IT411 : Digital Image Processing

Conducted By

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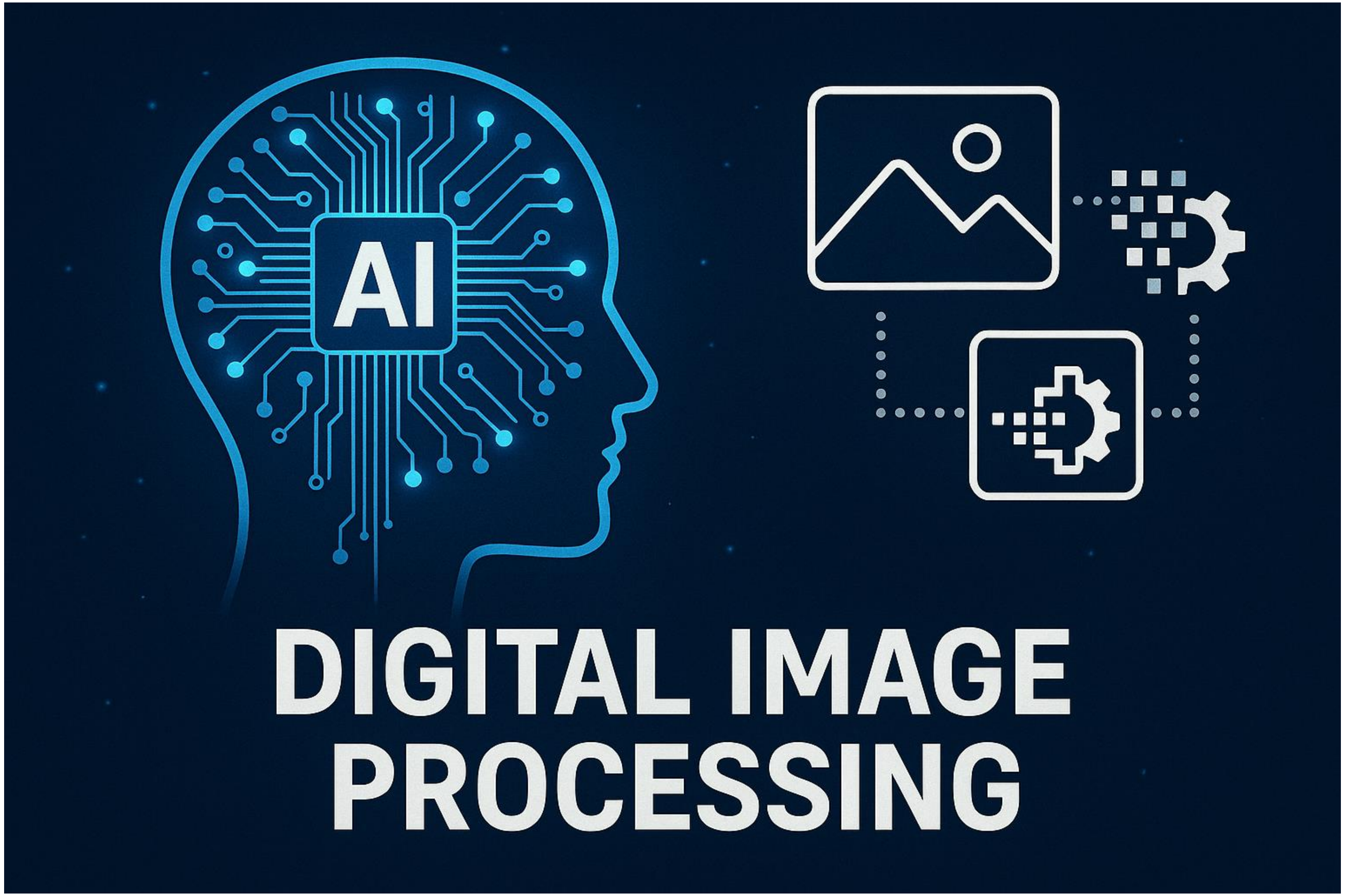
Sources:

Books, research papers, internet, prof. Dinesh Kumar Vishwakarma ppt. reference.

E5 ||29 July 2025



Who AM I ?

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- B.Tech (CSE) M.Tech (CSE) || Ph.D. coursework graduated
- Teaching Assistant IIT Delhi, Assistant Prof. GGSIPU, TA IIHT
- Journal, Book Chapters, Conferences papers
- Governance of AI ,Technology Diffusion, Social Media Analysis, User Behavior, Digital Healthcare , XAI in healthcare.

Course code: Course Title	Course Structure			Pre-Requisite
	L	T	P	
Digital Image Processing	3	-	2	-

Course Objective: To introduce to the concepts of digital image processing. The students will learn image transforms, image enhancement,restoration, morphological operations, edge detection, and segmentation algorithms.

S. NO	Contents
UNIT 1	**Introduction And Digital Image Fundamentals:** Digital Image Representation, Fundamental Steps in Image Processing, Elements of Digital image processing systems, Sampling and quantization, some basic relationships like neighbours, connectivity, Distance measure between pixels, Imaging Geometry.

UNIT 2	**Image Enhancement (Spatial Domain):** Gray level transforms, histogram equalization, histogram specification, basics of the spatial filtering, smoothing operators, image gradients, sharpening operators **Fuzzy logic:** basic definitions, fuzzy operations, fuzzy inference, application of fuzzy logic in image processing.
UNIT 3	**Image Enhancement (Frequency domain):** Two-Dimensional Fourier transform and its properties, basics of frequency domain filtering, smoothing and sharpening in frequency domain

UNIT 4	**Image Restoration:** modelling of image degradations, noise models, noise removal algorithms for impulse and Gaussian noise, Adaptive filtering, estimation of degradation function, inverse filtering. **Color Image Processing:** Color models, conversion between different models, color transforms, color smoothing and sharpening.

UNIT 5	**Morphological Image Processing:** Dilation, Erosion, opening and closing, hit and miss transform, boundary extraction, region filling, thinning, thickening, skeletons, pruning, Gray scale image dilation and erosion.
UNIT 6	**Discontinuity Detection:** point, line and edge detection, Sobel, Canny, and LoG edge detectors, edge linking. **Image Segmentation:** Thresholding, optimal and global thresholding, multiple thresholding, region growing, region splitting and merging, dam construction watershed segmentation algorithm, spatial techniques, frequency domain techniques.

S.No.	Name of Books/Authors/Publishers	Year of Publication / Reprint
1	Rafael C. Gonzalez, Richard E. Woods, Digital Image Processing', 3rd Edition, Pearson Education	2008
2	Anil K. Jain, Fundamentals of Digital Image Processing', Pearson	2002
3	William K. Pratt, Digital Image Processing' 6th Edition, John Wiley	2002
4	Rafael C. Gonzalez, Richard E. Woods, Steven Eddins,' Digital Image Processing using MATLAB, Pearson	2004

Performance Analysis

Quiz 1 / Assignment 1 – A week Before MTE

Mid term Examination

Image Processing Project Proposal –A week after MTE

Quiz 2 / Assignment 2 / Topic Presentation – from second week after MTE

Project Presentation – last week of classes before ETE

End Term Examination

Happy learning !

What is an **Image** ?

An image is like a picture on a screen or a photo.

It can be thought of as a **grid or table** with two directions: left-right (x) and up-down (y).

At each **spot (x, y)** in that grid, there's a **brightness level** or **color value**—this is called the **intensity.**

Intensity/Gray level Brightness at a point in the image **f(x, y)** A function that gives the image's brightness at point (x, y)

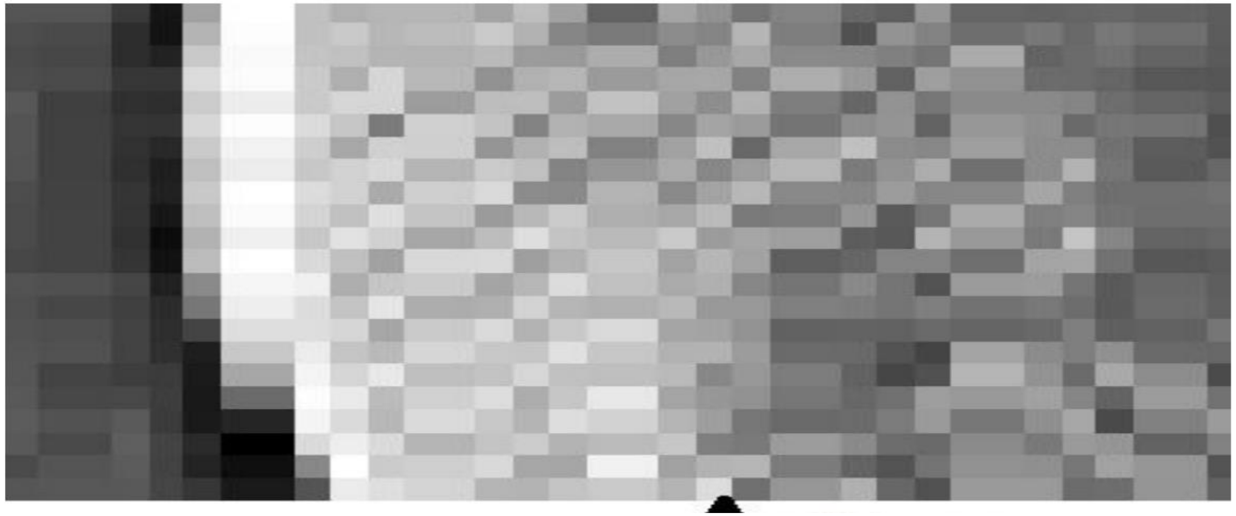


Fig: Zoomed image, where small white boxes inside the image represent pixels

An image can be represented as a **matrix**, where each entry is **f(x, y)** (the intensity of that pixel).
Example for a tiny 3×3 grayscale image:

$$f(x,y) = \begin{bmatrix} 0 & 128 & 255 \\ 64 & 192 & 100 \\ 255 & 0 & 50 \end{bmatrix}$$

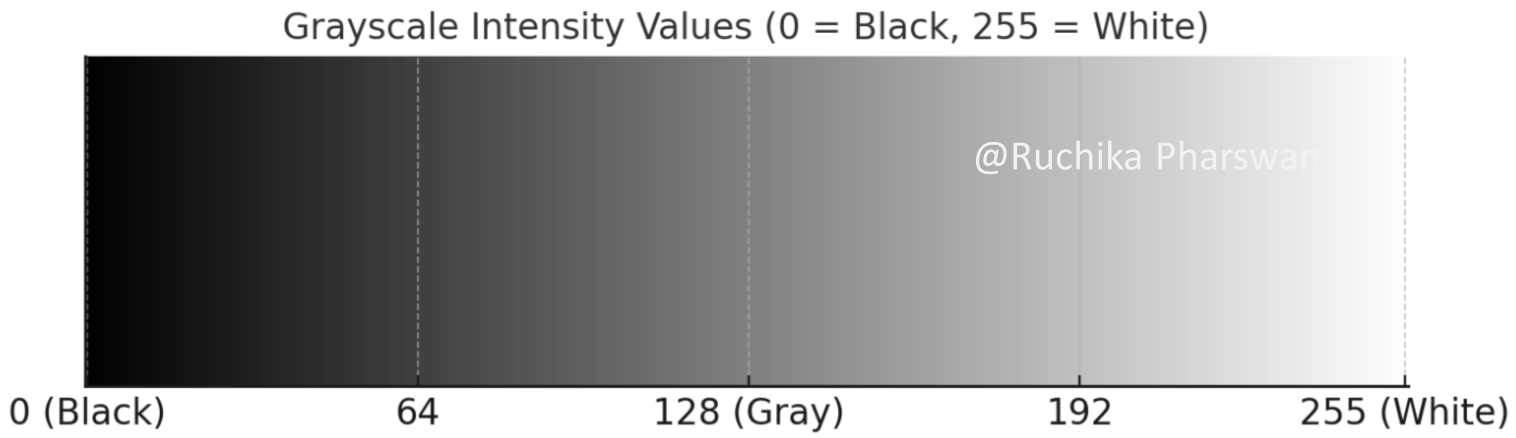
The 0–255 Intensity Scale (8-bit grayscale)

- **8-bit** means each pixel's intensity is stored in **8 binary bits** (like `10101100`).
- The smallest value **00000000** in binary = **0** in decimal.
- The largest value **11111111** in binary = **255** in decimal.
- This gives **256 possible values**: from **0 to 255**.

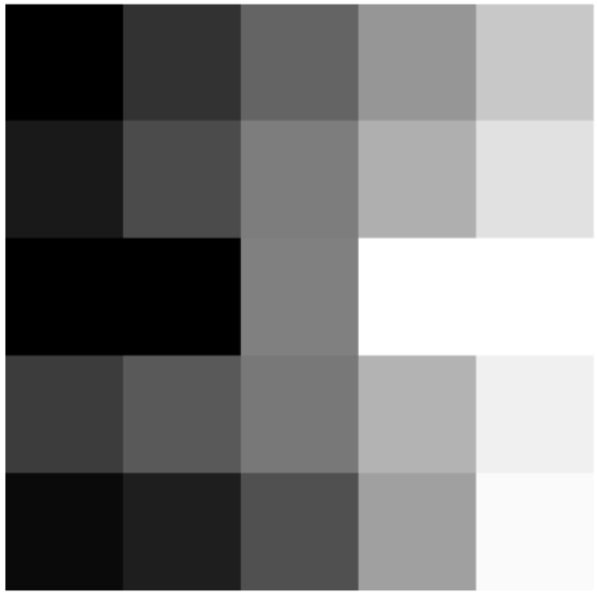
How these values relate to brightness

- **0** = **completely black** pixel (no light).
- **255** = **completely white** pixel (maximum light).
- Numbers **in between** are shades of gray:
  - Low numbers (1–50) → very dark gray.
  - Middle numbers (~128) → medium gray.
  - High numbers (200–254) → very light gray.

So the bigger the number, the **brighter** the pixel.



5×5 Grayscale Image

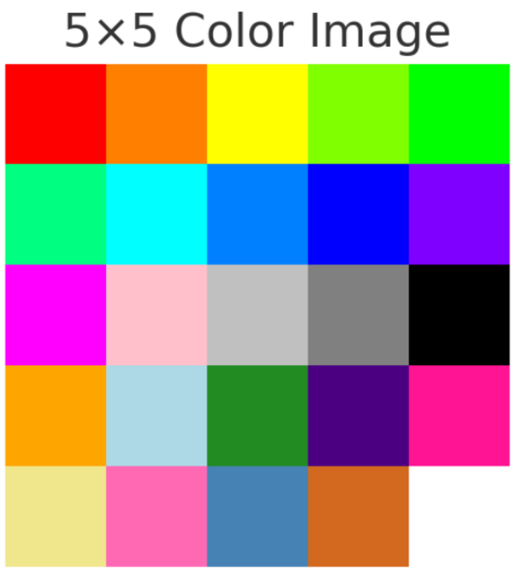


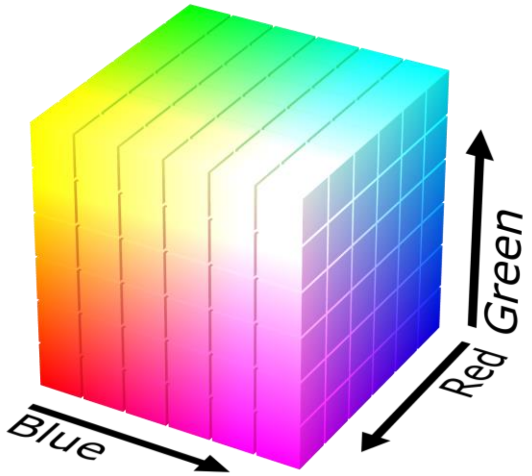
Can you draw the matrix ?

Intensity Matrix

0	50	100	150	200
25	75	125	175	225
0	0	128	255	255
60	90	120	180	240
10	30	80	160	250

What if the image is this :

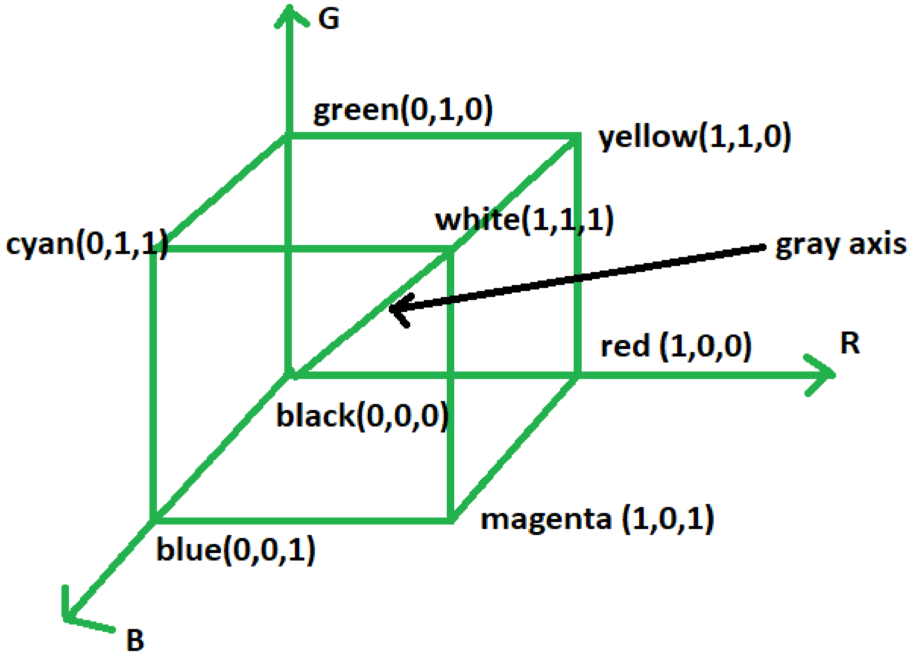




If the image were in **color** (RGB), instead of **one matrix**, you'd have **three matrices** — one for **Red**, one for **Green**, and one for **Blue**.

Each still uses the **0–255 scale**, but the combination of the three values decides the final color.

(255, 0, 0)	(255, 128, 0)	(255, 255, 0)
(0, 255, 128)	(0, 255, 255)	(0, 128, 255)
(255, 0, 255)	(255, 192, 203)	(192, 192, 192)



Terminologies

An image may be defined as a two-dimensional function, f(x, y), where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point.

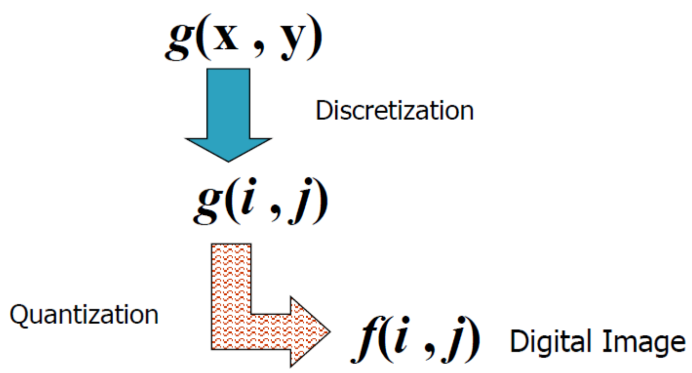
When x, y, and the amplitude values of **f** are all **finite, discrete** quantities, we call the image a digital image. The field of digital image processing refers to processing digital images by means of a digital computer.

Digital image is composed of a finite number of elements, each of which has a particular location and value. These elements are referred to as picture elements, image elements, pels, and pixels. Pixel is the term most widely used to denote the elements of a digital image.

Digital Image :

If x, y, and f (x, y) are all: **Finite** → limited number of positions and brightness values.

Discrete → counted in steps, not continuous (no half-pixels, no infinite shades).Then the image is a digital image → it can be stored and processed by a computer.



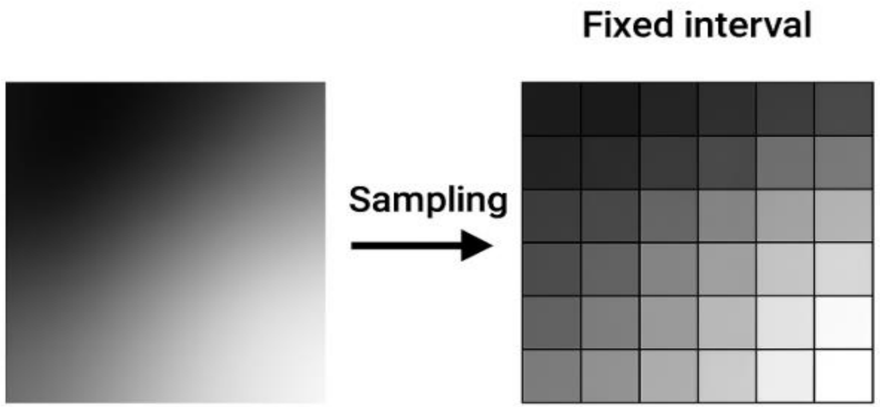
$f(i_0, j_0)$: Picture Element, Image Element, Pel, Pixel

Step 1: Continuous Image — $g(x, y)$

- This is the **real-world image**.
- **x** and **y** can take *any* values (continuous coordinates).
- Brightness/intensity can also be continuous.
- Example: A photo as captured by your eyes or an ideal camera sensor without digitization.

Step 2: Discretization — $g(i, j)$

- We **sample** the continuous image at fixed intervals.
- Now **i** and **j** are **integer coordinates** → pixels in a grid.
- Position is discrete, but **brightness values** may still be continuous.
- Think of it like drawing a grid over the photo and picking one sample point in each cell.



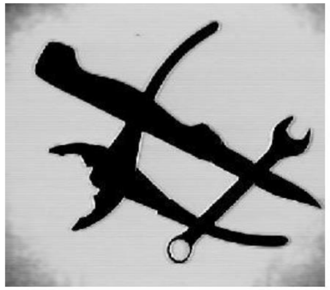
Step 3: Quantization — $f(i, j)$

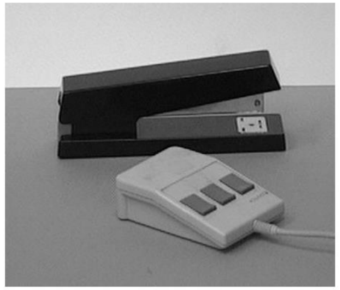
- We now **restrict brightness values** to a finite set of levels.
- For example:
  - In 8-bit grayscale → only 256 brightness levels (0 to 255).
  - In 1-bit image → only 2 brightness levels (black or white).
- After this step, the image is **fully digital** and ready for computer processing.

Applications & Research Topics

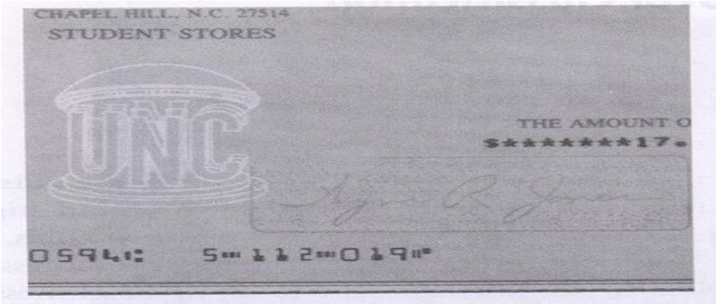
Signature Verification

Object Recognition



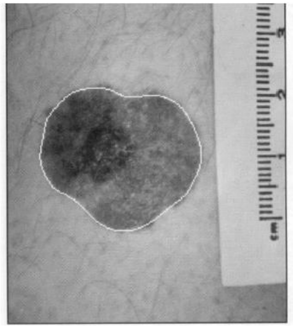


Document Handling

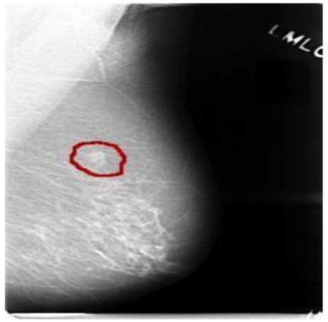


Medical Applications

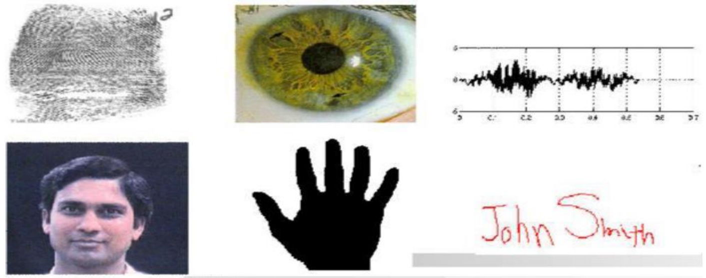
- skin cancer



- breast cancer

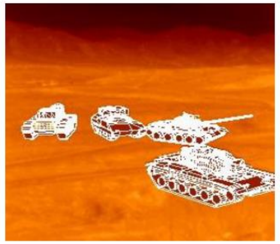


Biometrics



Target Recognition

- Department of Defense (Army, Airforce, Navy)

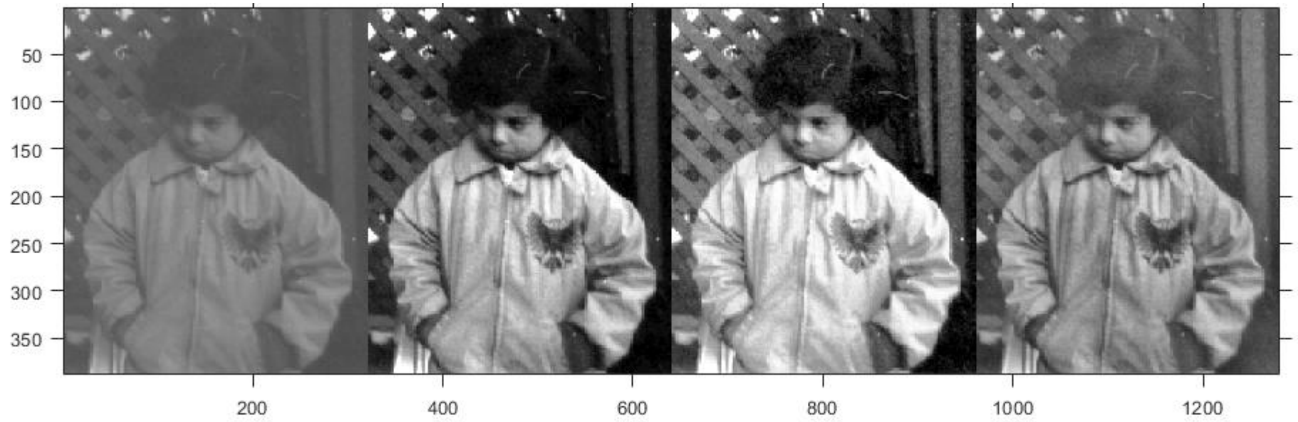


DIP Definition

A Discipline in Which Both the Input and Output of a Process are Images.

- **Input** → the blurry X-ray image.
- **Process** → apply image sharpening and noise removal (DIP techniques).
- **Output** → a clearer X-ray image where fractures are visible.

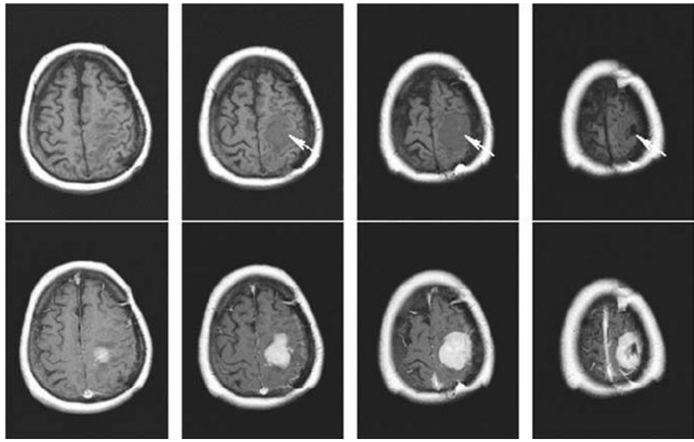
So: Image (blurry) → **Process** → Image (clear).



Important Tasks

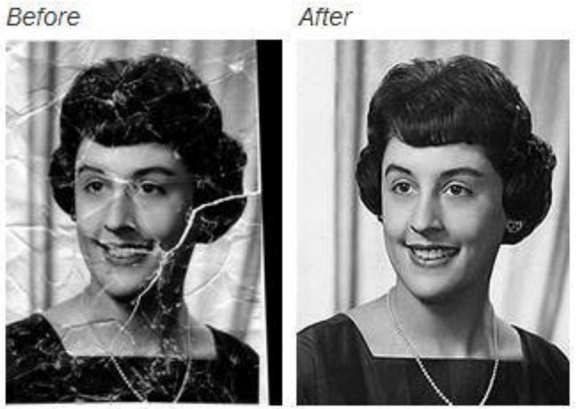
- **Visualization** - Find objects that are not visible in the image
- **Recognition** - Distinguish or detect objects in the image
- **Sharpening and restoration** - Create an enhanced image from the original image
- **Pattern recognition** - Measure the various patterns around the objects in the image
- **Retrieval** - Browse and search images from a large database of digital images that are similar to the original image

Enhancing a faint tumor in an MRI scan using contrast adjustment.



Face recognition in passport verification systems.

Restoring an old black-and-white photograph with scratches

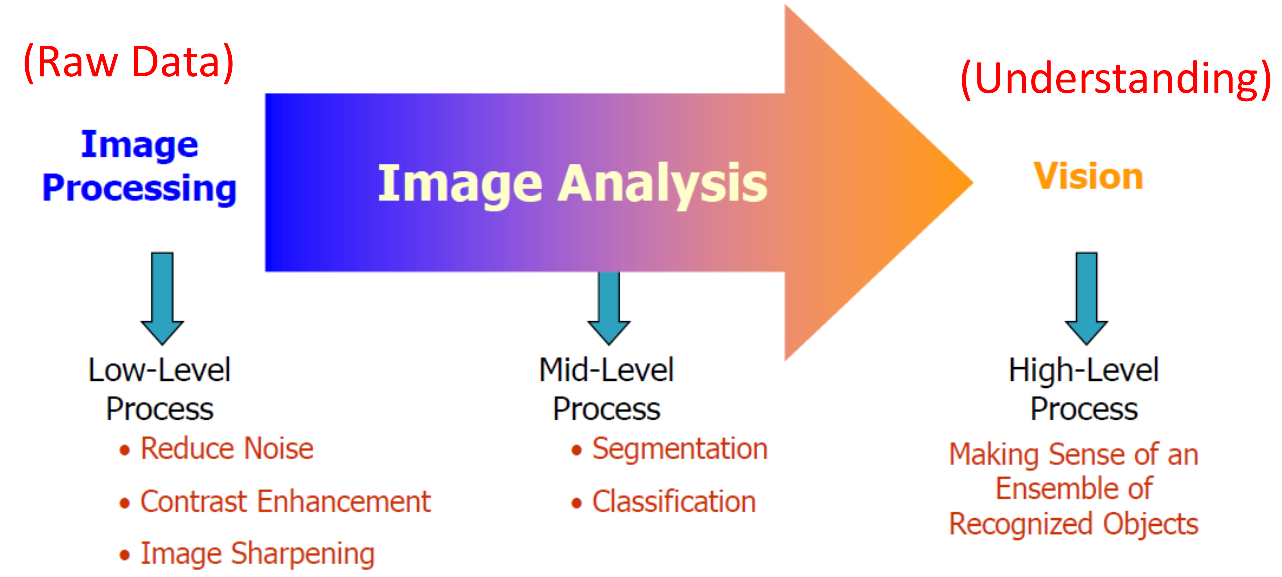


Detecting fingerprints or iris patterns in biometric security.

Method	Coded Pattern
Iris	Iris pattern
Fingerprint	fingerprints
voice	Voice characteristics
Signature	Shape of letters, writing Order, pen pressure
Face	Outline, shape & distribution of eyes, nose
Palm	size, length, & thickness hands

Google reverse image search (you upload a picture, and it finds similar ones).

Image Processing Levels



Type	Input	Output	Examples
Low Level Process	Image	Image	Noise removal, image sharpening
Mid-Level Process	Image	Attributes	Object recognition, Segmentation
High Level Process	Attributes	Understanding	Scene understanding, autonomous navigation

Example: Self-Driving Car

1. Low-Level Processing (Image → Image)

- Input: Raw camera image (pixels only).
- Operations:
  - Remove noise from camera sensors.
  - Enhance contrast to see lanes better at night.
  - Sharpen edges of traffic signs or vehicles.
- Output: A *clean, enhanced image*.

2. Mid-Level Processing (Image → Attributes)

- Input: Enhanced image.
- Operations:
  - **Segmentation**: divide the image into parts (road, car, pedestrian, traffic sign).
  - **Classification**: recognize what those parts are (e.g., "this is a pedestrian," "this is a stop sign").
- Output: **Attributes/objects** → labels like *pedestrian detected*, *lane detected*, *red stop sign*.

3. High-Level Processing (Attributes → Understanding)

- Input: Detected attributes/objects.
- Operations:
  - Interpret the scene: "Pedestrian is in crosswalk, must stop."
  - Make decisions: stop, slow down, or turn.
  - Integrate with other sensors (like radar/LiDAR).
- Output: **Understanding + Action Plan**.

Can you separate out levels ?

A hospital wants to build a smart **X-ray analysis system** that can help doctors diagnose bone fractures. The system goes through the following steps:

1. The raw X-ray image is collected from the machine.
2. The system removes noise and improves the contrast of the image to make bones clearer.
3. It then detects the edges of bones and segments the fractured regions.
4. Finally, it labels the fracture type (e.g., hairline fracture, compound fracture) and generates a diagnostic report for the doctor.

👉 Based on the **levels of image processing (low-level, mid-level, high-level)**, classify each step into its correct level and explain *why* it belongs there.

Can you separate out levels ?

A city is deploying a **smart traffic monitoring system** using cameras at intersections. The system works as follows:

1. The cameras capture continuous video streams of vehicles.
2. To reduce storage needs, the system compresses the video after enhancing brightness and contrast for nighttime visibility.
3. A module extracts features such as moving objects, their shapes, and sizes.
4. The system classifies objects into categories (car, bus, bike, pedestrian).
5. It then counts the number of vehicles per lane and generates live traffic reports for city authorities.

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1. **Cameras capture continuous video streams of vehicles.**
   - **Level:** Low-level
   - **Justification:** The raw image/video is acquired directly from sensors. No interpretation yet, just capturing pixels.

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2. **System compresses the video after enhancing brightness and contrast for nighttime visibility.**
   - **Level:** Low-level
   - **Justification:** Both **enhancement** (brightness/contrast) and **compression** deal with improving image quality and reducing size without interpreting content. These are pixel-based operations.

3. **A module extracts features such as moving objects, their shapes, and sizes.**
   - **Level:** Mid-level (with overlap to low-level)
   - **Justification:** Feature extraction is about detecting **edges, motion, and shapes** from the image. This goes beyond raw pixel manipulation, but it's not yet full understanding. It converts images into **descriptors** useful for later interpretation.

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4. **The system classifies objects into categories (car, bus, bike, pedestrian).**
   - **Level:** High-level
   - **Justification:** Classification involves **semantic interpretation** of the extracted features, mapping them into real-world concepts. This is decision-making.

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5. **It then counts the number of vehicles per lane and generates live traffic reports for city authorities.**
    - **Level:** High-level
    - **Justification:** Generating reports and traffic statistics requires reasoning based on recognized objects → a cognitive task beyond vision, supporting decision-making for humans.

Fundamental digital image processing steps

- Image Acquisition
- Image Enhancement
- Image Restoration
- Image Analysis
- Image Reconstruction
- Image Compression

1. Image Acquisition

- **What it means**: Capturing the image using a sensor or camera and converting it into a digital form.
- **Example**: A hospital captures an **X-ray image** of a patient's chest and stores it in the computer as a digital file (matrix of pixel values).

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2. Image Enhancement

- **What it means**: Making the image look better for human eyes (not necessarily scientifically accurate).
- **Techniques**: Increasing contrast, sharpening, adjusting brightness.
- **Example**: Enhancing the X-ray so that the ribs and lungs appear clearer for the radiologist.

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3. Image Restoration

- **What it means**: Improving the image by removing *known types of distortion or degradation*.
- **Techniques**: Removing blur due to camera motion, correcting noise from sensors.
- **Example**: If the X-ray got slightly blurred due to patient movement, DIP algorithms can restore sharpness.

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4. Image Analysis

- **What it means**: Automatically extracting **useful information** from the image.
- **Techniques**: Edge detection, segmentation, feature extraction.
- **Example**: Identifying a suspicious **spot/tumor** in the lung by analyzing shapes and textures in the X-ray.

5. Image Reconstruction

- **What it means**: Creating an image from raw data (often from sensors that don't directly produce a visible image).

- **Example**: In **CT scans**, the machine collects raw projection data, and DIP reconstructs a clear **3D cross-sectional image** of the body.

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6. Image Compression

- **What it means**: Reducing the size of the image for storage and transmission.
- **Techniques**: Lossless (no data loss, e.g., PNG) or lossy (some data discarded, e.g., JPEG).
- **Example**: Compressing the X-ray image before sending it over the hospital network to another doctor.

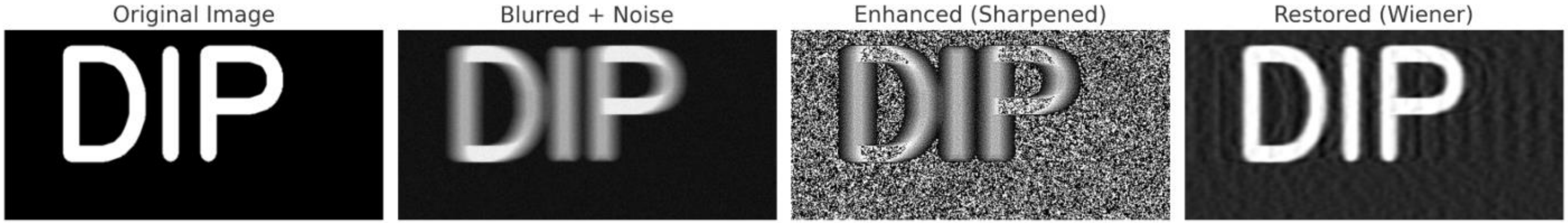
Is Enhancement and restoration same ?

◆ Enhancement

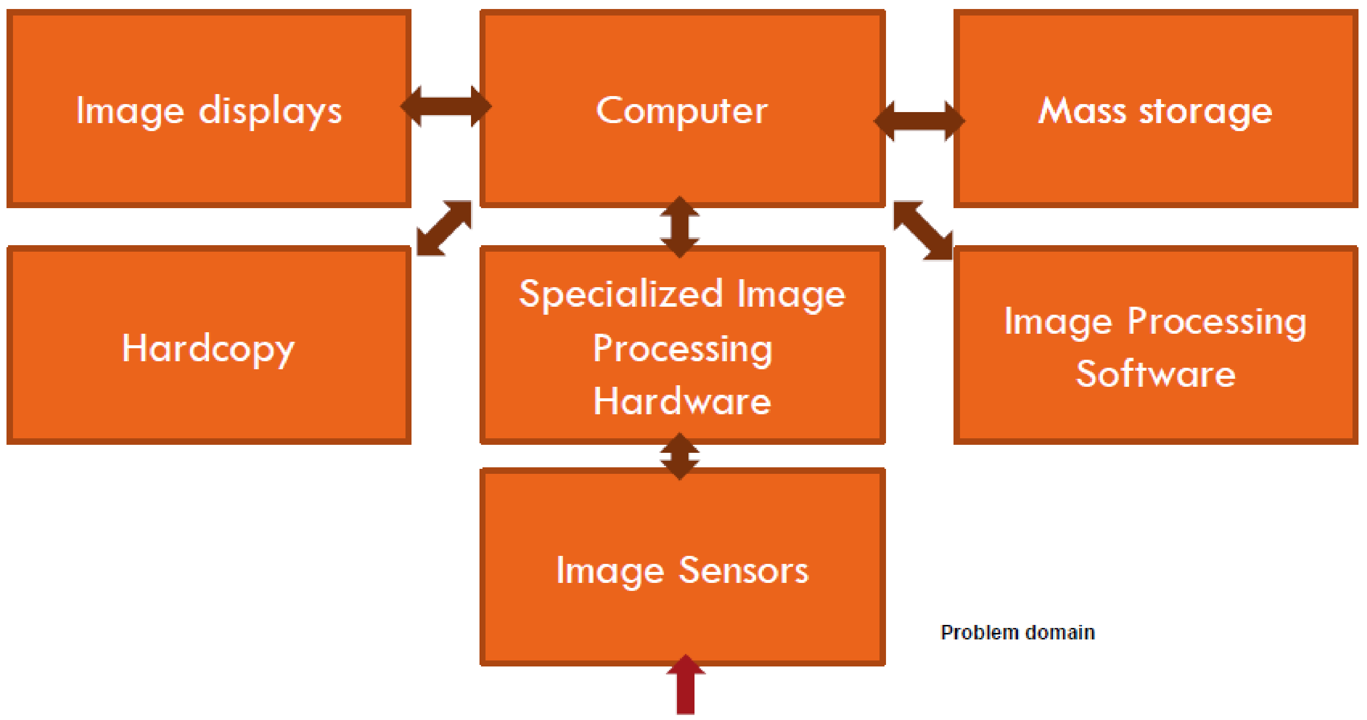
- Purpose: *Improve how the image looks* (subjective, human-oriented).
- Example: "This MRI looks too dark, let me increase contrast."
- Even if the image wasn't distorted, you might still enhance it.
- **No strict rules** — depends on human perception.

◆ Restoration

- Purpose: *Recover the original scene* (objective, physics/math-based).
- Example: "This MRI is blurry because of patient movement, let me deblur it using a known blur model."
- You only do it when you *know the image is degraded*.
- Uses mathematical models of degradation (blur, noise, distortion).



Components of Digital Image Processing System



1. **Image Sensors**
    - Physical devices (e.g., camera CCD, CMOS sensor, X-ray detector) that capture the scene/object and convert it into electrical signals → digital data.
    - Example: A mobile phone camera lens + sensor.
2. **Specialized Image Processing Hardware**
    - Dedicated hardware for fast operations like digitization (analog-to-digital conversion), arithmetic, logical image operations.
    - Used when high speed is required (e.g., real-time medical scans, satellite data).
    - Example: GPU, DSP (Digital Signal Processor).
3. **Computer**
    - General-purpose system to run DIP tasks. Ranges from a PC → powerful server / supercomputer depending on complexity.
    - Example: Running medical imaging software on a workstation.