Summary

- Binary images
- Thresholding
- Mathematatic Morphology
  - (also for non binary images)
- Connected components extraction

Binary Images

- In some cases it is necessary/useful to acquire/produce and/or process images whose pixels can only have 0/1 logical values
  - PBM or XBM image formats

```
000100100001000
000111100001000
000100100001000
```

Binary Images

- 1 actually can be considered as !=0
- 255 is often used for simplicity

0	0	0	255	0	0	255	0	0	0	255	0	0	0
0	0	0	255	255	255	255	0	0	0	255	0	0	0
0	0	0	255	0	0	255	0	0	0	255	0	0	0

Example

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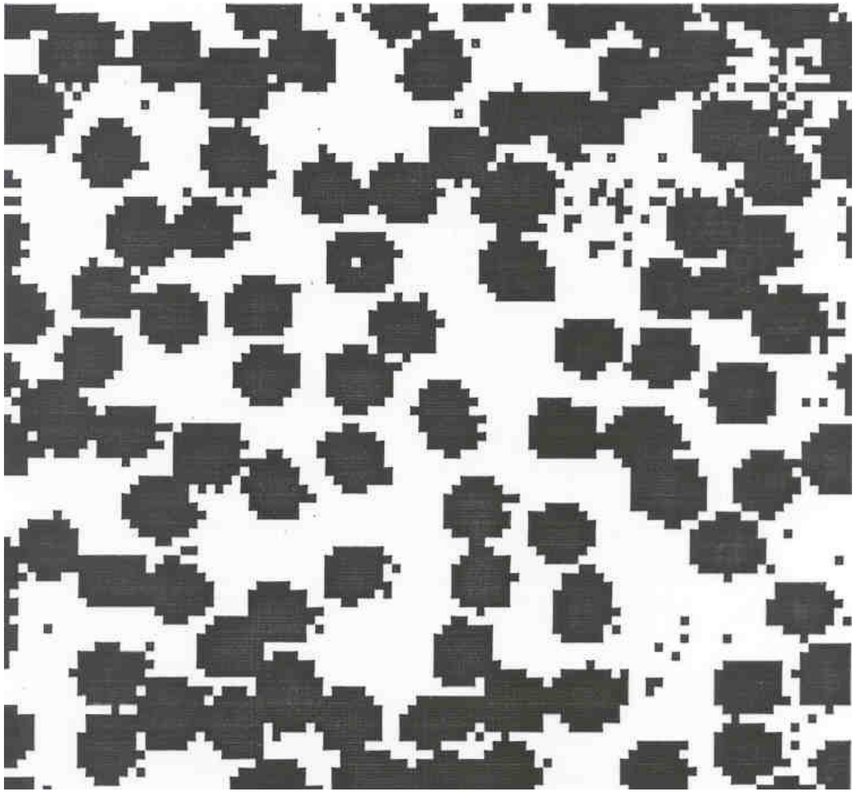
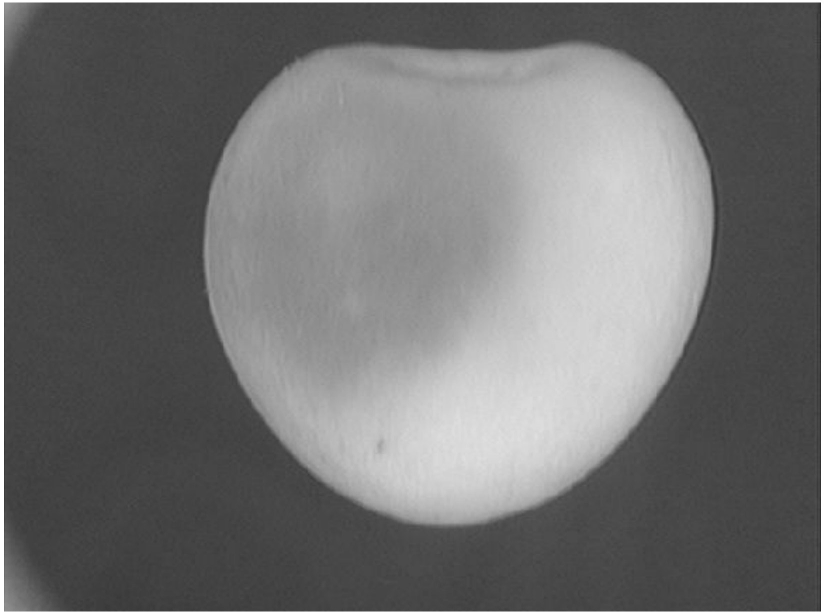
- Real image of blood cells
- We would like to estimate red blood cells
- Anyway they are not isolated (<50%)
- How we can separate them?



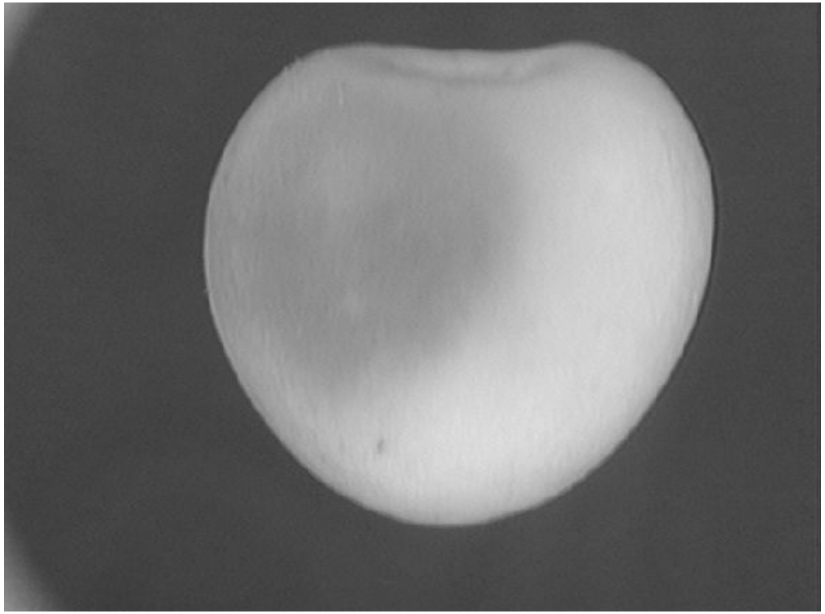
Thresholding



- We would like to discard a bruised apple
- How we can select the bruised part?
  - Extract “dark” pixels
- We can only use pixel brightness
- Thresholding:

$$out(r,c)=\begin{cases}0 & where \quad \mathrm{in}(r,c) < th \\ 1 & where \quad \mathrm{in}(r,c) \geq th\end{cases}$$

Thresholding

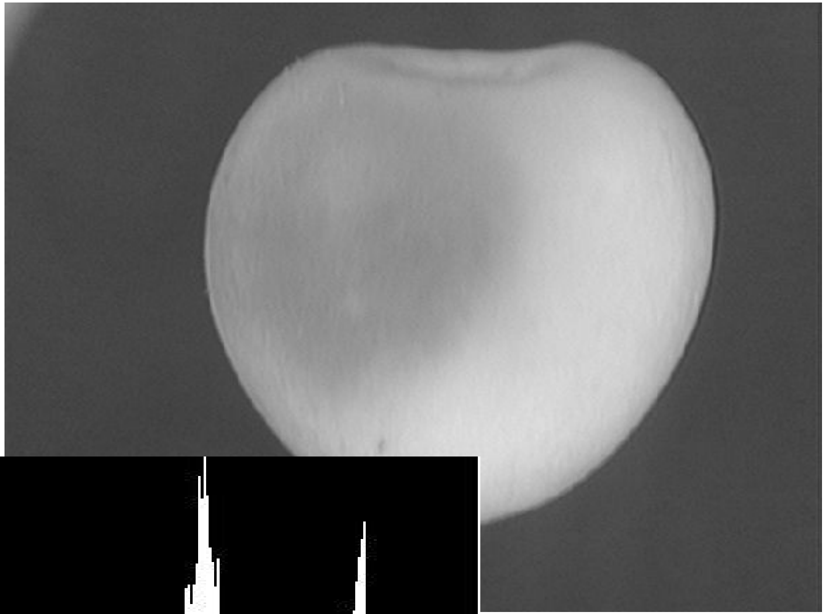


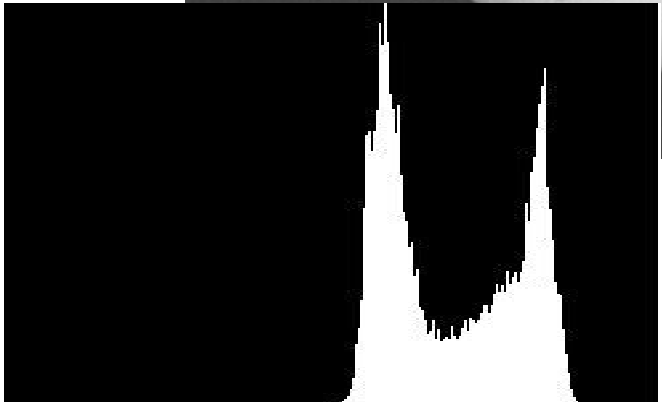
- Anyway we have:
  - "Good" apple part
  - Bruised apple part
  - Background
- How we decide about the threshold?

$$out(r,c)=\begin{cases}0 & where \quad \mathrm{in}(r,c) < th \\ 1 & where \quad \mathrm{in}(r,c) \geq th\end{cases}$$

Thresholding

- Anyway we have:
  - "Good" apple part
  - Bruised apple part
  - Background
- How we decide about the threshold?
- Histogram!

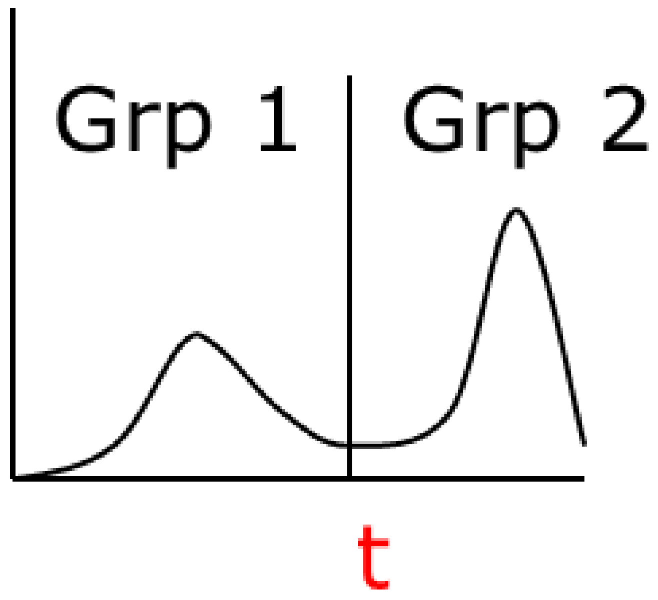




Otsu’s Method

- Best threshold computation
- Problem: find a *th* that minimize weighted sum of each group variance

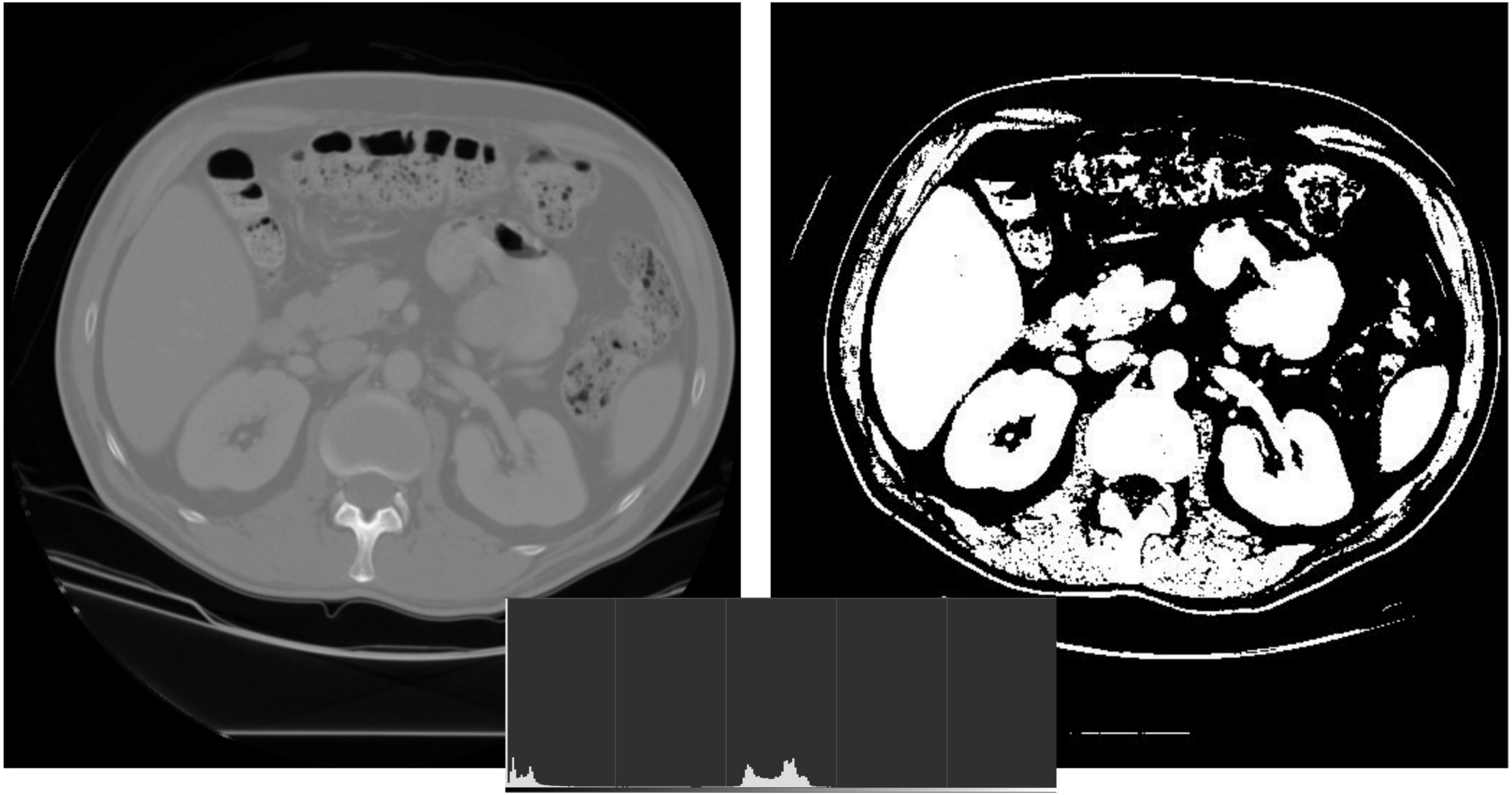
$$\sigma^2(th) = \sigma_1^2(th) \cdot w_1(th) + \sigma_2^2(th) \cdot w_2(th)$$



- $w_1(th)$ & $w_2(th)$ are the probability of belonging to group 1 or 2

$$w_1(th) = \sum_{i-0}^{th-1} h(i) \qquad w_2(th) = \sum_{i=th}^{L} h(i)$$

Otsu’s Method



Otsu's Method

Mathematical Morphology

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- Used to extract image components that are useful in the representation and description of region shape, such as
  - boundaries extraction
  - skeletons
  - convex hull
  - morphological filtering
  - thinning
  - pruning

Mathematical Morphology

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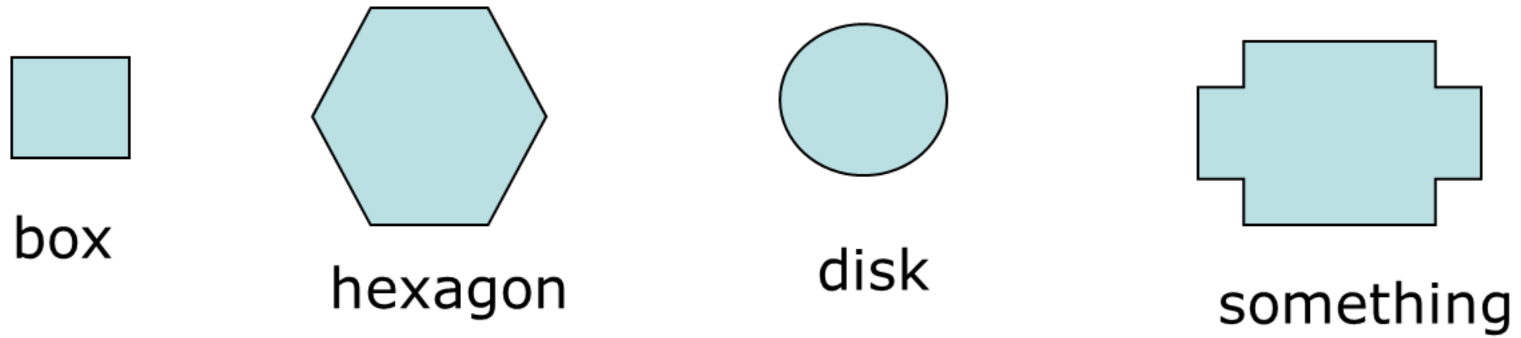
- Main operations
  - Erosion $\longrightarrow \ominus$
  - Dilation $\longrightarrow \oplus$
  - Opening $\longrightarrow \circ$
  - Closing $\longrightarrow \bullet$
  - Hit or Miss $\longrightarrow \otimes$

Structuring Element

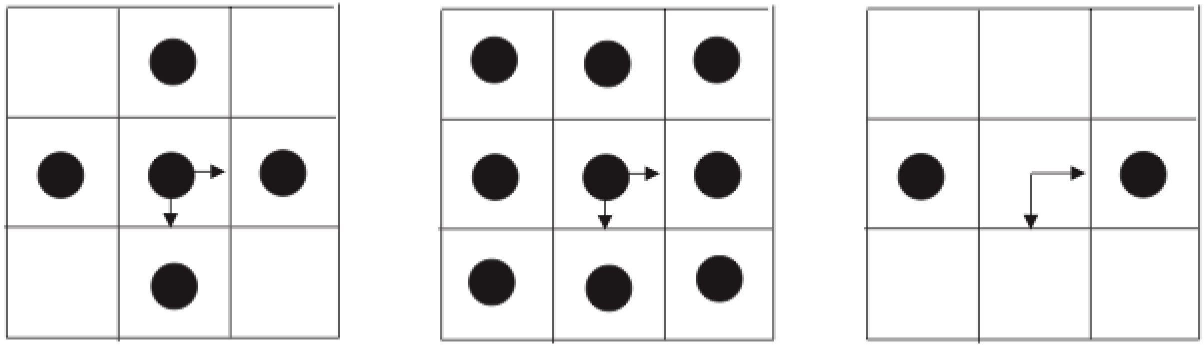
- Small “mask” to probe the image under study
- Structuring Element features an origin
- Shape and size must be adapted to geometric properties we would like to mask/obtain



box(length,width)

disk(diameter)

Structuring Element

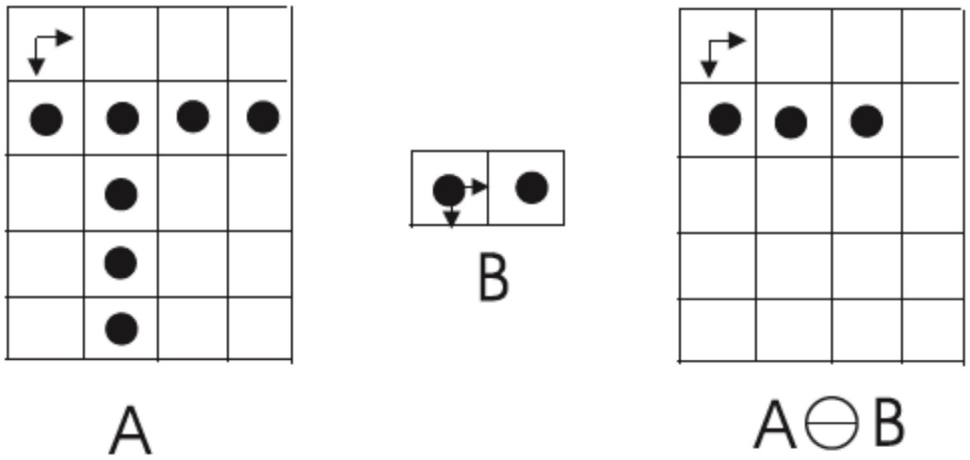


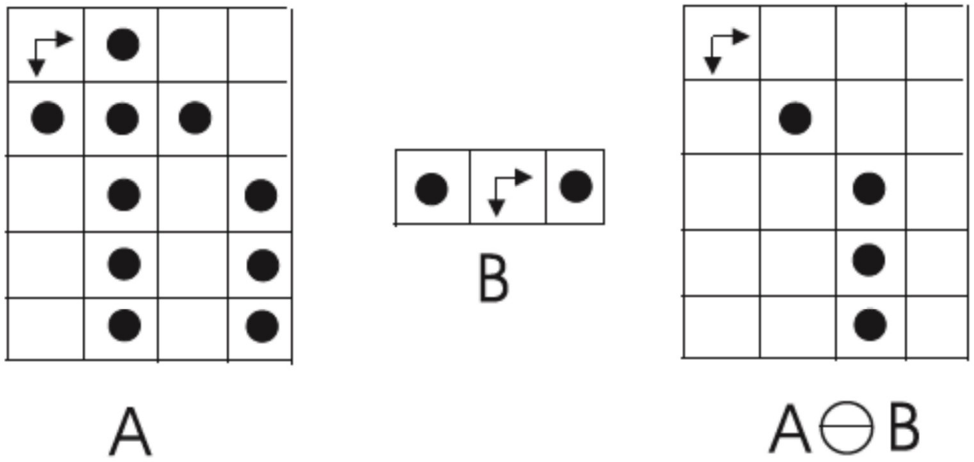
Erosion

- The structuring element B is "moved" (B_z) on the image A for a set of values z belonging to an Euclidean Space E
- The result is the set of z values for which B_z is in A

$$A \ominus B = \{ z \in E^2 : B_z \subseteq A \}$$

- Practically the structuring element is superimposed on all the pixel of the image.
  - When it completely fits the binary image the result is 1, otherwise 0
  - Logical AND
  - It shrinks image elements


A
B
A⊖B

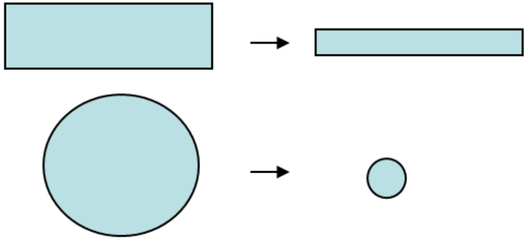

A
B
A⊖B

Erosion

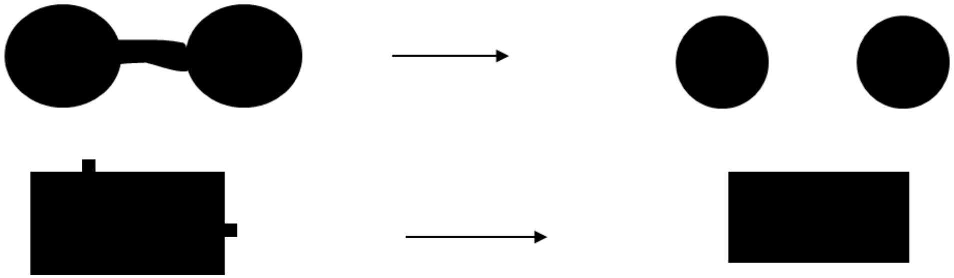
Erosion shrinks the connected sets of 1s of a binary image.

It can be used for

1. shrinking features

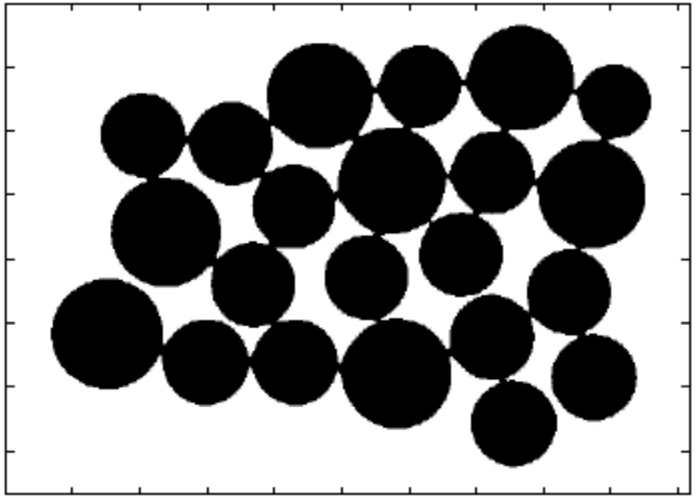


2. Removing bridges, branches and small protrusions



Erosion

- Consider the following image

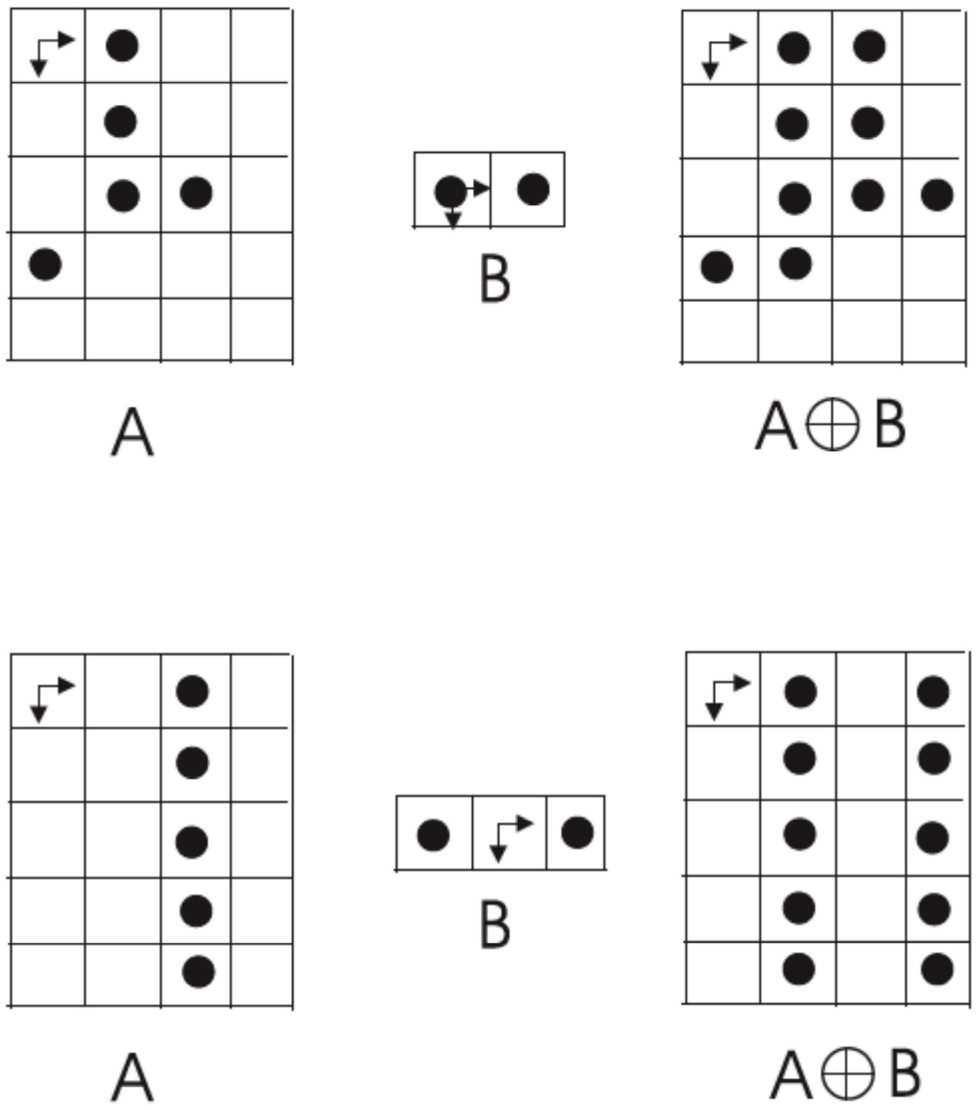


- We can use erosion to separate elements

Dilation $\oplus$

- Again the structuring element is superimposed on all the pixel of the image.
  - When it hits the binary image the result is 1, otherwise 0
  - Logical OR
- It "dilates" image elements

Dilation ⊕

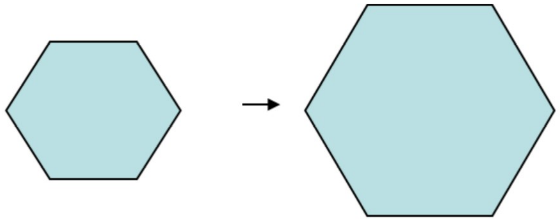


Dilation $\oplus$

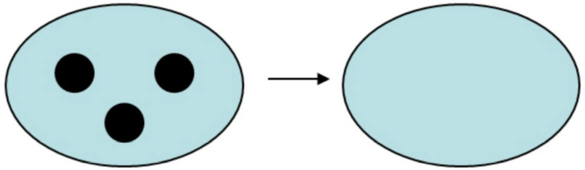
Dilation expands the connected sets of 1s of a binary image.

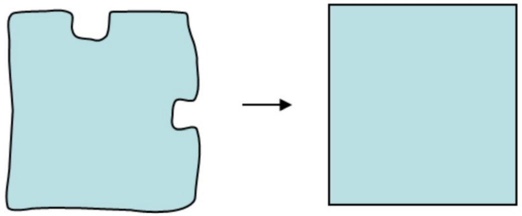
It can be used for

1. growing features



2. filling holes and gaps





Erosion + Dilation

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- We can use erosion and dilation to remove small details or to fill some gaps
- But they also affect other part of the image…
- Solution
  - Combine them!

Opening/Closing

- Opening
  - Erosion followed by dilation

$$A \circ B = (A \ominus B) \oplus B$$

- Closing
  - Dilation followed by erosion

$$A \circ B = (A \oplus B) \ominus B$$

- The same structuring element is used

Examples

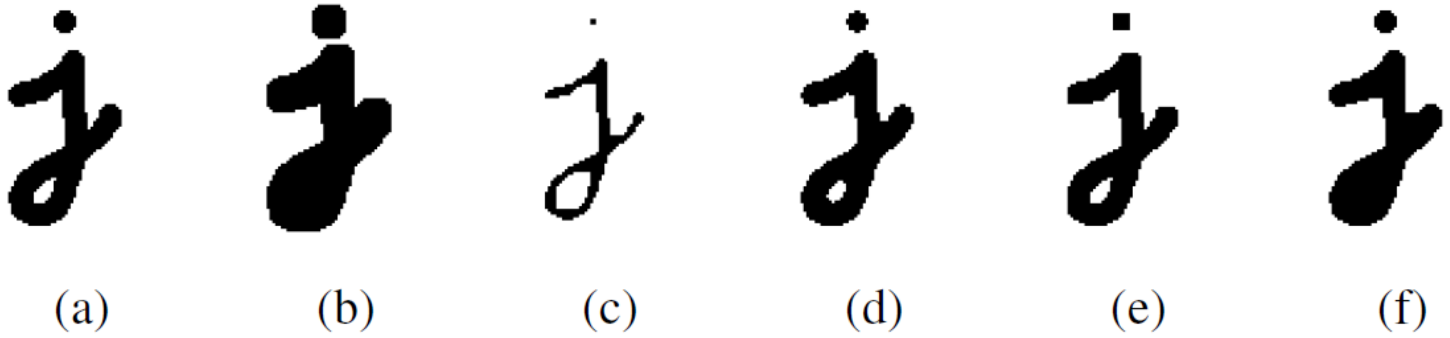


Figure 3.21 Binary image morphology: (a) original image; (b) dilation; (c) erosion; (d) majority; (e) opening; (f) closing. The structuring element for all examples is a 5×5 square. The effects of majority are a subtle rounding of sharp corners. Opening fails to eliminate the dot, since it is not wide enough.

Source: Szeliski

Hit or Miss ⊗

- Two "disjoint" structuring elements are used: A e B
  - $A \cap B = \emptyset$
- Two erosion are used and joined
  - $I \otimes X = (I \ominus A) \cap (I^c \ominus B)$
  - Where I^c is the complement for I and X = (A,B)
- The idea is that A should match shapes and B background
  - It can be seen as an "extended" SE

	1	
0	1	1
0	0	

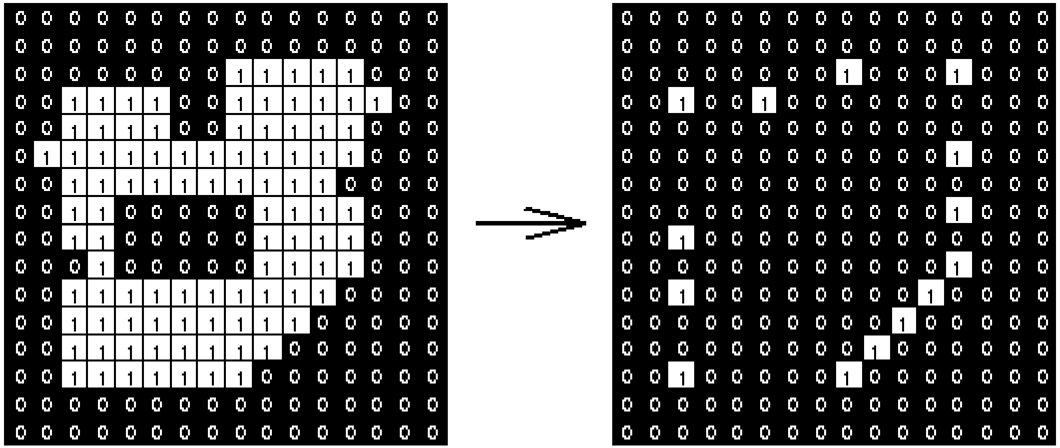
Hit or Miss ⊗

	1	
0	1	1
0	0	

	1	
1	1	0
	0	0

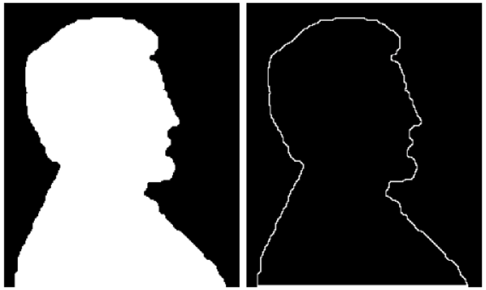
	0	0
1	1	0
	1	

0	0	
0	1	1
	1	



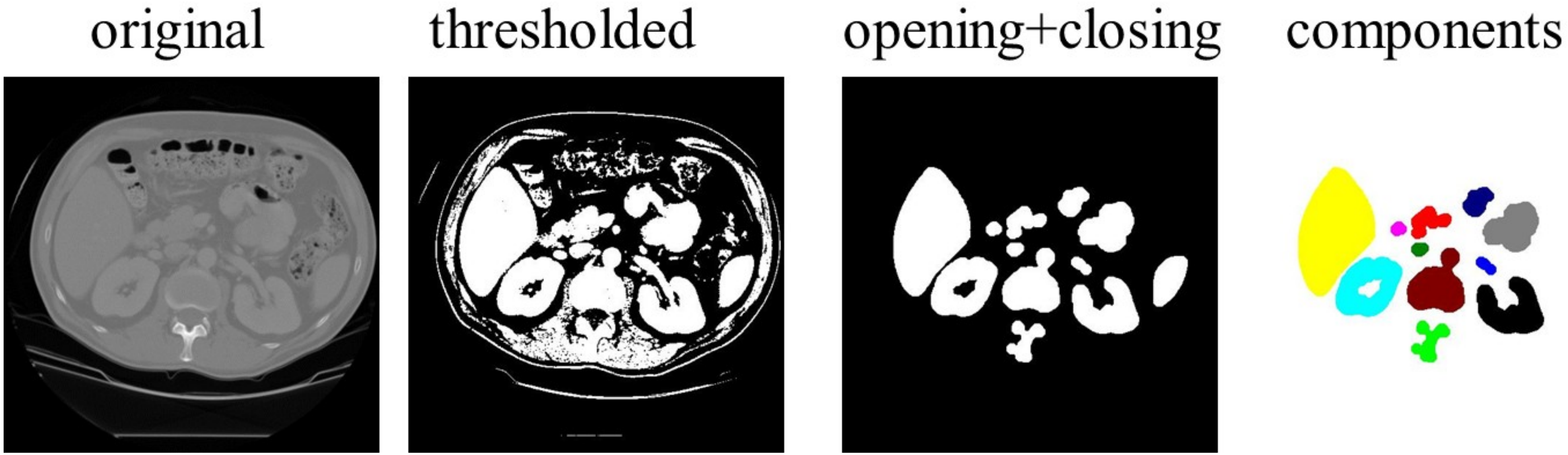
Other operations

- Other morphological complex operations can be used using union/intersection:
  - Border extraction
  - Skeletonization
  - Thinning
  - …



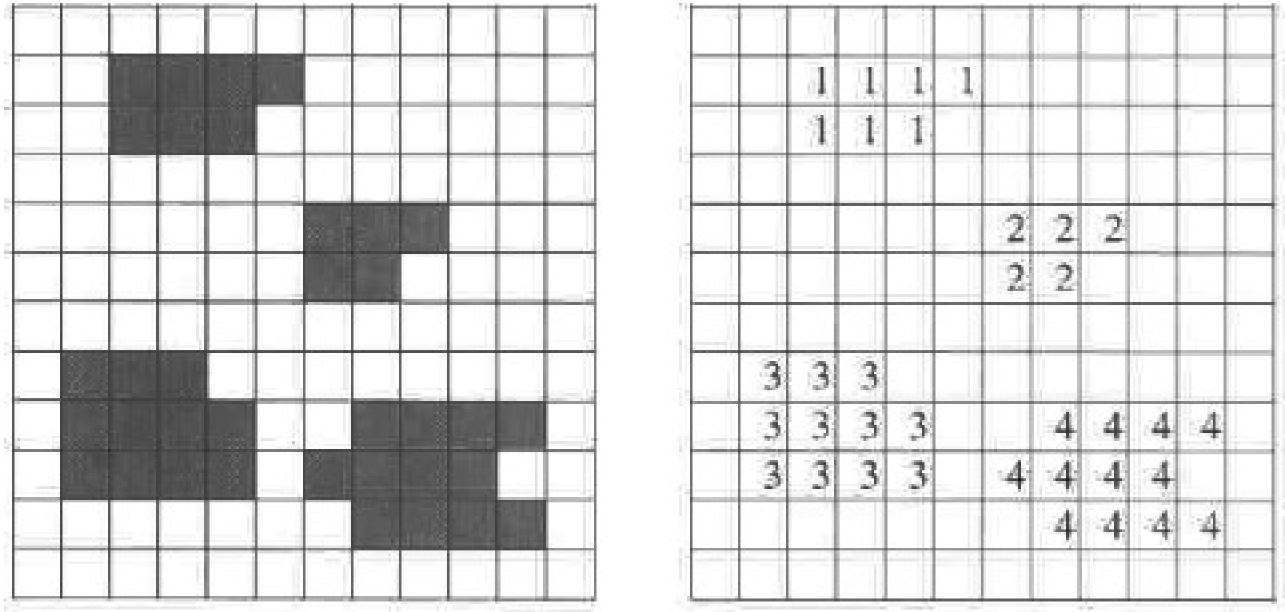
Connected Components

- A connected component is a **contiguous** group of pixels that have the **same value**
  - Actually not only binary images



Labelling algorithms for CC

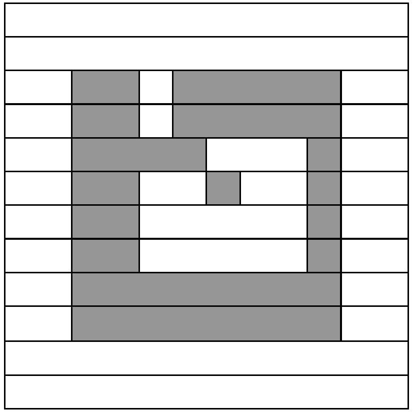
- We assign a unique label to each component



Source: R. Jain

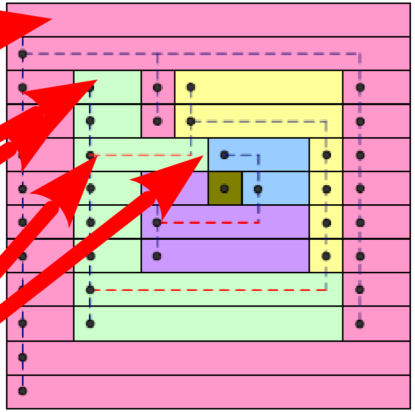
Labbelling algorithms for CC

- Different approaches can be used:
  - Recursive Tracking
  - Parallel Growing
  - Row-by-Row (widely used)



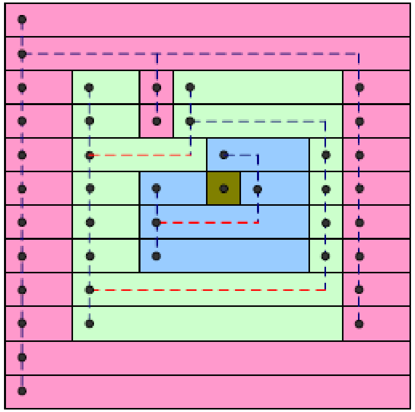
Row by Row Labelling algorithm

- 1^{st} pass:
  - First row:
    - Check left neighboor, do it have the same value?
      - Yes ⟶ same label
      - No ⟶ new label
  - Other rows
    - Check left and upper neighboor
      - They have same value and same label ⟶ same label
      - Current pixel have same value of only one of them ⟶ same label of that one
      - They have same value but different label (!) ⟶ set lowest label and track the equivalence
      - Otherwise ⟶ new label



Row by Row Labelling algorithm

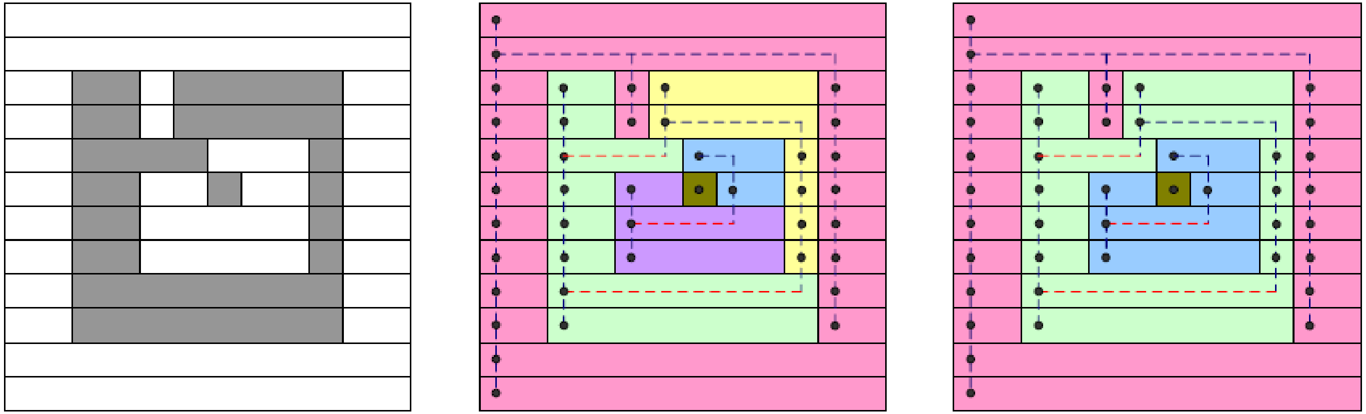
- 2^{nd} pass:
  - Durig 1st pass we have tracked label equivalences
  - Row by row change labels with lowest equivalent



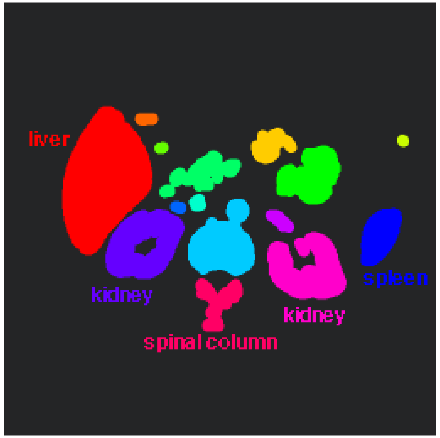
Labelling algorithms for CC

Source: Szeliski

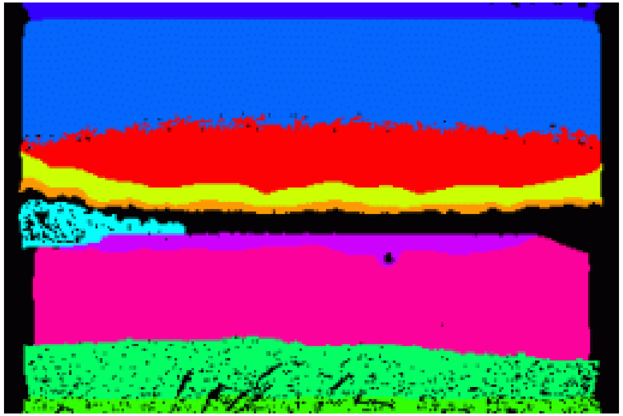
- Row by Row



Connected Components



connected components of 1's from cleaned, thresholded image



connected components of cluster labels

Grayscale Morphology

- Mathematical morphology can be extended to grayscale images
- Applications
  - Contrast enhancement
  - texture description
  - edge detection
  - thresholding

Grayscale Morphology

- In a grayscale image there is no “object” and “background”
- Min and Max operators are used
- Structuring element is still a mask
- Dilation $\longrightarrow$ max element under the mask wins
- Erosion $\longrightarrow$ min element under the mask wins
- Opening&Closing as before

Grayscale Morphology

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