Module 4: Image segmentation

- ## Image segmentation basics and types of image segmentation:

Image Segmentation Definition:

- Image segmentation is the process of partitioning an image into multiple segments to make it easier to analyze and understand.
- It involves dividing an image into meaningful regions or objects based on certain characteristics, such as intensity, color, or texture.

Types of Image Segmentation:

1) Discontinuity-based Segmentation:

- In discontinuity-based segmentation, partitioning is carried out based on instantaneous **changes in intensity values**.
- The focus is on identifying points, lines, and edges in the image.

Techniques for Discontinuity-based Segmentation:

1. **Point Detection:** Detecting isolated points or pixels with significant intensity differences compared to their neighbours.
2. **Line Detection:** Identifying straight or curved lines in the image based on variations in intensity along their lengths.
3. **Edge Detection:** Locating boundaries or edges between different regions in the image, where there are sharp intensity transitions.

2) Similarity-based Segmentation:

- In similarity-based segmentation, **pixels are grouped together if they are similar in some sense**, such as intensity, color, or texture.
- The goal is to group pixels that belong to the same object or region in the image.

Techniques for Similarity-based Segmentation:

1. **Thresholding:** Dividing the image into two or more regions based on a specified threshold value of intensity, color, or other feature.
    - Example: Binarizing an image into foreground and background based on a threshold intensity value.

2. **Region Growing:** Starting from seed points, adjacent pixels with similar characteristics are iteratively added to the same region until a stopping criterion is met.
    - Example: Growing a region around a seed pixel with similar intensity values.

3. **Region Splitting and Merging:** Initially, the entire image is considered a single region, which is then recursively split into smaller regions based on differences in characteristics.
    - Example: Dividing an image into smaller regions based on variations in intensity or color, then merging regions that are similar enough.

Imp ➢ Discontinuity based operators- Robert, Sobel, Prewitt

1. Robert Operator:

- The Robert operator is a simple edge detection operator used to detect edges in images.
- It consists of two 2x2 convolution masks that are applied to the image to compute the gradient approximation.

- The masks are designed to detect edges at 45-degree orientations.

Robert Operator Masks:

$$G_x = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \text{ and } G_y = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

Gx is the Mask for detecting vertical edges
Gy is the Mask for detecting horizontal edges

2. Sobel Operator:

- The Sobel operator is another edge detection operator used to find edges in images.
- It consists of two 3x3 convolution masks (one for horizontal changes and one for vertical changes) that are applied to the image.
- The masks are designed to emphasize edges in both the horizontal and vertical directions.

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \text{ and } G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Gx is the Mask for vertical edges
Gy is the Mask for horizontal edges

3. Prewitt Operator:

- The Prewitt operator is similar to the Sobel operator and is used for edge detection.

- It also consists of two 3x3 convolution masks (one for horizontal changes and one for vertical changes) that are applied to the image.
- Like the Sobel operator, it emphasizes edges in both horizontal and vertical directions, but the mask coefficients are slightly different.

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \text{ and } G_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Gx is the Mask for vertical edges
Gy is the Mask for horizontal edges

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➢ Discontinuity based Canny Edge Detection Algorithm:

1. Smoothing:

- The first step in Canny Edge Detection is to reduce noise in the image.
- This is achieved by applying a **Gaussian filter**, which blurs the image slightly.
- Smoothing helps in reducing the impact of noise on edge detection and makes it easier to detect true edges.

2. Gradient Calculation:

- After smoothing, the intensity gradients of the image are calculated.
- Techniques **like Sobel or Prewitt** operators are commonly used for gradient calculation.
- The gradient magnitude represents the strength of the edge, while the direction indicates the orientation of the edge.

3. Non-maximum Suppression:

- Non-maximum suppression is applied to thin out the detected edges.
- It involves suppressing **all gradient values except the local maxima**, which represent potential edges.
- This step ensures that the final edge map contains only thin lines corresponding to the strongest edges.

4. Double Thresholding:

- In double thresholding, two thresholds are set: a high threshold (T_high) and a low threshold (T_low).
- Pixels with gradient magnitudes above T_high are considered **strong edge pixels**.
- Pixels with gradient magnitudes between T_low and T_high are considered **weak edge pixels**.
- Pixels with gradient magnitudes below T_low are discarded.

5. Edge Tracking by Hysteresis:

- The final step is edge tracking by hysteresis, which helps determine which edges are true edges.
- Strong edge pixels identified in the double thresholding step are retained.
- *Weak edge pixels that are connected to strong edges are also considered as edge pixels*.
- *Weak edge pixels that are not connected to strong edges are discarded.*

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- similarity based segmentation and **Thresholding**

- **Similarity-based Segmentation:**

Similarity-based segmentation approaches aim to group pixels in an image based on their similarity in some sense.

Two common techniques used in similarity-based segmentation are thresholding and region growing.

Thresholding:

- Thresholding is a simple yet effective technique used for image segmentation.
- It involves **dividing an image into regions based on a threshold value**.
- There are different types of thresholding techniques:
    - **Global thresholding**: A single threshold is applied to the entire image.
    - **Local thresholding**: Different threshold values are applied to different regions of the image.
    - **Adaptive thresholding**: The threshold value is adjusted based on the local properties of the image.
- Thresholding converts a grayscale image into a binary image by classifying pixels as object or background based on their intensity values compared to the threshold.

Thresholding Example:

- In a thresholding example, suppose we have an image with a dark object against a bright background, resulting in a bimodal histogram.
- A threshold value (T) is selected to separate the object from the background:

  $f(x, y) < T$ implies object
  $f(x, y) \geq T$ implies backgroundThis process results in a segmented output image where the object and background are separated.

Thresholding Function:

- The thresholding function tests the image against a threshold value:

$T = T[x, y, p(x, y), f(x, y)]$

Where:

- (x, y) = coordinates of the pixels
- f(x, y) = intensity value of the pixels
- p(x, y) = local property in the neighborhood, centered at (x, y)

Automatic Global Thresholding:

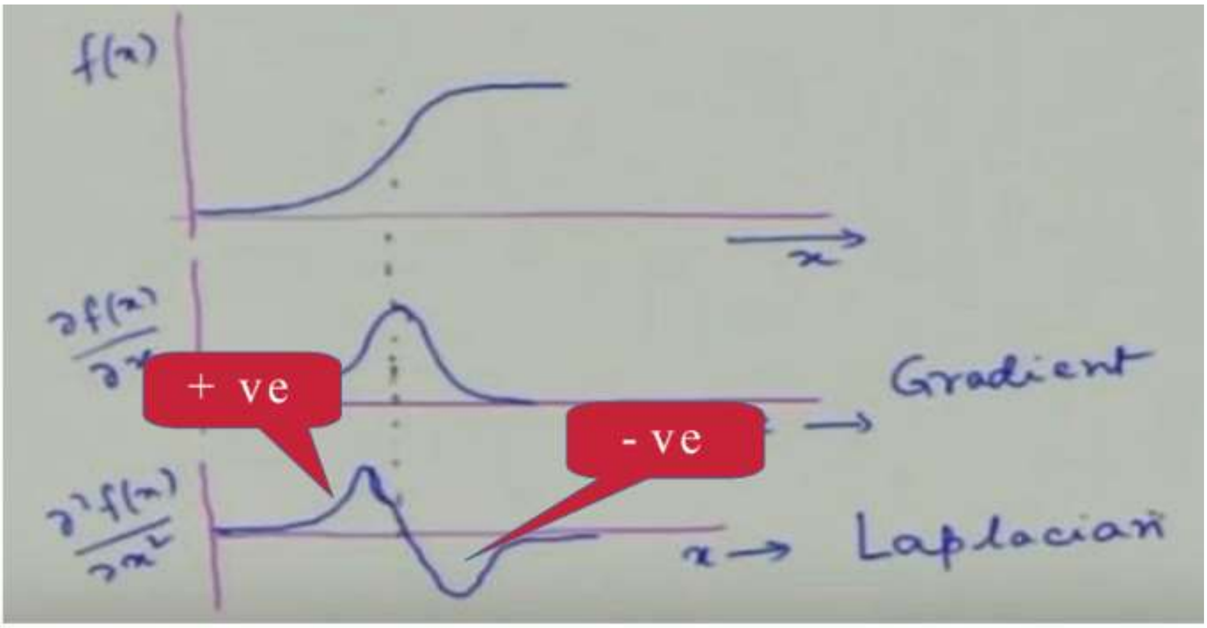
- Automatic global thresholding involves automatically selecting a threshold value to segment the image into two regions.
- If $T[f(x,y)]$ then it is global thresholding
- One common approach is to initialize a threshold value and iteratively refine it based on the mean intensity values of the segmented regions.
- This process continues until the difference between consecutive threshold values falls below a certain tolerance threshold.
- Automatic global thresholding works well when the illumination in the image is uniform.

Local Thresholding:

- Local thresholding is preferred when global thresholding fails, especially in cases of non-uniform illumination.
- If T[f(x,y), p(x,y)] then it is local thresholding
- In local thresholding, different threshold values are applied to different regions of the image.
- This helps in handling variations in illumination and results in better segmentation.

Boundary Detection using Gradient and Laplacian:

- Boundary detection is crucial in segmentation, especially in local thresholding.
- Gradient and Laplacian operators are used to detect boundaries.
- **Gradient provides the position of the edge, while Laplacian determines whether a point lies on the darker or brighter side of the edge.**



- By analyzing the gradient and Laplacian properties, boundaries between object and background regions can be detected accurately.

using three properties $f(x,y)$ $\nabla f(x)$ $\nabla^2 f(x,y)$

$s(x,y) = 0 \; if \; \nabla f(x,y) < T$ Not belong to boundary

$= +ve \; if \; \nabla f(x,y) \geq T \quad \nabla^2 f(x,y) \geq 0$ Belongs to Object

$= -ve \; if \; \nabla f(x,y) \geq T \quad \nabla^2 f(x,y) < 0$ Belongs to Background

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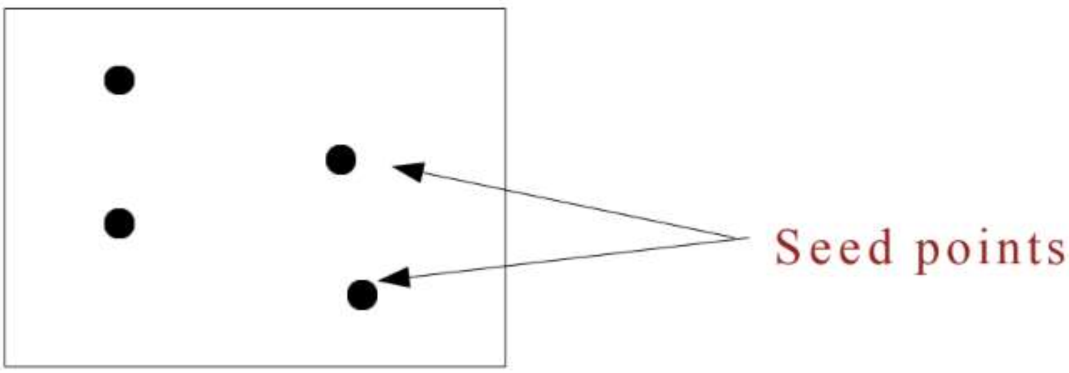
Here intensity of a pixel $f(x,y)$, its gradient $\nabla f(x,y)$, and the Laplacian of the pixel intensity $\nabla 2f(x,y)$

- similarity based segmentation and **Region Growing Technique**
  - - Region growing aims to create larger regions by iteratively grouping neighbouring pixels that share similar properties, such as intensity, color, or texture.
  - It begins with one or more seed points, either user-defined or automatically selected, which serve as starting points for region formation.

Algorithm Steps:

1. **Initialization**: Select seed points to initiate the process.
2. **Seed Growing Criteria**: Define a similarity criterion, often based on the intensity or color properties of pixels, to determine whether a neighboring pixel should be included in the growing region.



3. **Pixel Merging**: Compare the properties of neighboring pixels with the seed point(s). If the properties are sufficiently similar, merge the pixel with the region. Otherwise, skip it.

4. **Region Expansion**: Iteratively repeat the merging process until no further pixels can be added to the region.

Advantages:

- Region growing can **effectively handle images with varying backgrounds** and illumination levels.
- It produces coherent regions without the need for predefined parameters like edge detection thresholds.

Limitations:

- Region growing heavily relies on the selection of suitable seed points, which may require manual intervention
- The choice of similarity criteria and threshold values can significantly impact the segmentation results and may require tuning.

Example Application:

- In medical imaging, region growing is commonly used for tasks like tumor detection, where regions of abnormal tissue can be segmented based on their properties relative to surrounding healthy tissue.

➢ similarity based segmentation and **Splitting-Merging Technique**

Split and Merge using Quadtree

- The split and merge technique is **a region-based segmentation method t**hat operates by recursively splitting and merging regions in an image.
- It combines the principles of region splitting, where large regions are divided into smaller ones, and region merging, where adjacent regions with similar properties are combined.

Splitting Process:

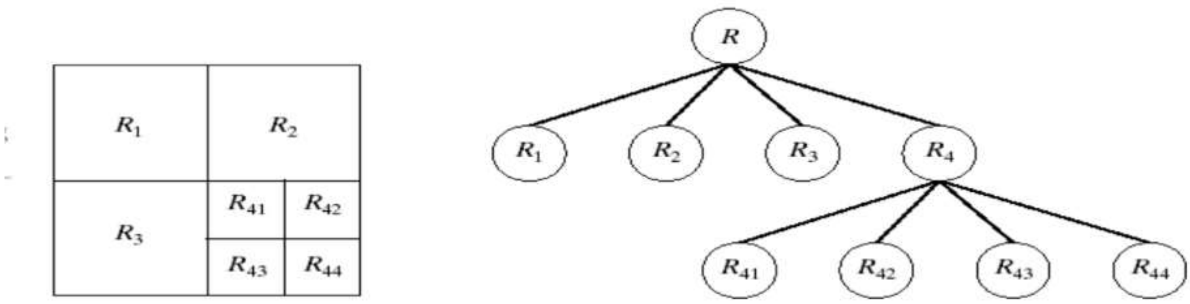
1. **Initial Region**: The entire image is considered as a single region.
2. **Homogeneity Test**: If the region fails to meet the homogeneity criteria (such as uniformity in intensity or color), it is split into four quadrants.
3. **Recursive Subdivision**: Each quadrant is then recursively subjected to the same splitting process until all resulting regions satisfy the homogeneity criteria or until a stopping criterion is reached.

Merging Process:

1. **Predicate Evaluation**: After splitting, adjacent regions are evaluated based on a predicate or measurement.
2. **Merge Criteria**: If adjacent regions share common characteristics according to the predicate, they are merged into larger regions.
3. **Iterative Process**: The merging process continues iteratively until no further merging is possible.

Quadtree Structure:

- The split and merge procedure often utilizes a quadtree data structure, where each node has exactly four descendants representing the four quadrants of a region.



Advantages:

- Allows for hierarchical organization of regions, providing a systematic approach to segmentation.

- Can handle complex images with varying structures and textures.
- Preserves spatial relationships between regions, facilitating subsequent analysis tasks.

Challenges:

- Determining the optimal splitting criteria can be challenging and may require domain-specific knowledge.
- Efficiency concerns arise when dealing with large images or high-dimensional data due to the recursive nature of the algorithm.