Unit 6: Image Segmentation

Yuba Raj Devkota | NCCS

Image Processing | CSIT 5

Unit 6	Image Segmentation	Teaching Hours (8)
Introduction	Definition, Similarity and Discontinuity based techniques	1 hr
Discontinuity Based Techniques	Point Detection, Line Detection, Edge Detection using Gradient and Laplacian Filters, Mexican Hat Filters, Edge Linking and Boundary Detection, Hough Transform	3 hrs.
Similarity based techniques	Thresholding: Global, Local and Adaptive Region Based Segmentation: Region Growing Algorithm, Region Split and Merge Algorithm	4 hrs.

Introduction to Image Segmentation

Segmentation is the process of partitioning a digital image into multiple regions and extracting the meaningful region which is known as Region of Interest (ROI)

- Region of Interest (ROI) vary with applications
- In fact no single universal segmentation algorithm exists for segmenting the ROI in all images
- Therefor many segmentation algorithms need to apply and pick that algorithm which performs the best for given requirement

Image Segmentation Algorithms are based on:

Similarity Principle
(Region Approach)

Objective is to group pixels based on common property to extract a coherent region

Discontinuity Principle
(Boundary Approach)

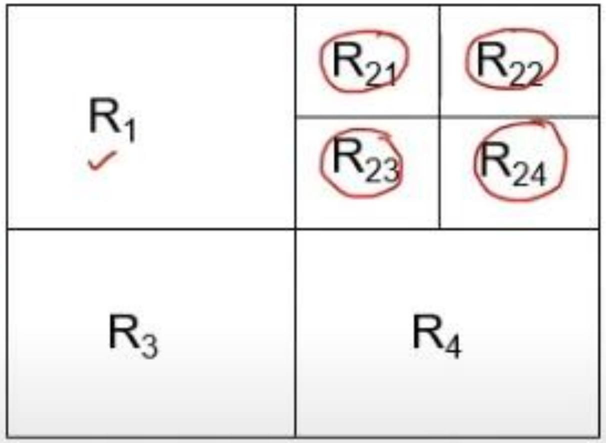
Objective is to extract regions that differ in properties like intensity, color, texture etc.

Definition of Image Segmentation

Example

An image can be portioned into many regions $R_1, R_2, R_3 \ldots R_n$

R = 7



5×5

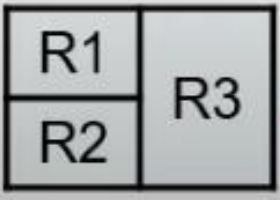
R1

R2

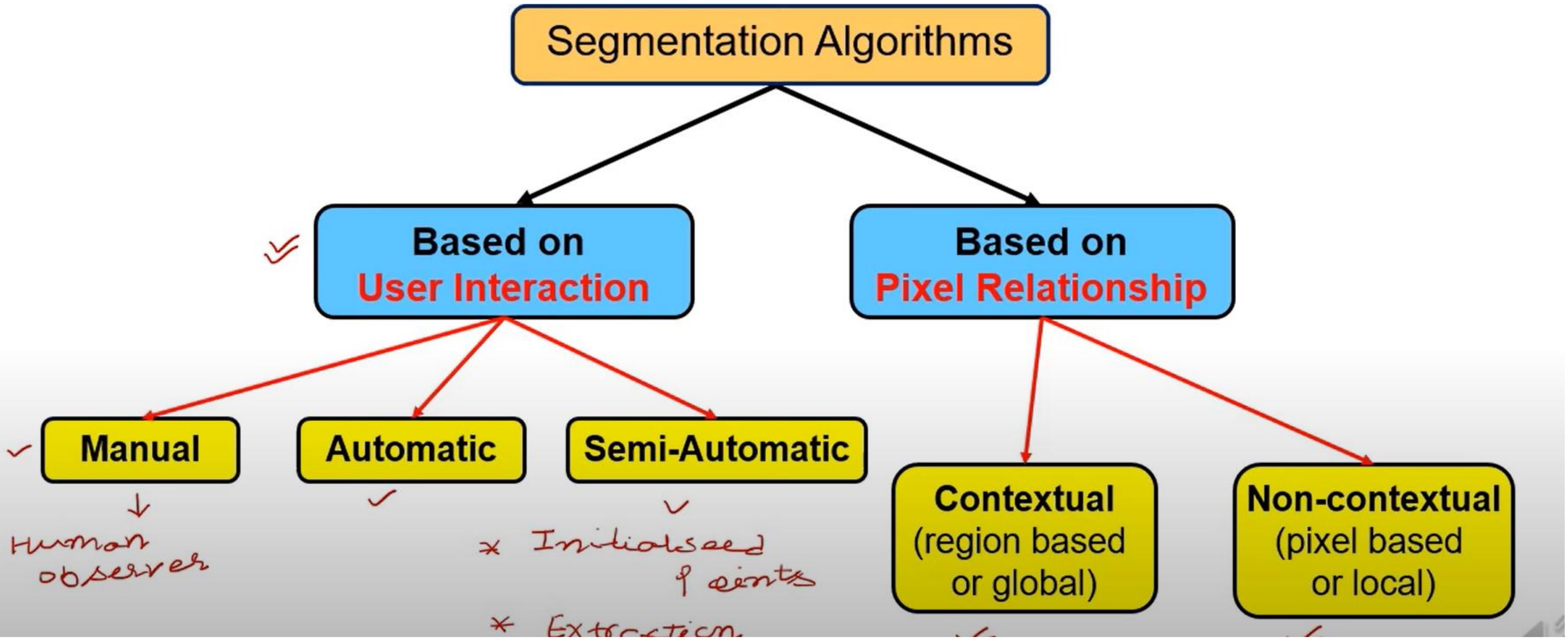
10	10	20	20	20
10	10	20	20	20
10	10	20	20	20
30	30	20	20	20
30	30	20	20	20

R3

10	10	20	20	20
10	10	20	20	20
10	10	20	20	20
30	30	20	20	20
30	30	20	20	20



Classification of Image Segmentation Algorithms



Detection of Discontinuities

Types of Grey Level discontinuities are:

- **Point**
  - * Isolated Point
- **Line**
  - * Horizontal
  - * Vertical
  - * Slanted
- **Edge**
  - * Object outline

Point Detection

An isolated point is a point whose grey level is significantly different from its background in a homogeneous area

Point Detection

An isolated point is a point whose grey level is significantly different from its background in a homogeneous area

3x3

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

3x3

Mask

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Image

Response of the mask:

$$R = \sum_{i=1}^{9} w_i z_i$$

If,
✓ **$|R| \geq T$**, a point is detected
where,
T is a non negative integer

-1	-1	-1
-1	8	-1
-1	-1	-1

✓

Sample Mask for Point Detection

Line Detection

In line detection, **four types of masks** are used to get the responses i,e, R_1, R_2, R_3 and R_4 for the directions vertical, horizontal, $+45^0$ and -45^0 respectively

Horizontal

−1	−1	−1
2	2	2
−1	−1	−1

Vertical

−1	2	−1
−1	2	−1
−1	2	−1

$+45^0$

−1	−1	2
−1	2	−1
2	−1	−1

-45^0

2	−1	−1
−1	2	−1
−1	−1	2

$R_1 \to LR$
$R_2 \to TB$
R_3
R_4

Response of the mask:

$$R_k = \sum_{k=1}^{4} \omega_k z_k$$

If, at a certain point in the image, $|R_i|>|R_j|$ for all $j \neq i$, that **point** is said to be more likely associated with a **line** in the direction of mask i

Edge Detection

- An edge is a set of connected pixels that lies on the boundary between two regions which differ in grey value. Pixels on edge is known as edge points
- **Edges provide an outline of the object**

In physical plane, **edge corresponds** to the **discontinuities in** depth, Surface orientation, change in material properties, light variations etc.

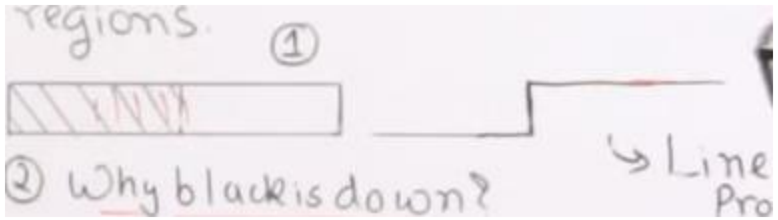
- It locates sharp changes in the intensity function
- Edges are pixels where brightness changes abruptly
- An edge can be extracted by computing the derivative of the image function
  - ✓ Magnitude of the derivative, indicates the strength or contrast of edge
  - ✓ Direction of the derivative vector, indicates the edge orientation

Edge Detection

Some of the commonly encountered edges in image processing are:

Step Edge | **Ramp Edge** | **Spike Edge** | **Roof Edge**

- **Step Edge:** An abrupt change in intensity
- **Ramp Edge:** A slow and gradual change in intensity
- **Spike Edge:** Quick change or immediately returns to original intensity level
- **Roof Edge:** It is not instantaneous over short distance



Intensity of black is low and white is more

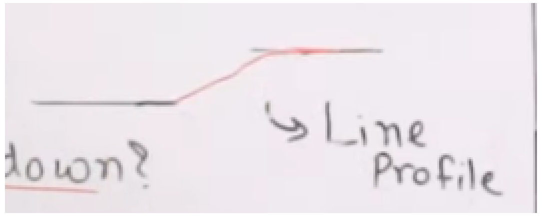
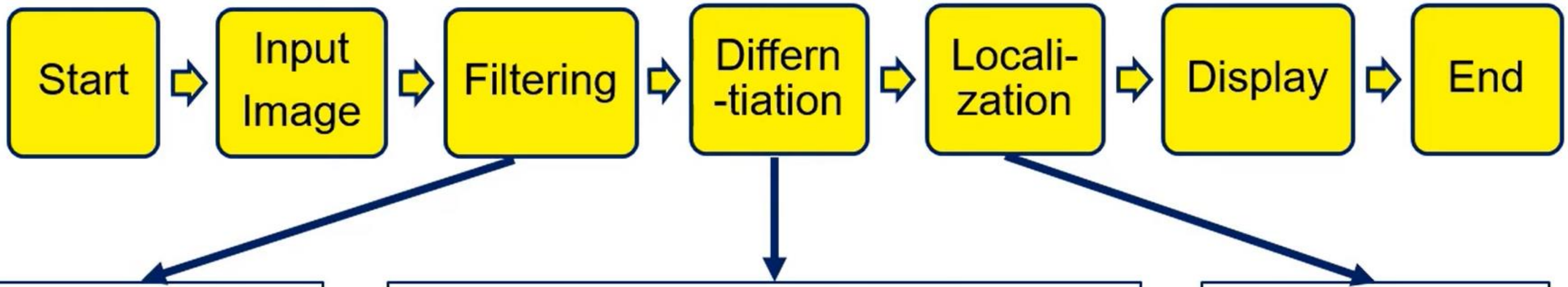


Image is slowing changing from black to white

Stages in Edge Detection



Filtering: It involves smoothing. This stage may be performed explicitly or implicitly

Differentiation: It distinguishes the edge pixels from other pixels

$f(x,y)$

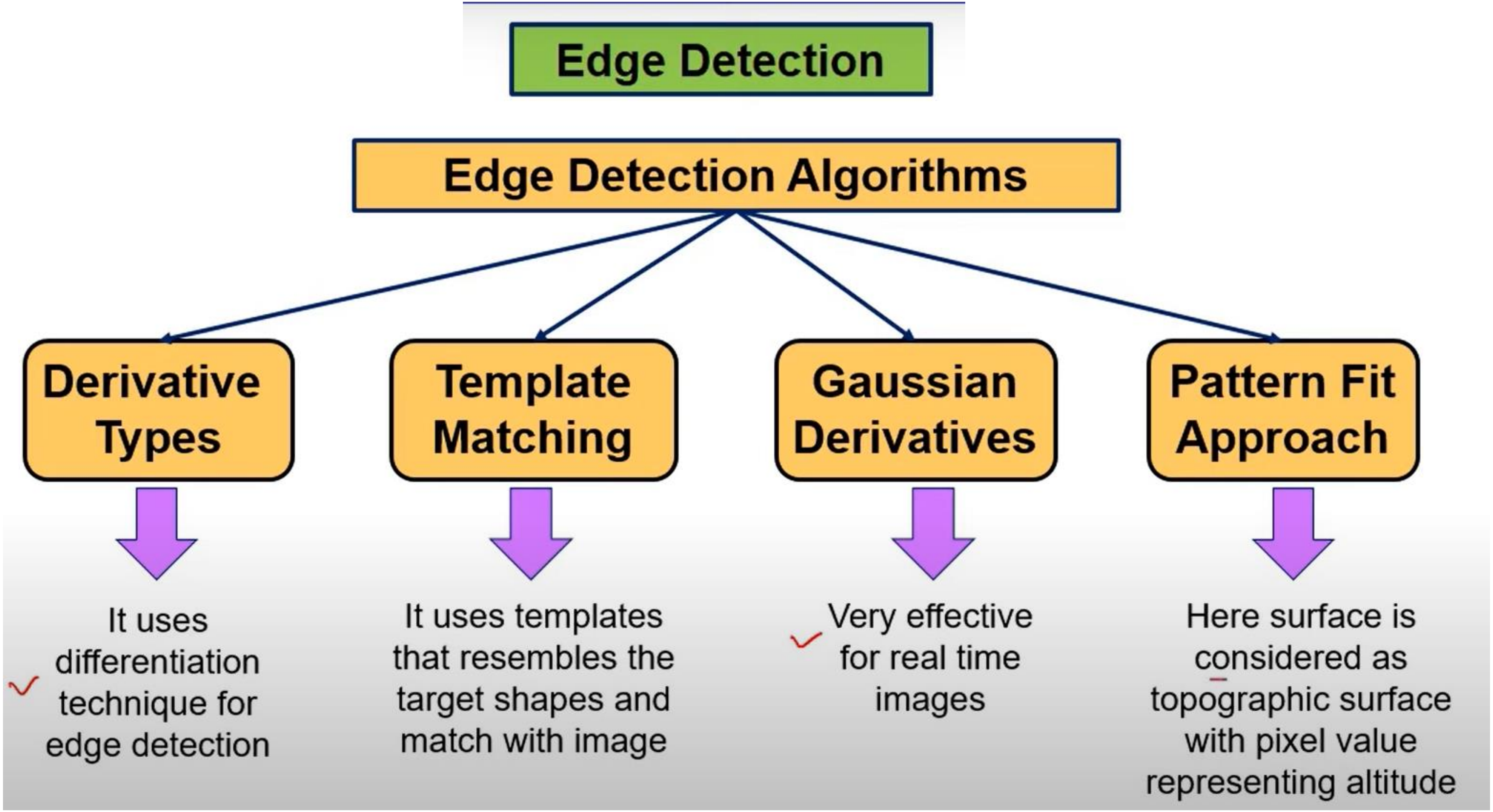
$$\text{Vector: } \nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \partial f / \partial x \\ \partial f / \partial y \end{bmatrix}$$

$$\text{Magnitude: } \nabla f = \text{mag}(\nabla \mathbf{f}) = \left[G_x^2 + G_y^2 \right]^{1/2} \approx |G_x| + |G_y|$$

$$\text{Direction of gradient: } \tan^{-1}\left(\frac{Gy}{Gx} \right)$$

θ

Localization: It determine the exact location of edge


Edge Detection
Edge Detection Algorithms
Derivative Types
Template Matching
Gaussian Derivatives
Pattern Fit Approach
It uses differentiation technique for edge detection
It uses templates that resembles the target shapes and match with image
Very effective for real time images
Here surface is considered as topographic surface with pixel value representing altitude

Gradient Filter

A gradient filter in image segmentation is a technique used to highlight areas of rapid intensity change in an image, which typically correspond to edges or boundaries between different regions. These boundaries are important for segmenting the image into meaningful parts.

- **Key Concepts:**

1. **Gradient**: In the context of images, the gradient represents the rate of change of intensity (brightness) in different directions. The gradient at a particular pixel is a vector with a magnitude (indicating the rate of intensity change) and a direction (indicating the direction of the steepest intensity increase).
2. **Gradient Filters**: These are convolutional filters that calculate the gradient of the image. Common gradient filters include:
    1. **Sobel Filter**: Computes the gradient by combining horizontal and vertical changes in intensity.
    2. **Prewitt Filter**: Similar to the Sobel filter but uses different convolution kernels.
    3. **Scharr Filter**: An optimized version of the Sobel filter for more accurate edge detection.
3. **Edge Detection**: By applying gradient filters, we can detect edges in an image. The edges are places where there is a significant change in intensity, which often corresponds to the borders of objects in the image.

First Order Derivative Filters

1) Roberts operators (Cross-gradient)

$$\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

$$\begin{bmatrix} z1 & z2 & z3 \\ z4 & z5 & z6 \\ z7 & z8 & z9 \end{bmatrix}$$

Image

2) Sobel operators

$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \qquad \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

3) Prewitt operators

$$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \qquad \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

Problems with Roberts Cross :

1) 2 x 2 masks are not easy to implement.

2) No. of calculations are more.

3) No. of neighboring pixels considered in one go are less.

To solve these problems, we make the following changes:

1) Change in the size of the mask.
2) Change in the no. of neighbouring pixels considered.

Q2. Apply Roberts, Sobel and Prewitt operators on the pixel (1,1) in the following image.

50	50	100	100
50	50	100	100
50	50	100	100
50	50	100	100

Input image

1) Roberts operator

$$\boxed{\begin{matrix} -1 & 0 \\ 0 & 1 \end{matrix}}$$

$= 50 \times (-1) + 100 \times 1$

$= -50 + 100 = \underline{\underline{50}}.$

2) sobel operator

$$\boxed{\begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix}}$$

$= 50(-1) + 50(-2) + 100(-1) + 50(1) + 50(2) + 100(1)$

$= \cancel{-50} - \cancel{100} - \cancel{100} + \cancel{50} + \cancel{100} + \cancel{100} = \underline{\underline{0}}.$

3) Prewitt operator

$$
\begin{array}{cccc}
50 & 50 & 100 & 100 \\
50 & 50 & 100 & 100 \\
50 & 50 & 100 & 100 \\
50 & 50 & 100 & 100
\end{array}
\ast
\begin{bmatrix}
-1 & -1 & -1 \\
0 & 0 & 0 \\
1 & 1 & 1
\end{bmatrix}
$$

Input image

$= -1(50+50+100) + 1(50+50+100)$

$= \underline{\underline{0}}.$

Hough Transform and Shape Detection

Hough transform is a feature extraction method for detecting simple shapes such as circles, lines etc. in an image

- Hough Transform takes the images created be edge detection operators but most of the time, edge map is disconnected
- Therefore Hough Transform is used to connect the disjoined edge points

Equation of Line:

$$y = mx + c$$

Where,
m = slope
c = intercept of the line

Problem is that, Infinite lines can be drawn connecting these points

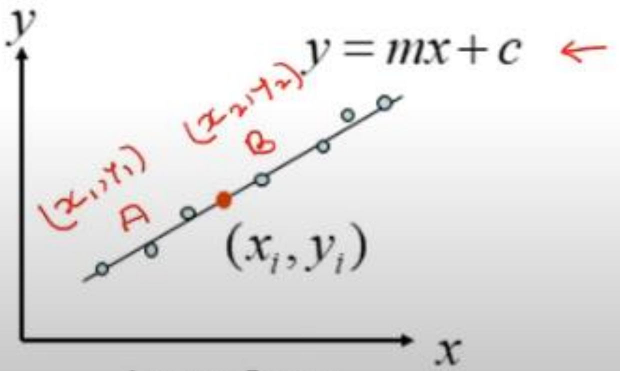
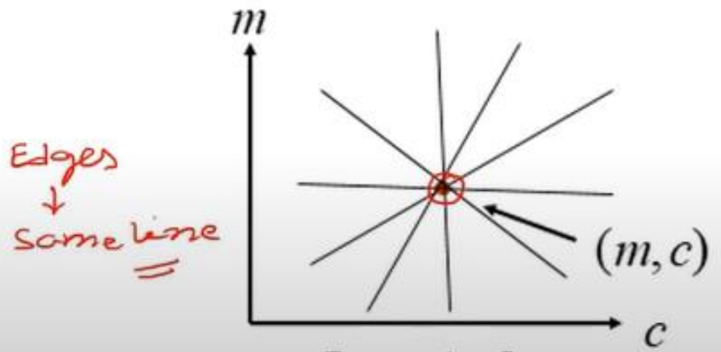


Image Space

Therefore an edge point in the x-y plane is transformed to the c-m

Point (x_i, y_i)

$$y_i = mx_i + c \quad or \quad \boxed{c = -x_i m + y_i}$$

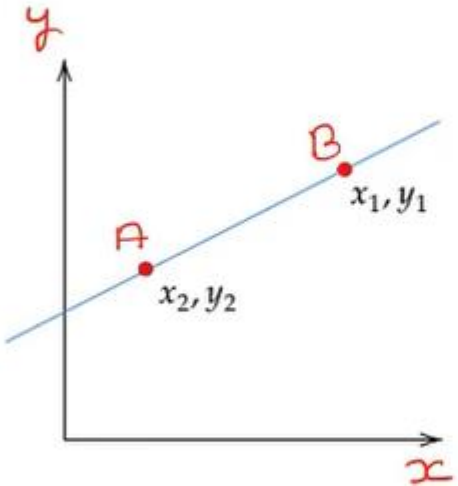


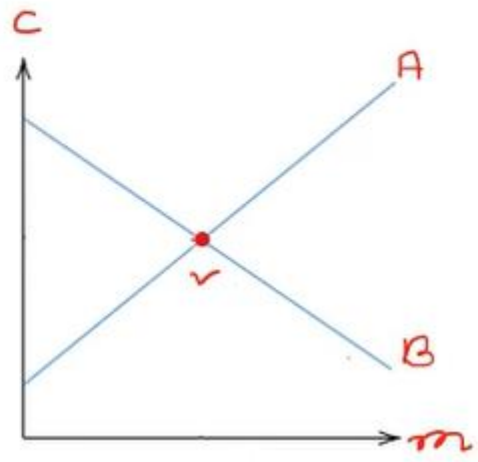
Parameter Space

Parameter space also called Hough Space

If A and B are two points connected by a line in spatial domain

They will be intersecting lines in Hough Space





Algorithm

Load the image

↓

Determine the image edges using any edge detector

↓

Quantize the Parameter Space, P

↓

Repeat the process for all pixels of image
If the pixel is an edge pixel, then

$$c = (-x)m + y$$

$$P(c.m) = P(c.m) + 1$$

↓

Show the Hough Space

↓

Find the local maxima in parameter space

↓

Draw the line using local maxima

(i) For $(x,y) = (1,2)$, $c = -m + 2$

if $c = 0$, $0 = -m + 2$
$\boxed{m = 2}$

if $m = 0$, $\boxed{c = 2}$

Thus, $(m,c) = (2,2)$.

(ii) For $(x,y) = (2,3)$, $c = -2m + 3$.

if $c = 0$, $0 = -2m + 3$
$2m = 3$
$m = 3/2 = 1.5$. $\boxed{m = 1.5}$

if $m = 0$, $\boxed{c = 3.}$

Thus, $(m,c) = (1.5,3)$.

(iii) For $(x,y) = (3,4)$, $c = -3m + 4$.

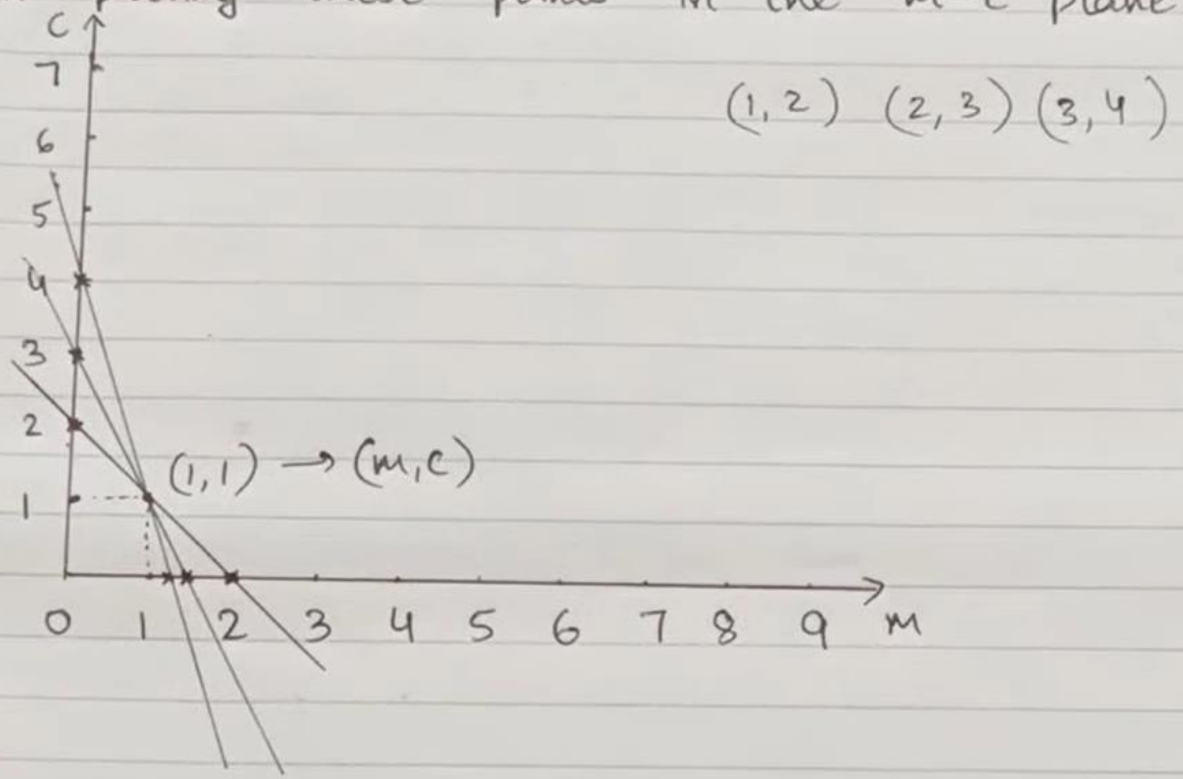
if $c = 0$, $0 = -3m + 4$
$3m = 4$
$m = 4/3 = 1.33$. $\boxed{m = 1.33}$

if $m = 0$, $\boxed{c = 4}$.

Thus $(m,c) = (1.33,4)$.

$(m,c) = (2,2), (1.5,3), (1.33,4)$.

On plotting these points in the m-c plane:



Original equation:
$$y = mx + c$$
Substituting $(1,1)$:
$\boxed{y = x + 1}$ → Final equation

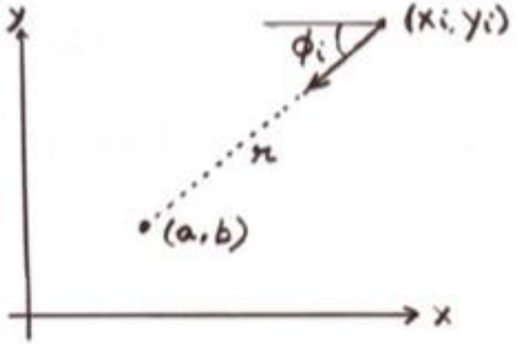
Hough Transform for other shapes can also be found

For a **Circle Detection**, it can be given as

$$(x_i - a)^2 + (y_i - b)^2 = r^2$$

- Edge Location (x_i, y_i)
- Edge Direction ϕ_i

(a, b, r)



- $a = x - r\cos\phi$
- $b = y - r\sin\phi$

Load the image

↓

Determine the image edges using any edge detector

↓

Quantize the Parameter Space, P

↓

Repeat the process for all pixels of image
If the pixel is an edge pixel, then calculate for all r

(a) $a = x - r\cos\phi$

$b = y - r\sin\phi$

$$P(a,b,r) = P(a,b,r) + 1$$

↓

Show the Hough Space

↓

Find the local maxima in parameter space

↓

Draw the Circle using local maxima

Principle of Thresholding

Thresholding is an important technique for image segmentation

- It produces uniform regions based on the threshold criteria, T
- Key parameter of thresholding process is the choice of threshold value

- If thresholding operation depends upon only grey scale value, it is known as **Global Thresholding**
- In case neighborhood properties (or some local properties) is also taken into account, method is known as **Local Thresholding**
- If case T depends on pixel coordinates also, it is known as **Dynamic (or Adaptive) Thresholding**

Thresholding is a function of:

- Spatial Coordinates i.e (x,y)
- Grey level of the pixel i.e f(x,y)
- Some local property of the image i.e A(x,y)

Therefore, thresholding operation can be expressed as:

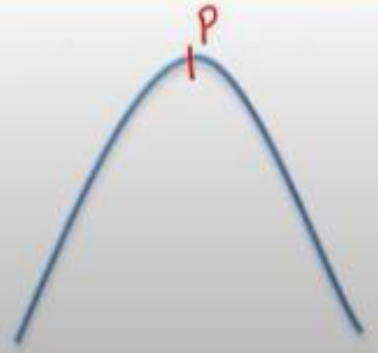
$$Th = T\,[x,y,\ f(x,y),\ A(x,y)]$$

Histogram and Thresholding

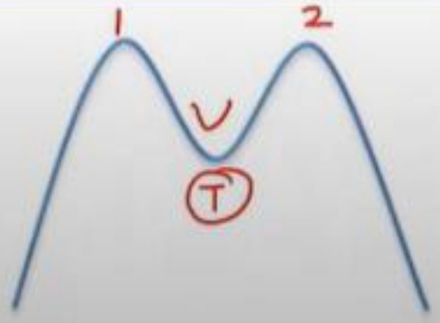
- The quality of thresholding algorithm depends on the selection of a suitable threshold
- Tool that helps to find the threshold is histogram

Types of Histograms

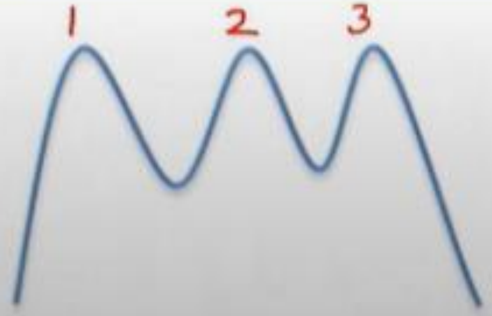
Unimodal Histogram



Bimodal Histogram



Multimodal Histogram



Global Thresholding

- In bimodal images, histogram have two distinct peaks separated by a valley between them
- Valley point is chosen as threshold (T)
- Then pixels of given image are compared with threshold

Threshold process is given as:

$$g(x,y) = \begin{cases} 1 & \text{if } f(x,y) \geq T \\ 0 & \text{otherwise} \end{cases}$$

The basic global threshold (T) is calculated as:

1) Randomly select an initial threshold T
2) Segment the image using two group of pixels G_1 and G_2
3) Determine mean (m_1) of the pixels (in G_1 group) that lie below T in histogram
4) Determine mean (m_2) of the pixels (in G_2 group) that lie above T in histogram
5) New threshold is:

$$T_{new} = (m_1 + m_1)/2$$

6) Repeat the step no.2-5 until the difference in T in successive iterations is less than a predefined limit

Multiple Thresholding

- Multilevel thresholding is a process that segments a gray level image into several distinct regions
- It is the **extension** of **simple thresholding technique**

$f_i \rightarrow$ value of input image pixel

$t_1, t_2, t_3 \dots t_n \rightarrow$ Multiple Threshold values

$g_1, g_2 \dots g_n \rightarrow$ values of output image

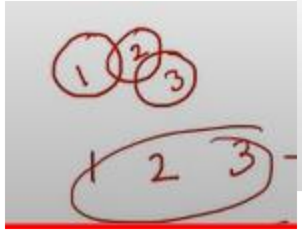
$$\text{output Image} = \begin{cases} g_1 & \text{if } 0 \le f_i \le t_1 \\ g_2 & \text{if } t_1 < f_i \le t_2 \\ \vdots & \\ g_n & \text{if } t_{n-1} < f_i < 255 \end{cases}$$

Adaptive Thresholding

- Adaptive thresholding changes the threshold dynamically over the image
- It is also known as **Dynamic Thresholding Algorithm**
- Adaptive thresholding works well in situations where image is affected by non-uniform illumination problem

Techniques to apply Thresholding algorithm

- Divide image into many overlapping sub-images
- Split the image into many sub regions



Separate histogram needs to be plotted for each Images and interpolation of them needs to be taken. So complex mechanism. Also the result may not be accurate

Some useful image statistics →

* Mean + c

c → constant

* median + c
* (Min + Max)/2

Region Growing Algorithm

- ❑ Region growing is a procedure that groups pixels or sub regions into larger regions
- ❑ Logic behind region growing algorithms is the **principle of similarity**

Similarity Criteria

Principle of similarity states that a region is **coherent** if all the pixels of that region are **homogeneous**

Homogeneity of regions is used as the main segmentation criterion in region growing

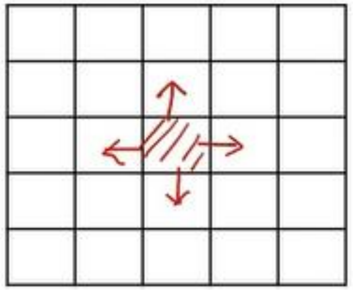
- gray level
- Color
- texture
- shape
- model etc.

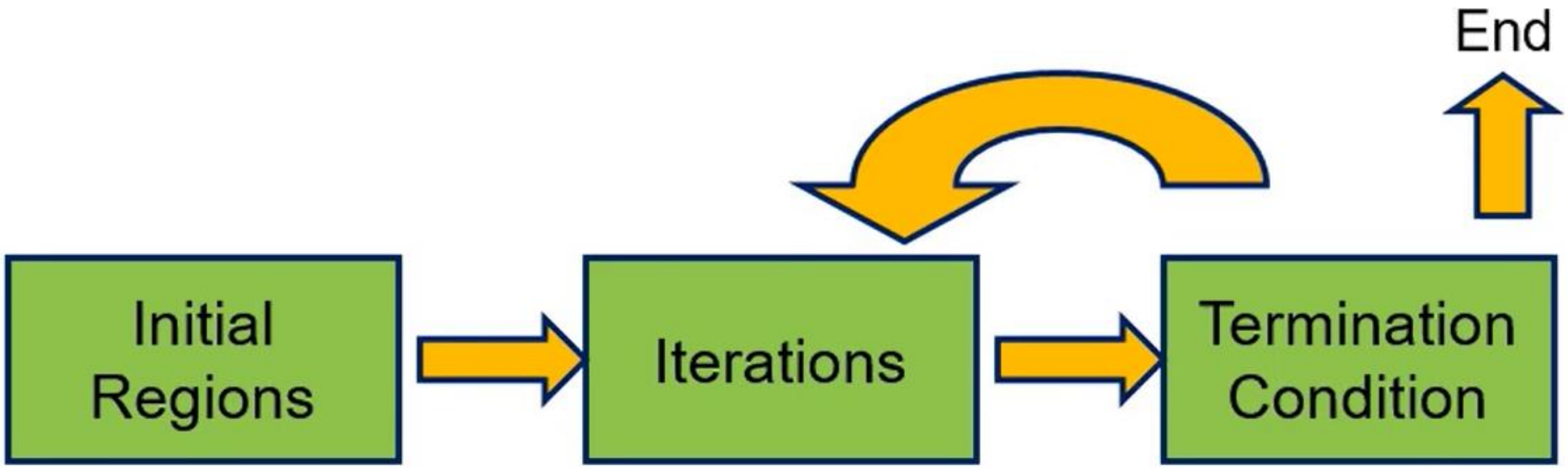
Choice of criteria affects segmentation results dramatically!

Major steps of the region growing algorithm are:

- ❑ Selection of the initial seed
- ❑ Seed growing criteria
- ❑ Termination of the segmentation process

5×5





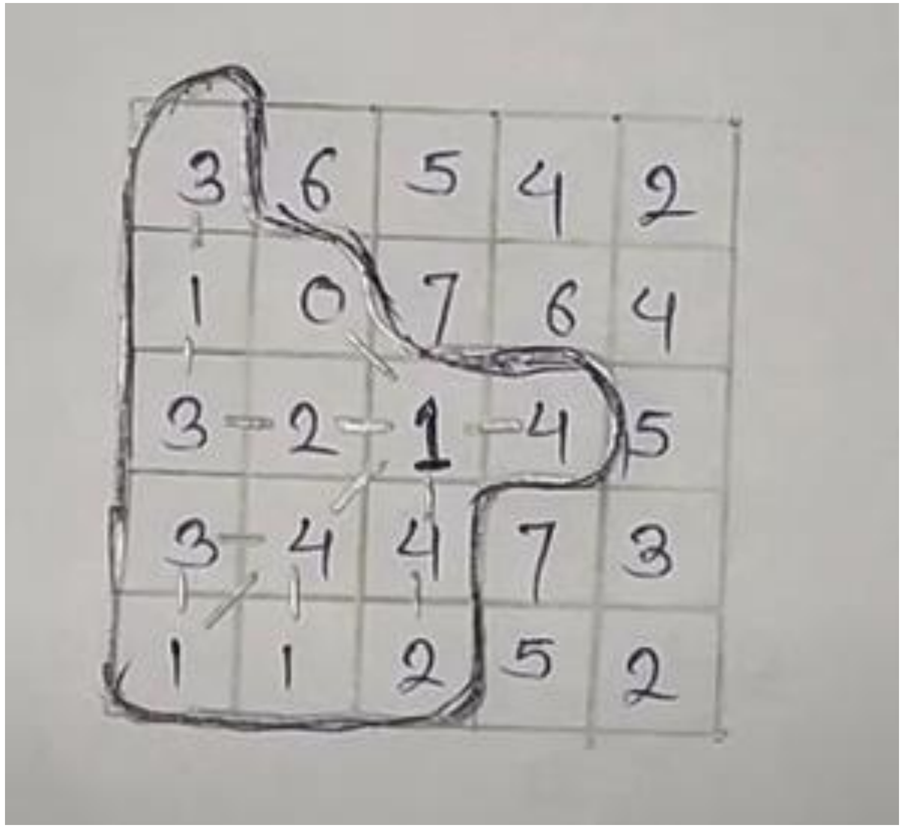
- ➢ Groups pixels into larger regions
- ➢ Starts with a **seed** region
- ➢ **Grows** region by **merging** neighboring pixels

Iterative process

- ➢ How to start?
- ➢ How to iterate?
- ➢ When to stop?

Q. Apply the region Growing on the following image. Assume the threshold value be <= 4.

3	6	5	4	2
1	0	7	6	4
3	2	1	4	5
3	4	4	7	3
1	1	2	5	2



Example: For a given image, show the results of region growing algorithm

1	0	7	8	7
0	1	8	9	8
0	0	7	9	8
0	1	8	8	9
1	2	8	8	9

* Seed point → s_1 9, s_2 1

* Threshold, T $\boxed{T \le 4}$

* $s_1 = 9$

$$|f(x,y) - f(x',y')| \le 4$$

$$|f(x,y) - 9| \le 4$$

$$f(x,y) = \{5, 6, 7, 8, 9\} \Rightarrow A$$

* $s_2 = 1$

$$|f(x,y) - f(x',y')| \le 4$$

$$|f(x,y) - 1| \le 4$$

$$f(x,y) = \{0, 1, 2, 3, 4, 5\} \Rightarrow B$$

Resultant Image

B	B	A	A	A
B	B	A	A	A
B	B	A	A	A
B	B	A	A	A
B	B	A	A	A

Split and Merge Algorithm

- ❑It is an alternative method of image segmentation
- ❑An image is sub-divided into arbitrary disjoined region
- ❑Arbitrary regions can be split and merged in order to satisfy the condition

The algorithm is stated in two phases

$$P(R_i) = False$$

Phase-I

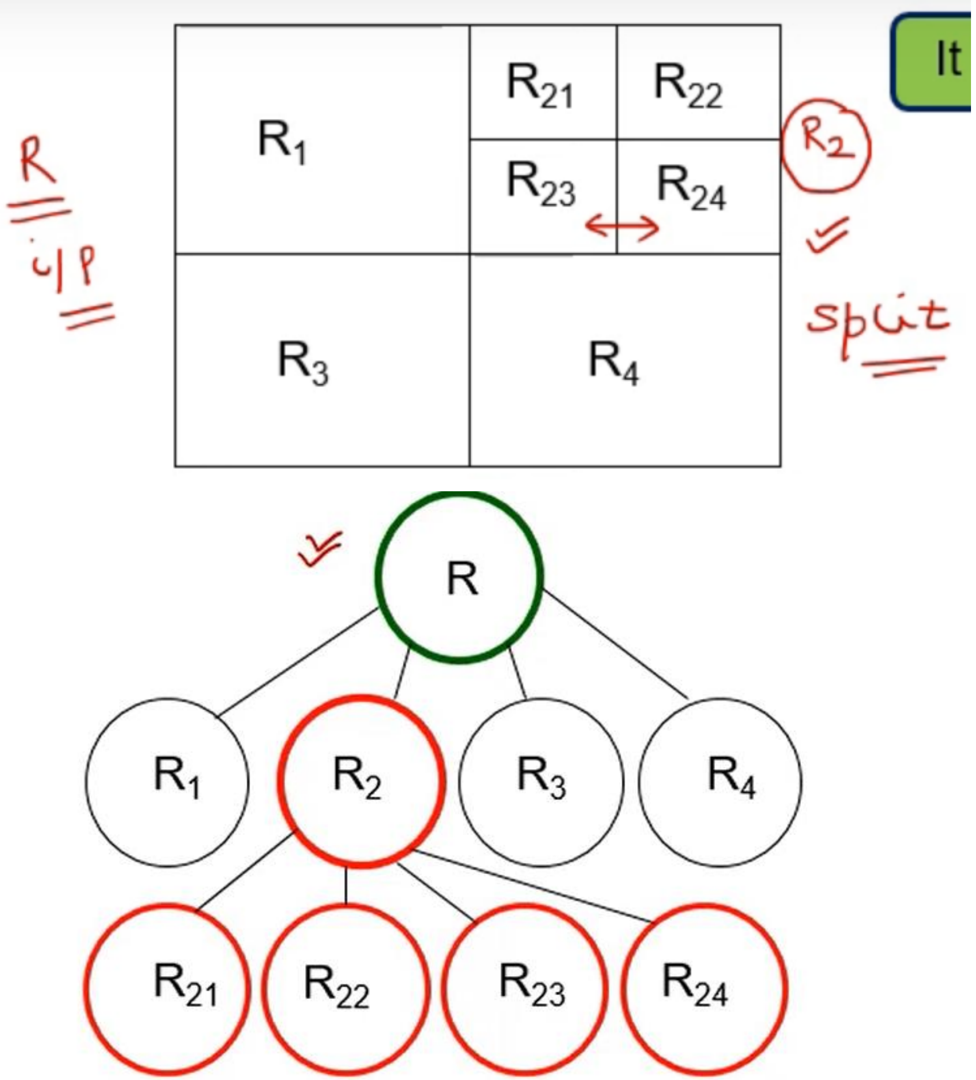
- ✓ Split & Continue subdivision process until some stopping criteria is fulfilled
- ✓ Often it is stopped when no further splitting is possible

Phase-II

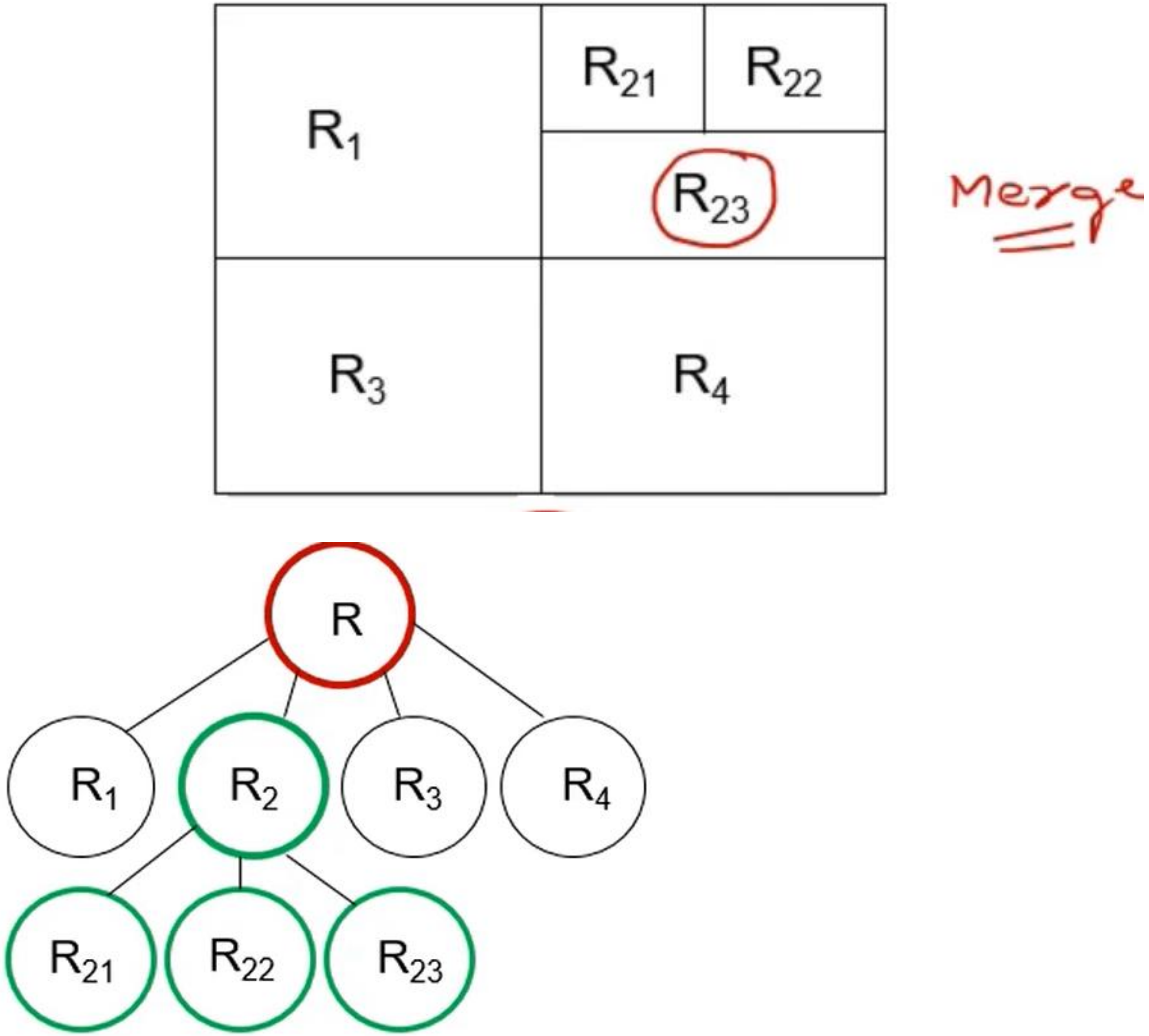
- ✓ Merge adjacent regions if the regions share any common criteria
- ✓ Stop the process when no further merging is possible

$$P(R_i \cup R_j) = True$$

It is also known as “**Divide and Conquer**” or “**Top Down**” approach



Quadtree of Splitting



Quadtree of Splitting and Merging

Example: For a given image, apply split and merge algorithm

6	5	6	6	7	7	6	6
6	7	6	7	5	5	4	7
6	6	4	4	3	2	5	6
5	4	5	4	2	3	4	6
0	3	2	3	3	2	4	7
0	0	0	0	2	2	5	6
1	1	0	1	0	3	4	4
1	0	1	0	2	3	5	4

Solution:

$\boxed{\text{Threshold, (T)} \leq 3}$

max. pixel = 7
min. pixel = 0] 7 − 0 = 7

condition does not satisfies → split

A B C D

$\left.\begin{matrix}7\\2\end{matrix}\right]$ 5 $\nleq$ 3

$\left.\begin{matrix}7\\0\end{matrix}\right]$ 7

6	5	6	6	7	7	6	6
6	7	6	7	5	5	4	7
6	6	4	4	3	2	5	6
5	4	5	4	2	3	4	6
0	3	2	3	3	2	4	7
0	0	0	0	2	2	5	6
1	1	0	1	0	3	4	4
1	0	1	0	2	3	5	4

Splitting

Merge

6	5	6	6	7	7	6	6
6	7	6	7	5	5	4	7
6	6	4	4	3	2	5	6
5	4	5	4	2	3	4	6
0	3	2	3	3	2	4	7
0	0	0	0	2	2	5	6
1	1	0	1	0	3	4	4
1	0	1	0	2	3	5	4

max.(1) − min(2)
max.(2) − min(1)

$\boxed{T \leq 3}$

Region Split and Merge Example

- Apply Region Split on following image. Assume that threshold value be <=4.

5	6	6	6	7	7	6	6
6	7	6	7	5	5	4	7
6	6	4	4	3	2	5	6
5	4	5	4	2	3	4	6
0	3	2	3	3	2	4	7
0	0	0	0	2	2	5	6
1	1	0	1	0	3	4	4
1	0	1	0	2	3	5	4

- Step 1: Identify Max and Min pixel value from the whole image
  - Max = 7
  - Min = 0
  - Max-Min= 7
  - 7 <= 4 (Condition false)
    - Split R image into R1a,R2b,cR3,R4d

- Step 2: Compute for R1a region. Min and Max
  - Max=7
  - Min=4
  - Max-Min=7-4=3
  - 3 <= 3 (Condition true)
    - No need to split R1a

- Step 3: compute for R3c region. Min and Max
  - Max=3
  - Min=0
  - Max-Min=3-0=3
  - 3 <= 3 (Condition true)
    - No need to split R3c

- Step 4: Compute for R2b region. Min and Max
  - Max=7
  - Min=2
  - Max-Min=7-2=5
  - 5 <= 3 (Condition false)
    - Split R2b into R2b1,R2b2,R2b3,R2b4.

- Step 6: Compute for R4d region. Min and Max
  - Max=7
  - Min=0
  - Max-Min=7-0=7
  - 7 <= 3 (Condition false)
    - Split R4d into R4d1,R4d2,R4d3,R4d4.

- Step 7: Compute for R4d1,R4d2,R4d3,R4d4 region. Min and Max
  - For all R4d1,R4d2,R4d3,R4d4 Condition have satisfied so no need to splitting.

5	6	6	6	7	7	6	6
6	7	6	7	5	5	4	7
6	6	4	4	3	2	5	6
5	4	5	4	2	3	4	6
0	3	2	3	3	2	4	7
0	0	0	0	2	2	5	6
1	1	0	1	0	3	4	4
1	0	1	0	2	3	5	4

R1a R2b

5	6	6	6	7	7	6	6
6	7	6	7	5	5	4	7
6	6	4	4	3	2	5	6
5	4	5	4	2	3	4	6
0	3	2	3	3	2	4	7
0	0	0	0	2	2	5	6
1	1	0	1	0	3	4	4
1	0	1	0	2	3	5	4

R3c R4d

Past Questions on Image Segmentation

- Explain how Hough transform is useful in line detection?
- Explain the region growing technique for image segmentation.
- Explain the adaptive thresholding and region split and merge techniques for image segmentation.(5+5)
- Explain in detail the region growing techniques for image segmentation. List the problems associated with region growing technique.(4+2)
- Explain in detail the region split and merge techniques for image segmentation. List the problems associated with region split and merge technique.(4+2)
- What is a gradient filter? Explain the Sobel gradient filter in detail along with its algorithm for implementation.(1 + 5)
- Explain the segmentation by thresholding. Explain how can you apply segmentation in line defection.
- How edges are detected using the gradient operators? Explain with suitable example.