A Novel Merging Method in Watershed Segmentation

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Abstract

The watershed transformation is the primary tool of Mathematical Morphology for image segmentation. However, the resulting image often appears oversegmented into a large number of tiny regions (basins), most of which are not significant in the problem of domain. In this paper, a method for removing non significant basins is presented. The notions of relative significance and intrinsic significance are introduced to restrict the merging of a basin to a number of suitably selected adjacent basins. Such a selection allows one to obtain a segmented image perceptually close to the original image. The good performance of the method is shown for the case of astronomic images.

1. Introduction

The segmentation of an image can be defined as its partition into different regions, each having certain properties. Uniformity criteria such as homogeneous grey-level distributions are generally used to group pixels into regions [3]. However, the number of regions produced may be too large, and most of them are likely to be perceptually insignificant; it is then necessary to reduce the total number of regions, by merging the less significant regions with adjacent significant regions.

In this paper, we pose segmentation in the framework of Mathematical Morphology [9], and discuss a method to reduce oversegmentation. According to the morphological approach, pixels are grouped around the regional minima of the image and the boundaries of adjacent groupings are precisely located along the crest lines of the gradient image. This is achieved by a transformation called the watershed transformation. As for removing non significant regions and to avoid the use of interactive processes, there are only few methods [2,5,7]. Several of these methods imply the modification of some of the features of the non significant regions, in order to merge these ones with other regions by iterating the watershed transformation.

Unfortunately, feature modification is often done without foreseeing the effect on the resulting fusion of adjacent regions; thus, it may happen that non significant regions are merged to form either an unexpected significant region or a region whose shape is greatly altered with respect to the expected shape.

The aim of our merging method is to overcome the limitations of the available procedures. The idea is to define the significance of a region by the properties of particular points of the line separating adjacent regions, and to use this information to select the adjacent regions with which the current region should be merged**.** Section 2 outlines the watershed transformation. Section 3 describes some features of a region which will be taken into account for the definition of its significance. In Section 4, the differences between two main processes for region removal (flooding and digging) are discussed. Section 5 includes the description of our method dealing with the oversegmentation problem, and presents an example of the application of our algorithm. Finally, concluding remarks are presented in Section 6.

2. Watershed Transformation

The watershed transformation is a region-based segmentation method [4], tailored to create a partition of the image into a number of regions, each including one *regional minimum,* i.e., a connected component of pixels with value P whose external boundary pixels have a value strictly greater than P. The watershed transformation requires that the input image has been transformed into an image where certain subsets identify elementary regions (*markers*) characterised by pixels with highly homogeneous grey-values. These markers are the regional minima found in the *gradient image* [5], which represents a replica of the input image enhancing the edges in the zones with higher variations of grey value. For the sake of simplicity, in the following we will use the term "grey-value" to indicate also the value associated to any pixel of the gradient image. Moreover, we will denote by GI the gradient image.

Starting from the markers, an iterated growing process is activated. The process can be accomplished in two different ways, which we briefly describe below by referring to the topographic representation of GI, where grey-values represent heights; in particular, *valley bottoms* are regional minima and correspond to markers.

If an imaginary rain pours over such a landscape, the water will flow down from high altitude areas along steepest descending paths up to the valley bottoms [1]. The whole set of pixels of the surface whose steepest descending paths reach a given regional minimum constitutes the *catchment basin* associated with this minimum. Thus, the catchment basins of the image are the draining areas of its regional minima. The lines of separation of these areas, corresponding to pixels from which different minima can be reached through steepest descending paths, are called *watershed lines* (WLs). See Figure 1.

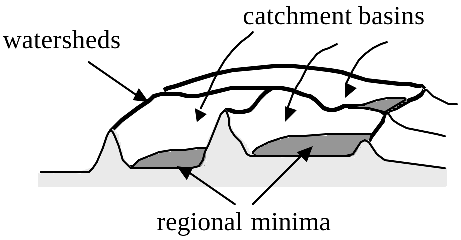

Figure 1: Watershed lines, catchment basins and regional minima in a cross section of the topographic model of the image.

This type of process involves a transformation of the current image so that each drop of water falling on the topographic surface can reach a regional minimum through a steepest descending path. This transformation can be obtained by computing the *lower complete image* of GI which is a replica of GI where the only pixels having no neighbours with a strictly lower grey-value are those belonging to the regional minima of GI. An efficient algorithm for its computation is given in [6]. In the lower complete image, it is always possible to find a steepest descending path linking a pixel to a regional minimum.

An alternative way to accomplish region growing can be modelled by an immersion process [10]. Let us assume that the valley bottoms are pierced and the image is slowly immersed into a lake. Starting from the regional minima at the lowest altitude, the water will progressively flood into the corresponding valleys and form catchment basins. In addition, let us assume that dams are progressively built at the places where water coming from different basins meet. The process terminates when the water reaches the highest peak (i.e., the greatest grey–value). At this step, the dams are interpreted as WLs and provide a tessellation of the input image into tiles corresponding to the different catchment basins.

Independently of the chosen growing process, the catchment basins are the regions of the segmented image, and the WLs identify the borders between adjacent regions. Both catchment basins and WLs are individually labelled.

To compute the catchment basins of the image, we have implemented a watershed transformation of the first type, based on the "hill climbing" algorithm [8]. We generate WLs after the construction of the catchment basins, according to the definition of WL given in [2].

3. Basin Characterisation

To reduce oversegmentation, significant basins should be preserved and non significant basins should be removed by aggregating them to significant ones. The notion of significance is then crucial and a characterisation of a basin is of interest to evaluate its significance. To introduce our notion of significance and useful parameters charactering a basin, some preliminary notions are introduced below.

3.1. Preliminary notions

The notation R_X will be used to refer to the regional minimum included by a given basin X, and PR_X will denote the value associated to any of its pixels.

Let X and Y be two adjacent basins and p the pixel having the minimal height along the WL separating X from Y; p is said the *local overflow of X (Y) with respect to Y (X)*. The notation LO_{XY} (LO_{YX}) will be used to indicate both p and its value. The lowest value of the local overflow pixels of X is called *overflow* of X and will be denoted by O_X. See Figure 2.

The depth of X when water reaches the local overflow LO_{XY} is said *local depth of X with respect to Y* and will be denoted by D_{XY}:

$$D_{XY} = LO_{XY} - PR_X$$

The absolute value of the difference of altitude between the regional minima R_X and R_Y is said *similarity parameter* SA_{XY}:

$$SA_{XY} = |PR_X - PR_Y|$$

clearly, $SA_{XY} = SA_{YX}$.

The similarity between X and Y turns out to be as greater as SA_{XY} is smaller. Local depths and similarity parameters are shown in Figure 3.

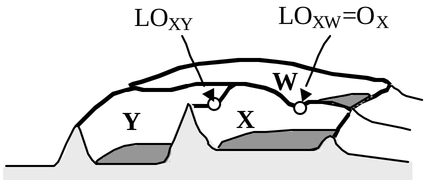

Figure 2: Local overflows of basin X.

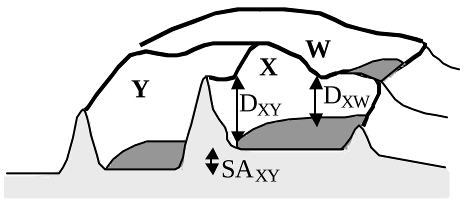

Figure 3: Local depths and similarity parameters.

3.2. Notion of significance

We consider the significance of a basin X as depending on the interaction of X with its adjacent basins. In this way, we are able to select the basins with which merging of X is more convenient. Such an interaction is evaluated by taking into account some features of the basin X and of its adjacent basin.

First, let us define the *relative significance* of X. We say that a basin X is significant with respect to an adjacent basin Y if the following holds.

$$SA_{XY} > At \text{ or } D_{XY} > Dt, \qquad (A)$$

where the thresholding values At and Dt are computed by taking into account the initial watershed transform and by analysing the frequencies of the similarity parameters and local depths associated to the basins.

We will also say that the WL dividing X from Y is a *strong separation with respect to* X when (A) holds.

Then, we define the *intrinsic significance* of X in terms of the relative significances of X, and distinguish three degrees of significance:

Strong significance, if any WLs surrounding X is a strong separation with respect to X.
Weak significance, if no WL surrounding X is a strong separation with respect to X.
Partial significance, in all other cases.

Basins which are not strongly significant are delimited by some weak WLs which correspond to weak variation of the grey levels between two regional minima, and these separations could be removed. We consider weakly or partially significant basins as non significant, and in Section 5 specific procedures will be described to merge them with other basins in order to create strongly significant basins.

4. Flooding and Digging

Oversegmentation can be diminished by considering an iterative process, every step of which is accomplished by removing the regional minima placed in the non significant basins and by applying the watershed transformation to the new image.

The regional minimum R_X of the catchment basin X can be removed by two kinds of processes, *flooding* and *digging*.

Flooding. To eliminate R_X, it is sufficient to assign the value O_X to all the pixels of X characterised by an altitude smaller than O_X. The raising of X to its overflow altitude produces a flooding through all points O_X of the WL of X, as soon as the watershed transformation is applied again. See Figure 4. Each steepest descending path from O_X to R_X is removed and a new steepest descending path is created from the pixels of X to the regional minimum of the adjacent basin (or to the regional minima of the adjacent basins, if there is more than one pixel with value O_X in the WL delimiting X). Basin X may be incorporated entirely into a single nearby basin, or may be split among several ones.

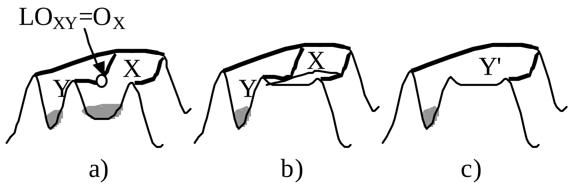

Figure 4: Removal of basin X by flooding. a) watershed transform; b) raising of the pixels of X having altitude less than O_X; c) watershed transform after flooding transformation.

In summary, a merging scheme based on flooding requires:

- a new transformation (the *flooding transformation*) of the current image in which every pixel p of X is raised to the overflow value O_X;
- a watershed transformation of the flooding transform.

Digging. Merging of X with an adjacent basin Y is achieved by creating a channel crossing the WL separating X from Y, so as to allow the water contained in X to flow towards Y. Since the channel should constitute a steepest descending path starting from R_X and terminating in R_Y, the construction of such a path requires that the altitude of R_Y be not greater than the altitude of R_X. If this is the case, a path Π_{pq} from a pixel p in R_X to a pixel q in R_Y is built and the value PR_X is assigned to all its pixels having a value greater than PR_X in the current image. Then, Π_{pq} is changed into a steepest descending path by transforming GI into its lower complete image. Thus, when the watershed transformation is newly applied to the modified image, R_X is no longer recognised as a regional minimum and the sets X and Y constitute a unique basin with R_y as regional minimum.

In this paper, we have chosen to minimise the maximal grey-value modification operated over the path. Accordingly, the sequence of pixels to be modified belongs to the minimal path passing through LO_{XY}. See Figure 5.

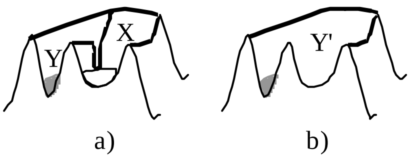

Figure 5: Removal of basin X in Figure 4a by digging. a) generation of a vertical crack in the watershed line from point LO_{XY} to the regional minimum of X; b) watershed transform after digging transformation.

In summary, a merging scheme based on digging requires:

- a new transformation (the *digging transformation*) of the current image in which a steepest descending path towards a selected adjacent basin is created for any basin X to be merged;
- a watershed transformation of the digging transform.

5. Region Merging

In this section, we show how the introduction of the notions of relative and intrinsic significance allow one to restrict the merging of a basin to suitably selected adjacent basins. Moreover, these notions allow the selection of a merging process appropriate to avoid some undesirable effects which may arise in the resulting segmentation when flooding or digging is adopted in uncontrolled manner. These effects are concerned with the change of the quality of a WL (from a strong separation to a weak separation, or vice versa) when the WL of a former basin becomes the WL of a new basin.

Flooding can be applied successfully whenever X is completely surrounded by WLs which are weak with respect to X (i.e., X is a weakly significant basin), as in the case of Figure 6.

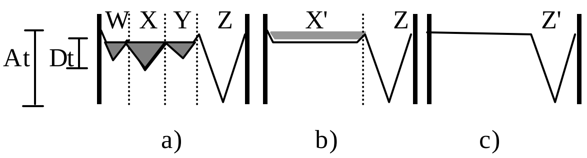

Figure 6: Result of flooding on adjacent basins. a) all weakly significant basins are raised to their overflow value; b) the resulting basin X' is still a weakly significant basin and is flooded; c) the resulting basins Z' is a strongly significant basin.

Such an assumption allows one to avoid undesired effects which may arise in the resulting segmentation when flooding is adopted on partially significant basin. Figures 7a and 7b show how the WL of X, which constituted a strong separation between X and W, becomes a weak separation between W' and Y'.

On the contrary, digging between X and Y can be an alternative to remove the regional minimum of X and to preserve the strong WL as shown in Figure 7c.

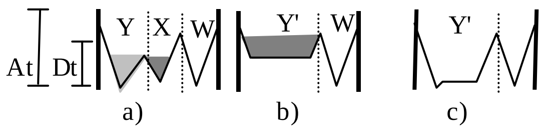

Figure 7: Different merging of adjacent partially significant basins. a) basins X and Y are raised to their overflow value; b) the resulting basins Y' is still non significant and the successive flooding will produce merging Y' with W; c) result of digging the weak WLs in Figure 7a.

We note that digging cannot be applied to a weakly significant basin X, since it may produce undesirable effects. For instance, the weak WL, in Figure 6a, separating Y from Z become, as shown in Figure 8, a strong WL when the new basin X' is created by digging and an unexpected significant region is created, which otherwise could not occur by applying flooding.

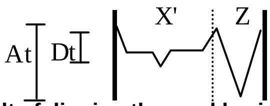

Figure 8: a) Result of digging the weakly significant basins of Figure 6a.

On the other hand, it is necessary to avoid the creation of a channel passing through the WL separating X from an adjacent basin Y, which is weak with respect to X and strong with respect to Y. If such a path is built, new steepest descending paths are generated and they may create a WL, delimiting the new basin Y’ (given by merging of X and Y), which is weak for Y’. This effect is avoided if digging is applied only to the WLs which are weak separations for any basin delimited by such lines.

In summary, flooding should be applied to any weakly significant basin X, i.e., surrounded only by WLs which are weak with respect to X, so as to avoid the modification of weak WLs, hence the generation of unexpected significant basins. On the other hand, to avoid the modification of strong WLs which might produce the removal of significant basins, digging should be taken into account for any partially significant basin X. In this case, however, digging should be applied only to any WL (separating X from Y), which is weak with respect to both X and Y.

5.1. Merging Process

We propose a merging iterative process in which each iteration consists of two steps, respectively applied on weakly significant basins, and then on partially significant basins.

In the first step, we assume that a weakly significant basin X can be merged with any of its neighbours, and to this purpose we use a flooding transform. Since some basins, resulting from a single flooding process, may still be weakly significant, this step is iterated until only partially and strongly significant basins are present in the image.

In the second step, the removal of a partially significant basin X is accomplished by merging X with its neighbours belonging to NS(X), where NS(X) is the set of adjacent basins which are non significant with respect to X (and with respect to which X is non significant) and whose regional minimum are at altitude not greater than PR_X. If NS(X) is not empty, a steepest descending path is created starting from R_X and terminating on R_Y, for any basin Y of the current NS(X), and the watershed transformation is repeated.

Due to the modifications of the degree of intrinsic significance of a basin occurring during the removal process, the whole merging process needs to be iterated to obtain basins which are all strongly significant.

Note that the initial values computed for At and Dt might be no longer valid for the final image, and have to be computed again. If one of these new values (At' or Dt') results greater than the previous value then the merging process is applied again. The whole process terminates when neither At nor Dt are greater than the previous values.

5.2. Experimental results

In this section, we show the results obtained by applying the algorithm to an astronomic image (Figure 10a). In this case, researchers are interested in giving evidence to zones which are not easily visible.

The watershed transformation is applied on the gradient image (Figure 9b) and includes 1651 basins and the threshold values computed on this watershed transform are equal to At=6 and Dt=3.

The result of our method using these thresholding values is shown in Figure 9c, constituted by 233 basins The values At and Dt are again computed on this image: the value of At doesn't change, while Dt increases to the value 5. By repeating the process with the new values of At and Dt, the number of basins decreases to 27. The values At and Dt are again computed on this image, but none of them results greater than the relative old values. Thus, this image is taken as the final segmented image and is shown in Figure 9d.

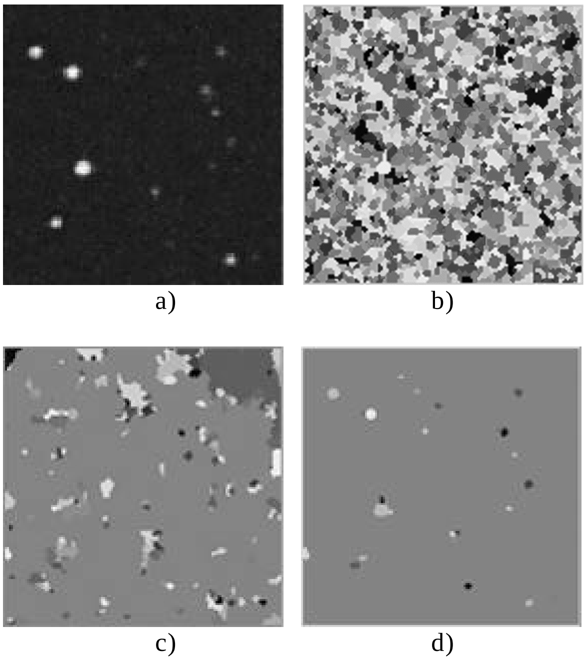

Figure 9: Result of the watershed segmentation of an astronomic image. a) input image; b) watershed transform adopting 4connectivity. The computed threshold values are At=6 and Dt=3. The number of basins NB is equal to 1651; c) after merging phase: NB=233. Updating of threshold values: At=6 and Dt=5; d) final segmentation: NB=27.

The results of our algorithm can be compared with those shown in Figure 10, produced by an algorithm by Bleau and Leon [2] adopting, for any basin X, the criterion of significance Depth$[X,O_X]>Dt$. Although different values of Dt were used, the results were not regarded, by researchers expert in the field, as satisfactory as the results we have obtained.

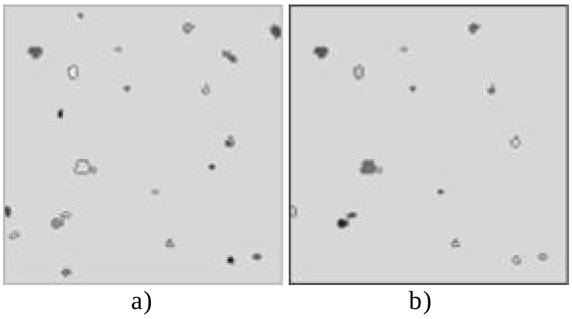

Figure 10: Results of the algorithm by Bleau and Leon [2] . a) Dt=5, the image results oversegmented; b) Dt=6, the image results undersegmented.

6. Conclusions

We have dealt with the oversegmentation problem, and have presented a new method for processing and merging regions by means of the watershed transformation. Since merging should be accomplished by aggregating less significant regions to more significant regions, the notion of significance is crucial. In this respect, to be able to select the regions with which merging is more convenient, we have considered the significance of a region as depending on its interaction with the adjacent regions, and have introduced the notions of relative significance and of intrinsic significance. We have distinguished three degrees of significance: strong, weak, and partial. Only weakly and partially significant regions are involved in the merging process.

The main goal we have pursued in reducing oversegmentation has been to obtain a segmented image still perceptually close to the original one. To this purpose, the merging process has been tailored in such a way to limit uncontrolled modifications of the typology of the WLs. It has been accomplished in different phases, each concerned with a particular type of regions, and image transformations such as flooding and digging have respectively been applied to weakly and partially significant regions.

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