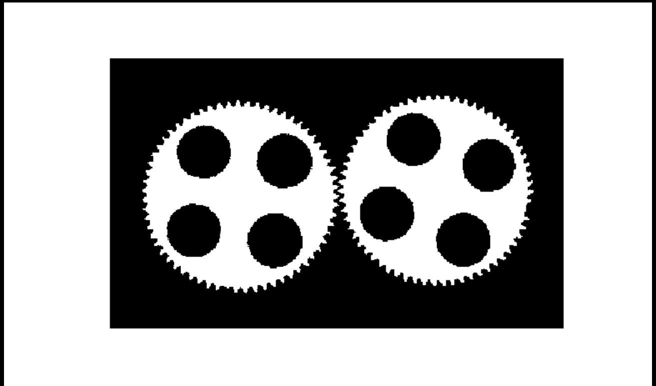
CS4495/6495
Introduction to Computer Vision

9B-L1 *Binary morphology*

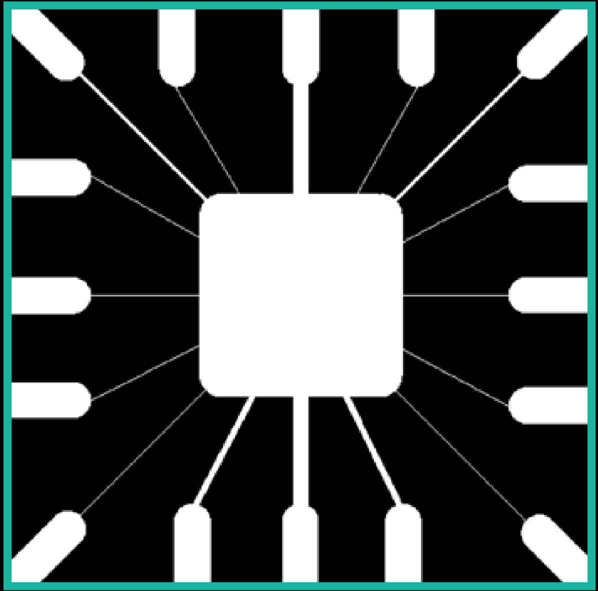


Binary Image Analysis

Operations that produce or process binary images, typically 0's and 1's

- 0 represents background
- 1 represents foreground

```
00010010001000
00011110001000
00010010001000
```

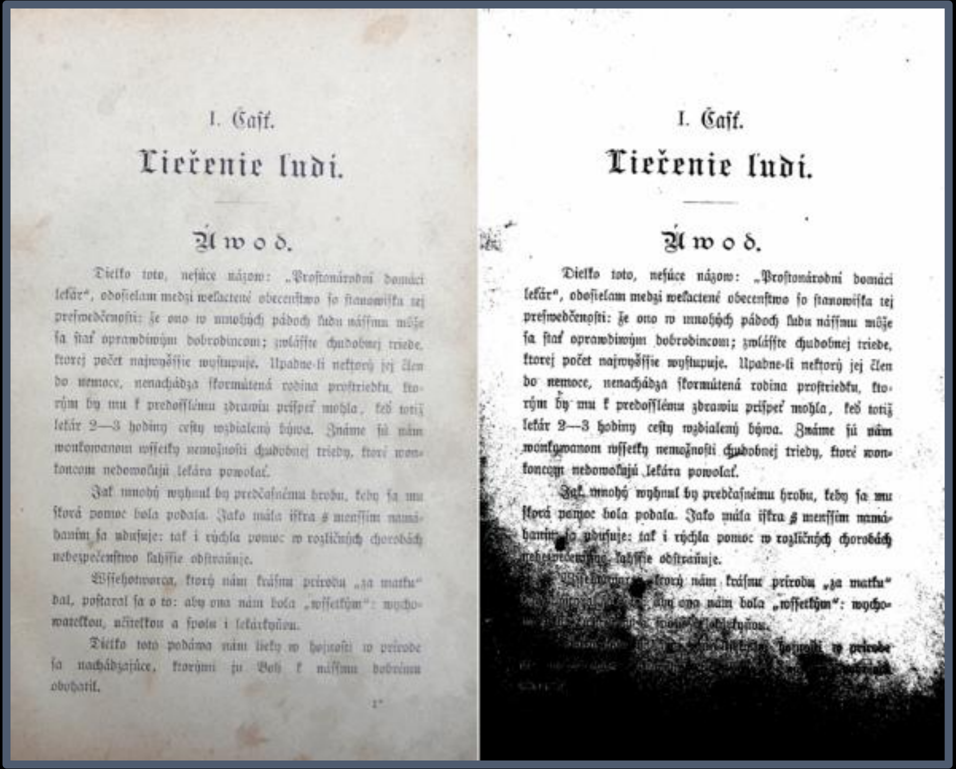


Slides: Linda Shapiro

Binary Image Analysis

Used in a number of practical applications

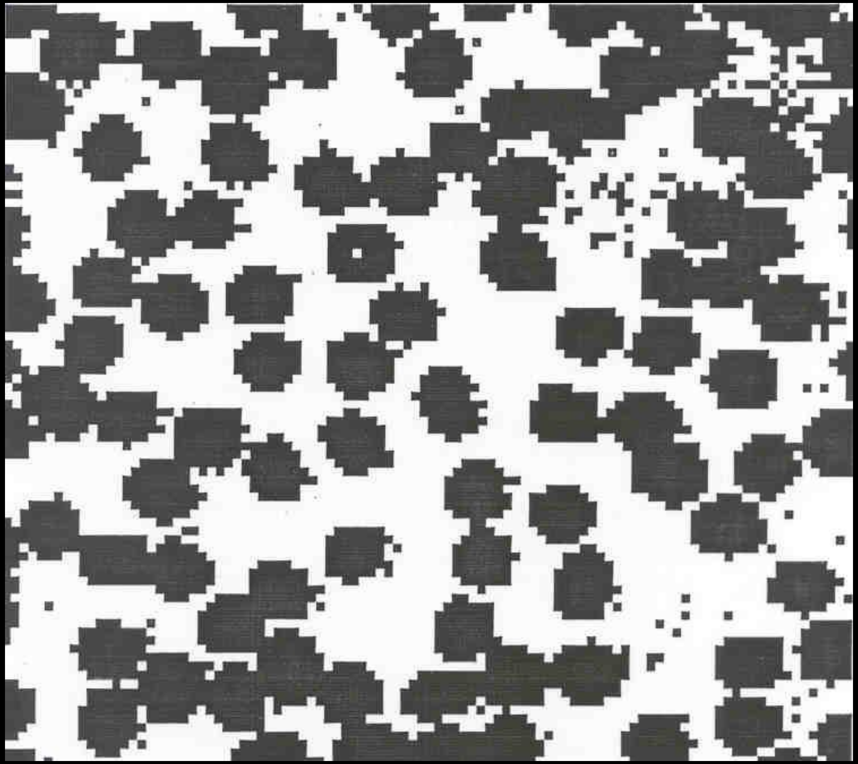
- Part inspection
- Manufacturing
- Document processing



What kinds of operations?

- Separate objects from background and from one another
- Aggregate pixels for each object
- Compute features for each object

Example: Red blood cell image



- Many blood cells are separate objects
- Many touch – bad!
- Salt and pepper noise from thresholding
- How useable is this data?

Results of analysis

- 63 separate objects detected
- Single cells have area about 50
- Noise spots
- Gobs of cells

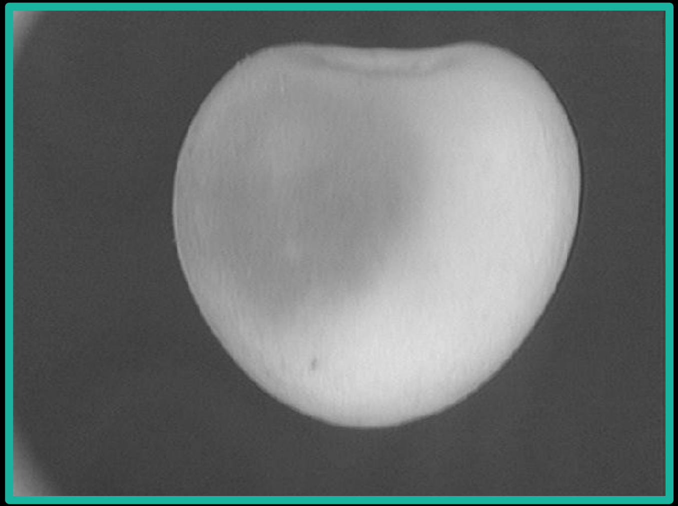
Object	Area	Centroid	Bounding Box	
1	383	(8.8 , 20)	[1 22 1 39]	
2	83	(5.8 , 50)	[1 11 42 55]	
3	11	(1.5 , 57)	[1 2 55 60]	
4	1	(1 , 62)	[1 1 62 62]	
5	1048	(19 , 75)	[1 40 35 100]	gobs
32	45	(43 , 32)	[40 46 28 35]	cell
33	11	(44 , 1e+02)	[41 47 98 100]	
34	52	(45 , 87)	[42 48 83 91]	cell
35	54	(48 , 53)	[44 52 49 57]	cell
60	44	(88 , 78)	[85 90 74 82]	
61	1	(85 , 94)	[85 85 94 94]	
62	8	(90 , 2.5)	[89 90 1 4]	
63	1	(90 , 6)	[90 90 6 6]	

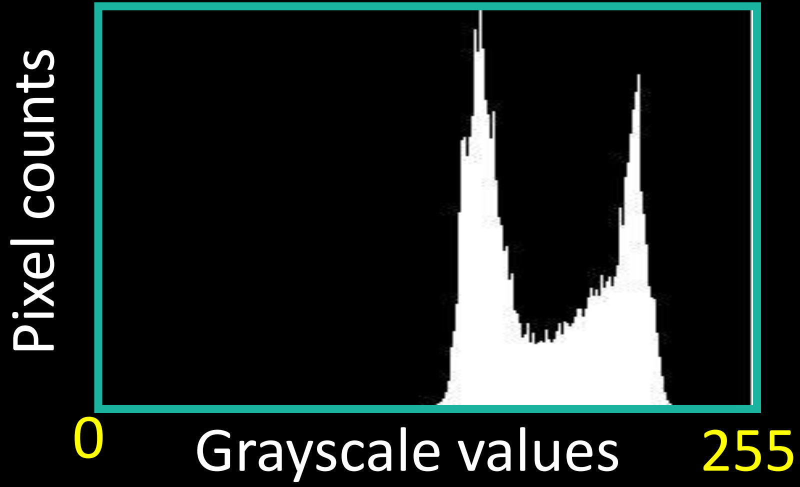
Useful Operations

- Thresholding a gray-scale image
- Determining good thresholds
- Connected components analysis
- Binary mathematical morphology
- All sorts of feature extractors, statistics (area, centroid, circularity, …)

Thresholding

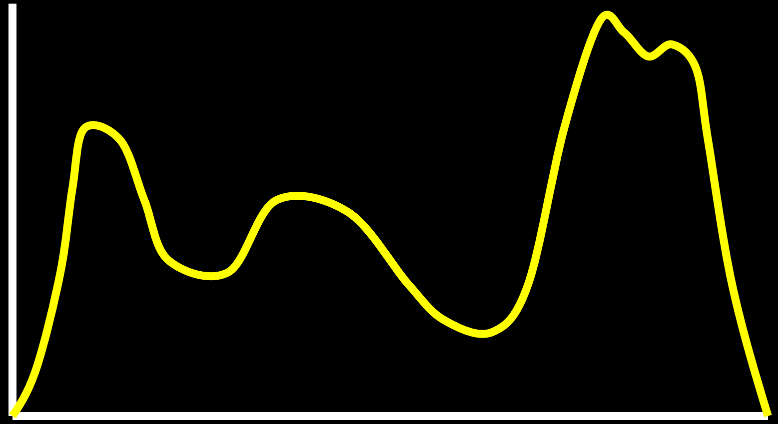
- Background is black
- Healthy cherry is bright
- Bruise is medium dark
- Histogram shows two cherry regions (black background has been removed)





Histogram-Directed Thresholding

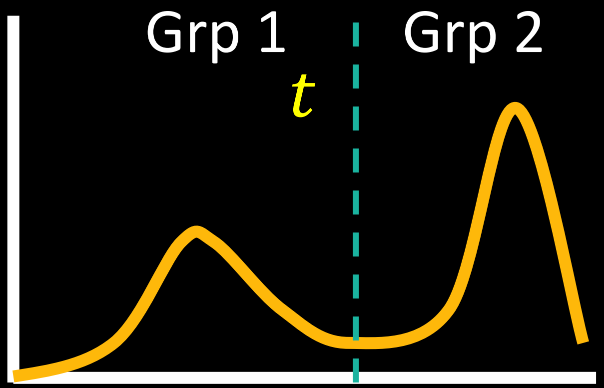
How can we use a histogram to separate an image into 2 (or several) different regions?



Is there a single clear threshold? 2? 3?

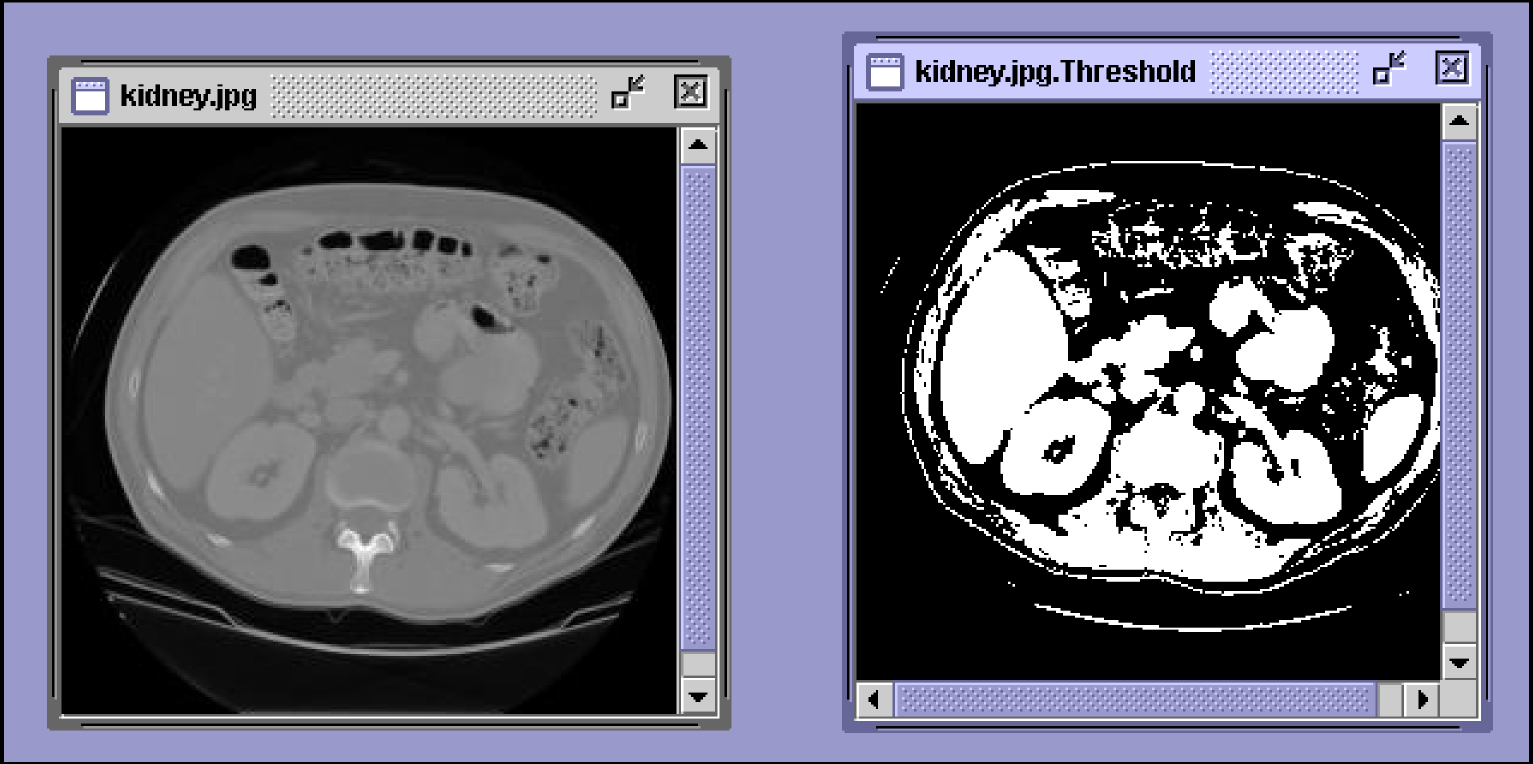
Automatic Thresholding: Otsu's Method

Assumption: The histogram is bimodal



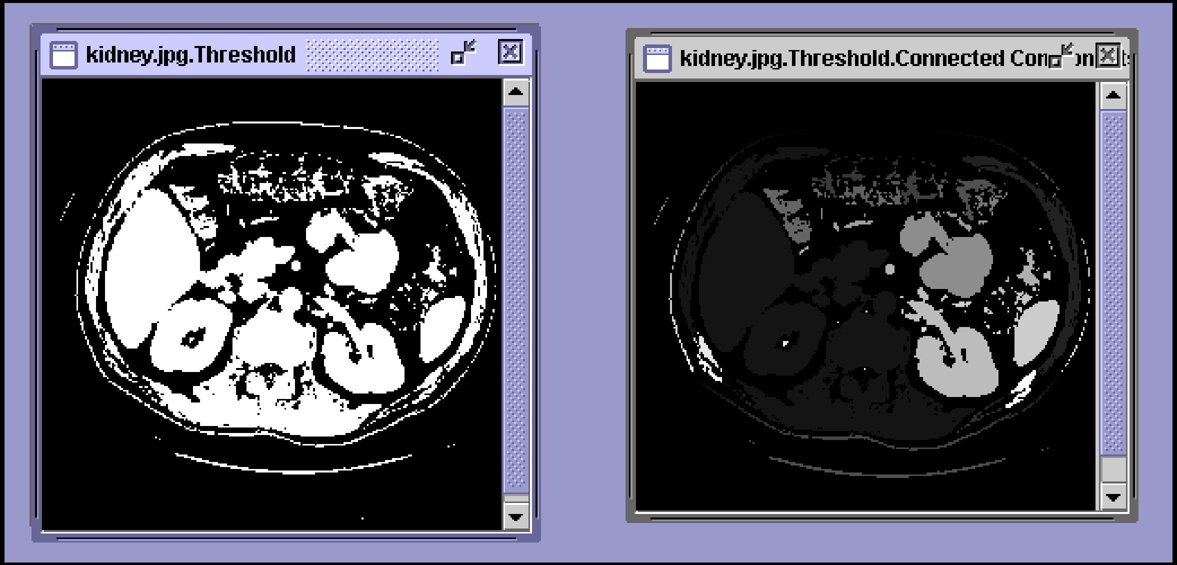
Method: Find the threshold t that minimizes the weighted sum of within-group variances for the two groups that result from separating the gray tones at value t

Thresholding Example



Connected Components Labeling

Once you have a binary image, you can identify and then analyze each connected set of pixels



Connected Components Methods

1. Recursive Tracking (almost never used)
2. Parallel Growing (needs parallel hardware)
3. Row-by-Row (most common)
   - Classical Algorithm
   - Efficient Run-Length Algorithm (developed for speed in real industrial applications)

Equivalent Labels

Original Binary Image

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

Equivalent Labels

CC = 0
Scan across rows:
- If 1 and connected:
  - Propgate lowest label behind or above (4 or 8 connected)
  - Remember conflicts
- If 1 and not connected:
  - CC++ and label CC
- If 0:
  - Label 0

Relabel based on table

```
0 0 0 1 1 1 0 0 0 0 1 1 1 1 0 1 1 1 1
0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 1 1 1
0 0 0 1 1 1 1 1 0 0 1 1 1 1 0 0 1 1 1
0 0 0 1 1 1 1 1 1 0 1 1 1 1 0 0 1 1 1
0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1
0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1
```

Equivalent Labels

CC = 0
Scan across rows:
- If 1 and connected:
  - Propgate lowest label behind or above (4 or 8 connected)
  - Remember conflicts
- If 1 and not connected:
  - CC++ and label CC
- If 0:
  - Label 0

Relabel based on table

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

Equivalent Labels

CC = 0
Scan across rows:
- If 1 and connected:
  - Propgate lowest label behind or above (4 or 8 connected)
  - Remember conflicts
- If 1 and not connected:
  - CC++ and label CC
- If 0:
  - Label 0

Relabel based on table

The ReLabeling Process

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

$1 \equiv 2$
$1 \equiv 3$

Equivalent Labels

CC = 0
Scan across rows:
- If 1 and connected:
  - Propgate lowest label behind or above (4 or 8 connected)
  - Remember conflicts
- If 1 and not connected:
  - CC++ and label CC
- If 0:
  - Label 0

Relabel based on table

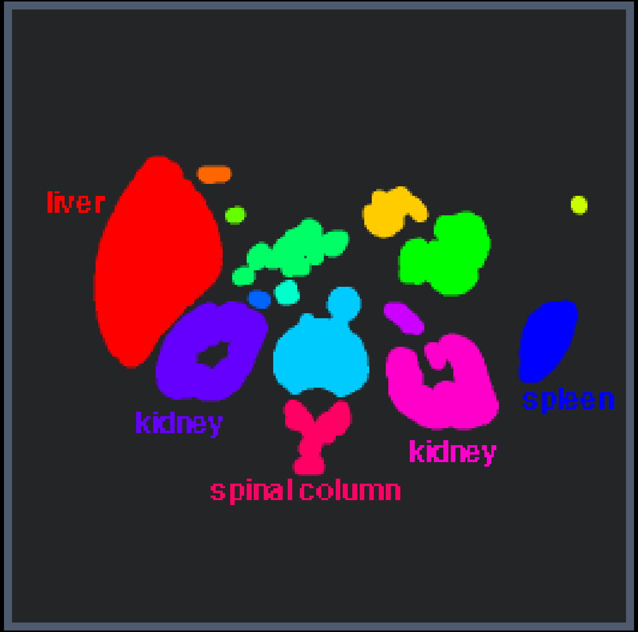
The ReLabeling Process

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

$1 \equiv 2$

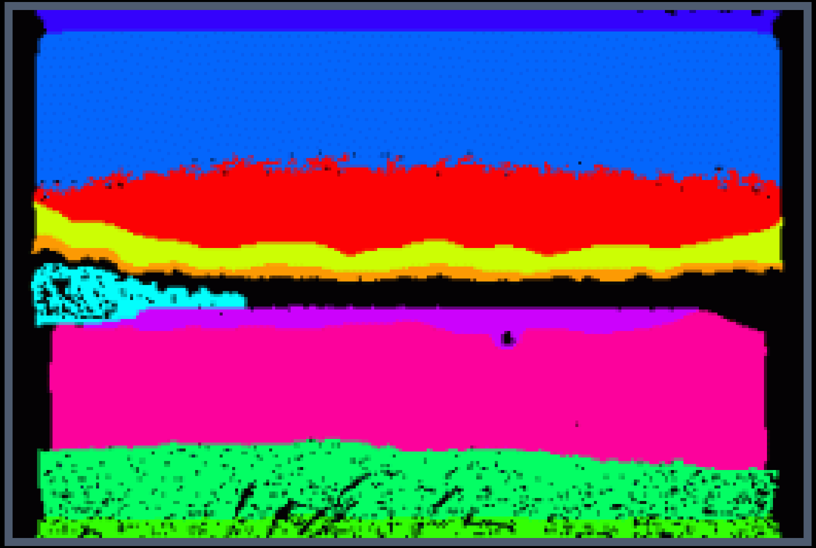
$1 \equiv 3$

Labeling shown as Pseudo-Color



Connected components of 1's from thresholded image

Labeling shown as Pseudo-Color



Connected components of cluster labels

Mathematical Morphology

Two basic operations

- Dilation
- Erosion

And several composite relations

- *Closing and opening*
- Thinning and thickening

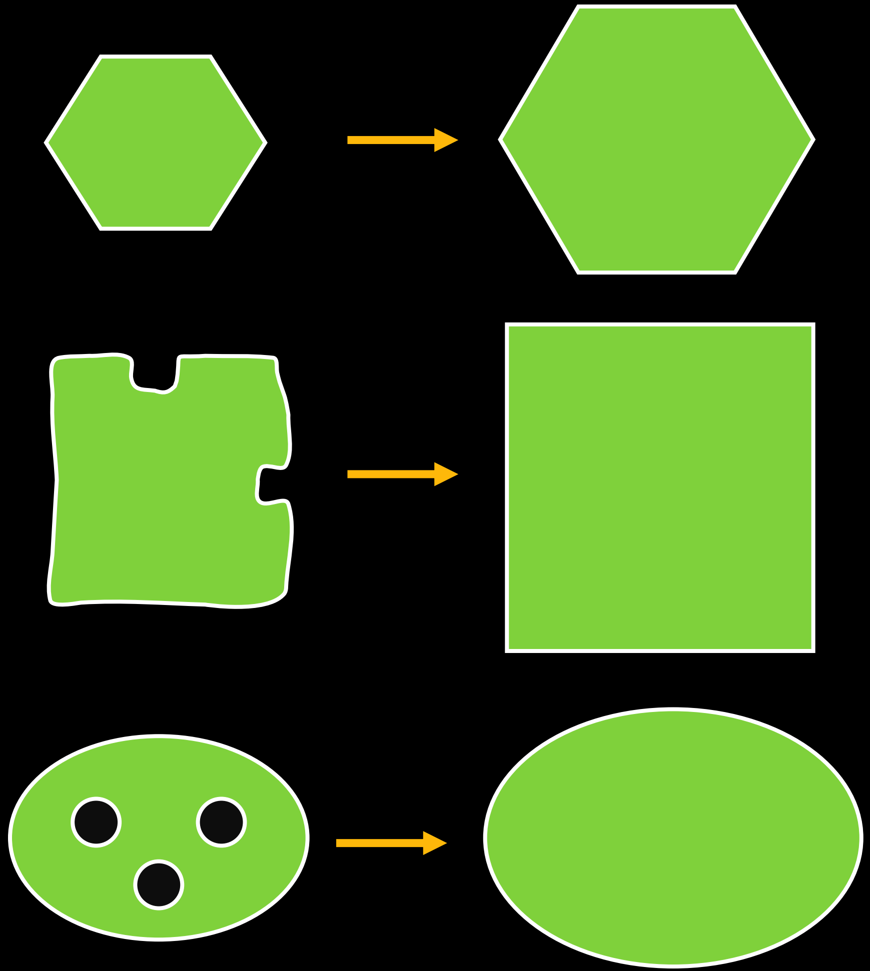
. . .

Dilation

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

It can be used for:

- Growing features
- Filling holes and gaps

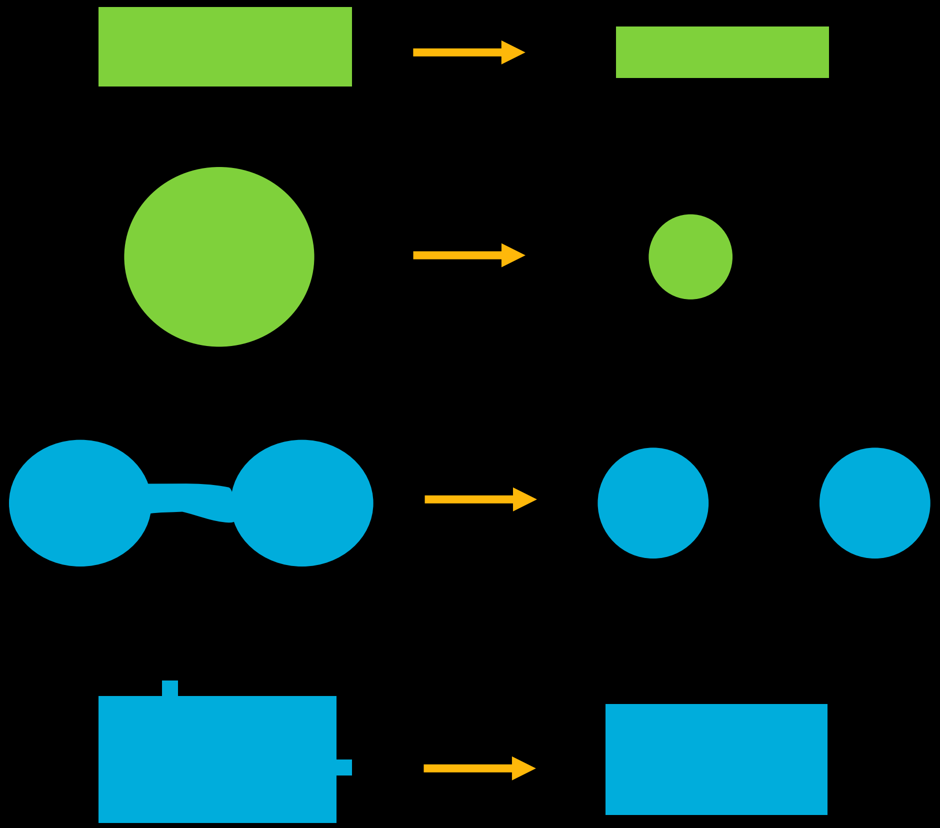


Erosion

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

It can be used for:

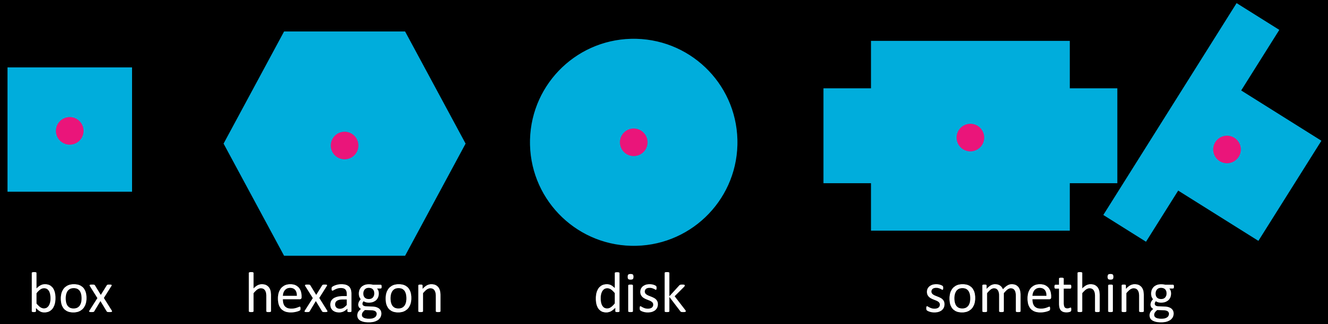
- Shrinking features
- Removing bridges, branches, protrusions



Structuring Element

A shape mask used in basic morphological ops.

- Any shape, size that is digitally representable
- With a defined origin

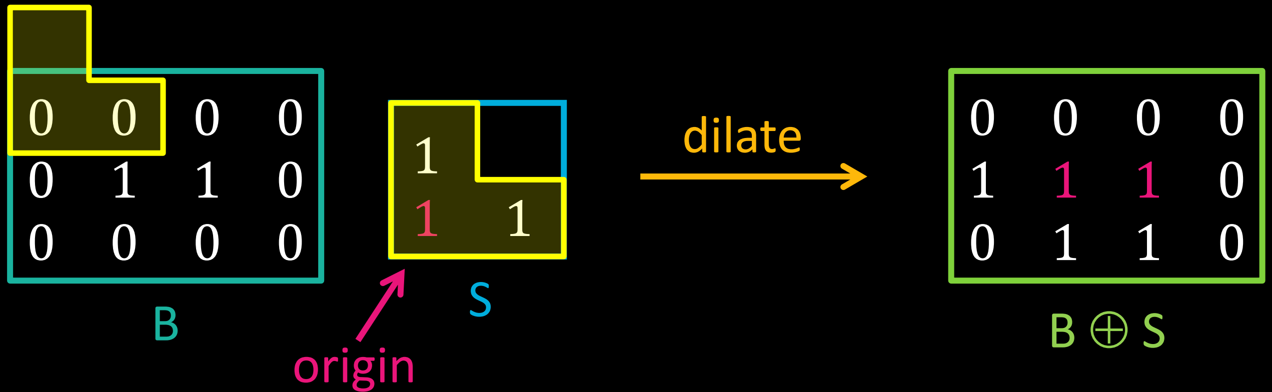


Box (length,width)   Disk (diameter)

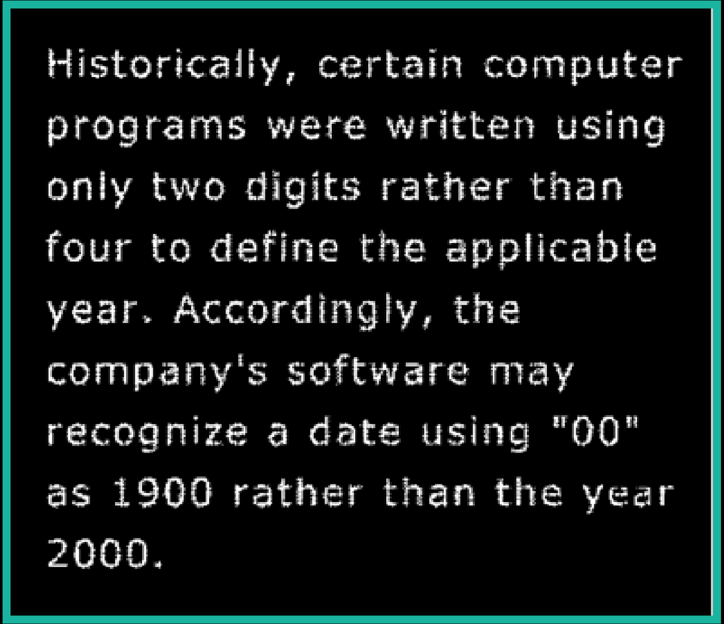
Dilation

Input: Binary image B, structuring element S

- Move S over B, placing origin at each pixel
- Considering only the 1-pixel locations in S, compute the binary *OR* of corresponding elements in B



Binary text example

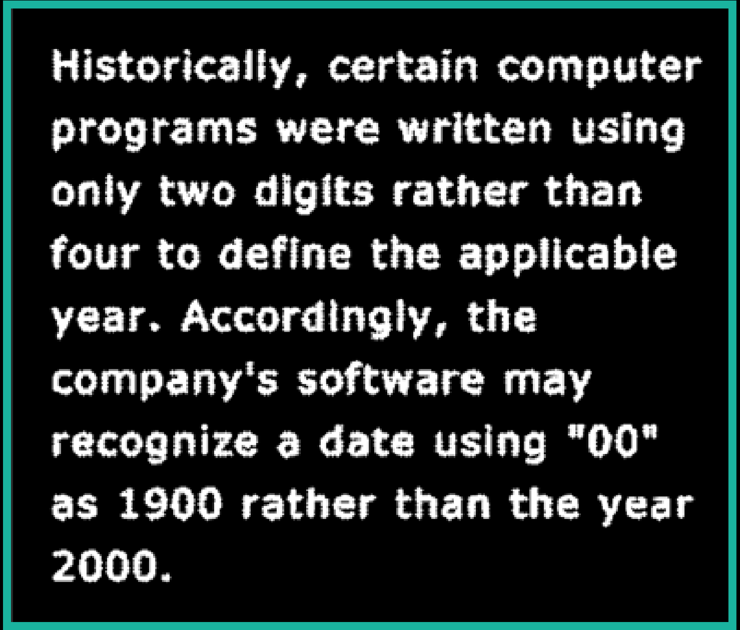


Historically, certain computer
programs were written using
only two digits rather than
four to define the applicable
year. Accordingly, the
company's software may
recognize a date using "00"
as 1900 rather than the year
2000.

Original

$$\begin{array}{ccc} & 1 & \\ 1 & \boxed{1} & 1 \\ & 1 & \end{array}$$

Structuring Element S



Historically, certain computer
programs were written using
only two digits rather than
four to define the applicable
year. Accordingly, the
company's software may
recognize a date using "00"
as 1900 rather than the year
2000.

Dilated by S

Quiz: Dilation

What is the result of this dilation?

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \oplus \begin{bmatrix} 1 & 0 & 1 \\ 0 & \boxed{1} & 0 \\ 1 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \quad \end{bmatrix}$$

Quiz: Dilation

What is the result of this dilation?

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \oplus \begin{bmatrix} 1 & 0 & 1 \\ 0 & \boxed{1} & 0 \\ 1 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

Erosion

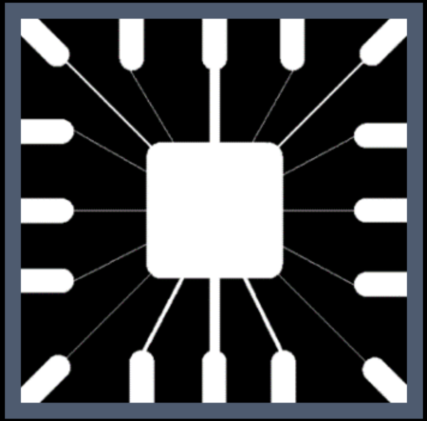
Input: Binary image B, structuring element S

- Move S over B, placing origin at each pixel
- Considering only the 1-pixel locations in S, compute the binary *AND* of corresponding elements in B

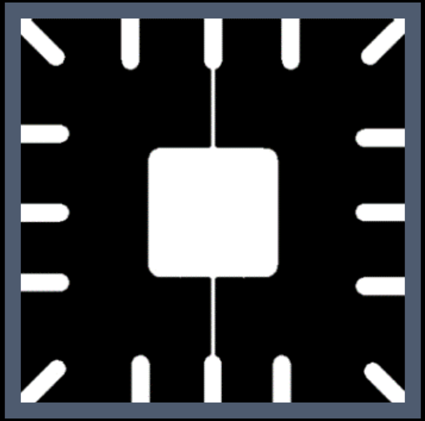
$$\underset{B}{\begin{array}{ccccc} 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{array}} \qquad \underset{S}{\begin{array}{c} 1 \\ 1 \\ 1 \end{array}} \qquad \xrightarrow{\text{erode}} \qquad \underset{B \ominus S}{\begin{array}{ccccc} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{array}}$$

origin

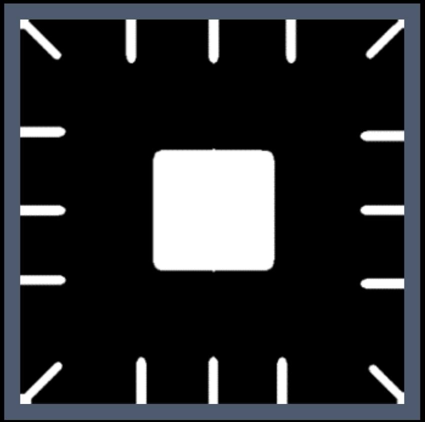
Effect of disk size on erosion



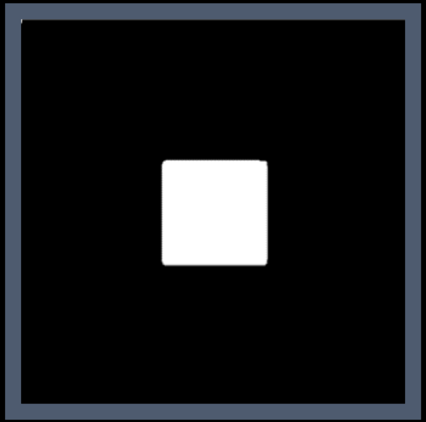
Original image



Erosion with a disk of radius 5



Radius 10



Radius 20

Slide: Ioannis Ivrissimtzis

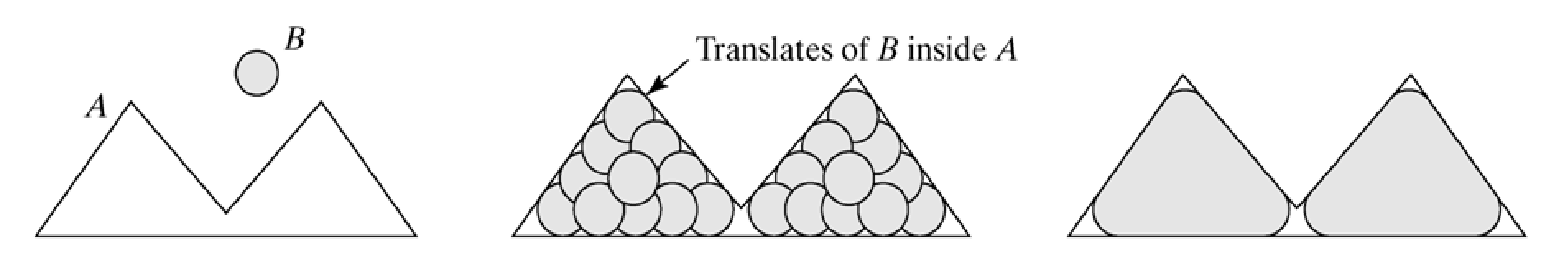
Opening and Closing

- The two most useful binary morphology operations are Opening and Closing

Opening and Closing

- Opening is the compound operation of erosion followed by dilation (with the same structuring element)
  - Can show that the opening of A by B is the union of all translations of B that fit entirely within A.

Opening



Binary image A and structuring element B

Translations of B that fit entirely within A

The opening of A by B is shown shaded

Intuitively, the opening is the area we can paint when the brush has a footprint B and we are not allowed to paint outside A.

Slide: Ioannis Ivrissimtzis

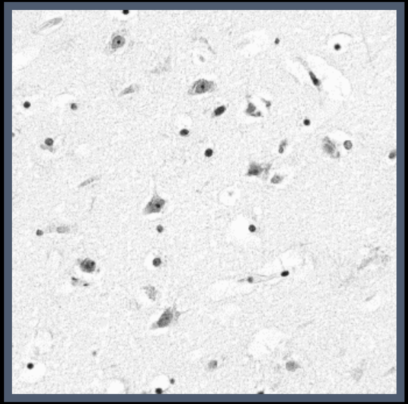
Opening and Closing

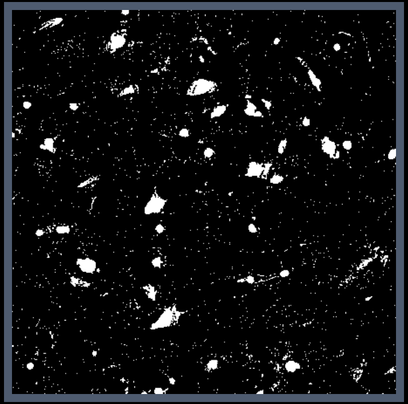
- Opening is the compound operation of erosion followed by dilation (with the same structuring element)
  - Can show that the opening of A by B is the union of all translations of B that fit entirely within A.
  - Opening is **idempotent:** Repeated operations has no further effects!

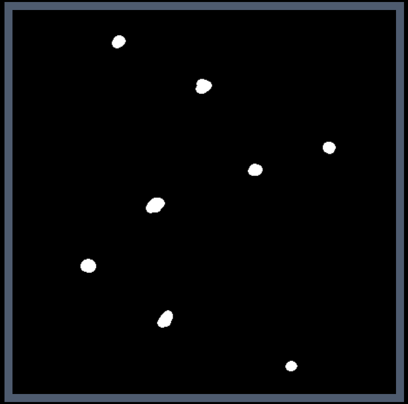
Opening example – cell colony

Use large structuring element that fits into big objects

- Structuring Element: 11 pixel disc





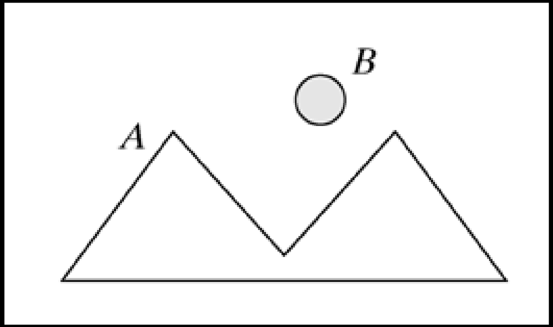


Slide: Thomas Moeslund

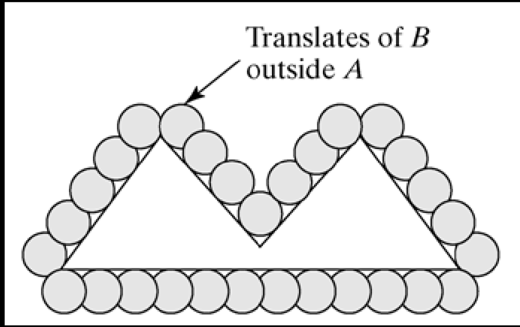
Opening and Closing

- Closing is the compound operation of dilation followed by erosion (with the same structuring element)
  - Can show that the closing of A by B is the complement of union of all translations of B that do not overlap A.

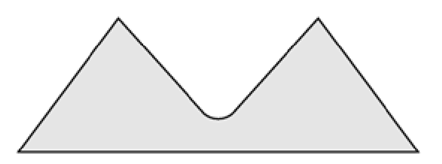
Closing



Binary image A and structuring element B



Translations of B that do not overlap A



The closing of A by B is shown shaded

Intuitively, the closing is the area we can not paint when the brush has a footprint B and we are not allowed to paint inside A.

Slide: Ioannis Ivrissimtzis

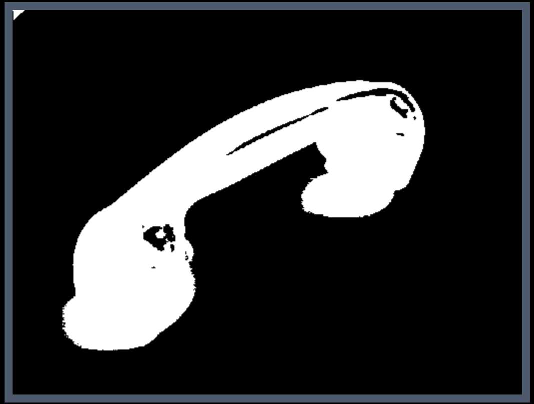
Opening and Closing

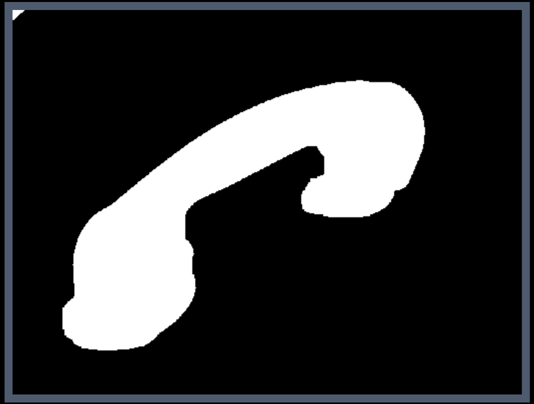
- Closing is the compound operation of dilation followed by erosion (with the same structuring element)
  - Can show that the closing of A by B is the complement of union of all translations of B that do not overlap A.
  - Closing is **idempotent:** Repeated operations has no further effects!

Closing Example - Segmentation

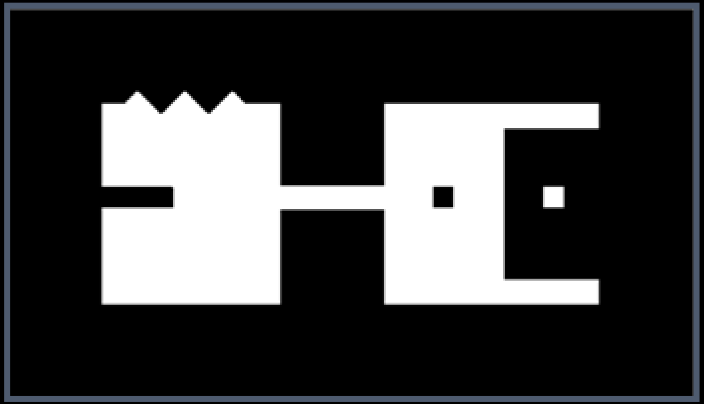
Simple segmentation:

1. Threshold
2. Closing with disc of size 20

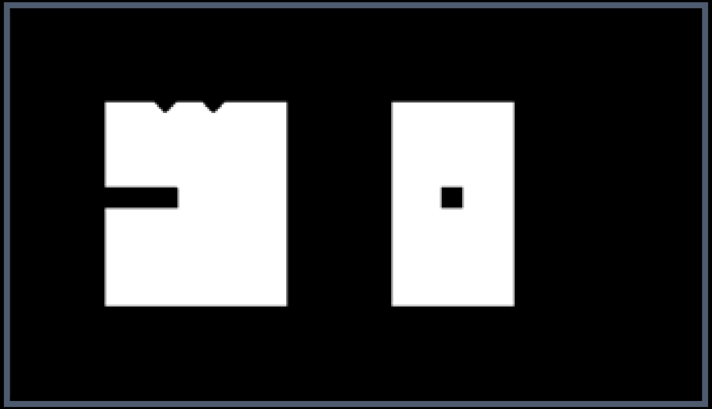




Slide: Thomas Moeslund

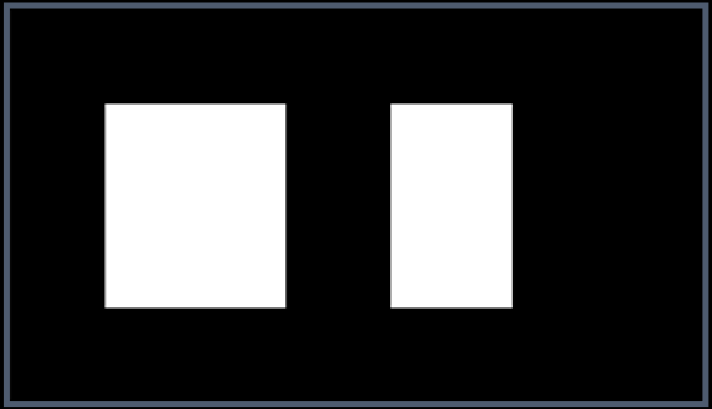


Original image



Opening

Closing



Opening followed by closing

Real example – Fingerprint analysis

Original image | Opening | Opening following by closing

Slide: Ioannis Ivrissimtzis

Some Basic Morphological Algorithms

- Boundary extraction
- Region filling
- Extraction of connected components
- Convex Hull
- Thinning
- Skeletons
- Pruning

Boundary extraction

Let $A \oplus B$ denote the dilation of A by B and let $A \ominus B$ denote the erosion of A by B.

The boundary of A can be computed as:

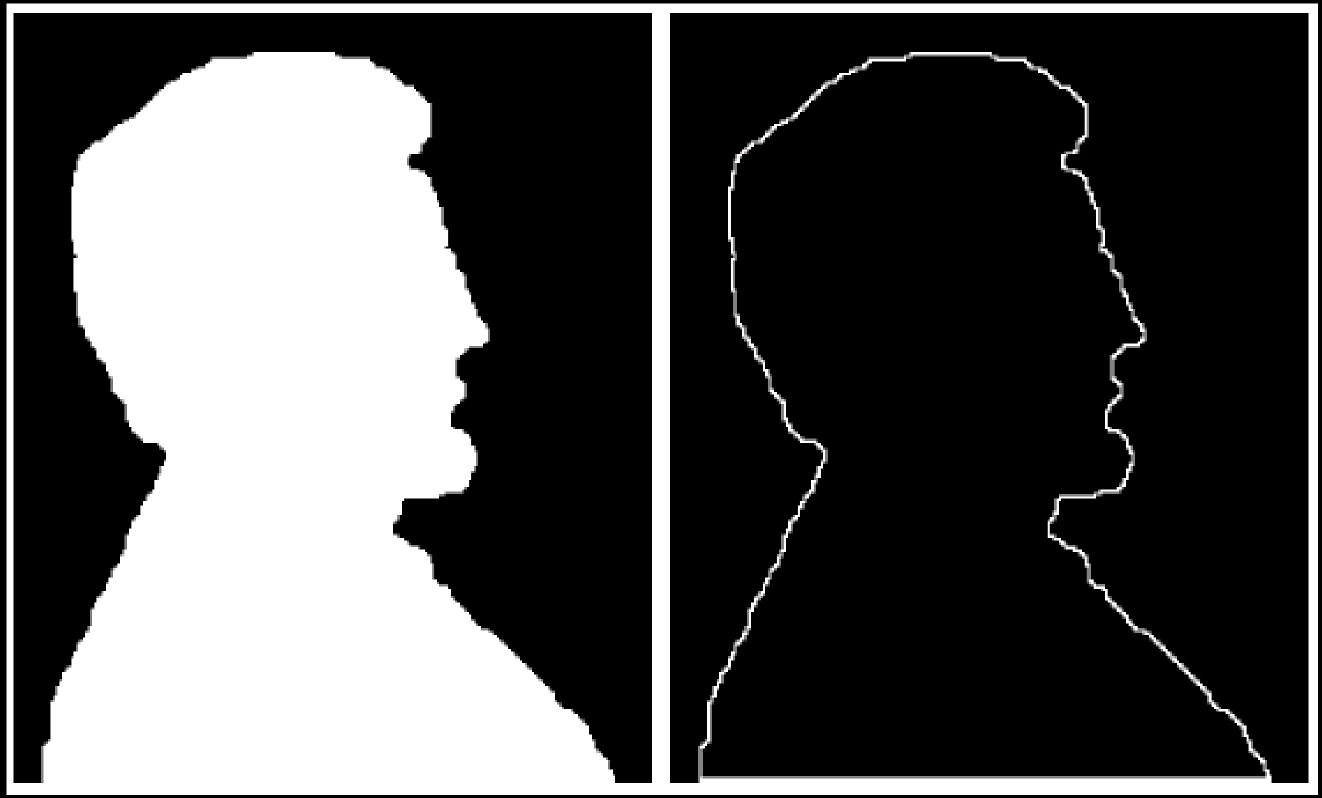
$$A - (A \ominus B)$$

where B is a 3x3 square structuring element.

That is, we subtract from A an erosion of it to obtain its boundary.

Slide: Ioannis Ivrissimtzis

Example of boundary extraction



Thinning

$$A \otimes B$$
$$= A - (A \circledast B)$$
$$= A \cap (A \circledast B)^c$$

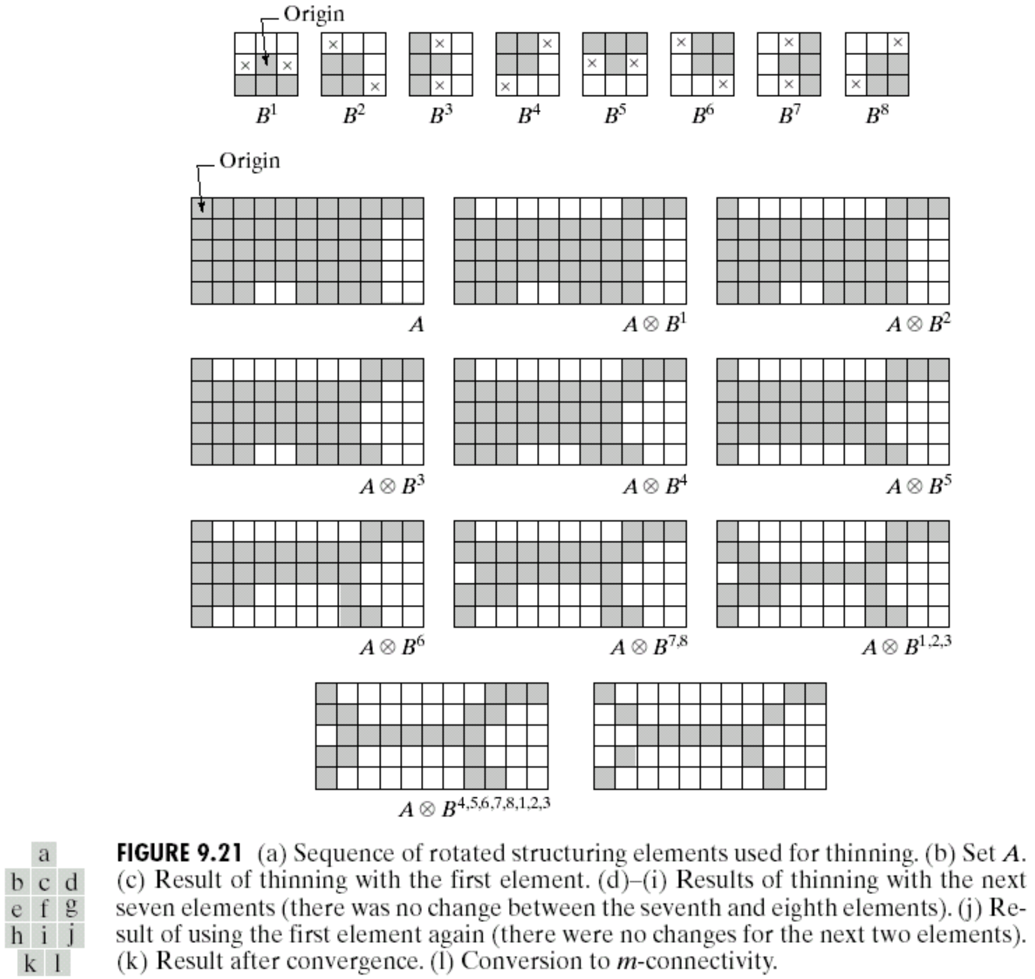


FIGURE 9.21 (a) Sequence of rotated structuring elements used for thinning. (b) Set A. (c) Result of thinning with the first element. (d)–(i) Results of thinning with the next seven elements (there was no change between the seventh and eighth elements). (j) Result of using the first element again (there were no changes for the next two elements). (k) Result after convergence. (l) Conversion to m-connectivity.

Thickening

$$A \odot B = A \cup (A \circledast B)$$

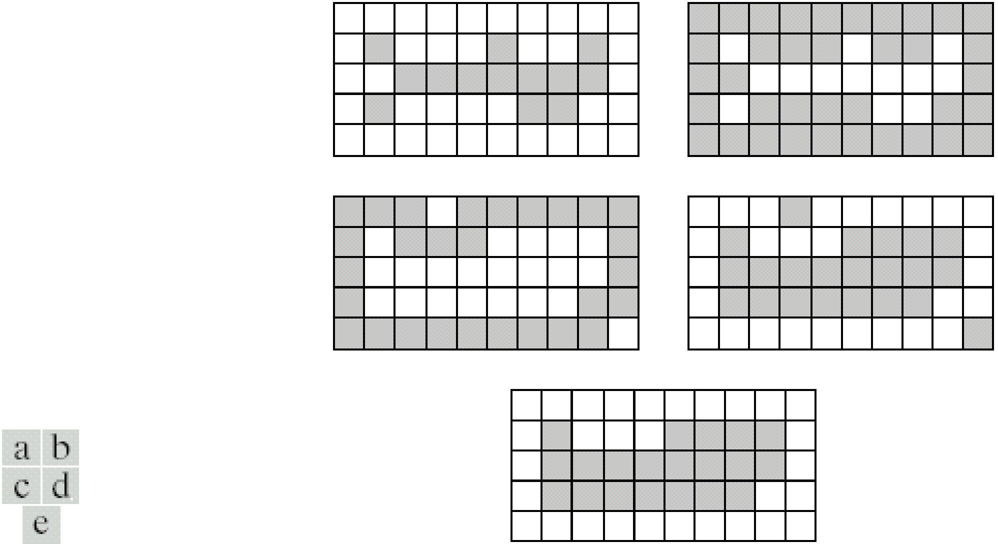


FIGURE 9.22 (a) Set A. (b) Complement of A. (c) Result of thinning the complement of A. (d) Thickened set obtained by complementing (c). (e) Final result, with no disconnected points.

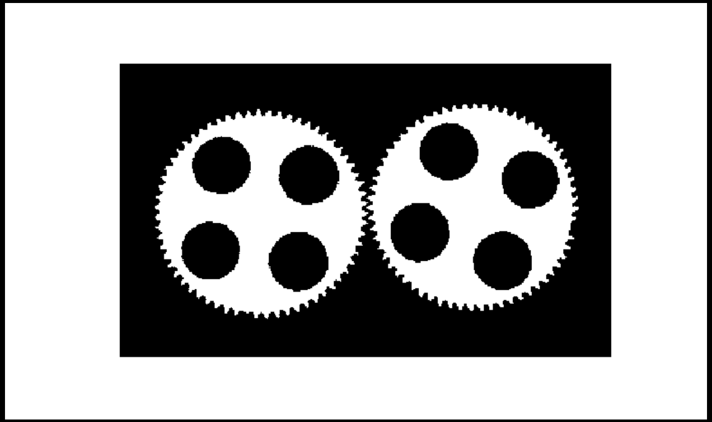
How powerful is morphology?

- It depends…

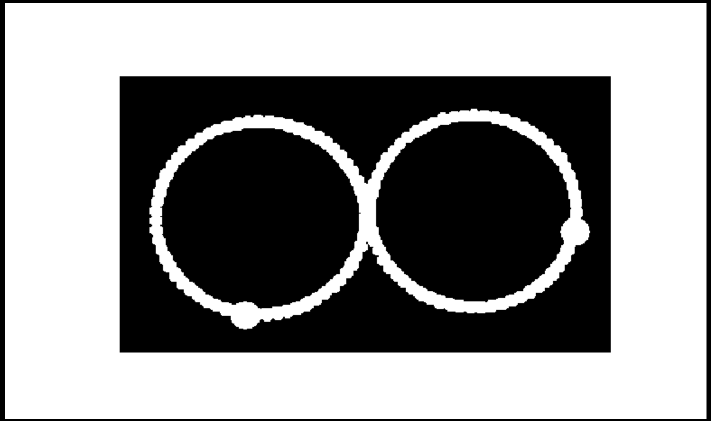
- If almost “clean” binary images then very powerful to both clean up images and to detect variations from desired image.

- Example…

Gear Tooth Inspection



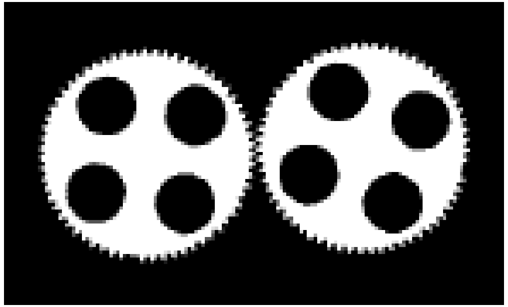
original binary image



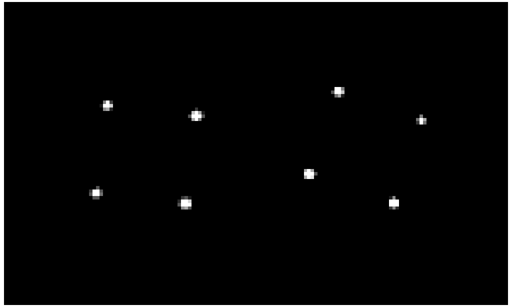
detected defects

How did they do it?

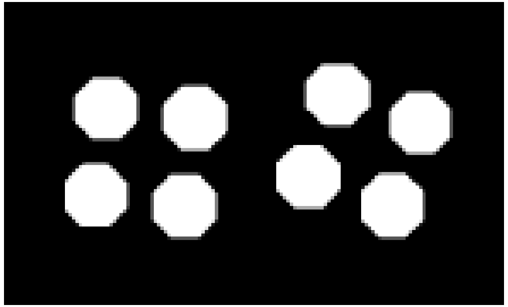
Slide by Linda Shapiro



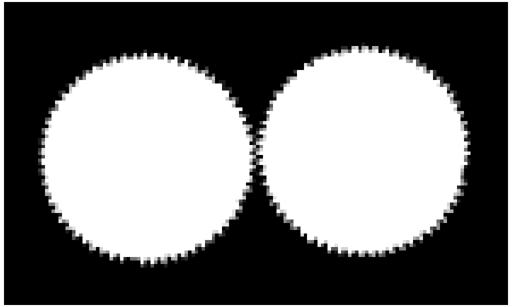
a) Original image B



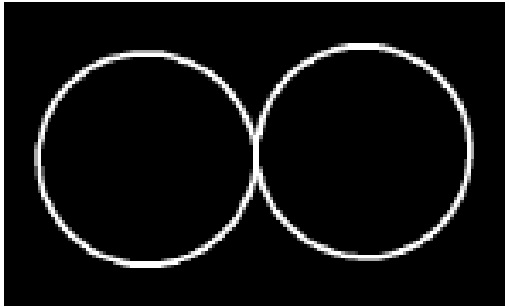
b) $B1 = B \ominus hole\_ring$



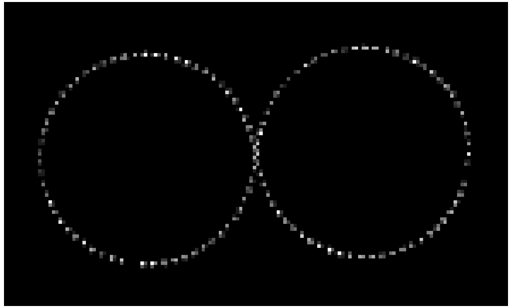
c) $B2 = B1 \oplus hole\_mask$



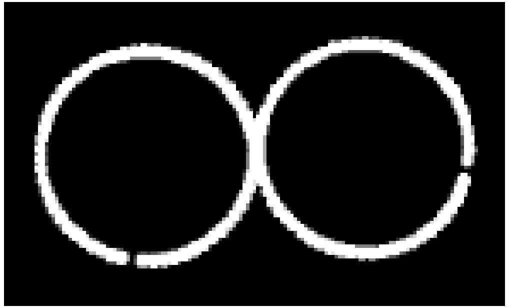
d) $B3 = B\ OR\ B2$



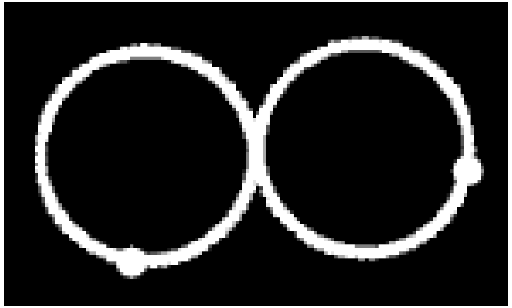
e) $B7$



f) $B8 = B\ AND\ B7$



g) $B9 = B8 \oplus tip\_spacing$



h) $RESULT = \left((B7 - B9) \oplus defect_{cue}\right)\ OR\ B9$

Geometric and Shape Properties

- area
- centroid
- perimeter
- perimeter length
- circularity
- elongation
- mean and standard deviation of radial distance
- bounding box
- extremal axis length from bounding box
- second order moments (row, column, mixed)
- lengths and orientations of axes of best-fit ellipse

Slide by Linda Shapiro