digital fundus images analysis,
morphological operations anuerisms,,
macula degeneration, neovascularization

Maria BERNDT-SCHREIBER*

MORPHOLOGICAL OPERATIONS IN FUNDUS IMAGE ANALYSIS

The potential importance of the mathematical morphological operations applied in the analysis of digital fundus images has been described. A proposal of appropriate computing tools has been demonstrated and sample applications have been shown for further developments.

1. INTRODUCTION

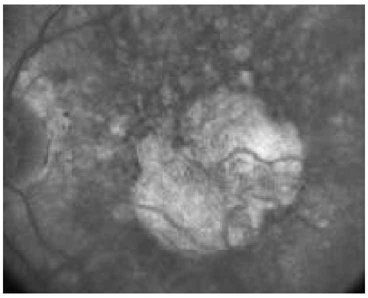
It was Luc Vincent [10] who first indicated the possibility of the use of mathematical morphological operations in the analysis of ophthalmic images among some other sample applications. In several aspects [11] he illustrated monitoring microaneurisms via typical morphological operations. In general, Luc Vincent extended the basic morphological approaches to grey-scale images and pointed out the role of appropriate adaptive structuring elements in practical applications [12].

There are several reasons why it is worth to develop the mathematical morphology based approach to investigate ophthalmic image data. The first one concerns the fact that, since the time of the pioneer works of Vincent nobody really implemented the morphological tools for the routine ophtalmic data analysis. Even though there are many attempts to apply the morphology approach to various image data e.g. in mammography and solar studies (see e.g [7,8]). The second one is related to recent studies of fundus images. Traditionally most attention has been focused on the glaucoma and diabetic retinopathy cases and the relevant changes observed for the so called nerve disk and cup areas. Recent studies of fundus images (e.g. [4,5,9]) reveal new important clinical observations outside the above areas. In fundus imaging age-related macula degeneration (AMD) and choroidal neovascularization (CNV) (the major cause of severe irreversible vision loss in most developed countries) are typical cases of sets of objects for pattern/shape recognition problems and are particularly suitable for exploiting morphological tools. Sample fundus images illustrating pathological changes are presented in the Figure 1, below. In the case of neovascularization processes often being due to pharmacology therapy, in nephrology e.g., the monitoring of the shapes and sizes of such changes is of a crucial importance in the current medical treatment. Last but not least is the progress of the observation technology enabling collecting fundus images of higher quality and resolutions. The new techniques of

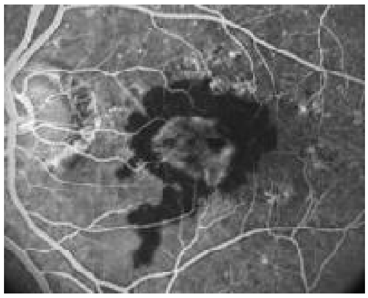
* Nicoalus Copernicus University, Faculty of Mathematics and Computer Science, 87-100 Toruń, ul. Chopina 12/18, Poland; berndt@mat.uni.torun.pl

spectral optical coherence tomography for *in vivo* imaging in ophthalmology introduced recently by Maciej Wojtkowski et al.(see e.g. [16-, 17]) are worth to be mentioned here as well.

In general, ophtalmic images may be essential for clinical diagnosing related to various civilization diseases, but it does imply the manipulation of many images (also acquired in different modalities). Unfortunately, a large part of the image analysis process is still done by hand.



(A)



(B)

Fig.1. Details of sample fundus images typical for (A) age-related macula degeneration AMD and (B) choroidal neovascularization CNV [13]

It is the aim of the present short note to suggest an extension of the previous studies, focused on the fractal based approach to digital fundus eye images [1-2], to a systematic study referring to mathematical morphology methods. In fact, it might accompany the fractal based approach as well in the future.

Below the basic definitions are recalled and application tools are introduced with sample results and conclusions for further studies.

2. COMPUTING TOOLS

2.1. BASIC MORPHOLOGICAL OPERATIONS

In the morphological approach the grey-scale images treated as functions are transformed in the spatial domain via morphological operations whose definitions are usually based on structuring elements – i.e. specially chosen shapes being used in the images as probes for detections of gaps, protrusions and size-based feature extractions. There is never a unique way to process an image – the procedure is always goal driving for extracting the objects of interest.

The basic operations: dilation of by a structuring element b, denoted $f \oplus b$, is defined as:

$$(f \oplus b)(x,y) = \max\{f((x-x',y-y') + b(x',y') \mid x',y' \in D_b\}, \qquad (1)$$

where D_b is the domain of b and f(x,y) is assumed to be equal $-\infty$ outside the domain of f.

Similarly, the grey-scale erosion of f by a structuring element b, denoted $f \ominus b$, is defined as:

$$(f \ominus b)(x,y) = \min \{f((x-x',y-y') + b(x',y') \mid x',y' \in D_b \} \tag{2}$$

where D_b is the domain of b and f(x,y) is assumed to equal $+\infty$ outside the domain of f.

In the computer algorithm the grey-scale dilations and erosions can be estimated by calculating maxima and minima respectively over a moving window – the structuring element.

Basing on the dilation and erosion operators the very useful morphological transformations: opening and closing can be derived as appropriate combinations of grey-scale dilations and erosions in the following way.

The opening by the structuring element b for a grey-scale image f is given by:

$$f \circ b = (f \ominus b) \oplus \tag{3}$$

It is simply the erosion of f by b followed by the dilation of the result by b. Similarly, the closing is the dilation followed by the erosion as it is given below:

$$f \bullet b = (f \oplus b) \ominus b \tag{4}$$

Both the transformations: opening and closing tend to smooth the original sets of objects but each in a different manner. The opening tends to remove the small protrusions in which the structuring element b cannot fit thus shrinking the original sets. The closing fills the gaps that cannot hold the structuring element making the original sets bigger. Opening suppreses bright details smaller than b, closing suppresses dark details - therefore both the operations often used in combinations for images may smooth them and remove a noise.

Among a variety of useful morphological filters transformations, derived from the grey-scale opening and closing, the so called *tophat*(TH) transformation is a very useful tool for extracting either dark or bright objects from non-uniform backgrounds. Formally the tophat transformation TH of a grey-scale image f with respect to opening is given by the pixelwise subtraction operator as presented below:

$$TH(f \circ b) = f - (f \circ b (5)$$

Its usefulness is related to the fact that the opening removes all the bright objects from the image, which cannot hold the structuring element; whereas the subtraction of the opened image from the original image f provides the retrieving of the removed elements.

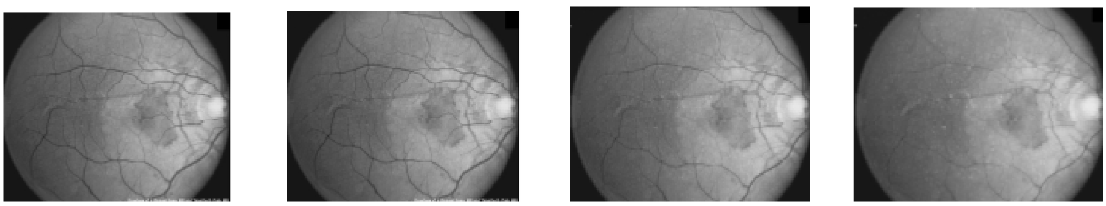
The grey-scale reconstruction is another useful operation extracting some image details. It is an iterative transformation involving two images and a structuring element. One image, the marker f, is the starting point for the transformation. The other image, the mask g, constrains the transformation. (Here the marker f must be a subset of g.) The reconstruction extracts the peaks of mask g which are marked by the marker image f. Morphological reconstruction has a broad spectrum of applications each determined by the selection of the marker and mask images, respectively.

All the basic morphological transformations have been implemented in the JMorph application and some sample results are presented below.

2.2. J MORPH APPLICATION

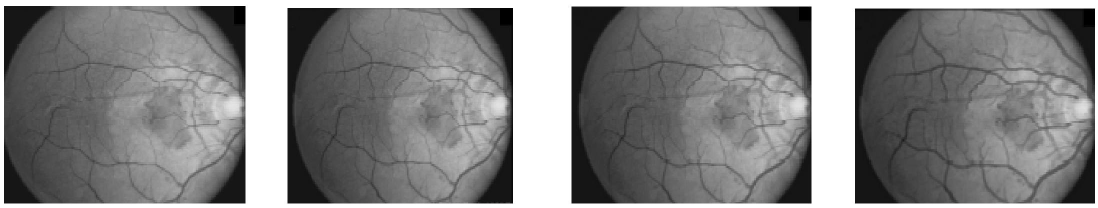
The original user friendly application, designed to support ophthalmic diagnosing, JMorph, has been prepared in Java with the use of Java Advanced Imaging Library [14]. It requires Java environment in version 1.5 SE or higher. First computing tests versus appropriate Matlab[6] and Image J [15] procedures have been succesfully reported in [3] for a set of sample fundus images[13].

In the Figures 2 and 3, below, the influence of the size of the structuring element b in the dilation and erosion processes is demonstrated. As it can be seen the size of b is essential for the saturations of the resulting images in both alternative procedures. The structures of the blood vessels network become either smoothed or sharper, respectively.



(A) original image (B) b=3 (C) b=5 (D) b=10

Fig.2. Dilation with various sizes of square structuring elements b



(A) original image (B) b=3 (C) b=5 (D) b=10

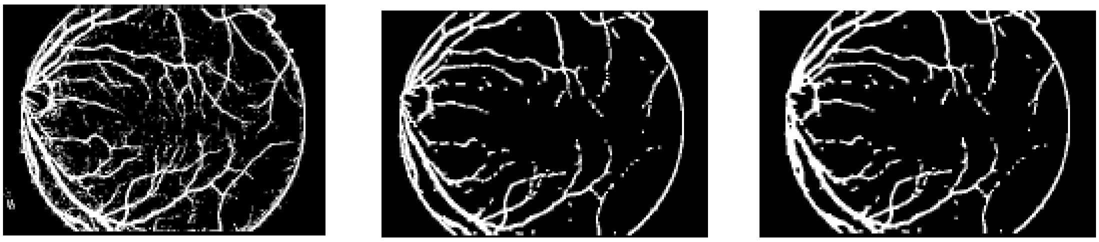
Fig.3. Erosion with various sizes of square structuring elements b

In the Figure 4 the original image is corrupted with a tiny dark noise. The operations of morphological closing removes the noise effectively not disturbing the general structure of the image data. The final result here again depends on the size of the structuring element b.

(A) original image (B) b=3 (C) b=5

Fig.4. Closing with various sizes of square structuring elements b

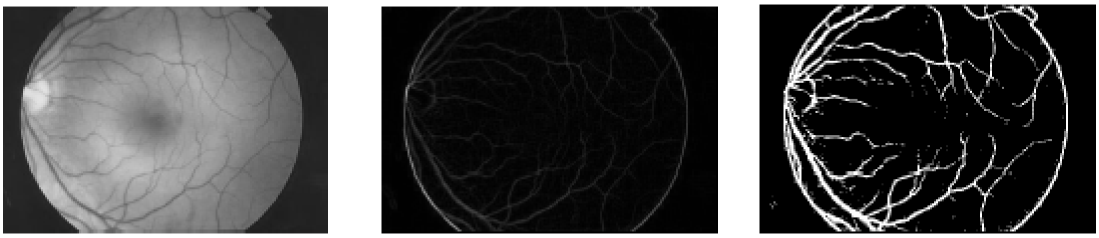
A similar final effect of removing a noise from a different type of original image may be obtained in a way demonstrated in the Figure 5. In this case, it is the result of using a sequence of closing and opening operations, respectively.



(A) original image (B) closing (C) opening

Fig.5. Removing a noise from the original image (A) with closing (B) and opening (C) operations, respectively.

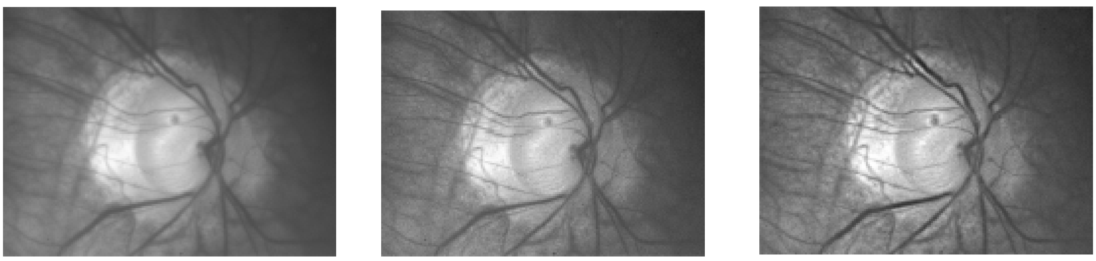
The thresholding operations should be always applied with a care since they are related to an irreversible loss of information contained in the original grey-scale image. They may however be useful in some situations e.g. as the one illustrated in the Figure 6, where the thresholding operation applied after dilation procedure provides a clear binary image of the blood vessels network very often interesting for physicians monitoring.



(A) original image (B) dilation (C) thresholding

Fig.6. Thresholding after dilation operations – leading to a clear binary image of blood vessels network.

In the Figure 7, below the results of extracting subtle details from the grey-scale image with the use of tophat transformations with different structuring elements are shown.
Here the original image represents the case of glaucoma development, with the swallowed disc area, and the possibility of extraction of the tiny details visible in the part (C) of the Figure 7 may be essential for a further observation and quantitative analysis.



(A) original image (B) b=5 (C) b=10

Fig.7. Tophat transformations for details extraction with different structuring elements b.

Microaneurisms, very important for the diagnosis in ophthalmology, are small and compact objects, brighter than the backgrounds in the eye fundus images. They are not connected to the network of the blood vessels which are usually thin and elongated. Sample results using the implemented morphological transformations in JMorph application module for extracting such types of details from the original images are illustrated in the Figure 8, below.

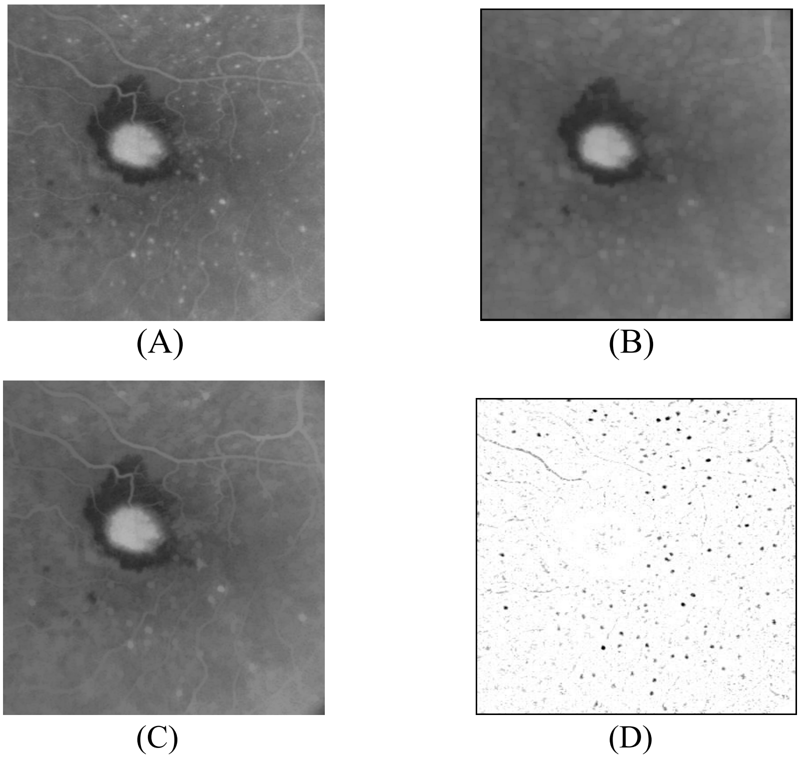


Fig.8. Extractions of aneurisms: (A) original image, (B) openings, (C) reconstruction, (D) detected aneurisms.

The original image data of the Figure 8 concern the case of age-related macula degeneration (AMD). The chance to observe the subtle aneurisms development is very important in the diagnosis and only the morphological approach provides such a possibility.

3. CONCLUSIONS

Preliminary results of the application of morphological operations to ophthalmic image data seem to show the morphological tools may appear very useful in the ophthalmology analysis as enabling, shape- and size-based feature extractions, detection of gaps, pattern matchings etc. The basic morphological operations dilations and erosion may be sophistically combined to create a complex transformation for a specific task in ophthalmology. General, reliable procedures for morphological operations however do not exist – they will remain goal driven tasks, for which domain specific knowledge should be always explored in advance.

For clinical applications concerning series of fundus images, the approach does require more detailed studies. In particular, it is well known that the results of morphological operations may strongly depend on the shapes and sizes of the used structuring elements.

For serial ophthalmic images using appropriate sequence of various combinations of dilations and erosions as well as an appropriate choice of marker and mask images in reconstruction procedures is a non-trivial task, requiring systematic investigations. Possible adaptive procedures providing an insight to their influence on the final results need further studies. The use of a series of morphological openings e.g. with different structuring elements, sometimes in different orientations, may provide a good starting point to elaborate adequate techniques, optimally robust, for a specific series of ophthalmic images. It has not been done so far and it is the subject of our interest. The mathematical morphology based operations might be essential in the stage of pre-processing procedures also in the more general fractal based approach. It is also the subject of our future studies.

BIBLIOGRAPHY

[1] ARŁUKOWICZ M., BERNDT-SCHREIBER M., BIEGANOWSKI L., BROŻEK M., JAZOWIECKA A., KAŹMIERSKA H., KOWALCZYK A., MUTRYNOWSKA J., Digital Imaging in Ophthalmology and Data Base Management System Supporting Medical Diagnoses , Acta Medica Vol.2, 2004, pp.5-15.

[2] BERNDT-SCHREIBER M., Fractal Based Approach to Morphological Analysis of Fundus Eye Images [in] Advances in Soft Computing -Computer Recognition Systems Springer Verlag 2005, pp.477-484.

[3] BERNDT-SCHREIBER M., KUNAT M., Methods of Mathematical Morphplogy in Action – a Proposal of Computer Application for Digital Fundus Eye Images. Proc. 3rd Int. Conf. on Theretical and Applied Aspects of Program System Development , Kiev Universty 2006.

[4] BOISSONNAT J.-D., CHAINE R., FREY P., MALANDAIN G., SALMON S., SALTEL E., THIRIET M., From Arteriographies to Computational Flow in Saccular Aneurismsm, Medical Image Analysis,- the INRIA Experience, Vol. 9, pp.133-143, 2005.

[5] CHAKRAVARTHY U., WALSH A.C., MULDREW A., UPDIKE P.G., BARBOUR T., SADA S.V.R. Quantitative Fluorescein Angiographic Analysis of Choroidal Neovascular Membranes: Validation and Correlation with Visual Functions, Investigative Ophthalmology and Visual Science Vol.48, pp. 349-354, 2007.

[6] GONZALEZ R.C., WOODS R.E., EDDINS S.L. , Digital Image Processing Using Matlab. Prentice Hall, 2004.

[7] NIENIEWSKI, M., Morphological Methods for Extraction of Microcalcification in Mammograms for Breast Cancer Diagnosis, Machine Graphics nad Vision Vol. 8, 1999, pp. 427-448.

[8] NIENIEWSKI, M., Extraction of Diffuse Objects from Images by Watershed and Region Merging. Example of Solar Images, IEEE Transactions on Systemsw, Man and Cybernetics Part B.Cybernetics Vol.34, 2004, pp. 796-801.

[9] SHAH S.M., TATLIPINAR S., QUINLAN E., SUNG J.U., TABANDEH H., NGUYEN, Q.D., FAHMY A.S., ZIMMER-GALLER I., SYMONS R.C.A., CEDERBAUM J.M., CAMPOCHIARO P.A. Dynamic and Quantitative Analysis of Choroidal Neovascularization by Fluorescein Angiography, Investigative Ophthalmology and Visual Science Vol.47, pp. 5460-5468, 2006.

[10] VINCENT L., Morphplogical Greyscale Reconstruction:Definition, Efficient Algorithm and Applicatiion in Image Analysis, Proc. IEEE Conf.on Comp.Vision and Pattern Recogg., pp 633-635, 1992.

[11] VINCENT L., Morphplogical Greyscale Reconstruction in Image Analysis: Application and Efficient Algorithms, IEEE Transactions on Image Processing Vol.2, pp.176-201,1993.

[12] VINCENT L. Current Topics in Applied Morphological Image Analysis [in] Current Trends in Stochastic Geometry and its Applications ,W.S. Kendall, O.E. Barndorff-Nielsen , M.C. Van Lieshout editors, Chapman & Hall, London 1997.

[13] Website http://www.e-medicine.com

[14] Websites for Java http://www.java.sun.com

[15] Website for ImageJ http://www.rsb.info.nih.gov/ij/

[16] WOJTKOWSKI M., SZKULMOWSKA A., BAJRASZEWSKI T., GORCZYŃSKA I., TARGOWSKI P., KAŁUŻNY J., J., KOWALCZYK A., Quantitative Analysis of Phoptoreceptor Layer in Macular Pathologies with Three Dimensional Spectral Coherence Tomography, Proc.SPIE 6130 (2006).

[17] WOJTKOWSKI M., SZKULMOWSKA A., SZKULMOWSKI M., BAJRASZEWSKI T., GORCZYŃSKA I., TARGOWSKI P., KAŁUŻNY J., J., KOWALCZYK A., Coherent Noise-Free Ophtalmic Imaging by Spectral Optical Coherence Tomography, Journal of Physics D: Applied Physics, Vol.38, 2006-2011(2005).