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Name: Mandar R Dighe 21BG033

R4: Chapter 2.

Structure of human eye.

- Eye is nearly sphere (with a diameter of 20 mm.
- It is enclosed by 3 membranes:-
  - cornea and sclera outer cover
  - Choroid
  - retina.
- Cornea → Tough and transparent tissue
- Continuous with cornea, the sclera is an opaque membrane that encloses the remaining optic globle.
- Below sclera → choroid
- choroid → It contains network of blood vessels that serves as the major source of nutrition to eye.
- Damage to choroid is ~~harm~~ full.
- Choroid is heavily pigmented → which helps reduce amount of extraneous light entering the eye.
- The choroid divided into the
  - ciliary body
  - iris.

- Iris → contracts or expands to control amount of light that enters the eye.

(pupil) → varies from 2mm to 8mm

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* Iris → front → visible pigment
  back → black pigment.

* lens → concentric lens → (most protein content)
* 60 → 70% of water * It is ~~covere~~ colored by a slightly yellow pigmentation that increases with age.

* lens absorbs 8% visible light spectrum. Infrared and ultraviolet light are absorbed by proteins within the ~~lens~~ lens, in excessive amount can damage the eye.

* The inner most membrane → retina
* when the eye is focused, light from an object is imaged on the retina.

* There are two types of receptors :-
  * cones
  * rods

6-7 (million). cones → located at center portion of retina (fovea)
* highly sensitive to color

* Humans can resolve fine details because of cones
* muscles rotate the eye until the image of a region of interest falls on (fovea).
* Cone - vision → bright light vision

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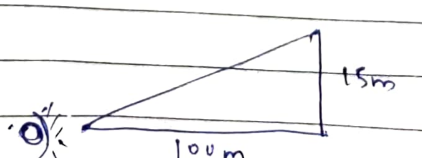
- The number of rods is much larger
75-150 million
- Rods capture overall image of the field of view
- Dim-light vision
- Absence of receptors in a region → These region is called blind spot

Image formation in the Eye

- In photographic camera, the lens has a fixed focal length.
- Focusing at various distances is achieved by ~~vari~~ varying the distance between lens and imaging plane, where the film is located.
- In human eye, the distance between the center of ~~image~~ lens and the imaging sensor is fixed, the focal length needed to achieve proper focus is achieved by varying the shape of lens.

- flattening → distant object
thickening → near object.

- center of lens to retina → 17 mm



height of object in retinal image (h)

$$\frac{15}{100} = \frac{h}{17\times10^{-3}}$$

$\boxed{h = 2.5 \text{ mm}}$

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Perception → by relative excitation of light receptors
which transforms radiant energy into electrical impulses
(that are decoded by brain)

Light and EM spectrum

- The range of colours we perceive in visible light is a small portion of the electromagnetic spectrum.

- One end of spectrum → radio waves with wavelengths billions of times longer than those of visible light.

- On other end → gamma rays with wavelengths millions of times smaller than those of visible light.

$$\lambda = \frac{c}{\nu}$$

λ (wavelength)
c → speed of light 3×10^8 m/s
ν → (frequency)

Energy of EM spectrum
$$E = h\nu$$
h → planck's constant

unit of energy → Electron-Volt)

frequency in Hertz (one Hz equal to one cycle of a sinusoidal ~~wave~~ wave per second)

EM waves → can be visualized as propagating sinusoidal waves with wavelength
↗ or they can be thought of as a stream of massless particles, each travelling ~~in~~ in a wavelike pattern and moving at the speed of light.

(Energy is proportional to frequency)

* Each ~~pa~~ massless particle contains a certain amount of energy, called a photon.

* High energy electromagnetic radiation, especially in the X-ray and gamma ray bands, is particularly harmful to living organisms.

* visible band of EM spans the range from 0.43 μm (violet) to 0.79 μm (red)

* Object that reflect a balanced spectrum of light across these wavelengths appear white, while those that selectively absorb certain wavelengths and reflect others appear colored

* Example :- A green object primarily reflects light in the range of approx 500 to 570 nm giving it a green appearence.

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* Monochromatic light, on the other hand consists a single wavelength (lacks color diversity)

* The intensity of monochromatic light determines its perceived brightness, ranging from black to various shades of gray ultimately to white
* This range of values are called as gray scale.

* Chromatic (color) → It spans from 0.4 μm to 0.8 μm

(W) (watt)
→ Radiance → (total amount of energy flowing from the light source)
lumens (lm) → Luminance → (amount of energy an observer perceives from light source)
→ brightness. → It is subjective descriptor of light perception that is practically impossible to measure

* The wavelength of an electromagnetic wave required to 'see' an object must be of the same size as, or smaller than the object.

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* A simple Image formation model

* We denote image by 2-D functions of the form $f(x,y)$

$f(x,y) \rightarrow$ scalar quantity

must be non-negative and finite

↳ physical meaning determined by source of image

↳ value $\propto$ energy radiated by a physical source.

$$0 \leq f(x,y) < \infty$$

$$f(x,y) = \underbrace{i(x,y)}_{\text{illumination}} \underbrace{r(x,y)}_{\text{reflectance.}}$$

$$0 \leq i(x,y) < \infty$$

$$0 \leq r(x,y) \leq 1$$

reflectance bounded by 0 (total absorption)
bounded by 1 (total reflectance)

let the intensity (gray level) of a monochrome image at any coordinates (x,y) be

$$l = f(x,y)$$

$\therefore \; L_{min} \le l \le L_{max}$

L_{min} is non-negative
L_{max} it is finite

$L_{min} = l_{min} \, r_{min}$

$L_{max} = l_{max} \, r_{max}$

the interval $[L_{min}, L_{max}]$ is called intensity (or gray) scale.

$[0, 1]$ or $[0, C]$

$l = 0$ is black

$l = 1$ or C is white.

* Image Sampling and Quantization

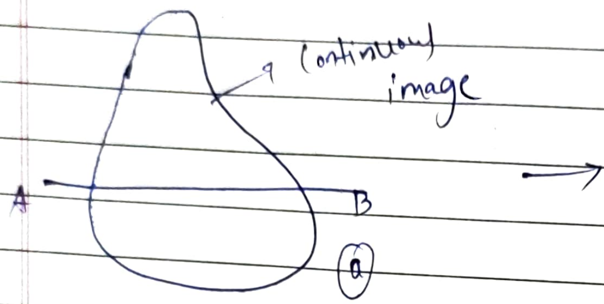
To create a digital image, we need to convert the continuous sensed data into a digital format

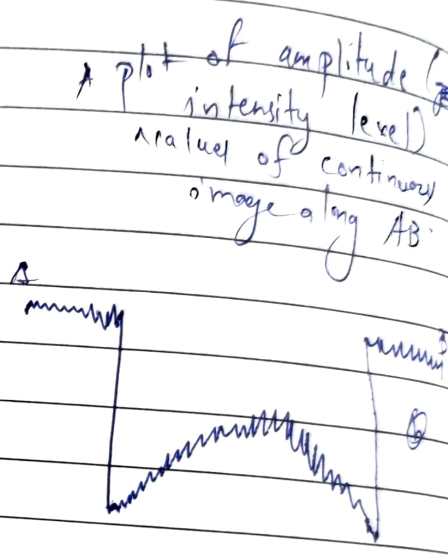
→ Sampling
→ quantization

* Continuous image → digital image.
* An image may be continuous with respect to x and y coordinates and also in amplitude.

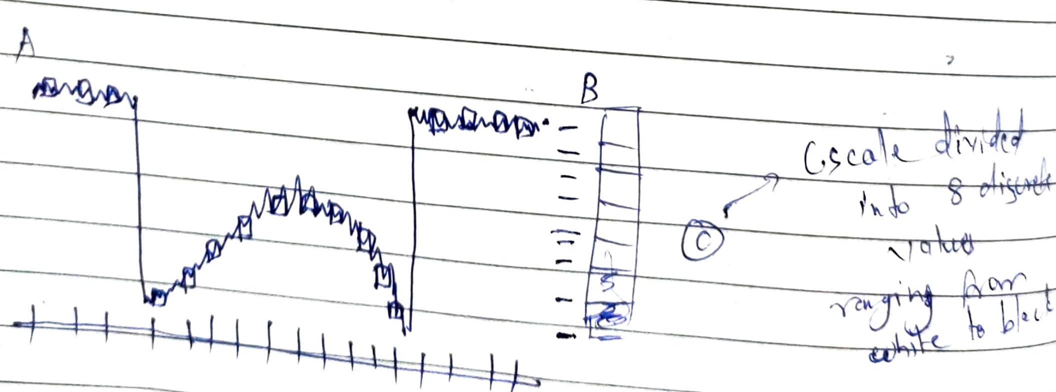
- Digitizing the co-ordinates value is called sampling

- Digitizing the amplitude values is called quantization.



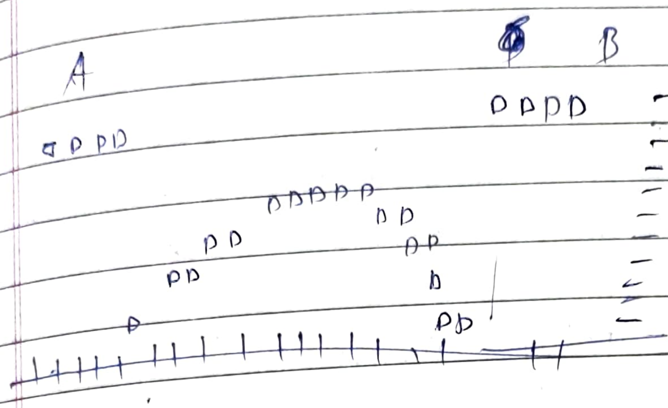


- We take equally spaced samples along line AB



- The values of the samples still span (vertically) a continuous range of intensity values.

- In order to form digital function the intensity values also must be converted (quantized) into discrete quantities final quantized and sampling



(this same procedure is followed from top to bottom of a image.

sampling accuracy → determined by factors like quality of optical components used in the system.

- Sensing strip
  - The number of sensors in a strip dictates samples in one direction.
  - mechanical motion determines samples in the other direction.
  - Quantization of sensor outputs finalizes image generation.

- Sensing array
  - No mechanical motion required
  - The number of sensors in the array sets the sampling limits in both directions.
  - Quantization of sensor output completes the process of generating a digital image.

Basic Relationship between pixels

Neighbour of a pixel

Let pixel p at (x, y) have 2 horizontal and 2 vertical neighbours with coordinates

$$\underbrace{(x+1, y), (x-1, y), (x, y+1), (x, y-1)}$$

4-neighbours of p. ($N_4(p)$)

The four diagonal neighbours of p have coordinates

$$\underbrace{(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)}_{N_D(p)}$$

$$N_8(p) = N_4(p) + N_D(p)$$

8 neighbours of p

The set of images locations of the neighbours of a point p is called the neighbourhood of p.

Adjacency, connectivity, regions and boundaries

- V be a 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 normal chromatic image V can be any subset of ~~the~~ 256 values.

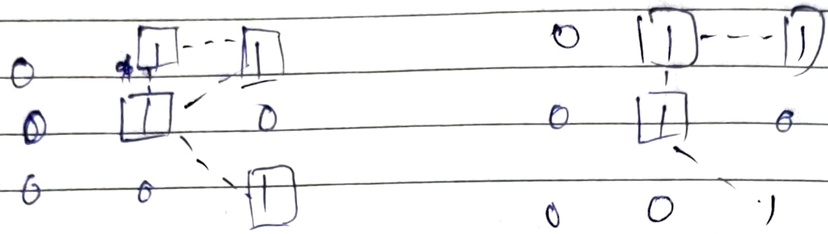
4-adjacency → Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$

8-adjacency → Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$

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.

- m-adjacency is modified version of 8-adjacency there are sometimes annomolies occuring when we use 8 adjacency to resolve that mixed-adjacency was introduced



m → connectivity → when you have straight line connectivity and diagonal both then you should connect it with straight line.

(x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent
the n is length of the path

if $(x_0, y_0) = (x_n, y_n)$ the path is <u>closed path</u>

Two pixels p and q are said to be <u>connected</u> 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 <u>connected</u> component

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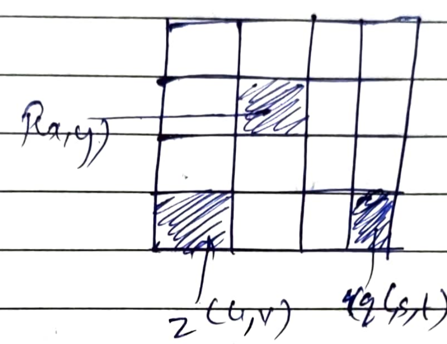
Distance measure

Image → $f(x,y)$, p, q, z are random pixels.

Distance function D

Properties of D

i) $D(p,q) \geq 0$



ii) $D(p,q) = 0$ if $p = q$

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

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

Distance measure

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

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

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

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pixels with D_4 distance ≤ 2 from (x,y) center point

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

pixels with D_8 distance ≤ 2 from (center point) (x,y)

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

* Introduction to the basic mathematical tools used in Digital image Processing.

element wise versus matrix operations

pixel by pixel basis

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \odot \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} a_{11}b_{11} & a_{12}b_{12} \\ a_{21}b_{21} & a_{22}b_{22} \end{bmatrix}$$

matrix product

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

Raising power of image → raising power of each pixel

~~Raising~~ Dividing image → dividing pixels

* Linear vs Non-linear operations

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

$$H[af_1(x,y) + bf_2(x,y)] = aH[f_1(x,y)] + bH[f_2(x,y)]$$
$$= ag_1(x,y) + bg_2(x,y)$$

(linear operator) if this condition

$$\sum[af_1(x,y) + bf_2(x,y)] = \sum af_1(x,y) + \sum bf_2(x,y)$$
$$= a\sum f_1(x,y) + b\sum f_2(x,y)$$
$$= ag_1(x,y) + bg_2(x,y)$$

(sum operator)

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Arithmetic operations

two images

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

~~g(x,y)~~

Using image ~~a~~ addition (averaging) for noise reduction

$$g(x,y) = f(x,y) + \eta(x,y)$$

$g(x,y)$ is corrupted image formed by addition of noise $\eta(x,y)$

~~removing~~ ~~A~~

reducing noise content of the output image by adding a set of noisy input images $\{g_i(x,y)\}$. This technique is used for image enhancement.

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

(If noise satisfies the constraints just stated, it can be shown that if an image $\bar{g}(x,y)$ is formed by averaging K different noisy images

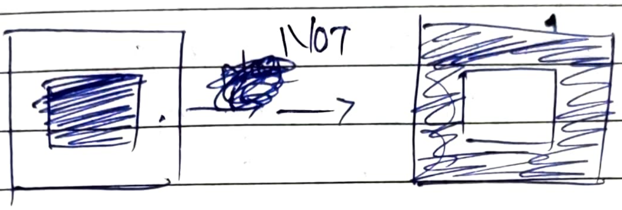
$$E\{\bar{g}(x,y)\} = f(x,y)$$

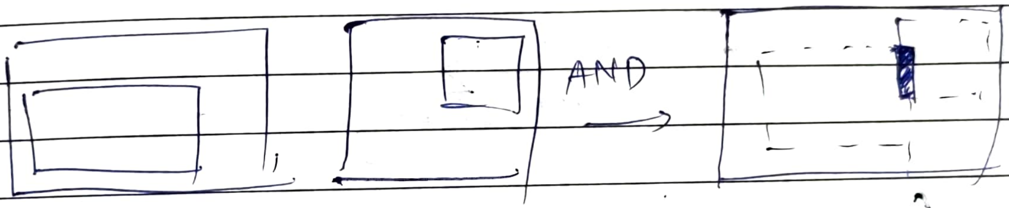
and

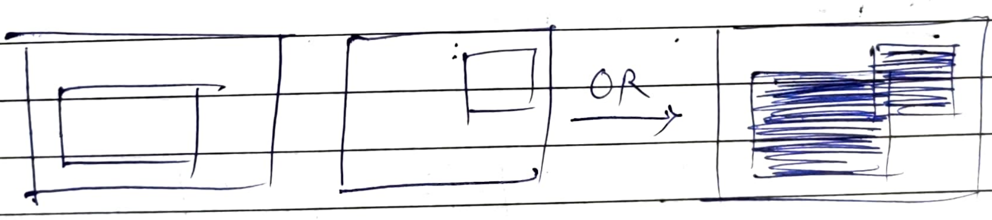
$$\sigma^2_{\bar{g}(x,y)} = \frac{1}{K}\sigma^2_{\eta(x,y)}$$

* Comparing images using subtraction
* using multiplication and division for shading correction and for masking.

Set and logical operations







Spatial operations

1) single-pixel operations
2) neighbourhood operations
3) geometric spatial ~~op~~ transformations

1) Single-pixel operations

$$s = T(z)$$

s: mapped intensity

z: intensity of pixel in original image

- used to obtain negative image

Neighborhood operations

S_{xy} denote set of coordinates of a neighborhood centered on an arbitary point (x,y)

Operation to compute average values of the pixels in a rectangular neighbourhood of size $m \times n$ centered on (x,y)

$$g(x,y) = \frac{1}{mn} \sum_{(r,c) \in S_{xy}} f(r,c).$$

Geometric transformations

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = T \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$(x', y') = (x/2, y/2) \rightarrow$ shrinks the image to half.

affine transformations $\rightarrow$ & scaling
& translation.
& rotation
& shearing

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = A \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

This transformation can be used for.

affine matrix.

Identity

$$A = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$x' = x$
$y' = y$

Scaling / Reflection

$$A = \begin{bmatrix} C_x & 0 & 0 \\ 0 & C_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$x' = C_x x$
$y' = C_x y$

Rotation

$$A = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$x' = x\cos\theta - y\sin\theta$
$y' = x\sin\theta + y\cos\theta$

Translation

$$A = \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

$x' = x + t_x$
$y' = y + t_y$

shear (vertical)

$$A = \begin{bmatrix} 1 & S_v & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$x' = x + S_v y$
$y' = y$

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shear(horizontal)

$$A = \begin{bmatrix} 1 & 0 & 0 \\ s_h & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$x' = x$
$y' = s_h x + y$