

AI Summer School 2025

Medical Imaging Informatics

University of Pittsburgh

Image Filtering, Morphology, Shape Analysis

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Learning Objectives

After completing this lecture, you should be able to:

- Understand image filtering and demonstrate what can be achieved by image filtering
- Understand the convolution operation
- Learn how image derivatives work
- Learn image semantic could be embedded in edges
- Understand edge detection metrics
- What does object segmentation mean and why we are doing it
- How do segmentation algorithms work
- How does the Watershed algorithm work in the context of object segmentation

Outline

- Image Histogram
- Image Filtering
- Image Derivative
- Edge Detection
- Object Segmentation
- Watershed Algorithm

Recall from the previous lectures



```
[[105 112 100 111 104 99 106 99 96 103 112 119 104 97 93 87]
[ 91 90 102 106 104 79 90 103 99 105 123 136 110 105 94 85]
[ 76 85 90 105 120 105 87 96 95 90 115 112 100 103 99 85]
[ 99 81 81 93 120 131 127 100 95 90 102 99 90 93 101 94]
[106 91 61 64 69 91 80 85 101 107 100 90 75 84 96 95]
[114 100 85 55 55 69 64 54 64 87 112 120 90 74 84 91]
[133 137 147 103 85 81 80 85 52 54 74 84 102 93 85 82]
[120 137 144 140 109 95 86 70 62 65 63 63 60 73 86 101]
[125 133 148 137 119 121 117 94 65 79 80 65 54 64 72 90]
[127 125 131 147 133 127 126 131 111 96 89 75 61 64 72 84]
[115 114 109 123 150 140 131 110 113 109 100 92 74 65 72 70]
[ 89 93 90 97 100 147 131 110 113 114 113 100 106 95 77 80]
[ 63 77 86 81 77 79 102 123 117 115 117 125 125 130 115 87]
[ 62 65 82 89 70 71 80 101 124 126 119 101 107 114 131 110]
[ 63 65 75 80 89 71 82 81 120 130 135 105 81 90 130 110]
[ 87 65 71 87 106 95 69 45 76 130 126 107 92 94 105 112]
[110 97 82 86 117 123 116 66 41 51 95 93 89 95 102 107]
[104 146 112 80 82 120 124 104 76 40 45 86 80 101 102 109]
[157 170 157 120 93 80 114 132 112 97 60 55 70 82 99 94]
[130 120 134 161 139 100 109 110 121 134 114 87 65 53 69 86]
[120 112 96 117 150 144 120 115 104 107 102 93 87 81 72 70]
[123 107 96 86 83 112 153 140 122 100 104 75 80 107 112 90]
[122 121 102 80 82 86 94 117 145 140 153 102 50 70 92 107]
[122 164 140 103 71 56 70 83 93 103 119 139 102 61 69 84]]
```

what the computer sees

Image from: <https://bam098.medium.com/image-classification-c8bcb1d7811e>

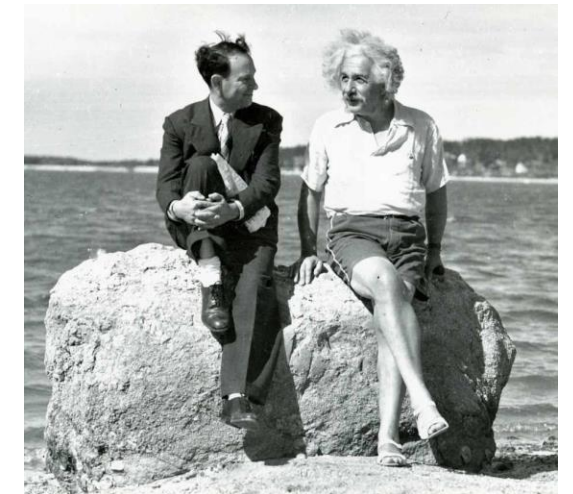


Image Filtering

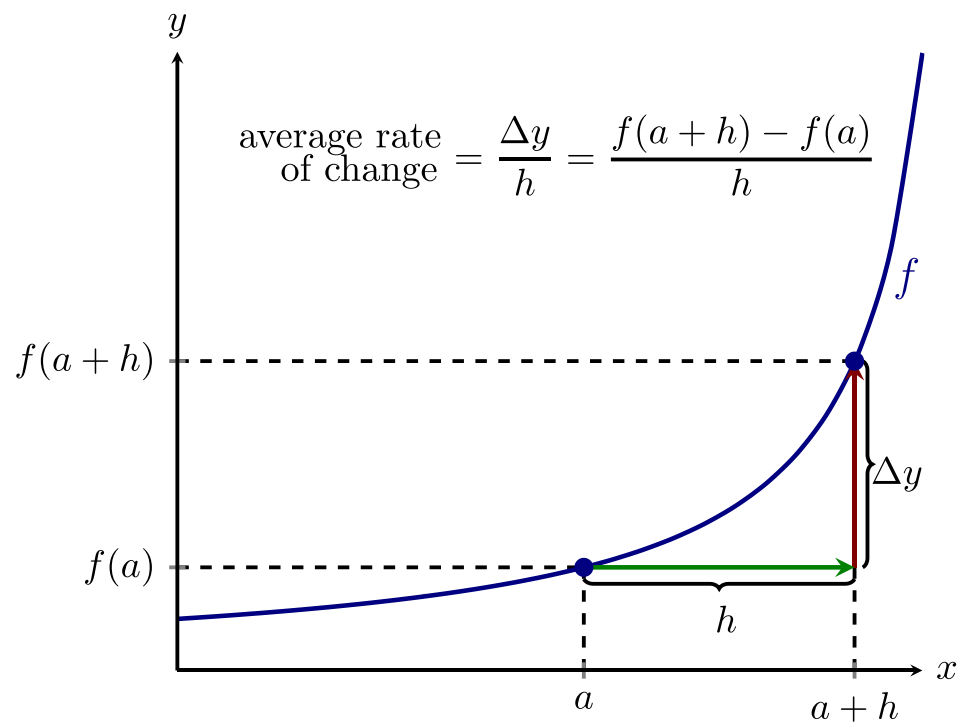
Applications:

- **Image quality enhancement:** denoising, contrast enhancement.
- **Information extraction from images:** edges, distinctive points, texture.
- **Pattern detection and recognition:** image matching

Derivative

Derivative: Rate of Change!!!

$$\frac{df}{dx} = \lim_{\Delta x \rightarrow 0} \frac{f(x) - f(x - \Delta x)}{\Delta x} = f'(x) = f_x$$



$$a = \frac{dv}{dt} \text{ acceleration}$$

Derivative of Functions and Discrete Derivative

$$y = x^4$$

$$\frac{dy}{dx} = 4x^3$$

$$\frac{df}{dx} = \lim_{\Delta x \rightarrow 0} \frac{f(x) - f(x - \Delta x)}{\Delta x} = f'(x)$$

$$\frac{df}{dx} = \frac{f(x) - f(x-1)}{1} = f'(x)$$

$$\frac{df}{dx} = f(x) - f(x-1) = f'(x)$$

$$\frac{df}{dx} = f(x) - f(x-1) = f'(x)$$

Backward Difference

$$\frac{df}{dx} = f(x) - f(x+1) = f'(x)$$

Forward Difference

Discrete Derivative; an example

$$f(x) = 11 \quad 15 \quad 12 \quad 10 \quad 14 \quad 25 \quad 19$$

$$f'(x) = 0 \quad 4 \quad -3 \quad -2 \quad 4 \quad 11 \quad -6$$

Derivative Filter | Derivative Mask: [-1 1]

Discrete Derivative; Image is 2D

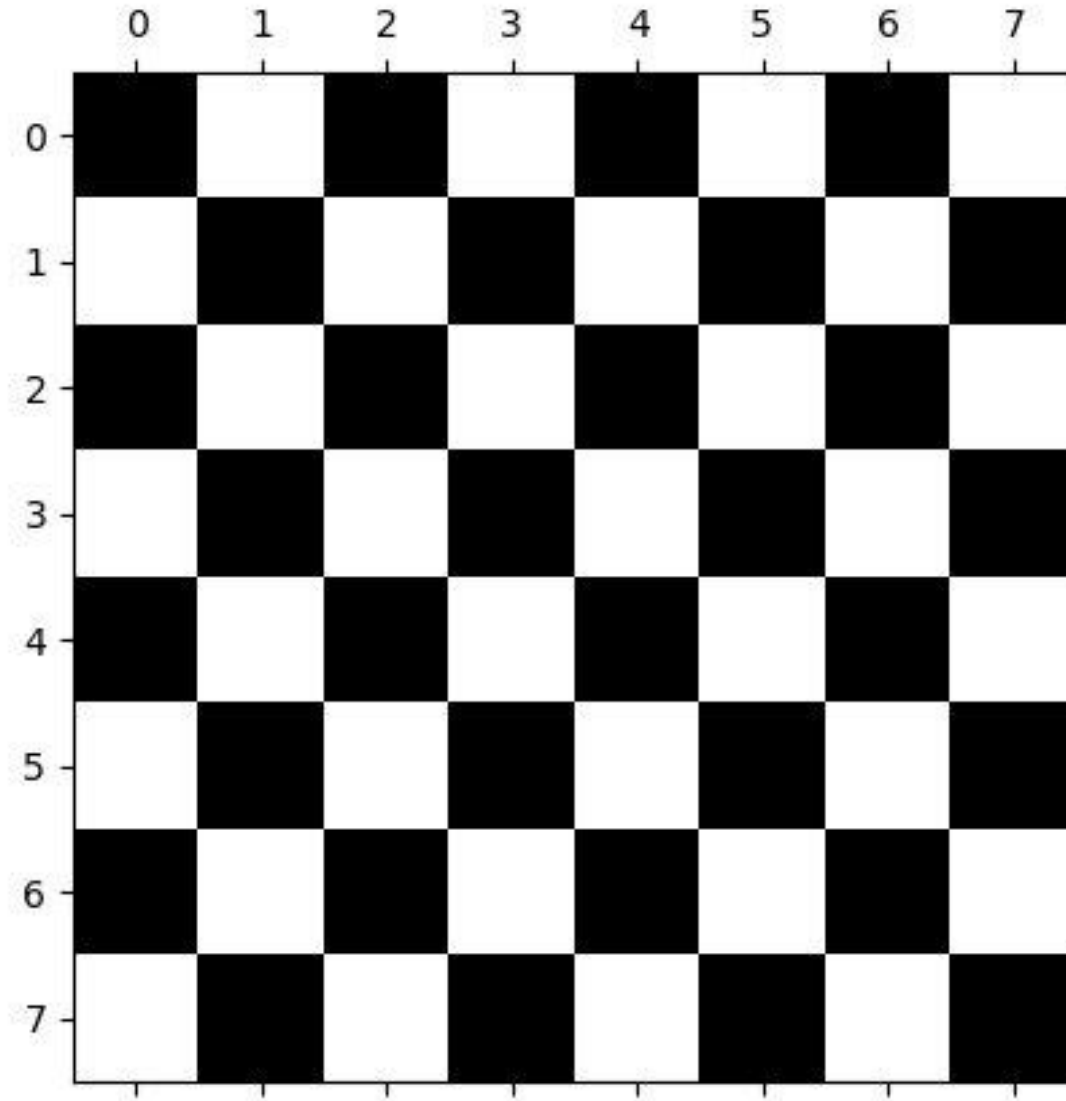
$$f(x, y)$$

$$\nabla f(x, y) = \begin{bmatrix} \frac{\partial f(x, y)}{\partial x} \\ \frac{\partial f(x, y)}{\partial y} \end{bmatrix} = \begin{bmatrix} f_x \\ f_y \end{bmatrix}$$

Derivative masks

$$f_x \Rightarrow \frac{1}{3} \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \quad f_y \Rightarrow \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$

Discrete Derivative



Convolution

In mathematics, Convolution is an operation which does the integral of the product of 2 functions (e.g., 2 signals), with one of the signals flipped.

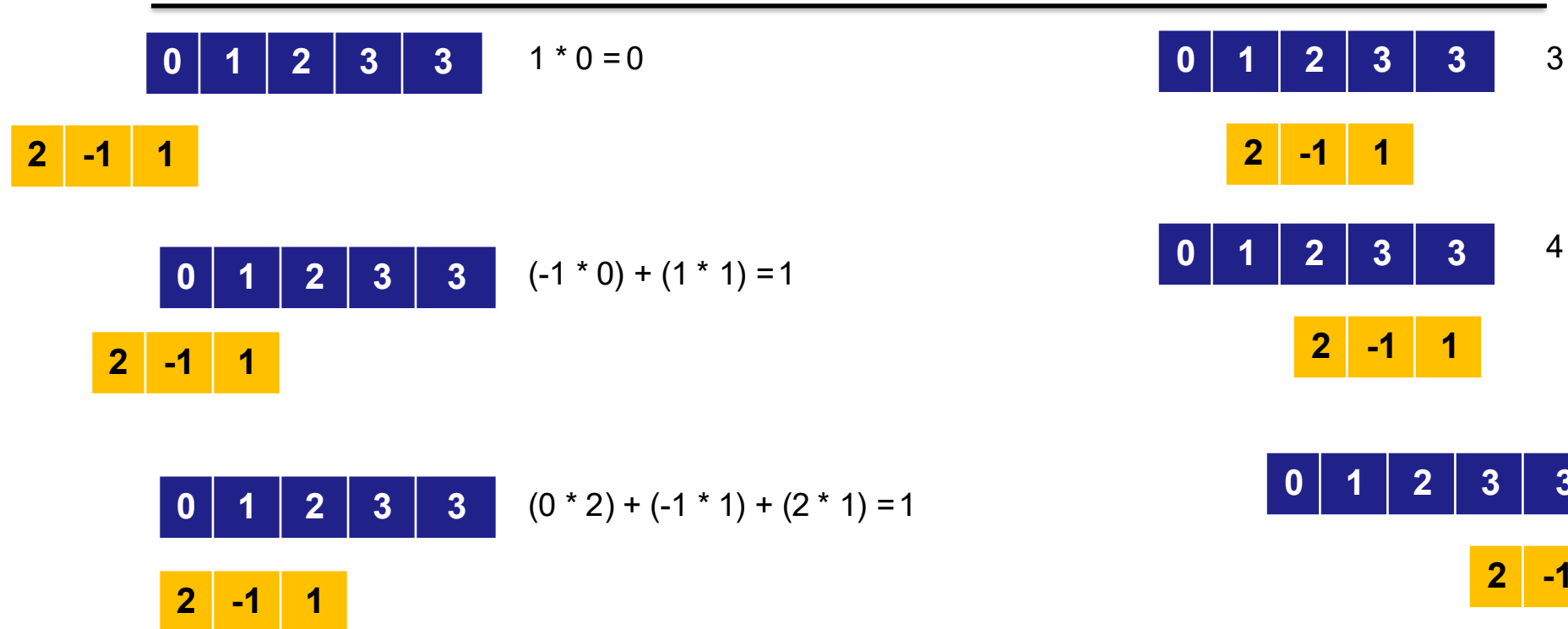
X

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

W

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

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



Convolution

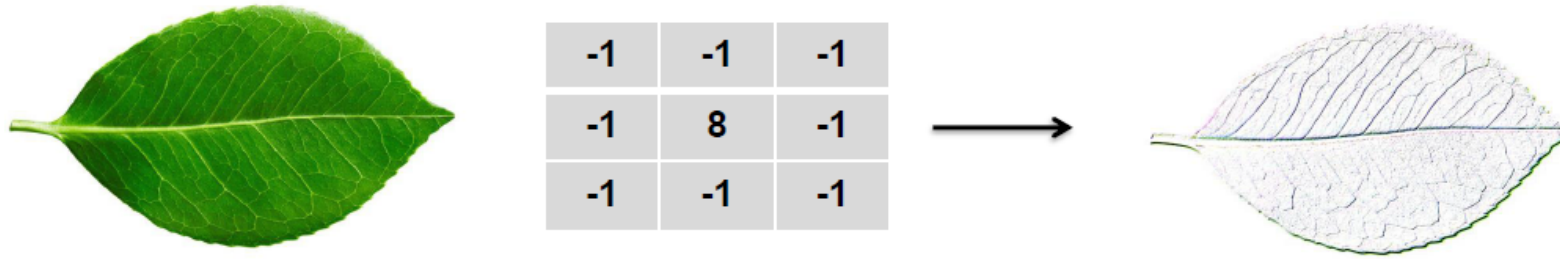
0	1	2	3	3	6
---	---	---	---	---	---

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

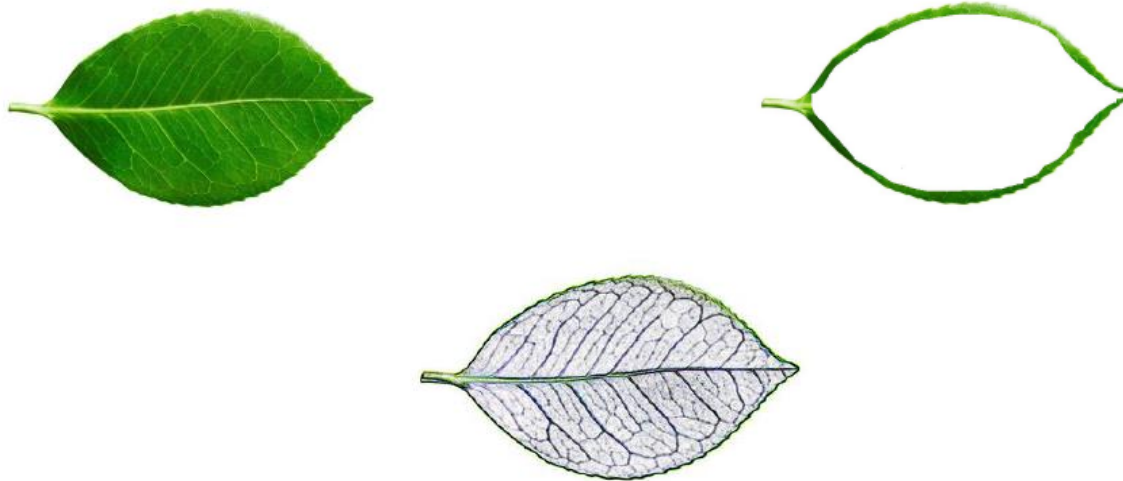
Output: X

0	1	1	3	4	3	6
---	---	---	---	---	---	---

Convolution



Convolution of an image (left) with an edge detector convolution kernel (middle). Right is the output.



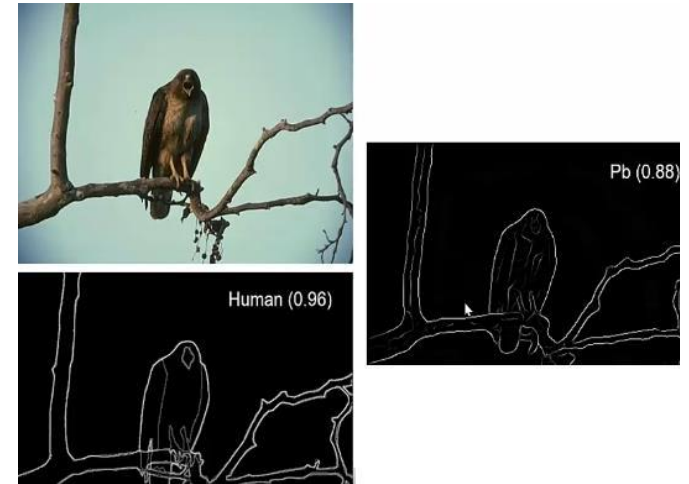
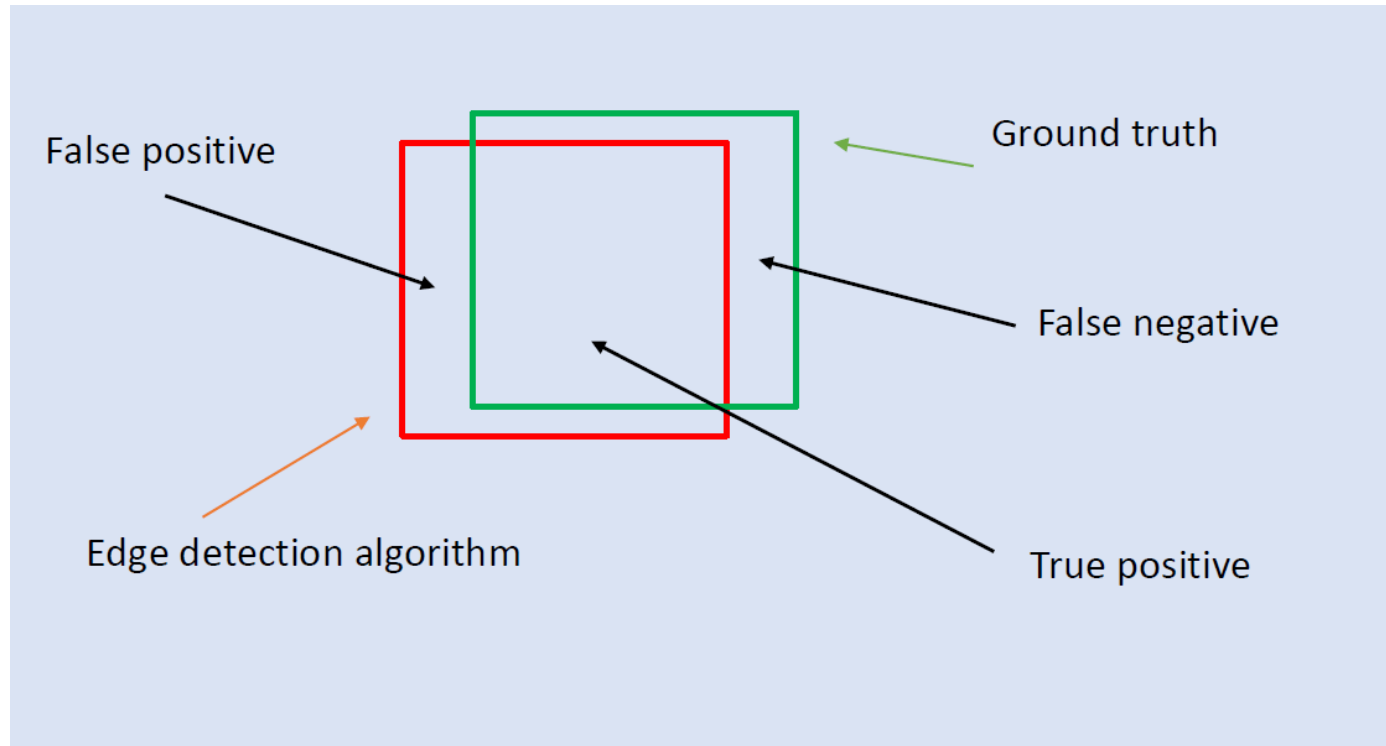
2-minutes break

Edge Detection: What?

Sudden changes in color or intensity.



Edge Detection: Metrics



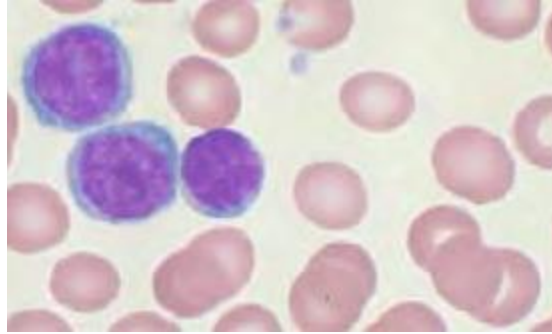
Slide Credit: James Hays

Object Segmentation

Object segmentation is the process of partitioning/dividing an image into multiple regions of interest (objects).

Some Applications:

- Counting objects in images
- Medical diagnosis
- Face recognition



Citation: Nelikanti A. Segmentation and Analysis of Cancer Cells in Blood Samples. Indian Journal of Computer Science and Engineering (IJCSE).. 2015.

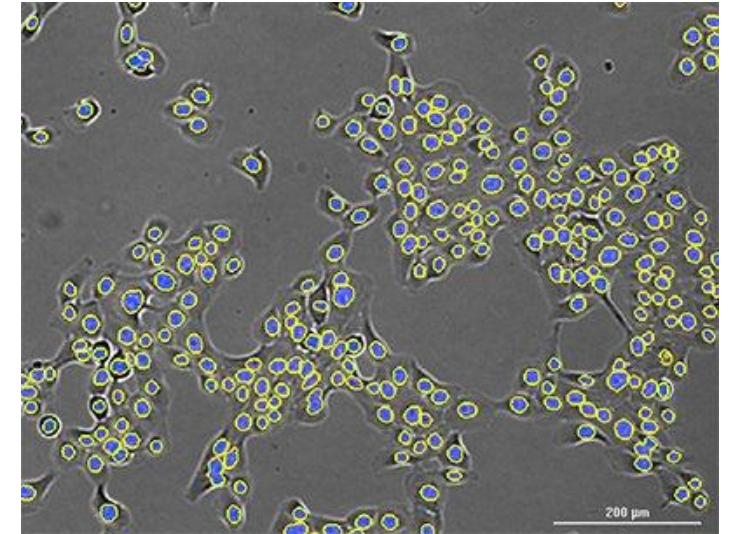


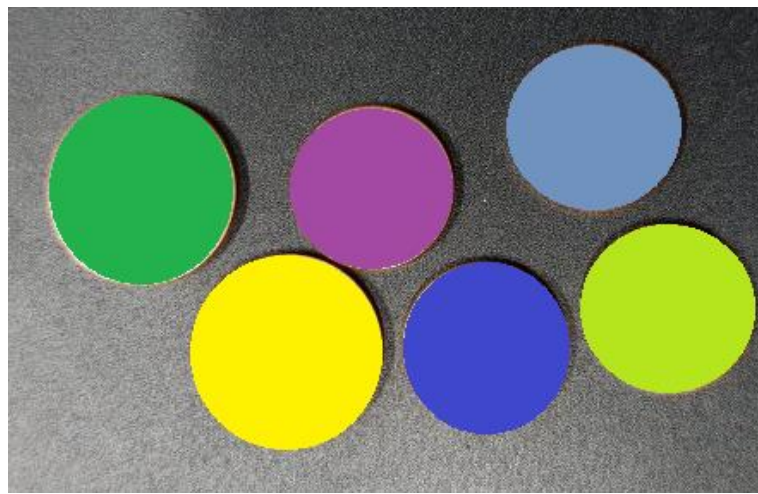
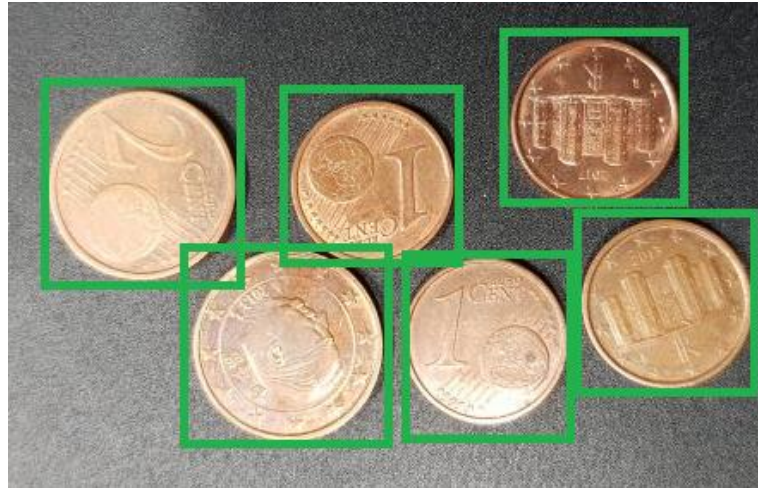
Image from:
<https://www.biotek.com/applications/cell-counting.html>



skin
hair
eyes
nose
mouth
background

Citation: Khan K, Mauro M, Leonardi R. Multi-class semantic segmentation of faces. In 2015 IEEE International Conference on Image Processing (ICIP) 2015 Sep 27 (pp. 827-831). IEEE.

Object Segmentation



Object Segmentation: Watershed Algorithm



Image from: <https://science.howstuffworks.com/environmental>

Object Segmentation: Watershed Algorithm



This is the strategy: We must think of a grayscale image as a topographic surface.

- high-intensity pixel values represent peaks (white areas)
- low-intensity values represent valleys or local minima (black areas)

Object Segmentation: Watershed Algorithm



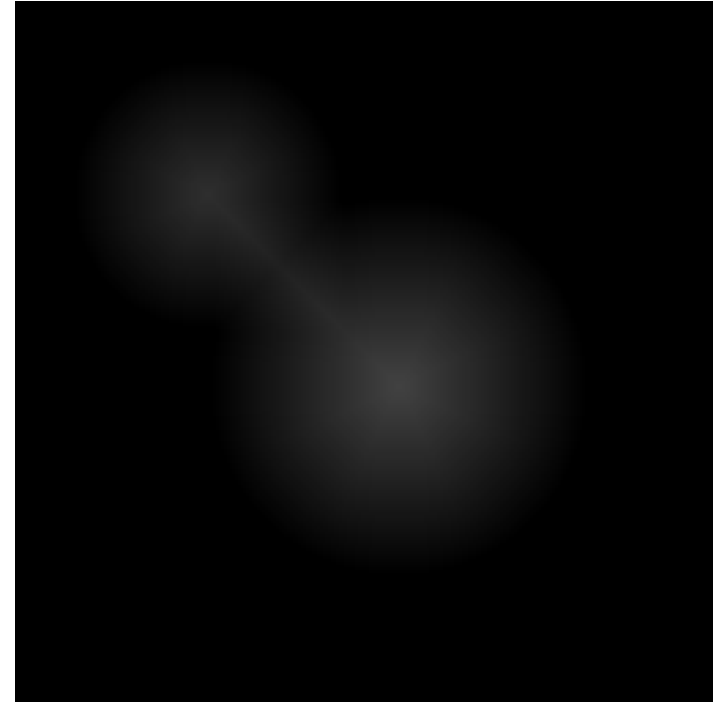
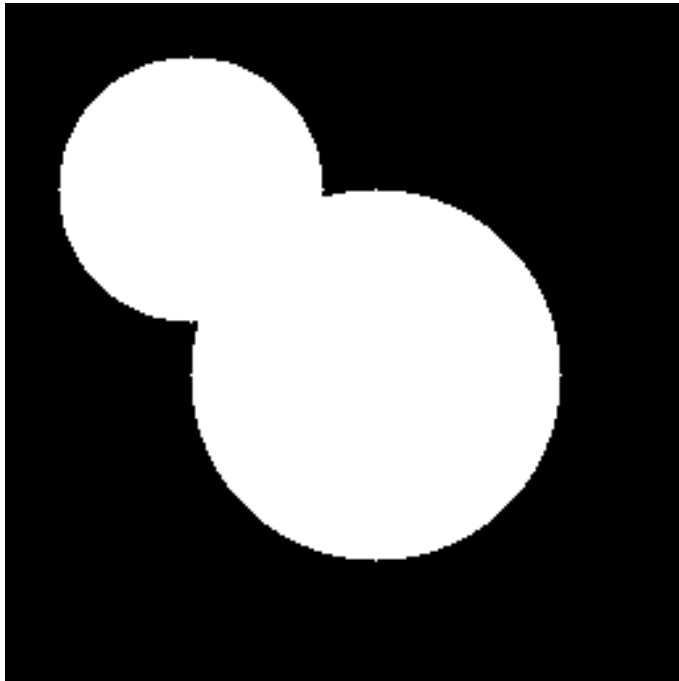
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Object Segmentation: Watershed Algorithm

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Object Segmentation: Watershed Algorithm

- Start with all pixels with the lowest possible value.
 - These form the basis for initial watersheds
- For each intensity level **k**:
 - For each group of pixels of intensity **k**:
 - **If** adjacent to exactly one existing region, add these pixels to that region
 - **Else if** adjacent to more than one existing regions, mark as boundary
 - **Else** start a new region

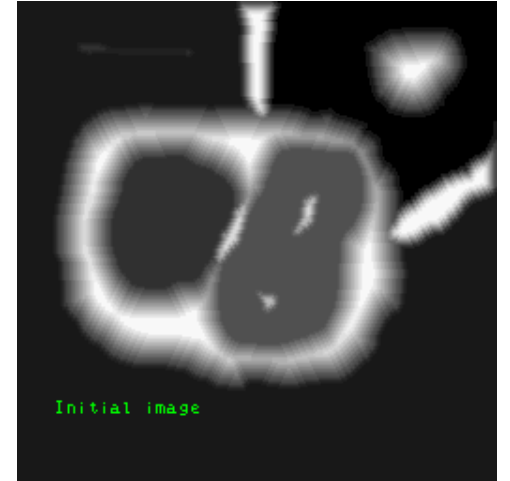


Image from: <http://datahacker.rs>

Thank you!

Questions!

