COLOR IMAGE SEGMENTATION

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INTRODUCTION

Segmentation is a key problems in image processing. In the framework of mathematical morphology the traditional method of segmentation is based on the watershed transform. We will see that this method may be analysed as a region growing algorithm, starting from a set of markers for all zones of interest. We then extend it to the segmentation of color images and illustrate it on paintings.

A TYPICAL SEQUENCE OF SEGMENTATION

Problem description

A detailed presentation of the techniques of morphological segmentation may be found in the thesis of Beucher (1) or in a review paper by Meyer and Beucher (2). An example in cytology will illustrate briefly these techniques : two nuclei have to be segmented (fig.1a), the presence of an inhomogeneous and textured background making the task difficult.

On the filtered gradient image, the contours of the cells appear clearly, but other structures in the background appear as well (fig.1b). How to select the most prominent contours ? A transformation called watershed line will allow us to get the result.

Construction of the watershed line by flooding

Flooding from the regional minima. By considering a grey-tone as an altitude, an image becomes a topographic surface. The concept and construction of the watershed line may then best be understood as a flooding process of this topographic surface. We bore a hole in each minimum of the relief and immerse the surface in a lake with a uniform vertical speed. Each hole acts as a water source. The delivery of each source is such that the water level is uniform over the whole relief and its level increases with uniform speed. The water, entering through the holes fills up the various catchment basins. In order to avoid the confluence of the floods coming from different minima, we build a dam along the lines where the floods would merge. After complete immersion only the dams emerge and separate the various catchment basins.

The gradient image (fig.2b) of the original profile (fig.2a) possesses 4 regional minima (a regional minimum is a plateau without lower neighbors). Each of them is labeled with a different color in fig.2c. Two minima belong to the background and two to the object to be segmented. The successive levels of the water end the erection of dams is illustrated by the fig.$2d - g$. The final result is in figure 2h. The object has been is cut in two parts : each minimum of the gradient image has become a separate catchment basin.

The same phenomenon is observed in real images : the flooding of the gradient image of fig.1b yields the watershed line illustrated in red in fig.1c. A severe oversegmentation has taken place. Each catchment basin is generated by a different regional minimum of the image. And although the gradient image seems relatively clean, there are many regional minima, even in the background. This fact is general : the construction of the watershed line leads to severe over-segmentations.

Flooding from selected sources

Description. In order to avoid over-segmentation, we need some additional information : suppose we know before flooding which minima correspond to the centers of the nuclei and which to the background. If we come back to our flooding scheme, we will bore a hole only in these selected places before immersing the relief. The flooding and the building of dams take place as previously. The catchment basins of the minima which are not pierced are filled up by overflowing of the neighboring catchment basin : as soon as the water reaches the saddle point between both basins, the water rushes through the pass and fills the so far empty basin. No dam is constructed between such basins. A dam is only constructed for separating floods originating from different pierced minima. At the end, the total surface will be covered by the flood, except the divide line which separates the catchment basins.

The introduction of three markers in Fig.2i, one for the object and two for the background, produces a flooding yielding the correct result, as may be seen in the figures 2j-m. This example shows that it is not necessary that the markers are chosen among the minima of the gradient image. Nor is it necessary that the various markers be connected particles. It is sufficient that they are labeled. Two particles with the same label will be considered to belong to the same region and no dam will be erected between them, if their flooded areas happen to merge. The initial position or shape of the markers also is not critical for the end result. All these features make this procedure very robust.

Construction of the markers. The finding of markers is problem dependent. In the case of cells we may chose the minima of a severely filtered image (fig.1d). In order to flood the gradient image, we need also a marker for the background. These outside markers are nothing else than the watershed line of the original image (in red in figure 1e), when it is flooded by sources placed at all inside markers.

Construction of the final contours. For detecting the final contours, one floods the gradient image from sources placed at the inside and outside markers detected above. The catchment basins corresponding to the inside markers are the binary masks of the nuclei (see fig.$1g - h$).

THE ORDER RELATION OF FLOODING

During the flooding of a topographic surface appears a dual order relation between the pixels (we consider here the flooding with sources placed at the regional minima of the function). It is clear that a point x is flooded before a point y if y is higher than x on the relief. This constitutes the first level of the hierarchy. It is simply the order relation between the grey-values. A second order relation occurs on the plateaus (a plateau is a connected set of uniform altitude). Before a plateau begins to be flooded all its neighboring points with a lower altitude have been flooded. The flood progresses inwards into the plateau with uniform speed. The first neighbors of already flooded points are flooded first. Second neighbors are flooded next, etc. This introduces a second order relations among points with the same altitude, corresponding to the time

when they are reached by the flood.
An algorithm which simulates the flooding has to reproduce this dual order relation. This is obtained quite naturally by using an ordered queue, described in the next section. An ordered queue allows to store points in any order and to retrieve them in the order of the flooding. For this reason, this structure is at the base of an elegant optimal implementation of the watershed line.

Description of an ordered queue

The 4 figures $3.1 - 3.4$ show how an ordered queue works. It can be seen in fig.3.1, that an ordered queue is in fact a series of simple queues (represented here as cylinders). Each simple queue is assigned a level of priority. In the drawings the priority is represented as a grey-tone : the darkest grey-tones correspond to the highest priorities. In our example, we have 5 levels of priority. All cylinders are open at the top, which means that at any moment it is possible to introduce a client of any priority in the queue. On the contrary, only the queue with the highest priority has an opening at its basement. Fig.3.2 shows the extraction of an element of the structure : it is the client who arrived first in the queue of highest priority still existing in the structure. If the attempt to extract a new element of the current queue fails, the queue is suppressed and the queue with the priority immediately below is opened for extracting the next elements (see fig.3.3). Fig.3.4 illustrates the last feature of an ordered queue : a late comer of high priority arrives, and the queue with the same priority has already been suppressed. Then the client is put at the end of the current queue of highest priority.

An optimal watershed algorithm

The input is now a grey tone function topo() to be flooded and a set of markers mark(), which serve as sources for the flooding. The markers are identified by labels. Each region will keep the label of the marker which has been the source of the flood. A marker may have several distinct connected components, as long as they share the same label.

Initialization. An ordered queue is created with as many levels of priority as there are grey-levels in the image topo(). All neighbor points of the markers are put into the ordered queue with an "appropriate priority". In the classical case, it is simply the altitude in the image to be flooded. But we will see that extensions of the basic scheme are obtained by changing the rules governing the priority assignment.

Growing of the markers.
For any point extracted of the ordered queue :
a) If this point has in its neighborhood one and only one labeled region, it is aggregated to this region. Its neighbors without labels and still outside the ordered queue are put into the ordered queue, again "with the same appropriate priority" as in the initialization phase.
b) If the point is neighbor of two regions with different labels, this point is a boundary point and gets a special label characterizing the frontiers.

Effect of various priority assignments

The classical watershed line. If the input image is a gradient image and we assign to each point put in the ordered queue a priority level decreasing with its altitude, we get the classical flooding of a relief (3).

A general region growing scheme. Let us consider again the profile in fig.2a. We obtained its contours by flooding its gradient image, starting from a set of markers (figures $2i - n$). We will now use the same watershed algorithm, with the same markers but with other rules fixing the priority of each point. The priority of a point will depend only on the grey value of this point and its already labeled neighbors, the grey values being taken in the original image and not in the gradient image.
The simplest similarity measure consists in computing the smallest grey-tone difference between the point in consideration and its already labeled neighbors. This produces a region growing algorithm where the point with the closest value to an already labeled point is aggregated to the corresponding region. Fig.$2o - q$ illustrate the successive states of the labeled regions : Fig.2o gives the initial position of the markers. The expansion among the points with a zero distance permits to fill up the background, yielding the result in fig.2p. A further expansion is obtained by treating the points at a distance 1. Aggregating all points at a distance 1 or 0 of a previously labeled point yields the result of fig.2q. This achieves the treatment, since the points at a higher distance are already frontier points. In this particular case we obtain the seam result as the conventional watershed algorithm using the gradient image (fig.2n). However, the points have not been aggregated to the regions in the same order.

THE SEGMENTATION OF COLOR IMAGES

The algorithm for segmenting color images belongs to the general class of region growing schemes we described in the previous section.
We will illustrate it on a simple example. A color profile is given in form of its three component profiles : red, green and blue (fig. $3a-c$). Two markers have also been defined (Fig.3d). The markers are labeled ; the left marker with a value three, the right marker with a value four.
We have now to chose a similarity measure between a point and its neighboring marked region. In our case we define it as the color difference between the point and its neighbor already in the marker. For the sake of simplicity we use a trivial color difference : if (rx, gx, bx) and (ry, gy, by) are the tri-stimulus values of two colored pixels x and y, we define the color difference by :

$$\text{Max}\ (|rx - ry|, |gx - gy|, |bx - by|)$$

This would certainly be a too coarse color measure in reality. We will discuss this problem later on.
Initialization : An ordered queue with four levels is created; four being the maximal color difference between two pixels. The neighbor points of the labeled region, i.e. the pixels b, e, h, and l are introduced in the ordered queues (Fig.3e), each with its priority level computed as indicated above. For instance, the pixel h is neighbor of the pixel i which already belongs to a labeled region ; the color distance between h and i being $1, h$ is put in the queue of priority 1. Each pixel present in the ordered queue is recognizable in the marker image by a special label 1. This label will be replaced by the definitive label once the point has been treated. This label 1 permits to avoid to put the same point twice in the ordered queue (this may happen in a $2d$-image).
Region growing : The first point to be extracted from the ordered queue is b. b has only one region with a label 3 in its neighborghood and gets the label 3. The pixel a is a neighbor of b, with the same color as $b; a$ is put in the ordered queue with the priority 0 (Fig.3f).
Simili modo the point l gets the label 4 (Fig.3g) and the point a the label 3 (Fig.3h). Being boundary points, they have no neighbors entering into the ordered queue during their treatment. The queue with the highest priority being now empty, is suppressed. The next point to treat is $h; h$ gets the label 4 and g is put in the same queue (Fig.3i). With the treatment of g, f enters in the queue (Fig.3j). Finally f itself is given the label 4. Its neighbor e has the label 1, indicating its presence in the queue. The queue of priority 1, being now empty, is suppressed (Fig.3k). The next point to treat is e. The pixel e is neighbor of two distinct labeled regions and gets the special

label 2, indicating that e is a frontier point (fig.3l). No new point entering into the ordered queue, the queue is now empty and the treatment is achieved.

APPLICATION TO THE SEGMENTATION OF PAINTINGS

This method has been applied by A.Gourdon to the segmentation of paintings (4). The purpose of the study was to construct a simplified view of paintings of the Louvres in a form allow to put them in a database. We show here the result of the segmentation of a famous painting by Gauguin, Ararea (Fig.4a). With a drawing editor, the regions of interest are markerd (Fig.4b). The result of the segmentation is overlaid in fig.4c with the original image. For each region, an homogeneous mean color is then computed and replaces the original colors in the fig.4d. This gives a simplified mosaic image of the original scene. In this case an euclidean color distance has been computed. Better results were obtained with the HLS color coordinate system than with the RGB color system.

CONCLUSION

The segmentation method described in this paper gives good results but has a drawback : it needs a set of markers. Methods have to be developed to find such markers automatically in color images. On the other hand, a better segmentation could probably be obtained by using uniform color metrics as described by Tajima (5).

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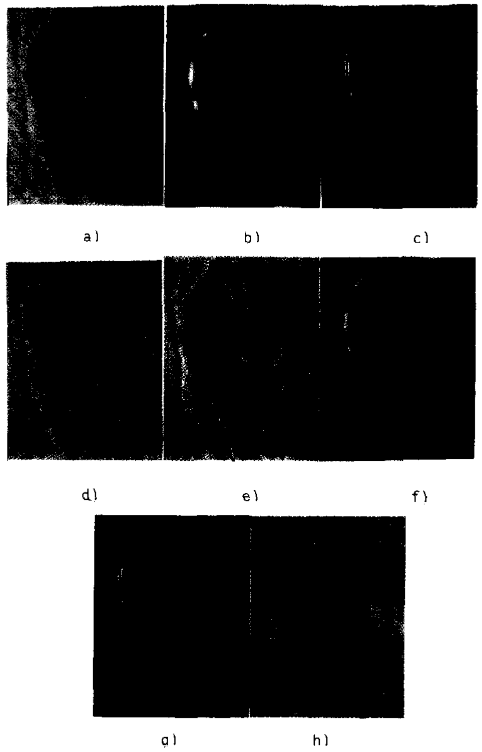

Fig.1: Morphological segmentation of nuclei

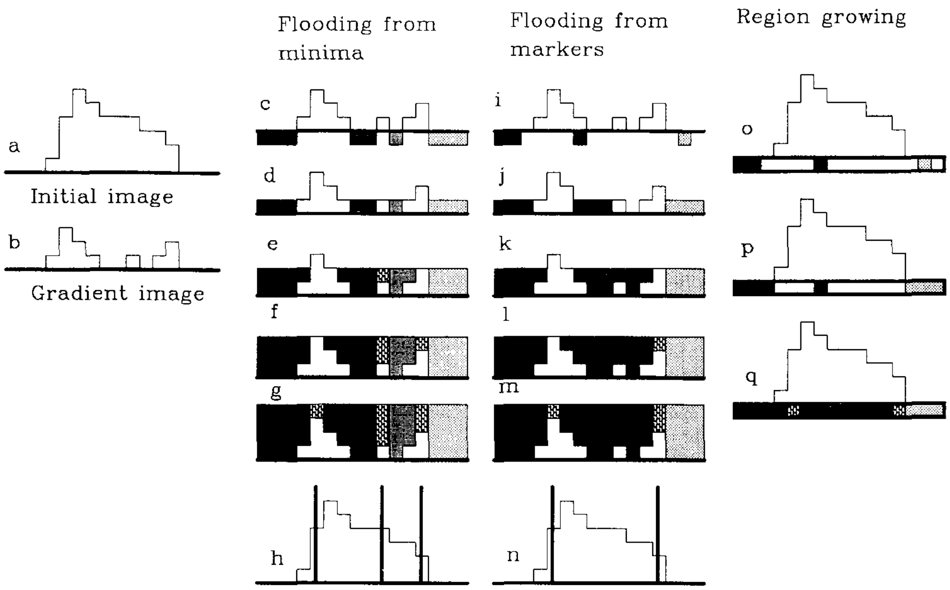

Fig.2 : Comparison between various region growing algorithms

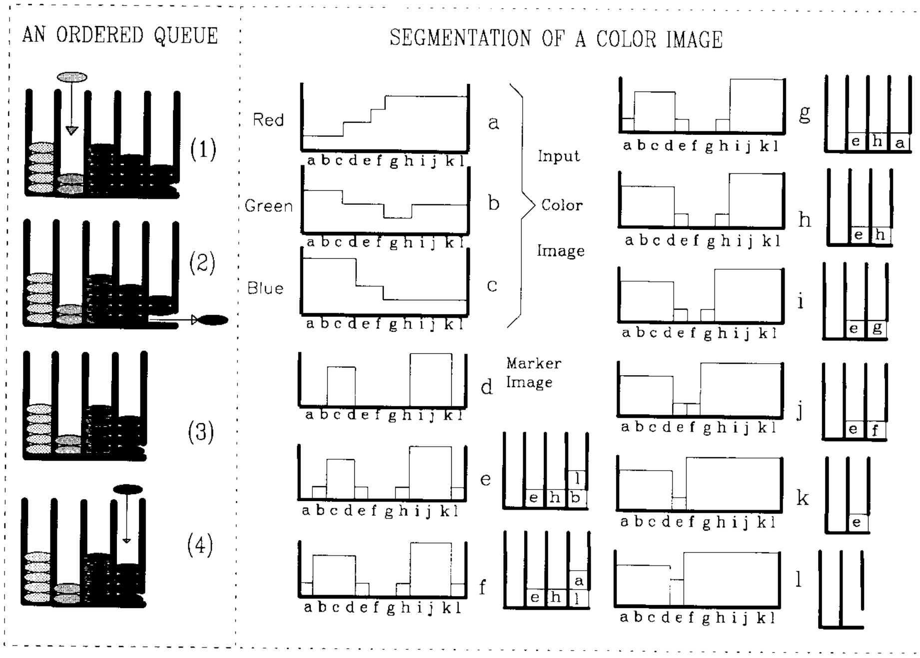

Fig.3 : Principles of an ordered queue and color segmentation

Fig.4 : Color segmentation from a set of markers