Student Id: IT21189944
Module Code:

**** Lecture 1 Intro to Image Processing ****

Image processing helps computers understand and improve images. It's useful both for humans (making images clearer) and machines (for automation and analysis).Real-Time Examples:For Humans: Improving a blurry photo using an app.For Machines: Automatically detecting cracks in manufactured goods using cameras.

1.Application

Human Perception : Employ methods capable of enhancing pictorial information for human interpretation and analysis. **(i)Noise Filtering:** Removes random specks in old or low-quality images.Ex: Removing grainy noise from a CCTV recording.**(ii)Content Enhancement:** Adjusts brightness/contrast. **Contrast enhanc** improve Low contrast.Ex: Enhancing satellite images to make terrain more visible,**De-blurring:** Fix motion and defocus blur.**(iii)Medical Imaging:** Helps doctors detect conditions using tools like MRI or Ultrasound.Ex: detecting tumors in a brain scan.**(iv)Remote Sensing:** Terrain Mapping, Borneo Fire

Machine Vision Applications: Focus on extracting data from image for computer processing.ex: industrial inspections, target detection, fingerprint recognition, satellite data analysis.**Automated inspection examples.** ***Industrial Inspection:** Machines check quality of products. Ex: A bottling plant checking if bottles are filled correctly.***Security Surveillance:** Tracking people or objects.ExCameras in airports following suspicious activity. * **Boundary Detection, *MRI Inspection, *IC Inspection**

2.Video Sequence Processing

Analyzing moving images (videos) to detect motion. Security cameras tracking a moving person.Doctors studying organ motion in ultrasound videos.

3.Image Compression

Reducing file size of images by removing unnecessary data.

Types of Redundancy:Pixel Redundancy: Neighboring pixels are often similar.**Coding Redundancy:** Same pixel values repeated.**Psycho-visual Redundancy:** Human eyes can't detect small changes in color/brightness.Ex: Using JPEG to reduce the size of a photo before uploading it online.

4. History of Image Processing

1920s: Sending images through submarine cables (Bartlane System).1964: NASA used image processing to enhance pictures of the moon (Ranger 7).

Justi:Technology evolved from analog cables to advanced digital tools, showing the increasing importance of image clarity and transmission.

5.Image Representation

An image is a 2D light intensity function,f(x,y) this provides a codinate. Images are made up of small units called pixels arranged in a grid. Each pixel has a value(intensity) (e.g., brightness).**Discretization:** Spatial discretization by grids and intensity discretization by quantization.Image Sizes: Common sizes include 256×256, 512×512, 640×480, and 1024×1024. Types: **Grayscale:** Black & white shades (0 to 255),**Binary:** Only black or white (0 or 1),**Color:** Each pixel has Red, Green, and Blue (RGB) components.

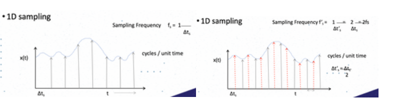
6. Steps in Digital Image Processing

(i)Image Acquisition: Capture the image.Involves an imaging sensor and digitizing the signal it produces. (e.g., from a camera).**(ii)Preprocessing**:Enhances image quality through techniques like filtering and contrast enhancement.(e.g., noise removal).**(iii)Segmentation:** Divide the image into parts (e.g., object vs. background).**(iv)Feature Extraction:** Find important parts (e.g., corners, edges).**(iv)Recognition and Interpretation:** Assigns a label to an object based on its descriptor, and interpretation assigns meaning to a set of labeled objects.**(vi)Knowledge Base:** Supports efficient processing and cooperation between different modules.

**** Lecture 2 : Image Digitization Process ****

Computers can only process digital data-numbers, not continuous signals like light. But real-world images are analog (continuous) and need to be converted into digital form to be stored, processed, and shared. scenery → scan → categorize → print → transfer → store. **What Is Image Digitization:** In real number there can be infinite points at a given two points. so need to convert to a discrete setup.Digitization is the process of converting a real-world image into a digital image using two steps,**(i)Sampling**: Picking specific points from the image (like drawing a grid and choosing pixels).**(ii)Quantization:** Assigning a numerical value (like brightness or color) to each sampled point.Theoretically, there are infinite colors and brightness values in a real-world image. But computers can't handle infinite numbers—they need finite, countable data.**Desired Digital Image Format:** We want to turn an image into a 2D matrix (like an Excel table) where each cell (pixel) has a number indicating its color or brightness. sampler → quantization → Digital computer (store) → Digital to analog converter → Display

1.Sampling: This is the process of converting the continuous spatial coordinates of an image into discrete spatial samples. It represents the image by a 2D finite matrix. Sampling frequency (fs) = 1 / Δts, where Δts is the sampling interval.



some values can be loss so we get the medium value (1 / Δts)/2 wich is (fs) = 2(1 / Δts). curve values then set to 0.

2.Quantization:process of converting the continuous intensity values of an image into a finite set of discrete intensity levels. all continuous value get a discrete value. **Quantization Rule:** Define a set of decision or transition levels {tk,k=1,2,3,...,L+1}, where t1 is the minimum value and tL+1 is the maximum value. A continuous value U is quantized to rk if tk<U<tk+1.A digital image is represented by a matrix of numbers.The number of gray levels (or intensity levels) determines the bit depth.

Binary images: {0,1} values, requiring 1 bit per pixel. 1 channel.**Grayscale images:** Typically {1..256} values, requiring 8 bits per pixel (2^8 = 256),1 channel.**Color images:** Often represented by three channels (e.g., Red ({1..256}), Green ({1..256}), Blue({1..256}), each with {1..256} intensity levels, resulting in 24 bits per pixel (8 bits * 3 channels).

Total bits = size (M * N) X bits (bit counts above)

**** Lecture 3 - Image Enhancement ****

Enhance certain filters in image to get the most suitable result for the situation. Two enhance techniquest.

(i)**Spatial domain:** Directly alters pixel values. Fast and intuitive .(Adjusting brightness on your phone photo editor)

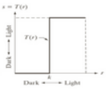
(ii)Frequency Domain: Works on the Fourier transform of the image (frequency info).Helps in operations like noise reduction(Removing periodic noise (e.g., stripes in scanned images)Depending on the neighborhood image processing can be done as Point processing, Local proces, Global processing

Spatial Domain Techniques

1.Point Processing : Changes each pixel individually using a transformation fucntion (S = T(r)). change apply to exact given location input f(x,y) -apply T-> output g(x,y).Example: Inverting a photo (Image Negative),A black pixel becomes white, and vice versa,Useful in medical imaging to highlight veins in X-rays.

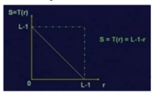
(a) Identity Transformation: No changes to input and same output. it's like y = mx + c graph

(b) Threshold Transformation: determine r value according to



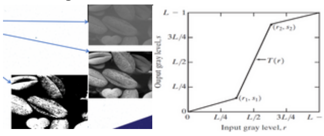
given threshold value s → 0 if (r <= m), s → 255 if (r > m). m is the given threshold value. according to above transformation output only have 0 and 255 values.

(c) Negative Transformation : This transformation inverts the intensity levels of an image. if r = 50 → s = 255 - 50 = 205.



this converts high intensity → low intensity and opposite. This is puseful for enhancing white or gray detail embedded in dark regions, such as in medical mammograms.

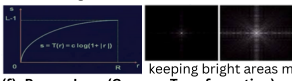
(d) contrast stretching: Expands pixel values (intensity range) to cover a wider range (e.g., from [50, 150] → [0, 255]): after converting values will be (50,0)(150,255).ex: Enhancing satellite



images taken at night so terrain differences are visible.

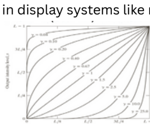
(e) Log Transformation: when Low-intensity values need to be spread out.High-intensity values should be compressed.

s = c log(1+ r) too bright reduce and dark won't be too dark. if r=20, s=c*log(20+1) = 140.10 || s=255, c = 255/log(256)= 105



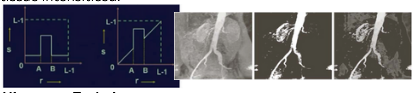
Enhancing dark parts of security footage while keeping bright areas mangable

(f) Power Law (Gamma Transformation) : Defined by $s=cr^{\gamma}$. These transformations are crucial because many imaging devices (capture, display, printing) respond according to a power law. If y < 1 → brighten image, If y > 1 → darken image.Used in display systems like monitors, cameras.



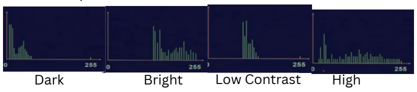
ex: Gamma correction in YouTube or image viewers to display the image as the human eye perceives it. to get more bright we combine the dark and light together.

(g) Gray Level Slicing: Highlights specific intensity ranges: there are two common approchers → (i)Binary: turn the selected range white, rest black , (ii)Brighten selected range, leave others.ex: Detecting tumors in medical images by highlighting specific tissue intensitiesd.



Histogram Techniques

Shows how pixel intensities are distributed



Dark Bright Low Contrast High

Application of Histo processing: Image Enhancement, Image statistics, Image compression, Image segmentation

Histogram Equalization: Spreads out pixel intensities evenly across the available range.Ex:Making license plates more visible in blurry CCTV footage.Justi: Equalization makes hidden features pop by balancing brightness levels.(7 is L-1 → bit img). replace r values with these s values.

[redacted]

r_k	n_k	$p_r(r_k) = n_k/MN$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	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

$$s_0 = T(r_0) = 7\sum_{j=0}^{0} p_r(r_j) = 7\times 0.19 = 1.33 \rightarrow 1$$

$$s_1 = T(r_1) = 7\sum_{j=0}^{1} p_r(r_j) = 7\times (0.19+0.25) = 3.08 \rightarrow 3$$

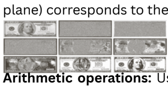
$s_2 = 4.55 \rightarrow 5$ $s_3 = 5.67 \rightarrow 6$

$s_4 = 6.23 \rightarrow 6$ $s_5 = 6.65 \rightarrow 7$

$s_6 = 6.86 \rightarrow 7$ $s_7 = 7.00 \rightarrow 7$

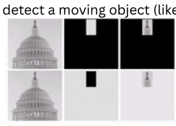
SLIIT

Bit-plane Slicing : Pixels in a digital image are composed of bits. For an 8-bit grayscale image, each pixel is represented by 8 bits.Bit-plane slicing involves decomposing an image into its individual bit planes. For example, an 8-bit image can be separated into 8 binary images, where each binary image (bit plane) corresponds to the value of a



specific bit position across all pixels (e.g., the most significant bit plane, the least significant bit plane).

Arithmetic operations: Used for manipulating entire images or comparing two.Addition: Brightening images or averaging multiple images.Subtraction: Detect changes (e.g., motion detection).Multiplication/Division: Contrast control or shading correction.Ex: Subtracting two photos taken seconds apart to detect a moving object (like a car or a person).



Logic Operations (For Binary Images): AND: Useful in masking operations,OR: Combines features,NOT: Inverts the image.Ex:Isolating objects (like coins on a black background) by masking irrelevant parts.

**** Lecture 4 - Spatial Filtering ****

Spatial filtering means processing an image based on the value of a pixel and its neighbors using a small matrix (called a mask, kernel, or filter). Point processing is completed in lec 3.

Neighborhood processing/ Local processing: Processing pixel is always in the middle. sub image is called mask / kernal / filter / window / template. it containing coefficients (weights) that are applied to the corresponding pixels in the neighborhood.

ex: Input [50,20,10, 50,30,0, 20,20,10] Mask [w1,w2,w3, w4,w5,w6, w7,w8,w9]. Weighted sum = (50*w1) + (20 * w2)+.. this is **correlation** mask. it uses mask as it is. for **convolution** mask it rotates 180 upside down. so the new mask would be [W9,w8,w7..] like wise.

Boundary Handling : For pixels near the image boundary, the neighborhood might fall outside the image.

Zero Padding: Assuming outside pixels have a value of 0.

Replicated Boundary Pixels: Replicating the values of the boundary pixels to fill the outside regions.

Types of Spatial Filters : (1) Linear Filters: (i)Low pass filter - good for noise reduction and also it blur image **(ii) High Pass -** Enhances edges and fine details by detecting rapid intensity changes. **(iii) Band Pass -** Keeps a certain frequency range. **(2) Non Linear Filters: (i)Median, (ii) Max (iii)min (iv)mid-point (v)Alpha trimmed**

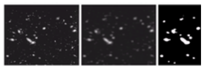
(1)Low pass filter / Averaging filter: [1,1,1,1,1,1,1,1,1] if weights are equal to 0 the filter is called as box filter (if all weights are same).Then divide sum of weights.For a 3x3 mask, the simplest arrangement is to have all the coefficient values equal to one (neighborhood averaging) scale the result by dividing by 9 . ex: {5,3,8,2,8,9,2,5,7] if 8 is highlighted it gets as the mid point value and use boundary to fill the outlines. then apply 3X3 averaging with 1. after that divide the sum of weight by 9. 28/9=3.1

if the mask size is increased (5X5) there will be more blur. for this we assign different weights for different direction of the mask. weighted average for below filter will be 1/16

ex: Input weights assign based on the distance middle → [1,2,1 highest, hori and vertical → 2, diagonally → 1

2,4,2 application: Noice reduction: Noise reduction

1,2,2] (Random noise results in sharp transitions in



gray levels.Blur edges) Reducing irrelevant details ,Bridging small gaps in lines and curves

(2) Non Linear Filters: No weighted sum, get by ordering values: 20,20,50,50,60,70,80,90,100

(i)Median Filter: get median value (60), good for salt and pepper **(ii) Max Filter**: get highest value(100). good for reduce pepper noise **(iii) Min filter:** get lowest value (20). good for reduce salt noise **(iv) mid point:** get low and high and divided by 2 (20+100)/2. good for gaussian (random dust) or uniform noise.**(v) Alpha trimmed:** ignore high and low values and get sum and divide by count. It is useful for multiple noise types, such as a combination of salt-and-pepper and Gaussian noise.

(3) Mean Filters

These are not linear nor non linear. simple methods to reduce noise in spatial domain.

(i)Arithmetic mean filter: similar to averaging filter with equal weights. reduce gausian noise by Blurring. if it's 3X3, Σ(r)/MN = 20+10../9 **(ii) Geometric mean filter:** reduce gaussian by bluring but less than arithmetic. $\Pi(r)^{1/MN}$ = $(20*10*..)^{1/9}$. **(iii) Harmonic mean filter:** remove salt. No blurring. MN/Σ(1/r) = 9/((1/20+1/10..) **(iv) Contra harmonic filter:** $\Sigma(r)^{Q+1}/\Sigma(r)^{Q}$. Q=order of the filter. Q=> positive: can remove pepper noise. Q=> negative: can remove salt noise.**Applications:** Noise removal (low-pass, median), Edge enhancement (high-pass), Detail suppression or enhancement , Restoration of old photos ,Image preprocessing before object detection

**** Lecture 5 - Sharpning Filters ****

This is one of the linear filter, HighPass filter/ sharpening filter. **Averaging** - Blures and reduce noise, similar to integraion, removes noise,Smooths small details.Ex: Averaging: Used in blur filters in photo editing apps to remove blemishes or smooth skin. **sharpening** - highlight details (lines, edges, points) . similar to differentiation ,Enhances edges,Reveals fine textures.Ex: Used in enhancing old scanned documents to make faded text readable.

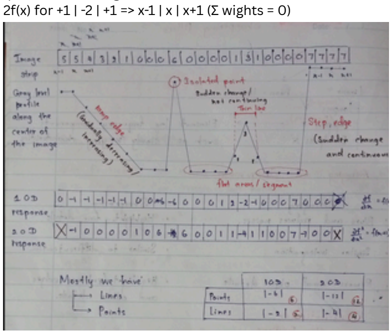
Differentiation: Differentiation may be used for edge enhancement (detail sharpening).The most common method for differentiating is the gradient.

Derivative Functions

(i)First order derivative(FOD) (df/dx): Finds edges by detecting changes in intensity, Produces thicker edges, Formula

(1D): f'(x) = f(x+1) - f(x). for -1 | +1 => x | x+1

(ii) Second-order derivative (d^2f/dx^2) : Highlights thin lines, points, and edges better,Produces a double peak at edges (positive then negative),Formula (1D): f''(x) = f(x+1) + f(x-1) - 2f(x) for +1 | -2 | +1 => x-1 | x | x+1 (Σ wights = 0)



Second order Derivative gives strong response to details like thin lines and iso points.1OD has strong response to gray level step. 2OD produce a double response at edges. 2OD is better for image enhancements. if want more thick edges use 2OD. if want original edges use 1OD.

2OD Filters

(1) Laplacian ((d^2f/dx^2)+ (d^2f/dy^2)):

0 -1 0 This is a popular sharpening filter. It detects intensity

-1 4 -1 changes in all directions (isotropic). This is basic

0 -1 0 laplacian mask. center positive. others are negative

1 1 1 if it has -8 in the middle it is general laplacian filter. if

1 -8 1 this has 4 in the middle and -1 around it is customized

1 1 1 basic laplacian.

Used in document scanning to sharpen text that is blurred or faded, improving readability. positive value as the answer

(**2) Composite laplacian:** based on basic laplacian. mid has 5

High-pass filters: Let high-frequency components (edges, fine details) pass,Block low-frequency components (smooth areas, background).Ex: In satellite images, sharpening filters help bring out buildings, roads, or deforestation patterns that might be otherwise blurry.(1) Unsharp Masking:

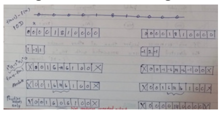
(i)Unsharp Masking: Subtracts blurred version from original **f_sharp = f - f_blurred (ii) High-Boost Filtering:** Keeps more of the original image by scaling **f_highboost = A * f - f_blurred.** Ex:Used in photo editing software like Photoshop or Lightroom:Sharpening the eyes in a portrait, Enhancing edges in a product image

**** Lecture 06: Edge Detection ****

Edge detection finds places in an image where pixel intensity changes sharply—these changes usually signify object boundaries, textures, or features.

Edge pixel: Intensity change suddenly. **Edge:** set of connected edge pixels.**Line:** Edge segment where the intensity on either side are high or low.**Point:** A line with one pixel.**Real-world example:** Detecting lane lines in a self-driving car's camera feed.

(1) Point Detection: Uses the Laplacian operator (basic or general) (2nd derivative).Highlights single bright or dark spots.A point is detected if the Laplacian (abs value). result ≥ threshold (we can get threshold by multiplying the highest pixel value by 90/100. if the point is greater than or equal to threshold they have value 1 and others are 0.Ex Detecting micro calcifications in medical images (small bright dots in X-rays). **(2) Line Detection:** use laplacian.Uses special masks to detect horizontal, vertical, and diagonal lines.Can use thresholding to keep only the strongest lines.Ex: Reading lines on a scanned form (like



underlines or table borders).Absolute values (Doubles the thickness). if Positive values only. we remove negative (Thinner lines)

If mask is smaller than the line response is 0. Thin ine can be easily detected by laplacian. to properly detect a line mask should be larger than the line. There for laplacian is good with thinner lines. (cannot change mask size 3 X 3).

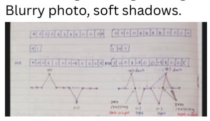
Directed Lines: pointes that are aligned with a straight ines.

Horizontal			+45°			Vertical			−45°		
−1	−1	−1	−1	−1	2	−1	2	−1	2	−1	−1
2	2	2	−1	2	−1	−1	2	−1	−1	2	−1
−1	−1	−1	2	−1	−1	−1	2	−1	−1	−1	2

if m4 response is higher than all other mask the direct lines are associatesd with m4/s direction. (-45 diagonal)

Edge Models

(1) Step Edge: Transition between 2 intensity values over one pixel. sudden dark to bright. 00008888 like wise. ex: Computer graphics, barcodes **(2) Ramp Edge:** Gradual intensity change. Result in blurred and noisy images. slope is inversely proportional to the degree of blurring. dark → dark to bright → bright . high ramp slope low blurring. Ex: Blurry photo, soft shadows.

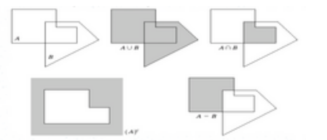


(3) Roof Edge: Intensity change over finite distance (roof). ex: Edges of small round objects (pens, wires)

zero crossing will indicate the transform happens on which direction. 1OD gives edge and 2OD gives exact location of the edge. **profile** is the chart we gonna draw after the derivatives. **1OD operators:** Sobel (smoother, common), Prewitt (simpler, faster),Roberts (sharper, older). these are **less sensitive to noise**. based on the direction there are separate masks (vertical, horizontal, diagonal (-45,45). we can apply to x and y direction and get the output and to remove noise we can use an averaging filter. **2OD Operators: Laplacian** Single mask for all directions(Isotpic), High sensitive to noise may produce double edges., solution for high sensitivity to noise is laplacian of Gussion (LOG) → First smooth the image with a Gaussian blur, Then apply the Laplacian.Ex: Used in fingerprint recognition to extract clean edges of ridges.

**** Lecture 7 : Morphological Image Processing ****

Shaping and cleaning up objects in an image, especially in black-and-white images (binary images). Think of it like trimming, growing, or reshaping blobs in an image. Sets in mathematic morphology represent objects in an image: binary image (0 = black, 1 = white).

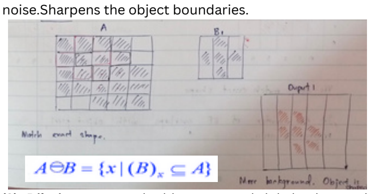


Structural Element / Sub Image (SE)

has different shapes. but need to mark the center. This is used with morphological operators.

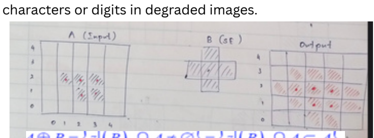
Morphological Operators

(1) Erosion: Shrinks or thins the white (object) areas in a binary image. and background area expanded. need to match exact shape. in final output show only the relevant center parts from the mask. **How it works:** A structuring element (a small shape like a 3x3 square) moves over the image.A pixel stays white only if all pixels under the structuring element are also white.If not, the pixel becomes black.**ex:** Removes small white noise.Sharpens the object boundaries.



$$A \ominus B = \{x \mid (B)_x \subseteq A\}$$

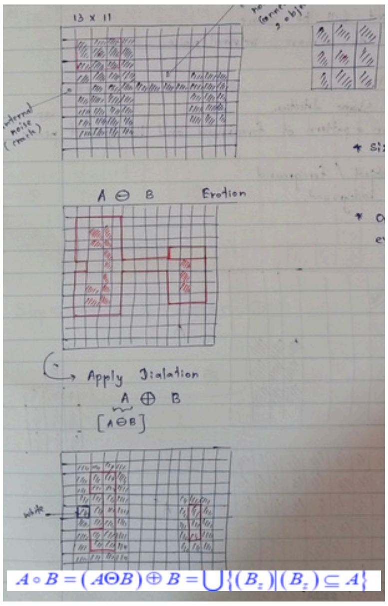
(2) Dilation : expand object area. shrink background area.Normally apply to binary images.Grows or thickens white regions. we don't match exact shapes. if the center of SE overlaps with object pixel, regenerate area. **How it works:**The structuring element moves over the image.If any pixel under it is white, the pixel becomes white.**Effect:**Fills holes and connects nearby shapes.Useful when the object is too thin or broken. **Ex**: In license plate recognition, dilation helps fill broken characters or digits in degraded images.



$$A \oplus B = \{z \mid (\hat{B})_z \cap A \neq \emptyset\} = \{z \mid [(\hat{B})_z \cap A] \subseteq A\}$$

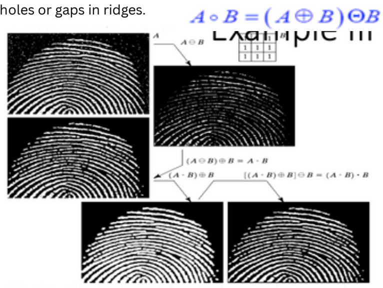
(3) Opening: Erosion followed by dilation. **Effect:** Removes small white spots, but keeps larger shapes intact.Smooths contours and breaks small connections.Used in preprocessing scanned documents to remove small specks (dirt, ink spots).

First apply erosion and then apply dilation with same Structural Element

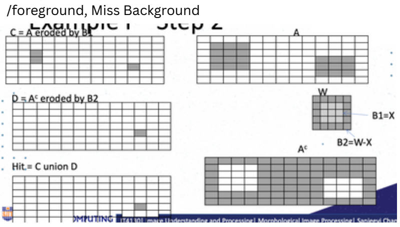


(4) Closing: Dilation followed by erosion. **Effect:**Fills small black holes or gaps, Fuses narrow breaks and preserves bright regions.**Ex:** In fingerprint analysis, closing helps fill small holes or gaps in ridges.

$$A \circ B = (A \oplus B) \Theta B$$

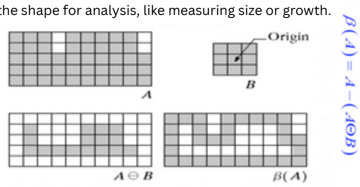


(5)Hit Or Miss: Basic tool for shape detection. Detects a specific shape pattern (foreground + background) in a binary image. Ex: Used to detect a particular symbol (e.g., arrow, triangle) in logos or signs in documents.**concept:** Hit Object /foreground, Miss Background

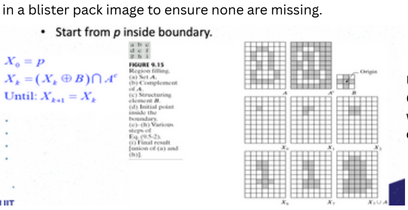


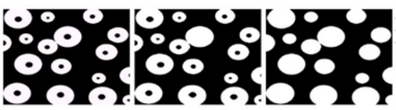
Applications of Morphological Operations

1. Boundary Extraction: Finds the outline of an object. The resultant image after subtracting the eroded image from the original image has the boundary of the objects extracted. **Ex:** Extracting borders of tumors in MRI scans. **Justi:**Helps isolate the shape for analysis, like measuring size or growth.

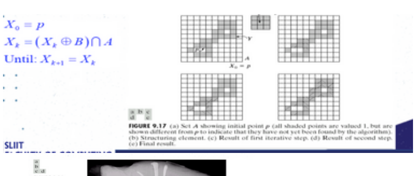


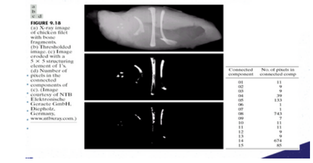
(2) Region Filling: opposite of above.Fills a closed object starting from a point inside it.**Ex:** Counting the number of pills in a blister pack image to ensure none are missing.





(3) Connected component extraction:





Summary

Erosion → Shrink/clean noise → Medical imaging (remove noise)
Dilation → Grow/fill gaps → License plate enhancement
Opening → Remove small noise → Document cleaning
Closing → Fill small holes → Fingerprint analysis
Hit-or-Miss → Detect pattern → Logo detection in images
Boundary Extraction → Outline detection → Tumor edges in MRI
Region Filling → Fill enclosed area → X-ray enhancements
Connected Components → Identify objects → Pill counting

**** lecture 08 -Color Image Processing ****

1.What is Color Image Processing?

It's how computers understand, represent, and manipulate color in images. Unlike black-and-white images, color images contain multiple channels (like Red, Green, Blue) to represent the full spectrum of color we see.

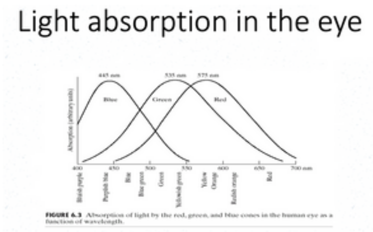
2. Color Fundamentals

- **Achromatic = no color (like black, white, and gray)**
- **Chromatic = color-based light**
  - **- Radiance = total energy (W)**
  - **- Luminance = how bright we perceive the light (lm)**
  - **- Brightness = subjective sense of light intensity**

Your phone camera adjusts brightness and color balance when you take a photo in dim light, using color fundamentals to make it look natural.

3. How We Perceive Color

Our eyes have three types of cone cells sensitive to Red, Green, and Blue. This is the foundation for trichromatic theory and models like RGB.



4.Distinguish color

• **Brightness** (Subjective)
• **chromaticity** (Hue - Dominant wavelength ,Saturation -Degree of saturation and amount of added white light are inversely proportional)

5. Color Representation Models

(i) RGB Model (Red, Green, Blue): Used in: TVs, monitors, cameras . A full-color image uses 24 bits per pixel (8 bits per channel) ,Total colors possible: 2^{24} = 16.7 million, **Ex:**When you take a selfie, the photo is stored using RGB values each pixel gets a red, green, and blue intensity.**Justi:**
RGB is ideal for display devices because screens emit light directly in red, green, and blue.

(ii)Safe RGB Colors: These are a subset of 216 colors that display consistently on all monitors.Levels: 0, 51, 102, 153, 204, 255 (6 levels × 3 channels)
Ex: Web-safe colors were used in early websites to ensure consistency across different devices.

(iii) CMY/CMYK Model (Cyan, Magenta, Yellow, Black) : Used in: Printing , Derived from subtracting RGB from white.CMYK adds black (K) for deeper contrast and ink-saving.**Ex:**Printers use CMYK inks to produce a full-color image on paper**.Justi:** Printers don't emit light—they reflect it, so subtractive mixing works better.Cyan=G+B , Yellow=R+G , Magenta=R+B. black color need to provide from outside since combine create a muddy black. (CMY and black)

(iv)HSI Model (Hue, Saturation, Intensity): Hue = actual color (like red, green, blue), Saturation = purity of color (more saturation = less white mixed in) ,Intensity = brightness
Ex: Image editing software like Photoshop lets users change color using HSI because it matches human intuition. **Justi:** HSI is better for human-centric tasks, like adjusting makeup in selfies or segmenting colored objects.

6. RGB ⇔ HSI Conversion

RGB → HSI: Useful when you want to segment or analyze an image based on hue (e.g., detecting skin tone)
HSI → RGB: Useful when you want to render the image after processing.**Real-Time Use:** Skin detection in AI-based face filters uses hue to isolate skin regardless of lighting.

7. Gray-Level to Color Transformations

Turning a grayscale image into a colored one by mapping gray levels to colors (like thermal maps or weather radar images).
Ex: Thermal cameras or weather radar maps that show temperature or rainfall using colors (e.g., blue = cold, red = hot).

Advantages and Disadvantages

1. **RGB** → Screens, cameras → Simple, supported by hardware → Not perceptually intuitive
2. **CMY/CMYK** → Printing → Matches ink-based mixing → Not suited for screens
3. **HSI/HSV** → Editing, segmentation → Intuitive for humans → Complex conversions

Use RGB when dealing with digital displays or sensors , Use CMYK when preparing images for printing ,Use HSI/HSV/HSL when working with color-based filtering, detection, or enhancements.