HUMAN VISUAL PERCEPTION, GESTALT PRINCIPLES AND DUALITY REGION-CONTOUR

Application to Computer Image Analysis of Human Cornea Endothelium

Yann Gavet, Jean-Charles Pinoli
Centre Ingénierie et Santé & Laboratoire LPMG, UMR CNRS 5148
École Nationale Supérieure des Mines, Saint-Etienne, France

Gilles Thuret, Philippe Gain
Faculté de Médecine, Saint-Etienne, France

Keywords: Pattern recognition, segmentation, grouping, cognitive and biologically inspired computer vision, mathematical morphology, medical image analysis, computational geometry, Gestalt Theory, Contour closure, Mosaic reconstruction, image analysis.

Abstract: The human visual system is far more efficient than a computer to analyze images, especially when noise or poor acquisition process make the analysis impossible by lack of information. To mimic the human visual system, we develop algorithms based on the gestalt theory principles: proximity and good continuation. We also introduce the notion of mosaic that we reconstruct with those principles. Mosaics can be defined as geometry figures (squares, triangles), or issued from a contour detection system or a skeletonization process. The application presented here is the detection of cornea endothelial cells. They present a very geometric structure that give enough information for a non expert to be able to perform the same analysis as the ophthalmologist, that mainly consists on counting the cells and evaluating the cell density.

1 INTRODUCTION

Image processing specialists have often the same problem. People come with their images of their own domain of excellence, for example in the field of ophthalmology, which is the application frame of the present paper. They ask for counting the cells in the corneal endothelium (fig. 1), adding it might not be difficult because a child could perform it.

If it were so simple, it would be a long time we should have had to work on another subject. To characterize the quality of the cornea, ophthalmologists first evaluate the cell density and then the shape irregularities of the cells. One method consists on detecting the contours of the cells and then compute the parameters, like cell density or hexagonality (Gain et al., 2002; Debayle et al., 2006). Softwares using the first detection method (Gain et al., 2002) are currently used in biomedical laboratories, but the specialists are still not satisfied because they have to spend a few minutes checking and correcting the cell borders, a work that a child could do (fig. 2).

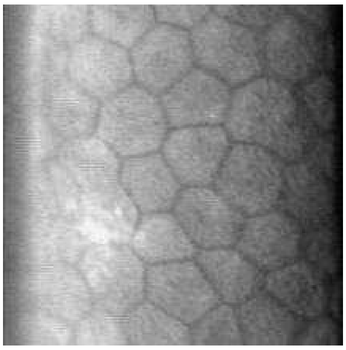

Figure 1: 215×215 pixels ($0.036 mm^2$) image of a human corneal endothelium acquired by specular optical microscopy. The endothelial cells are theoretically hexagonally shaped. The borders appear as dark contour lines on this image. But sometimes (for example at the bottom left of the image) the borders are nearly of the same intensity level as the inside of the cells, so the segmentation of these cells cannot be only based on the intensity information.

1.1 Theoretical Human Vision Processing

When there is not enough information about contours in an image, no algorithm can really detect anything.

Gavet Y., Pinoli J., Thuret G. and Gain P. (2007).
HUMAN VISUAL PERCEPTION, GESTALT PRINCIPLES AND DUALITY REGION-CONTOUR - Application to Computer Image Analysis of Human Cornea Endothelium.
In *Proceedings of the Second International Conference on Computer Vision Theory and Applications - IU/MTSV*, pages 221-224

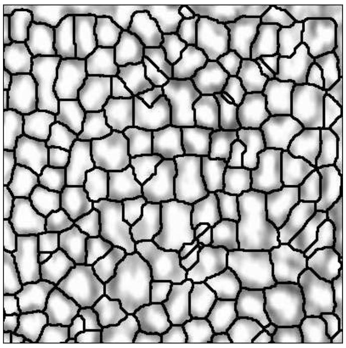

Figure 2: 400 × 400 pixels ($0.4mm^2$) image of a human corneal endothelium acquired by standard optical microscopy. A software used by ophthalmologists has performed a detection of contours in this image. The detected cell map appears globally relevant, but some misdetection can be clearly observed at several locations, (Debayle et al., 2006).

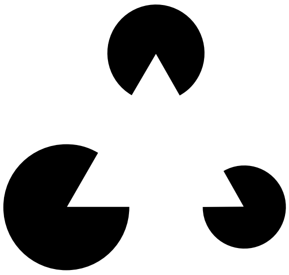

Figure 3: A Kanizsa illusory triangle. Though not drawn, the triangle is perfectly seen, or more precisely percepted.

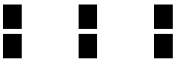

Figure 4: Grouping of elementary rectangles here is done by proximity.

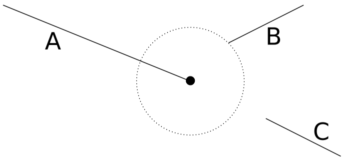

Figure 5: Each segment is grouped to the closest one following the proximity principle. The circle shows the Euclidean distance value from the extremity (marked point) of the segment to the closest extremity. The segments A and B are thus grouped by proximity.

But the fact is that the we see and infer informations, as illusory or subjective contours, that are not really present in this image (Koffka, 1935) as for the Kanisza triangle (Kanizsa, 1980) in the fig. 3.

This is not *because we are intelligent*, it has been proved that many animals could see illusory contours (barn owls (Nieder, 2002), bees, etc.). Then, how does the human visual system do to distinguish the cells? Is there an efficient method that could be implemented in a computer to efficiently detect them? The Gestalt Theory (Wertheimer, 1938) shows simple visual effects that mainly consist on grouping some stimuli together according to certain principles (*proximity*, *good continuation*, *symmetry*, etc.). Although very attractive, they are not proved (they are asserted by Wertheimer and the gestaltists as axioms), but recent works show that these laws are biologically or/and cognitively relevant (Kovács and Julesz, 1993; Mullen et al., 2000). More, they appear really simple and close to a mathematical or algorithm description, but in fact, they are not. Those are reasons to develop computer programs to test the effects of the gestalt principles.

2 ALGORITHMS: COMPUTER VISION OF MOSAICS

This section introduces some gestalt principles (subsection 2.1) used on a real corneal endothelium (subsection 2.2). This conducts to define a mosaic as a network of contours.

2.1 Implementing Gestalt Principles

The most basic objects used to described the gestalt principles are points or curves. At first sight, a curve can be simplified as a set of segments and the following algorithms use them as inputs to the gestalt principles.

Proximity

Experiences done by (Kubovy and Gepshtein, 2000) prove that *proximity* plays an important role in grouping objects together (fig. 4 and 5).

Good Continuation

Good continuation (fig. 6) is the visual effect noticed when grouping is done with objects that shows a continuity of direction.

By using Gabor patches, (Dakin and Hess, 1999) and (Mullen et al., 2000) prove that *good continuation* (in an angular variation of 30°) is important for the vision: lines have not to be continuously drawn, even if closed contours are visually more important than

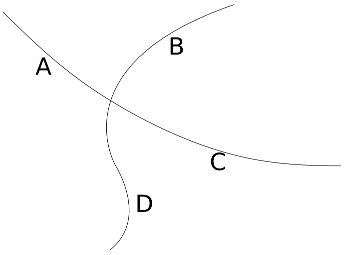

Figure 6: The lines A-C and B-D are grouped by good continuation. Visually, we have to do an effort to see the groups A-B and C-D.

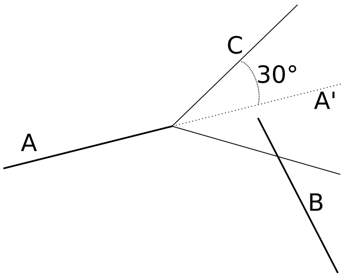

Figure 7: The direction (cone C) of continuation is defined by the segment A and an angle of 30° around the continuing direction A'. If another extremity is inside the cone C, it is considered as a *weak continuation*, as opposed to good continuation (fig. 8).

incomplete ones (Kovács and Julesz, 1993) (see fig. 7 and 8).

Geodesic Proximity and Continuation

The distance transform is an operation that takes an object and compute the Euclidean distance from this object to any other point in the image (Rosenfeld and Pfaltz, 1966): the result is the so-called *distance map*, that can be represented as an image. The distance transform is also used to compute the skeleton (Blum and Nagel, 1978). The *geodesic distance map* is the representation of the geodesic distance from the object.

By using the Gestalt theory, the geodesic distance map can be seen as a mix of proximity and continuation. Each extremity of the contour is linked to the nearest (by the geodesic distance) other extremity.

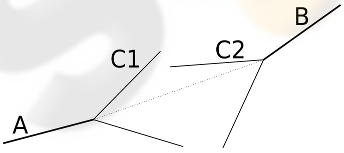

Figure 8: The *good continuation.* is considered when the weak continuity (fig. 7) is effective for every extremity. C1 and C2 englobe respectively the extremities of B and A.

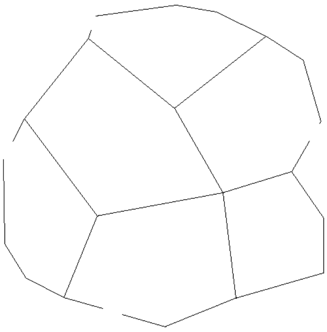

Figure 9: A simple mosaic. Holes are randomly performed into it and the algorithm tries to close them.

2.2 From the Corneal Endothelium

According to (Marr, 1983), the first stage of perception consists in contour detection. This is the way ophthalmologists analyze the cells in the corneal endothelium.

The contours of the cells can be detected by using mathematical morphology (Serra, 1988). Our algorithm is inspired from (Chazallon and Pinoli, 1997). With the skeleton of the borders of the cells (Blum and Nagel, 1978), the goal is now to reconstruct the cells with the principles described previously.

This type of image, e.g. the partition of the image by planar objects, can be shown in different domains, like materials (grains, dendrites), satellite imagery of fields or cities, etc. This is why we now introduce an abstraction of such a network we call a mosaic.

A 2D *mosaic* is a binary set of curves (we used segments at first approximation) (fig. 9) in the Euclidean plane space that can be the result of a contour detection or a skeletonization of objects. For testing purposes, we use a hand-drawn mosaic as the reference, and perform holes on it: one part of the segments are randomly erased to be then reconstructed (fig. 9).

2.3 Results

Proximity and *good continuation* perfectly close the theoretical mosaic (see fig. 9), because they are really adapted to the holes done into the it and to its segment structure. About the real cornea (fig. 10), *proximity* and *good continuation* show their limits: the algorithm can link two extremities that are very far from each other (and draws a segment that crosses the mosaic). The geodesic proximity can somehow be considered as a synthesis of *proximity* and *continuation*,

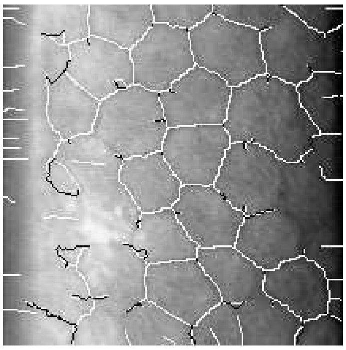

Figure 10: Application of the geodesic distance to reconstruct the corneal endothelium. This method shows the limits of a pure contour approach. The white pixels represent the contours detected, and the black pixels represent the closure computed. The regional information is necessary to find a good closure.

but is not enough to give what was visually expected.

3 CONCLUSION

We decided to begin with simple principles of vision and to implement them one by one. Those simple principles reconstruct well simple mosaics. But real mosaics like corneal endothelium are complex. The conclusion of these tests is that when ophthalmologists count cells on the endothelium, a lot of visual effects occur at the same time, not only *proximity* and *continuation* (fig. 10). To improve our methods, we have combined *proximity* and *continuation* with a distance criteria (the *geodesic continuation*), and the reconstruction is not good yet.

As suggested by Marr, the human visual system performs a *Bottom-up-Top-down* dual analysis; we think that there is more than that: the human visual system is sensitive to the duality region-contour and unceasingly reinterpret the informations collected.

PERSPECTIVES

In a near future, we will use regional informations to choose where to close the cells; and the *proximity* and *continuation* methods will tell us how.

The perspectives for this work are to use regional descriptors, size and shape parameters and contours informations at the same time. We will also introduce comparison methods between the mosaics to evaluate the reconstruction, and test some other methods with it. Those will be part of a PhD Thesis (Gavet, 2007).

REFERENCES

Blum, H. and Nagel, R. N. (1978). Shape description using weighted symmetric axis features. *Pattern Recognition*, 10(3):167–180.

Chazallon, L. and Pinoli, J.-C. (1997). An automatic morphological method for aluminium grain segmentation in complex grey level images. *Acta Stereol*, 16(2):119–130.

Dakin, S. C. and Hess, R. F. (1999). Contour integration and scale combination processes in visual edge detection. *Spatial Vision*, 12:209–327.

Debayle, J., Gavet, Y., and Pinoli, J.-C. (2006). *Image analysis and recognition*, chapter General Adaptive Neighborhood Image Restoration, Enhancement and Segmentation, pages 29–40. Lecture Notes in Computer Science 4141. Springer Berlin / Heidelberg.

Gain, P., Thuret, G., Kodjikian, L., Gavet, Y., Turc, P. H., Theillere, C., Acquart, S., Petit, J. C. L., Maugery, J., and Campos, L. (2002). Automated tri-image analysis of stored corneal endothelium. *Br J Ophthalmol*, 86(7):801–808.

Gavet, Y. (2007). Human vision principles and completion of mosaics. application to human corneal endothelium. PhD Thesis. To be published.

Kanizsa, G. (1980). *Grammatica del vedere. Saggi su percezione e Gestalt.* Il Mulino, Bologna.

Koffka, K. (1935). *Principles of Gestalt Psychology*. Harcourt Brace.

Kovács, I. and Julesz, B. (1993). A Closed Curve is Much More than an Incomplete One: Effect of Closure in Figure-Ground Segmentation. *PNAS*, 90(16):7495–7497.

Kubovy, M. and Gepshtein, S. (2000). *Perceptual Organization for Artificial Vision Systems*, chapter Gestalt: from phenomena to laws, pages 41–71. Kluwers Academic Publishers.

Marr, D. (1983). *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information.* Henry Holt & Company.

Mullen, K. T., Beaudot, W. H. A., and McIlhagga, W. H. (2000). Contour integration in color vision: a common process for the blue-yellow, red-green and luminance mechanisms? *Vision Research*, 40(6):639–655.

Nieder, A. (2002). Seeing more than meets the eye: processing of illusory contours in animals. *Journal of Comparative Physiology A: Sensory, Neural, and Behavioral Physiology*, 188(4):249–260.

Rosenfeld, A. and Pfaltz, J. L. (1966). Sequential operations in digital picture processing. *J. ACM*, 13(4):471–494.

Serra, J. (1988). *Image analysis and mathematical morphology: Vol. 2.* London: Academic Press.

Wertheimer, M. (1938). *A sourcebook of Gestalt Psychology*, chapter Laws of Organization in Perceptual Forms (partial translation), pages 71–88. Hartcourt, Brace.