Exercises for
Chapter 9: Image Visualization

1 EXERCISE 1

Consider a classical 2D color image, represented as a 2D array of RGB pixel colors. What type of grid does best represent this image: unstructured, structured, rectilinear, or uniform? What type of data attribute best encodes the data values (scalar, vector, color, tensor, or other)? What type of interpolation scheme is most appropriate to use for these data attributes (piecewise-constant, piecewise-linear, or other)? Justify your answer.

2 EXERCISE 2

Consider the use of a binary 3D voxel volume to store a 3D shape, such as created by the *binvox* voxelization program. For this specific purpose, 'empty' voxels located outside the 3D shape are 'wasted' in terms of storage in the voxel volumes. For very high voxelization resolutions, storing such voxels may lead to prohibitively large 3D volumes which may not even fit in the memory of your computer. Imagine and describe a scheme to store such 3D binary volumes which is memory-efficient (has a low overhead for storing empty voxels) and is also computationally-efficient (has a fast random access time to determine if a location at given coordinates is inside or outside the shape).

3 EXERCISE 3

Edge detection is a fundamental tool in image processing for the location of important boundaries between different similar-color or similar-luminance structures present in the image.

Describe in brief three different edge detection methods for 2D grayscale images. For each method, mention one typical advantage and one typical disadvantage, as opposed to the other two methods.

Hints: For the advantages and disadvantages, consider desirable method properties such as computational complexity, quality of the delivered edges, and robustness to noise.

4 EXERCISE 4

An important subfield of image processing focuses on the detection, analysis, and processing of so-called *shapes* present in such images. However, there is no precise and/or unanimously accepted definition of what a shape is in an image. Considering a 2D grayscale image, give your own definition of what a shape is. Be as precise as possible, in terms of listing the properties that make a certain image region be regarded as a shape or not. Next, comment on the possible limitations of your definition.

5 EXERCISE 5

Thresholding is one of the simplest, and most used, methods to find shapes in grayscale image: Given such an image, thresholding extracts shapes as all image elements (pixels or voxels) which have a grayscale value above or below a given threshold-value, or within a threshold-value range. Name and explain three challenges that thresholding-based segmentation has for the retrieval of shapes in real-world grayscale images.

6 EXERCISE 6

Mean shift segmentation is an attractive method for the unsupervised finding of similar-value, compact, regions in an image, thereby leading to a simple image segmentation approach. However, mean shift has also several challenges. List three such challenges that potentially make the application of mean shift hard in real-world segmentation applications, and explain these challenges in terms of the mean-shift algorithm.

Hints: Consider application challenges, such as the difficulty of finding the 'correct' segment borders in certain image times; parameter-setting challenges; and computational challenges.

7 EXERCISE 7

Consider a 2D or 3D binary image describing a set of shapes of various sizes (called the foreground) surrounded by background elements (pixels or voxels). In many applications, we want to eliminate all foreground components of the shape whose size (in pixels or voxels) is below a given user-threshold. Describe an algorithm to perform this operation which is linear in the number of pixels or voxels of the input image.

8 EXERCISE 8

Morphological operations such as dilation, erosion, opening, or closing are essential building blocks of more advanced segmentation, smoothing, or shape detection and analysis operations for binary images. For an isotropic structuring element (disk in 2D or ball in 3D), describe two different methods for computing such operations. Give the computational complexity of both methods as a function of the structuring element size and the input image characteristics (*e.g.* total number of pixels, number of foreground pixels, or number of pixels on the foreground-background interface).

9 EXERCISE 9

Distance transforms are important in many image and shape processing operations such as smoothing, segmentation, registration, and simplification. Describe, in brief, three different algorithms for computing distance transforms of digital 2D shapes. For each algorithm, discuss one advantage and one disadvantage.

Hints: For advantages and disadvantages, consider the computational complexity, implementation complexity, and accuracy.

10 EXERCISE 10

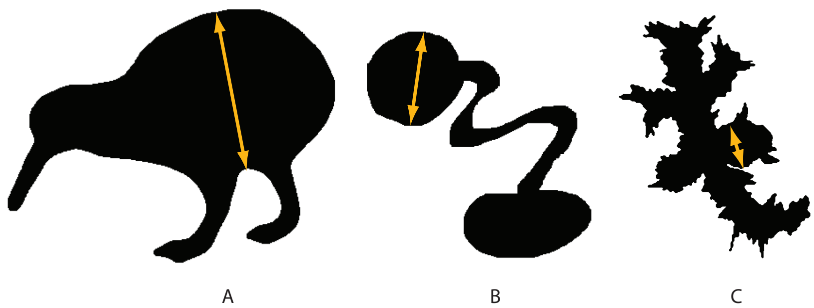
Skeletons, or medial axes, are fundamental shape descriptors used for the analysis, comparison, registration, and simplification of 2D and 3D shapes. Consider the computation of skeletons of binary 2D and/or 3D shapes represented as pixel, respectively voxel, images. Name and discuss three challenges for computing such skeletons.

11 EXERCISE 11

Consider a 2D or 3D binary shape represented by a pixel, respective voxel, grid. Intuitively, when we look at such shapes, we can easily say when certain shapes are (locally) thicker than other. For example, in the figure below, we can say that shape A has a maximal thickness larger than shape B, whereas shape C has a maximal thickness smaller than shape B. The maximal thicknesses of the three shapes are indicated by the bright-colored arrows on the figures.

Describe a method that, given a binary shape, computes the maximal thickness of such a shape. The method should be simple to implement, efficient to compute, deliver the same maximal thickness value for a given shape irrespective of its rotation in the image or voxel volume, and require no user input.

Hints: Think of the relation of the thickness to the shape boundary's distance transform.



Maximal shape thickness indicated by light-colored lines for three 2D shapes.

12 EXERCISE 12

Given a (2D) shape S, the medial axis transform $MAT(S)$ produces a set of points and distance-values $\{p_i \in S, d_i > 0\}$ where p_i are the medial axis points, and d_i are the (minimal) distances from these points to the boundary ∂S of S. The medial axis transform offers a lossless way to encode S, *i.e.*, we can reconstruct an exact copy of S from its $MAT(S)$. In this context, answer the following questions

- How can we reconstruct S from $MAT(S) = \{p_i \in S, d_i > 0\}$? Describe a simple algorithm for this.

- In the discrete case, S can be encoded *e.g.* by (the foreground pixels of) a digital image.

The same holds for the points $\{p_i\}$ of $MAT(S)$. Assuming that we need an integer to store each coordinate x and respectively y of every pixel, and a floating-point value to store each d_i, and that integers and floats have the same number of bytes of storage, is $MAT(S)$ a more memory-efficient way to store a shape than the direct description of S? Detail your answer

Hints: For the second question, consider what is the *minimal* amount of information required to store a shape S, taking into account that all its interior pixels have the same (foreground) value. Next, consider how the feature-transform (FT) links the boundary of a shape with its skeleton in terms of point cardinality.

13 EXERCISE 13

The mean shift procedure described in Chapter 9, Section 9.4.2, is an effective tool for image segmentation. For a *two*-dimensional color image, *e.g.* represented with colors in the *three*-dimensional RGB space, mean shift requires computing a $n = 5$-dimensional density field. This is an expensive procedure. Consider a simplification of the mean shift segmentation where we compute a three-dimensional density field using the RGB color components, *i.e.*, ignore the two spatial dimensions. What will be the difference between the segmentation applied by this technique and the original technique that uses $n = 5$ dimensions? Sketch a simple example image to illustrate these differences.

End of Exercises for
Chapter 9: Image Visualization