Lecture 5
Binary Image Processing

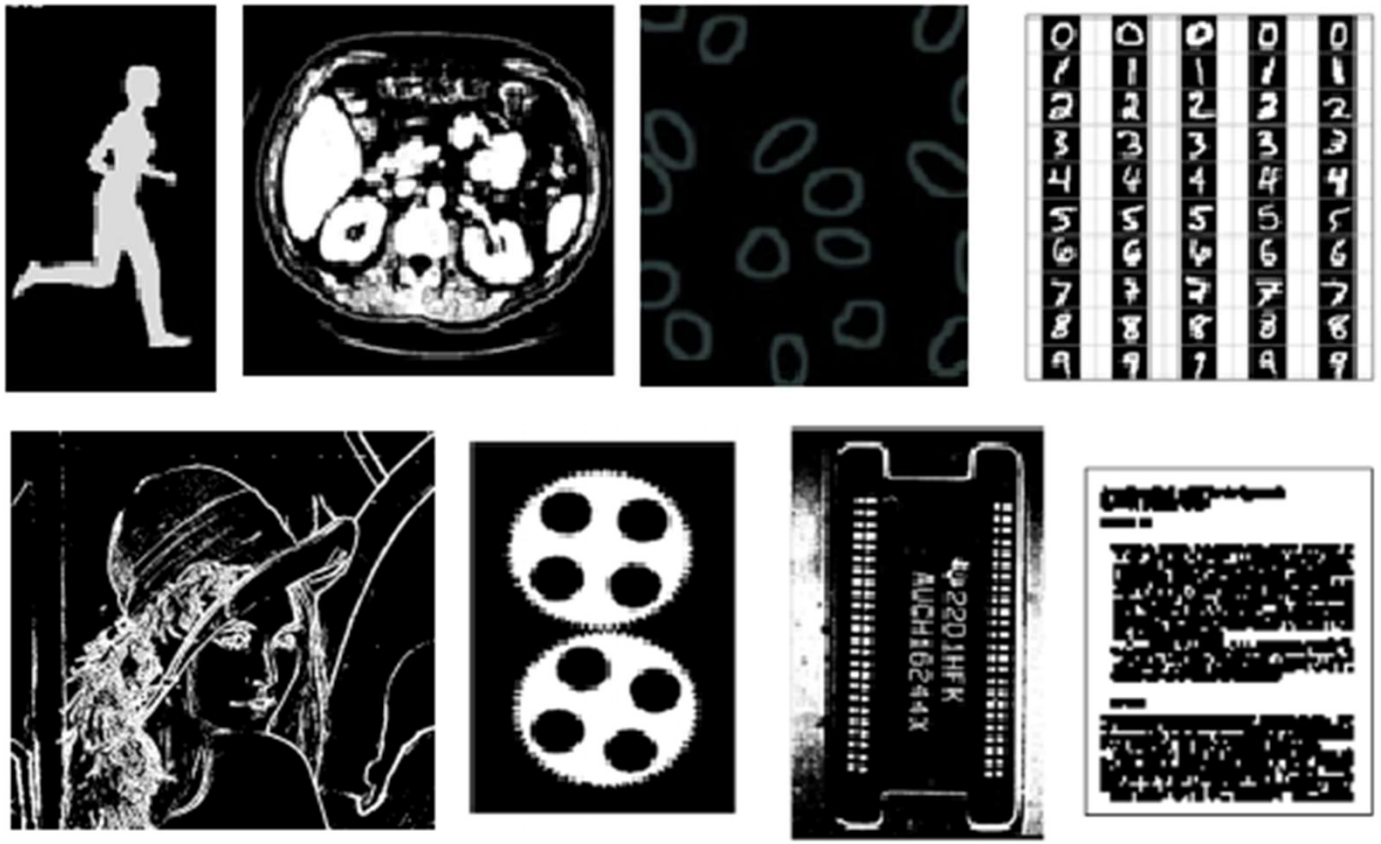
Lecture Outline

- What are binary images?
- Morphological Operations
- Blob Extraction (and labelling)
- Blob Description

What are binary images?

Are they of any good use?

Binary Images



Binary image processing: Tasks

- Convert the image into binary form
  - **Thresholding**
- Clean up the thresholded image
  - **Morphological operators**
- Extract separate blobs
  - **Connected components**
- Describe the blobs with region properties

Binary images

› **Two** pixel values
  – Foreground and background
  – Mark region(s) of interests (ROI)

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

Thresholding

› Grayscale image ⇒ **Binary image**

› Useful if object of interest's intensity distribution is distinct from background

› Here are some scenarios…

$$F_T(i,j) = \begin{cases} 1 & if\ F(i,j) \geq T \\ 0 & otherwise \end{cases}$$

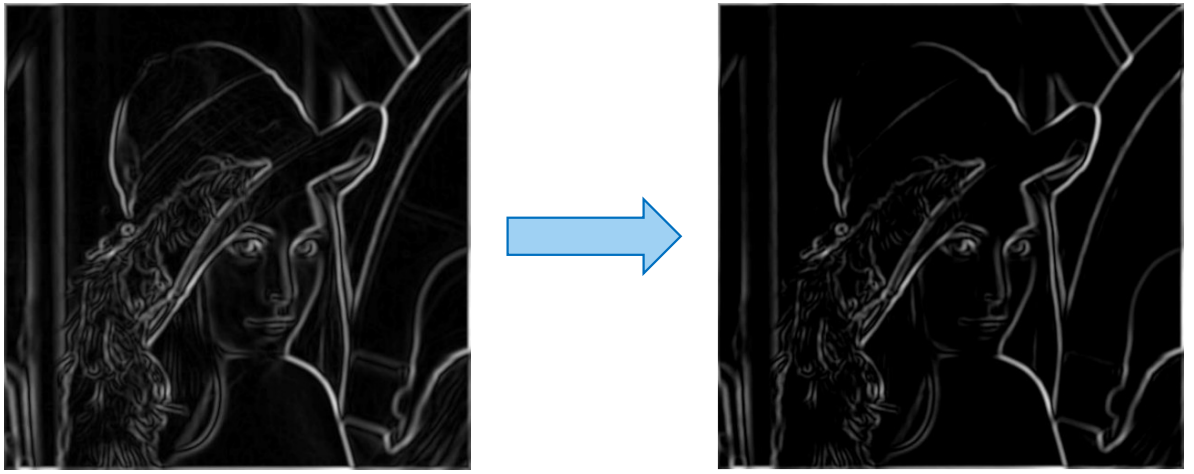
$$F_T(i,j) = \begin{cases} 1 & if\ T_1 \leq F(i,j) \leq T_2 \\ 0 & otherwise \end{cases}$$

$$F_T(i,j) = \begin{cases} 1 & if\ F(i,j) \in Z \\ 0 & otherwise \end{cases}$$

Thresholding: Uses

› Given a grayscale image or an intermediate matrix of values ⇒ **threshold** to create a **binary output**

Edge detection



Gradient magnitude

Find strong gradient that are above a certain **threshold**

Output will be
1 : edge
0 : non-edge

Thresholding: Uses

› Given a grayscale image or an intermediate matrix of values ⇒ **threshold** to create a **binary output**

Background Subtraction

Background — Captured scene

Output will be
1 : movement
0 : non-movement

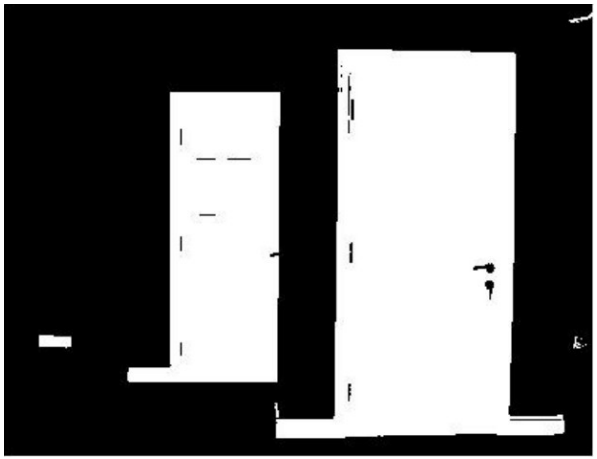
Find pixels that **differ significantly** from the "empty" background

Thresholding: Uses

› Given a grayscale image or an intermediate matrix of values ⇒ **threshold** to create a **binary output**

Intensity-based Detection

Image



Find pixels that dark, **corresponding to the detection** of dark-intensity doors

Output will be
1 : object of interest
0 : background

Thresholding: Uses

› Given a grayscale image or an intermediate matrix of values ⇒ **threshold** to create a **binary output**

Colour-based Detection

Image

Find pixels that are **within a certain hue (colour)** range, e.g. skin colour

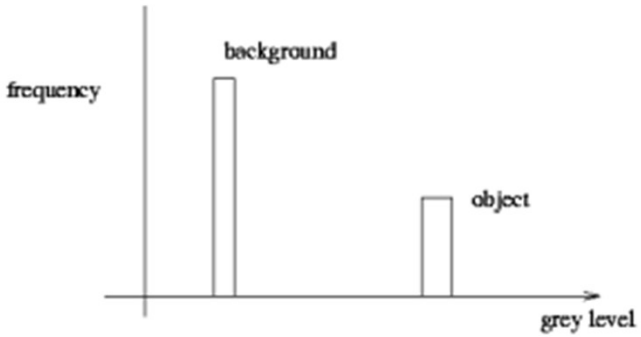
Output will be
1 : object of interest
0 : background

What to use?

› What is a suitable information to use to convert this gif into a binary image/clip of only the dog?

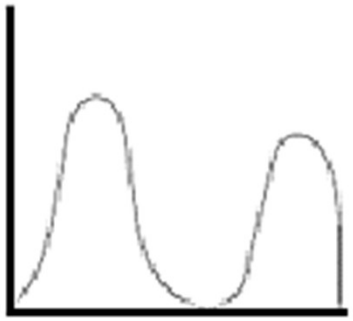
A. Edges
B. Background
C. Color
D. All of the above

Histograms: Nice case

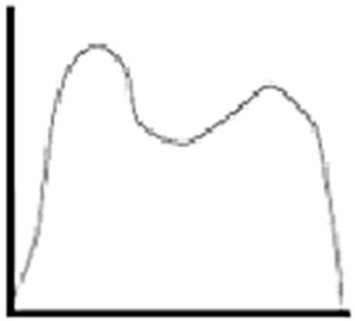


Ideal histogram: light object on a dark background

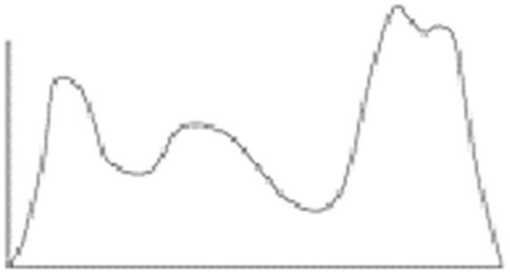
Histograms: Not-so-nice case



Two distinct modes
Easy



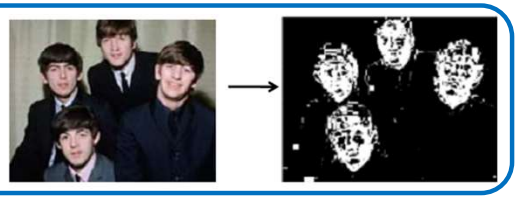
Overlapping modes
Challenging!



…

Two tasks ahead

Revisiting this task ⇒



1. What to do with “noisy” binary outputs?

2. How to demarcate (mark) multiple regions of interest?
   - Count objects
   - Compute further features from objects

Morphological Operations

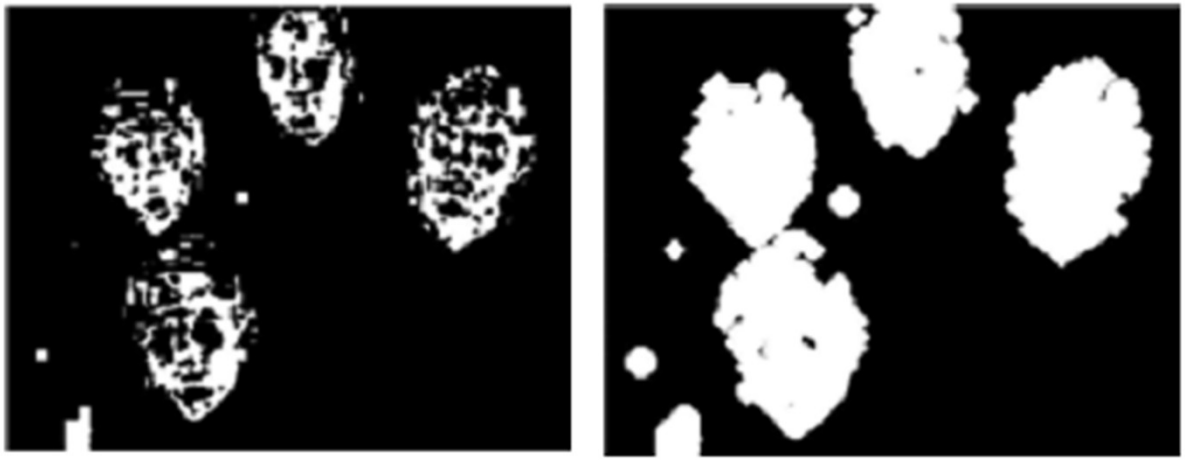
Dealing with noisy binary output

Morphological operators

- Change the shape of the foreground regions via intersection/union operations between a scanning structuring element and binary image
- Useful for cleaning up result from thresholding
- Basic operators:
  - **Dilation**
  - **Erosion**

Dilation

- Expands connected regions
- “Grow” pixels
- Fill holes



Before dilation

After dilation

Erosion

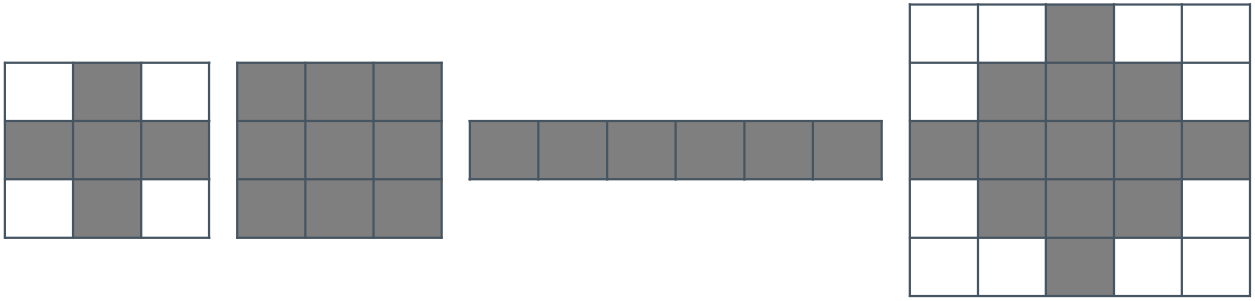
- Erodes connected regions
- “Trim” pixels
- Removes bridges, branches, noise

Before erosion

After erosion

Structuring elements

› Masks of varying shapes and sizes are used for morphological operations:



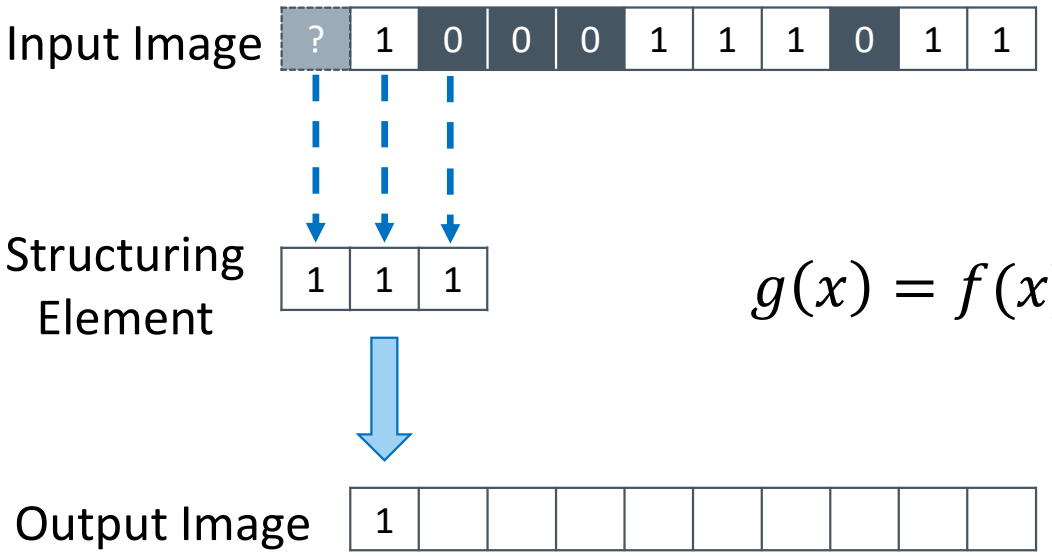
› Scan mask across foreground pixels to transform the binary image

Dilation vs. Erosion

› At each position:

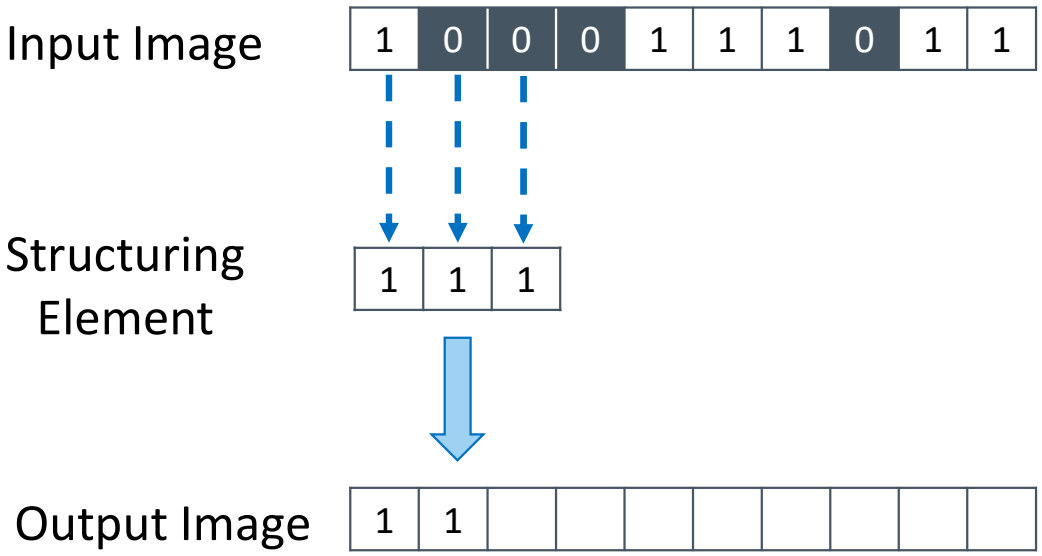
– **Dilation**: If current pixel is foreground, **OR** the structuring element with the input image

1-D Example of Dilation

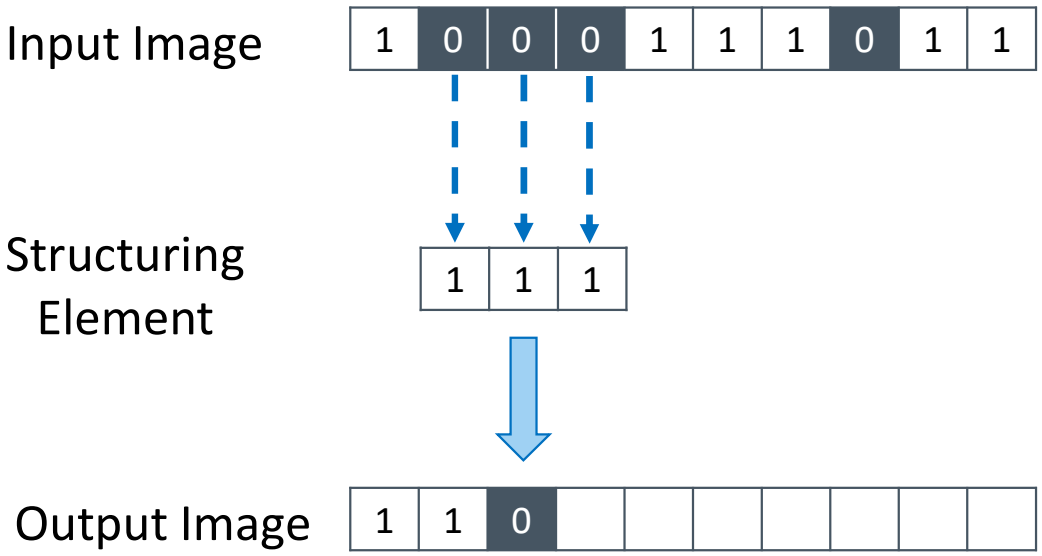


$$g(x) = f(x) \oplus SE$$

1-D Example of Dilation

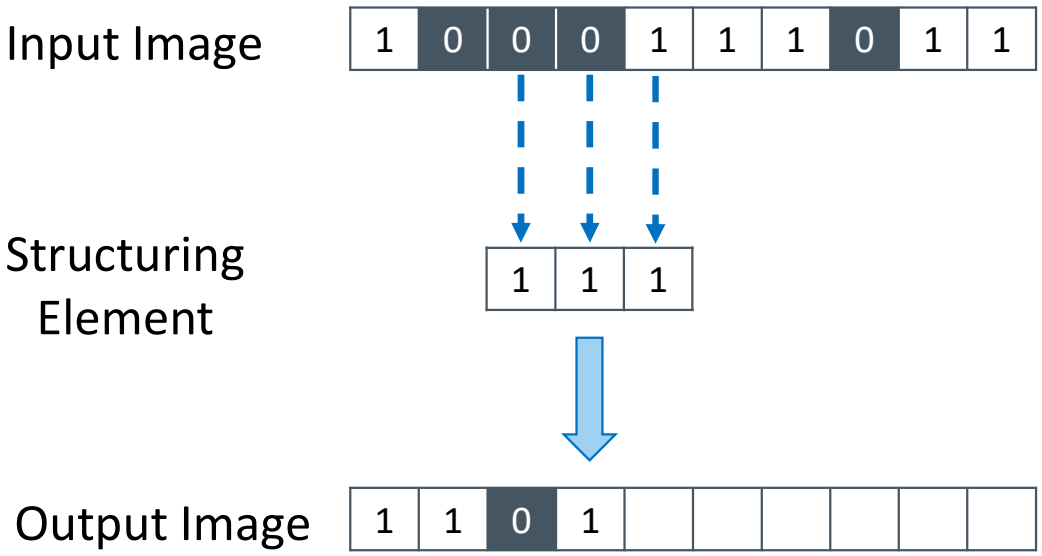


1-D Example of Dilation

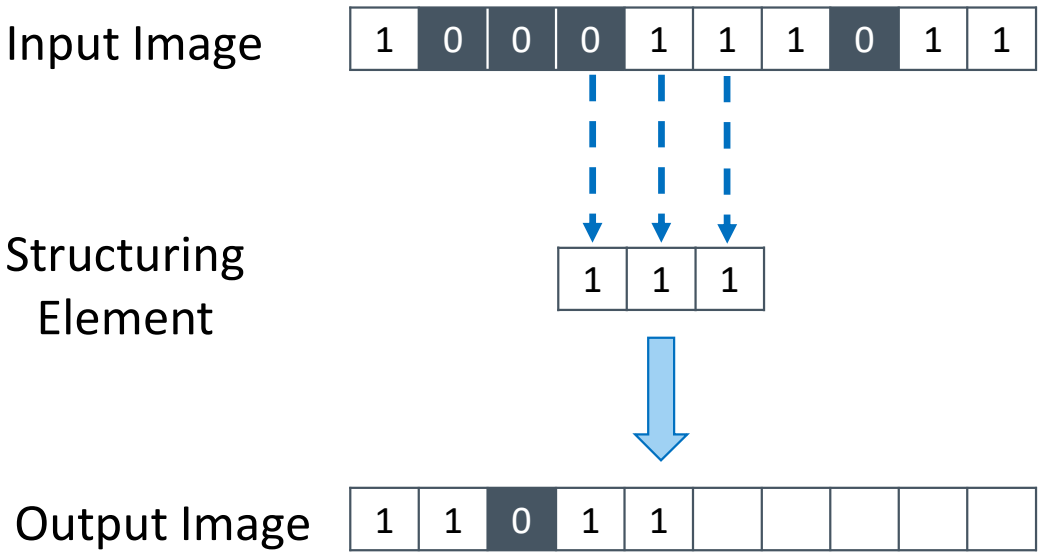


Remember: OR-ing only happens when there is a FOREGROUND PIXEL.

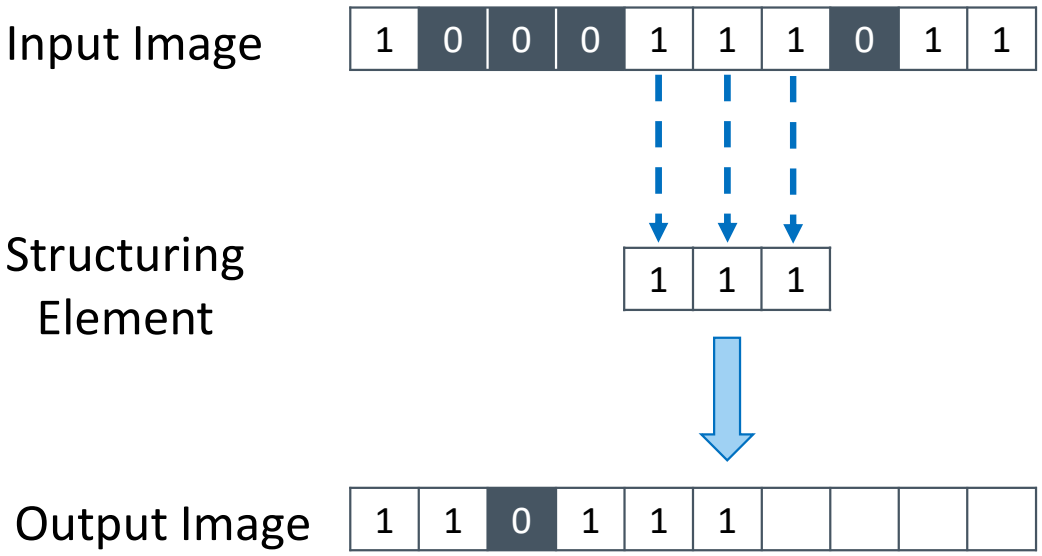
1-D Example of Dilation



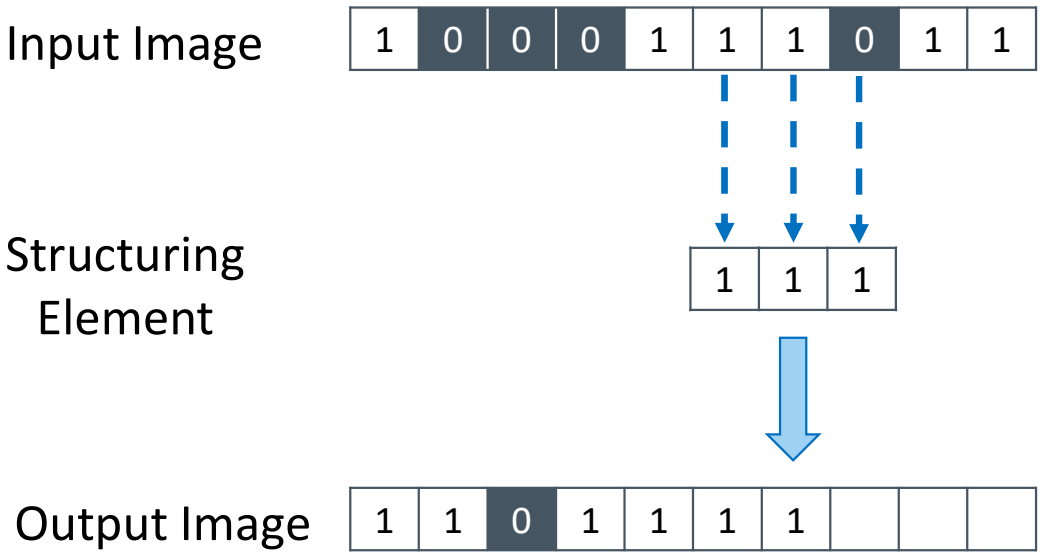
1-D Example of Dilation



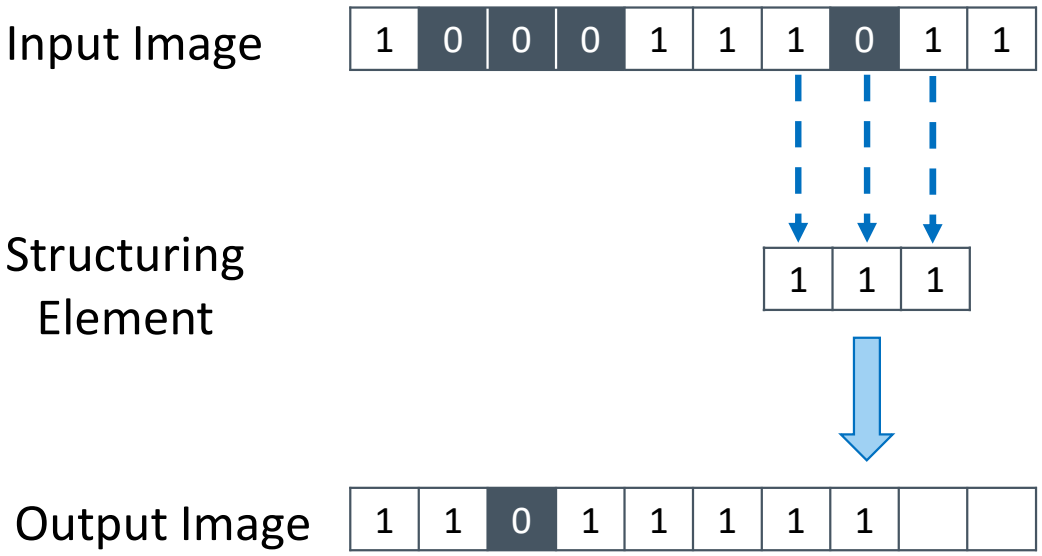
1-D Example of Dilation



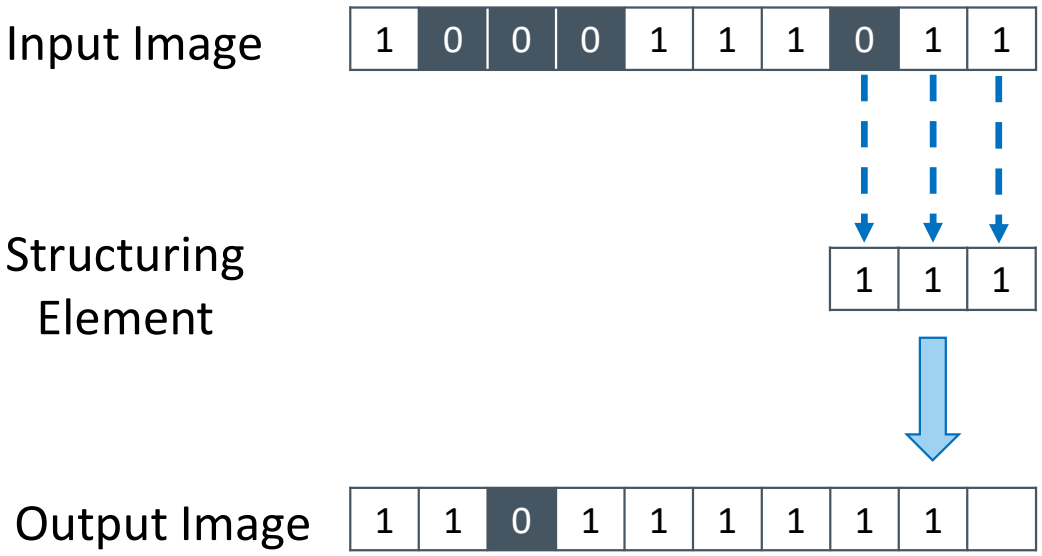
1-D Example of Dilation



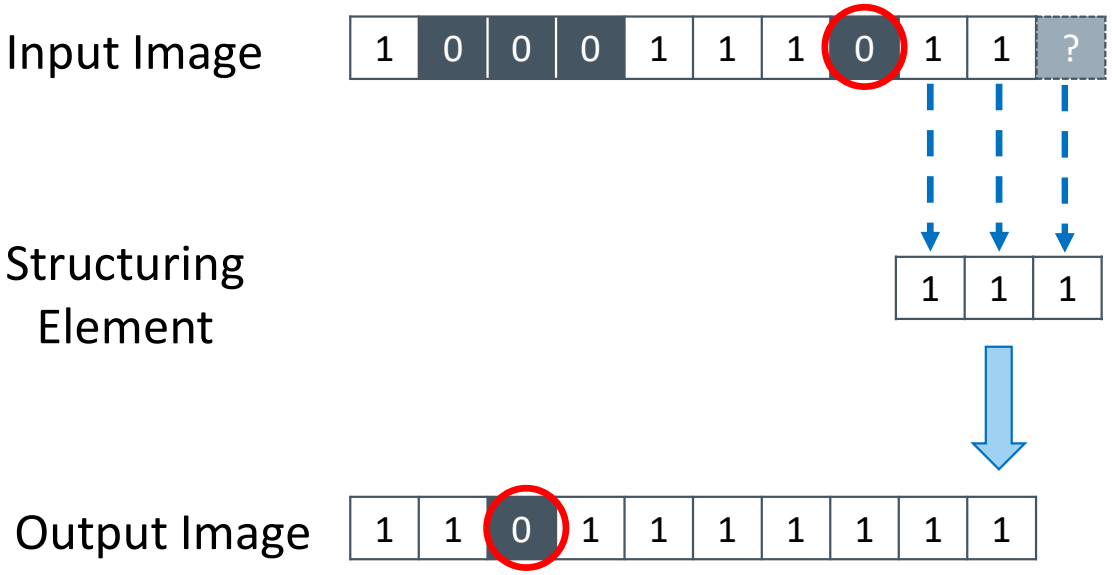
1-D Example of Dilation



1-D Example of Dilation



1-D Example of Dilation

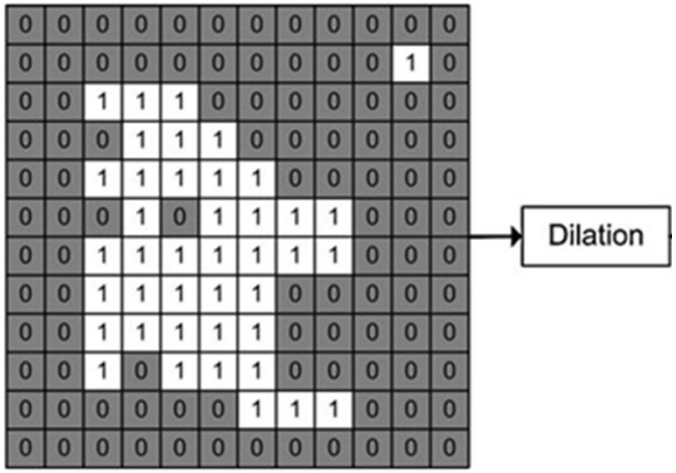


What do you observe here?

2-D Example of Dilation

› Using a 3x3 structuring element, with the middle center pixel taken as the reference pixel:

1	1	1
1	1	1
1	1	1



A. More 1s, and thicker white regions
B. More 0s and thinner white regions
C. No change

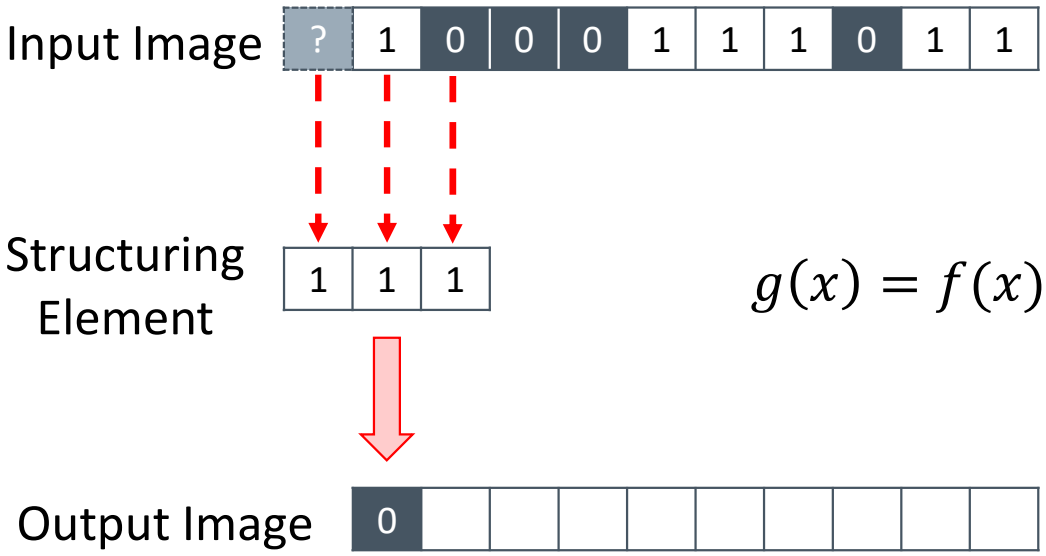
What would be the output?

Dilation vs. Erosion

› At each position:

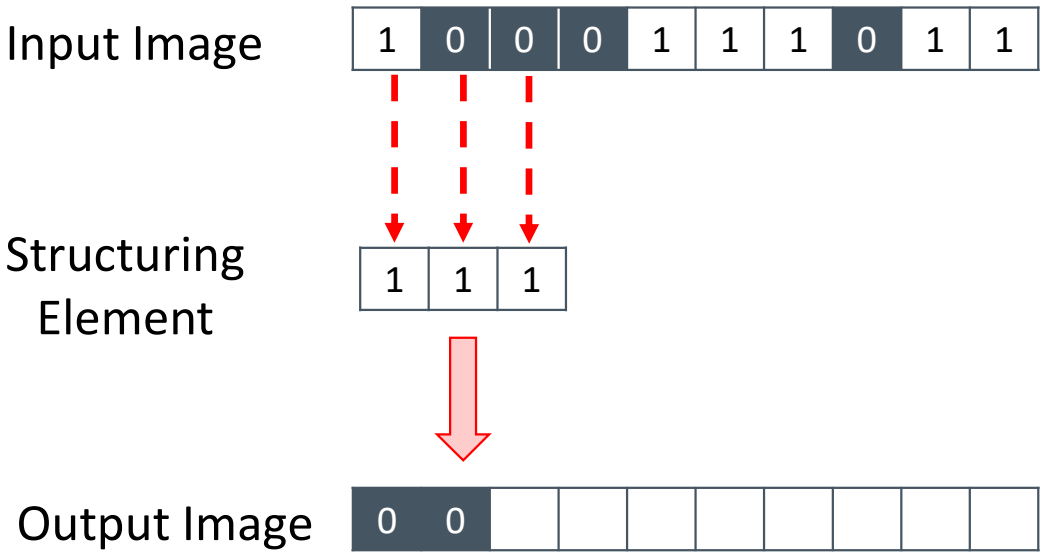
- **Dilation**: If current pixel is foreground, **OR** the structuring element with the input image.
- **Erosion**: If **every pixel** under the structuring element's nonzero entries is foreground, **OR** the current pixel with structuring element (at reference point).

1-D Example of Erosion

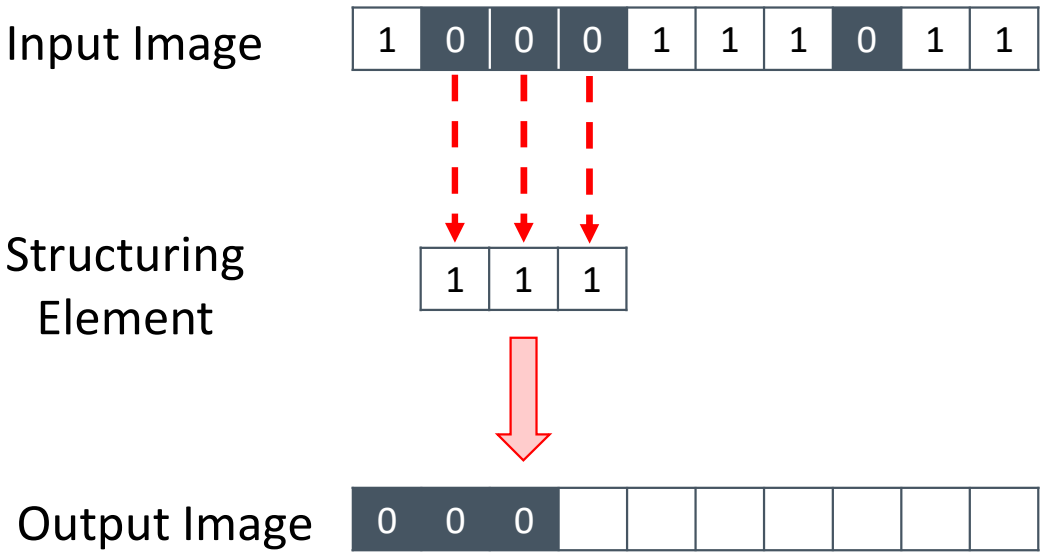


$$g(x) = f(x) \ominus SE$$

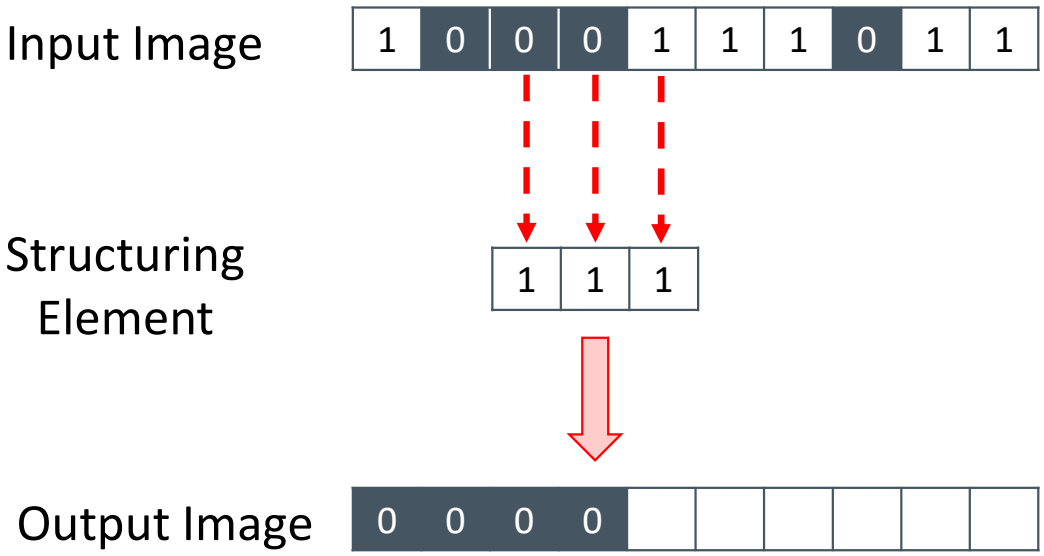
1-D Example of Erosion



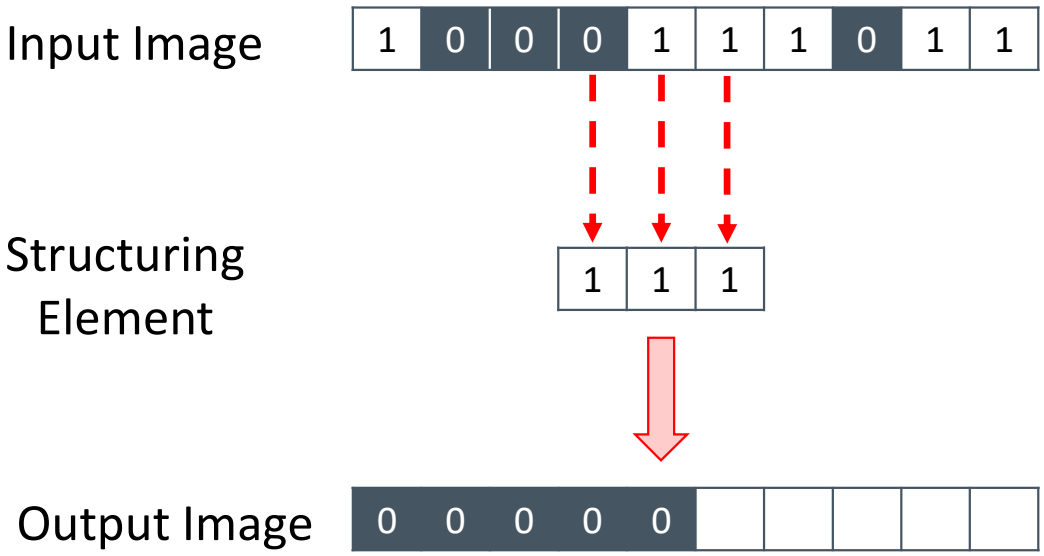
1-D Example of Erosion



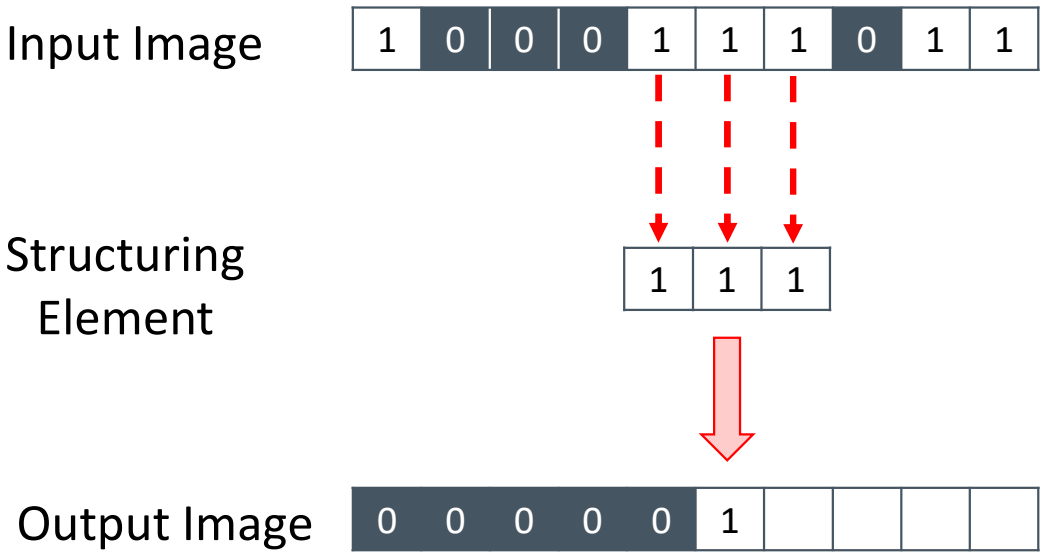
1-D Example of Erosion



1-D Example of Erosion

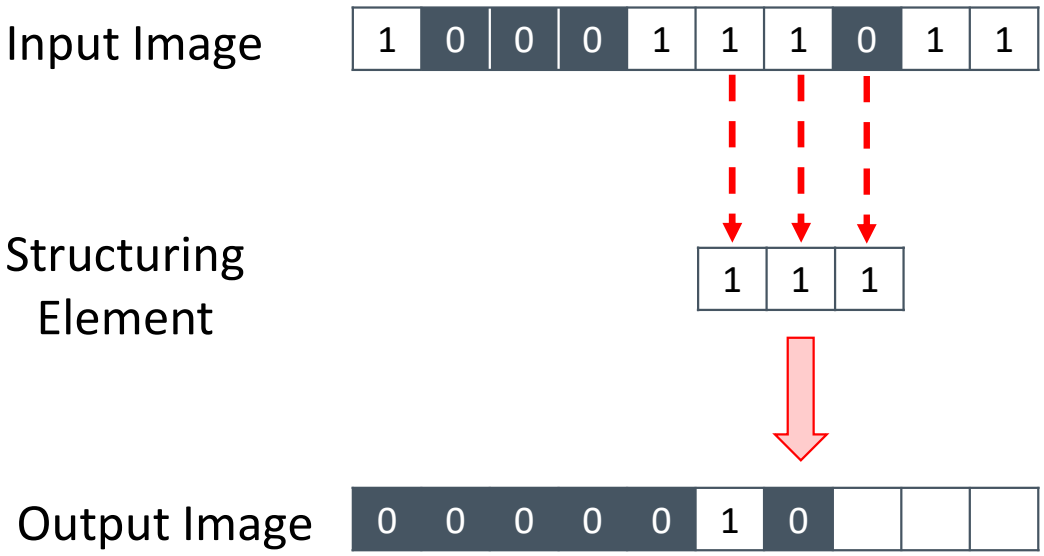


1-D Example of Erosion

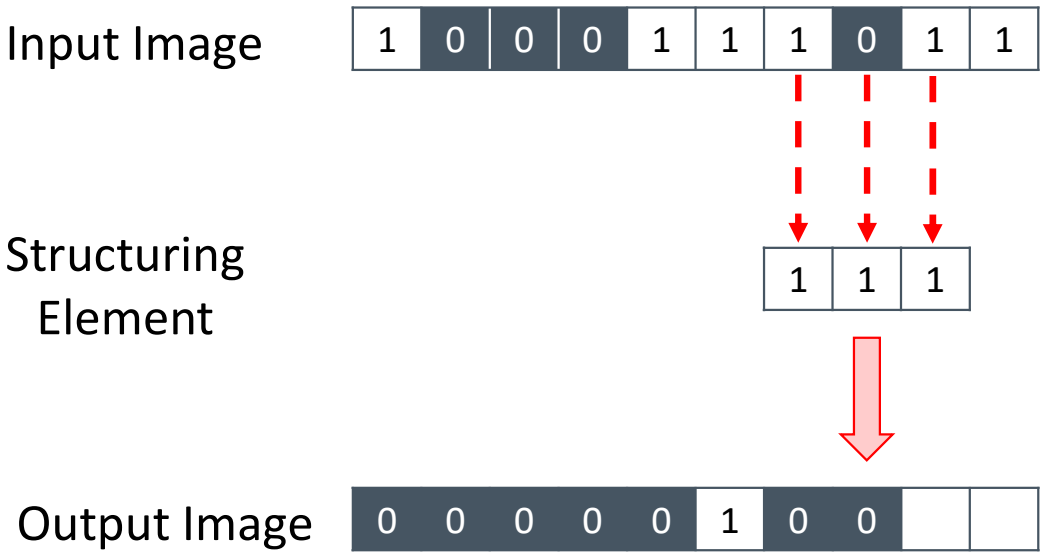


Remember: OR-ing only happens when ALL are FOREGROUND PIXELS.

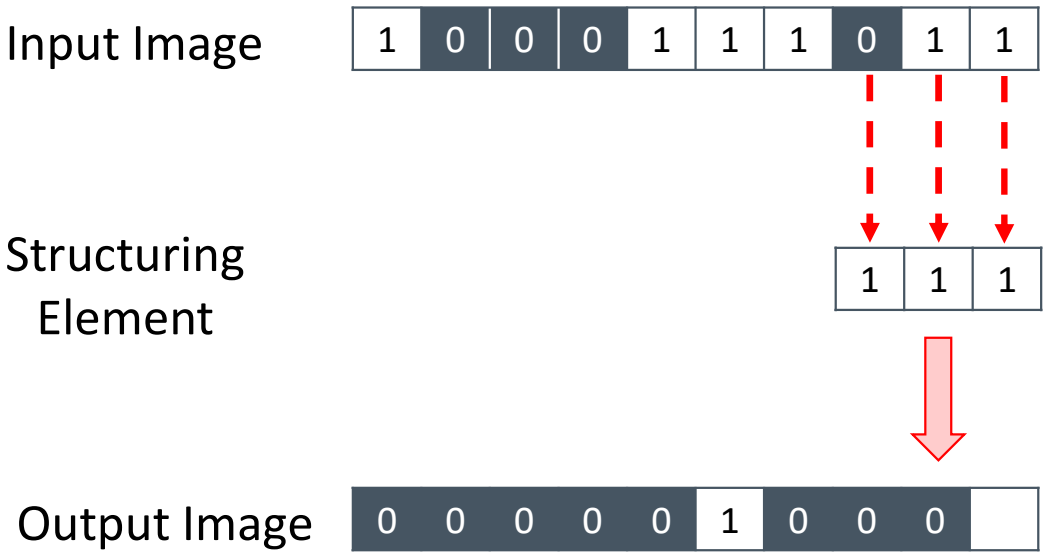
1-D Example of Erosion



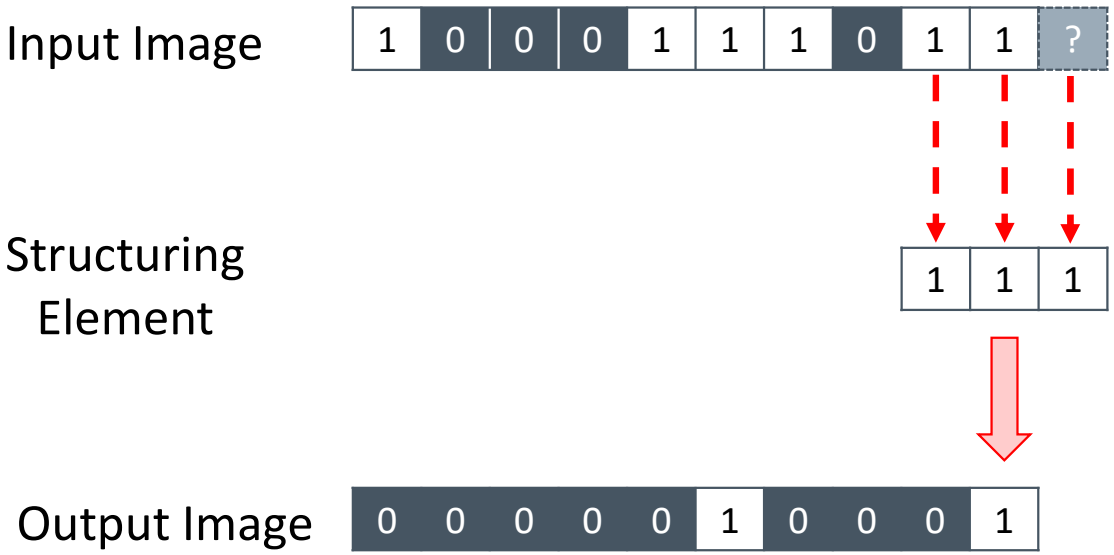
1-D Example of Erosion



1-D Example of Erosion



1-D Example of Erosion

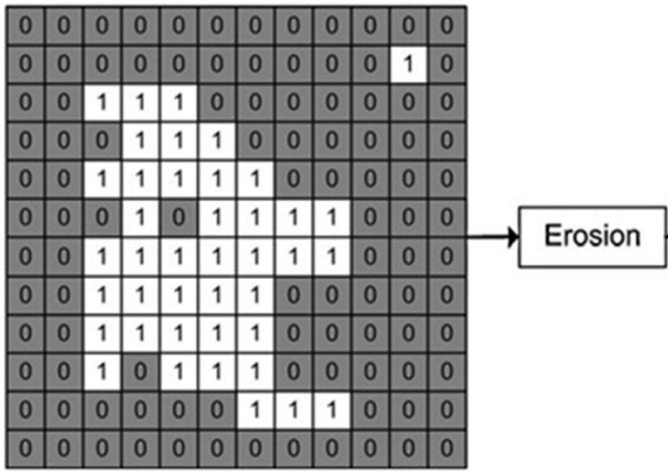


What do you observe here?

2-D Example of Erosion

› Using a 3x3 structuring element, with the middle centre pixel taken as the reference pixel:

1	1	1
1	1	1
1	1	1



A. More 1s, and thicker white regions
B. More 0s and thinner white regions
C. All the white disappear

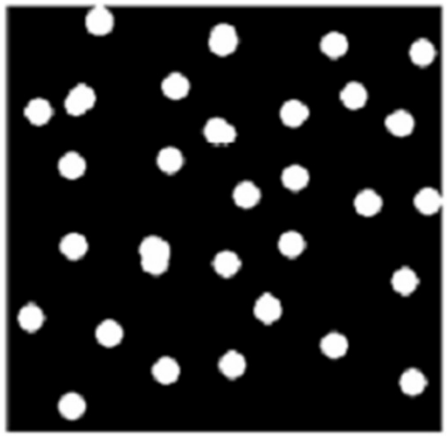
What is the output again?

Opening

› Erode, then dilate

› Remove small objects, keep original shape

Before opening



After opening

Closing

› Dilate, then erode

› Fill holes, but keep original shape

Before closing

After closing

Morphology operators on grayscale images

› Dilation and erosion typically performed on binary images

› If image is grayscale: for dilation take the neighbourhood **max**, for erosion take the **min**

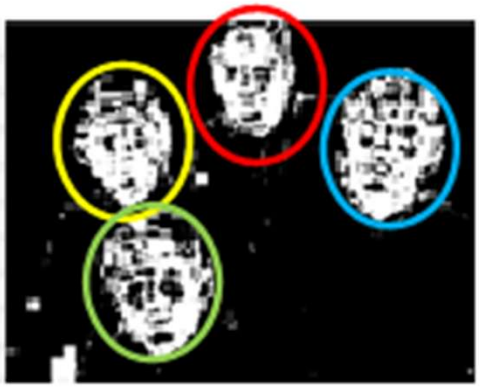
Connected Components / Region Labelling

Marking multiple regions of interest

Two tasks ahead

1. What to do with “noisy” binary outputs?

2. How to demarcate (mark) multiple regions of interest?
   - Count objects
   - Compute further features from objects



Connected Components

› Identify distinct regions of “connected pixels” by labelling

Binary Image

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

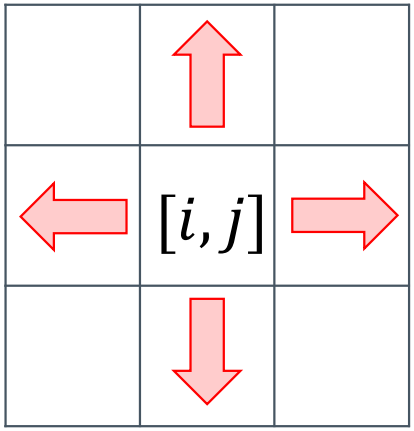
1	1	0	1	1	1	0	2
1	1	0	1	0	1	0	2
1	1	1	1	0	0	0	2
0	0	0	0	0	0	0	2
3	3	3	3	0	4	0	2
0	0	0	3	0	4	0	2
5	5	0	3	0	0	0	2
5	5	0	3	0	2	2	2

Connected Components Labeling

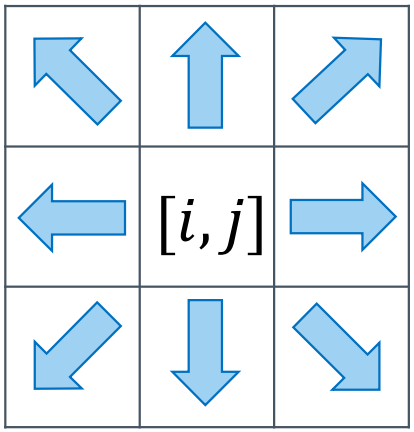
From Computer Vision (Shapiro & Stockman)

Connectedness

› Defining which pixels are considered neighbours



4-connected



8-connected

Recursive method

1. Negate the binary image (so that 1-pixels become negative-1's)
   - to distinguish unprocessed pixels (-1) from those of component label 1
2. Find an unlabelled pixel (-1), assign it a new label
3. Search to find its neighbours (that have value -1)
   - following scan-line order

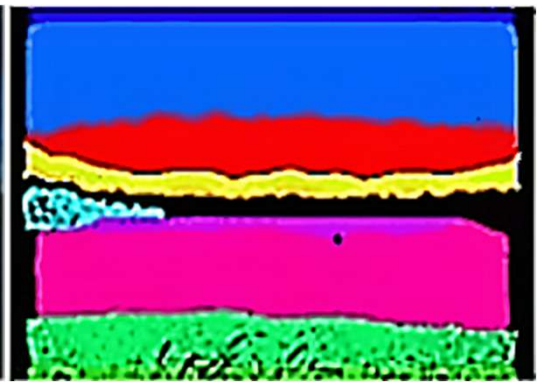
Four-neighborhood

Eight-neighborhood

4. Recursively repeat to find their neighbours till there are no more left
5. Go back to (2) and repeat.

Connected components

Connected components of 1's from thresholded image



Connected components of cluster labels

Region properties

› Given connected components, can compute simple features per blob, such as:
  - **Area** (number of pixels in the region)
  - **Centroid** (average x and y position of pixels in region)
  - **Bounding box** (min and max coordinates)
  - **Circularity** (ratio of mean distance to centroid over std.)

Circularity

› Measure of “round-ness” of a region

› Circularity values – **large** ⟹ more circular in shape

› There are a few methods. Simplest formula:

$$C = \frac{4 \times Area \times \pi}{(Perimeter)^2}$$

The circularity measure expects a value between 0 and 1.

Closer to 1, rounder the component.

Circularity

› Haralick (1974) proposed a quite robust measure for circularity:

circularity

$$C_2 = \frac{\mu_R}{\sigma_R} \tag{3.12}$$

where μ_R and σ_R are the mean and standard deviation of the distance from the centroid of the shape to the shape boundary and can be computed according to the following formulas.

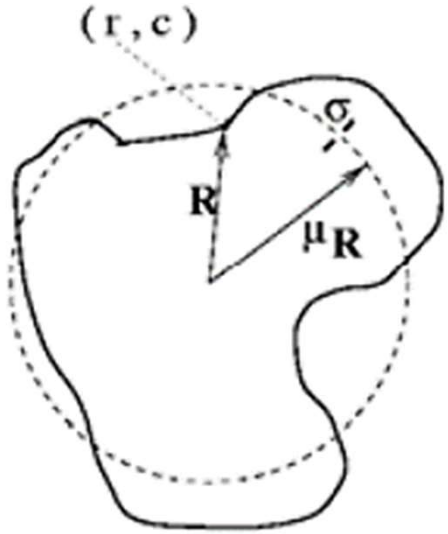
mean radial distance:

$$\mu_R = \frac{1}{K}\sum_{k=0}^{K-1} \|(r_k, c_k) - (\bar{r}, \bar{c})\| \tag{3.13}$$

standard deviation of radial distance:

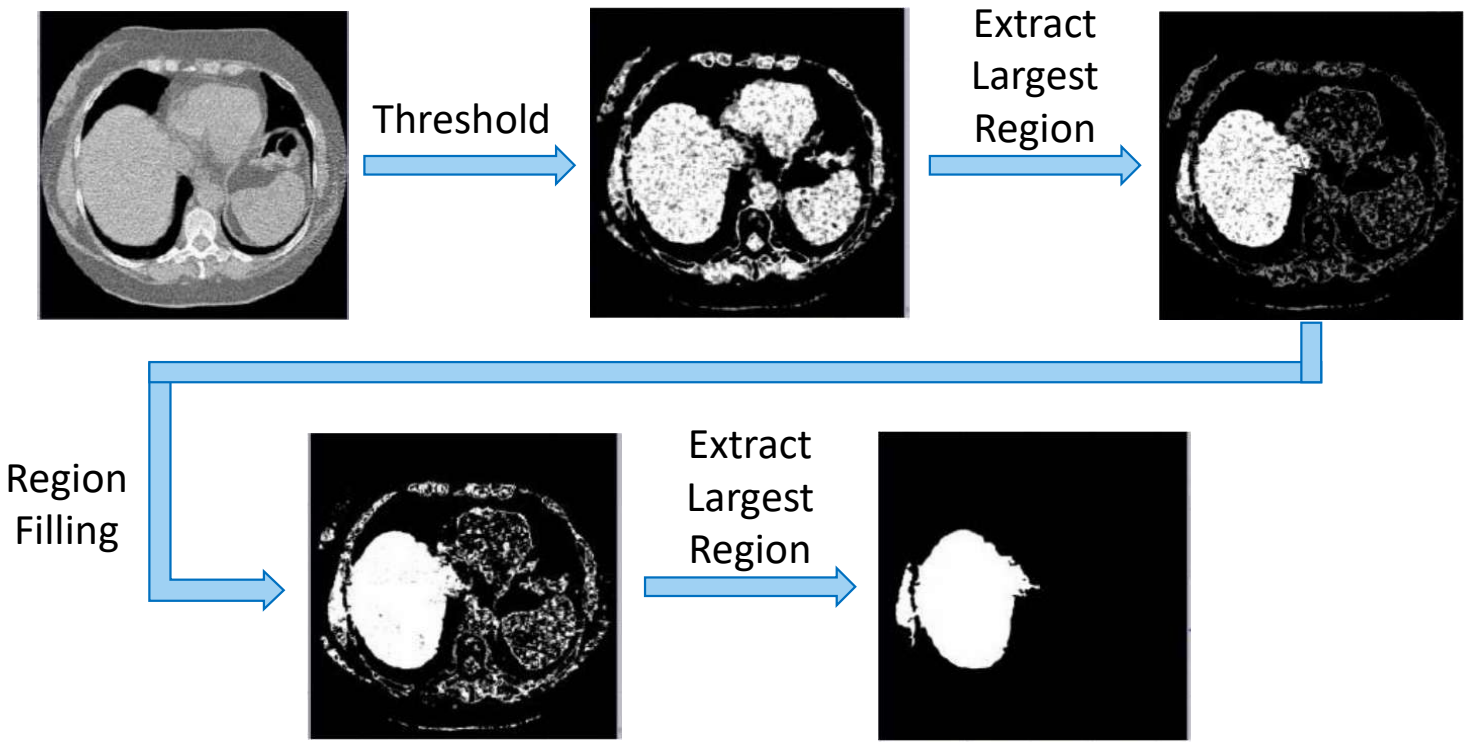
$$\sigma_R = \left(\frac{1}{K}\sum_{k=0}^{K-1} [\|(r_k, c_k) - (\bar{r}, \bar{c})\| - \mu_R]^2\right)^{1/2} \tag{3.14}$$

where the set of pixels (r_k, c_k), $k = 0, \ldots, K-1$ lie on the perimeter P of the region. The circularity measure C_2 increases monotonically as the digital shape becomes more circular and is similar for digital and continuous shapes.



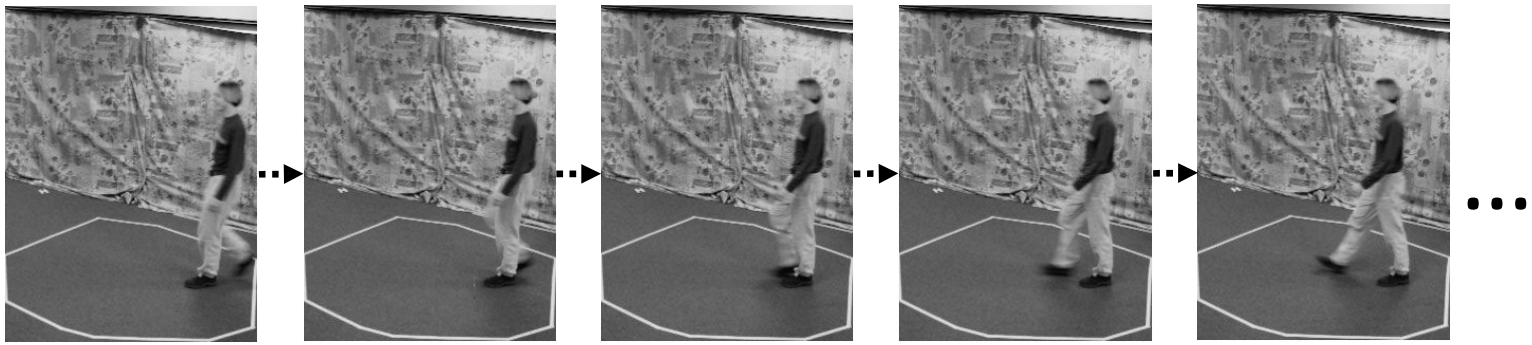
Application Examples

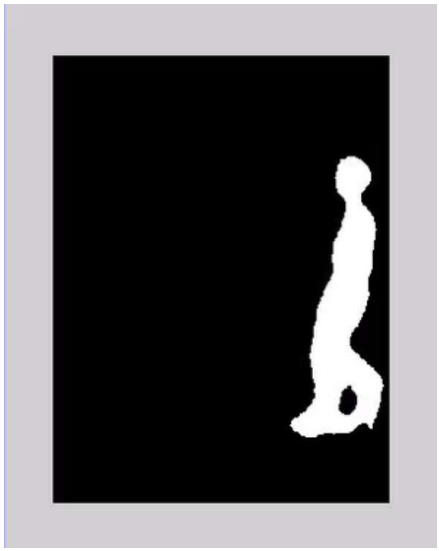
Example: Segmentation of a liver



Jie Zhu, Cornell University

Example: Background subtraction + blob detection





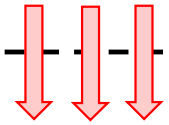
Binary images

- **Pros**
  - Can be fast to compute, easy to store
  - Simple processing techniques available
  - Lead to some useful compact shape descriptors
- **Cons**
  - Hard to get “clean” silhouettes
  - Noise is common in realistic scenarios
  - Can be too coarse of a representation
  - Not 3D in nature

Techniques that get us what we want

› Operations, techniques

Derivative filters
Smoothing, morphology
Thresholding
Connected components
Matched filters
Histograms



› Features, representations

Edges, gradients
Blobs/regions
Local patterns
Textures
Color distributions

SUMMARY

- Binary Images
  - Thresholding
- Morphological operations
  - Dilation, erosion, opening, closing
- Connected components & region labelling
- Region properties
  - Area, centroid, bounding box, circularity
- Next
  - Colour
- Recommended Reading
  - [Gonzalez & Woods] Chapter 9 & 10 (10.3 in particular)
  - [Forsyth & Ponce] Chapter 9 (9.5.4 in particular)