Module : 1

- Digital image processing
- Image, digital image.
- pixel
- Digital Image processing
- Fields that use digital Img processing
- Appl^n
- fundamental steps in digital Image processing
- Image processing basics.
- Image sensing
- Interlacing
- CRT with characteristics
- Image interpolation
- Image Resolution.
- Relationship bet^n pixels (Connectivity, Adjacency, Paths, Neighbours, Regions & boundaries
- Distance measures
- Transformation matrix
- Color fundamentals
  - CMYK, CMY, YIQ, RGB, YUV, YCbCr, HSI
- Image formats

Module 1

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Introduction to Digital Image Processing

▷ Image
- An image is two or three dimensional visual scene.
- Array / Matrix pixel arranged in columns and rows.

  pixel → picture element (i_0, j_0)

▷ Aspect Ratio (AR)
- Ratio of width with height
- Common AR : 4:3 (Standard TV)

  16:9 (widescreen)

▷ Digital Image
- $f(x,y)$
- x and y are spatial (→ Plane) co-ordinates and amplitude of f at any pair of co-ordinates (x,y).
- Image that is discretized in spatial co-ordinates and intensity values.
- Represented as matrix of pixels, with each pixel having numeric value representing its intensity.

Color image : $f(x,y) = [r(x,y), g(x,y), b(x,y)]$

▷ Digital Image processing
- Involves the manipulation of digital images using algo to improve their quality and extract useful info.
-

Image Processing → Image Analysis → Vision

HW 1 : Brightness Vs Intensity

Two principles
- 1] Improvement of pictorial info.
- 2] processing of img data for storage, transmission & representation

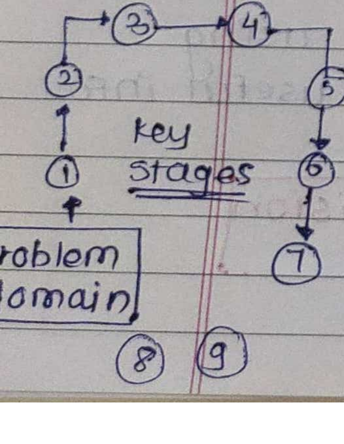
1) Image processing
- Low level processing
  - Reduce noise (unwanted sound)
  - Image sharpening
  - Contrast enhancement

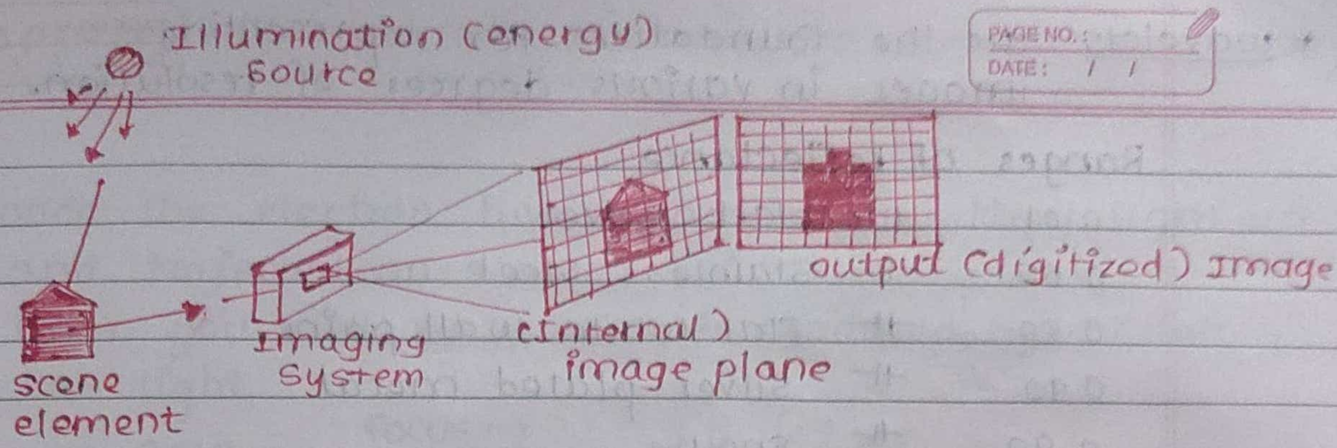
2) Image Analysis
- Mid level processing
  - Segmentation
  - Classification.

3) Vision.
- High level processing
  - Making sense of an ensemble of recognized object.

▷ Fundamental steps in digital Image processing

It involves :
1. Image acquisition (Involves preprocessing
2. Image enhancement
3. Image Restoration
4. Morphological processing
5. Segmentation
6. Object Recognition
7. Representation & Description
8. Compression
9. Color Image processing.





1. Image acquisition : Caputure of an image using various devices like cameras/sensors.
2. Image enhancement : Improving quality of an image.
3. Image restoration : Removing noise/distortions.
4. Morphological processing : Analyzing and processing the shapes & structure within image
5. Segmentation : Dividing an image.
6. Object recognition : Identifying & classifying objects within an image.
7. Representation & description : describing features of an image.
8. Compression : Reducing storage size of an image.
9. Color image processing : manipulating & analyzing color information in images. (this area has been gaining more importance)

▷ Image formation model :

Image formation model describes how an image is formed based on interaction betn illumination & reflectance.

illumination → Process of lightning

reflectance → determines how much light it reflects at diffnt wavelengths.

HW 2 : Study CRT ?

* wavelets : are the foundation for representing images in various degrees of resolution.

Ranges of reflectance

0.01	for	black velvet
0.65	-11-	Stainless steel
0.80	-11-	Flat-white wall paint.
0.90	-11-	Silver plated metal
0.93	-11-	snow

Representation Schemes

1. vector representation (uses geometrical primitives like points, lines and polygons for image representation)

2. Raster representation (Represents images as grid of pixels. with each pixel having specific value)
   - allows fill up the colors in graphics.

3. Scanning (Process of systematically capturing / Reading the intensity values of pixels in an image)

4. Interlacing : (Technique where odd and even lines are scanned separately & combined to form a complete image)

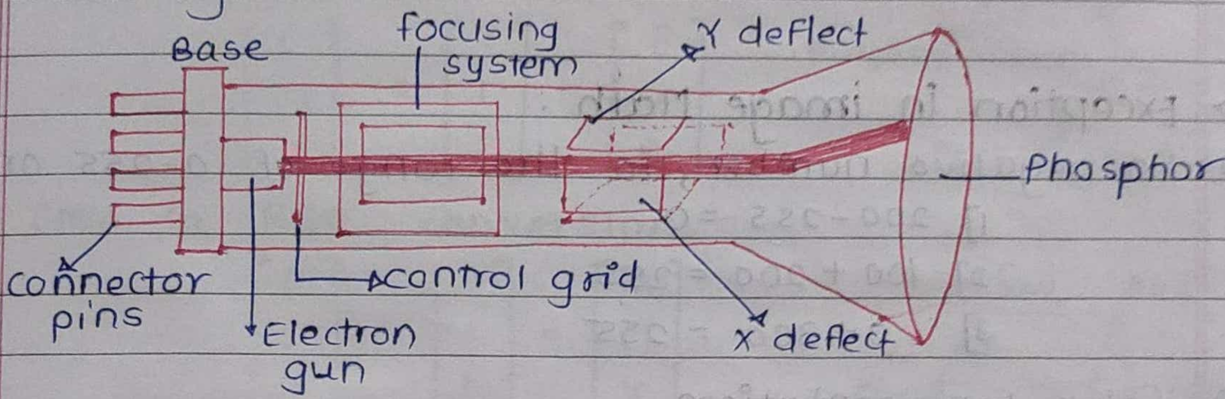
HW 2 : CRT (Cathode Ray Tube)

- Tech used in computer monitors and televisions
- Image on CRT display is created by firing electrons from the back of tube of phosphorous located towards the front of screen.

① Fluorescence : Light emitted while phosphor is being struck by electrons.

② Phosphorescence :- Light emitted once the electron beam is removed.

- once the electron heats phosphorus, they light up and Projected on screen.
- Color you view on screen is produced by blending RGB light.



- Phosphor ⟶ Fluorescene, Phosphoresence, Persistence } Characteristics
  ↳ (Time for removal of excitation to the moment when phosphoresence has decayed to 10%)

HW 1 Brightness Vs Intensity

→ Brightness : Subjective perception of how light / Dark an image appears to human eye.

→ Intensity : Refers to amount of light or radiation emitted, transmitted or received per unit area.

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- BPP : Bits per ~~[illegible]~~ pixel

Use : Numpy , Matplotlib

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- Assignment 1 (RGB imggo) as well as arithmetic ope
- Assignment 1 continued (enhancement)
- Assignment 2 (Inverted image)

▷ Exception in image Math :

i) No negative number, in the range of 0-255 only

1] 200 - 255 = 0

2] 100 + 200 = 255

3] 0 + 300 = 255

2) Color representation

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1] Color fundamentals

- Additive color model
  - RGB (Red, Green, Blue)
  - Colors created by adding diffnt intensities of red, green, blue light
  - Full intensity = in white
    absence of all three = Black

- Subtractive color model
  - CMY (Cyan, Magenta, Yellow) - secondary colo
  - Color created by subtracting diffnt amounts of cyan, magenta, yellow pigments from white light.

RGB : 24-bit color cube

$(2^8)^3 = 16,777,216$ colors.

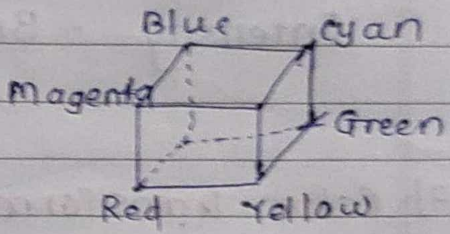
* RGB and CMY

Relation :

- complementary color model

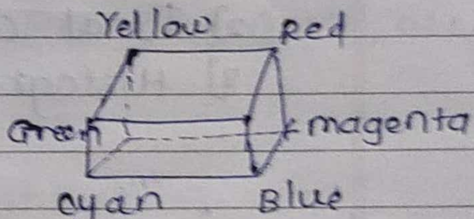
RGB to CMY conversion

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



CMY to RGB conversion

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$



* CMYK and CMY and YIQ

CMY → (cyan, Magenta, Yellow)

→ used in color mixing for display

CMYK → cyan, Magenta, Yellow, Black/key

YIQ –

→ Y is luminance (Brightness)

IQ is chrominance (color info)

→ used in television broadcasting.

YIQ defined by → NTSC (National Television sys committee)

chromaticity :

- Hue and saturation together

Hue ↓ dominat color wave length

saturation → Relative purity

* YUV and YCbCr
YUV : Y is brightness. U & V represents color info
YCbCr : Y is luminance. Cb (blue chromaticity), and Cr (red chromaticity)

* HSI :
Hue - Dominant color wavelength
Saturation - Purity of the color
Intensity - Brightness of the color.

2] Color transformation
1] Color correction : Adjust color balance
2] Tonal correction : Adjust tonal range
3] Histogram processing : manipulating the distribution of pixel intensities of an image

* Questions :
1] Find CMY for RGB (0.2, 1, 0.5)

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} \Rightarrow \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 0.2 \\ 1 \\ 0.5 \end{bmatrix} \Rightarrow \begin{bmatrix} 0.8 \\ 0 \\ 0.5 \end{bmatrix}$$

$\therefore$ CMY (0.8, 0, 0.5)

2] Find RGB for CMY (0.15, 0.75, 0)

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} \Rightarrow \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 0.15 \\ 0.75 \\ 0 \end{bmatrix} \Rightarrow \begin{bmatrix} 0.85 \\ 0.25 \\ 1 \end{bmatrix}$$

$\therefore$ RGB (0.85, 0.25, 1)

- $Y = 0.257 * R + 0.504 * G + 0.098 * B + 16$
- $Cr = 0.439 * R + 0.368 * G - 0.071 * B + 128$
- $Cb = 0.148 * R - 0.291 * G + 0.439 * B + 128$

Run length encoding

3] Expand decimal string compressed by RLE and represented as 981435

— 888888888884555

4] Define

i] Screen resolution

- Number of distinct pixels that can be displayed on screen.
- Common resolution HD, Full HD, QHD, etc

ii] Aspect ratio

- Ratio of width with height

iii] Pixel / Character

- Smallest addressable unit in graphical image is pixel
- — " — " — in text is character.

5] Compute size of 640 x 480 image at 240 pixel per inch.

— $\frac{640}{240} \times \frac{480}{240}$

$\Rightarrow 2.66 \times 2$

6] Compute resolution of 2x2 inch image that has 512 x 512 pixels.

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— $\frac{512 \times 512}{2 \times 2}$ i.e $\boxed{\frac{512}{2} = 256}$

7] If an img. has height of 2 inches & an Aspect ratio (AR) of 1.5, find width

— $AR = W/H$

$1.5 = W/2$

$\therefore \boxed{W = 3}$

8] If we want to resize a 1024×768 image to one that is 640 pixels wide with same AR, what would be height of resized image?

— Original img $= 1024 \times 764$

$AR1 = \frac{1024}{768}$

New resized img $= 640 \times x$

$AR2 = \frac{640}{x}$

$AR1 = AR2$

$\frac{1024}{768} = \frac{640}{x}$

$1024x = 640 \times 768$

$\therefore \boxed{x = 480}$ — i.e height.

9) If we use 12-bit pixel values in a look-up

table how many entries does the table have?

- $2^{12} = 4096$

10) If we use direct coding of RGB values with 2 bits per primary color, how many possible colors do we have for each pixel?

- $2^2 \times 2^2 \times 2^2 = 64$

11) What is size frame buffer (bytes) is needed with resolution 1024 x 768 ; 24 bits per pixel.

- $1024 \times 768 \times 24/8$ bytes.

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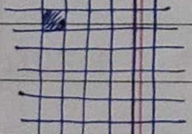
* Pixel :
  - Picture element
  - smallest unit of digital image.
  - Tiny square represents a single point in an image and holds information about its color / Intensity



  - for grayscale pixel value denotes = brightness
    for color image pixel value denotes = info about color components (RGB)

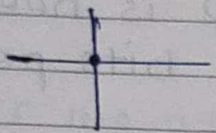
* Relationships betn pixels :-

Image is denoted by $F(x,y)$ and p, q are used to represent individual pixels of image.

Imp ▷ **Neighbours of a pixel**

4- Neighbours of p : $N4(p)$

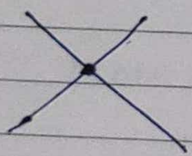
- pixel p at (x,y) has 4-horizontal/vertical neighbours at



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

diagonal-neighbours of p : $ND(p)$

- pixel p at (x,y) has 4 diagonal neighbours at



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

8- Neighbours of p : $N8(p)$

- 4 Neighbours of p ($N4(p)$) and 4 diagonal-neighbours of p ($ND(p)$) are the 8-neighbours of p

▷ Imp **Adjacency betn pixels**

Let V be the set of intensity values used to define adjacency.

Three types :

1] 4-adjacency

- two pixels p and q with values from V are 4adjacent if q is in the set $N4(p)$

2] 8-adjacency

- two pixels p and q with values from V are 8adjacent if q is in the set $N8(p)$

3] m-adjacency : (mixed adjacency)

- two pixels p and q with values from V are madjacent iff
  1) q is in $N4(p)$

     OR

  2) q is in $ND(p)$ and set $N4(p) \cap N4(q)$ has no pixels whose values are from V. (i.e $N4(p) \cap N4(q)$ is empty)

Imp → Connectivity betn pixels

- used for establishing boundaries of objects and components of regions in an image.
- Two pixels are connected if :
  1. They are adjacent in some sense. (4/8/m-adjacency)
  2. If their gray scale statisfy a specified criteria of similarity.

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- Types on the basis of adjacency.
1) 4-connectivity - if they are 4-adjacent
2) 8-connectivity - " 8-adjacent
3) m-connectivity - " m-adjacent

Example
1]

0	1	1
0	2	0
0	0	1

Arrangement of pixels
V = {1,2}
find path from (1,3) to (3,3)

⇒ ①

0	1 ←	1
0	↓ 2	0
0	0	1

path from (1,3) to (3,3)
using 4-connectivity

⇒ (1,3) (1,2) (2,2) — No path
as from (2,2) — we can't move horizontal/vertical manner.

②

0	1 ←	1
0	↓ 2 ↙	0
0	0 ↘	1

path from (1,3) to (3,3)
using 8-connectivity

(i) ⇒ (1,3) (1,2) (2,2) (3,3)
(ii) ⇒ (1,3), (2,2), (3,3)

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

path from (1,3) to (3,3) using m-connectivity

- from (1,3) we have two choices
  - $\underset{p}{(1,3)} \rightarrow \underset{q}{(1,2)}$
  - $\underset{p}{(1,3)} \rightarrow \underset{q}{(2,2)}$

- check conditions of m-connectivity :

choice (1)

$\underset{p}{(1,3)} \rightarrow \underset{q}{(1,2)}$

i) q is from $N_4(p)$
→ our $N_4(p)$ is {(1,2) (2,3)}

∴ one condition satisfied so we can choose this path

thus path will be
(1,3) (1,2) (2,2) (3,3)

Choice (2)

$\underset{p}{(1,3)} \longrightarrow \underset{q}{(2,2)}$

i) q is from $N_4(p)$
→ our $N_4(p)$ is {(1,2) (2,3)} condition invalid

ii) q is from $N_D(p)$
→ our $N_D(p)$ is {(2,2)}
and
→ $N_4(p) \cap N_4(q) = \emptyset$
→ {(1,2) (2,3)} ∩ {(1,2), (
$\neq \emptyset$

∴ Both conditions are invalid!
thus we can't choos
this path

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<u>Example 2</u>

$$\begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 & 1 & 2 & 3 \end{matrix}$$

$V = \{1, 2\}$

Find path from (4, 1) to (1, 4) & also find path length.

→ ① 4- connectivity / path

$$\begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 & 1 & 2 & 2 \end{matrix} \qquad \begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 \rightarrow & 1 \rightarrow & 2 & 2 \end{matrix} \qquad \text{or} \qquad \begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 \rightarrow & 1 \rightarrow & 2 \rightarrow & 2 \end{matrix}$$

No path using 4- connectivity

② 8 - connectivity / path (consider smallest one)

$$\begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 \rightarrow & 1 \rightarrow & 2 \rightarrow & 2 \end{matrix} \qquad \begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 \rightarrow & 1 & 2 & 2 \end{matrix} \qquad \begin{matrix} 4 & 2 & 3 & 2 \\ 3 & 3 & 1 & 3 \\ 2 & 3 & 2 & 2 \\ 2 \rightarrow & 1 \rightarrow & 2 \rightarrow & 2 \end{matrix} \quad \text{--- etc}$$

This is smallest = length 4

path = (4,1) (4,2) (3,3) (2,3) (1,4)

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③ m - connectivity / path

4	2	3	2
3	3	1	3
2	3	2	2
2	1	2	2

Not possible

4	2	3	2
3	3	1	3
2	3	2	2
2	1	2	2

two choices

(4,3) / (3,3)

$\boxed{\begin{array}{cc} p & q \\ (4,2) & (4,3) \end{array}}$

cond ① $N_4(p) = \{(4,1)\ (4,3)\}$
statisfied thus valid
as q is in $N_4(p)$

4	2	3	2
3	3	1	3
2	3	2	2
2	1	2	2

path length = 5

path = (4,1) (4,2) (4,3)
(3,3) (2,3) (1, 4)

$\boxed{\begin{array}{cc} p & q \\ (4,2) & (3,3) \end{array}}$

cond ① $N_4(p) = \{(4,1), (4,3)\}$
not statisfied
as q is not in $N_4(p)$

cond ②
$N_D(p) = \{(3,3)\}$
q is in $N_D(p)$
and

$N_p(4) \cap N_4(q) \neq \phi$

$\{(4,1)\ (4,3)\} \cap \{(3,4)\ (4,3)\}$

$= \{(4,3)\}$

∴ cond ① & ② fails
invalid choice

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Region and boundaries

i) Boundary
- Border
- Boundary of region R is set of pixel in region that have one or more neighbours that are not in R

ii) foreground & background.

Questions ① In following arrangements of pixels, are two regions (of 1's) adjacent?

Region i)

1	1	1
1	0	1
0	1	0

Region ii)

0	0	1
1	1	1
1	1	1

true for 8-adjacent

False for 4-adjacent

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* Fields that Use DIP
- X-Ray Imaging
- Gamma-Ray -ll-
- Imaging in ultravoilet band
- Imaging in visible & infrared bands
- Imaging in microwave bands
- Imaging in radio Bands

• Gamma-Ray-Imaging
- Includes majorly nuclear medicine
- The approach is to inject a patient with radioactive isotope that emits gamma rays as it decays.
- Images are produced by gamma ray detectors.

* Appl^n of digital img processing
1] Document handling
2) Signature verification
3] Biometrics
4] Fingerprint verification
5] -ll- identification
6] Target recognition by (Army, Navy, etc)
7] Traffic monitoring
8] Face detection
9) Face recognition
10] Facial expression recognition
11] Hand gesture recognition
12] medical Appl^n (sking, breast cancer)
13] Morphing
14] Inserting Artificial obj. into scene.
15] Human activity Recognition
16] Autonomous vehicles (land, water, space)
17] Interpretation of Aerial photography.

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* Image processing basics :

- Pixel values are most often grey levels in the range 0-255 (Black - White).

Raster scan display :

- Frame refresh : display can be refreshed to draw new images continously.
- Flicker elimination : Electron beam must strike all pixels frequently to prevent flickering with critical fusion freq. around 60 times per second.
- Scanning : Process occurs from left - right top - bottom.
- Scanning signals :
  - Horizontal sync pulse : Signals the start of new scan line
  - Horizontal retrace : Time for movement from end of current scan line to the start of next.
  - Verticle sync pulse - Signals start of the next field.
  - Veritcle retrace : Time for movement from bottom of current field to the top of next.

* Image interpolation :

- Process of using known data to estimate values at unknown location.
- Used for zooming & shrinking.

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* Distance measures :

① Euclidean distance –
distance betⁿ p and q is defined as

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

or

$$\sqrt{(x-s)^2 + (y-t)^2}$$

② City block distance –
distance betⁿ p and q :

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

③ Chess board distance –
distance betⁿ p and q

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

Example

	1	2	3
1			q
2		p	
3			

1] P(2,2) and q (1,1)

A] $D_e(p,q) = \sqrt{(2-1)^2 + (2-1)^2}$

$= \sqrt{2}$

B] $D_4(p,q) = |2-1| + |2-1|$

$= 2$

c] $D_8(p,q) = \max(|2-1|, |2-1|)$
$= \max(1,1)$
$= 1$

2) $P(2,2)$ and $q(1,3)$

A] $D_e(P,q) = \sqrt{(2-1)^2+(2-3)^2}$
$= \sqrt{1+1}$
$= \sqrt{2}$

B) $D_4(P,q) = |2-1| + |2-3|$
$= 1+1$
$= 2$

c) $D_8(p,q) = \max(|2-1|, |2-3|)$
$= \max(1,1)$
$= 1$

Questions ①

compute euclidean distance (d_1) & city block distance (d_2) and chess board distance (d_3) where $P(3,0)$ & $q(2,3)$

→ $\sqrt{10}$, 4, 3

② No. of bits required for 256 × 256 image with gray levels 32.

→ 327680 (256 × 256 × 5)

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③ Effect caused by under sampling is called
- aliasing

④ img f1 = $\begin{bmatrix} 1 & 3 & 7 \\ 5 & 15 & 175 \\ 200 & 50 & 150 \end{bmatrix}$ and img f2 $\begin{bmatrix} 50 & 150 & 125 \\ 45 & 55 & 155 \\ 200 & 50 & 75 \end{bmatrix}$

calculate img f1 + img f2
img f1 - img f2.

Assume 8-bit image

- $f1+f2 = \begin{bmatrix} 51 & 153 & 132 \\ 50 & 70 & 255 \\ 255 & 100 & 255 \end{bmatrix}$ $f1-f2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 20 \\ 0 & 0 & 75 \end{bmatrix}$

⑤

* Transformation in computer graphics:

1] Translation
2] Rotation
3] scaling
4] Reflection
5] shear

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1] Scaling : $\begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix}$

2] Rotation (clockwise) : $\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$

3] Rotation (anticlockwise) : $\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$.

4] Translation : $\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ t_x & t_y \end{bmatrix}$

shift in x-direction — t_x t_y — shift in y direction

5] Shearing in x-direction $\begin{bmatrix} 1 & 0 \\ sh_x & 1 \end{bmatrix}$

6] Shearing in Y-direction $\begin{bmatrix} 1 & sh_y \\ 0 & 1 \end{bmatrix}$

7] Shearing in both direction $\begin{bmatrix} 1 & sh_y \\ sh_x & 1 \end{bmatrix}$

8] Reflection (about x-axis) $\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

9] Reflection (about Y-axis) $\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$

10] Reflection (about origin) $\begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$

11] Reflection (about Y=X) $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

12] Reflection (about Y=-X) $\begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix}$

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* Color fundamentals:

Basic quantities to describe quality of light source:

1) Radiance: Total amount of energy that flows from light source (in W)
2) Luminance: A measure amount of energy an observer perceives from light source (in lm)
3) Brightness: A subjective descriptor that embodies the achromatic notion of intensity and is practically impossible to measure.

* Image formats:

1] JPG (.jpg, .jpeg, .jpe, .jif, .jfif, .jfi)
- 24-bit
- complex image full of vivid colors & for realistic pictures.

2] PNG (.png)
- 8, 24 or 48 bit
- 24-48 bit pngs are referred as true color (16 million colors)

3] GIF (.gif)
- 8-bit
- 256 colors

4] WEBP (.webp)
- developed by google
- quality and compression

5] TIFF (.tiff, .tif)

6] PSD (.psd)

module 2

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* Image enhancement

- Image enhancement sharpens image features such as edges, boundaries or contrast to make a graphic display more helpful for analysis.
- It doesn't increase inherent info. content but makes chosen features easier to detect by increasing their dynamic range.

* Techniques

Point operation	Spatial operation	Transform operation	Pseudo-coloring
- 1) Contrast stretching	- 1) Noise smoothing	- 1) Linear filtering	- 1) False Coloring
- 2) Noise clipping	- 2) Median filtering	- 2) Root filtering	- 2) Pseudo-Coloring
- 3) Window slicing	- 3) LP, BP & HP filtering	- 3) Homo-morphic filtering	
- 4) Histogram modeling	- 4) Zooming		

① Point operation

- Contrast stretching : Increase dynamic range of gray scale.
- Noise clipping : Special case of contrast stretching, useful for noise reduction.
- Window slicing : Segmentation of gray level regions.

- Histogram modeling : Analyzing and manipulating image histogram.

② Spatial Operation
- Noise smoothing : Reduce noise by spatial filtering.
- Median filtering : Replaces each pixel value with the median of its neighbour value
- HP, BP, LP Filtering : High Pass, Band-Pass and Low Pass filtering
- zooming : Enlarge or shrinks image.

③ Transform operation
- Linear filtering : Convolution of image with linear, position-invariant operator.
- Root filtering : Applies root transformation
- Homomorphic filtering : Decomposes an img into reflectance and illumination comp. for enhancement.

④ PseudoColoring
- False Coloring : Assigns arbitary colors to represent intensities.
- Pseudo coloring : Enhance contrast by assigning colors based on intensity levels.

* Difficulty :
Quantifying enhancement criteria is the greatest difficulty in img. enhancement.

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* Image enhancement methods based on :

1] Spatial-domain enhancement method :
- Based on direct manipulation of image pixels.
- formulated as :

$$g(x, y) = T[f(x,y)]$$

where, g is the o/p
f is the i/p
T is operation on f defined over a neighbourhood of (x,y).

2] Frequency-domain enhancement method :
- Enhances img $f(x,y)$ by convoluting with a linear, position-invariant operator.
- 2D convolution performed using DFT

* Point operation :
- Here each pixel in an image is independently transformed based on its own intensity value.
- involves mapping each point in i/p image to corresponding point in o/p image.
- transformation can be expressed as

$$v(m,n) = f\,(u(m,n))$$

intensity value at (m,n)

corresponding intensity in o/p img by applying f

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- f is transformation which can be linear or non-linear
- Point operations are zero-memory operations (As they don't require any info about neighbouring pixels)

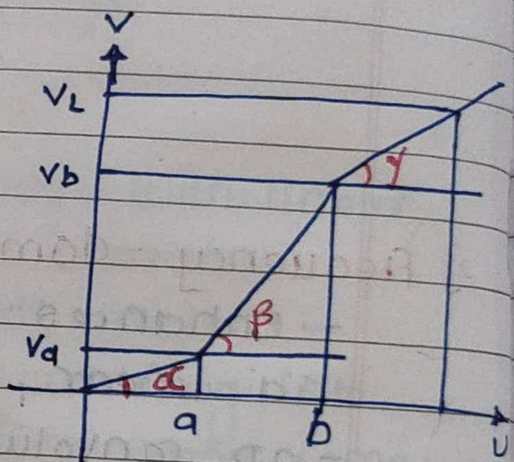
① Contrast stretching :

- Idea is to increase dynamic range of gray level in an image.

- expressed as :

$$v = \begin{cases} \alpha u & 0 \le u < a \\ \beta(u-a) + v_a & a \le u < b \\ \gamma(u-b) + v_b & b \le u < L \end{cases}$$

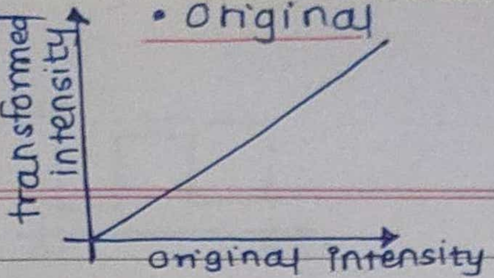
max intensity level



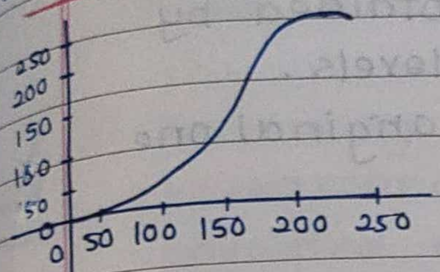
- for dark region stretch $\alpha > 1$, $a = L/3$
- — " — mid — " — $\beta > 1$, $b = 2/3L$
- — " — bright — " — $\gamma > 1$

- Result of contrast stretching
  $(r_1, s_1) = (r_{min}, 0)$ // map min intensity to 0.
  $(r_2, s_2) = (r_{max}, L-1)$ // map max intensity to L-1.

• Original

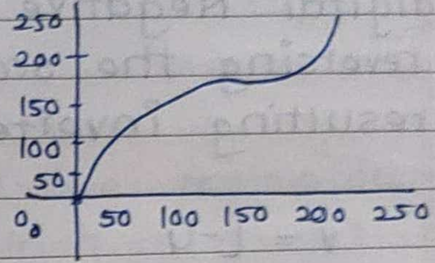


• Contrast increasing



- decrease Low intensity
- increase high intensity

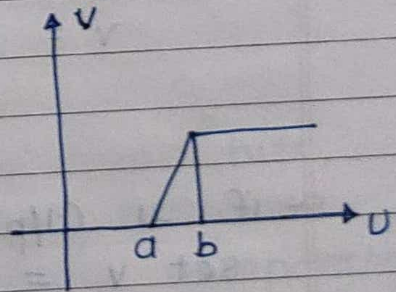
• Contrast decreasing



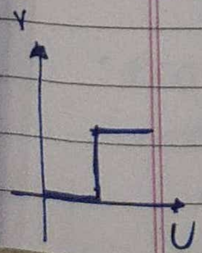
- Increase low intensity
- decrease high intesity

② Clipping and Thresholding
- special case of contrast stretching.
- Clipping :
    • special case of contrast stretching where $\alpha = \gamma = 0$
    • Useful for noise reduction when i/p signal known to lie in range [a, b]

$$f(u) = \begin{cases} 0 & 0 \le u < a \\ \alpha u & a \le u \le b \\ L & u \ge b \end{cases}$$

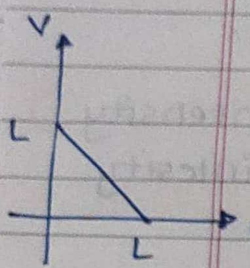


- Thresholding :
    • Special case of Clipping, where lower threshold (a) and upper threshold (b) set to t
    • Gives binary o/p, where pixel intensities assigned based on whether they fall below or above specified threshold.



③ Digital Negative :

- digital Negative in an img obtained by reversing the scaling of gray levels.
- resulting inverted image of original one.



$v = L - u$

(subtract i/p intensity values from max intensity level L , results in v digital negative o/p)

- Used in medical image.

④ Intensity level slicing

- slicing in segmentation of gray level regions from rest of the image.

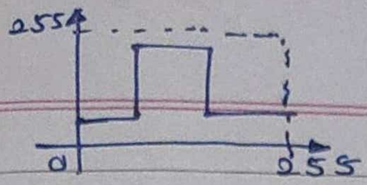
$$v = \begin{cases} L & a \le u \le b \\ 0 & \text{otherwise} \end{cases} \quad ①$$

$$\begin{cases} L & a \le u \le b \\ u & \text{otherwise} \end{cases} \quad ②$$

- if u (i/p intensity) is betn [a, b] then set v = max intensity (L)
- otherwise if u is not in [a, b] then set v = 0 or u

- GRAY-LEVEL SLICING :

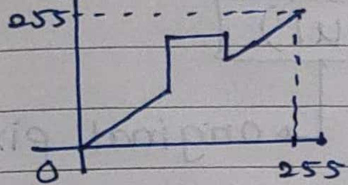
① Non-preserving background :
background is not preserved (i.e



regions outside the specified range are removed from final result)

② Preserving background :

- background is preserved (i.e region outside specified range are retained in result).



⑤ Bit - extraction :

- transformation used to extract <u>visually significant bits from pixel values</u>, allow for determining no. of significant bits an image.
- Bit extraction helps for identifying relevant info.

• <u>Process</u> :

- Each pixel in img represented by binary bits, transformation involves selecting n^{th} MSB from each pixel value and display it separately
- Higher order bits contains majority of visually significant data

• Example : for 8-bit img :

0 to 127 —— MSB is 0 (so all map to 0)

128 to 255 —— MSB is 1

⑥ Range compression:
- technique for compressing dynamic range of pixel values, particularly when dynamic range of processed img exceeds capability of display device.
- Common used transformation function for Range compression

$$\boxed{s = c\log(1 + |u|)}$$

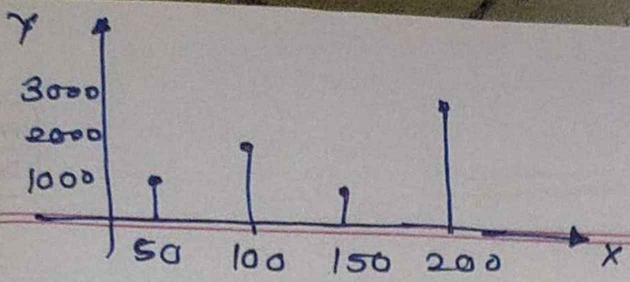
Compressed pixel value

original pixel value

scaling constant

⑦ Image subtraction and Change detection:
- used for comparing two images & highlighting differences betn them.
- Used in medical image & security system.
- Image subtraction provides straightforward way to check difference or change.
- Subtract pixel values of one from another img.

⑧ Histogram modeling:
- Histogram modeling tech. are used to modify the img so that it's histogram has desired shape, thereby enhancing visual quality.



- Histogram is basically graph with intensities on x-axis and their freq. on Y-axis.
- Useful for stretching low contrast levels with narrow histogram.

- Histogram modeling involves manipulating an image's histogram to achieve specific distribution of intensities.
- achieved through : Histogram equalization
  - " Specification
  - " matching.

→ Histogram equalization:
- Transform an i/p img to o/p img with uniform histogram distribution
- •) T(r) transformation function is Single valued & monotonically increasing in interval [0,1], ie order from black to white in gray scale.
- •) $0 \le T(r) \le 1$ for $0 \le r \le 1$, guarantees consistent mapping.

$$\boxed{s = T(r)}$$

r is gray level in i/p img.

o/p (enhanced img)

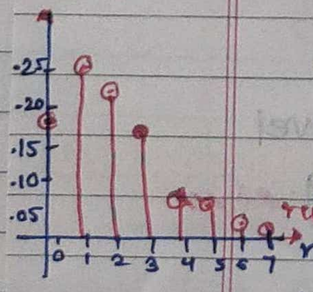
Method :
- Defining $T(r)$ as CDF (cummulative freq. distribution function) of PDF (probability density function) of gray levels in i/p image
- PDF : represents probability with areas
  CDF : — " — — " — Vertical distances

PDF and CDF
- PDF is derivative of CDF.
- • $f(x) \longrightarrow$ PDF $\longrightarrow [\, f(x) \geq 0$ for all $x\,]$
  • derivative of $f(x) \longrightarrow$ CDF

Example :

3-bit image ($L=8$), size 64×64 pixel, $MN = 4096$, give $P_r(r_k)$ for each r_k

Gray levels r_k	histogram n_k	PDF $P_r(r_k) := n_k / MN$
$r_0 = 0$	790	0.19 ⇒ (790 / 4096)
$r_1 = 1$	1023	0.25 (1023 / 4096)
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02



(quant val)

CDF = S_K — Approx. to nearest gray level.

0.19	1/7
0.19 + 0.25 = 0.44	3/7
0.44 + 0.21 = 0.65	5/7
0.65 + 0.16 = 0.81	6/7
0.81 + 0.08 = 0.89	6/7
0.89 + 0.06 = 0.95	1
0.95 + 0.03 = 0.98	1
0.98 + 0.02 = 1.00	1

$$S_N = L-1 \times \sum_{j=0}^{N}$$

$\therefore$ $s_0 = 7 \times 0.19 = 1.33$ — 1

$s_1 = 7 \times (0.19 + 0.25) = 3.08$ — 3

$s_2 = 7 \times (0.65) = 4.55$ — 5

$s_3 = 7 \times 0.81 = 5.67$ — 6

$s_4 = 7 \times 0.89 = 6.23$ — 6

$s_5 = 7 \times 0.95 = 6.65$ — 7

$s_6 = 7 \times 0.98 = 6.86$ — 7

$s_7 = 7 \times 1.00 = 7$ — 7

$\therefore$ Final Transformation :

$r_0 \to s_0$ $1 \to 790$ pixels maps to 1

$r_1 \to s_1$ $3 \to 1023$ — " — to 3

$r_2 \to s_2$ $5 \to 850$ — " — to 5

$r_3 \rightarrow s_3$ $656 + 329 = 985$ ——— 11 ——— 6

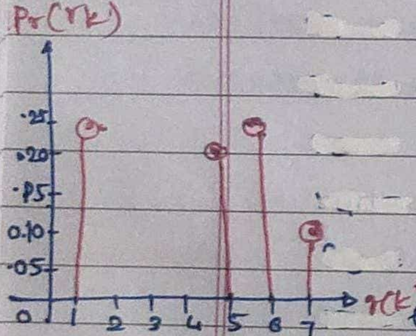
$r_4 \rightarrow s_4$ $656 + 329 = 985$ ——— 11 ——— 6

$r_5 \rightarrow s_5$ $245 + 122 + 81 = 458$ ——— 11 ——— 7

$r_6 \rightarrow s_6$ $245 + 122 + 81 = 458$ ——— 11 ——— 7

$r_7 \rightarrow s_7$ $245 + 122 + 81 = 458$ ——— 11 ——— 7

Now



0	–	–
1	790	790/4096 = 0.19
2	–	–
3	1023	0.24
4	–	–
5	850	0.21
6	985	0.24
7	458	0.11

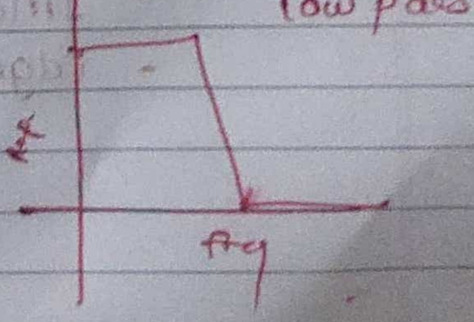
* Histogram matching
- Also called histogram specification
- Involves transforming an image so its histogram matches specified histogram
- that means manipulation in pixels of i/p image should be done.

* local histogram processing:
  - Involves using a neighbourhood mask over the image, with the mask size specified to be smaller than entire image.
  - mask is moved pixel by pixel across the image and histogram processing is done on each pixel.

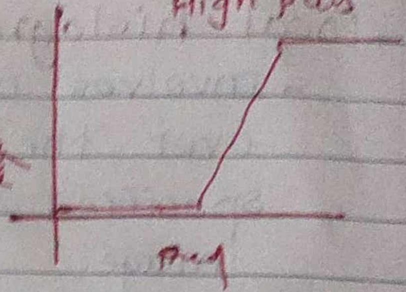
* Image filtering
  - Filters are defined using convolution mask (kernels)
  - These kernels consist of non-zero value arranged in small neighbourhood, typically near central pixel.
  - kernel generally have odd # rows and # colums for getting center easily.

Filters

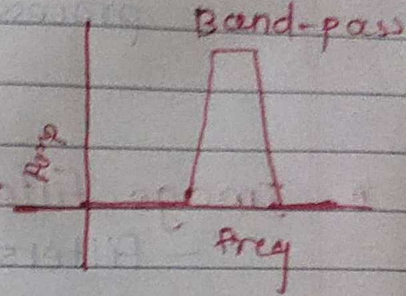
(1) low pass filter
- reduces high-freq components
- preserves low-freq. info



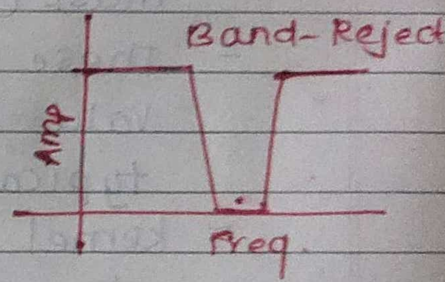
(2) High-pass filter:
- Preserve high-freq components
- reduces low-freq components



(3) Band pass filter:
- defines a range of freq. and preserves only those comp.
- Reduce all components outside range.



(4) Band Reject (Notch) filter
- Ignores that Narrow range of freq.
- and preserves freq. outside range.



- Noise Reduction
- Image enhancement
- Edge detection

Module 3

Image transform

- operation to change default image representation, so that all info. present in image is preserved but image representation will be different.

Need

1. mathematical convenience
   - Every action in spatial/time domain will impart in freq. domain
2. Extraction of more info

* Faster fourier Transfor (FFT)

- way to compute DFT quick
- steps
  1. divide original vector into 2
  2. calculate FFT for each recursively
  3. merge result.

- saves time
  1. direct computation $- 2^{2n}$
  2. FFT takes $= n2^n$

  ie $2^n/n$ time saved!!

* Fourier Transform

- mathematical operation
- transforms a continous function such as image or signal from

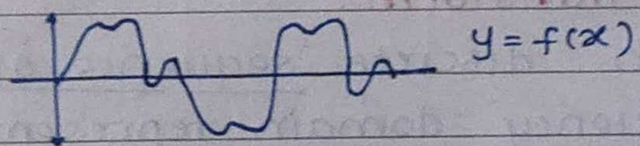
time or spatial domain → freq domain

Analyse effect of transmission medium, Noise

- Fourier transform decompose the image into real and imaginary parts, represents different freq.
- Periodic function decomposed into sines & cosines.

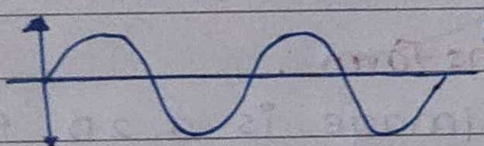
Suppose, we have complex fun $f(x)$

Complex $f(x)$



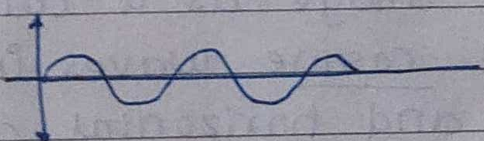
$y = f(x)$

sin1



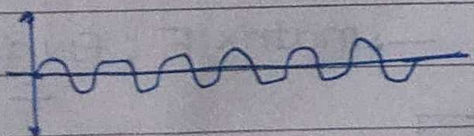
$y = \sin x$

sin2



$y = \frac{1}{3}\sin 2x$

sin 3



$y = \frac{1}{5}\sin 4x$

$$f(x) = \sin x + \frac{1}{3}\sin 2x + \frac{1}{5}\sin 4x$$

* FFT : Fast fourier Transform computes DFT quickly.

* Discrete fourier transform :

- mathematical operation to transform discrete sequence of pixels in a digital image from

$$\boxed{\text{Spatial/ pixel domain}} \longrightarrow \boxed{\text{frequency domain}}$$

-
-
-
-

} same points like fourier transform.

① 1D fourier Transform :

- transform discrete <u>sequence of numbers</u> into frequency domain representation.
- written as sum of sines and cosines.

② 2D fourier Transform :

- As we know, image is a 2D function
- It represents image as a combination of <u>sine</u> and <u>cosine</u> waves in both the vertical and horizontal dimesions.
-

$F = F(f)$ → matrix F, fourier transform of f

$f = F'(F)$ → matrix f, is inverse fouries transform of F

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- for M x N matrix.

forward FT → $$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \exp\left[-2\pi i\left(\frac{xu}{M} + \frac{yv}{N}\right)\right]$$

inverse FT → $$f(x,y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v) \exp\left[2\pi i\left(\frac{xu}{M} + \frac{yv}{N}\right)\right]$$

* IMP Properties of 2D fourier transform
-

① similarity

forward & inverse transforms are same except

① scale factor in 1/MN — in inverse transform.

② Negative sign —— in forward transform.

$$\rightarrow F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \exp\left[\underbrace{-}_{\text{diff}}2\pi i \underbrace{\boxed{\left(\frac{xu}{M} + \frac{yv}{N}\right)}}_{\text{same}}\right]$$

$$\rightarrow f(x,y) = \underbrace{\frac{1}{MN}}_{\text{differing}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \exp\left(2\pi i \underbrace{\boxed{\left(\frac{xu}{M} + \frac{yv}{N}\right)}}_{\text{same}}\right)$$

② DFT as a special filter.

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- $\exp\left[\pm 2\pi i\left(\frac{xu}{M} + \frac{yv}{N}\right)\right]$

these values are just basic functions and can be computed in advance.

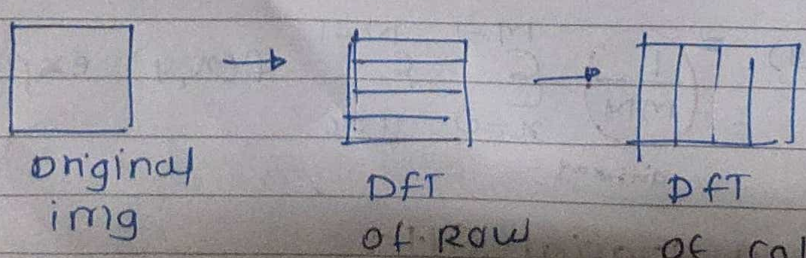
③ Separability :

- filter elements can be expressed as product

$$\underbrace{\exp\left[2\pi i\left(\frac{xu}{M} + \frac{yv}{N}\right)\right]}_{\text{2 DFT}}$$

$$= \underbrace{\exp\left[2\pi i \frac{xu}{M}\right]}_{\substack{\text{1D DFT} \\ \text{(row)}}} \cdot \underbrace{\exp\left[2\pi i \frac{yv}{N}\right]}_{\substack{\text{1D DFT} \\ \text{(column)}}}$$

- using separability we can use 1D DFT's to calculate rows then columns of 2D fourier transform.



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④ Linearity :

- DFT of sum is equal to sum of individual DFT's
- —"— product is —"— product —"— —"—

$$F(f+g) = F(f) + F(g)$$

$$F(kf) = k.F(f) \quad \text{— k is a scalar.}$$

⑤ Convolution property :

- convolution of two signal in time/spatial domain = multiplication in freq. domain.

- convolution of img M spatial filter s'

$$F(M * s) = F(M) \cdot F(s')$$

$$M * s = F(m) \cdot F(s')$$

$$M * s = F^{-1}(F(m) \cdot F(s'))$$

Example

$$S = 32 \times 32$$

$$M = 512 \times 512$$

① direct computation :

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$32 \times 32 = 1024$ — for each pixel.

$\therefore$ for entire img $= 512 \times 512 \times 1024$
$= 26,84,35,456$

② using DFT

- Each row 4608 multiplication.

$\therefore$ for all rows $= 4608 \times 512$
$= 2,359,296$

same for col { $\therefore$ for all column $= 4608 \times 512$
$= 2,359,296$

$\therefore$ Total $= 4718592$ — multiplications for entir img

⑥ DC component :

in $$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \cdot \exp\left[-2\pi i\left(\frac{xu}{M} + \frac{yv}{N}\right)\right]$$

* if $F(0,0)$ is $v = u = 0$
then

$$F(0,0) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \exp(0) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)$$