin{bmatrix} 32 \\ -8 \\ 0 \\ -8 \end{bmatrix}$$

$$DFT\ of\ 2ndColumn = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} -2 \\ -2 \\ -2 \\ -2 \end{bmatrix} = \begin{bmatrix} -8 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$DFT\ of\ 3rd\ Column = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$DFT\ of 4th\ Column = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} -2 \\ -2 \\ -2 \\ -2 \end{bmatrix} = \begin{bmatrix} -8 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Two dimensional DFT of image F(u,v)=$Kernel$ X F(x,y) $Kernel^T$

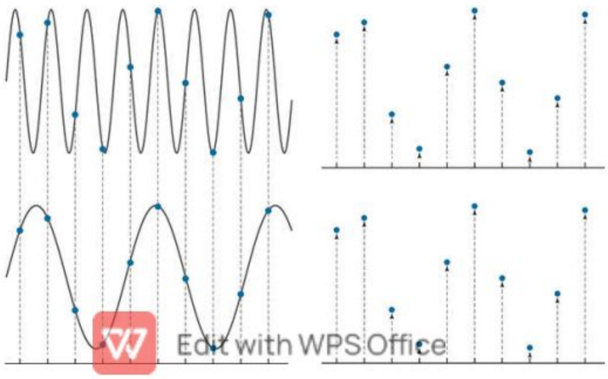
$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \times \begin{bmatrix} 0 & 1 & 2 & 1 \\ 1 & 2 & 3 & 2 \\ 2 & 3 & 4 & 3 \\ 1 & 2 & 3 & 4 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & -j \end{bmatrix}$$

2D DFT of 4 x 4 gray scale image

$$\begin{bmatrix} 32 & -8 & 0 & -8 \\ -8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -8 & 0 & 0 & 0 \end{bmatrix}$$

Literally, the word ***alias*** *means "a false identity." In the field of signal processing, aliasing refers to sampling phenomena that cause* different signals to become indistinguishable from one another after sampling; or, viewed another way, for one signal to "masquerade"
as another.

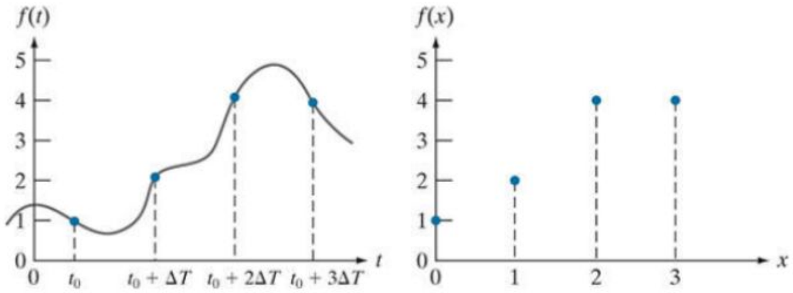
a b
c d



## *EXAMPLE 4.4: The mechanics of computing the DFT.*

Figure 4.12(a) shows four samples of a continuous function, *f*(*t*), taken $\Delta T$ units apart. Figure 4.12(b) shows the samples in the *x*-domain. The values of *x* are 0, 1, 2, and 3, which refer to the number of the samples in sequence, counting up from 0. For example, $f(2) = f(t_0 + 2\Delta T)$, the third sample of *f*(*t*)

a b



From Eq. (4-44) , the first value of $F(u)$ [i.e., $F(0)$] is

$$F(0) = \sum_{x=0}^{3} f(x) = [f(0) + f(1) + f(2) + f(3)] = 1 + 2 + 4 + 4 + 11$$

The next value of $F(u)$ is

$$F(1) = \sum_{x=0}^{3} f(x)e^{-j2\pi(1)x/4} = 1e^{0} + 2e^{-j\pi/2} + 4e^{-j\pi} + 4e^{-j3\pi/2} = -3 + 2j$$

Similarly, $F(2) = -(1 + 0j)$ and $F(3) = -(3 + 2j)$. Observe that *all* values of $f(x)$ are used in computing *each* value of $F(u)$.

If we were given $F(u)$ instead, and were asked to compute its inverse, we would proceed in the same manner, but using the inverse Fourier transform. For instance,

$$f(0) = \frac{1}{4}\sum_{u=0}^{3} F(u)e^{j2\pi u(0)} = \frac{1}{4}\sum_{u=0}^{3} F(u) = \frac{1}{4}[11 - 3 + 2j - 1 - 3 - 2j] = \frac{1}{4}[4] = 1$$

# Translation and Rotation

Translation of f(x,y) by (x0,y0) is equal to F(u,v) is multiplied by DFT component of (x0,y0).

$$f(x,\ y)e^{j2\pi(u_0x/M+v_0y/N)} \Leftrightarrow F(u-u_0, v-v_0)$$

$$f(x\ -\ x_0, y\ -\ y_0) \Leftrightarrow F(u,v)\ e^{-j2\pi(x_0u/M+y_0v/N)}$$

Rotation of f(x,y) by Q is equal to F(u,v) is equal to rotation Q

$$x = r\cos\theta \qquad y = r\sin\theta \qquad u = \omega\cos\varphi \qquad v = \omega\sin\varphi$$

$$f(r,\theta+\theta_0) \Leftrightarrow F(\omega,\varphi+\theta_0)$$

# THANK YOU ALL

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