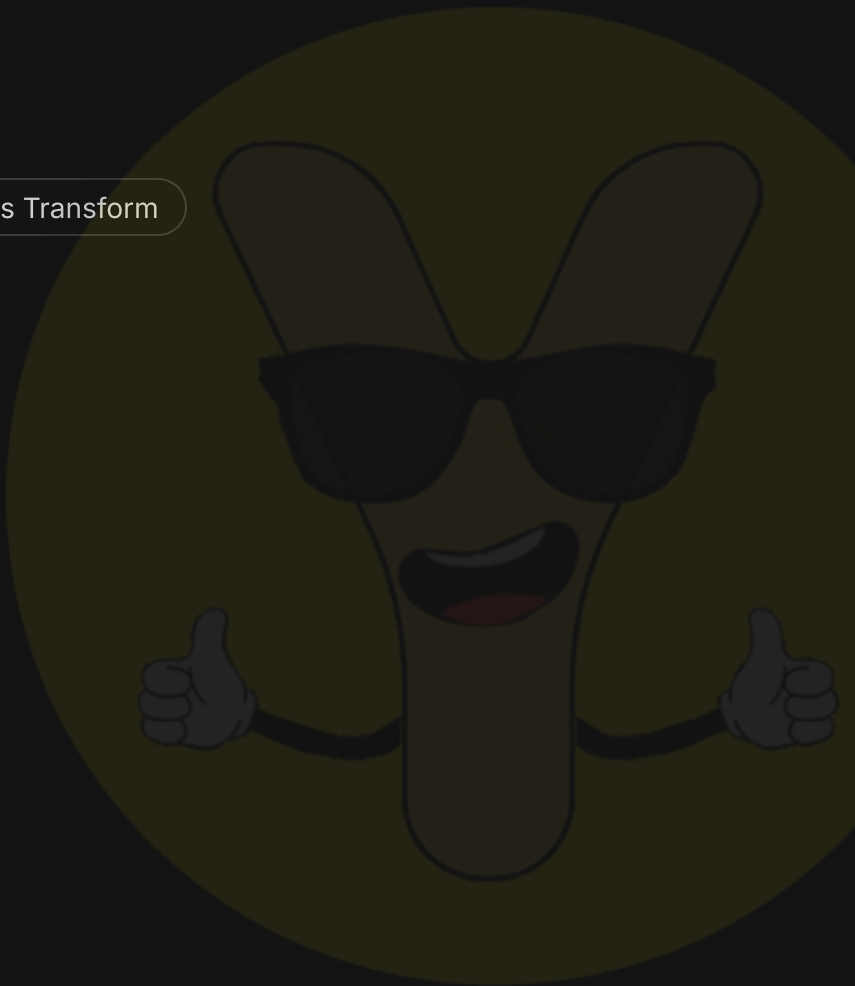
AKTU · 3RD YEAR · SEMESTER 6 · BCDS061

Image Analytics

Unit 2 — Morphological Image Processing

- Morphological Image Processing: Fundamentals
- Erosion and Dilation
- Opening and Closing
- Hit or Miss Transform
- Some Basic Morphological Algorithms
- Morphological Reconstruction
- Grayscale Morphology



DECODED BY

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Morphological Image Processing Fundamentals

MORPHOLOGY

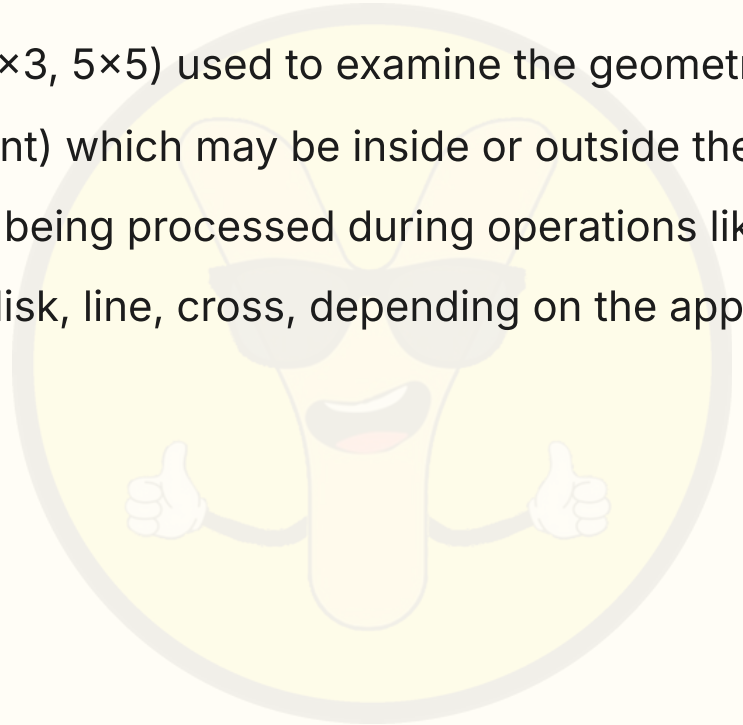
A branch of biology dealing with the form and structure of animals and plants. In image processing, it refers to tools for probing image structures using a small shape called a structuring element.

- Based on set theory mathematics.
- Operates primarily on binary and grayscale images.
- Used for extracting image components that are useful in the representation and description of region shape.

Structuring Elements

The fundamental probe used in morphological operations.

- A small binary image matrix (e.g., 3×3, 5×5) used to examine the geometric features of the input image.
- Contains an origin (or reference point) which may be inside or outside the structuring element.
- Defines the neighborhood of pixels being processed during operations like erosion and dilation.
- Can have various shapes: square, disk, line, cross, depending on the application requirement.



Erosion Fundamentals

EROSION

A morphological operation that shrinks or thins objects in a binary image by stripping away boundary pixels.

- Formula: $A \ominus B = \{z | (B)_z \subseteq A\}$.
- Erosion of set A by structuring element B is the set of all displacements z such that B translated by z is contained in A.
- Used to remove small irrelevant features, noise, and decouple touching objects.

Erosion Working Principle

Explain the step-by-step working mechanism of binary erosion.

1. Position the origin of the structuring element B over a pixel in the image A.
2. Check if all pixels covered by B coincide with foreground pixels (1s) in A.
3. If the condition holds, set the output image pixel at that origin to 1.
4. Otherwise, set the output image pixel to 0.
5. Repeat this for all pixel positions in the image.

Pixels where the structuring element does not fully fit inside the foreground are eroded to the background.

Dilation Fundamentals

DILATION

A morphological operation that grows or thickens objects in a binary image by adding pixels to the boundaries.

- Formula: $A \oplus B = \{z | (B)_z \cap A \neq \emptyset\}$.
- Dilation of set A by structuring element B is the set of all displacements z such that B and A overlap by at least one element.
- Used to bridge gaps, fill holes, and connect broken parts of an object.

Dilation Working Principle

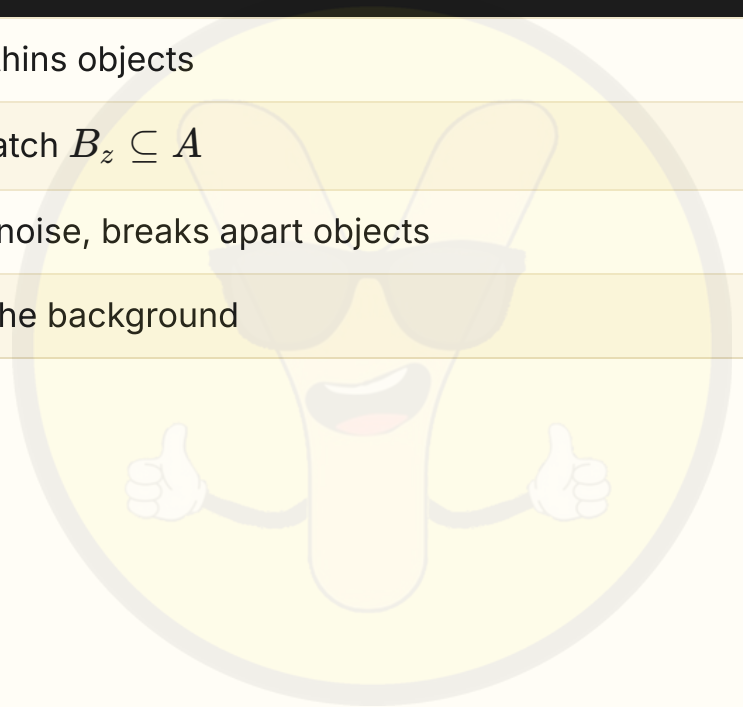
Explain the step-by-step working mechanism of binary dilation.

1. Position the origin of the structuring element B over a foreground pixel in image A.
2. Reflect the structuring element about its origin.
3. Superimpose the reflected structuring element onto the image at the current pixel location.
4. If any of the pixels in the reflected structuring element overlap with foreground pixels in A, set the target pixel to 1.
5. Repeat for all pixels to expand the boundaries.

The foreground regions expand outward by the shape and size defined by the structuring element.

Erosion vs Dilation

Feature	Erosion	Dilation
Basic Action	Shrinks / thins objects	Expands / thickens objects
Set Theory	Subset match $B_z \subseteq A$	Intersection match $B_z \cap A \neq \emptyset$
Main Purpose	Removes noise, breaks apart objects	Fills holes, bridges gaps
Effect on Background	Expands the background	Shrinks the background



Opening Fundamentals

OPENING

Erosion of an image followed by dilation of the eroded result using the same structuring element.

- Formula: $A \circ B = (A \ominus B) \oplus B$
- Smooths object contours, breaks thin connections, and removes thin protrusions.
- Preserves the overall size and shape of larger regions while eliminating fine details smaller than the structuring element.

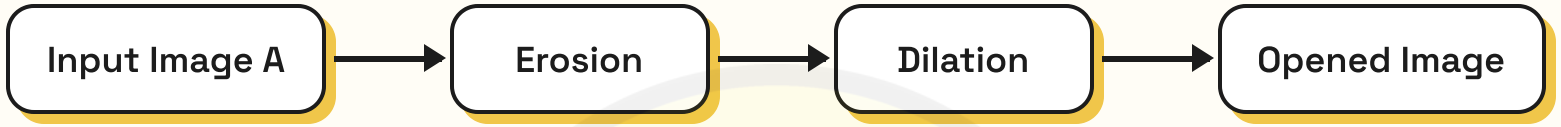
Closing Fundamentals

CLOSING

Dilation of an image followed by erosion of the dilated result using the same structuring element.

- Formula: $A \bullet B = (A \oplus B) \ominus B$
- Fills small holes, narrow gaps, and smooths object boundaries from the inside.
- Connects nearby objects and repairs fractured segments without significantly altering the overall object size.

Opening and Closing Flow



Pipeline for Morphological Opening: erosion removes small elements, subsequent dilation restores the size of retained shapes.

Hit-or-Miss Transform

HIT-OR-MISS TRANSFORM (HMT)

A shape detection and pattern matching morphological operation used to find specific configurations of foreground and background pixels.

- Formula: $A \odot B = (A \ominus B_1) \cap (A^c \ominus B_2)$
- Structuring element B is composed of two disjoint parts: B_1 for foreground matching and B_2 for background matching.
- Crucial for skeletonization, thinning, and finding corner or endpoint configurations.

Basic Morphological Algorithms

Combining fundamental operations to solve complex image processing tasks.

- Boundary Extraction
  - Extracts the outer boundary of a region.
  - Formula: $\beta(A) = A - (A \ominus B)$
- Hole Filling
  - Fills interior background regions.
  - Uses iterative dilation combined with complement and intersection.
- Connected Component Labeling
  - Identifies and groups connected pixels into distinct objects using dilation loops.



Boundary Extraction Algorithm

Write the steps to extract the boundary of a binary region A using morphology.

1. Step 1: Erode image A using structuring element B: $E = A \ominus B$.
2. Step 2: Subtract the eroded image E from the original image A.
3. Step 3: The resulting difference image contains only the boundary pixels of the objects in A.

Boundary $\beta(A) = A - (A \ominus B)$.

Morphological Reconstruction

MORPHOLOGICAL RECONSTRUCTION

An advanced morphological process involving two images: a marker image (containing starting points) and a mask image (constraining the transformation).

- Involves iterative geodesic dilation of the marker under the mask until stability is reached.
- Preserves the exact shape of components that are marked while completely eliminating unmarked structures.
- Superior to standard opening/closing because it does not distort original shapes.

Applications of Reconstruction

Why morphological reconstruction is preferred in advanced machine vision.

- Opening by Reconstruction: Eliminates bright details lighter than their surroundings without altering the shapes of remaining objects.
- Closing by Reconstruction: Fills dark holes without modifying object boundaries.
- Peak Detection: Extracts regional maxima and minima efficiently.
- Filtering: Removes noise while keeping edge locations pristine.

Grayscale Morphology Fundamentals

GRAYSCALE MORPHOLOGY

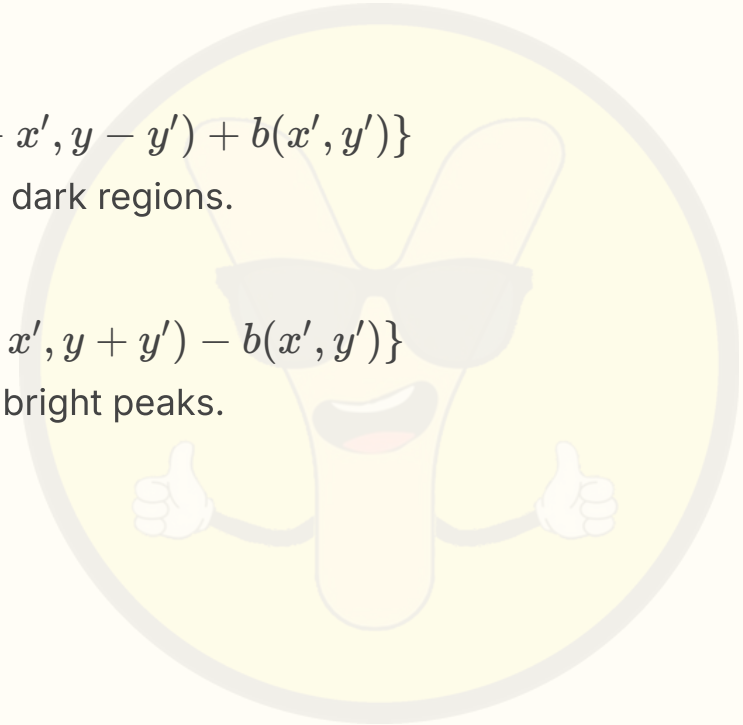
Extension of binary morphology to grayscale images, where pixel values represent intensity instead of binary 0 or 1.

- Structuring elements can be flat (constant height) or non-flat (having height values added to spatial coordinates).
- Replaces set theory operations with minimum (infimum) and maximum (supremum) operators.
- Maintains intensity gradations while smoothing or enhancing image features.

Grayscale Operators

Mathematical definitions for grayscale erosion and dilation.

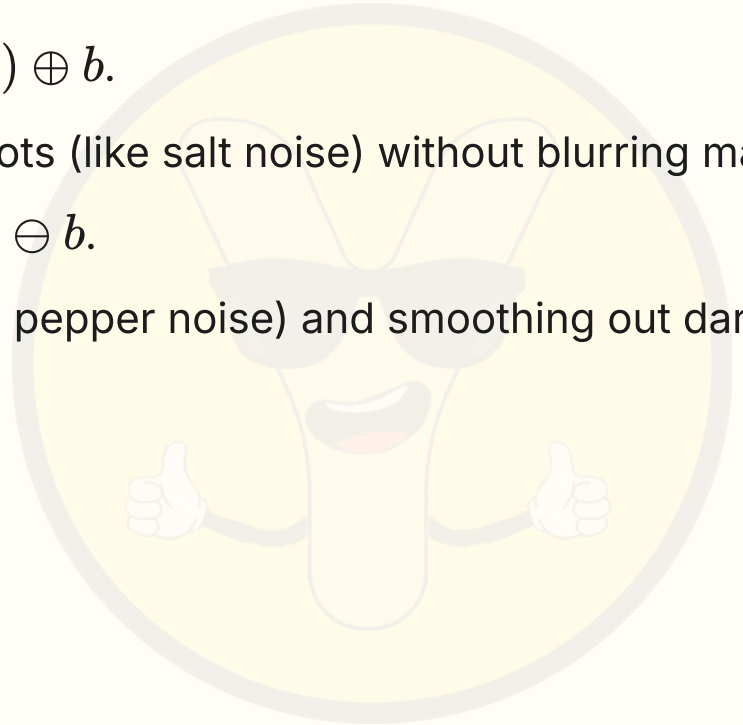
- Grayscale Dilation
  - Formula: $(f \oplus b)(x, y) = \max\{f(x - x', y - y') + b(x', y')\}$
  - Expands bright regions and diminishes dark regions.
- Grayscale Erosion
  - Formula: $(f \ominus b)(x, y) = \min\{f(x + x', y + y') - b(x', y')\}$
  - Expands dark regions and suppresses bright peaks.



Grayscale Opening and Closing

Compound operations in intensity images.

- Grayscale Opening: $f \circ b = (f \ominus b) \oplus b$.
- Useful for removing bright noise spots (like salt noise) without blurring major edges.
- Grayscale Closing: $f \bullet b = (f \oplus b) \ominus b$.
- Useful for removing dark holes (like pepper noise) and smoothing out dark valleys.



Exam corner

- **Q1** Define basic morphological operations. Explain erosion and dilation with mathematical formulas and suitable examples.
- **Q2** What is the difference between opening and closing? Explain how they are used for noise removal.
- **Q3** Explain the Hit-or-Miss transform and its significance in shape detection and thinning algorithms.
- **Q4** Describe the algorithm for boundary extraction and hole filling using binary morphology.
- **Q5** What is morphological reconstruction? How does it differ from standard opening and closing operations?
- **Q6** Explain grayscale morphology. Write the formulas for grayscale dilation, erosion, opening, and closing.
- **Q7** Write short notes on: (a) Structuring Element (b) Geodesic Dilation.

Unit 2 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 3 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

