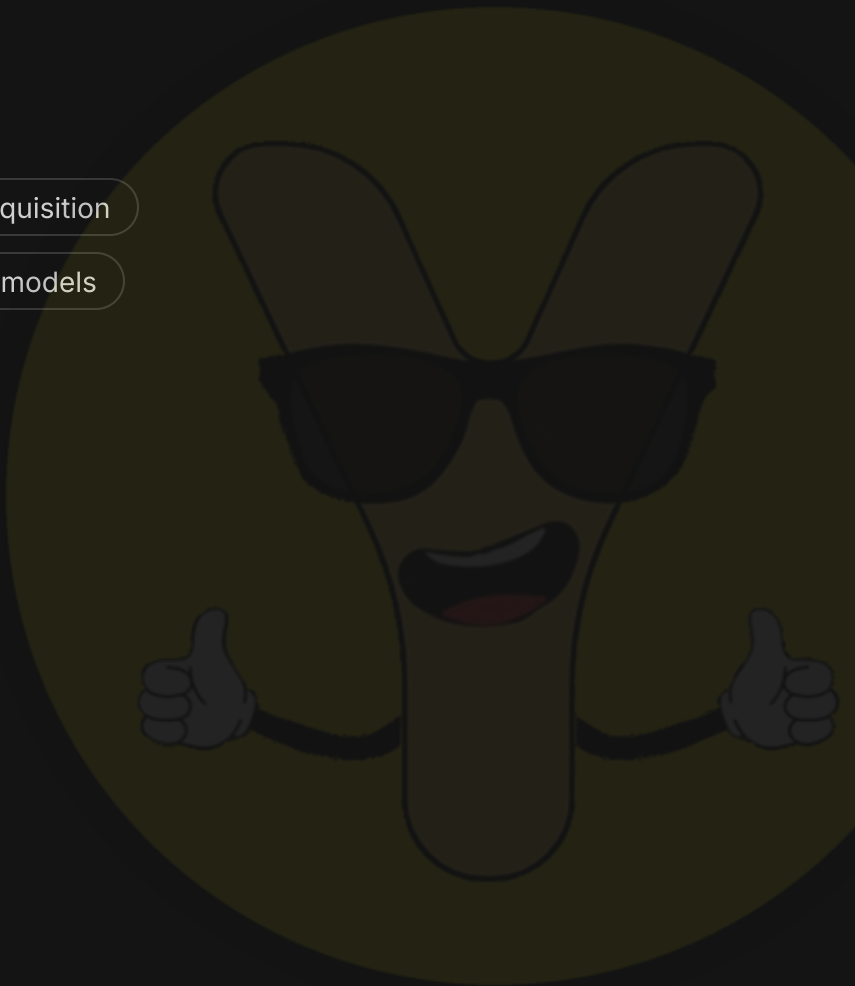
AKTU · 3RD YEAR · SEMESTER 5 · BCS057

Image Processing

Unit 1 — Digital Image Fundamentals

- Steps in Digital Image Processing
- Components
- Elements of Visual Perception
- Image Sensing and Acquisition
- Image Sampling and Quantization
- Relationships between pixels
- Color image fundamentals
- RGB, HSI models
- Two-dimensional mathematical preliminaries
- 2D transforms
- DFT
- DCT



DECODED BY

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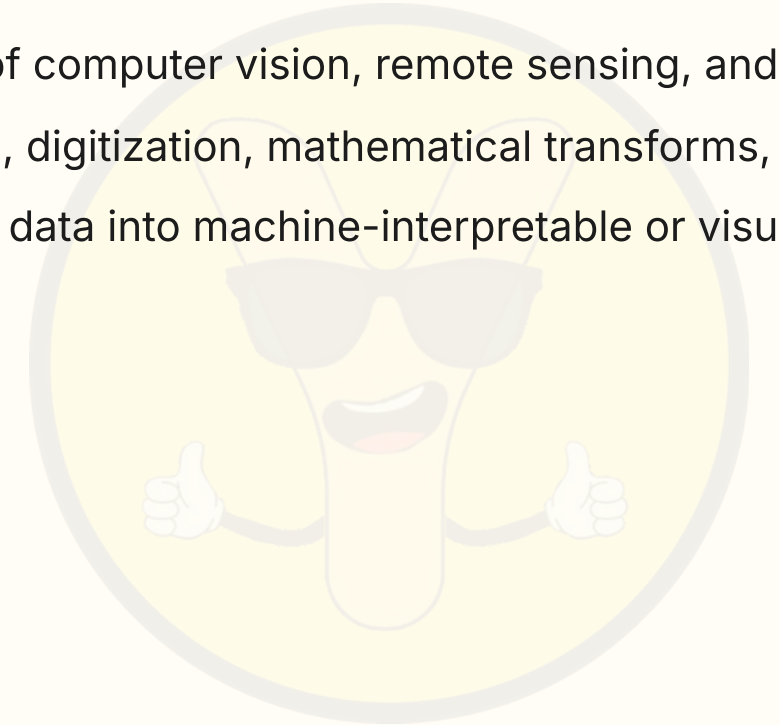
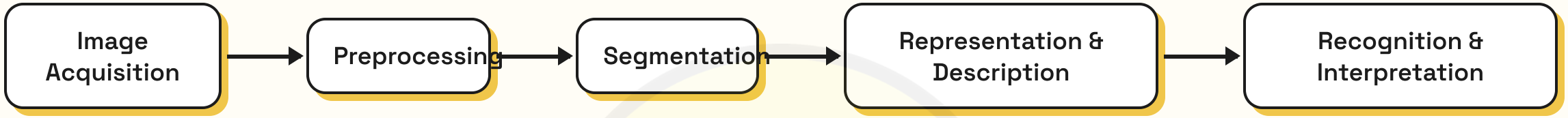
Digital Image Fundamentals - Overview

Introduction to fundamental concepts, models, and mathematical tools used in digital image processing.

- Image processing forms the core of computer vision, remote sensing, and medical diagnostics.
- Unit covers perception, acquisition, digitization, mathematical transforms, and color models.
- Crucial for transforming raw visual data into machine-interpretable or visually enhanced outputs.



Steps in Digital Image Processing



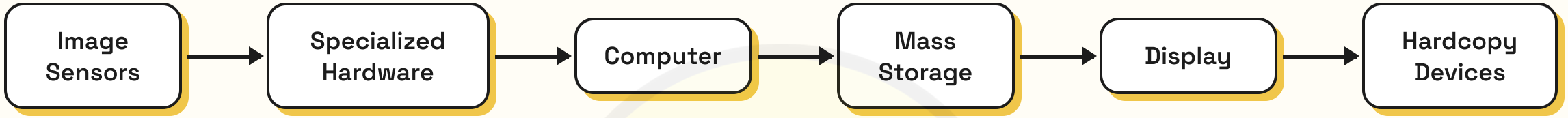
Sequential stages of processing an image from input capture to high-level machine understanding.

Steps in Digital Image Processing: Detailed Flow

Explanation of each processing stage from raw input to semantic output.

- Image Acquisition:
  - Captures sensor data and yields initial digital image.
  - Involves scaling, lighting, and camera setup.
- Preprocessing:
  - Enhances contrast, removes noise, and isolates regions of interest.
  - Prepares data for downstream feature extraction.
- Segmentation & Representation:
  - Partitions image into constituent objects.
  - Converts data into boundary chains or skeletal forms.
- Recognition & Interpretation:
  - Assigns labels to objects (Recognition).
  - Assigns meaning to an ensemble of recognized objects (Interpretation).

Components of a General Image Processing System

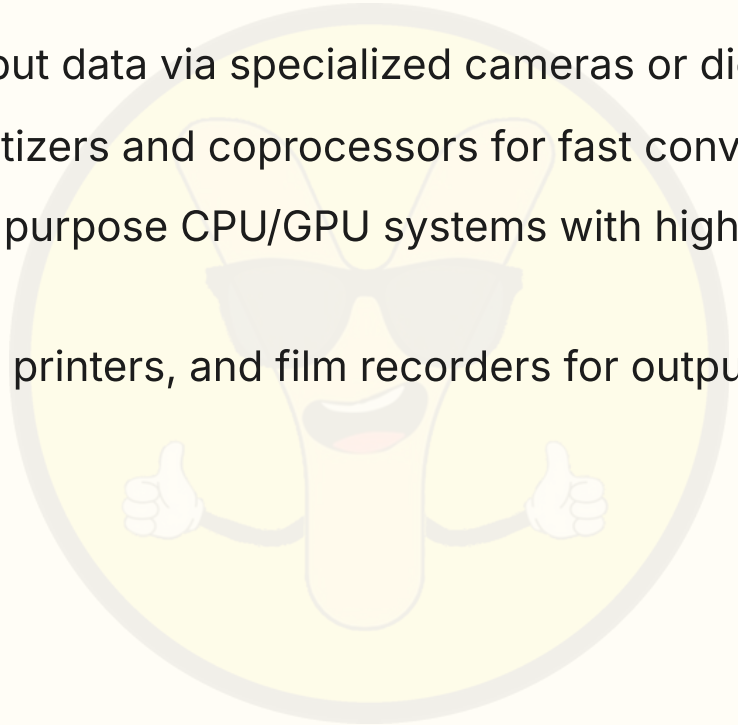


Hardware and software components required to capture, process, store, and display digital images.

Components of an Image Processing System

Hardware modules working together to execute complex vision tasks.

- Image Sensors: Provide physical input data via specialized cameras or digital arrays.
- Specialized Hardware: Includes digitizers and coprocessors for fast convolution operations.
- Computer & Mass Storage: General purpose CPU/GPU systems with high capacity drives for large image databases.
- Display & Hardcopy: Monitors, laser printers, and film recorders for output visualization.

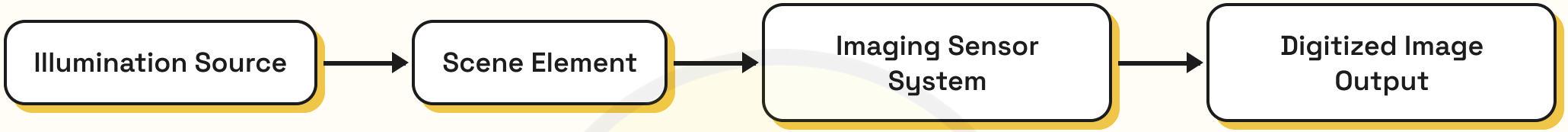


Elements of Visual Perception

Understanding human vision is vital because processing algorithms are often tuned to human perceptual limits.

- Structure of Human Eye:
  - Light enters through cornea, passes lens, and focuses on retina.
  - Retina contains photoreceptors: Cones (color, high detail) and Rods (monochrome, low light).
- Brightness Adaptation:
  - Visual system handles vast illumination levels through dynamic range adaptation.
  - Subjective brightness is a logarithmic function of light intensity.
- Mach Band Effect:
  - Visual system exaggerates contrast at intensity discontinuities.
  - Crucial perceptual illusion in edge detection and filtering.

Image Sensing and Acquisition



Physical setup for capturing digital images using energy sources and sensor arrays.

Image Sensing and Acquisition Details

Conversion of physical energy into digital image arrays.

- Illumination Source: Energy reflection or transmission from a scene (e.g., X-ray, light, ultrasound).
- Sensor Strips & Arrays: CCD or CMOS linear strips and 2D matrices convert light energy into voltage.
- Single Sensor Capture: Uses mechanical motion in X-Y directions to scan a point-by-point scene.
- Sensor Arrays: Capture complete 2D planes instantly via electronic integration across pixel elements.

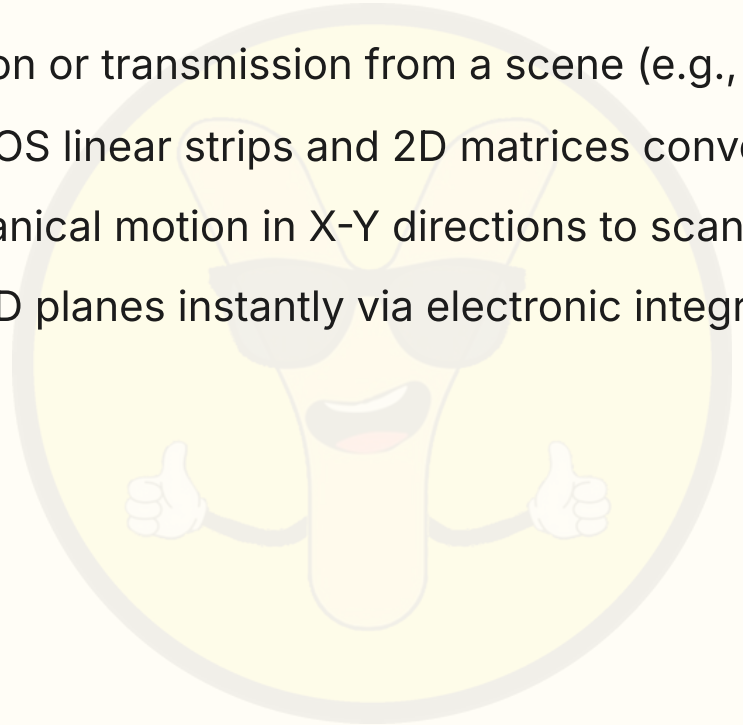


Image Sampling and Quantization

DIGITIZATION

The process of converting a continuous spatial image into a discrete digital matrix.

- Sampling: Digitizing spatial coordinates (x, y). Determines spatial resolution.
- Quantization: Digitizing the amplitude values (intensity levels). Determines gray-level resolution.
- An image is represented mathematically as a 2D matrix of size $M \times N$.

Sampling and Quantization Impact

Explain how varying sampling interval Δx and quantization levels L affect image quality.

1. Higher sampling rate reduces pixelation and captures fine spatial details.
2. Lower sampling rate introduces false contours and aliasing artifacts.
3. Higher quantization levels $L = 2^k$ provide smoother intensity transitions.
4. Lower quantization levels cause false contouring in smooth shaded regions due to large step sizes.

Optimal balance of spatial resolution and gray levels prevents aliasing and false contouring while maintaining manageable file sizes.

Relationships Between Pixels

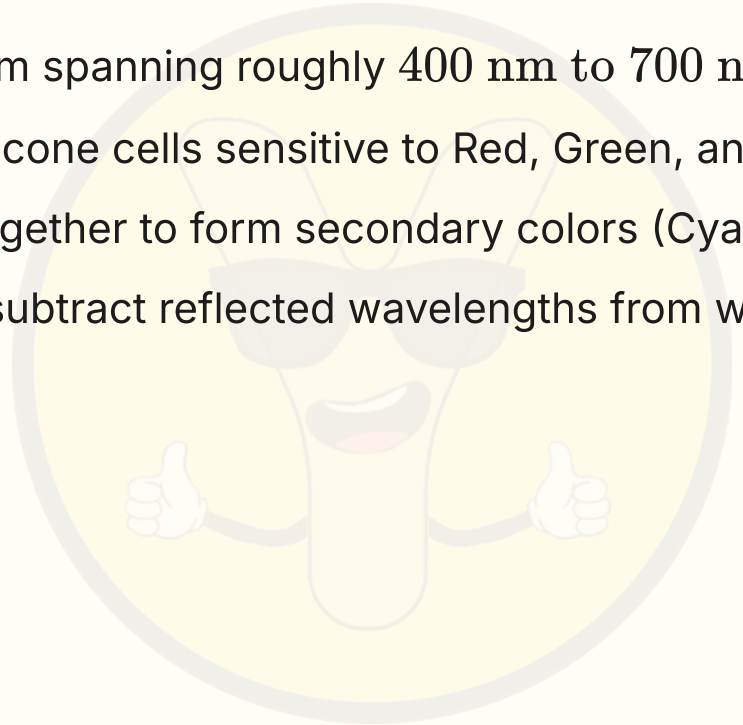
Spatial relationships define how pixels connect, neighbor, and form paths within an image matrix.

- Neighbors of a Pixel:
  - 4-Neighbors $N_4(p)$: Horizontal and vertical adjacent pixels.
  - Diagonal Neighbors $N_D(p)$: Four diagonal corner pixels.
  - 8-Neighbors $N_8(p)$: Combination of $N_4(p)$ and $N_D(p)$.
- Connectivity:
  - Adjacency requires pixels to share specific gray-level properties V.
  - Types: 4-adjacency, 8-adjacency, and m-adjacency (mixed adjacency to resolve ambiguity).
- Distance Measures:
  - Euclidean distance: $D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$.
  - City-block distance D_4 and Chessboard distance D_8.

Color Image Fundamentals

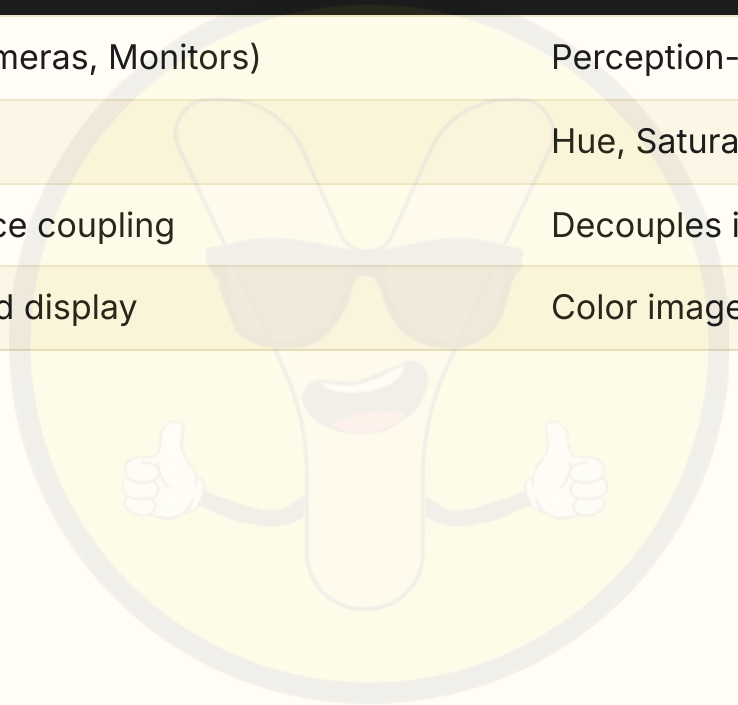
Color perception and representation in digital systems based on human tri-stimulus theory.

- Light is an electromagnetic spectrum spanning roughly $400\ \text{nm}$ to $700\ \text{nm}$.
- Human eye contains three types of cone cells sensitive to Red, Green, and Blue wavelengths.
- Primary colors of light (RGB) add together to form secondary colors (Cyan, Magenta, Yellow).
- Primary colors of pigments (CMY) subtract reflected wavelengths from white light.



Comparison of RGB and HSI Color Models

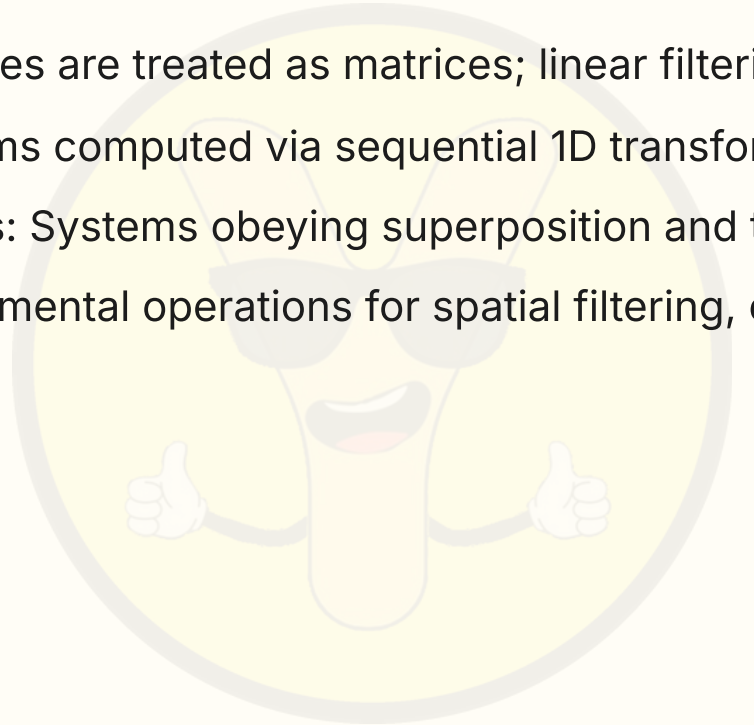
Feature	RGB Model	HSI Model
Orientation	Hardware-oriented (Cameras, Monitors)	Perception-oriented (Human vision)
Components	Red, Green, Blue	Hue, Saturation, Intensity
Coupling	High color and luminance coupling	Decouples intensity from color info
Use Case	Color image capture and display	Color image processing and segmentation



Two-Dimensional Mathematical Preliminaries

Essential mathematical tools for analyzing and manipulating digital images.

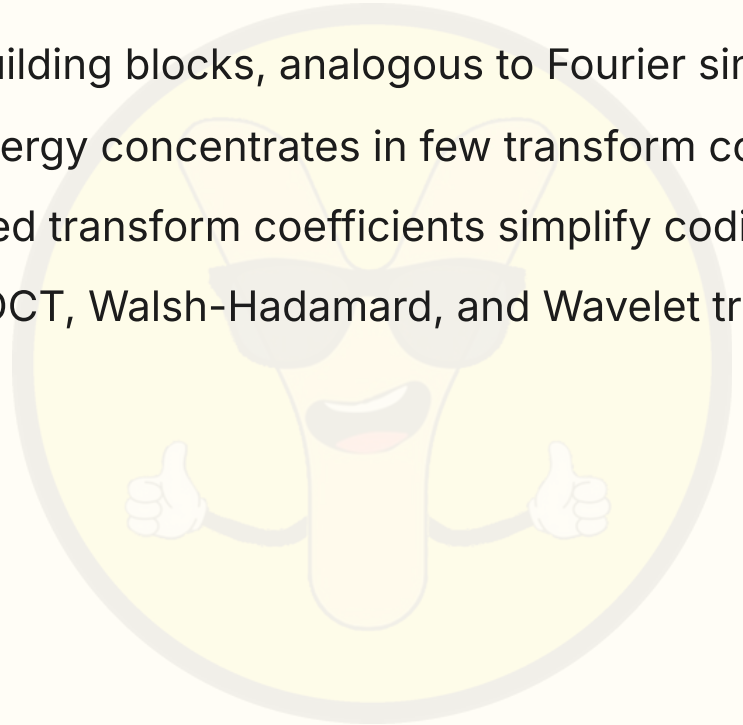
- Matrix and Vector Operations: Images are treated as matrices; linear filtering is matrix multiplication.
- Separable Transforms: 2D transforms computed via sequential 1D transforms along rows and columns.
- Linear, Shift-Invariant (LSI) Systems: Systems obeying superposition and time/space invariance.
- Convolution and Correlation: Fundamental operations for spatial filtering, edge detection, and smoothing.



Introduction to 2D Transforms

Converting spatial domain images into transform domains for analysis and compression.

- Transform basis functions act as building blocks, analogous to Fourier sinusoids.
- Energy Compaction: Most signal energy concentrates in few transform coefficients (e.g., in DCT).
- Redundancy Reduction: Uncorrelated transform coefficients simplify coding and transmission.
- Common Transforms: 2D DFT, 2D DCT, Walsh-Hadamard, and Wavelet transforms.



Two-Dimensional Discrete Fourier Transform (DFT)

2D DFT

Mathematical transformation mapping a spatial image matrix into its frequency domain representation.

- Forward 2D DFT formula: $F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) e^{-j2\pi(ux/M + vy/N)}$.
- Inverse 2D DFT formula: $f(x,y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v) e^{j2\pi(ux/M + vy/N)}$.
- Separability property allows computing 2D DFT using successive 1D DFTs along rows then columns.

Properties and Applications of 2D DFT

Key mathematical characteristics utilized in frequency domain filtering.

- Translation and Periodicity: DFT assumes infinite spatial periodicity in both x and y directions.
- Rotation: Rotating the input image rotates its corresponding Fourier spectrum by the same angle.
- Convolution Theorem: Convolution in the spatial domain equals multiplication in the frequency domain.
- Applications: Filtering periodic noise, edge enhancement, and fast computation via FFT algorithms.

Two-Dimensional Discrete Cosine Transform (DCT)

2D DCT

A Fourier-related transform using only real cosine basis functions, highly efficient for image compression.

- Forward 2D DCT formula uses cosine terms, avoiding complex exponential computations.
- Superior energy compaction compared to DFT; concentrates most image signal variance into top-left low-frequency coefficients.
- Standard foundation for lossy image and video compression formats such as JPEG and MPEG.

Exam corner

- **Q1** Explain the fundamental steps in Digital Image Processing with a neat block diagram.
- **Q2** What is image sampling and quantization? Discuss their effects on spatial and gray-level resolution.
- **Q3** Explain the structure of the human eye and describe brightness adaptation and the Mach band effect.
- **Q4** Define 4-neighbors, 8-neighbors, and m-adjacency. Give examples for each.
- **Q5** Compare RGB and HSI color models. Why is HSI preferred for color image processing?
- **Q6** State and explain the formula for 2D Discrete Fourier Transform (DFT) and its properties.
- **Q7** Why is 2D Discrete Cosine Transform (DCT) preferred over DFT in image compression standards like JPEG?

Unit 1 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 2 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

