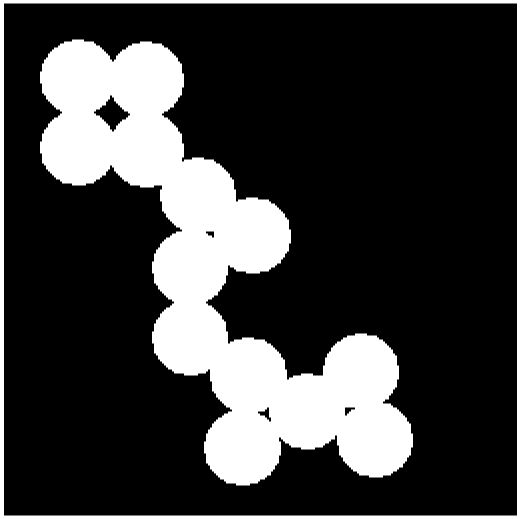
Binary Image Processing

Binary Images

- "Binary" means
  - 0 or 1 values only
  - Also called "logical" type (true/false)
- Obtained from
  - Thresholding gray level images
  - Result of feature detectors
- Often want to count or measure shape of 2D binary image regions
- Typical applications
  - Objects on a conveyor belt
  - Characters and text, maps
  - Chromosomes
  - Fingerprints
  - Circuit boards
  - Overhead aerial images



Outline

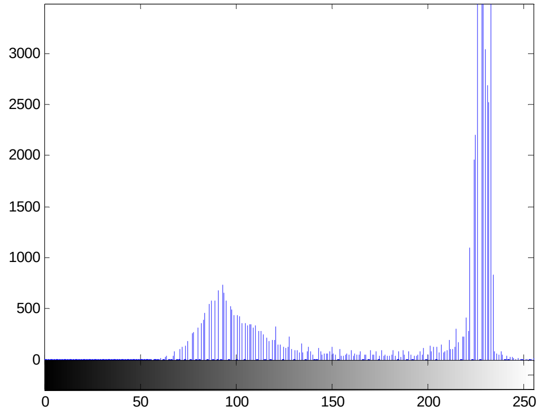
- Thresholding
- Logic operations
- Connected components
- Morphological operators
- Region properties, moments
- Lab – example to find fiducial target

Thresholding

- Convert gray scale image to binary (0s and 1s)
- Simplifies processing and computation of features
- Can use a single threshold value (global) or a local value (adaptive)

Thresholding in Matlab:

```
B = I > t;
```



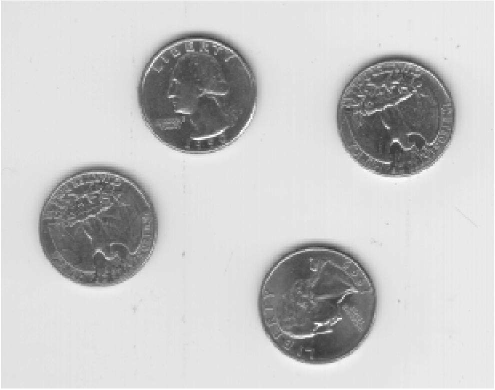
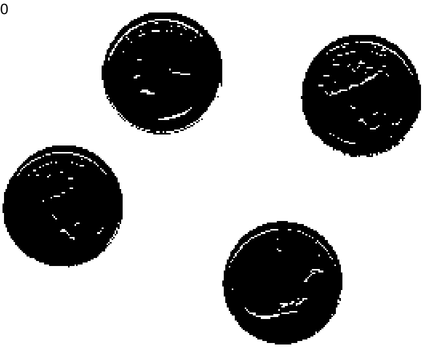


Image "eight.tif"

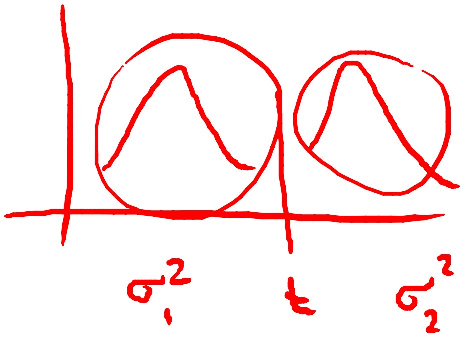


Global Threshold Computation

- Assume histogram is bimodal
- Choose threshold value to separate modes, and minimize classification error
- Otsu algorithm: minimize the within-group variances

VARIANCE: $\sigma^2 = \frac{1}{N}\sum (x_i - \bar{x})^2$ $\bar{x} = \frac{1}{N}\sum x_i$

$$\sigma_w^2 = N_1\sigma_1^2 + N_2\sigma_2^2$$



Matlab Examples

- Images
  - cameraman.tif, eight.tif, coins.png
- Functions
  - `t = graythresh(I)  % Otsu algorithm`
  - `BW = im2bw(I,t);   % performs thresholding`

Logic Operations

- Recall truth tables for logic operators

AND

x	y	z
0	0	0
0	1	0
1	0	0
1	1	1

OR

x	y	z
0	0	0
0	1	1
1	0	1
1	1	1

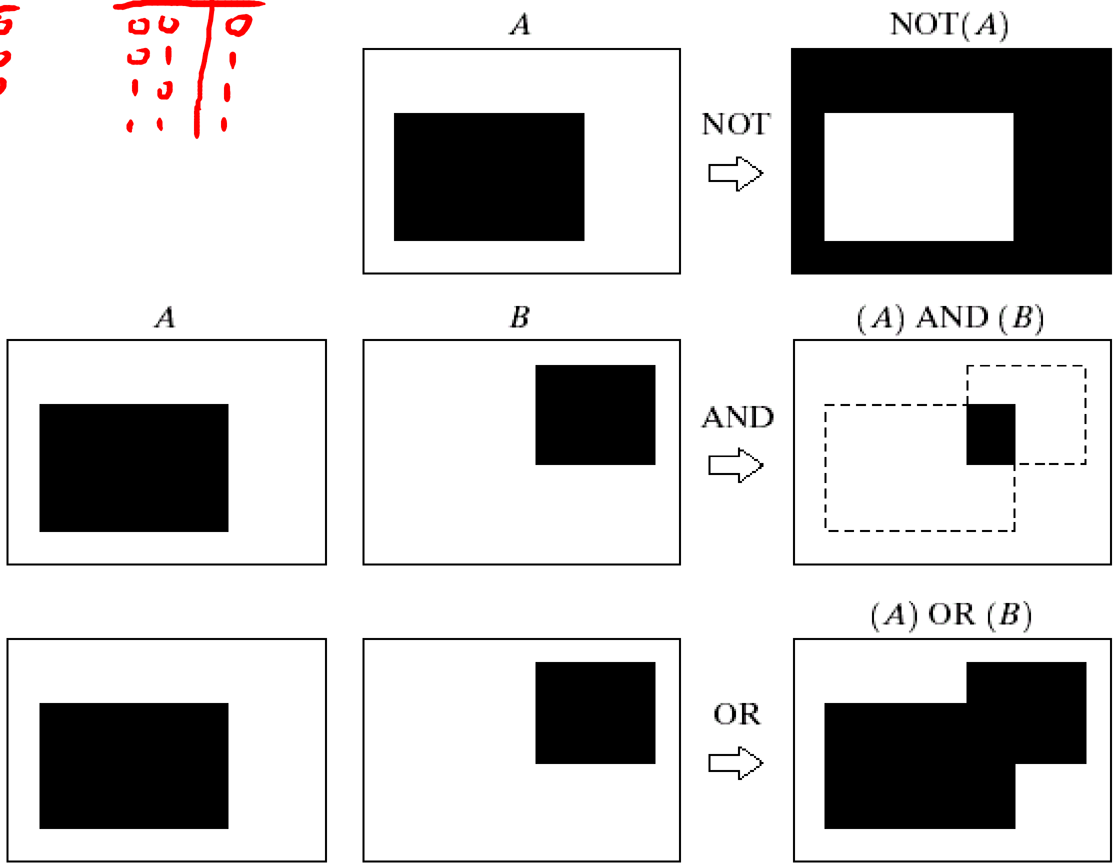
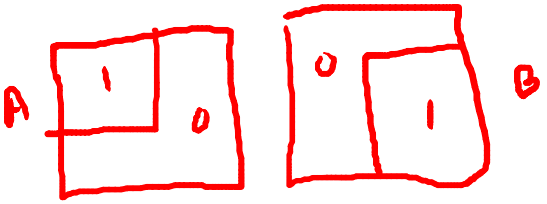


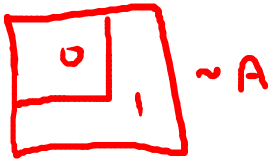
FIGURE 9.3 Some logic operations between binary images. Black represents binary 1s and white binary 0s in this example.

Also XOR, NAND, NOR

Matlab

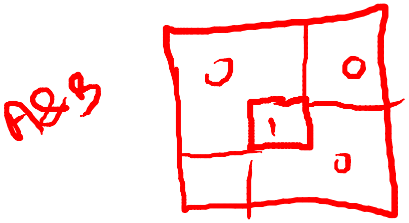


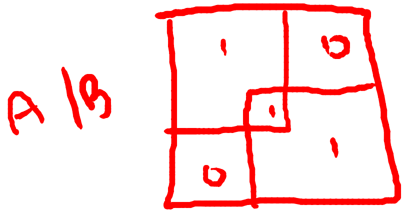
- Create binary images
  - A=false(10,10), A(1:6,1:6)=true;
  - B=false(10,10), B(4:10,4:10)=true;
- NOT
  - ~A
  - imcomplement(A)   % works on gray level too



Does a photo negative: 255-A

- AND
  - A&B;
- OR
  - C = A|B;





- Can also do bitwise AND, OR, etc of unsigned integers
  - A=uint8(zeros(10,10)), A(1:6,1:6)=30;
  - B=uint8(zeros(10,10)), B(4:10,4:10)=120;
  - bitand(A,B);

30   0 0 0 1   1 1 1 0

128 64 32 16   8 4 2 1

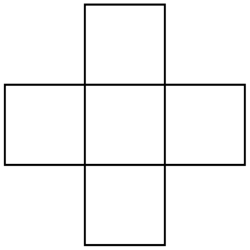
120   0 1 1 1   1 0 0 0

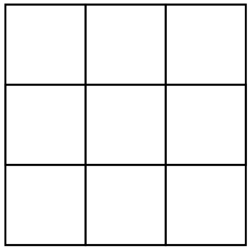
0 0 0 1 1 0 0 0

$= 24_{10}$

Connected Components

- Define adjacency
  - 4-adjacent
  - 8-adjacent

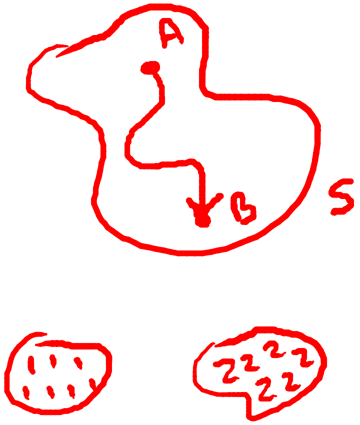




- Two pixels are connected in S if there is a path between them consisting entirely of pixels in S

- S is a (4- or 8-) connected component ("blob") if there exists a path between every pair of pixels

- "Labeling" is the process of assigning the same label number to every pixel in a connected component



Example

- Hand label simple binary image

	1	1				
	1	1				
			1	1		
	1		1	1		
	1		1			1

Binary image

	1	1				
	1	1				
			2	2		
	3		2	2		
	3		2			4

Labeled image (4-connected)

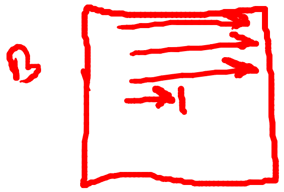
	1	1				
	1	1				
			1	1		
	2		1	1		
	2		1			3

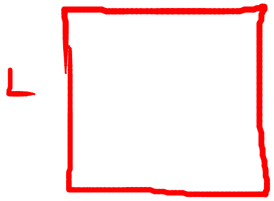
Labeled image (8-connected)

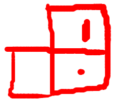
A Fast Labeling Algorithm

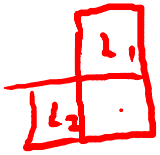
- One pass through image to assign temporary labels and record equivalences
- Second pass to replace temporary labels with equivalence labels
- Data:
  - B(r,c) is the input binary image
  - L(r,c) is the output labeled image

```
for c=1 to MAXCOL       {
        for r=1 to MAXROW       {
                if B(r,c) == 0 then
                        L(r,c) = 0;       % if pixel not white, assign no label
                else       {
                    IF   L(r-1,c)==0 && L(r,c-1)==0
                            L(r,c)= NUMLABEL++;

                    ELSE   L(r-1,c)≠0 && L(r,c-1)==0
                            L(r,c) = L(r-1,c)

                    ELSE   L(r,c-1) ≠0 && L(r-1,c) ==0
                            L(r,c) = L(r,c-1)

                    ELSE   L(r,c-1) ≠0 && L(r-1,c) ≠0
                            L(r,c) = $L_1$
                            RECORD   $L_1$,$L_2$ EQUIV
                END
        END
END
```









EQUIV	TEMP
1	1,2
2	3
3	4,5,6

Example

	1	1		1	
	1	1		1	
		1	1	1	
		1	1	1	

Binary image

	1	1		2	
	1	1		2	
		1	1	2	
		1	1	2	

Temporary labels after 1st pass

	1	1		1	
	1	1		1	
		1	1	1	
		1	1	1	

Final (equivalence) labels after 2nd pass

EQUIV	TEMP
1	1, 2

Matlab Example

- Labeling connected components (white blobs)
  - `im2bw`
    - threshold to convert to binary image
  - `bwlabel`
    - do connected component labeling
    - generate an image of labels
  - `label2rgb`
    - for visualization
    - converts each label to a random color

- If we want to find black blobs
  - `imcomplement`
    - Flip black and white regions
  - then repeat steps

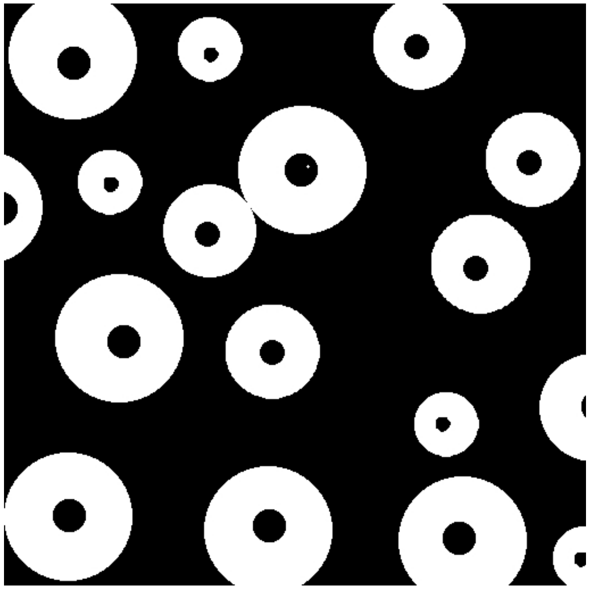


Image Fig9-16(a).jpg

```
>> I = imread('Fig9.16(a).jpg');
>> imshow(I,[])
>> whos
  Name       Size             Bytes  Class    Attributes

  I        512x512           262144  uint8

>> BW = im2bw(I, graythresh(I));
>> figure, imshow(BW)
>> [L,num] = bwlabel(BW);
>> figure, imshow(L,[])
>> num

num =

    17

>> RGB = label2rgb(L);
>> figure, imshow(RGB)
>> BW = imcomplement(BW);
>> [L,num] = bwlabel(BW);
>> RGB = label2rgb(L);
>> figure, imshow(RGB)
```

Binary Image Morphology

- Operations on binary images:
  - dilation and erosion
  - opening and closing
- Uses include
  - shrinking and expanding regions
  - eliminating small regions or holes
- Operations are performed with a “structuring element” S
  - a small binary image
  - like a filter mask

Dilation

1	1	1
1	**1**	1
1	1	1

S

- Defined as

$$B \oplus S = \bigcup_{b \in B} S_b$$

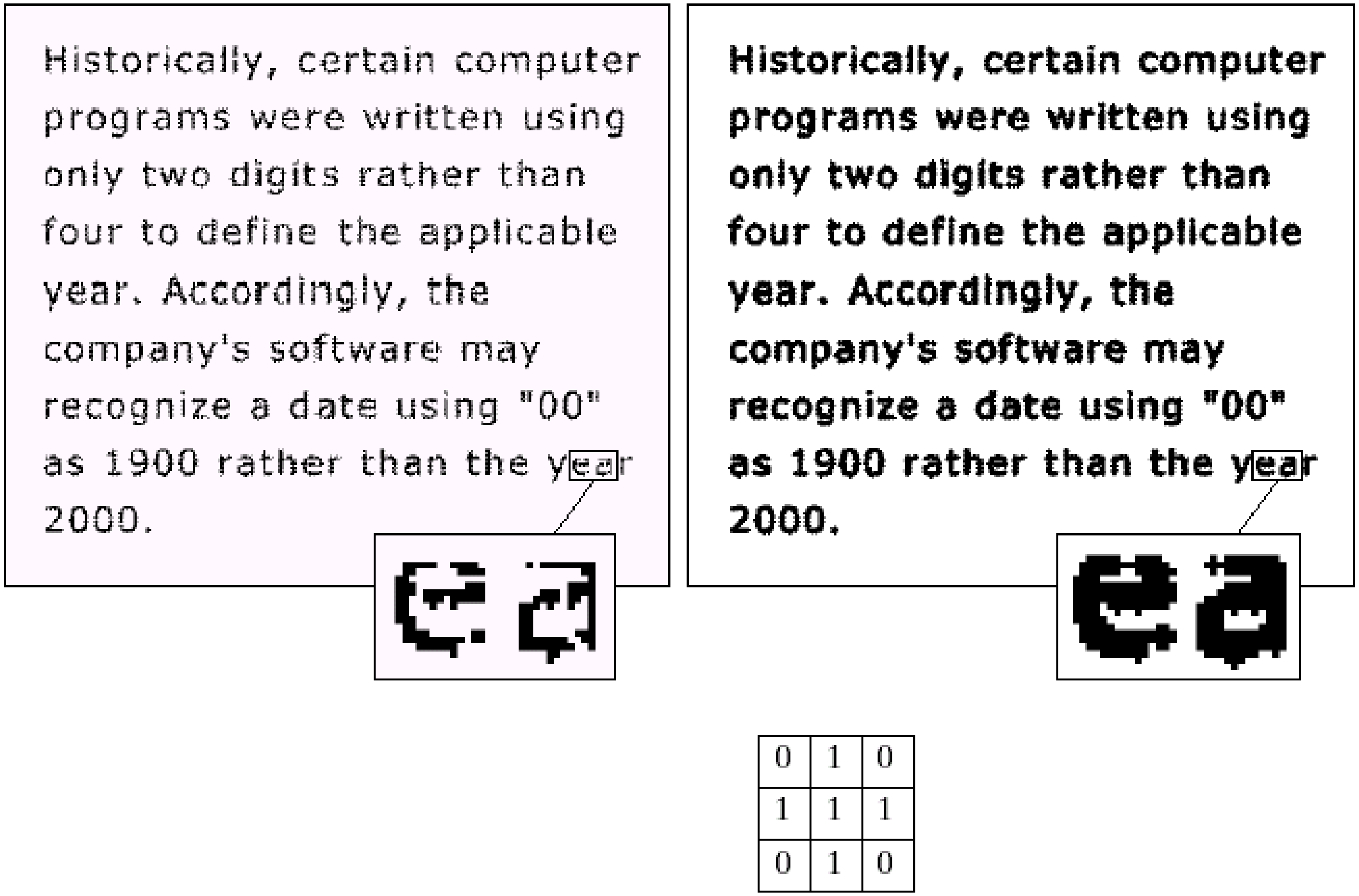
- where
  - S_b is the structuring element S, shifted to b
- Procedure
  - Sweep S over B
  - Everywhere the origin of S touches a 1, OR S with B
- Expands regions

		1		1	
		1	1		

B

	1	1	1	1	1
	1	1	1	1	1
	1	1	1	1	1
	1	1	1	1	

$B \oplus S$



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.

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0	1	0
1	1	1
0	1	0

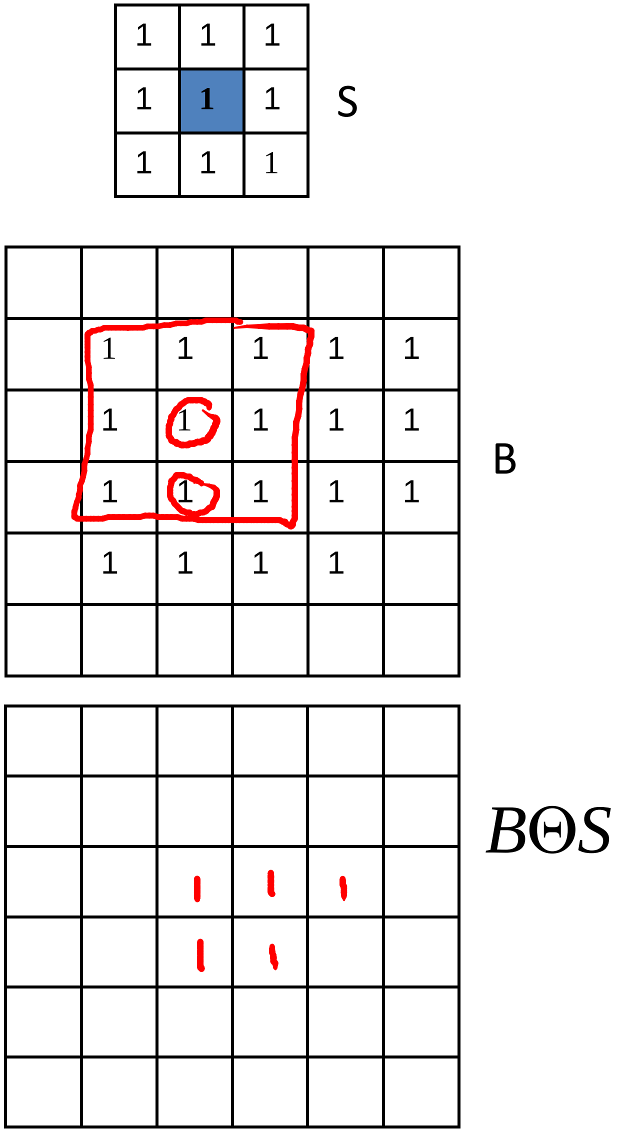
FIGURE 9.5
(a) Sample text of poor resolution with broken characters (magnified view). (b) Structuring element. (c) Dilation of (a) by (b). Broken segments were joined.

Erosion

- Defined as

$$B \Theta S = \{ b \mid b + s \in B, \forall s \in S \}$$

- Procedure
  - Sweep S over B
  - Everywhere S is completely contained in B, output a 1 at the origin of S
- Shrinks regions



S

1	1	1
1	**1**	1
1	1	1

B

	1	1	1	1	1
	1	1	1	1	1
	1	1	1	1	1
	1	1	1	1	

$B \Theta S$

		1	1	1	
		1	1		

Matlab

- Create a structuring element
  - `strel(‘disk’, 5)     % disk shape, radius=5`
- Dilation
  - `imdilate(I,S)`
- Erosion
  - `imerode(I,S)`

Openings and Closings

- Opening
  - Erosion followed by dilation
  - Eliminate small regions and projections

$$B \circ S = \left(B \Theta S\right) \oplus S$$

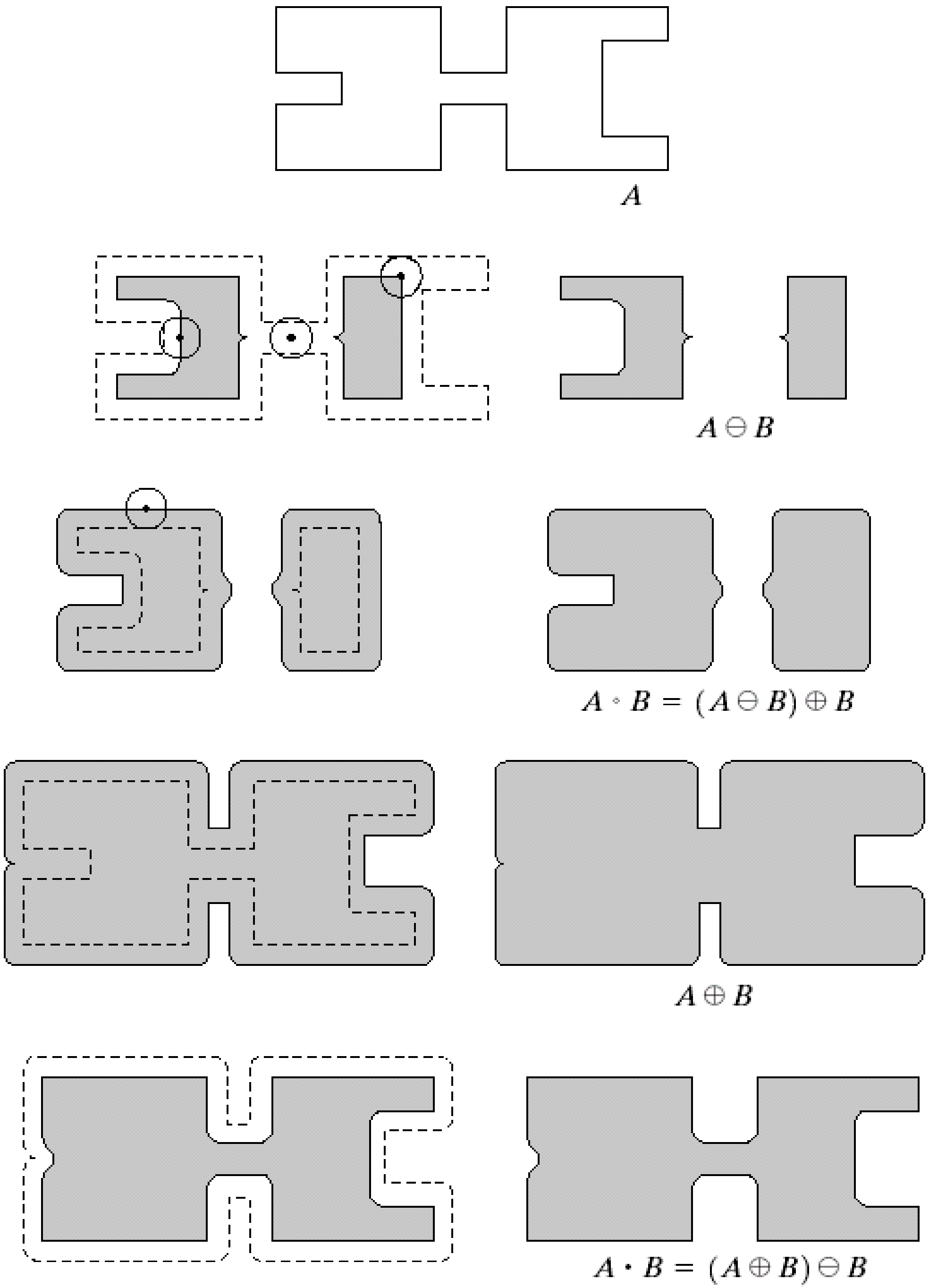
- Closing
  - Dilation followed by erosion
  - Fill in small holes and gaps

$$B \bullet S = \left(B \oplus S\right) \Theta S$$

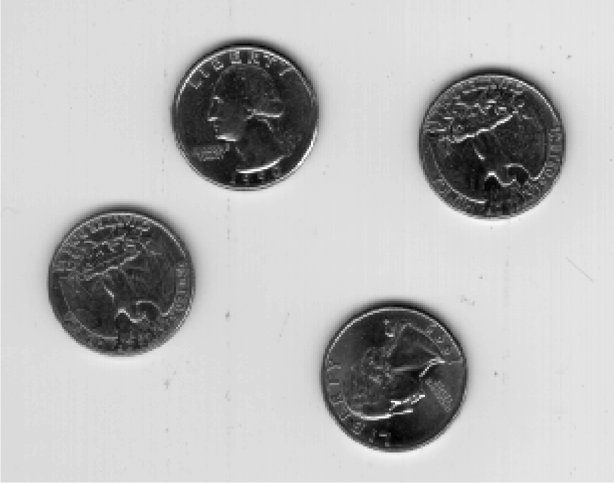
- Matlab `imopen, imclose`

a
b c
d e
f g
h i

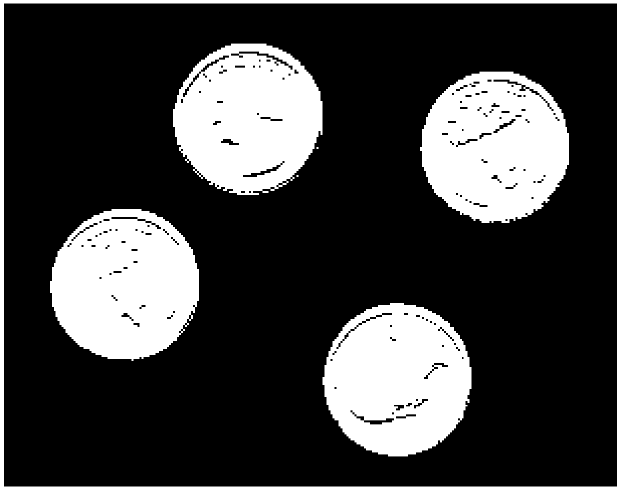
FIGURE 9.10 Morphological opening and closing. The structuring element is the small circle shown in various positions in (b). The dark dot is the center of the structuring element.


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

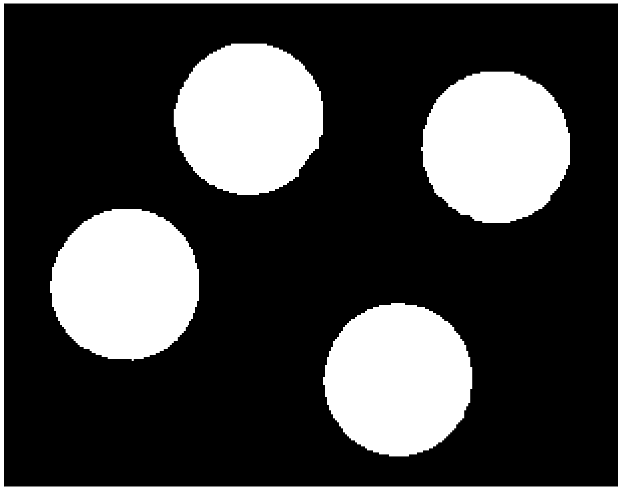
Closing Example



Matlab image “eight.tif”



threshold, complement



close with disk of radius=5

Region Properties

- Basic features

$$\text{Area} \quad A = \sum_{(r,c)\in R} 1 \qquad \text{Centroid} \quad \bar{r} = \frac{1}{A}\sum_{(r,c)\in R} r, \quad \bar{c} = \frac{1}{A}\sum_{(r,c)\in R} c$$

- Higher order moments

$$\mu_{rr} = \frac{1}{A}\sum_{(r,c)\in R}(r-\bar{r})^2, \quad \mu_{cc} = \frac{1}{A}\sum_{(r,c)\in R}(c-\bar{c})^2, \quad \mu_{rc} = \frac{1}{A}\sum_{(r,c)\in R}(r-\bar{r})(c-\bar{c})$$

- Principal axes
  - computed from second order moments

- Matlab function `regionprops(L)`

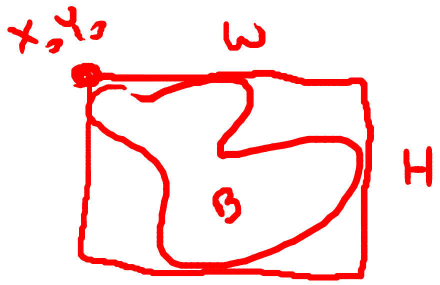
Matlab Structures

- A structure is an array with named "fields"
- Access using: *structurename.fieldname*
- See Matlab help for more info
- Example

TO ACCESS

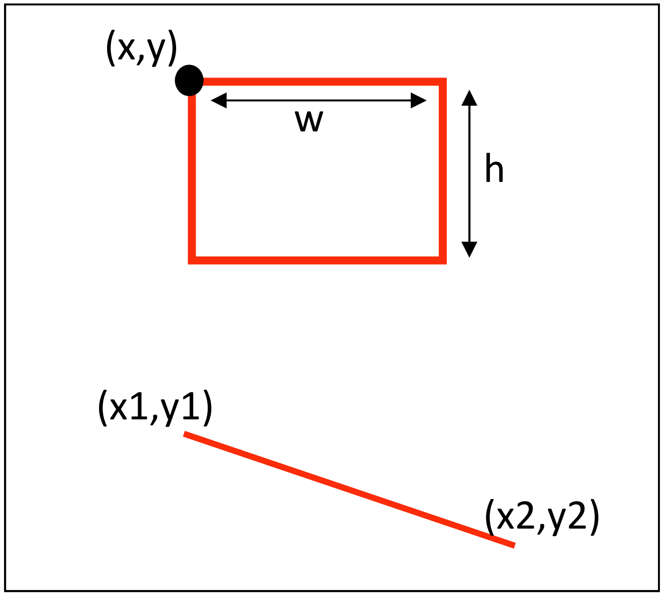
BLOBS(2). AREA

```
>> blobs = regionprops(L);
>> blobs(1)

ans =

           Area: 2058  X      Y
       Centroid: [15.7216 179.8717]
    BoundingBox: [0.5000 133.5000 34 93]

                  X0       Y0
```



Matlab Graphics

```
rectangle('Position', [x y w h]), ‘EdgeColor’, ‘r’);
```



```
line([x1 x2], [y1 y2], ‘Color’, ‘r’);
```

Matlab Example

- Draw bounding box around largest blob
- Draw cross hair on its centroid

```
>> I = imread('Fig9.16(a).jpg');
>> BW = im2bw(I, graythresh(I));
>> L = bwlabel(BW);
>> blobs = regionprops(L);
>> areas = cat(1, blobs(:).Area);  % concatentate along dimension 1
>> [value, index] = max(areas);
>>
>> value
value =
      14240

>> index
index =
    6

>> imshow(I)
>> rectangle('Position', blobs(index).BoundingBox, 'EdgeColor', 'w');

>> rectangle('Position', [x0-1 y0-1 3 3], 'EdgeColor', 'k');
```