EMPLOYING PROPERTIES OF THE HUMAN VISUAL SYSTEM FOR IMAGE SEGMENTATION

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I INTRODUCTION

We have become used to the fact that the information processing of digital computers is so much superior to that of human beings because of the digital computers precision of data storage and retrieval, its speed, its working in higher dimensions and its ability to perform complicated mathematical operations. This is almost opposite in image processing. While human viewers can easily find contours, differentiate textures, detect and track objects, perceive depth and analyse with ease image contents, present computer based image processing systems perform rather slow and show very limited capabilities. Because of this lack our approach to image analysis, especially image segmentation, is to study properties of the human visual system and perception in order to arrive at better algorithms and new concepts for the solution of specific problems in image processing. In the following results of some of our efforts are presented namely in contour detection, texture analysis, and knowledge representation to be used for the segmentation of natural images.

II CONTOUR DETECTION

One method of separating objects from each other and from background is to find the contours which surround the objects. Therefore contour detection is one of the key techniques in image segmentation. The processing of visual information by the human visual system includes contour detection as well after some initial preprocessing steps. Due to nonlinear processes in the retina and lateral inhibition of neighbouring cells, the human visual system performs a bandpass filtering on the incoming image and shows adaptive properties to slowly changing intensity values. On its way from the retina to the corpus geniculatum laterale the original gray level image is step by step reduced to its binary contours. These contours are further processed in the cortex and higher centers of the brain. Those proper-

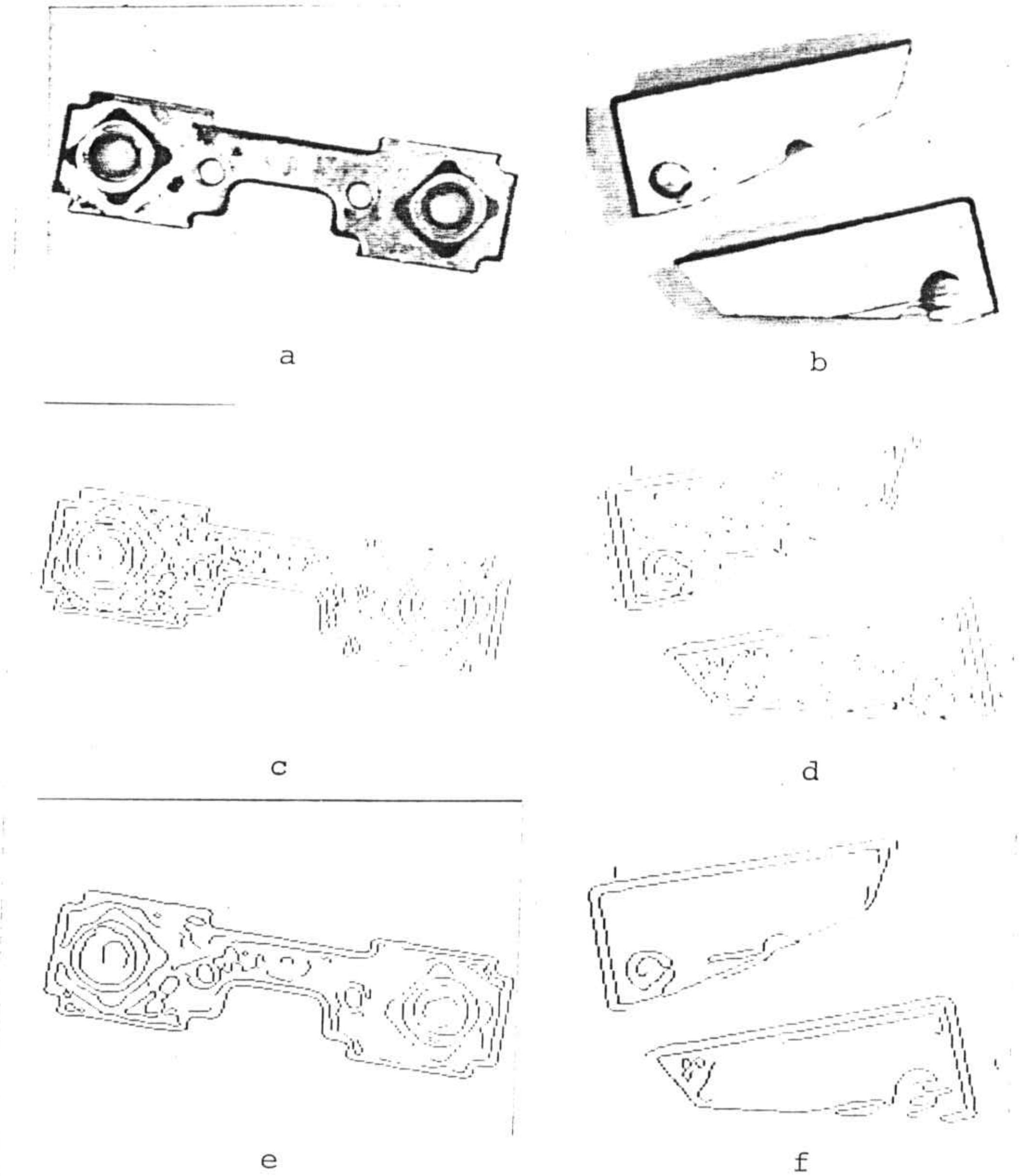


Fig.1: CONTOUR DETECTION: (a),(b) original gray level images; (c),(d) contour detection under consideration of the bandpass characteristic and adaptation properties of the retina; (e),(f) elimination of contours of minor "strength"

ties of the visual system which contribute most significantly to human contour perception are

a) the frequency response of the retina
b) adaptation
c) noise reduction by closing of small contour gaps and elimination of short contours of low "contour strength".

These properties have been modelled on the basis of physiological measurements and subjective tests from the literature and measurements derived from our own experiments. Some results of our model are given in Fig.1. The model has been reduced to a very efficient algorithm which needs a computation time equivalent to that of a simple Sobel operator and is suitable for implementation in hardware.

III TEXTURE ANALYSIS

Frequently objects in a monochrome image can be described as being those subimages which are homogeneous in some local property. We call this local property "texture". Objects can be separated from each other and the background by textural differences exceeding a threshold. Our goal is to develop an algorithm which automatically indicates textural differences in all those cases where humans perceive spontaneously textural differences as well.

In earlier publications it has been shown by JULESZ that it is important to differentiate between textures which can be described by first order statistics and higher order statistics. Higher order statistics contain in addition to pure gray level statistics information about direction and shape of micropatterns. Fig.2 shows an example for an artificial test pattern containing pairs of textures which humans can and such which humans cannot spontaneously differentiate. Key elements for the perception of micro patterns in the human visual system are various two-dimensional filters of different spatial extent and orientation sensitivity. These filters are found in the visual cortex and process the binary images which have previously been described. These spatial filters constitute an important component in our model of texture perception. Fig.2b shows the output and Fig.2c the local energy from one of the directional filters. Fig.2d indicates that the model produces segmentation results which are in agreement with human perception.

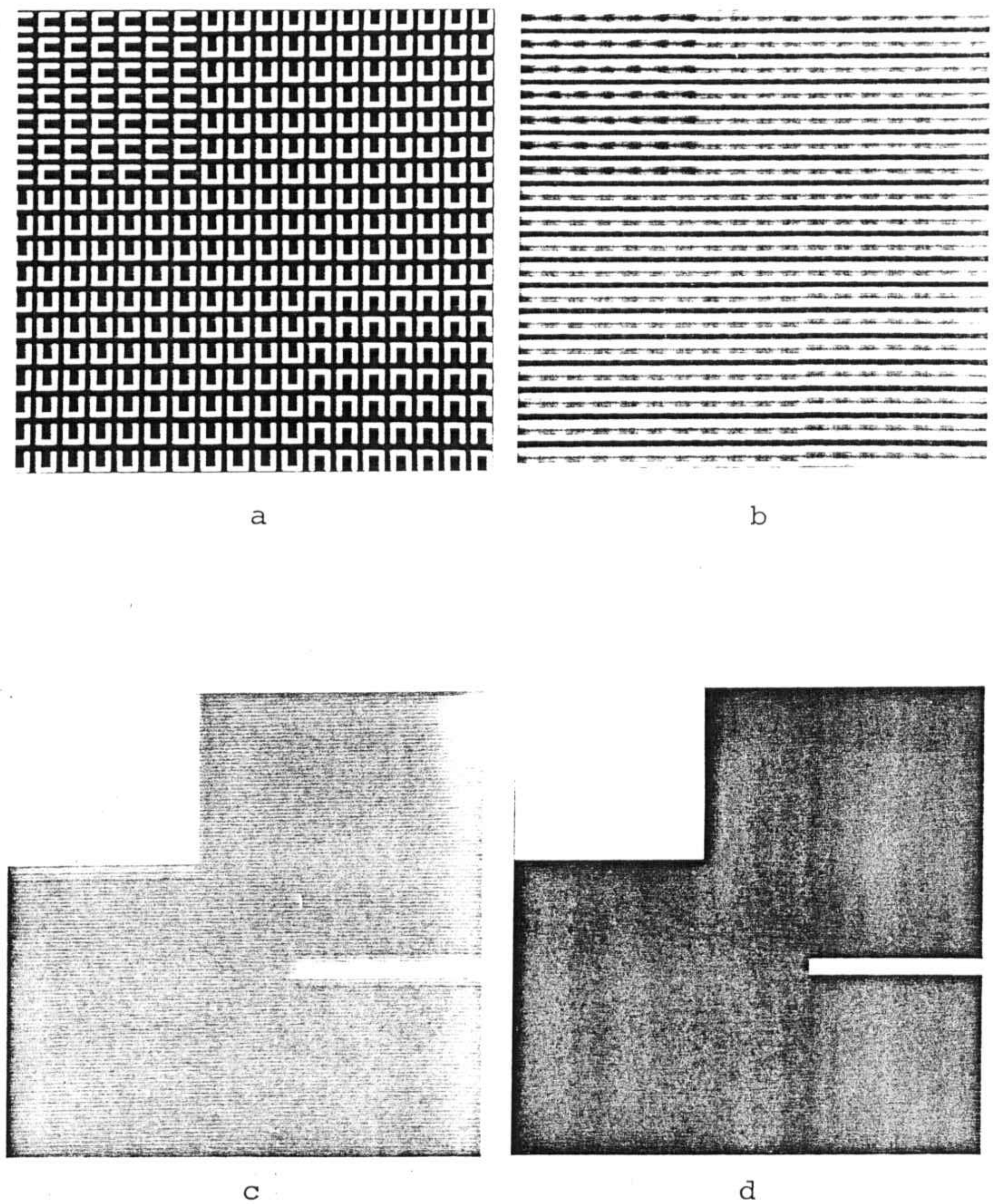


Fig.2: TEXTURE ANALYSIS: (a) original image containing areas which differ in statistics of second order and in statistics of higher order; (b) directional filtering applied to (a); (c) local energy of signal on the output of (b); (d) image segmentation by thresholding of (c)

IV FORMULATION OF A PRIORI KNOWLEDGE ABOUT SCENE CONTENT

Contour detection and texture analysis are local techniques. These methods are equivalent to a human analyzing an image line sequentially through a small aperture. Only in a very few cases it is possible to achieve a correct image segmentation just by local techniques. The fast and reliable assessment of visual information by humans can only be explained by additional use of global information like shape, size, neighborhood relations, spatial orientation, etc. and prior knowledge about the scene content and about the properties of the objects in the scene. We studied the formulation of a priori knowledge including local and global properties of a scene on the example of microscopic images of leucocytes. It was observed that the segments we were interested in like "nucleus", "cytoplasm", "background", "thrombocyte", "erythrocyte", etc. either consists of one or a few homogeneous regions. Therefore we subdivided the digitized image into regions which are homogeneous in some local property. We call these regions "blobs". All segments consist of one or several connected blobs. Global properties of the segments can now be used to aid the segmentation process by marking measurements on different arrangements of connected blobs. Prior knowledge about the scene content is used by limiting the number of segment types in the scene to a finite number of pregiven classes. In our case these classes are for instance "nucleus", "cytoplasm", "erythrocytes", etc. For each blob likelihoods are calculated which describe the chance of that particular blob belonging to each of the pregiven segment classes. The likelihoods are updated continuously on the basis of a comparison of local and global measurements from that blob with well known properties of this special segment class which has been collected during an earlier learning phase. Finally all connected blobs with the highest likelihood for the same segment class are combined in order to produce the resulting segment mask. Further a priori knowledge is used during a postprocessing step. Some of the segmentation steps are demonstrated on a cell sample in Fig.3.

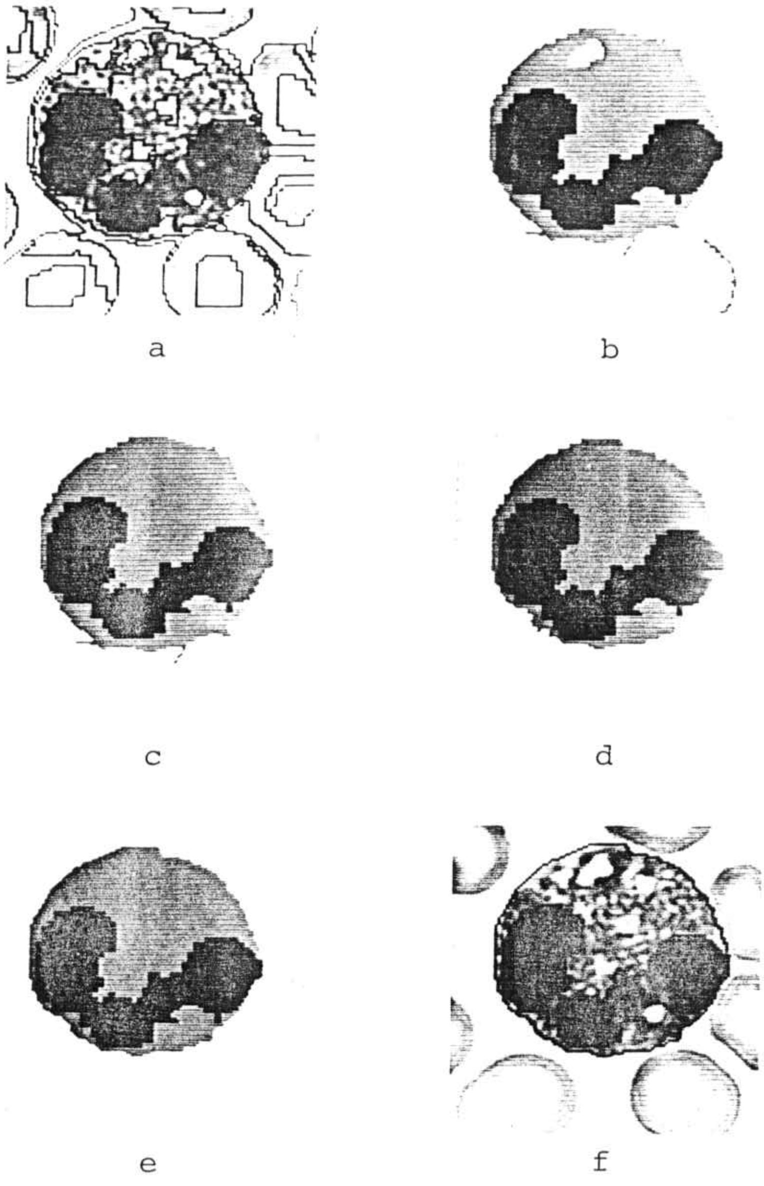
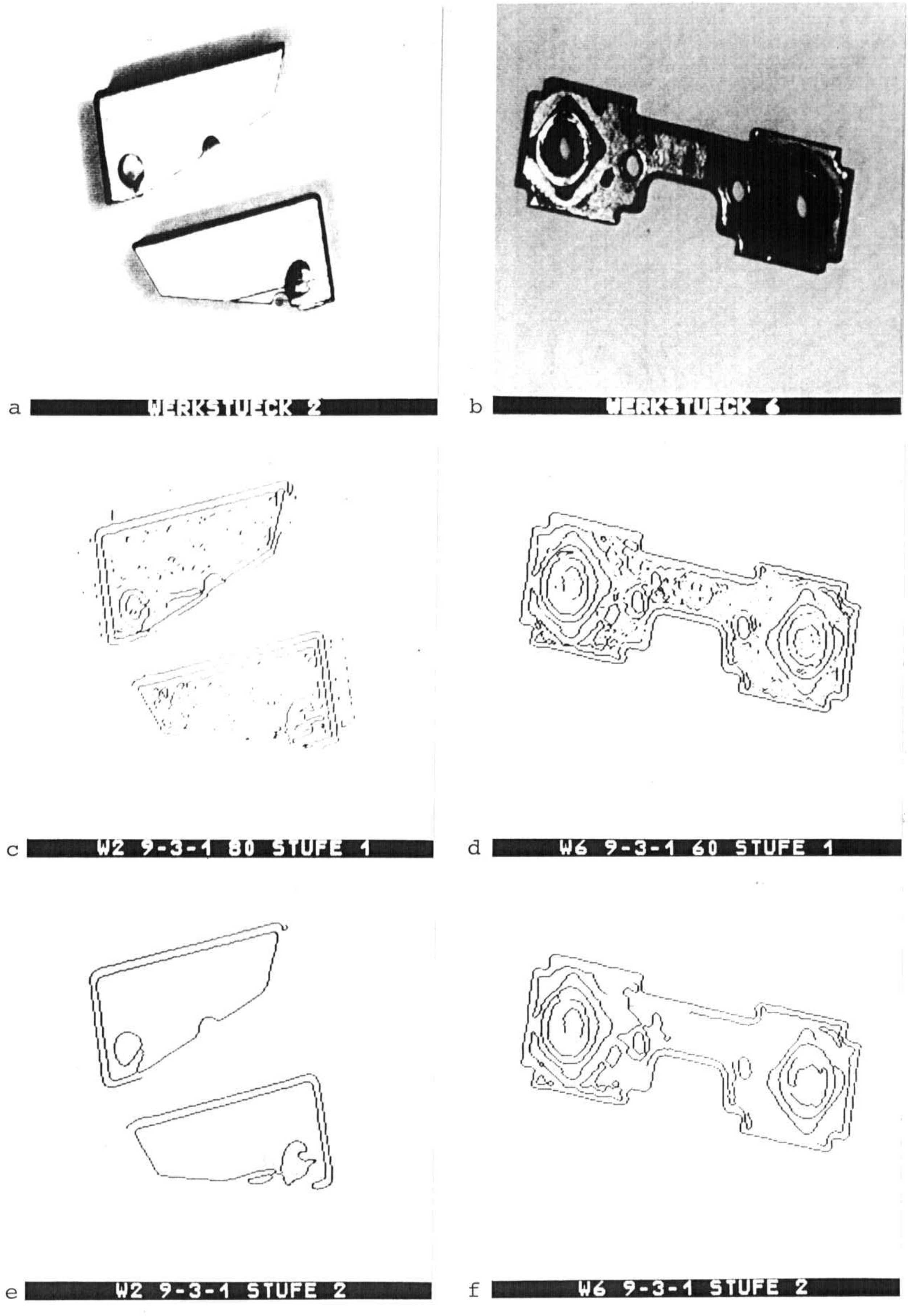


Fig.3: ENTERING OF A PRIORI KNOWLEDGE (APK) INTO THE SEGMENTATION OF LEUCOCYTES: (a) uniform regions detected by a Split & Merge algorithm; region labelling on the basis of photometric apk (b); topological apk about neighborhood relations (c); and morphological apk (d). (e) shows nuclear and cytoplasmic masks after postprocessing and (f) gives the resulting boundaries of nucleus and cytoplasm superimposed to the original image



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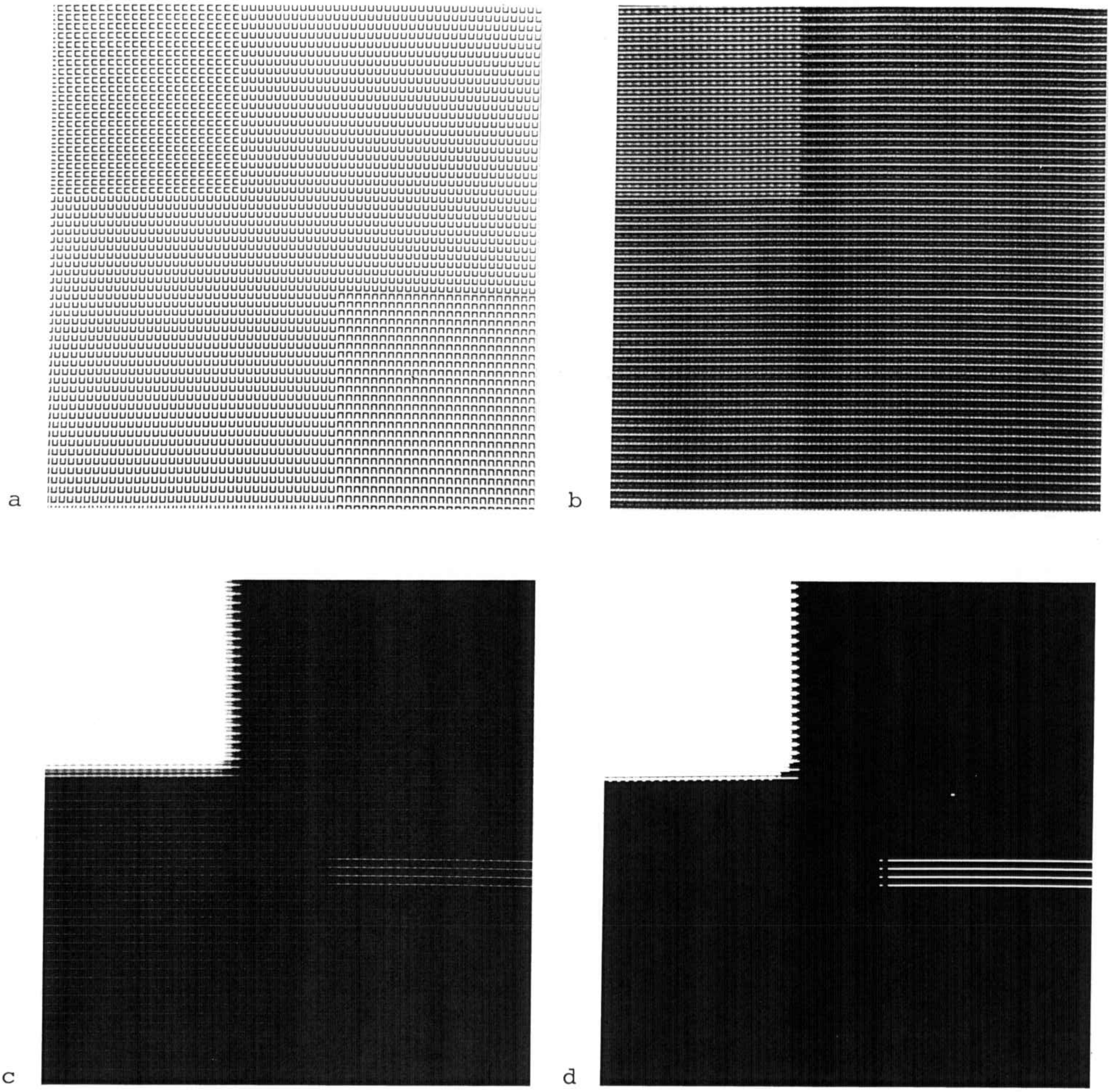

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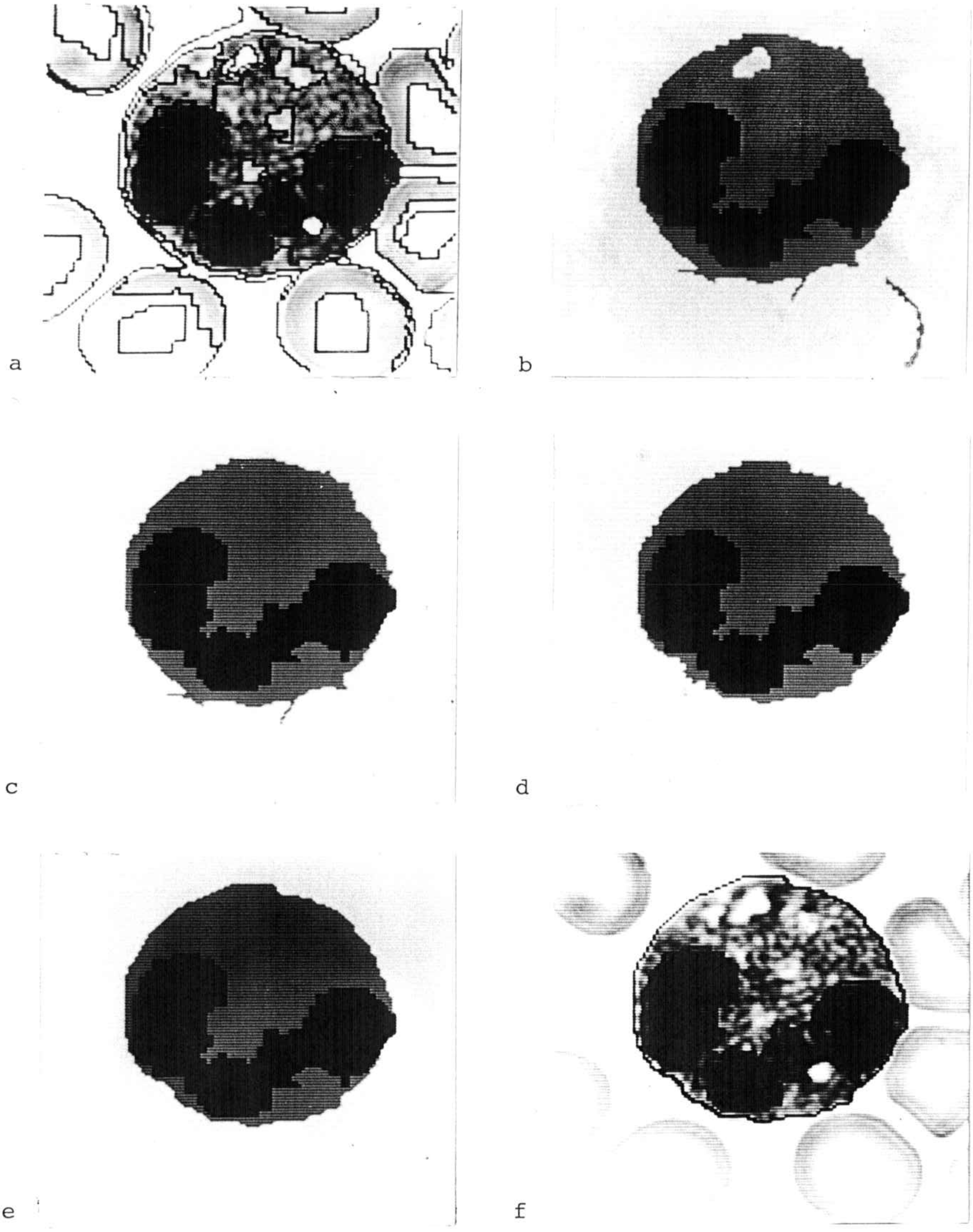

Figure 3: ENTERING OF A PRIORI KNOWLEDGE (APK) INTO THE SEGMENTATION OF LEUCOCYTES: (a) uniform regions detected by a Split & Merge algorithm; region labelling on the basis of photometric apk (b); topological apk about neighborhood relations (c); and morphological apk (d). (e) shows nuclear and cytoplasmic masks after postprocessing and (f) gives the resulting boundaries of nucleus and cytoplasm superimposed to the original image.