Image Segmentation

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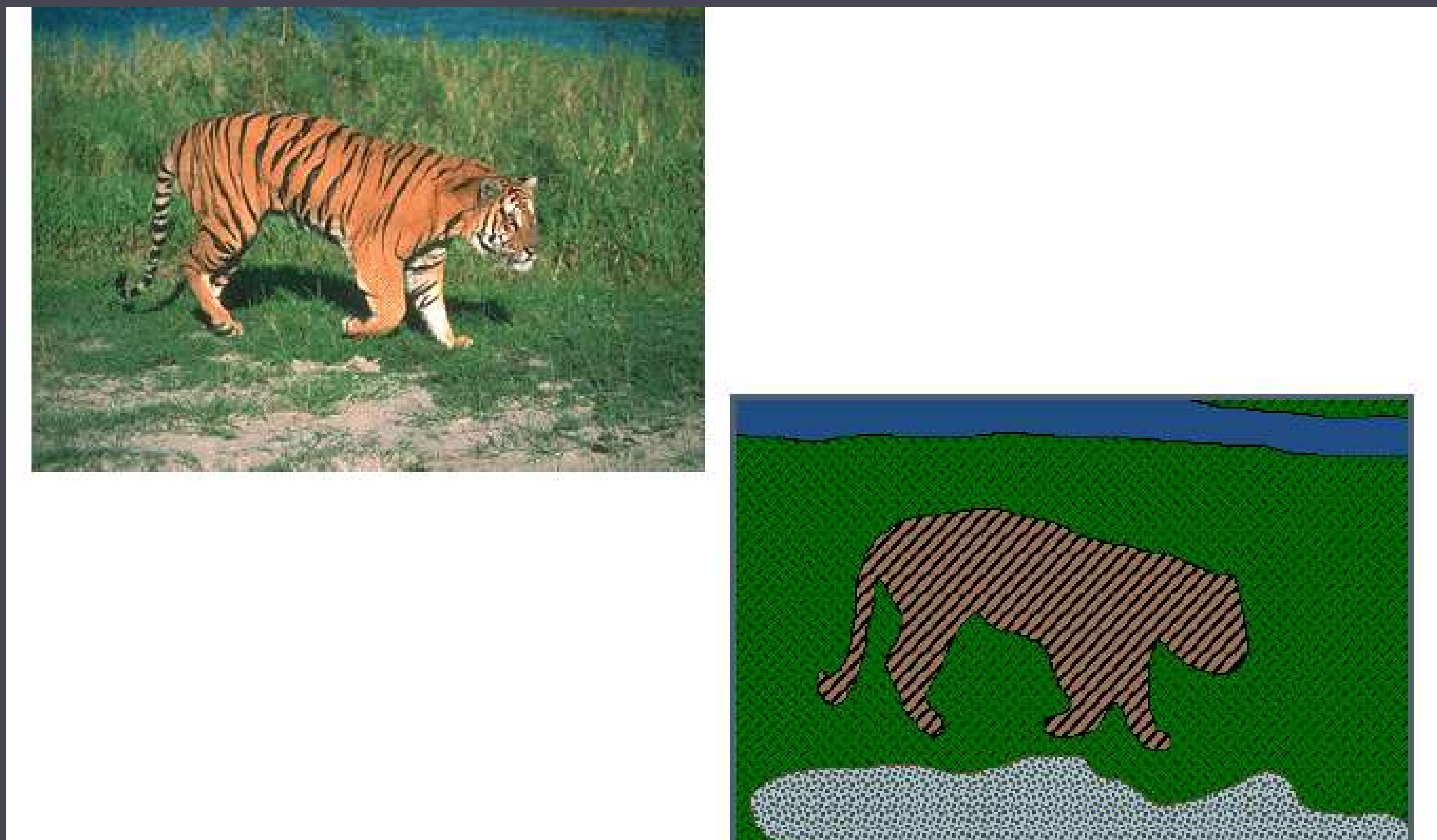


Topic's to be covered

- Introduction to Image analysis and segmentation
- Detection of Discontinuity
  - Point, line, edge and combined detection..
- Edge linking and boundary detection
  - Local processing, hough transform, graph-theoretic technique..
- Thresholding
  - Global thresholding, Optimal thresholding, threshold selection..
- Region oriented segmentation
  - Region growing, Region splitting and merging..

Introduction to image segmentation

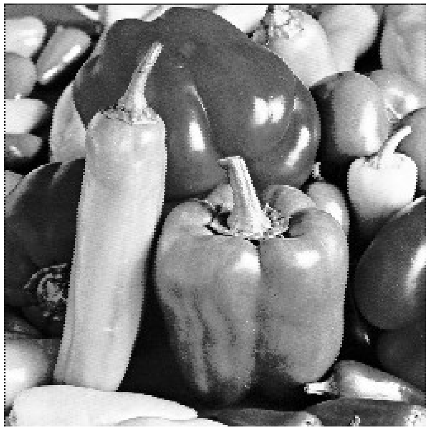
- The purpose of image segmentation is to partition an image into *meaningful* regions with respect to a particular application
- The segmentation is based on measurements taken from the image and might be *greylevel*, *colour*, *texture*, *depth* or *motion*

Introduction to image segmentation

- Usually image segmentation is an initial and vital step in a series of processes aimed at overall image understanding
- Applications of image segmentation include
  - Identifying objects in a scene for object-based measurements such as size and shape
  - Identifying objects in a moving scene for *object-based video compression (MPEG4)*
  - Identifying objects which are at different distances from a sensor using depth measurements from a laser range finder enabling path planning for a mobile robots

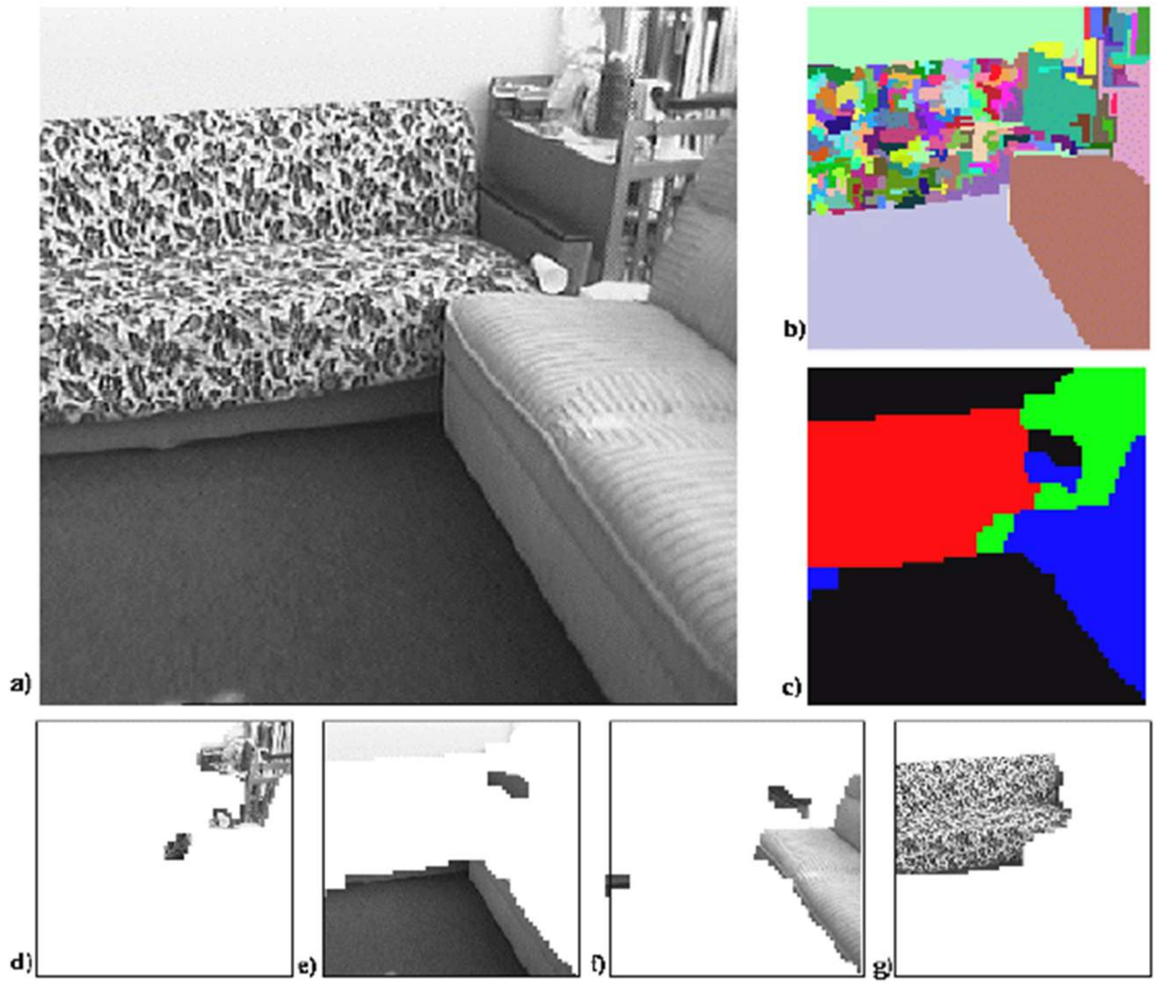
Introduction to image segmentation

- Example 1
  - Segmentation based on greyscale
  - Very simple 'model' of greyscale leads to inaccuracies in object labelling



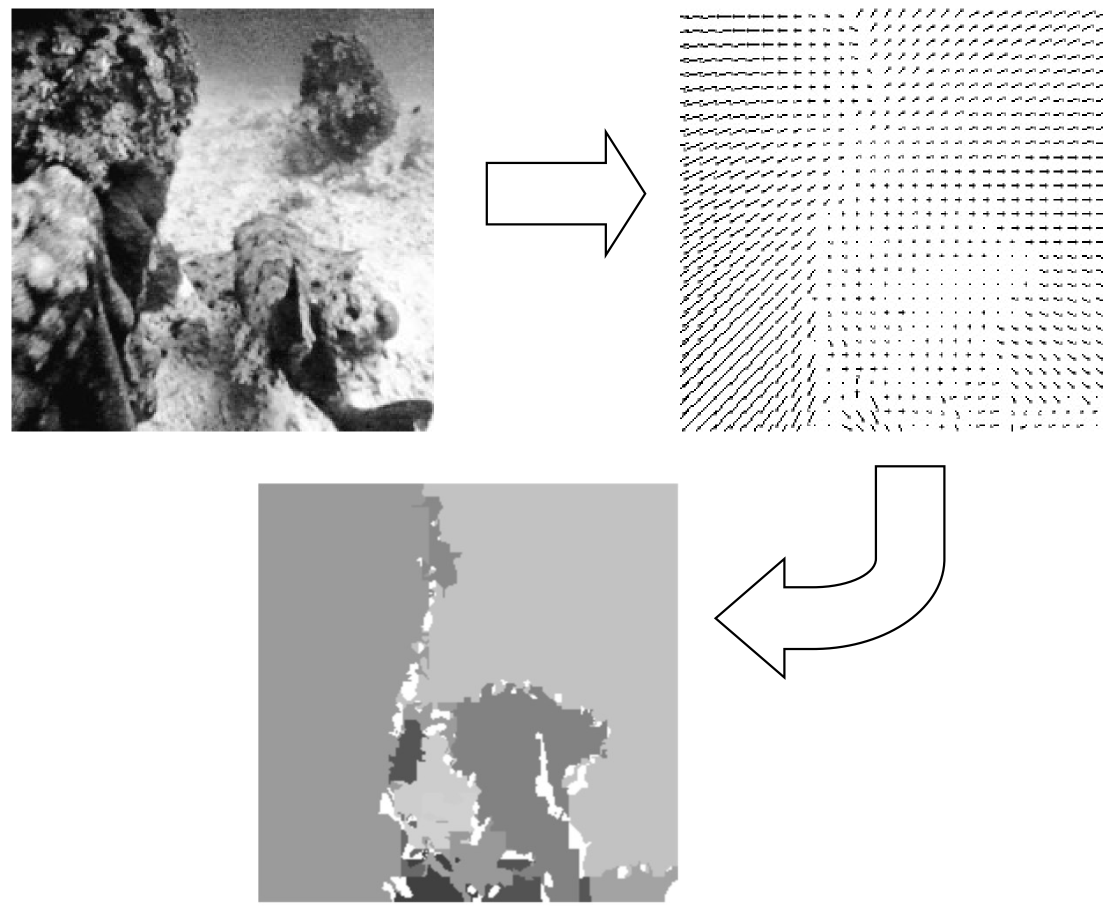
Introduction to image segmentation

- Example 2
  - Segmentation based on texture
  - Enables object surfaces with varying patterns of grey to be segmented



Introduction to image segmentation

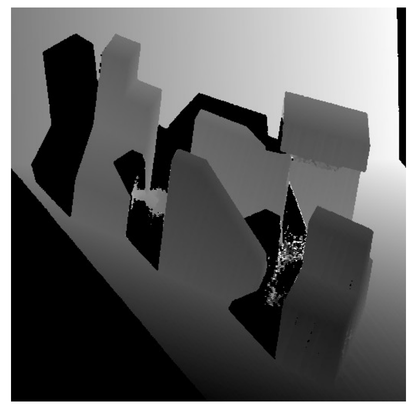
- Example 3
  - Segmentation based on motion
  - The main difficulty of motion segmentation is that an intermediate step is required to (either implicitly or explicitly) estimate an *optical flow field*
  - The segmentation must be based on this estimate and not, in general, the true flow



Introduction to image segmentation

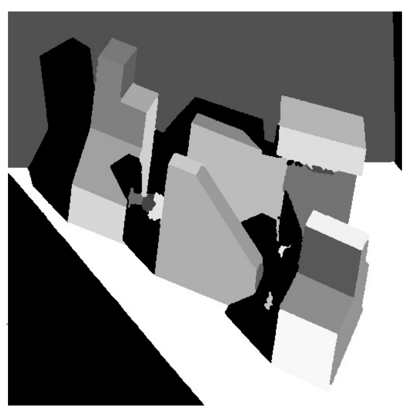
- Example 3
  - Segmentation based on depth
  - This example shows a range image, obtained with a laser range finder
  - A segmentation based on the range (the object distance from the sensor) is useful in guiding mobile robots

Original image



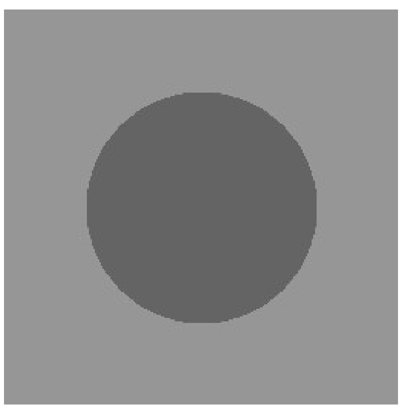
Range image

Segmented image

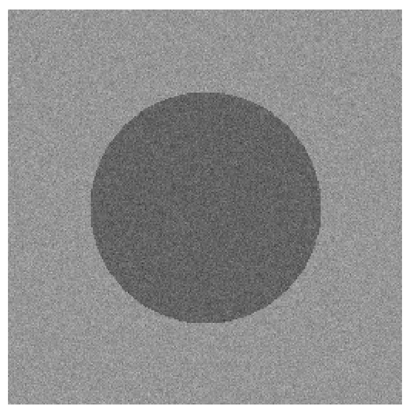


Greylevel histogram-based segmentation

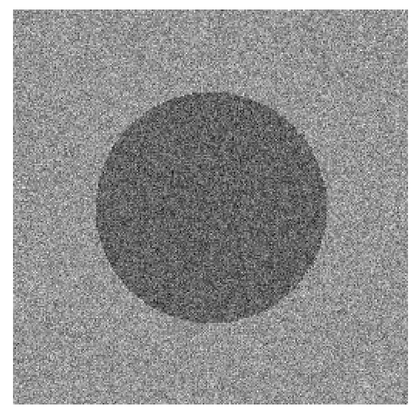
- We will look at two very simple image segmentation techniques that are based on the greylevel histogram of an image
  - Thresholding
  - Clustering
- We will use a very simple object-background test image
  - We will consider a zero, low and high noise image



Noise free



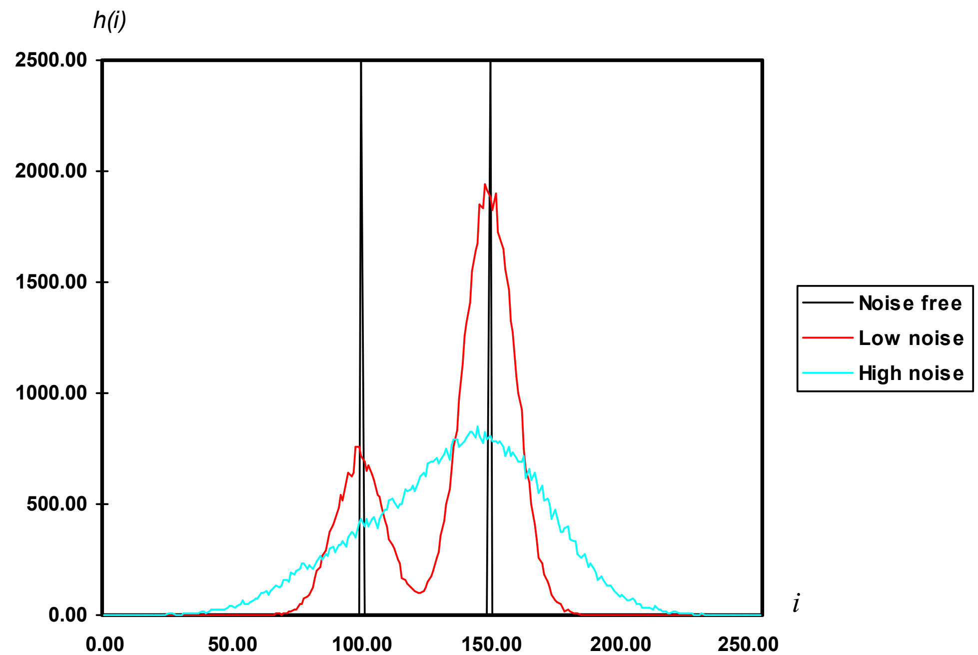
Low noise



High noise

Greylevel histogram-based segmentation

- How do we characterise low noise and high noise?
- We can consider the histograms of our images
  - For the noise free image, its simply two spikes at i=100, i=150
  - For the low noise image, there are two clear peaks centred on i=100, i=150
  - For the high noise image, there is a single peak – two greylevel populations corresponding to object and background have merged



Greylevel histogram-based segmentation

- We can define the input image *signal-to-noise ratio* in terms of the mean greylevel value of the object pixels and background pixels and the additive noise standard deviation

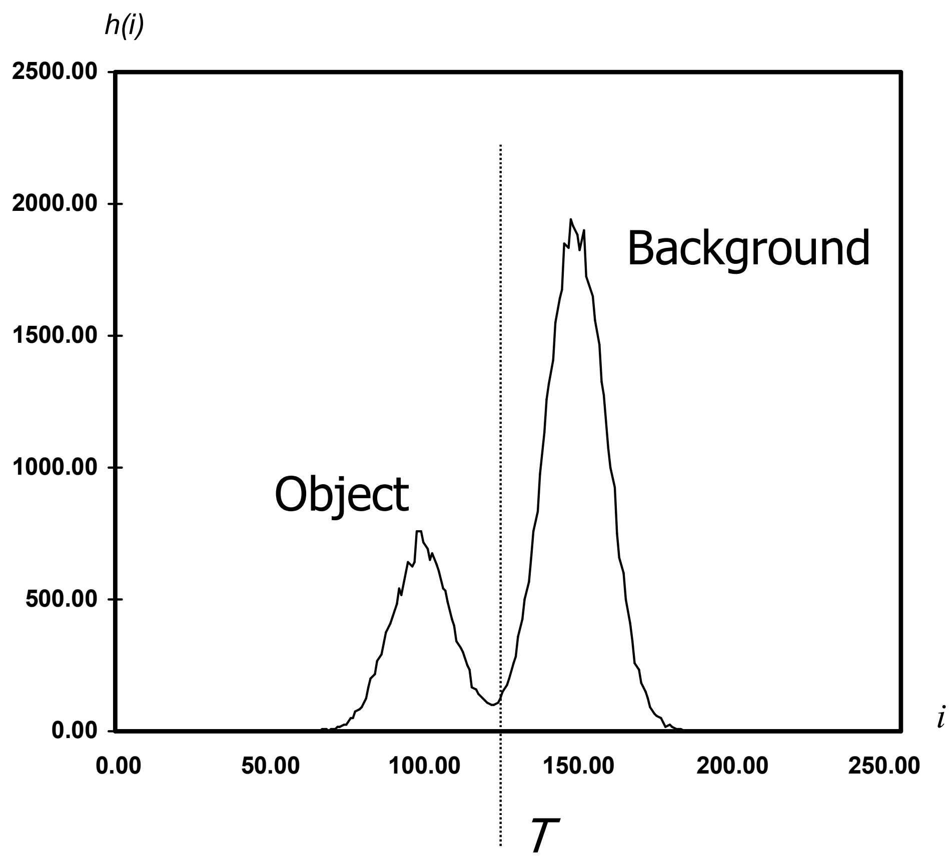
$$S / N = \frac{|\mu|}{\sigma}$$

For our test images :

S/N (noise free) = ∞
S/N (low noise) = 5
S/N (low noise) = 2

Greylevel thresholding

- We can easily understand segmentation based on thresholding by looking at the histogram of the low noise object/background image
  - There is a clear 'valley' between to two peaks



Greylevel thresholding

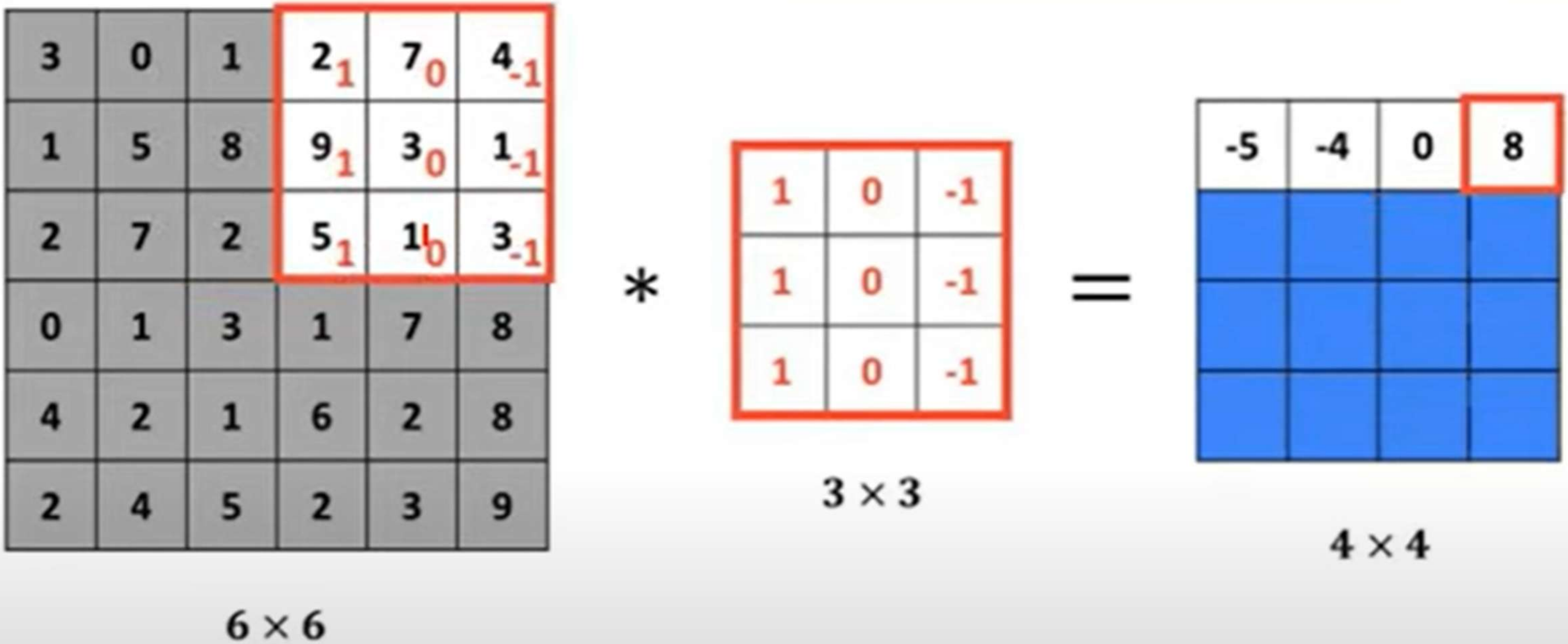
- We can define the greylevel thresholding algorithm as follows:
  - If the greylevel of pixel p <=T then pixel p is an object pixel

  else
  - Pixel p is a background pixel

Introduction

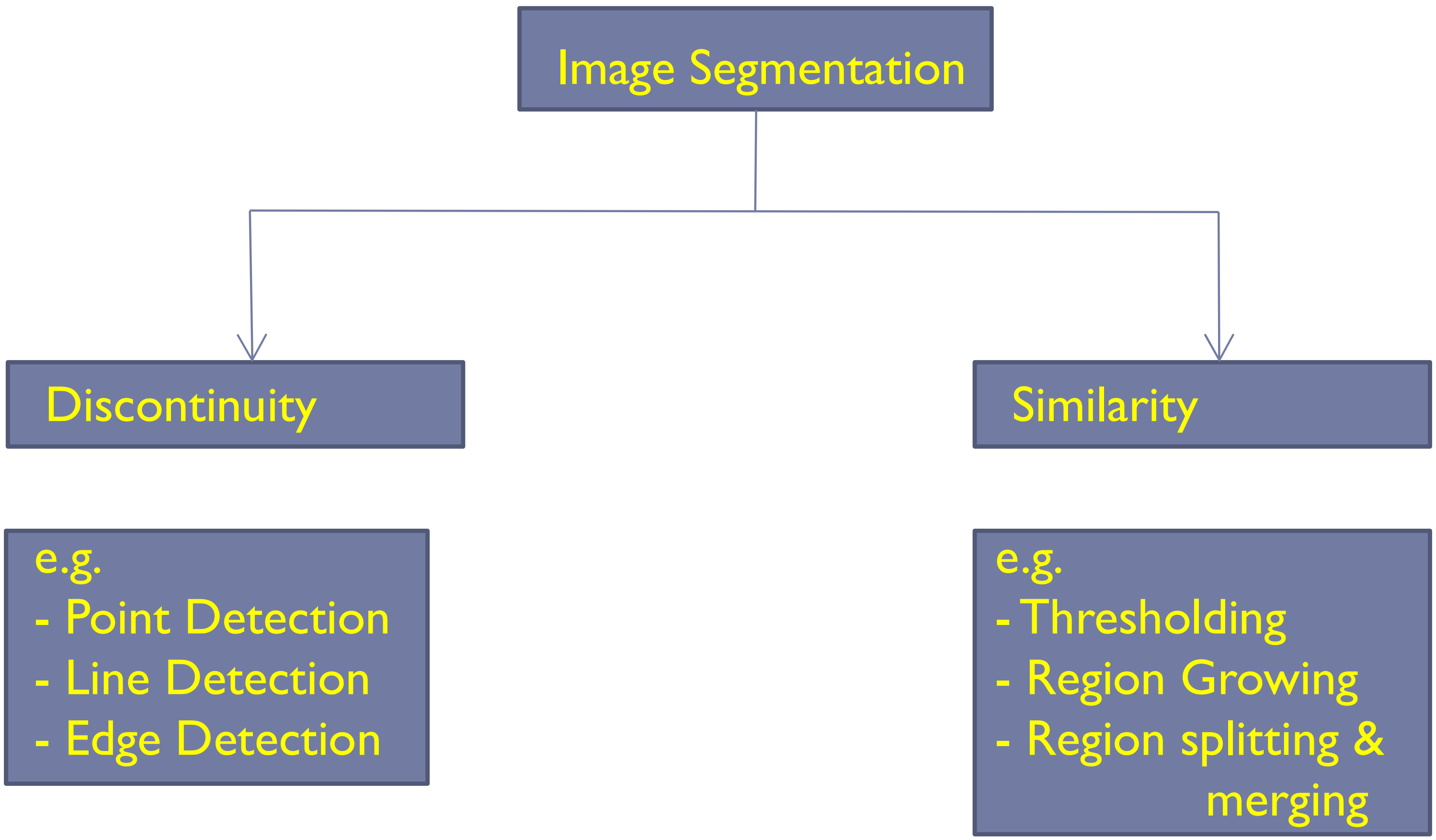
- Image analysis:-

  Techniques for extracting information from an image.
- Segmentation is the first step for image analysis.
- Segmentation is used to subdivide an image into its constituent parts or objects.
- This step determines the eventual success or failure of image analysis.
- Generally, the segmentation is carried out only up to the objects of interest are isolated. e..g. face detection.
- The goal of segmentation is to simplify and/or change the representation of an image into something that is more meaningful and easier to analyse.



$$2 \times 1 + 9 \times 1 + 5 \times 1 + 7 \times 0 + 3 \times 0 + 1 \times 0 + 4 \times -1 + 1 \times -1 + 3 \times -1 = 8$$

Classification of the Segmentation techniques



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

Discontinuity & Similarity.

Discontinuity: Approach is to partition image based on abrupt changes in intensities (edges).

e.g. point, line, edge.

Similarity: Approach is to partition the image based on similar regions according to predefined criteria.

e.g. thresholding, region growing, region splitting & merging.

Point Detection

- Point detection can be achieved with **simple high frequency (sharpening) mask given below**.
- Point is a **high frequency signal.**
- Two types of points can be detected.
- Bright point on dark background. for e.g. **10 10 10 10 10 240 10 10 10 10 10**
- Dark point on bright background. for e.g. **240 240 240 240 240 10 240 240 240 240 240**
- Threshold is used.
- Pixels are detected as Points that are above a **set threshold**

Point Detection Mask

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

$$|R| > T$$

Mask (w_i)

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

Image (z_i)

z1	z2	z3
z4	z5	z6
z7	z8	z9

z_i: Gray level of pixel

w_i: Response of mask

T: Threshold (Non Negative)

|R|: Response of the mask for $\mathbf{z_5}$ point

Point Detection

- Based on Masking…

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

- Find response R.
- The emphasis is strictly to detect points. That is, differences those are large enough to be considered as isolated points.
- So, compare and separate based on

$$|R| > T$$

- Where R = Response of convolution

  T = Non negative threshold value

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

$$|R| > T$$

10	10	10
10	200	10
10	10	10

R=1600-80=1520=255

R=1520/9=169

200	200	200
200	10	200
200	200	200

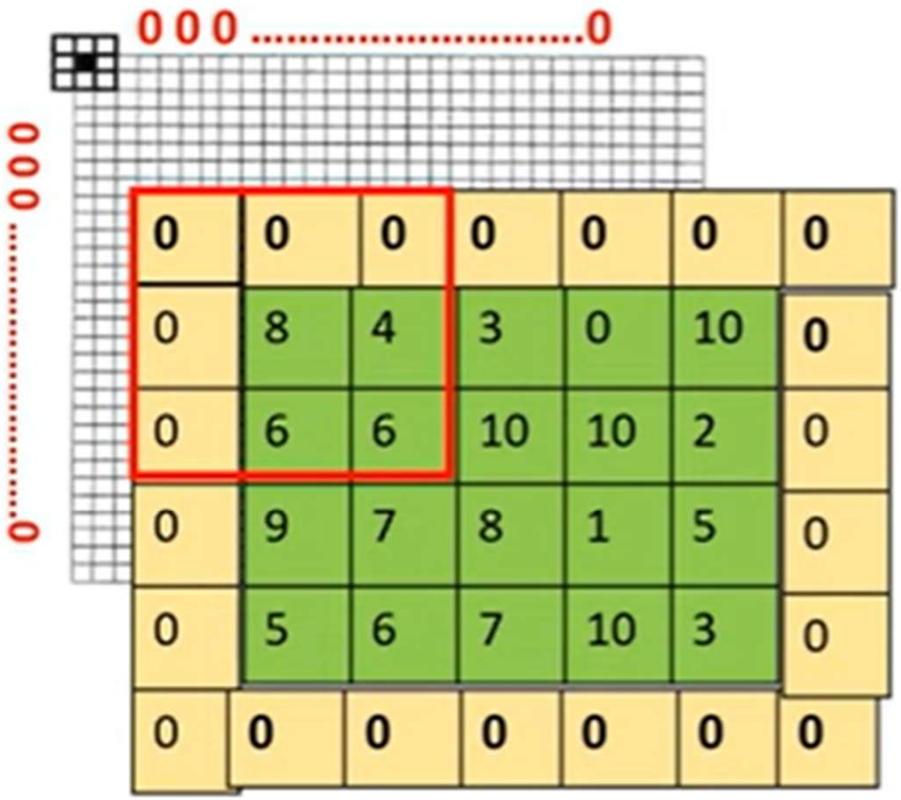
R=80-1600=-1520=1520=255

R=1520/9=169

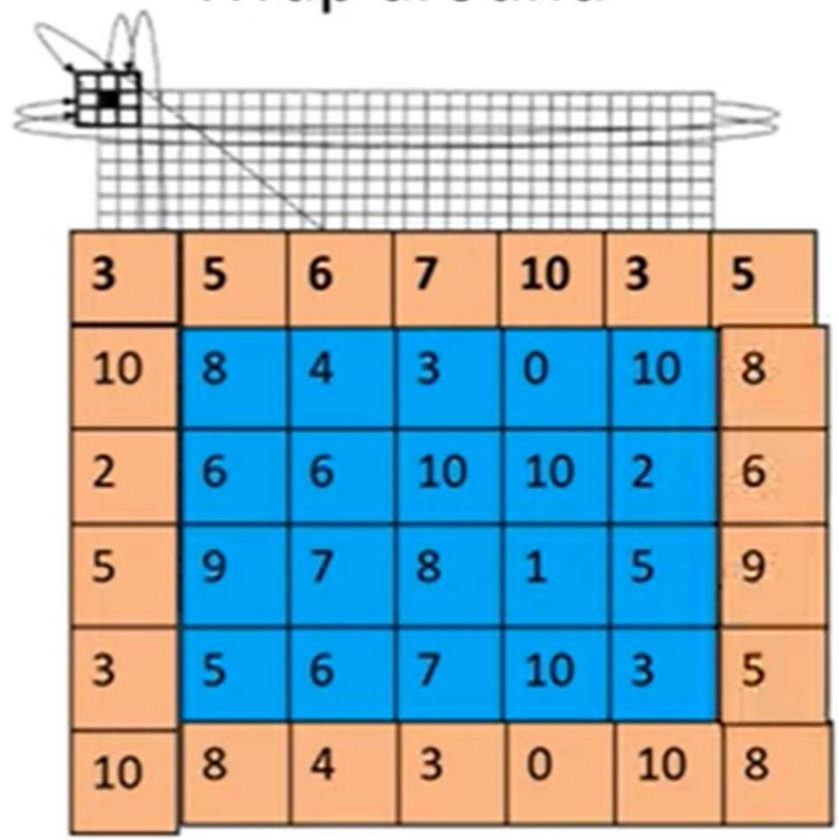
T=150

Handling Pixels Close to Boundaries

Pad with zeroes



Wrap around



Point Detection(Example)

Line Detection

-1	-1	-1
2	**2**	**2**
-1	-1	-1

Horizontal

-1	**2**	-1
-1	**2**	-1
-1	**2**	-1

Vertical

-1	-1	2
-1	2	-1
2	-1	-1

45^0

2	-1	-1
-1	2	-1
-1	-1	2

-45^0

Horizontal Mask: Respond more strongly to horizontally oriented lines

Vertical Mask: Respond more strongly to vertically oriented lines

45^0 Mask: Respond more strongly to 45^0 inclined lines

-45^0 Mask: Respond more strongly to 45^0 inclined lines

Line Detection

Horizontal Line

-1	-1	-1
2	2	2
-1	-1	-1

45 degree inclined Line

-1	-1	2
-1	2	-1
2	-1	-1

Vertical Line

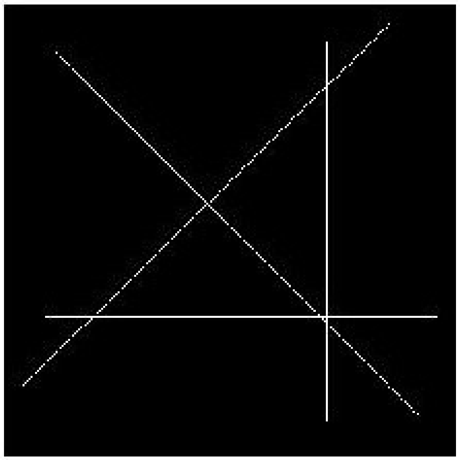
-1	2	-1
-1	2	-1
-1	2	-1

-45 degree inclined Line

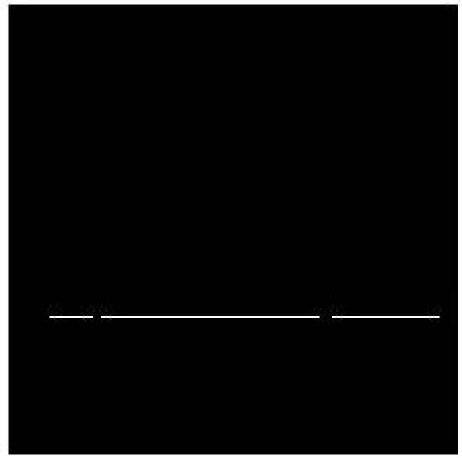
2	-1	-1
-1	2	-1
-1	-1	2

Line Detection(Cont.)

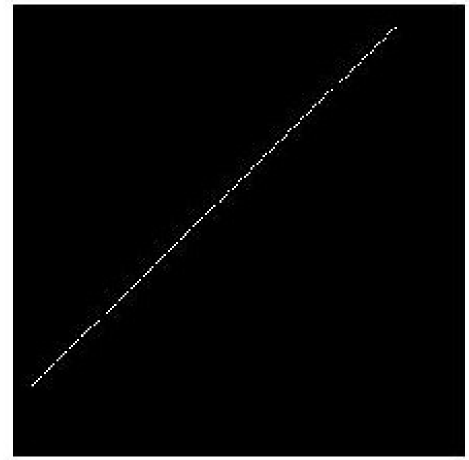
Original Image



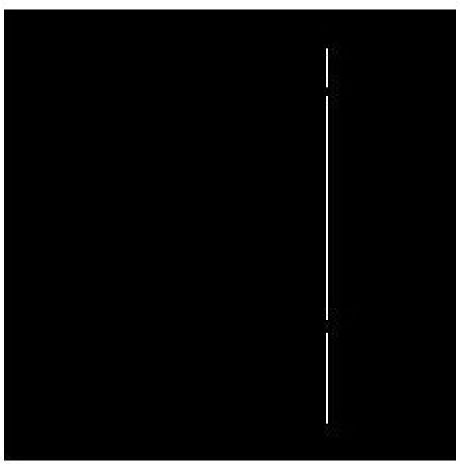
Horizontal line detection



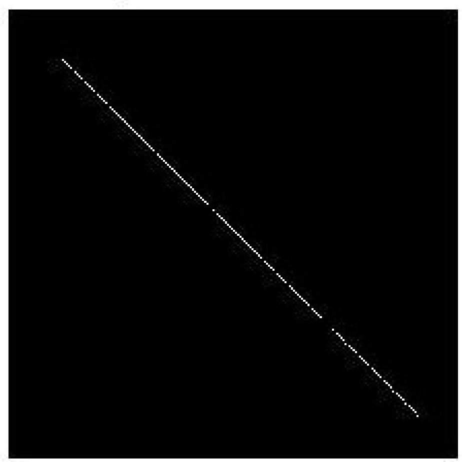
45 degree inclined line detection



Vertical line detection



135 degree inclined line detection



Let's have a look at this 6×6 image. It has light on the left and dark on the right. If we convolve it with the vertical edge detection filter it will result in detection of the vertical edge. This vertical edge is shown in the middle of the output image as we can see in the picture below.

10	10	10	0	0	0
10	10	10	0	0	0
10	10	10	0	0	0
10	10	10	0	0	0
10	10	10	0	0	0
10	10	10	0	0	0

$*$

1	0	-1
1	0	-1
1	0	-1

$=$

0	30	30	0
0	30	30	0
0	30	30	0
0	30	30	0

An example of a vertical edge detection. Here we have light to dark transition.

Edge Detection

Robert's Mask

-1	0
0	1

0	-1
1	0

Prewitt Operator

-1	-1	-1
0	0	0
1	1	1

-1	0	1
-1	0	1
-1	0	1

Sobel Operator

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Laplacian

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

In grey scale image pixel intensity varies from 0 to 255

0 – Black

255 - White

Binary Image

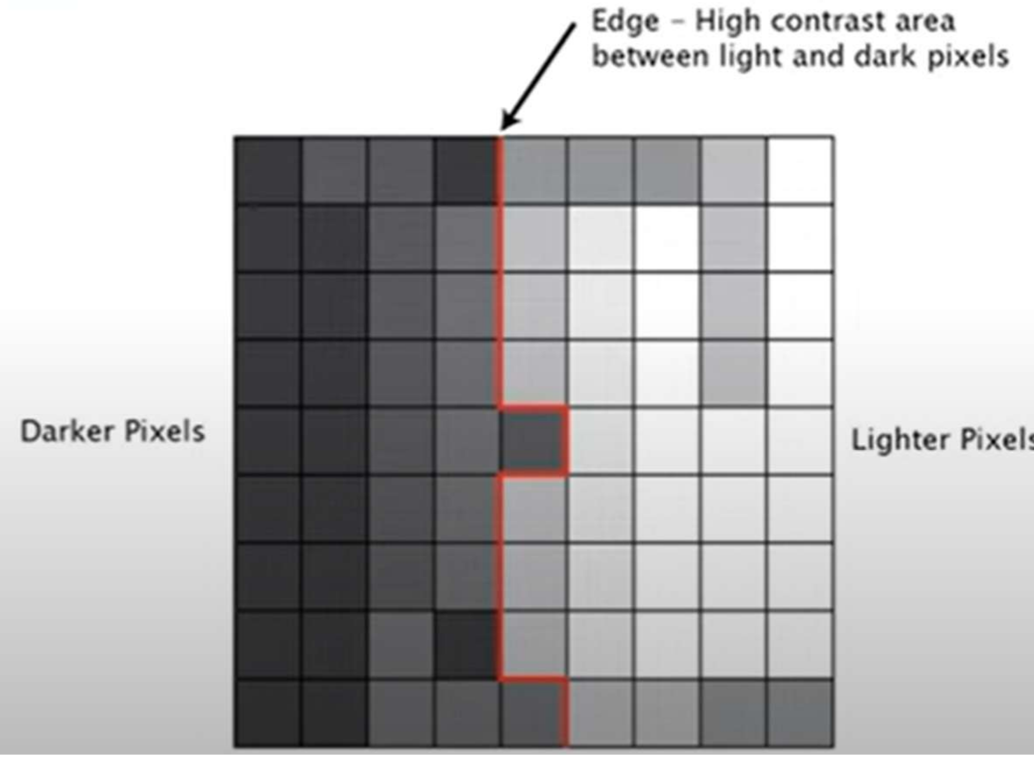
0 – Black

1 – White

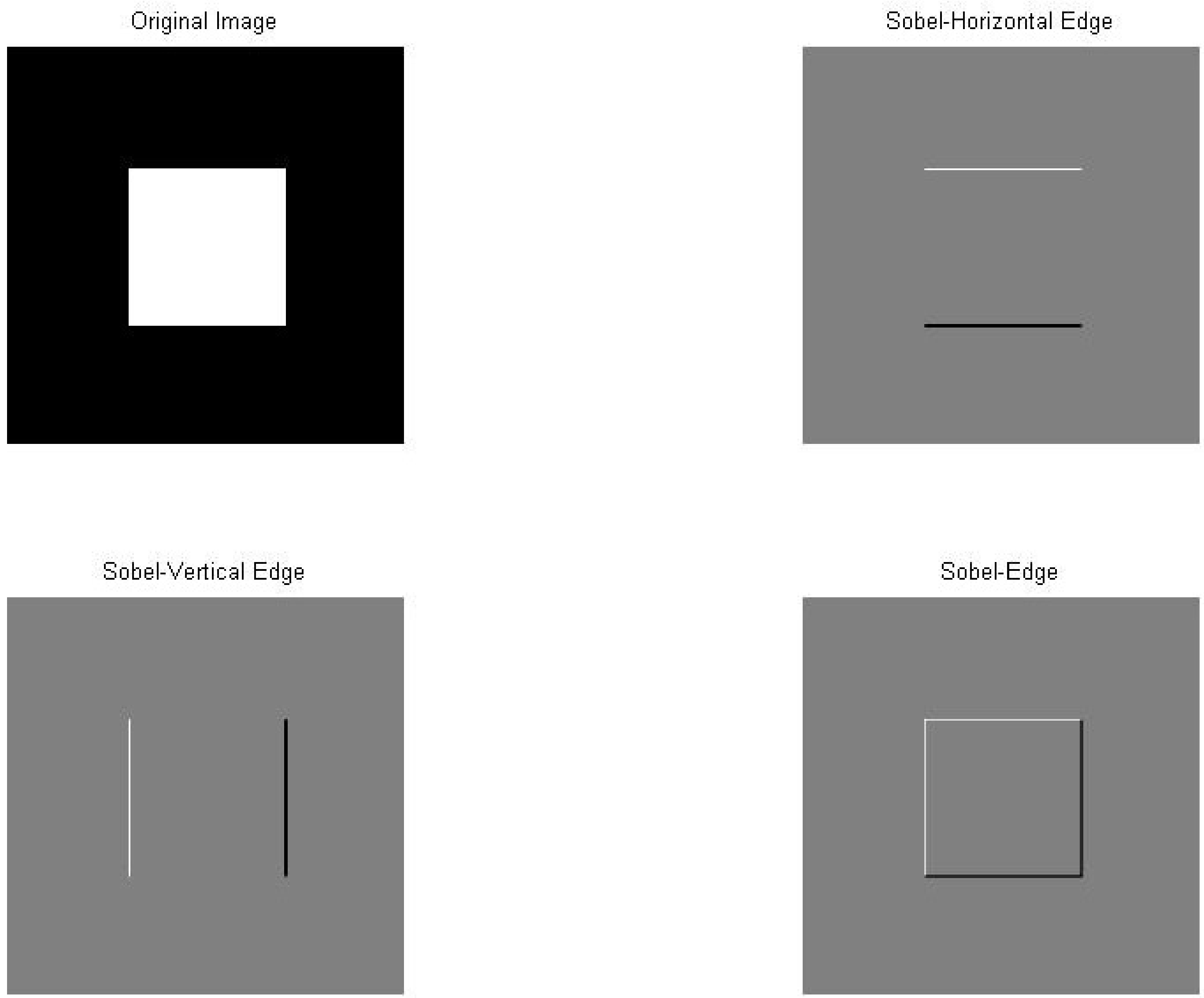
What is an Edge ?

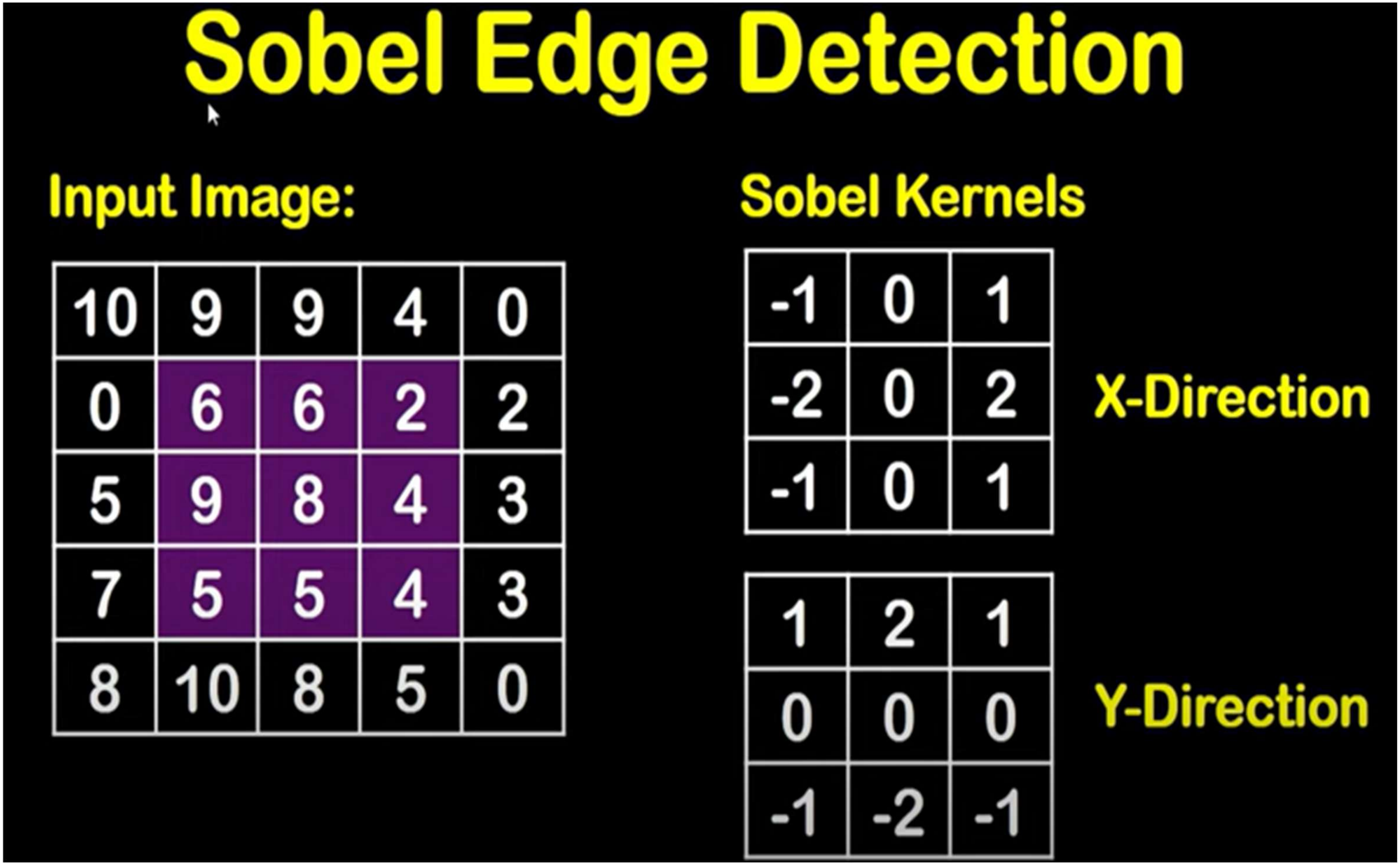
There are three types of edges:

- Horizontal edges
- Vertical edges
- Diagonal edges



Edge Detection(Example)




Sobel Edge Detection
Input Image:
10 9 9 4 0
0 6 6 2 2
5 9 8 4 3
7 5 5 4 3
8 10 8 5 0
Sobel Kernels
-1 0 1
-2 0 2
-1 0 1
X-Direction
1 2 1
0 0 0
-1 -2 -1
Y-Direction

Ix

X	X	X	X	X
X	14	-18	-22	X
X	10	-15	-16	X
X	-1	-12	-17	X
X	X	X	X	X

Iy

X	X	X	X	X
X	6	2	-2	X
X	-4	1	-4	X
X	-5	-2	1	X
X	X	X	X	X

Ix

14	-18	-22
10	-15	-16
-1	-12	-17

Iy

6	2	-2
-4	1	-4
-5	-2	1

Magnitude

15	18	22
11	15	16
5	12	17

- **Threshold** = (15 + 18 + 22 + 11 + 15 + 16 + 5 + 12 + 17) / 9 = **15**

Sobel Edge Detection

Magnitude

15	18	22
11	15	16
5	12	17

Threshold = 15

Edge

0	1	1
0	0	1
0	0	1

Prewitt Edge Detection

Input Image:

10	9	9	4	0
0	6	6	2	2
5	9	8	4	3
7	5	5	4	3
8	10	8	5	0

Prewitt Kernels

X-Direction

-1	0	1
-1	0	1
-1	0	1

Y-Direction

1	1	1
0	0	0
-1	-1	-1

Ix

X	X	X	X	X
X	8	-14	-18	X
X	7	-10	-11	X
X	1	-11	-15	X
X	X	X	X	X

Iy

X	X	X	X	X
X	6	1	-2	X
X	-5	0	-2	X
X	-4	-2	2	X
X	X	X	X	X

Prewitt Edge Detection

Ix

8	-14	-18
7	-10	-11
1	-11	-15

Iy

6	1	-2
-5	0	-2
-4	-2	2

Magnitude

10	14	18
9	10	11
4	11	15

Threshold = (10 + 14 + 18 + 9 + 10 + 11 + 4 + 11 + 15) / 9 = 11

Prewitt Edge Detection

Magnitude

10	14	18
9	10	11
4	11	15

Threshold = 11

Edge

0	1	1
0	0	0
0	0	1

Region-based segmentation is a **fundamental image segmentation technique** in digital image processing, where an image is partitioned into meaningful regions (groups of connected pixels) based on **similarity criteria** such as intensity, color, or texture.

Unlike edge-based segmentation (which focuses on discontinuities), region-based methods focus on **homogeneity inside a region**.

Main Idea

- Pixels that are **similar** to each other are grouped together into regions.
- The similarity is defined using thresholds on **intensity, color, or statistical measures**.
- A region is grown or merged until it satisfies a homogeneity criterion.

Steps in Region-Based Segmentation

1. **Region Growing**
   - Start with a **seed pixel.**
   - Add neighboring pixels to the region if they are similar (e.g., intensity difference < threshold).
   - Continue until no more pixels can be added.
   - Advantage: Produces connected regions.
   - Disadvantage: Sensitive to noise and seed choice.
2. **Region Splitting**
   - Start with the whole image.
   - If a region is not homogeneous, split it into quadrants.
   - Keep splitting until all regions satisfy the homogeneity condition.
   - Disadvantage: Produces blocky regions.
3. **Region Merging**
   - Start with small regions (e.g., each pixel as a region).
   - Merge adjacent regions that are similar.
   - Continue until no further merging is possible.

Applications

•Medical imaging (tumor/organ detection).

•Remote sensing (land classification).

•Object recognition in computer vision.

Q1. Apply region growing on the following image with initial point at (2,2) and threshold value as 2. Use 4 connectivity.

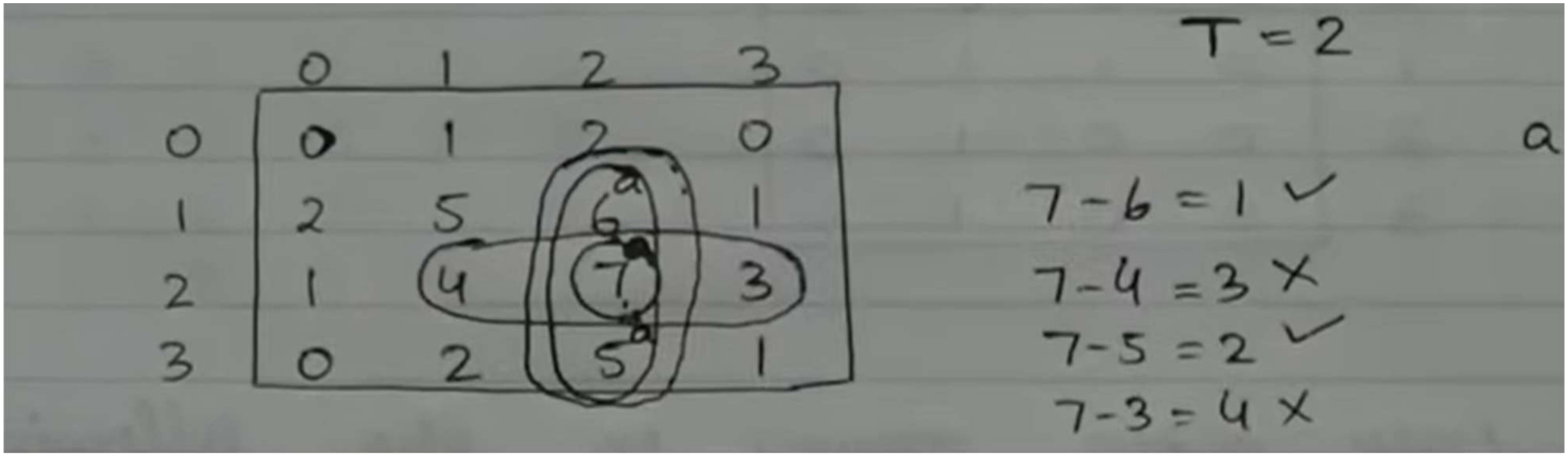
$T = 2$

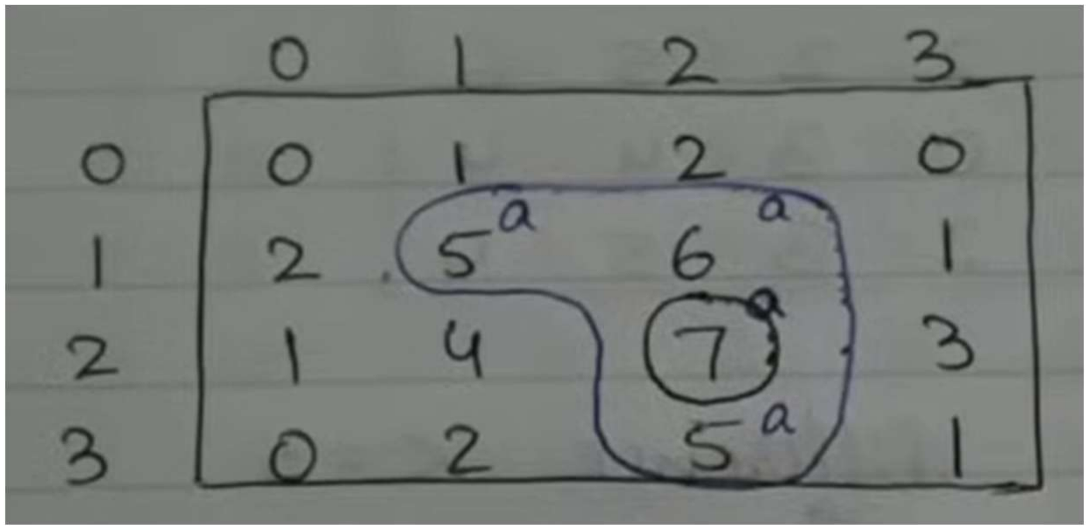
	0	1	2	3
0	0	1	2	0
1	2	5	6	1
2	1	4	(7)	3
3	0	2	5	1

Ans. The segmented region is shown in the following figure.

Condition → absolute difference <= 2.

4 way connectivity





Segmented image obtained from region growing:

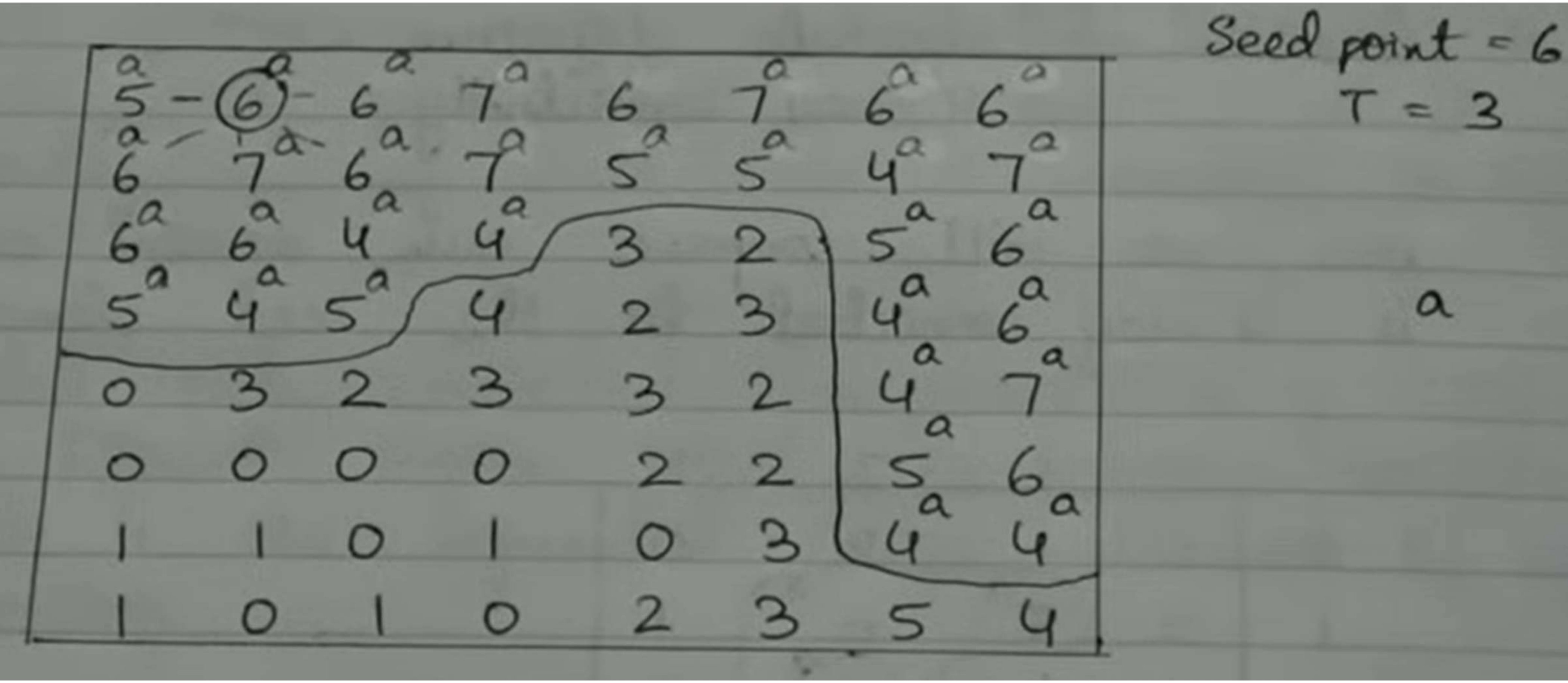
	0	1	2	3
0	0	0	0	0
1	0	1	1	0
2	0	0	1	0
3	0	0	1	0

Q2. Apply region growing on the following image with seed point as 6 and threshold value as 3.

Seed point = 6
T = 3

5	(6)	6	7	6	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

s. Condition → absolute difference <= 3.
8 way connectivity.


Seed point = 6
T = 3
a
5 6 6 7 6 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

Condition → absolute difference <= 3.
8 way connectivity.

Seed point = 6.

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

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	0	0	1	1
1	1	1	0	0	0	1	1
0	0	0	0	0	0	1	1
0	0	0	0	0	0	1	1
0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0

→ Segmented Image

Q3: Apply splitting and merging on the following image with threshold value equal to 3.

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

$T = 3$

Ans. Condition : absolute difference $<= 3$.

Max value = 7

Min value = 0

$|7 - 0| = 7$ which is greater than 3.

Therefore we will split the region into 4 sub-regions.

Splitting

	5	6	6	6	7	7	6	6	
(a)	6	7	6	7	5	5	4	7	(b)
	6	6	4	4	3	2	5	6	
	5	4	5	4	2	3	4	6	
	0	3	2	3	3	2	5	7	
(c)	0	0	0	0	2	2	5	6	(d)
	1	1	0	1	0	3	4	4	
	1	0	1	0	2	3	5	4	

In region (a):

Max = 7 Min = 4

$|7-4| = 3$ which is equal to threshold.

Therefore, no need to split.

(a) (b) (c) (d)

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	5	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

$|7 - 2| = 5$

$|3 - 0| = 3$

$|7 - 0| = 7$

In region (b):

Max = 7 Min = 2

$|7-2| = 5$ which is greater than 3.

Therefore we will split the region (b) into 4 sub-regions.

In region (c):

Max = 3 Min = 0

$|3-0| = 3$.

So no need to split.

In region (d):

Max = 7 Min = 0

$|7-0| = 7$.

So we will split into 4 sub-regions.

					(b1)		(b2)		
	5	6	6	6	7	7	6	6	
(a)	6	7	6	7	5	5	4	7	(b)
	6	6	4	4	3 (b3)	2	5 (b4)	6	
	5	4	5	4	2	3	4	6	
	0	3	2	3	3 (d1)	2	5 (d2)	7	
(c)	0	0	0	0	2	2	5	6	(d)
	1	1	0	1	0 (d3)	3	4 (d4)	4	
	1	0	1	0	2	3	5	4	

Furthermore, we will check all the sub-regions. Since all of them are <= 3, no further splitting is required.

Merging

Check adjacent regions, if they are falling within the threshold, then merge.

Consider regions (a) and (b1)

Max = 7   Min = 4

$|7-4| = 3$. ✓ Merge.

Consider regions (a b1) and (b2)

Max = 7 Min = 4

|7-4| = 3. ✓ Merge.

Consider regions (a b1 b2) and (b4)

Max = 7 Min = 4

|7-4| = 3 ✓ Merge

Consider regions (a b1 b2 b4) and d2

Max = 7 Min = 4

|7-4| = 3 ✓ Merge.

Similarly, merge (a b1 b2 b4 d2) with (d4).

Similarly, merge (c), (d1), (b3) and (d3)

Final segmented image: