Computer Vision – 3
Segmentation

MAP-I Doctoral Programme

Miguel Tavares Coimbra

Outline

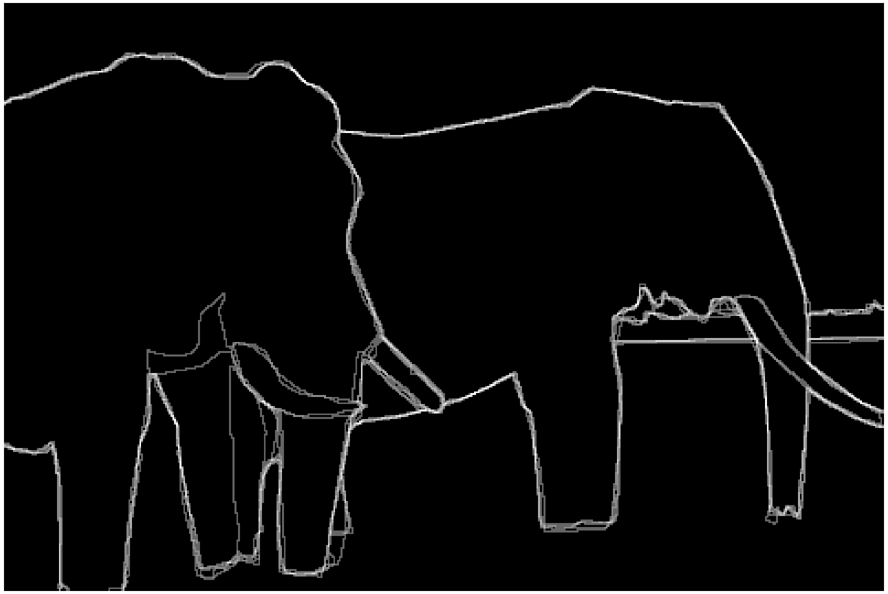
- Thresholding
- Region-based Segmentation
- Morphological Filters

Acknowledgements: Most of this course is based on the excellent courses offered by Prof. Shree Nayar at Columbia University, USA and by Prof. Srinivasa Narasimhan at CMU, USA. Please acknowledge the original source when reusing these slides for academic purposes.

Topic: Thresholding

- Thresholding
- Region-based Segmentation
- Morphological Filters

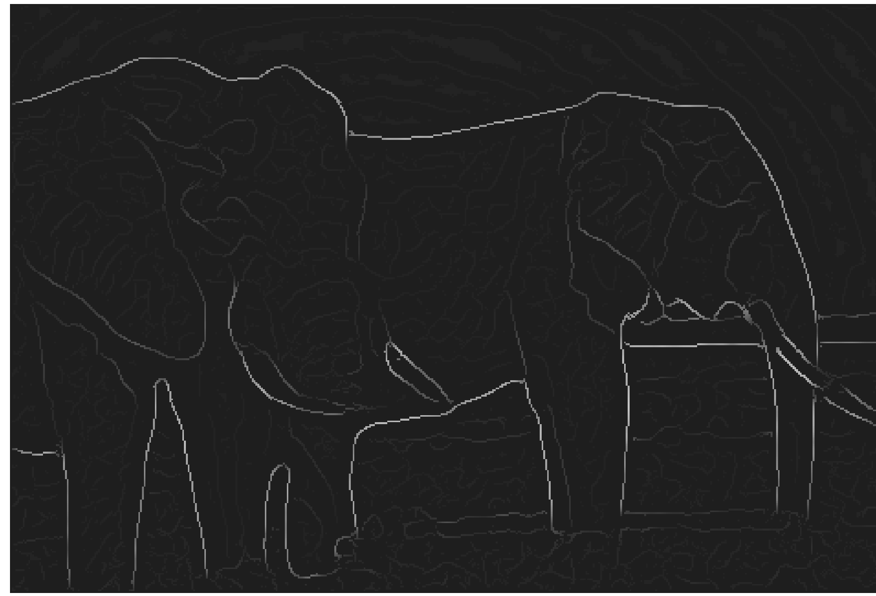
Boundaries of Objects



Marked by many users

http://www.eecs.berkeley.edu/Research/Projects/CS/vision/grouping/segbench/bench/html/images.html

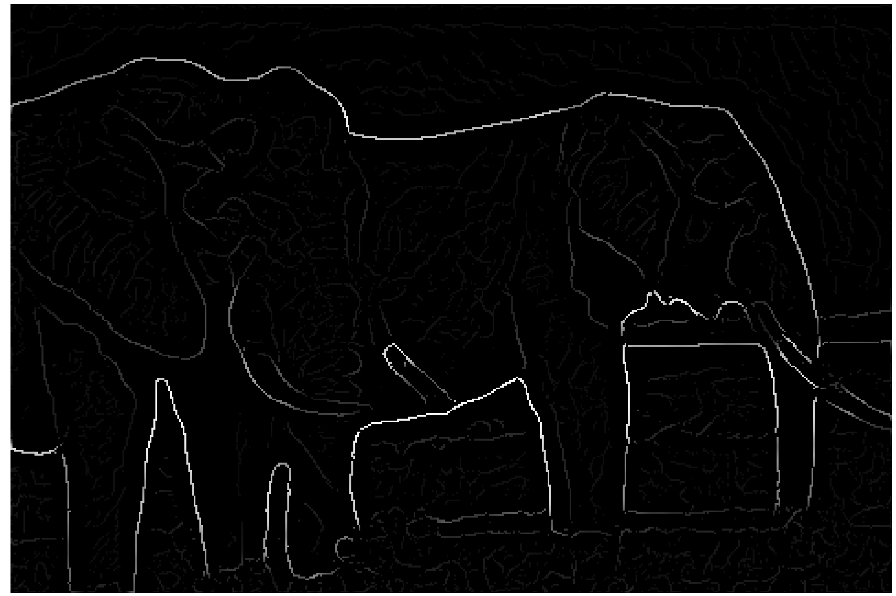
Boundaries of Objects from Edges



Brightness Gradient (Edge detection)

- Missing edge continuity, many spurious edges

Boundaries of Objects from Edges

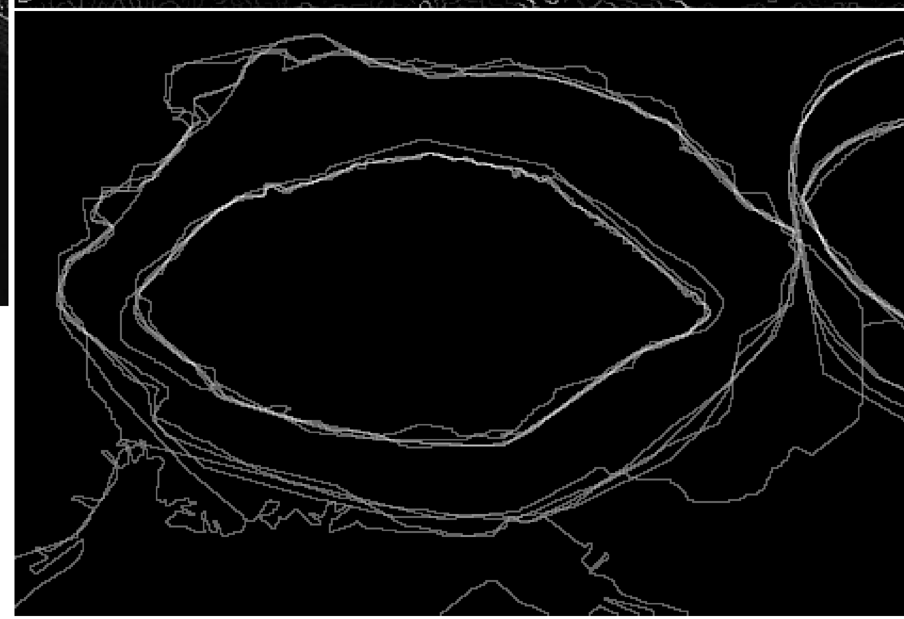


Multi-scale Brightness Gradient

- But, low strength edges may be very important

Machine Edge Detection

Image



Human Boundary Marking

Boundaries in Medical Imaging

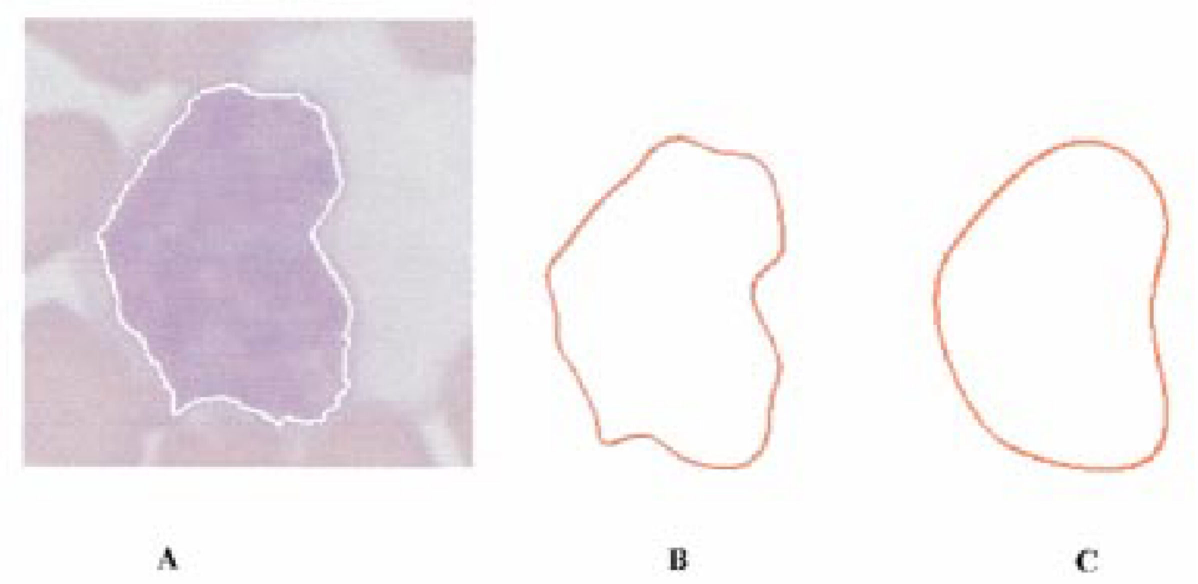
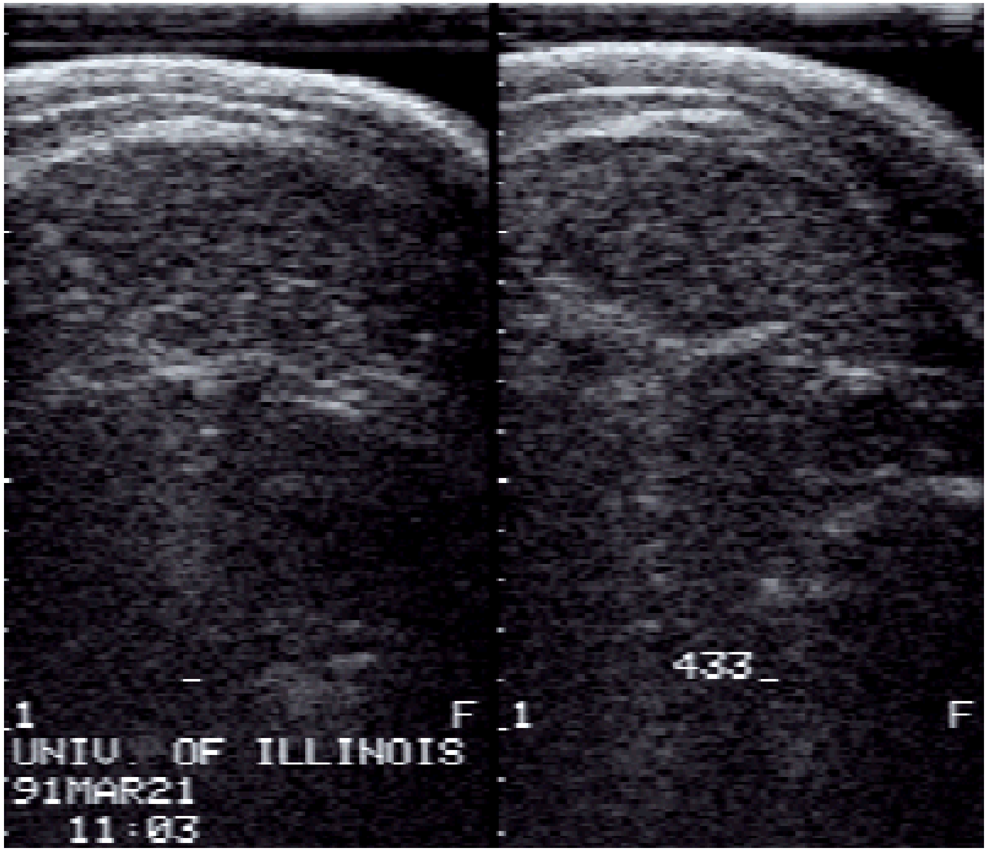


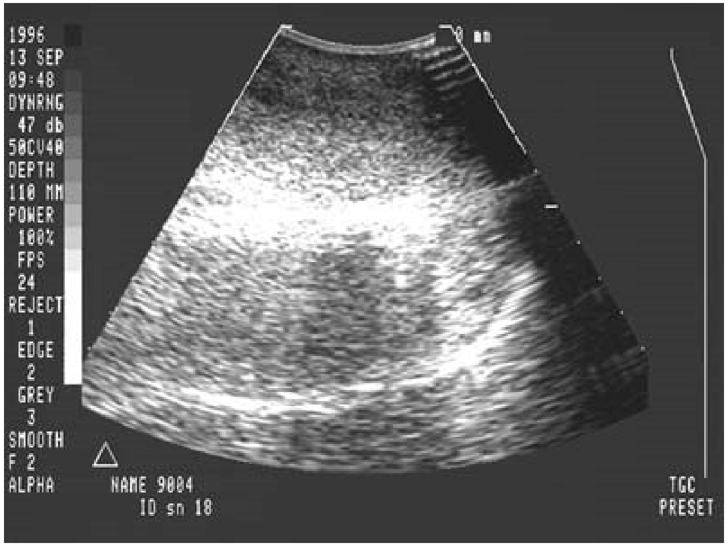
Fig. 2. Representation of a closed contour by elliptic Fourier descriptors. (a) Input. (b) Series truncated at 16 harmonics. (c) Series truncated to four harmonics.

Detection of cancerous regions.

[Foran, Comaniciu, Meer, Goodell, 00]

Boundaries in Ultrasound Images



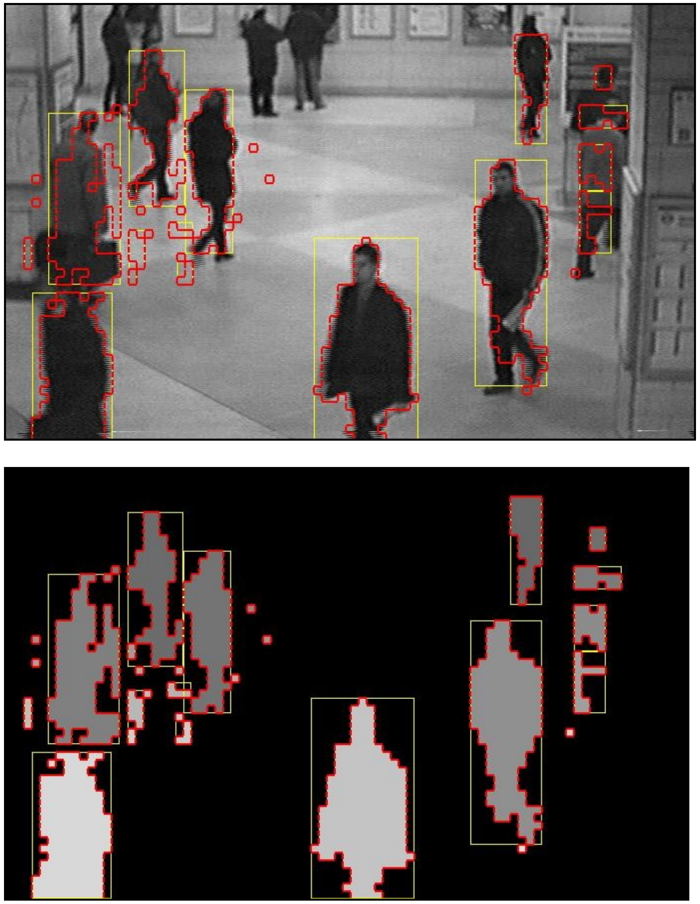


Hard to detect in the presence of large amount of speckle noise

Sometimes hard even for humans!

What is ‘Segmentation’?

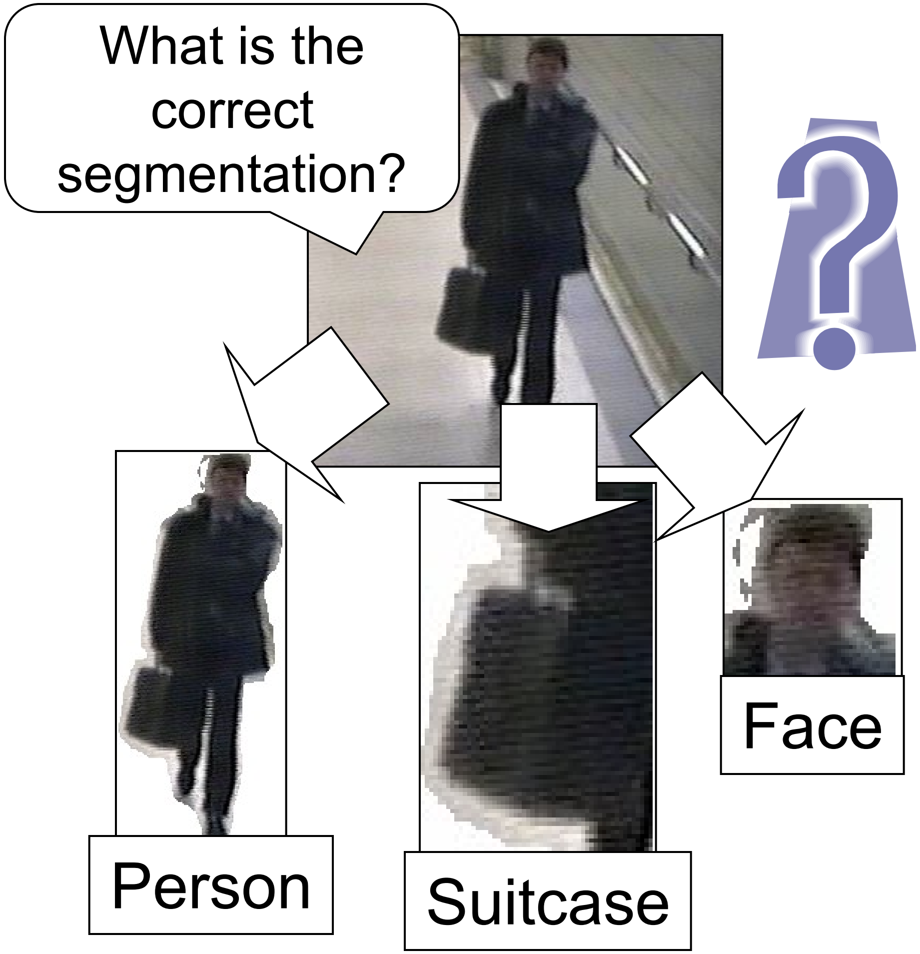
- Separation of the image in different areas.
  - Objects.
  - Areas with similar visual or semantic characteristics.



Not trivial! It is the holy grail of most computer vision problems!

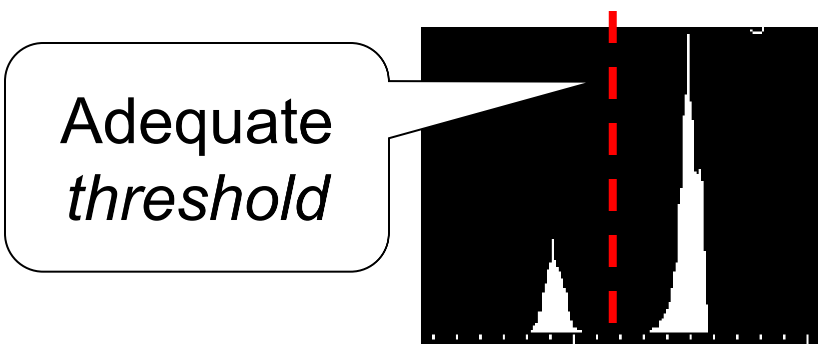
Subjectivity

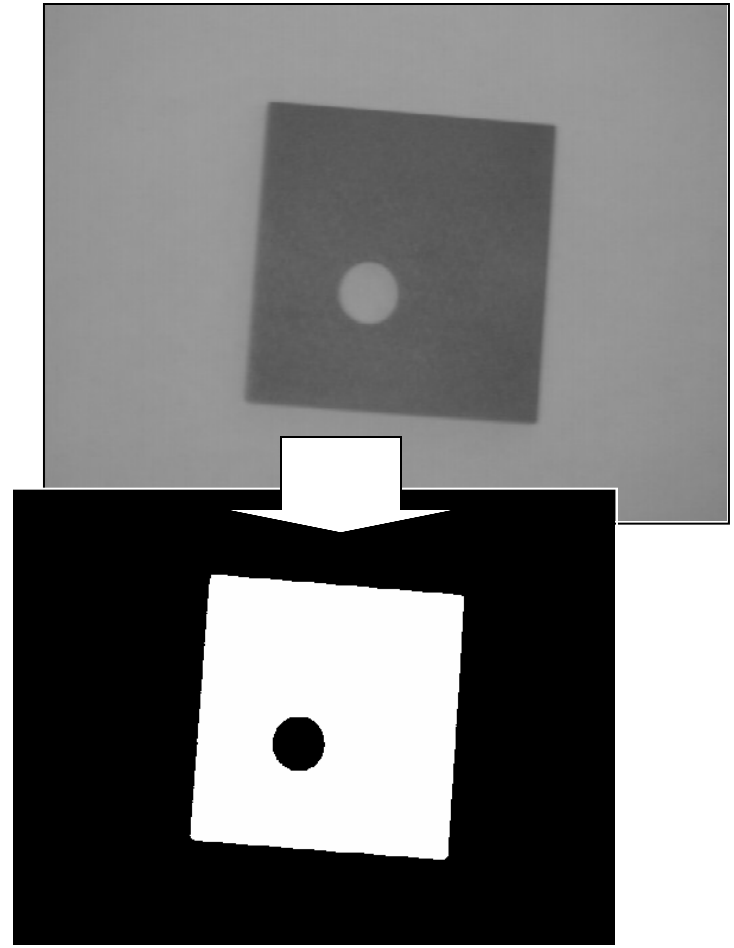
- A 'correct' segmentation result is only valid for a specific context.
  - Subjectivity!
  - Hard to implement.
  - Hard to evaluate.



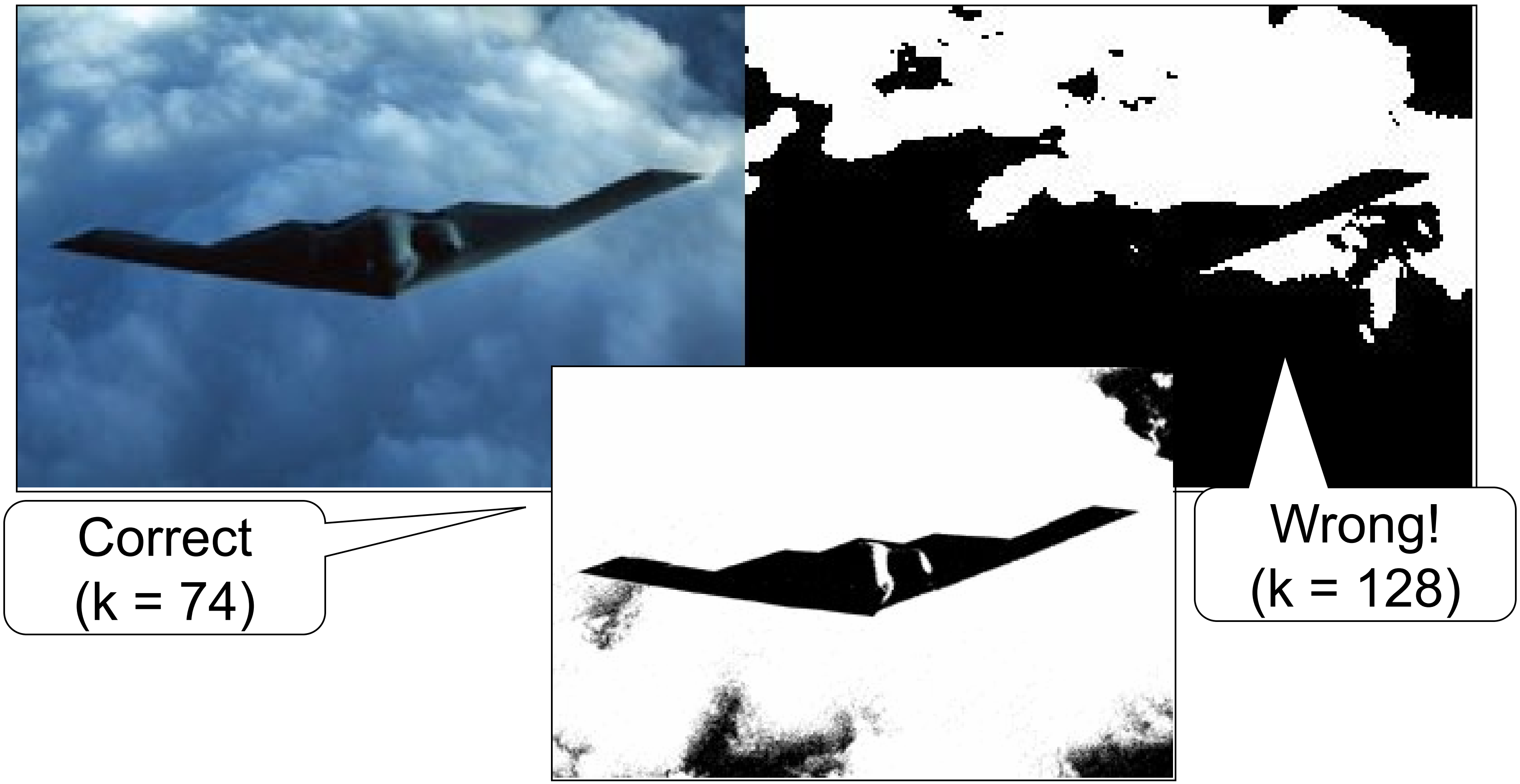
Core Technique: *Thresholding*

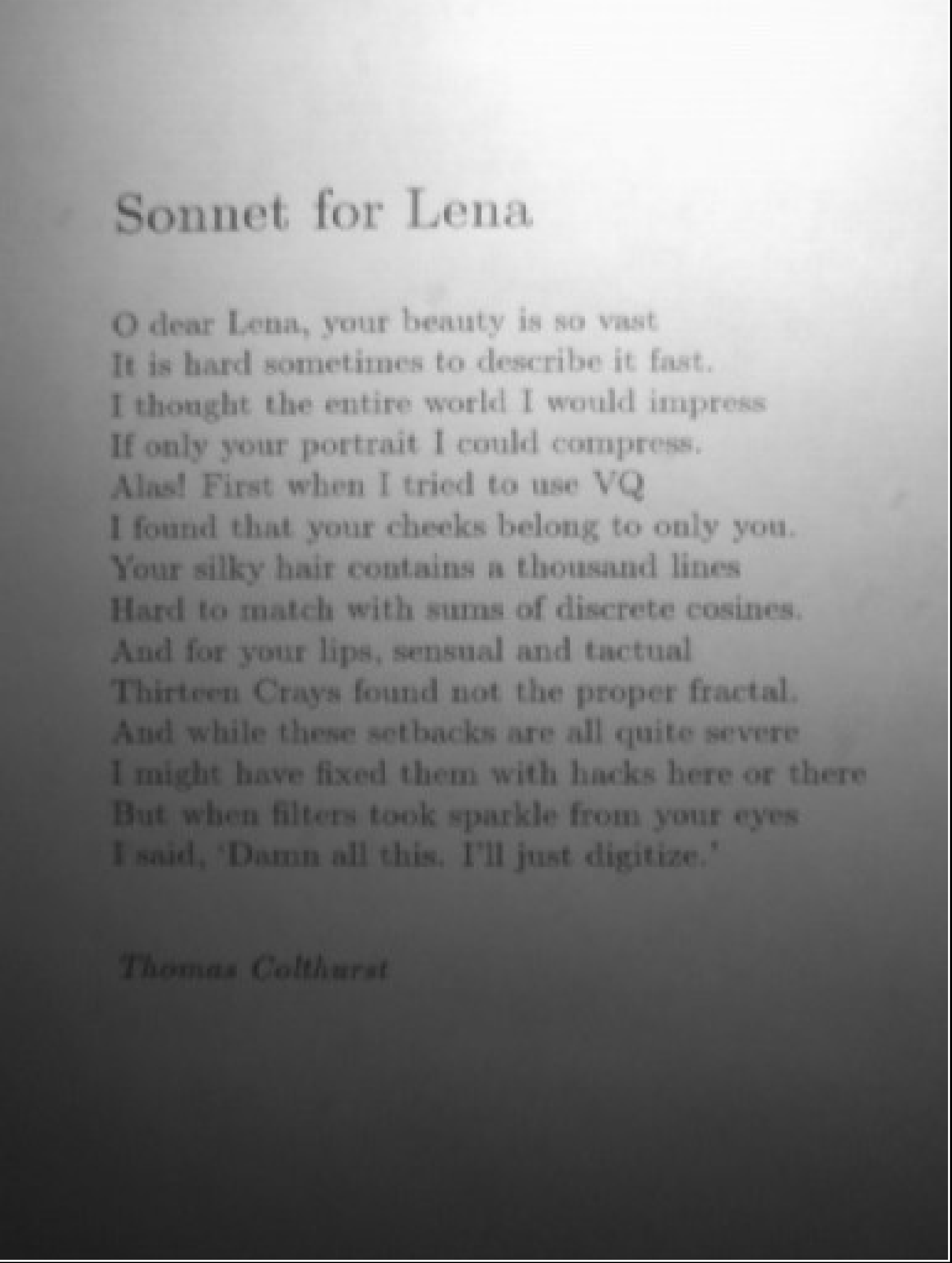
- Divide the image into two areas:
  - 1, if *f(x,y)>K*
  - 0, if *f(x,y)<=K*
- Not easy to find the ideal ***k*** *magic number.*
- Core segmentation technique
  - Simple
  - Reasonably effective

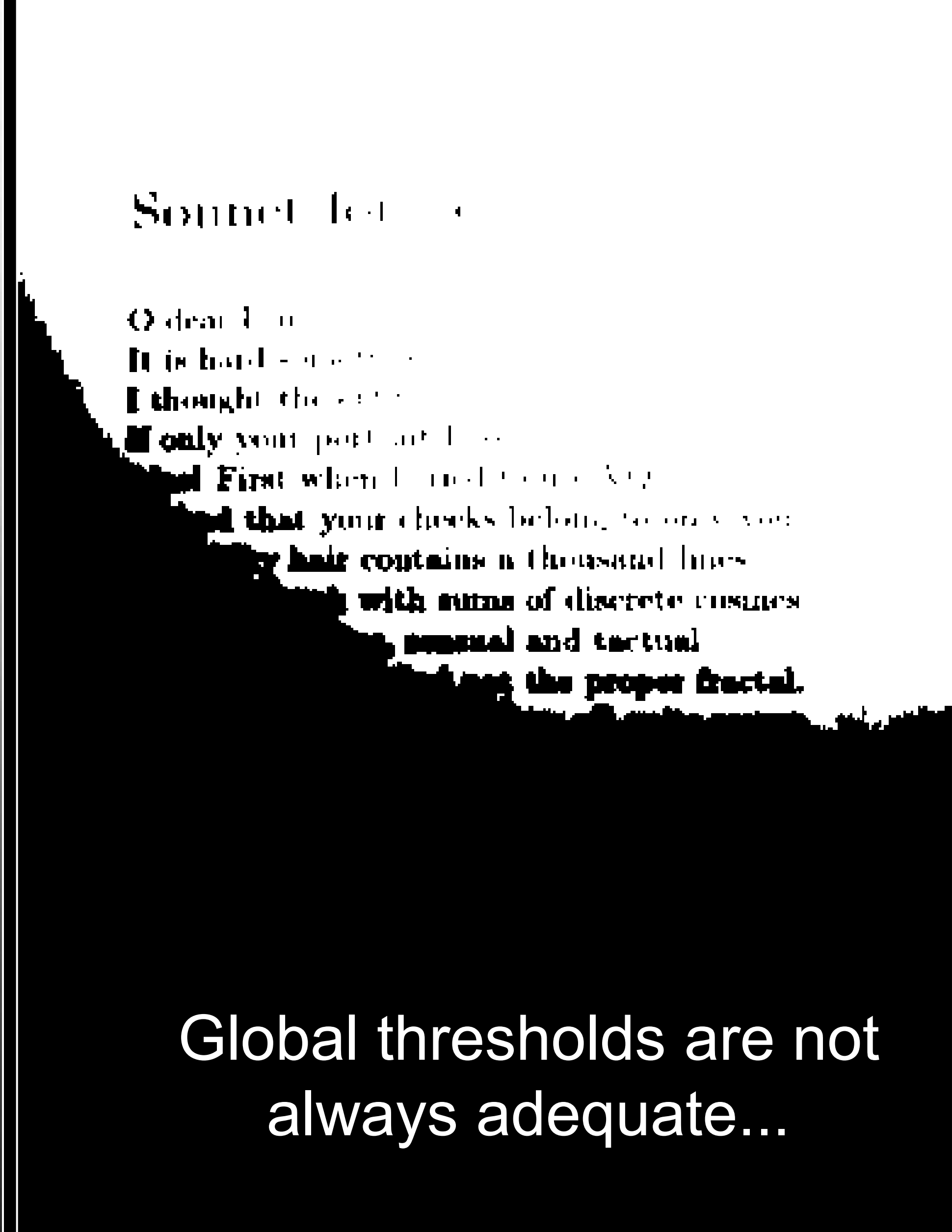




Finding the ‘magic number’





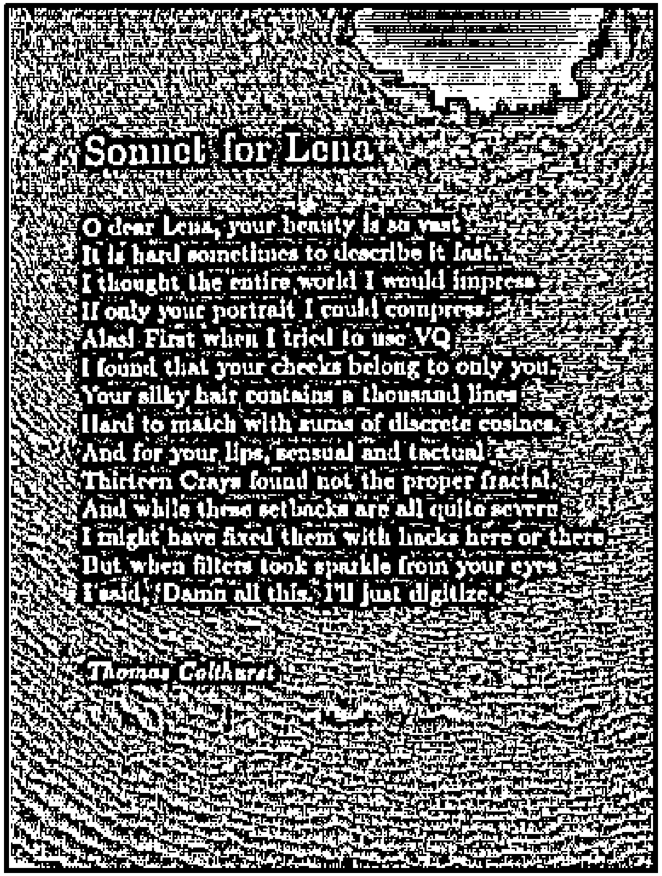


Global thresholds are not always adequate...

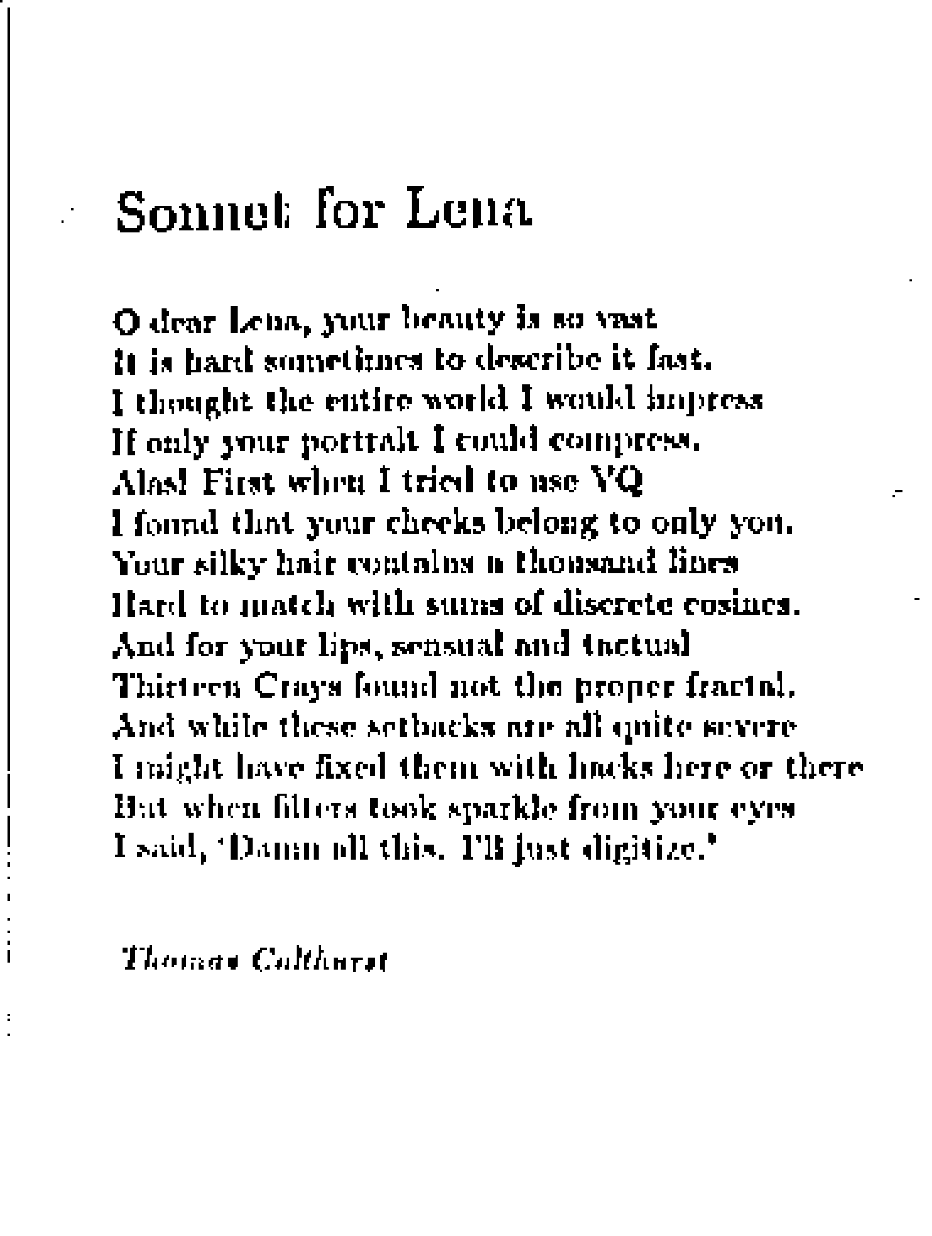
http://www.cee.hw.ac.uk/hipr/html/adpthrsh.html

Adaptive Thresholding

- Adapt the threshold value for each pixel.
- Use characteristics of nearby pixels.
- How?
  - Mean
  - Median
  - Mean + K
  - ...



Mean of 7x7 neighborhood

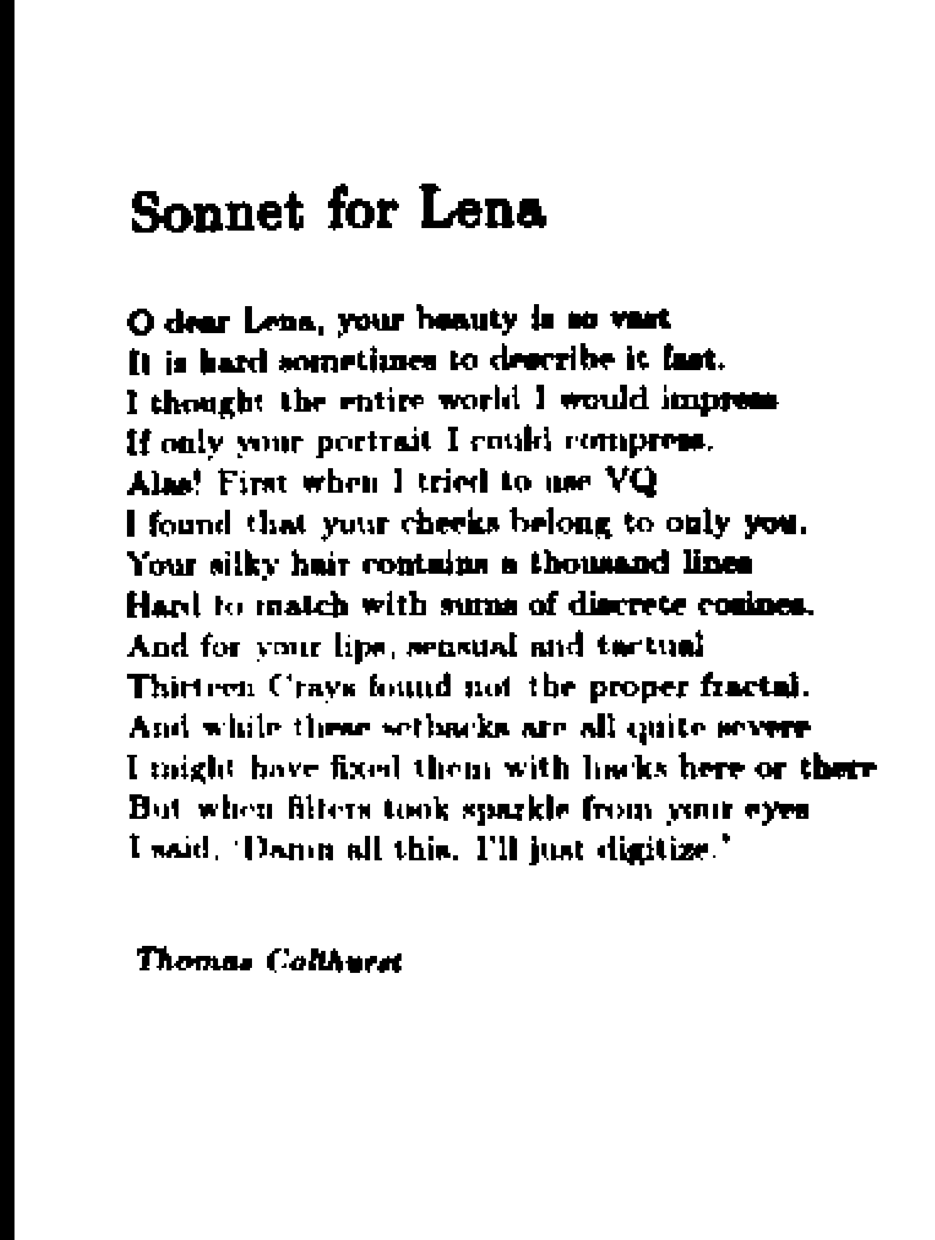


Sonnet for Lena

O dear Lena, your beauty is so vast
It is hard sometimes to describe it fast.
I thought the entire world I would impress
If only your portrait I could compress.
Alas! First when I tried to use VQ
I found that your cheeks belong to only you.
Your silky hair contains a thousand lines
Hard to match with sums of discrete cosines.
And for your lips, sensual and tactual
Thirteen Crays found not the proper fractal.
And while these setbacks are all quite severe
I might have fixed them with hacks here or there
But when filters took sparkle from your eyes
I said, 'Damn all this. I'll just digitize.'

Thomas Colthurst

7x7 window; K = 7



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Thomas Colthurst

75x75 window; K = 10

Topic: Region-based Segmentation

- Thresholding
- Region-based Segmentation
- Morphological Filters

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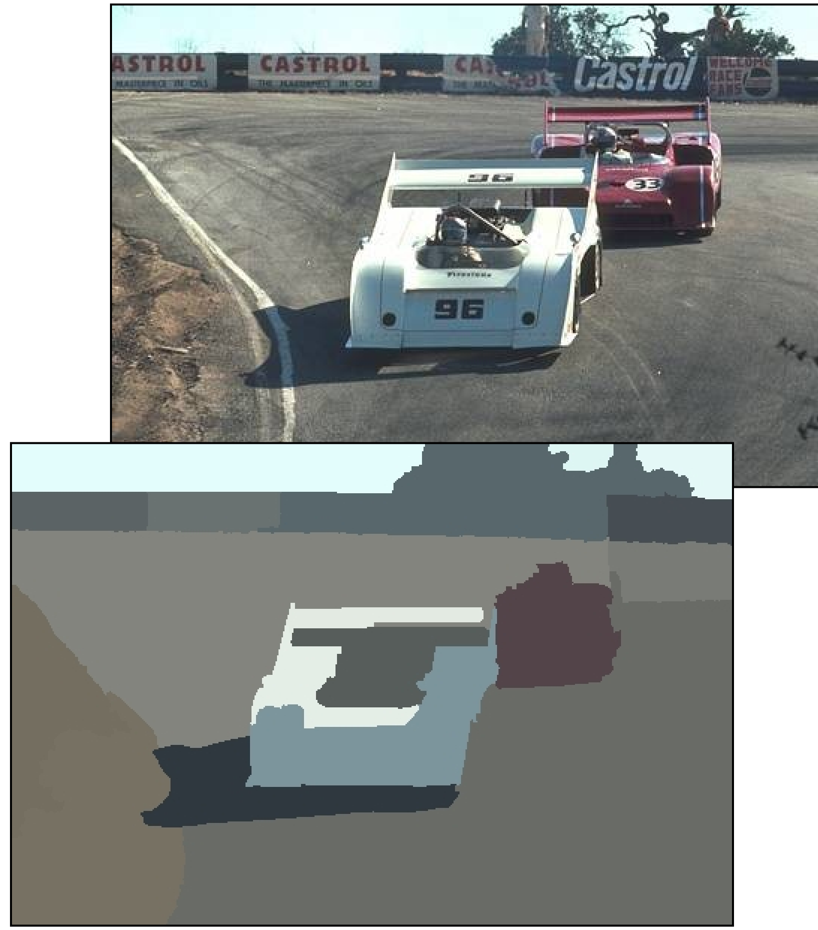
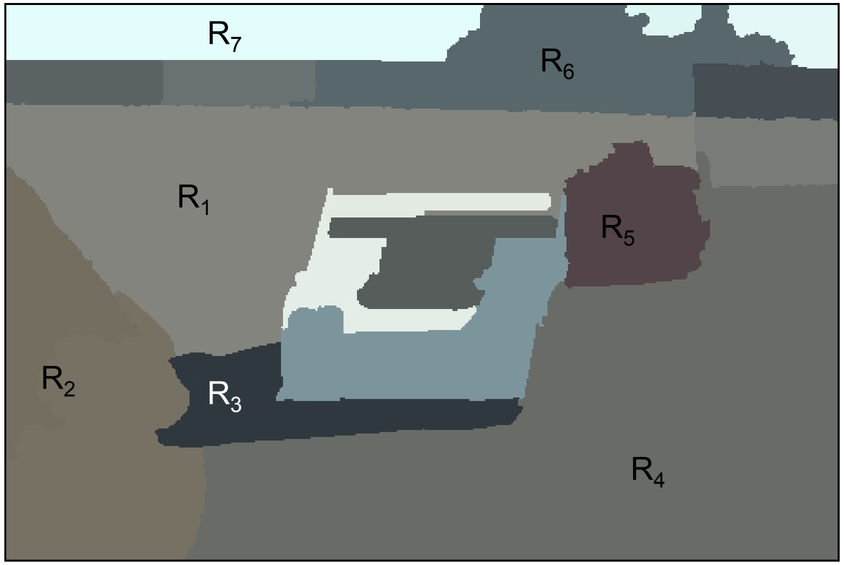
Why Region-Based Segmentation?

- Segmentation
  - Edge detection and Thresholding not always effective.
- Homogenous regions
  - *Region-based segmentation.*
  - Effective in noisy images.



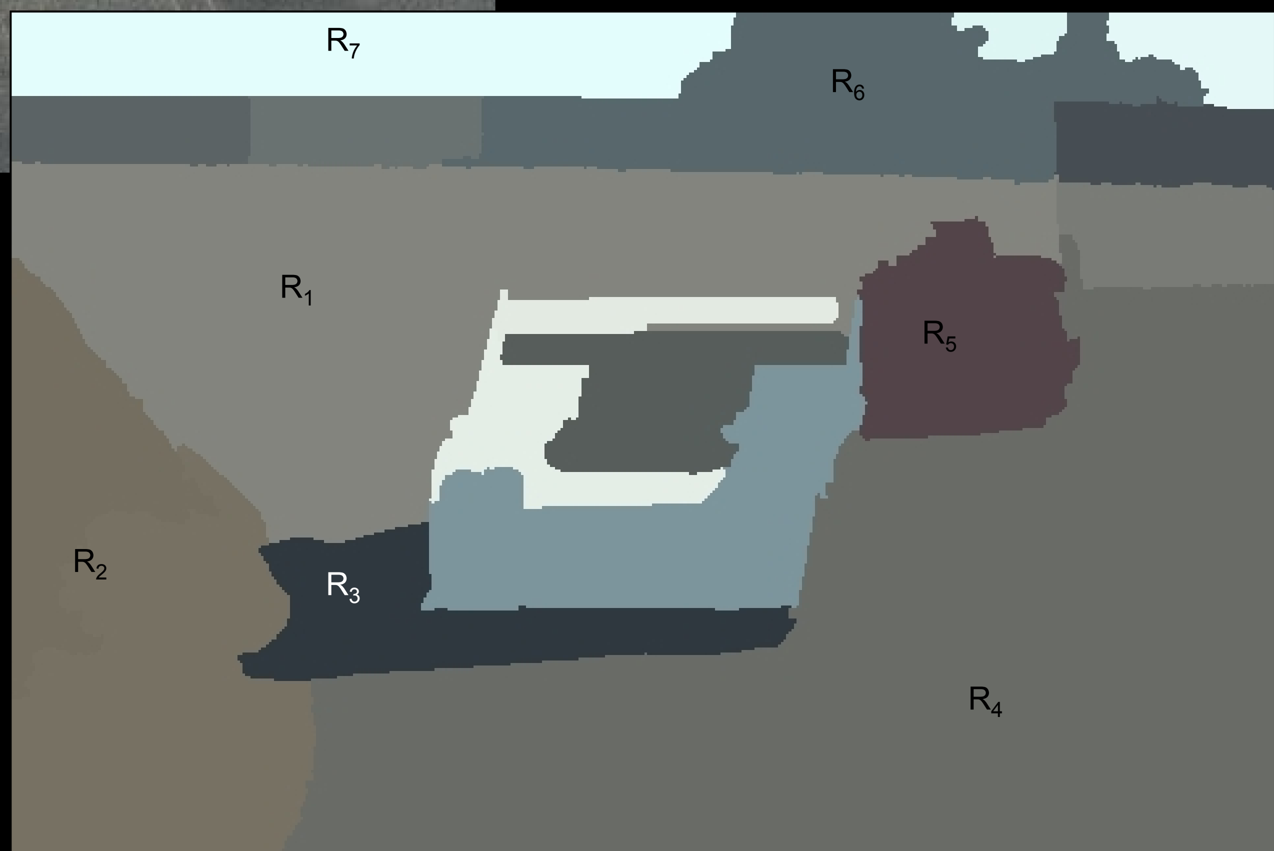
Definitions

- Based on *sets*.
- Each image R is a set of regions R_i.
  - Every pixel belongs to one region.
  - One pixel can only belong to a single region.



$$R = \bigcup_{i=1}^{S} R_i \qquad R_i \bigcap R_j \neq 0$$


CASTROL
CASTROL
Castrol
96
96
33


R_7
R_6
R_1
R_5
R_2
R_3
R_4

Basic Formulation

Let R represent the entire image region. Segmentation partitions R into n subregions, R_1, R_2, ..., R_n, such that:

a) $\bigcup_{i=1}^{n} R_i = R$

b) R_i is a connected region, $i = 1, 2, \ldots, n$.

c) $R_i \cap R_j = \phi$ for all i and $j, i \neq j$

d) $P(R_i) = TRUE$ for $i = 1,2,\ldots,n$.

e) $P(R_i \cup R_j) = FALSE$ for $i \neq j$.

a) Every pixel must be in a region

b) Points in a region must be connected.

c) Regions must be disjoint.

d) All pixels in a region satisfy specific properties.

e) Different regions have different properties.

How do we form regions?

- Region Growing
- Region Merging
- Region Splitting
- Split and Merge
- Watershed
- ...

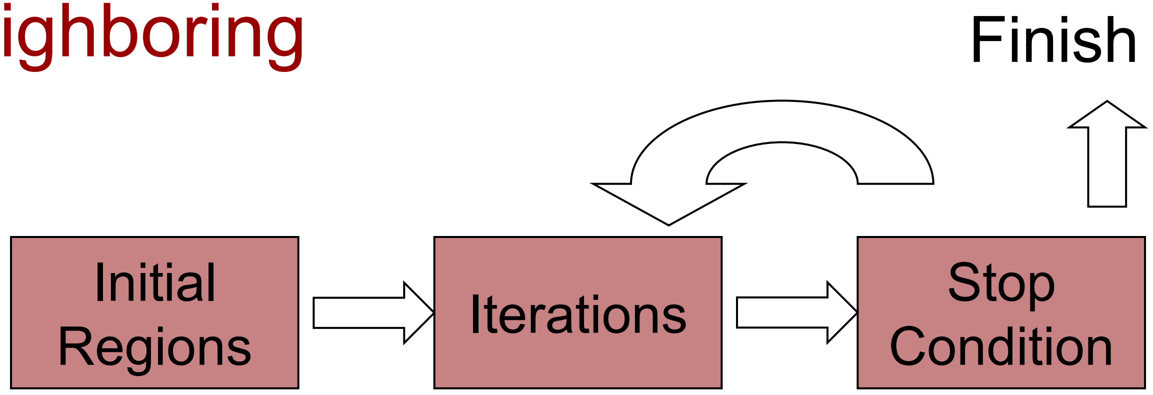
0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

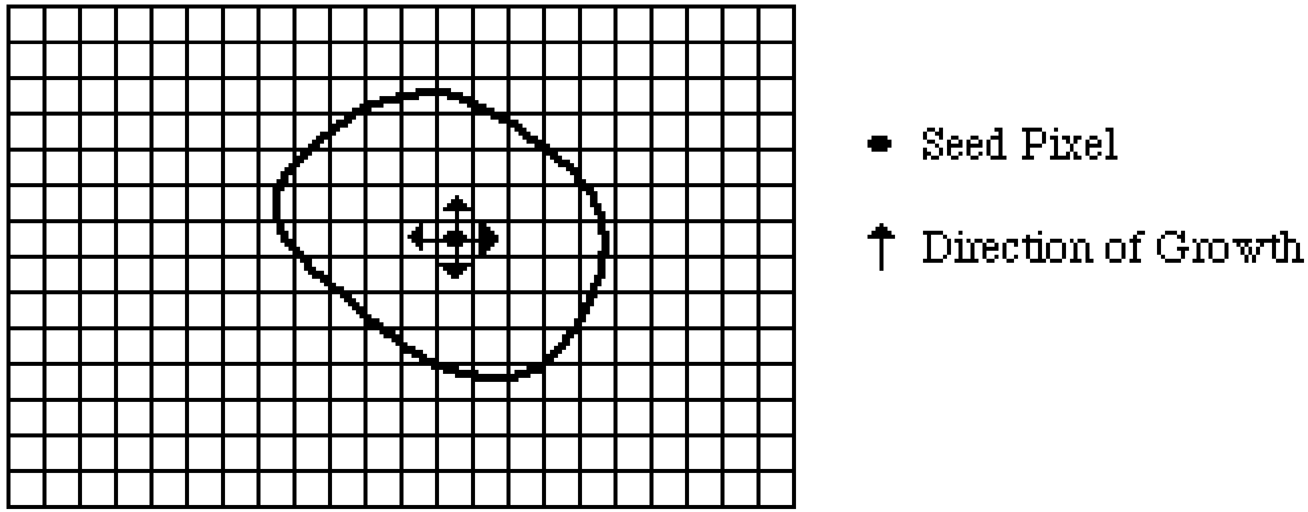
What a computer sees

Region growing

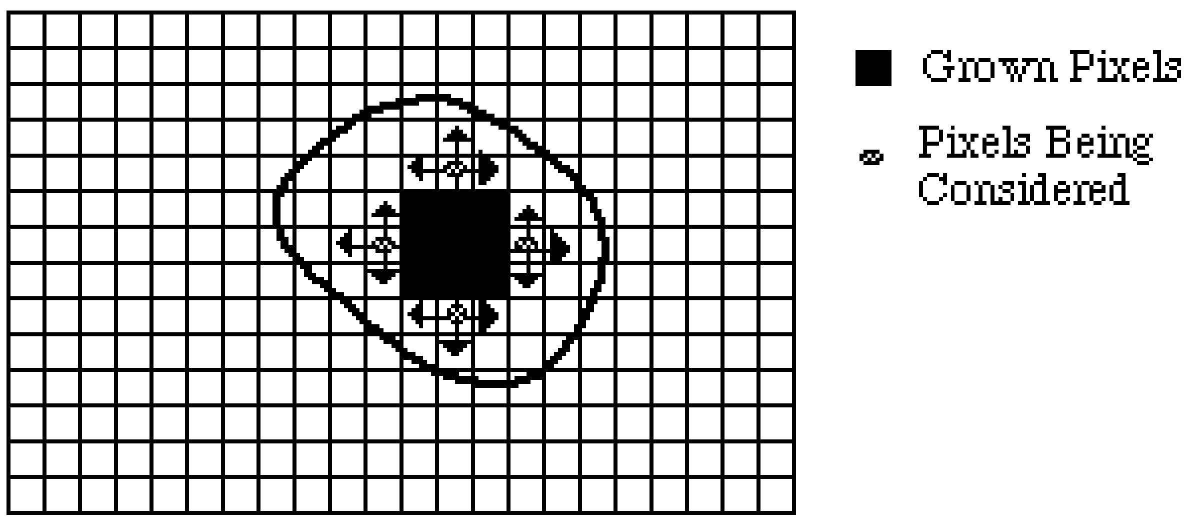
- Groups pixels into larger regions.
- Starts with a **seed** point.
- **Grows** region by **merging** neighboring pixels.

- Iterative process
  - How to start?
  - How to iterate?
  - When to stop?





(a) Start of Growing a Region



(b) Growing Process After a Few Iterations

Region merging

- Algorithm
  - Divide image into an initial set of regions.
    - One region per pixel.
  - Define a **similarity criteria** for merging regions.
  - **Merge** similar regions.
  - Repeat previous step until no more merge operations are possible.

Similarity Criteria

- Homogeneity of regions is used as the main segmentation criterion in region growing.
  - gray level
  - color, texture
  - shape
  - model
  - etc.

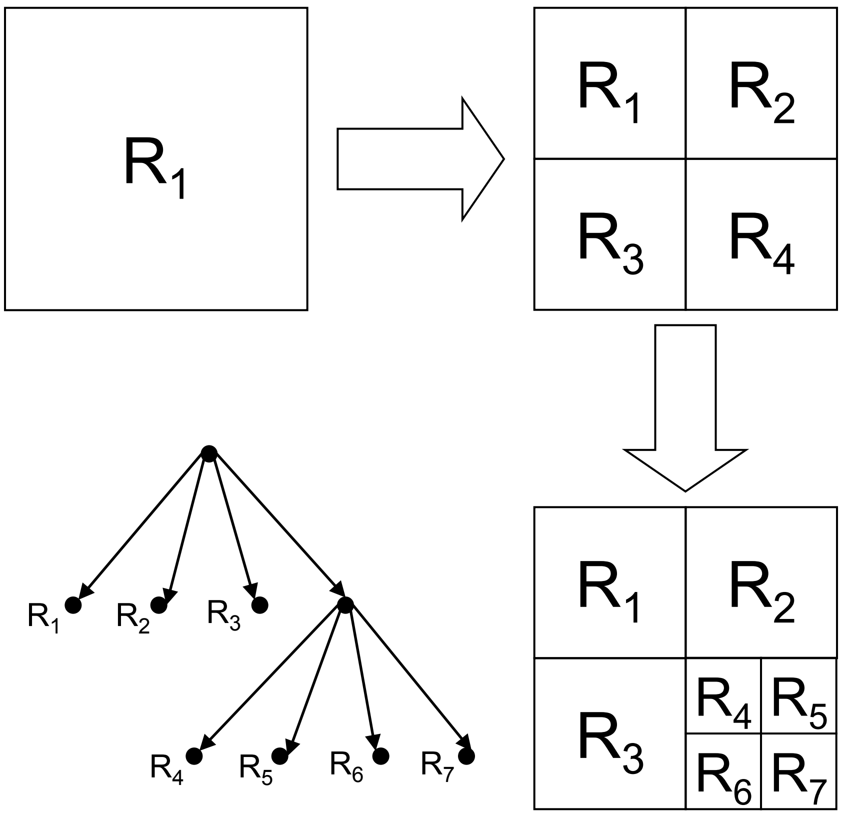
> Choice of criteria affects segmentation results dramatically!

Gray-Level Criteria

- Comparing to Original Seed Pixel
  - Very sensitive to choice of **seed point**.
- Comparing to Neighbor in Region
  - Allows gradual changes in the region.
  - Can cause significant drift.
- Comparing to Region Statistics
  - Acts as a **drift dampener**.
- Other possibilities!

Region splitting

- Algorithm
  - One initial set that includes the **whole image**.
  - **Similarity criteria**.
  - Iteratively **split** regions into sub-regions.
  - Stop when no more splittings are possible.



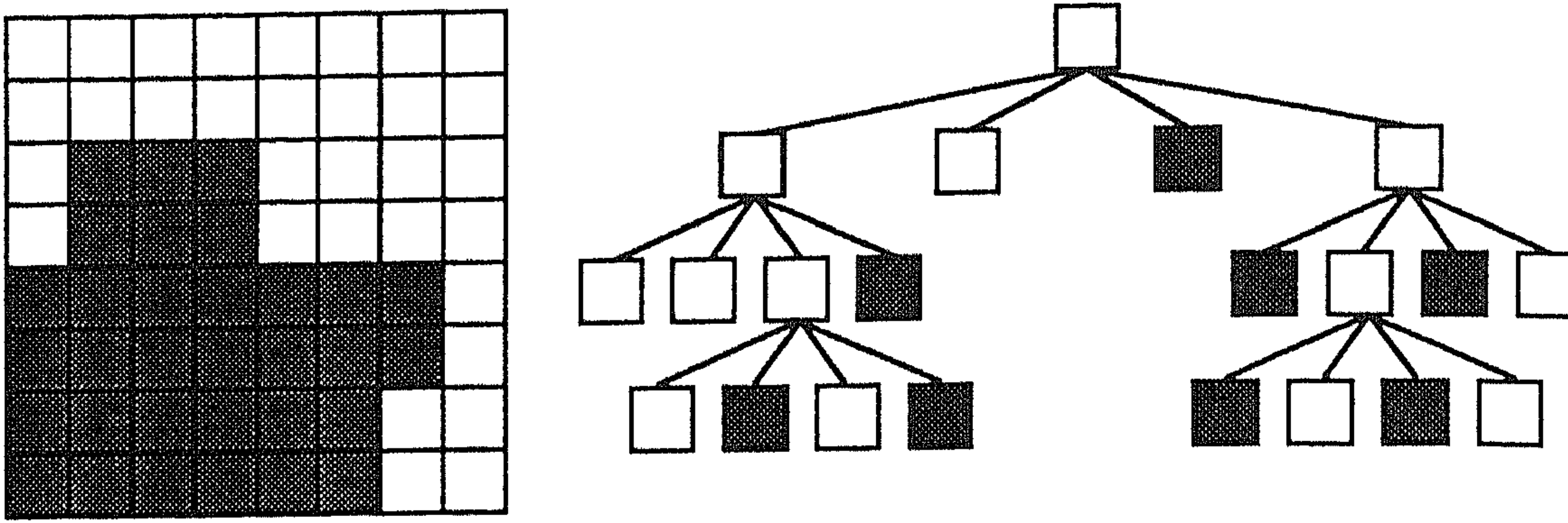
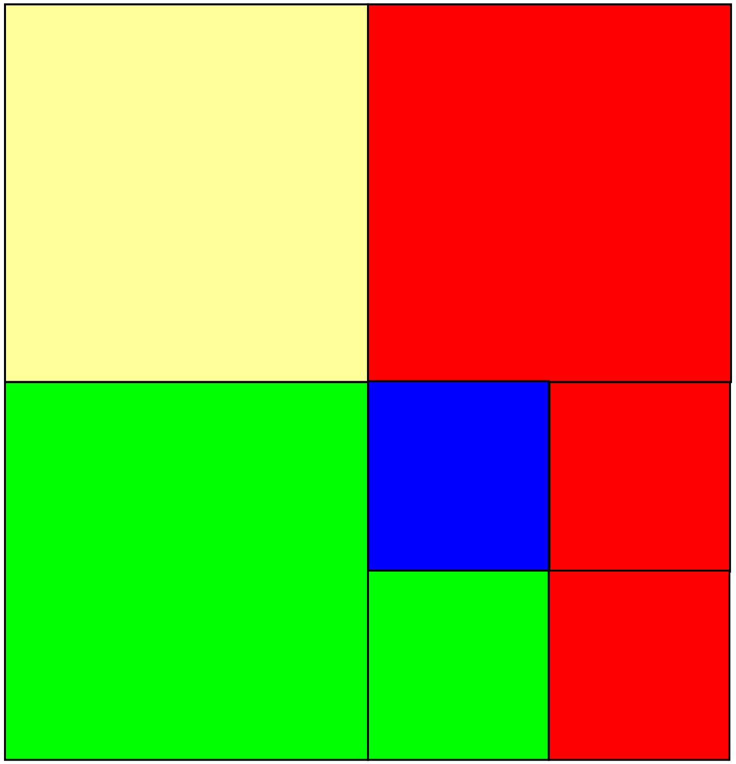


Figure 5.23 A quad-tree representation of an 8×8 binary image.

[Machine Vision; David Vernon]

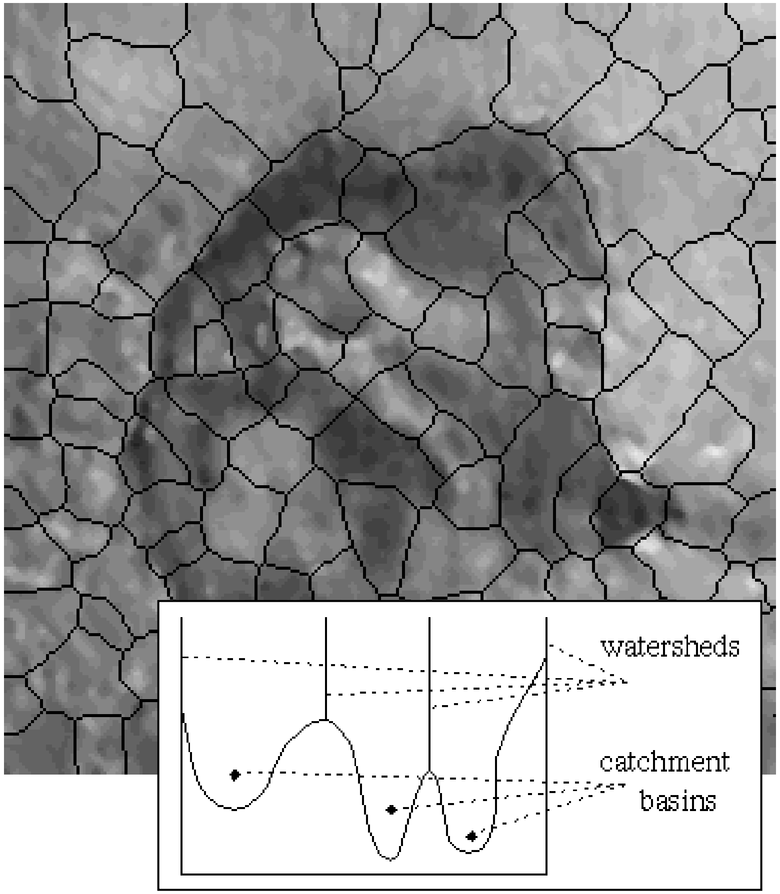
Split and Merge

- Combination of both algorithms.
- Can handle a larger variety of shapes.
  - Simply apply previous algorithms consecutively.



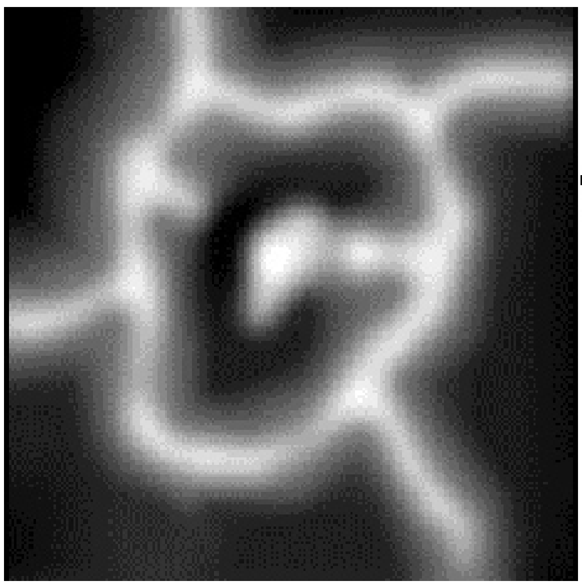
The *Watershed* Transform

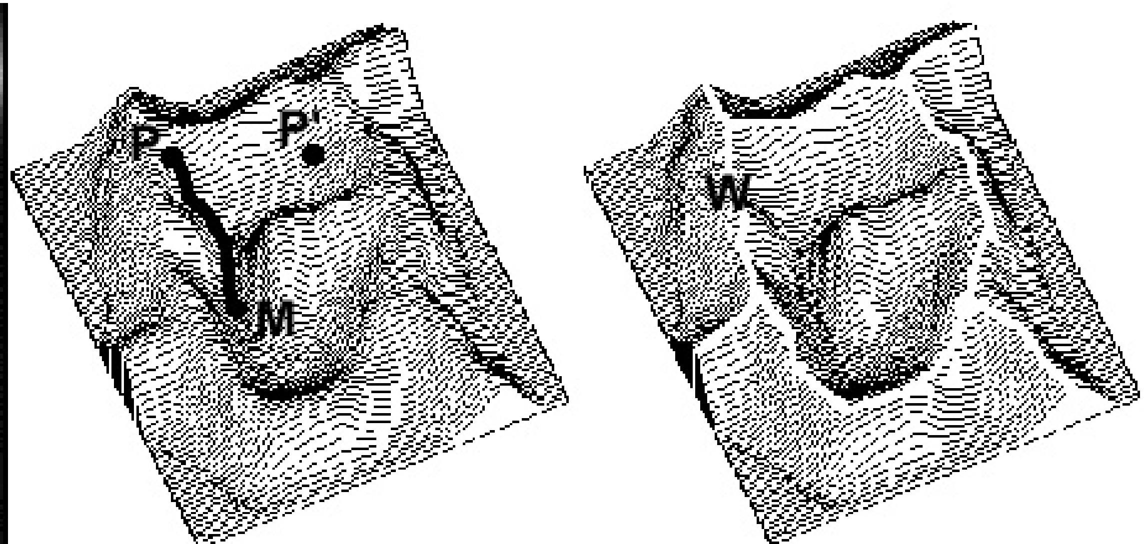
- Geographical inspiration.
  - Shed water over rugged terrain.
  - Each lake corresponds to a region.
- Characteristics
  - Computationally complex.
  - Great flexibility in segmentation.
  - Risk of over-segmentation.



The Drainage Analogy

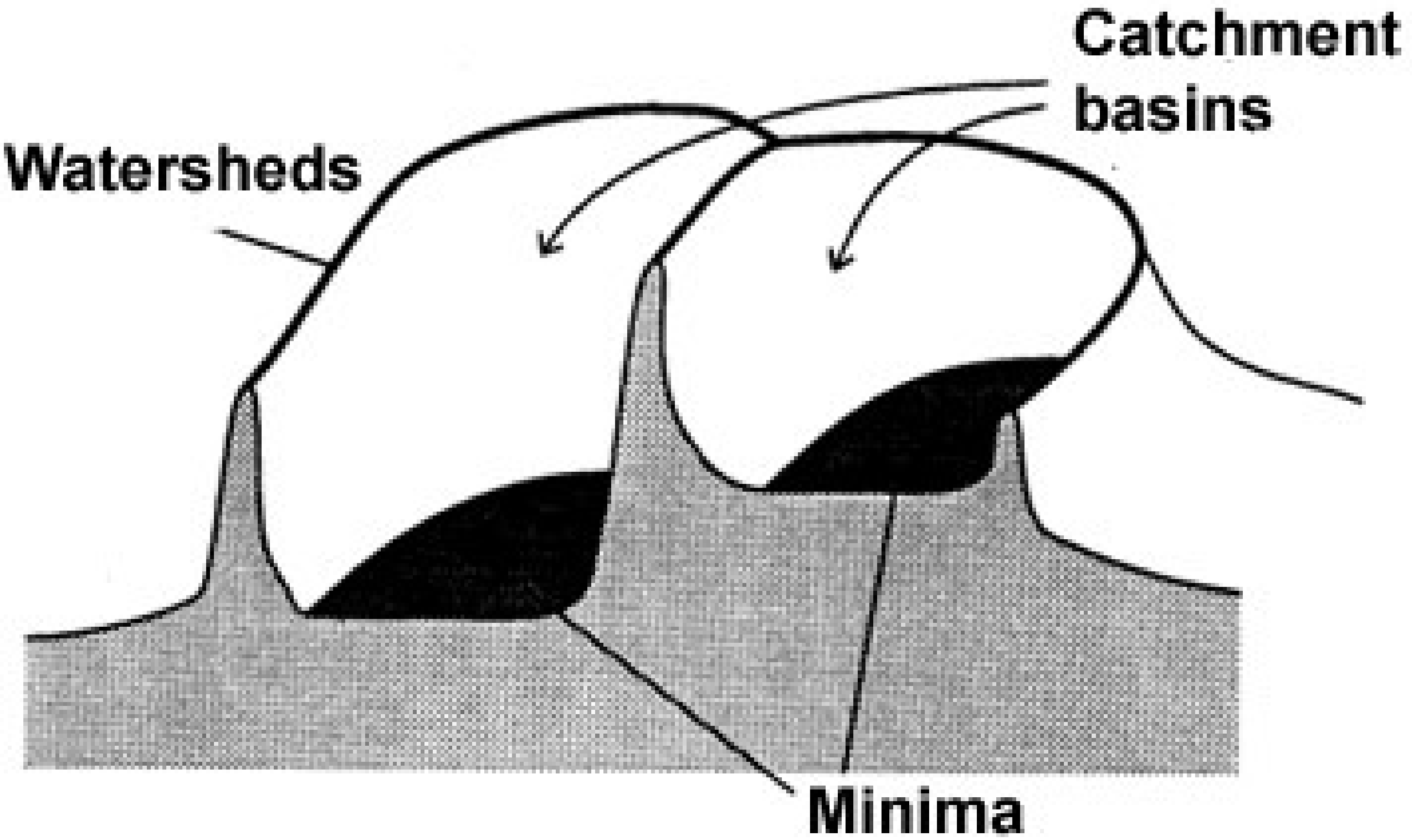
- Two points are in the same region if they drain to the same point.

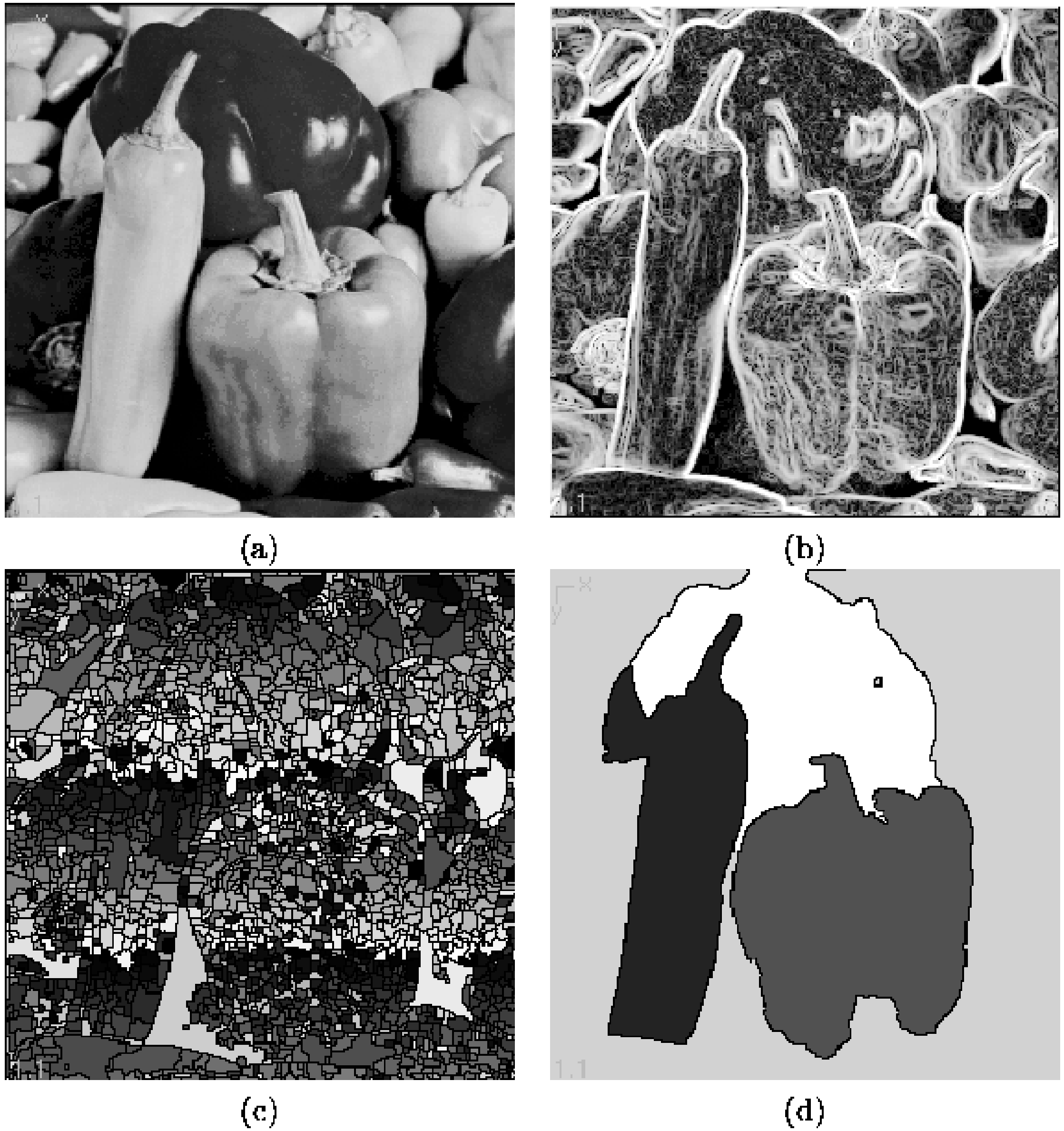




Courtesy of Dr. Peter Yim at National Institutes of Health, Bethesda, MD

The Immersion Analogy





[Milan Sonka, Vaclav Hlavac, and Roger Boyle]

Figure 5.51: *Watershed segmentation: (a) original; (b) gradient image, 3×3 Sobel edge detection, histogram equalized; (c) raw watershed segmentation; (d) watershed segmentation using region markers to control oversegmentation. Courtesy W. Higgins, Penn State University.*

Over-Segmentation

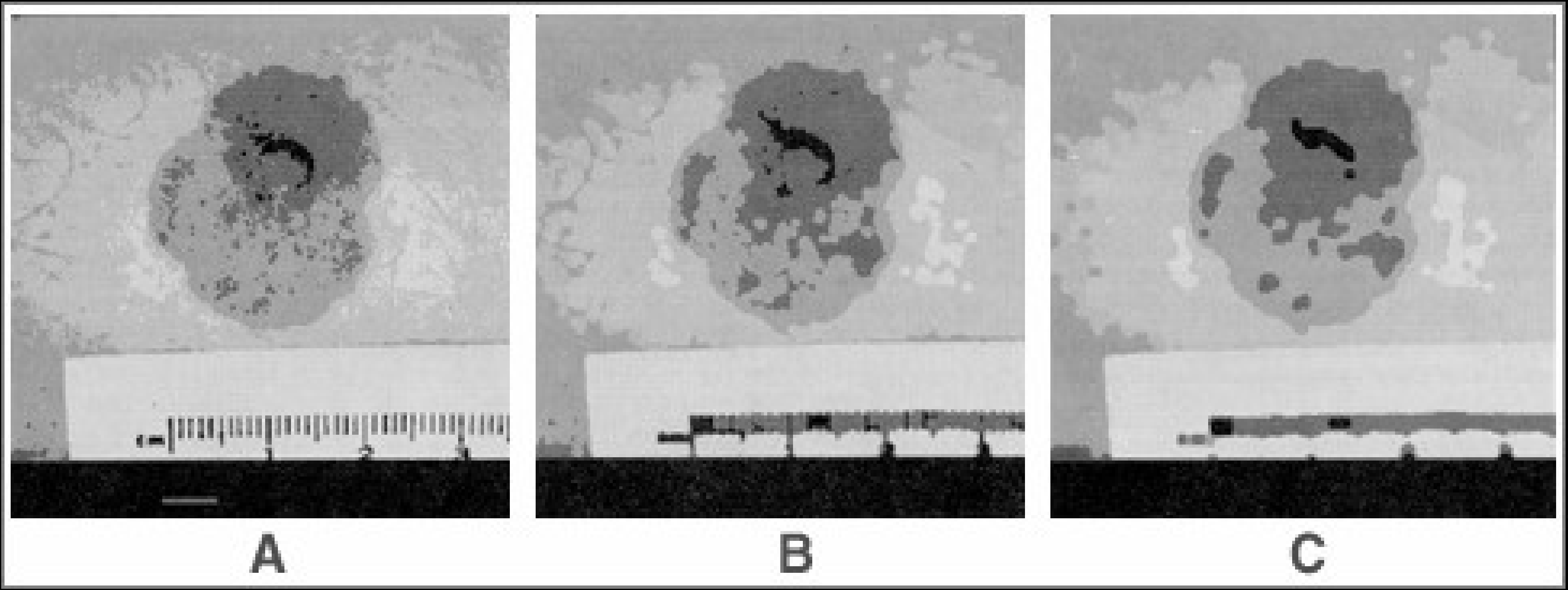
- Over-segmentation.
  - Raw watershed segmentation produces a severely oversegmented image with hundreds or thousands of catchment basins.
- Post-Processing.
  - Region merging.
  - Edge information.
  - Etc.

Topic: Morphological Filters

- Thresholding
- Region-based Segmentation
- Morphological Filters

Mathematical Morphology

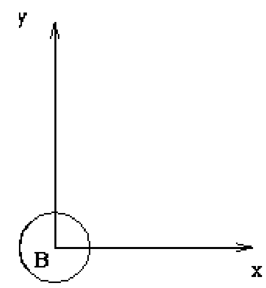
- Provides a mathematical description of geometric structures.
- Based on *sets*.
  - Groups of pixels which define an image region.
- What is this used for?
  - Binary images.
  - Can be used for **post-processing** segmentation results!
- Core techniques
  - Erosion, Dilation.
  - Open, Close.

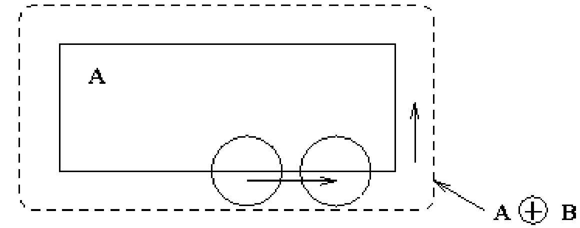


Tumor Segmentation using Morphologic Filtering

Dilation, Erosion

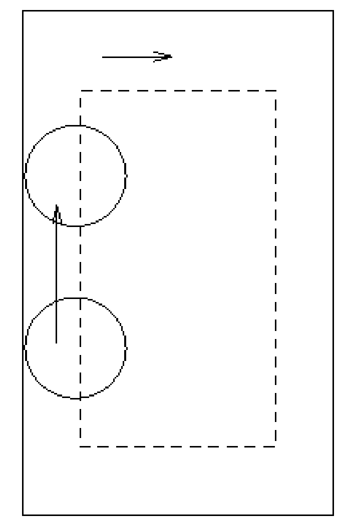
- Two sets:
  - Image
  - Morphological ***kernel.***
- Dilation (D)
  - Union of the **kernel** with the **image** set.
  - Increases resulting area.
- Erosion (E)
  - Intersection.
  - Decreases resulting area.





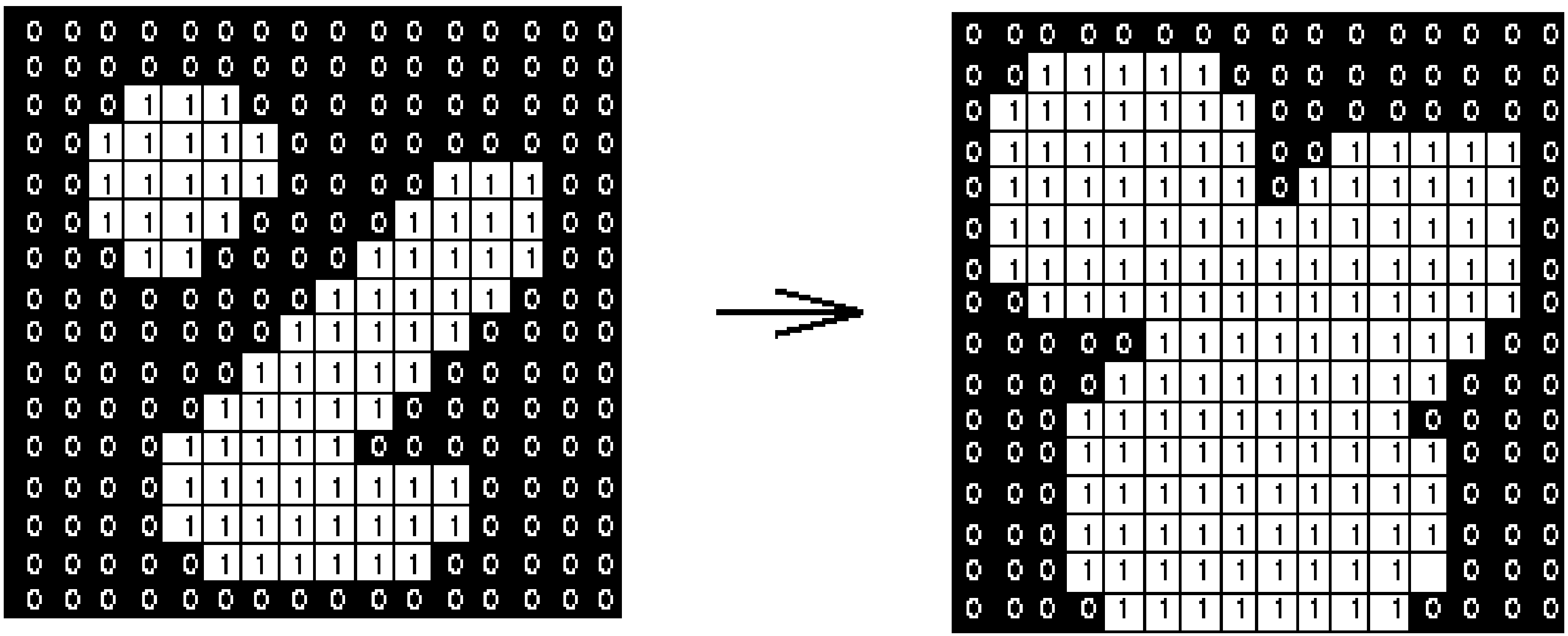
$$D(A,B) = A \oplus B = \bigcup_{\beta \in B} (A + \beta)$$

$$E(A,B) = A \ominus (-B) = \bigcap_{\beta \in B} (A - \beta)$$



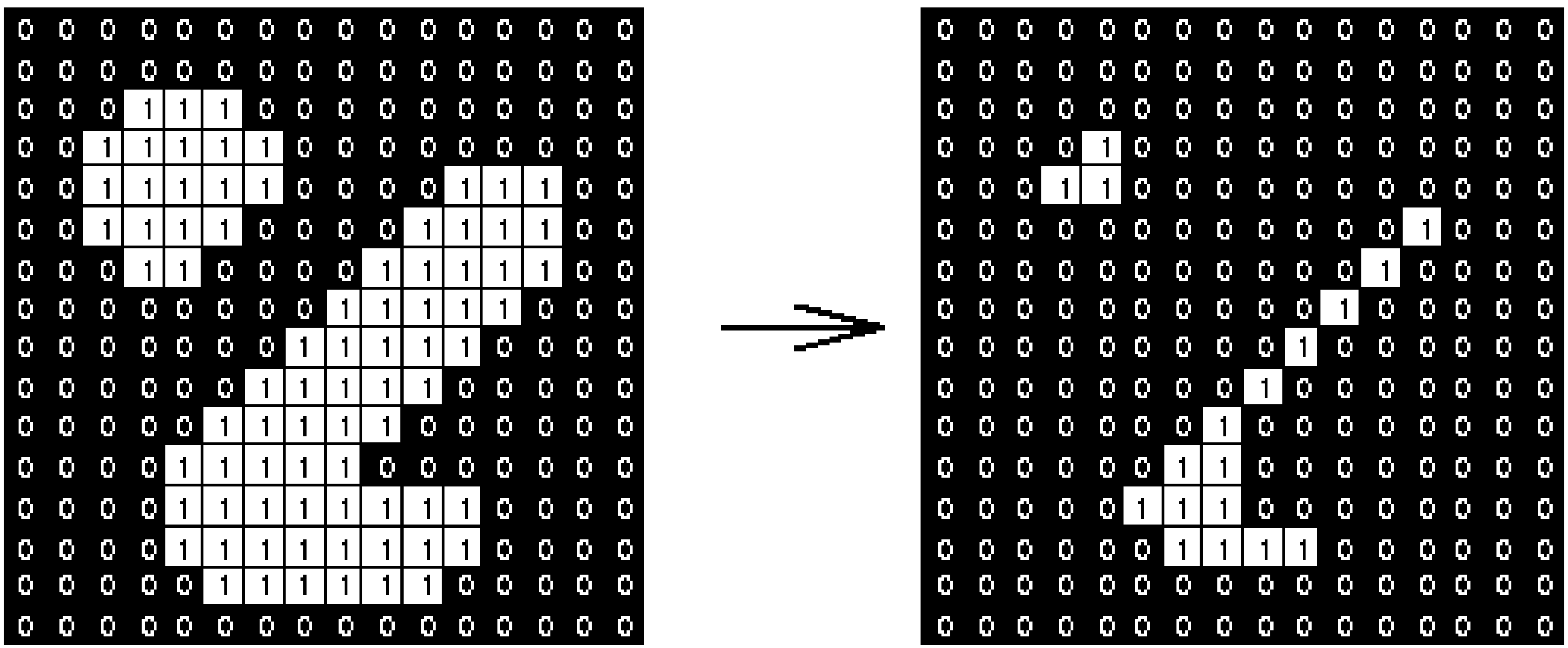
Dilation

- Example using a 3x3 morphological kernel



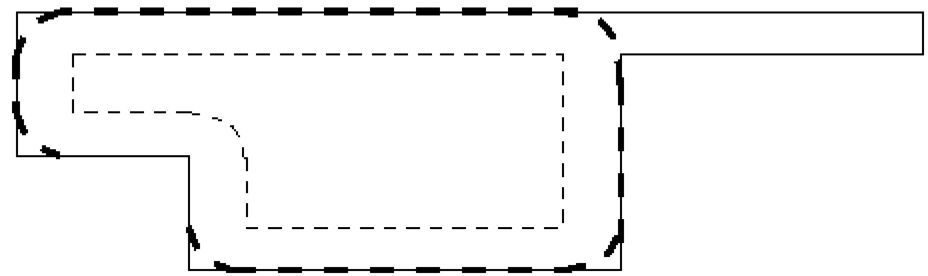
Erosion

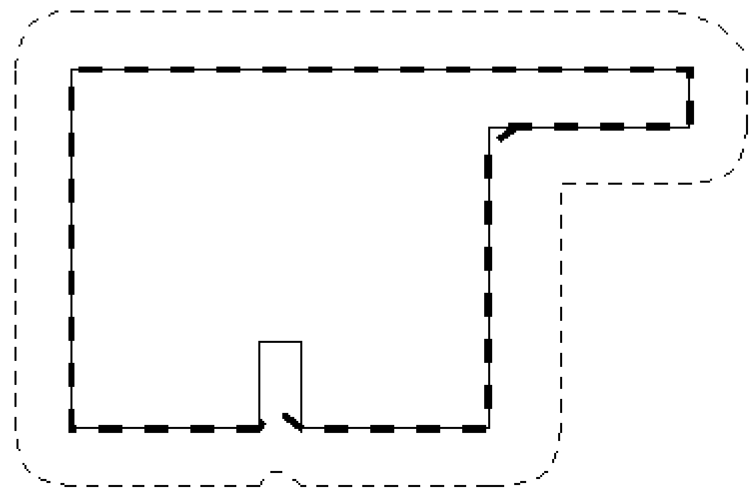
- Example using a 3x3 morphological kernel



Opening, Closing

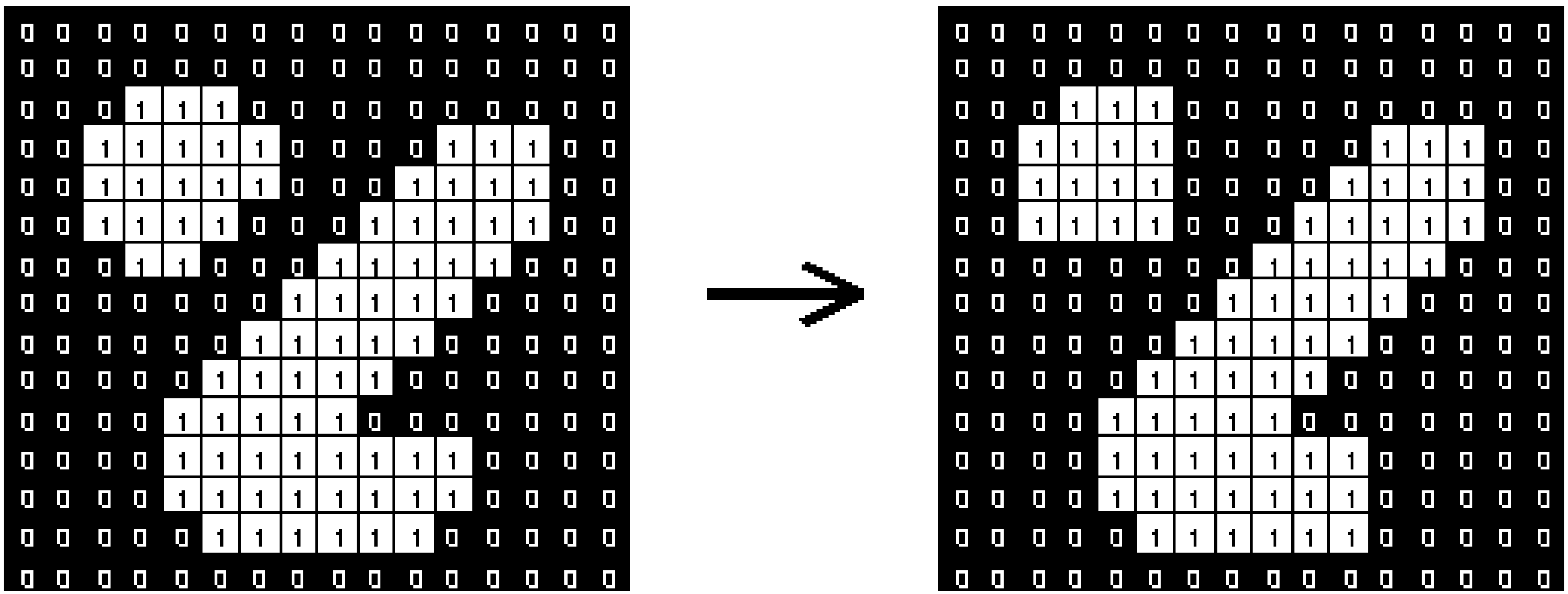
- Opening
  - **Erosion**, followed by **dilation**.
  - Less destructive than an erosion.
  - **Adapts** image shape to kernel shape.
- Closing
  - **Dilation**, followed by **erosion**.
  - Less destructive than a dilation.
  - Tends to **close** shape irregularities.





Opening

- Example using a 3x3 morphological kernel



Closing

- Example using a 3x3 morphological kernel

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

→

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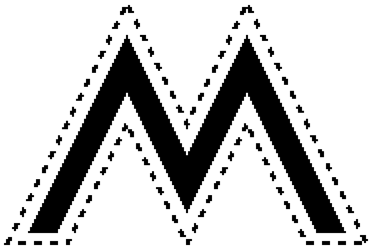
0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0
0	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
0	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0
0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Core morphological operators

Dilation

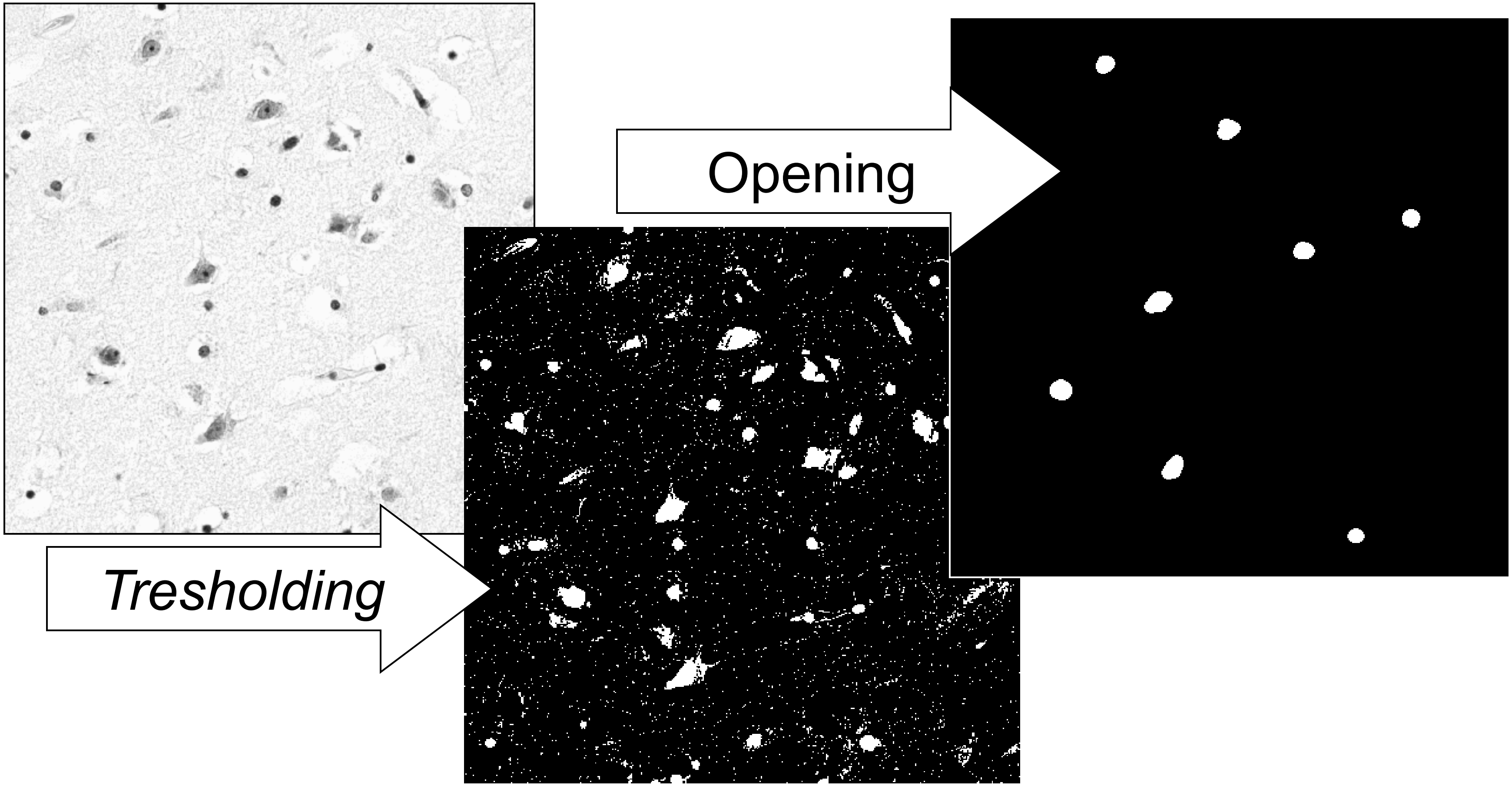


Erosion

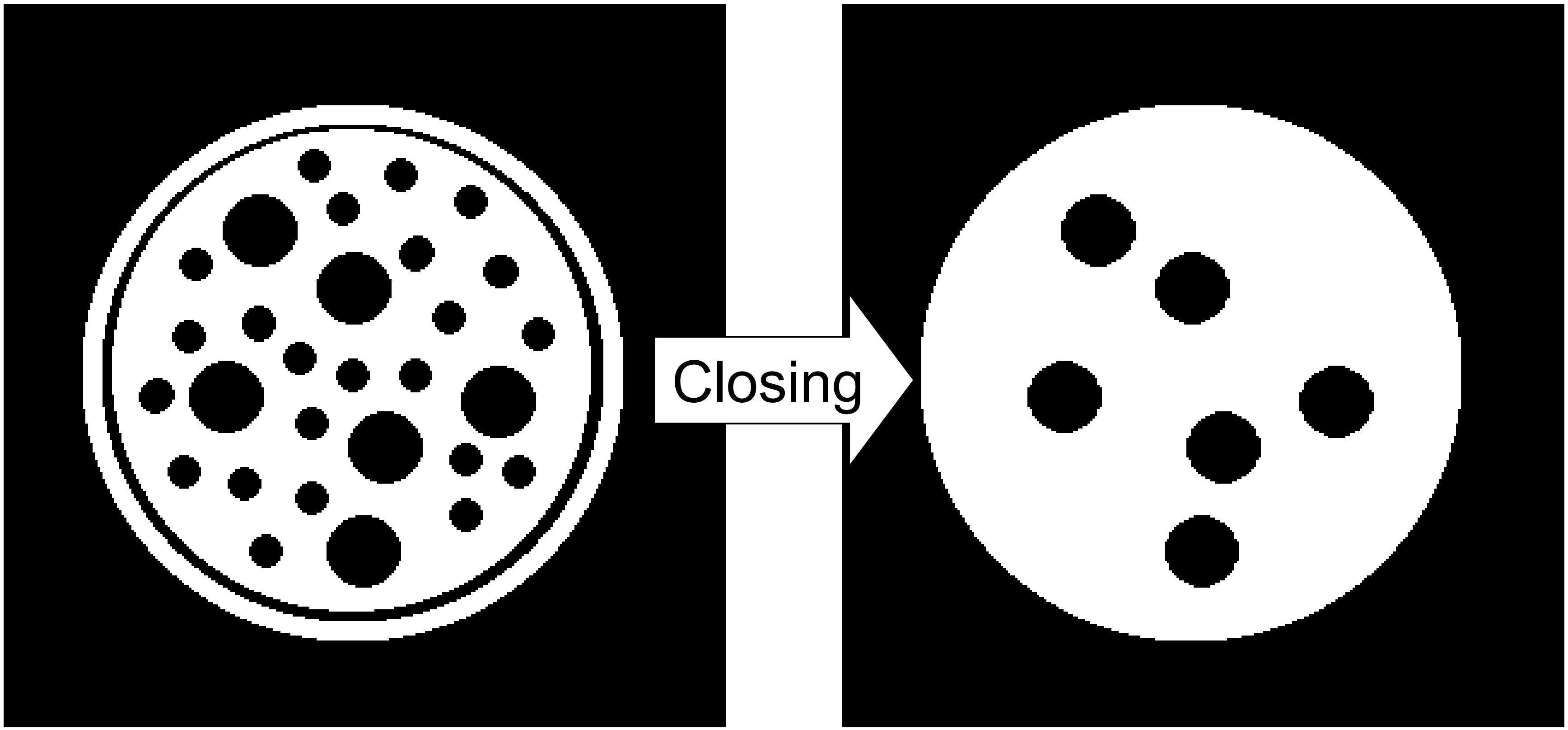
Closing

Opening

Example: Opening

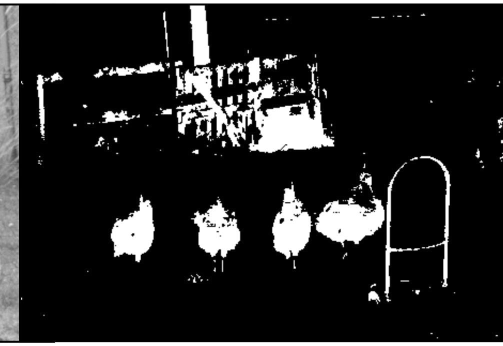


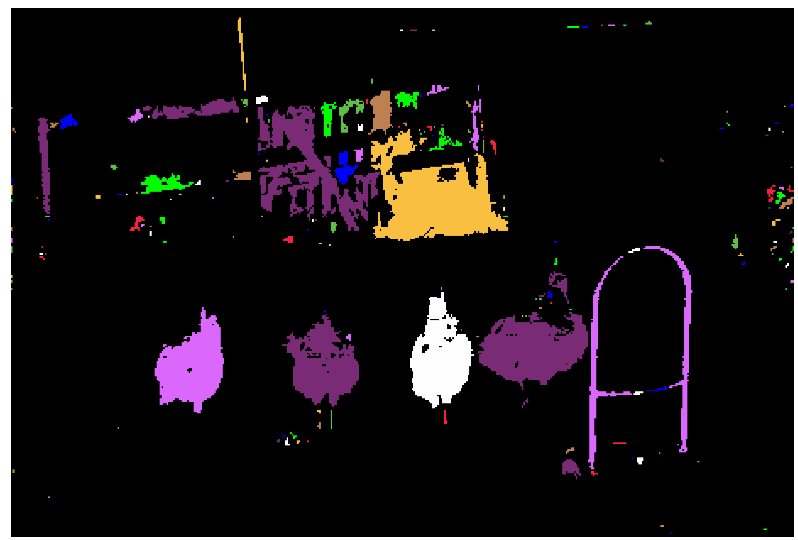
Example: Closing



Connected Component Analysis

- Define ‘**connected**’.
  - – 4 neighbors.
  - – 8 neighbors.
- Search the image for **seed points**.
- Recursively obtain all **connected points** of the seeded region.





Resources

- Gonzalez & Woods – Chapter 7 and 8
- Russ – Chapter 7
- N. Otsu, “A threshold selection method from gray-level histograms,” IEEE Trans. Sys., Man., Cyber., vol. 9, pp. 62–66, 1979.