Amirkabir University of Technology
(Tehran Polytechnic)

Assignment 5
Don't Underestimate Morphology!

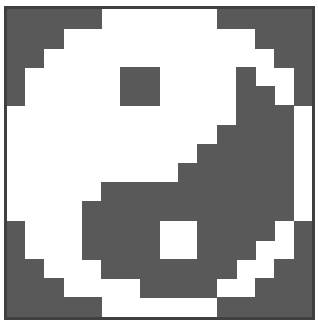
Homeworks Guidelines and Policies

- ***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.

- ***Assignment Deadline.*** Please submit your work **before the end of Aug 1st**.
- ***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 **ali.the.special@gmail.com**. You may also find me in the pattern recognition and image processing lab, 3rd floor, CEIT building.

1. Exercising Morphological Operators Calculation Procedure (12 Pts.)

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



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

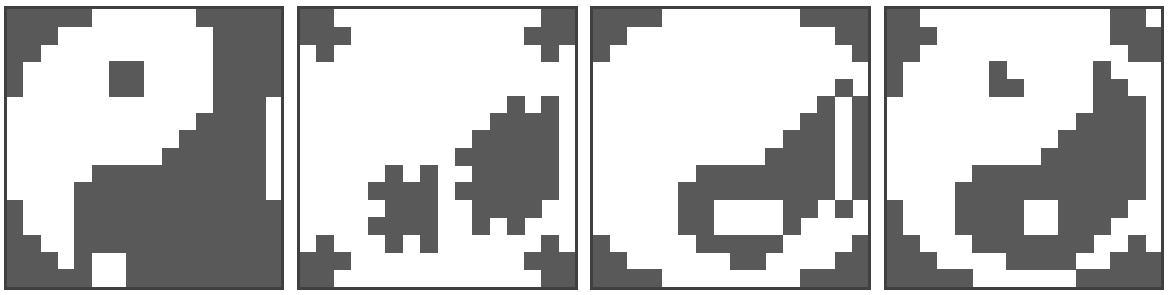
Given below is a 16×16 binary image used in this part of the problem. First, we apply four different unknown morphological operations among **Erosion**, **Dilation**, **Opening** and **Closing** on the input image. Determine the type of the morphological operation used alongside the given **Structuring 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

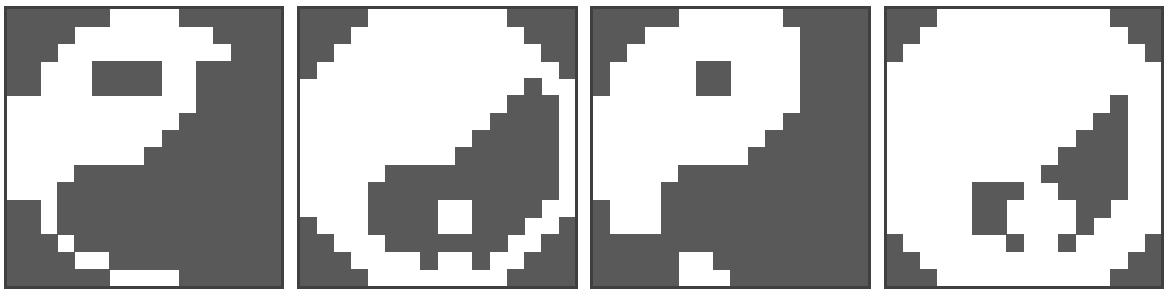
d.
0	1	1
0	0	1
0	0	0



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

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

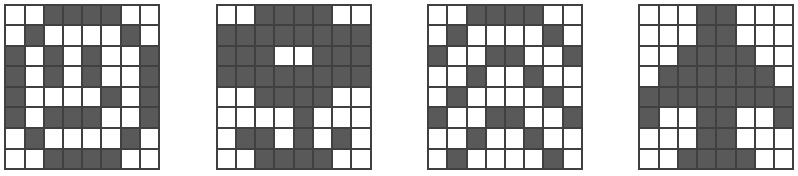
e. Erosion f. Closing g. Opening h. Dilation



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

In the final part, the goal is to investigate more complicated morphological algorithms. Obtain the required properties within the following 8×8 inputs.

i. Positions of the corners j. Boundaries k. Connected components l. Skeleton

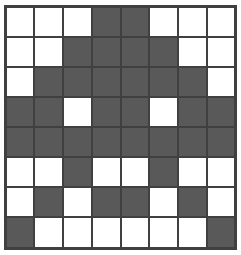


(i) **(j)** **(k)** **(l)**

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

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

The goal of this problem is to evaluate your fundamental knowledge of **Image Compression** techniques. First, consider the following binary image.



a. Find the runlength representation. Note that you must assume that 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 when using 1 bit for each pixel to indicate whether the pixel is black or white?

Next, assume an 8-bit gray-scale image given as below.

0	16	64	64
80	100	85	16
72	452	85	255
70	64	170	255

g. Instead of 8 bits, we would like to use 2 bits to represent each pixel. Find the value assigned to each pixel. If we would like the value of each pixel to be remained between 0-255, explain how you would do such mapping.
h. Find the root-mean square error and mean-square signal-to-noise ratio for the output image you obtained in the previous part.

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

Index	Entry
1	a
2	-
3	r
4	t

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

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

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

Finally, consider a JPEG compression procedure in which instead of 8×8 image blocks, blocks of the size 4×4 are used. The coefficients generated by applying DCT on a 5×5 block of luminance value as well as the quantisation table are given below.

3) 140	4) 20	5) 8	6) 5
7) 23	8) 18	9) 7	10) 8
11) 15	12) 10	13) 6	14) 2
15) 9	16) 5	17) 1	18) 2

k. Find the values assigned to each pixel after performing quantisation.
l. Assume the quantised table is transmitted as a one dimensional vector. In what order will it be transmitted, and why? Write down the ordered vector.
m. Find the run length encoding of the vector in the previous part.
n. What kind of additional compression techniques can be used when several such spatially neighboring 4×4 blocks are transmitted? Justify your answer.

5	12	16	30
12	14	20	30
14	20	32	35
20	25	29	40

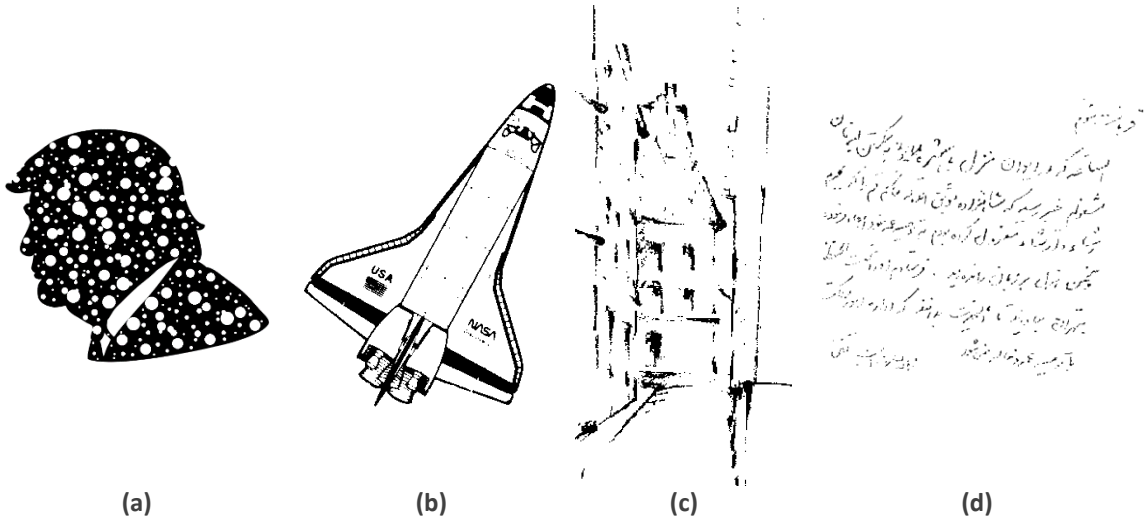
3. Warming Up with Some Cool Applications of Binary Image Morphology (12 Pts.)

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

Image Morphological Operations can be more clearly explained in binary images. The effect of each morphological operator on the pixels of an image and the role of structuring element and its properties like position of the origin and size are more perceivable when these operators are applied over 1-bit images.

For this reason, let's start with some binary images before handling more complicated problems. Here, you are provided with a set of binary images (Figure 1) and you are asked to perform certain tasks on each one of them. Note that in this problem you are not allowed to use built-in functions to perform morphological operations. In other words, you have to implement them yourself.

a. Consider the image in Figure 1, part a. Use an appropriate procedure consisting of proper morphological operation(s) to fill the holes inside the figure. The final output must be as clear as possible with the fewest artefacts possible.
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 part b of Figure 1.
c. Assume the binary painting 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 Amir Kabir to Naser al-Din Shah Qajar. As can be seen, most letters are separated and sentences can hardly be read. Try to fill the gaps and obtain a clear readable output.



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

Figure 1 A set of binary images used as the input images of each part (a) Binary image of Donal Trump with white holes of different sizes (b) A schematic of a NASA space shuttle (c) A painting with mostly separated lines (d) An old handwriting attributed to Amir Kabir

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.

This problem aims to introduce some of these applications. Like the previous problem, here you are required to extract desired details from the input images (Figure 2) using relevant morphological operators. 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.

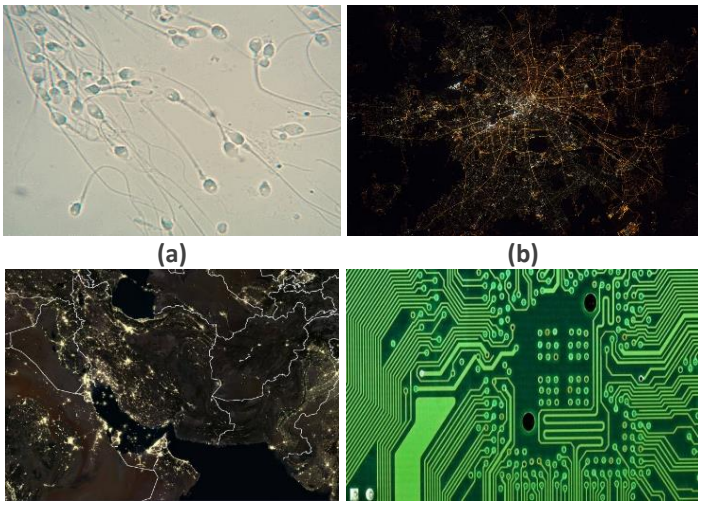


Figure 2 Input images (a) Microscopic image of human body cells (b) Satellite image of the city of Berlin at night (c) Satellite image of Iran and some neighboring countries (d) An unknown printed circuit board

a. You are given a microscopic image 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 second 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 use appropriate morphological operations to detect the main roads and remove the remaining undesired areas around them. Highlight the streets with appropriate colors.
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 (or brightest) cities in the map. Display the map with the whereabouts of the 10 most crowded cities clearly highlighted with colored points.
d. Final part concerns extracting relevant information from 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: Although the morphological operations might be applied on grayscale images, the output images must be colored.

5. Yet Another Application of Morphological Operators: Image Filtering (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 outputs you obtained, 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

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 items based on their sizes. Certainly not the smartest way around, but let's investigate whether this task could be accomplished by morphological operations.

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

The image in Figure 4 has been captured from the items you picked. 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!

In each part, you are asked to extract details from the given image taken from your cart. Note that 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 picked 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.

5400 Toman ***6500 Toman*** ***5450 Toman*** ***4000 Toman*** ***4000 Toman***

12900 Toman ***12500 Toman*** ***6500 Toman*** ***18075 Toman*** ***2500 Toman***

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

In your second visit to this supermarket you have picked the same items, but with different quantities of products. This time the captured image of your items has become more complicated (Figure 6), creating a more realistic scenario.

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 (of any brand).
j. Calculate the total cost of the cart.

Figure 6 Similar items are now arranged with different angles and overlapping

Note: To speed up the operations, you are free to resize the images to your liking.

7. Further Study: JPEX XL, Next-Gen Image Codec (20 Pts.)

Keywords: *Image Compression, JPEG, JPEG XL*

Even though **JPEG** image compression standard is nearly a quarter of century old, it is still the most popular format used for digital images representation and thousands of new JPEG images are being taken as you are reading this. While universally adopted, JPEG doesn't address many modern use cases such as high dynamic range (HDR), transparency, responsive web, lossless and so on.

During the years, various formats have attempted to address these shortcomings, but in turn have introduced new challenges. Several extensions to JPEG has also been introduced, including JPEG XR and JPEG XT. Yet the compression results are still not satisfying in many aspects.

In the year 2017, JPEG committee announced that it was working to introduce the next generation image coding standard, called **JPEG XL**. The upcoming format shows promising performance as it is able to produce well-compressed images that are nearly indistinguishable – or in some cases, identical to – the original images, as can be seen in Figure 7.

Figure 7 Comparison of JEPG XL compression result with those obtained by other compression techniques (a) Original image (783 KB) (b) JPEG (53 KB) (c) WebP (53 KB) (d) HEIC (55 KB) (e) JPEG q95 (253 KB) (f) JPEG XL (53 KB)

In this section, the goal is to get you familiar with this new state-of-the-art image compression standard by scrutinizing 2019 paper "*JPEG XL: next-generation image compression architecture and coding tools*". The paper PDF file is attached to this assignment. Please read it carefully, and answer the following questions based on your understanding of the paper.

a. Clearly explain the necessity of introducing a new compression standard as well as the shortcomings of the current methods.
b. What are the advantages of JEPG XR over JPEG?
c. Write down a comprehensive summary of JEPG XL architecture.
d. What differences do you notice between JPEG XL and JPEG compression procedures? What are the purposes of these modifications?
e. Write a brief review of the paper based on your understanding of the proposed method.

Note 1: you are free to utilize relations and images from the paper, but a mere translation wouldn't be of much worth.

Note 2: Your answers may not be totally accurate, but your efforts are worthwhile.

8. 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 3×3 square structuring element twice on an image, and applying a 5×5 square structuring element just once on the image. Is there any difference in the output 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