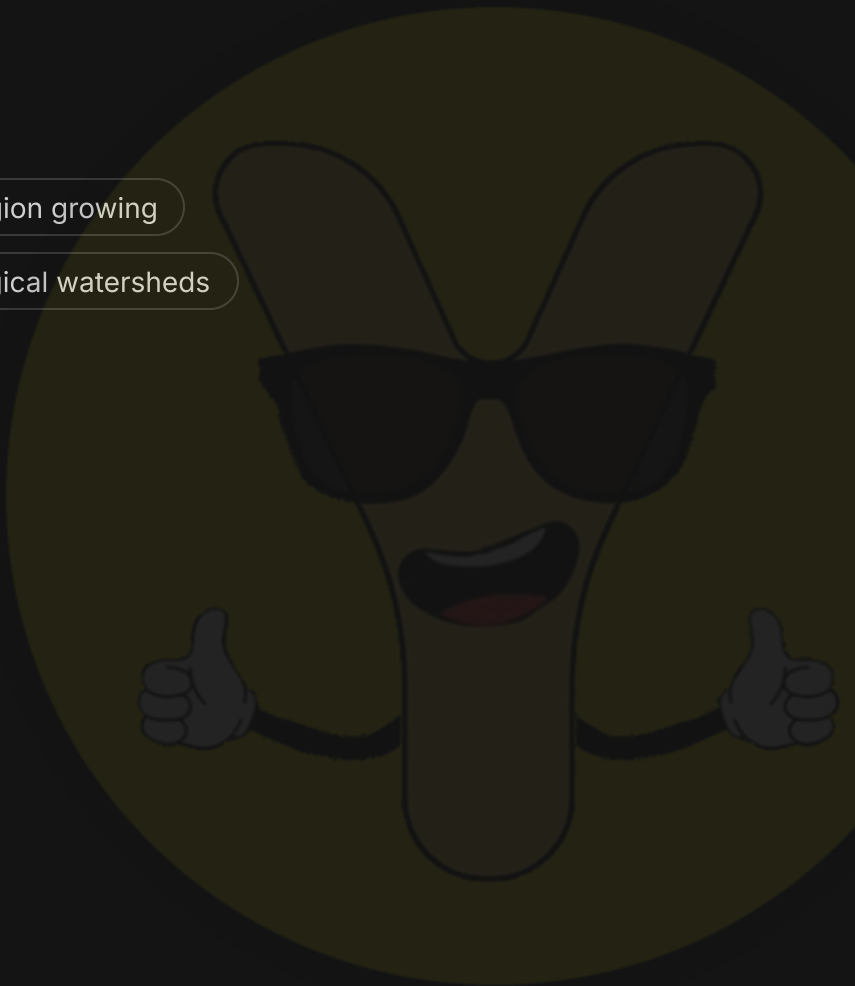
AKTU · 3RD YEAR · SEMESTER 5 · BCS057

Image Processing

Unit 4 — Image Segmentation

- Edge detection
- Edge linking via Hough transform
- Thresholding
- Region based segmentation
- Region growing
- Region splitting and merging
- Morphological processing- erosion and dilation
- Segmentation by morphological watersheds
- Basic concepts
- Dam construction
- Watershed segmentation algorithm



DECODED BY

Chirag Jain

Founder, Ycotes · Gold Medalist in Artificial Intelligence, IIT Madras · taught 10,000+ students

Introduction to Image Segmentation

IMAGE SEGMENTATION

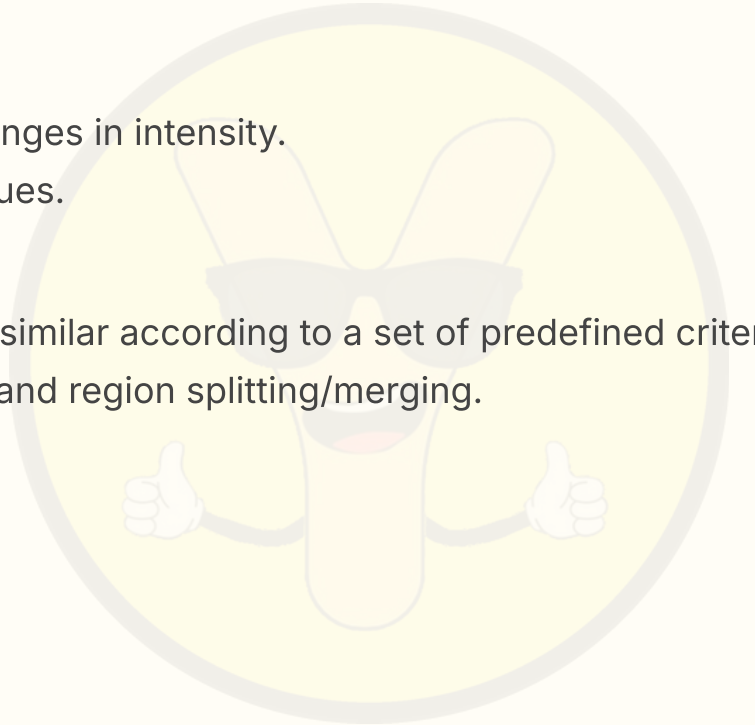
The process of partitioning a digital image into multiple segments or sets of pixels to simplify or change the representation of an image into something more meaningful and easier to analyze.

- Locates objects and boundaries (lines, curves) in images.
- Assigns a label to every pixel such that pixels with the same label share certain characteristics.
- Crucial step between low-level image processing and high-level image analysis.

Fundamental Concepts of Segmentation

Segmentation algorithms generally are based on one of two basic properties of intensity values:

- Discontinuity
  - Partition an image based on abrupt changes in intensity.
  - Includes edge detection based techniques.
- Similarity
  - Partition an image into regions that are similar according to a set of predefined criteria.
  - Includes thresholding, region growing, and region splitting/merging.



Edge Detection: Principles

Edge detection finds boundaries of objects by detecting discontinuities in gray levels.

- An edge is a set of connected pixels that lie on the boundary between two distinct regions.
- Edges are characterized by high gradient magnitude.
- First-order derivatives highlight edges using gradient vectors: $\nabla f = [G_x, G_y]^T$.
- Gradient magnitude is given by $|\nabla f| \approx |G_x| + |G_y|$.
- Second-order derivatives use Laplacian zero-crossings to locate edges.

Common Edge Detection Masks

Spatial masks are convolved with the image to calculate derivatives.

- Sobel Operator
  - Uses 3×3 kernels to compute horizontal and vertical gradients with smoothing.
  - Provides better noise suppression than simpler difference operators.
- Prewitt Operator
  - Similar to Sobel, but with constant coefficients instead of centered weights.
- Laplacian Operator
  - Second-order derivative $\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$.
  - Sensitive to noise; usually preceded by Gaussian smoothing (LoG).

Edge Linking via Hough Transform

HOUGH TRANSFORM

A feature extraction technique used in image analysis to find imperfect instances of objects within a certain class of shapes by a voting procedure.

- Bridges fragmented edge pixels into continuous curves or lines.
- Maps points in the image space $(x, y) \rightarrow$ curves in the parameter space.
- Robust to occlusions and noise missing edge points.

Hough Transform for Line Detection

A line in image space can be represented in polar coordinates:

- Polar equation: $x\cos\theta + y\sin\theta = \rho$.
- ρ is the perpendicular distance from origin, and θ is the angle of vector.
- A single point (x_i, y_i) in image space corresponds to a sinusoidal curve in parameter (ρ, θ) space.
- Collinear points in image space intersect at a common point (ρ', θ') in parameter space.
- Accumulator cells are used to count intersections.

Thresholding Fundamentals

IMAGE THRESHOLDING

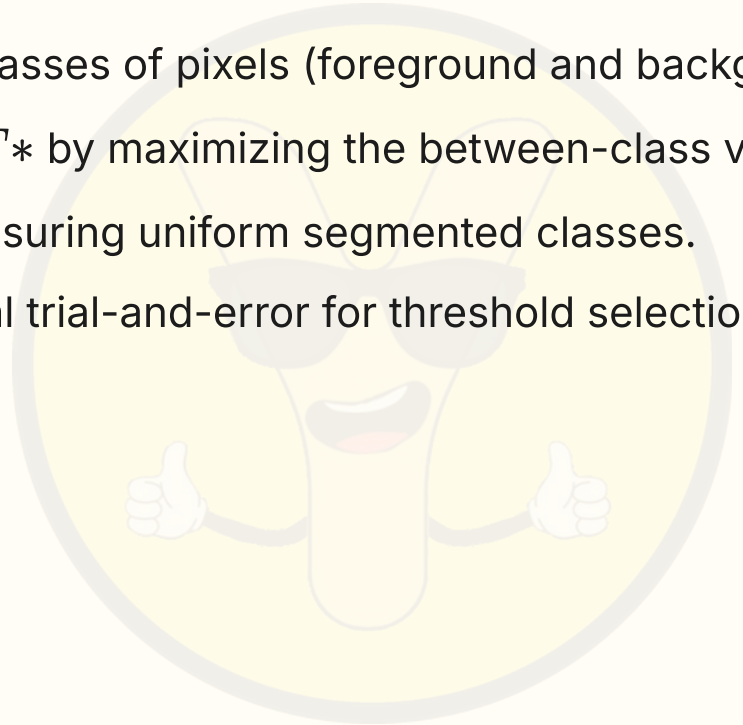
A simple yet effective method of partitioning an image into a foreground and background by comparing pixel intensities against a defined threshold value T.

- Output binary image $g(x, y) = 1$ if $f(x, y) \geq T$; else 0.
- Global thresholding uses a single T for the entire image.
- Adaptive or local thresholding varies T across the image based on neighborhood characteristics.

Otsu's Thresholding Method

An automatic global thresholding technique based on cluster variance minimization.

- Assumes the image contains two classes of pixels (foreground and background).
- Calculates the optimum threshold $T*$ by maximizing the between-class variance $\sigma_B^2(T)$.
- Minimizes within-class variance, ensuring uniform segmented classes.
- Fully automated, requires no manual trial-and-error for threshold selection.



Region-Based Segmentation

REGION-BASED SEGMENTATION

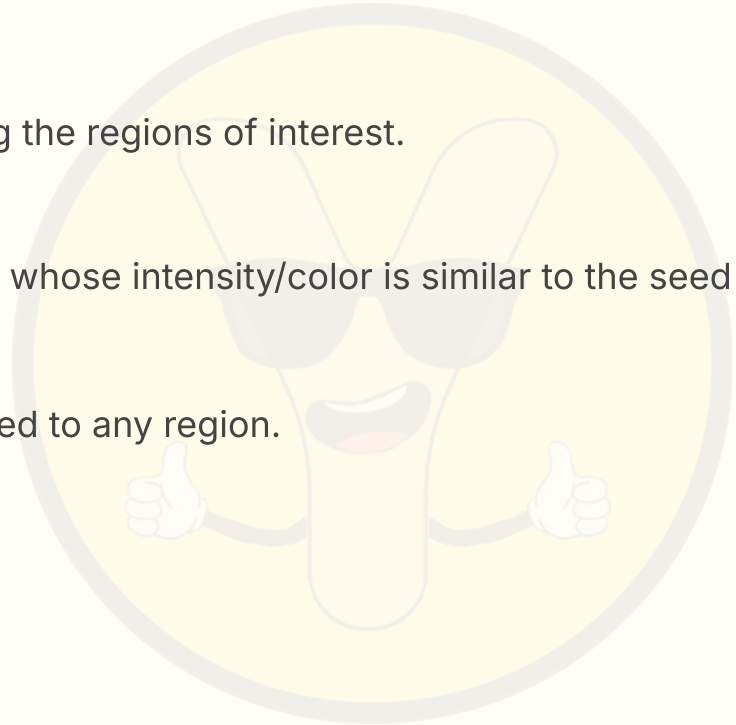
Techniques that group pixels into larger regions based on predefined similarity criteria, rather than finding edges between regions.

- Directly divides image into coherent regions.
- Less sensitive to noise compared to purely edge-based approaches.
- Core methods include Region Growing and Region Splitting & Merging.

Region Growing Algorithm

A procedure that groups pixels or sub-regions into larger regions based on predefined criteria.

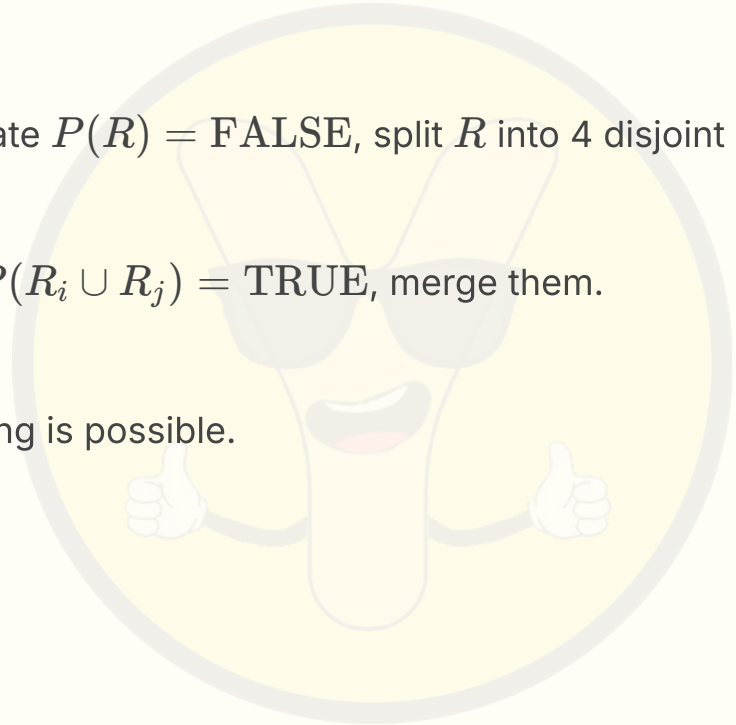
- Step 1: Seed Selection
  - Select a set of seed points representing the regions of interest.
- Step 2: Neighborhood Inclusion
  - Append unallocated neighboring pixels whose intensity/color is similar to the seed (e.g., $|f(x,y) - \text{mean}| \leq \text{Threshold}$).
- Step 3: Iteration
  - Repeat until no more pixels can be added to any region.



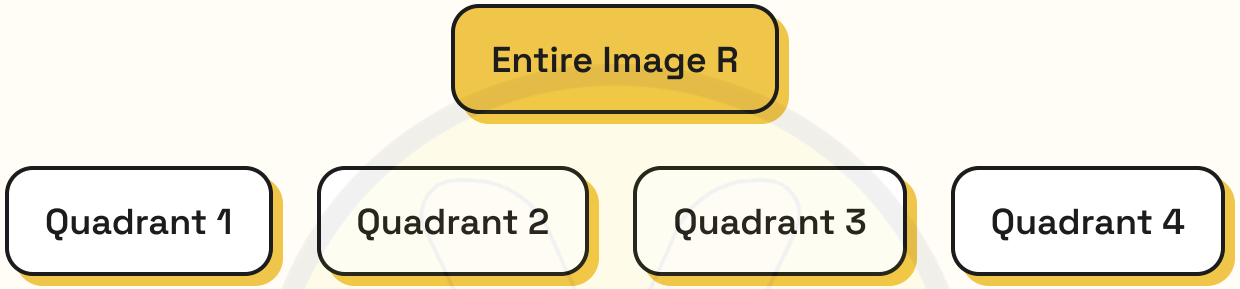
Region Splitting and Merging

Quadtree-based approach that does not require initial seed points.

- Splitting
  - Start with the entire image R. If predicate $P(R) = \text{FALSE}$, split R into 4 disjoint quadrants.
- Merging
  - If adjacent regions R_i and R_j satisfy $P(R_i \cup R_j) = \text{TRUE}$, merge them.
- Termination
  - Stop when no further splitting or merging is possible.



Region Splitting and Merging Quadtree



Recursive quadtree decomposition used in region splitting algorithms.

Morphological Processing: Dilation

MORPHOLOGICAL DILATION

An operation that grows or thickens objects in a binary image, controlled by a structural element.

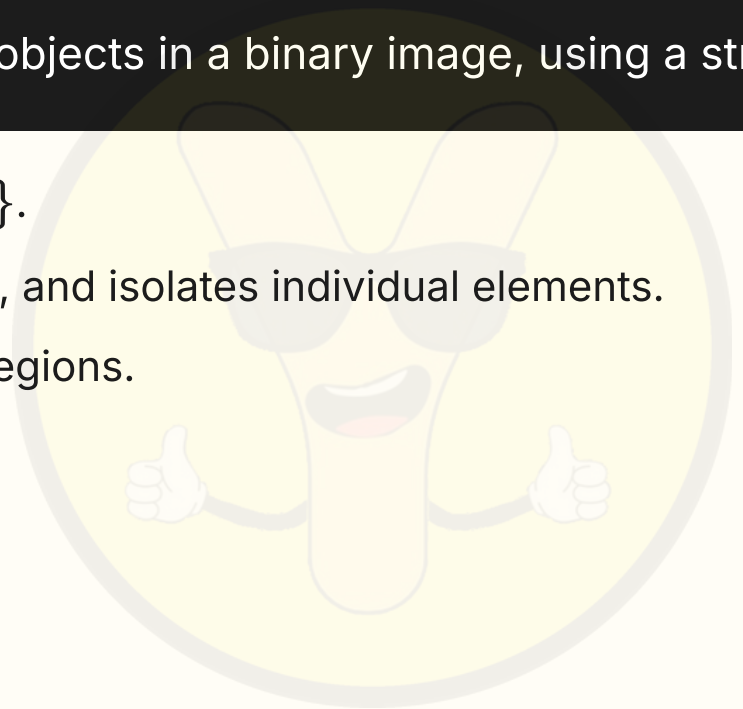
- Formula: $A \oplus B = \{z \mid (B)_z \cap A \neq \emptyset\}$.
- Expands the image pixels; fills in small holes and gaps.
- Used to bridge broken segments and expand region boundaries.

Morphological Processing: Erosion

MORPHOLOGICAL EROSION

An operation that shrinks or thins objects in a binary image, using a structuring element.

- Formula: $A \ominus B = \{z \mid (B)_z \subseteq A\}$.
- Removes small details, noise points, and isolates individual elements.
- Shrinks boundaries of foreground regions.



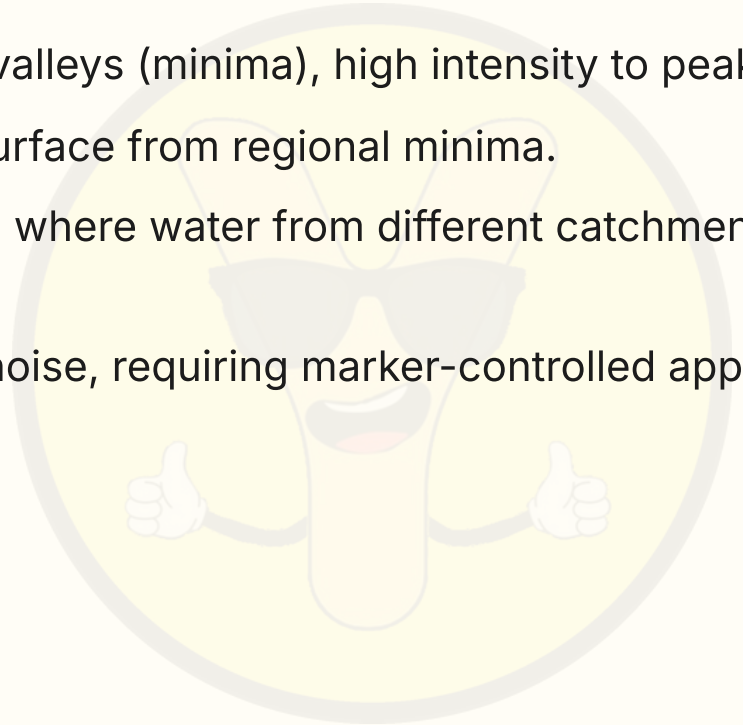
Comparison of Dilation and Erosion

Feature	Dilation	Erosion
Effect on Object	Expands / Thickens	Shrinks / Thins
Mathematical Symbol	$\oplus$	$\ominus$
Primary Use	Filling gaps and holes	Removing noise and spurs
Set Operation	Intersection non-empty	Subset inclusion

Watershed Segmentation: Basic Concepts

Derived from geography, watershed transformation views an image as a topographic surface.

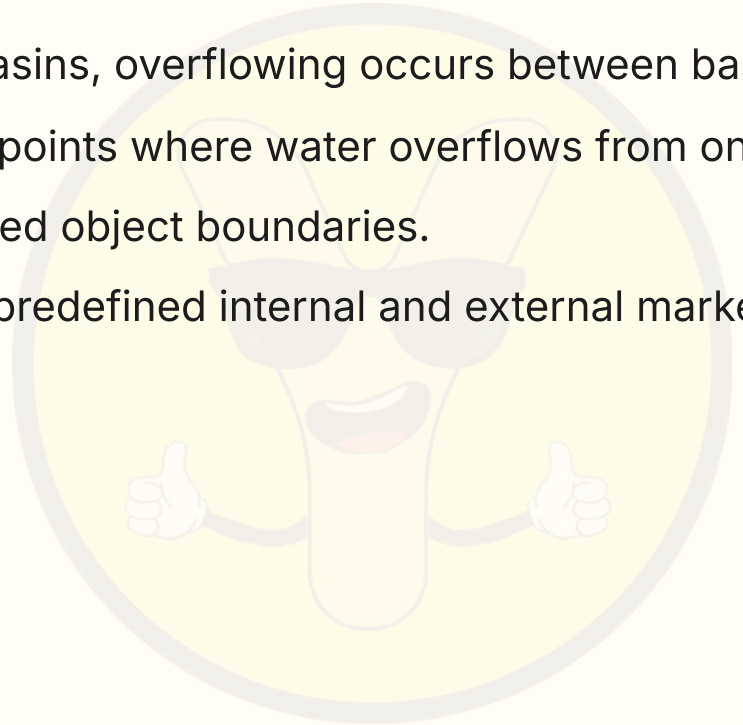
- Low intensity pixels correspond to valleys (minima), high intensity to peaks.
- Imagine flooding the topographic surface from regional minima.
- Watershed lines (dams) are erected where water from different catchment basins would merge, preventing over-merging.
- Prone to oversegmentation due to noise, requiring marker-controlled approaches.



Dam Construction in Watersheds

Preventing merging of waters from distinct catchment basins.

- As water level rises in catchment basins, overflowing occurs between basins.
- Dams (watershed lines) are built at points where water overflows from one basin to another.
- These dams form the final segmented object boundaries.
- Marker-controlled watershed uses predefined internal and external markers to limit local minima and stop unnecessary dam construction.



Watershed Segmentation Algorithm Steps

Standard algorithmic flow for computing morphological watersheds:

- Step 1: Compute gradient image to highlight object boundaries as high topographic relief.
- Step 2: Initialize set of markers (internal markers for objects, external for background).
- Step 3: Modify the gradient image using morphological techniques (minima imposition) so it only has minima at marker locations.
- Step 4: Apply flooding/immersion simulation starting from markers.
- Step 5: Extract final watershed boundary lines.

Exam corner

- **Q1** Explain the role of first and second-order derivatives in edge detection with suitable masks.
- **Q2** Derive and explain the working principle of Hough Transform for line detection.
- **Q3** What is Otsu thresholding? Explain how it maximizes between-class variance.
- **Q4** Compare and contrast Region Growing and Region Splitting & Merging techniques.
- **Q5** Define Dilation and Erosion mathematically. Give examples of their applications.
- **Q6** Explain the concept of watershed segmentation. How are dams constructed in topographic surfaces?
- **Q7** Write short notes on marker-controlled watershed segmentation to solve oversegmentation.

Unit 4 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 5 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

