Amirkabir University of Technology
(Tehran Polytechnic)

# Assignment 5
## Don't Underestimate Morphology!

### Homeworks Guidelines and Policies

- ***What you must hand in.*** It is expected that the students submit an assignment report (HW5_[student_id].pdf) as well as required source codes (.m or .py) into an archive file (HW5_[student_id].zip).
- ***Pay attention to problem types.*** Some problems are required to be solved *by hand* (shown by the icon), and some need to be implemented (shown by the icon).
  Please don't use implementation tools when it is asked to solve the problem by hand, otherwise you'll be penalized and lose some points.
- ***Don't bother typing!*** You are free to solve by-hand problems on a paper and include picture of them in your report. Here, cleanness and readability are of high importance. Images should also have appropriate quality.
- ***Reports are critical.*** Your work will be evaluated mostly by the quality of your report. Don't forget to explain what you have done, and provide enough discussions when it's needed.
- ***Appearance matters!*** In each homework, 5 points (out of a possible 100) belongs to compactness, expressiveness and neatness of your report and codes.
- ***Python is also allowable.*** By default, we assume you implement your codes in MATLAB. If you're using Python, you have to use equivalent functions when it is asked to use specific MATLAB functions.
- ***Be neat and tidy!*** Your codes must be separated for each question, and for each part. For example, you have to create a separate .m file for part b. of question 3. Please name it like p3b.m.
- ***Use bonus points to improve your score.*** Problems with bonus points are marked by the icon. These problems usually include uncovered related topics or those that are only mentioned briefly in the class.
- ***Moodle access is essential.*** Make sure you have access to Moodle because that's where all assignments as well as course announcements are posted on. Homework submissions are also done through Moodle.

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- ***Assignment Deadline.*** Please submit your work **before the end of Jul 28th**.
- ***Delay policy.*** During the semester, students are given 7 free late days which they can use them in their own ways. Afterwards there will be a 25% penalty for every late day, and no more than three late days will be accepted.
- ***Collaboration policy.*** We encourage students to work together, share their findings and utilize all the resources available. However you are not allowed to share codes/answers or use works from the past semesters. Violators will receive a zero for that particular problem.
- ***Any questions?*** If there is any question, please don't hesitate to contact me through the following email address: **ali.the.special@gmail.com**.

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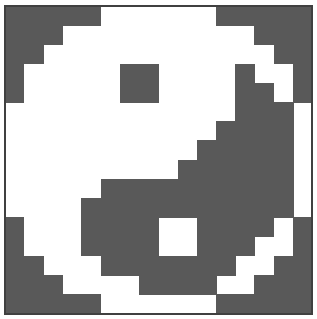
## 1. Mastering Image Morphological Operators Calculations (12 Pts.)

**Keywords**: *Image Morphology, Image Logical Operations, Structuring Element, Image Dilation, Image Erosion, Image Opening, Image Closing*

The first task includes several problems concerning **Morphological Operations** for binary images, which you are required to solve by hand.



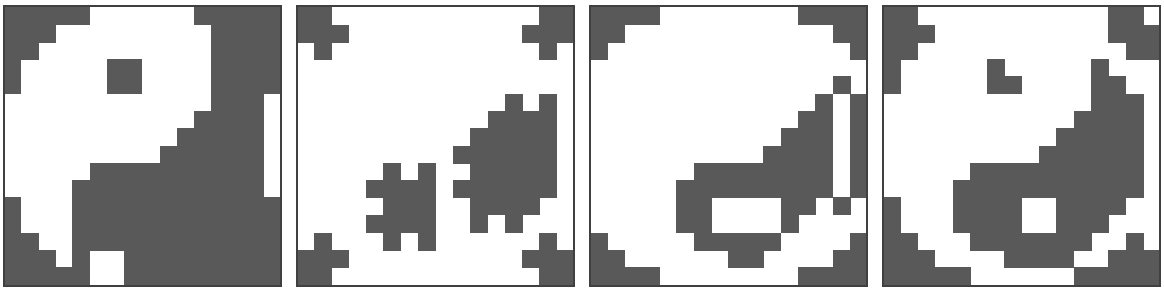
Given below is a $16\times16$ binary image used in each part of this problem. First, we apply four different unknown morphological operations among **Erosion**, **Dilation**, **Opening** and **Closing** on the input image. Determine the type of morphological operation used alongside the given **Structuring Elements** to give the results in the following figure. .

a.
| | | |
|---|---|---|
| 0 | 1 | 0 |
| 0 | 1 | 0 |
| 0 | 1 | 0 |

b.
| | | |
|---|---|---|
| 1 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 1 |

c.
| | | |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 1 |
| 0 | 0 | 0 |

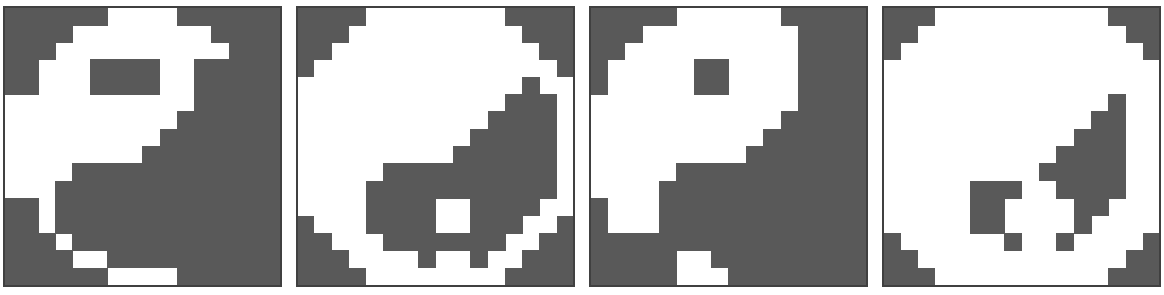
d.
| | | |
|---|---|---|
| 0 | 1 | 1 |
| 0 | 0 | 1 |
| 0 | 0 | 0 |



**(a)** **(b)** **(c)** **(d)**

Consider another set of results obtained by applying certain morphological operations on the input image. Given the type of the operations used, find the $3\times3$ structuring elements for each part. Note that the origin of these structuring elements is always in the centre.

e. Erosion f. Closing g. Opening h. Dilation



**(e)** **(f)** **(g)** **(h)**

In the final part, the goal is to investigate more complicated morphological algorithms. Perform the following tasks on the input image.

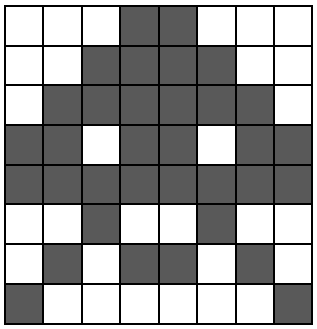
i. Determine the positions of the corners.
j. Extract the boundaries.
k. Fill the holes.
l. Extract the connected components.
m. Obtain the skeleton of the shape.

## 2. Fundamentals of Image Compression (10 Pts.)

**Keywords**: *Image Compression, Huffman Coding, Zig-Zag Ordering, Run-Length Coding, Entropy Coding, Peak Signal-to-Noise Ratio*

The goal of this problem is to evaluate your fundamental knowledges of **Image Compression** techniques.

First, consider the following binary image.



a. Find the runlength representation. Note that you must assume a line always starts with "white", and specify the white runlength and then the black runlength alternatively. Put a "EOL" symbol at the end of each line.
b. Find the corresponding zig-zag ordered vector to this image.
c. We want to use a single Huffman codebook to code the white and black runlengths. Write down the probability distribution of the symbols to be coded.
d. Next, generate the Huffman code for all possible runlength symbols. You must consider "EOL" symbols as well.
e. Calculate the average number of bits per coded symbol. How does it compare with the entropy of the symbol?
f. What is the average bit rate (bits/pixel) for this method? What about the compression ratio compared to using 1 bit for each pixel to indicate whether the pixel is black or white?

Now consider the following table as the initial dictionary for LZW algorithm.

| Index | Entry |
|---|---|
| 1 | a |
| 2 | - |
| 3 | r |
| 4 | t |

g. Output of the LFW encoder on a sequence is below. Decode the sequence.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 4 | 6 | 8 | 4 | 2 | 1 | 2 | 5 | 10 | 6 | 11 | 13 | 6 |

h. Encode the decoded sequence using the same initial dictionary. Does your answer match the sequence given above? Explain.

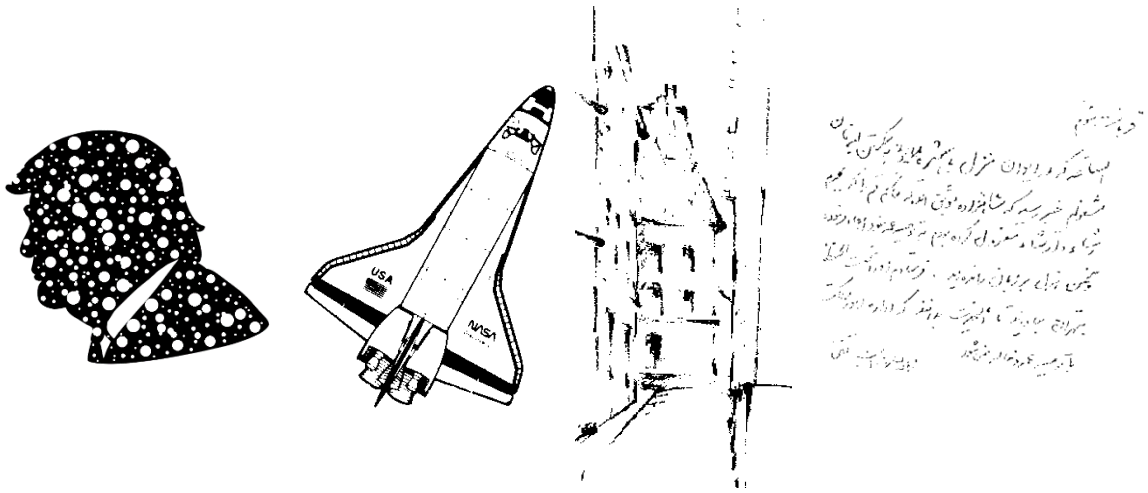
## 3. Warming Up with Binary Images (12 Pts.)

**Keywords**: *Image Morphology, Image Logical Operations, Structuring Element, Image Dilation, Image Erosion, Image Opening, Image Closing*

**Image Morphological Operations** can be more clearly explained in binary images. The effect of each morphological operation on an image and the role of structuring element and its properties like position of the origin and size are more perceivable when these operations are applied to 1-bit images. For this reason, let's start with some binary images first. Note that you are not allowed to use built-in functions to perform morphological operations, i.e. you have to implement them yourself.

a. Consider the image in Figure 1, part a. Using an appropriate procedure consisting of proper morphological operation(s) to fill the holes inside the figure. The final results must be as clear as possible, similar to the image in part b.
b. Morphological operations can also be used to extract relevant features from an image. Try to use these operations in order to remove certain features (like diagonal lines) from the image given in Figure 1, part b.

c. Assume the binary image in Figure 1-c. Use thickening alongside other morphological operations to process this image. Reduce all lines to a single pixel width and obtain their maximum length.
d. Figure 1-d displays a letter which is said to be wrote by Amirkabir to Naser al-Din Shah Qajar. As can be seen, the letters are separated and sentences can hardly be read. Try to fill the gaps and obtain a clear readable result.



**(a)** **(b)** **(c)** **(d)**

*Figure 1 Input images provided for each part (a) Binary image of Donal Trump with white holes of different sizes (b) A schematic of a NASA shuttle (c) A painting consisting of some houses in an alley (d) Handwriting attributed to Amirkabir*

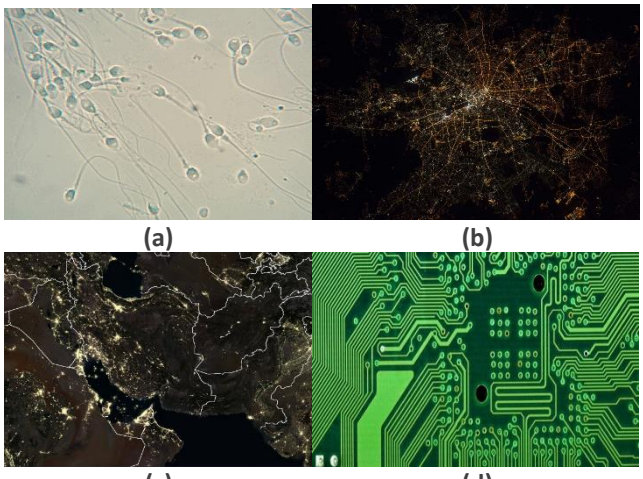
## 4. Beyond Bi-Level Images: Broadening Image Morphology Applications (16 Pts.)

**Keywords**: *Image Morphology, Structuring Element*

As you are very well aware, the scope of **Image Morphological Operations** is not limited to binary images. One can apply these operations on grayscale images and obtain fine results based on the intended application.

Here you are going to practice some of the related problems. Note that you are not necessarily supposed to obtain perfect results, as some of the tasks are a bit difficult to deal with. You must try your best nonetheless.

a. Given below are two microscopic images of human body cells which can be used in various medical applications. Your task is to implement an algorithm to count the number of cells inside each image.
b. Now comes the third task, in which the goal is to create a street map from a satellite image taken from the city of Berlin at night. You must



**(a)** **(b)** **(c)** **(d)**

*Figure 2 Input images (a) Microscopic image of human body cells (b) Satellite image of Berlin at night (c) Satellite image of Iran (d) An unknown printed circuit board*

use appropriate morphological operations to detect the main roads and remove the remaining areas of the image. Highlight the streets properly.

c. This part is somehow similar to the previous one, as it utilizes another satellite image taken at night. This time the goal is to find and display the most crowded cities in this map in the Figure 2-c. Display the map with the whereabouts of the 10 most crowded (or brightest) cities clearly highlighted with colored points.
d. Finally, you are an image of a printed circuit board. Use morphological operations to remove the lines within the board, while keeping the circles. Then try to remove the circles while keeping the lines. Note that the output of the colored input must also be colored.

## 5. Applying Image Morphological Operations for Filtering Images (12 Pts.)

**Keywords**: *Grayscale Image Morphology, Image Morphological Filtering, Morphological Noise Reduction, Morphological Edge Detection*

A more complicated application of **Image Morphology** in grayscale images is **Image Filtering**, where the goal is to apply different types of filtering, e.g. smoothing filter, using a combination of **Morphological Operations**.

In this problem, your task is to examine some of these operations, and compare their results.

a. Load the image "trump_dance.jpg" and apply morphological smoothing using dilation and erosion.
b. Repeat part a. with opening and closing. Compare the results obtained from part a. and b., and comment on their performance in **Noise Reduction**.
c. Load the image "trump_tower.jpg" and apply morphological 2nd derivatives using dilation and erosion.
d. Repeat part c. with opening and closing.
e. Repeat part c. with dilation, erosion, opening and closing. Compare the results obtained from part c., d., and e., and comment on their performance in **Edge Detection**.
f. Load the image "trump_eclipse.jpg" and apply morphological gradient using dilation and erosion.
g. Repeat part f. with opening and closing.
h. Repeat part f. with dilation, erosion, opening and closing. Compare the results obtained from part f., g., and h., and comment on their performance in **Edge Detection**.


**(a)** **(b)** **(c)**

*Figure 3 Input images of the problem (a) Part a and b (b) Part c to e (c) Part f to h*

**Allowed MATLAB functions**: `imdilate()`, `imerode()`, `imopen()`, `imclose()`, `strel()`

## 6. Image Processing as Supermarket Cash Register (25 Pts.)

**Keywords**: *Image Morphological Operations, Image Binarization, Image Logical Operations, Image Thresholding, Hit and Miss Transform, Opening Top-Hat, Boundary Detection, Region Filling*

You're going shopping in your local supermarket which is equipped with a machine vision based system to calculate customers' cart totals. This system captures images from the top view of the items placed on the register conveyor belt, and then applies image processing techniques to first remove the background and then categorize each item based on its size. Certainly not the smartest way around, but let's see if this task could be accomplished by morphological operations.

The image in Figure 4 has been captured from your items. The price of each item is also displayed in Figure 5. Note that these prices might not be still the same on the date you are reading this!

*Figure 4 A top view image of the items on the register conveyor belt*

In each part, you are asked to extract details from the given image using image morphological operations. You must support your answers with enough explanation as well as the results of morphological operations you performed on the image.

a. How many items have you bought in total?
b. Calculate the number of biscuits you bought.
c. What is the total money you spent on canned tunas (of any brand)?
d. Calculate the total number of the items produced by the brand Cheetoz.
e. Calculate the total cost of the cart.


*Figure 5 Price of the selected items (As of Tir, 9th)*

In your second visit to this supermarket you will buy the same items with different quantities of products. This time the captured image of your items has become more complicated, creating a more realistic problem, Figure 6.

f. Count the total number of your selected items.
g. Find the number of spaghetti you bought.
h. Determine the cost of cheese in your cart.
i. Calculate the cost of drinks (on any brand).
j. Calculate the total cost of the cart.


*Figure 6 The items are now with different angles and overlapping*

## 7. Some Explanatory Questions (8 Pts.)

Please answer the following questions as clear as possible:

a. Define “spatial scalability” and “amplitude scalability”, and explain how the JPEG 2000 image coding method achieves them.
b. Imagine you want to determine a connected component given one point of this component. How might you use conditional dilation to accomplish this task?
c. Why is it not an appropriate approach to use dilation in order to fill small noisy holes in objects? Explain.
d. Assume two distinct approaches: applying a $3\times3$ square structuring element twice on an image, and applying a $5\times5$ square structuring element just once on the image. Is there any difference in the final image? Which approach is faster, and why?
e. Does the position of the origin within the structuring element affect the result of the opening? Justify your answer.
f. Is it possible to perform erosion using hit-and-miss? Explain.
g. Explain how one can use hit-and-miss transform alongside NOT operation in order to perform dilation.
h. Finding the approximate convex hull using thickening is known to be so slow. Explain the reason.

*Good Luck!*
*Ali Abbasi*