INTERACTIVE IMAGE SEGMENTATION WITH INTEGRATED USE OF THE MARKERS AND THE HIERARCHICAL WATERSHED APPROACHES

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Abstract: The watershed transform is a well-known approach for image segmentation. Watershed from markers and hierarchical watershed are derived from the watershed transform and are suitable for interactive image segmentation: in the former, the user can edit markers and control the segmentation result; in the latter, the user can select an image partition from a nested set of partitions. We investigate and propose ways to transition from one approach to other. Such transitions can be used to integrate both approaches in such a way that allow us to make full use of the strengths of both. We present examples that illustrate the use of the proposed transitions in conjunction with several interaction possibilities from both approaches.

1 INTRODUCTION

Segmentation is an important stage in almost every problem involving digital image analysis. The goal of the segmentation process is to partition the spatial domain of the image, delimiting the regions of interest that correspond to the target objects of the analysis in question.

Since it is not always possible to facilitate the segmentation process, systems developed to automatically segment images are usually restricted to specific domains. Even for a particular application purpose, formal specification of the parameters of a segmentation algorithm can be very difficult. In many cases, in order to obtain a satisfactory result, a post-processing of the partition (obtained through automatic techniques) is necessary. Moreover, the concept of a good partition may depend on the purpose of its use and may be highly subjective.

Interactive segmentation systems are appropriate to deal with several of these issues. The user can manage the segmentation process, having full control over the level of detail of the desired partition.

The watershed transform (Beucher and Meyer, 1993) is a well-known segmentation tool from mathematical morphology. There are two approaches suitable for interactive segmentation:

- the *watershed from markers* approach reduces the segmentation problem to finding a set of markers for the regions of interest. The desired partition can be obtained by interactively handling the set of markers;
- the *hierarchical watershed* generates a nested partitions set, with partitions of the image at several resolution levels. The user can navigate through the hierarchy in order to select a partition with the desired level of detail for each region of interest.

In the hierarchical watershed approach, the underlying structure is the region adjacency graph (RAG) of an initial fine partition. While pixels correspond to the atomic units in images, in the hierarchical approach the atomic units are the regions of the finest partition. Thus, in any partition derived from the hierarchy, all resulting regions are unions of some primitive regions.

The formal definition of watershed on graphs made possible a unifying treatment for segmentation, regardless of the atomic unit considered (Meyer, 2001b). We say that partitions are at region level precision if the graph considered is the RAG, whereas they are at pixel level precision if the graph considered is the 4 or 8-adjacency graph of the pixels.

Since the number of nodes in the RAG is considerably smaller than the number of pixels in the image, most of the operations on the hierarchy or its underlying RAG can be performed very efficiently. Several interaction possibilities have been considered in the context of the hierarchical approach (Meyer, 2001b;

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Marcotegui and Zanoguera, 2002; Hahn and Peitgen, 2003). These works introduce ideas to interactively handle the hierarchical structure, some in conjunction with markers operating on the RAG.

However, if one desires to place contours beyond those at the border of the primitive regions, it is important that the watershed from markers also operates at pixel level precision. Another feature that may be interesting is computing markers corresponding to a given partition obtained from operations performed on the hierarchy. Such markers may be edited and the corresponding partition be refined as desired, or they can be used as a training data by systems aiming to automatically generate markers for a given application.

In this work we study how to make transitions between the hierarchical and the markers approaches. Such transitions would be useful to integrate both approaches in such a way as to allow switching back and forth between them, and thus making full use of the interaction possibilities from both approaches.

Since markers can be considered on the RAG or on the pixel adjacency graph, transitions between both approaches may imply change in the precision. Transitions from region to pixel level precision can be made without information loss. However, transition in the opposite direction may result in information loss (not all partitions that are possible in pixel level precision are possible in the region level precision).

This paper is organized as follows. In Section 2 we recall some basic concepts and results from previous works needed to present our results. In Section 3 are the main contributions of this work. We discuss how to map a partition of the hierarchy to an equivalent set of markers and, conversely, the partition corresponding to a set of markers to a hierarchy that contains it as one of the partitions. In particular we show that if the markers corresponding to a given partition are computed on the RAG, then the exact recovery of the partition with pixel level precision can not be guaranteed, but the possible differences between the original and the recovered partitions are well characterized. In Section 4 we describe how the proposed transitions can be used in an interactive segmentation environment, in conjunction with some interaction possibilities from both approaches. These interaction features have been implemented in the *SegmentIt* software tool, available at *http://watershed.sourceforge.net/*. Examples illustrating the use of these features are presented. Finally, in Section 5 we summarize the contributions of this work.

2 PRELIMINARIES

2.1 Watershed

The watershed transform is a robust segmentation tool, since the watershed lines produced are very close to the object boundaries. Its most intuitive formulation is a flooding simulation. The image (usually a gradient image such as the morphological gradient, instead of the original image) is considered as a topographic surface, and a hole is made in each of its regional minima. Then, the surface is submerged at a constant speed (uniform flooding) making the water arise through its holes. When fronts of water coming from different minima are about to merge, a dam is built to avoid it. The flooding process continues until only the dams, which stands for the watershed lines, are visible over the water surface. This approach, known as *classical watershed*, has an over-segmentation problem, due to the fact that gradient-like images are very sensitive to noise and texture, which results in a catchment basin (a region of the partition) for each regional minima. Each catchment basin from the classical watershed is called a *primitive catchment basin*.

In order to reduce this over-segmentation problem, one can use the *watershed from markers*. This approach is exactly the same as the classical watershed, except that the holes at the surface are made in a selected set M of markers instead of at the regional minima.

2.2 Graphs

A weighted graph $G = (V, E, w)$ consists of a set V of vertices and a set E of edges, $E \subseteq V \times V$, weighted by a cost function w. Two vertices u and v are said adjacent if $(u, v) \in E$. $N(u)$ denotes the neighborhood of u: $N(u) = \{v \in V : (u, v) \in E\}$. A path $\pi(u, v)$ from u to v is a sequence $\langle u = v_1, v_2, \ldots, v_n = v\rangle$ of vertices such that $(v_i, v_{i+1}) \in E, 1 \le i < n$ and $v_i \neq v_j, 1 \le i < j \le n$. The concatenation of the paths π_1 and π_2 is denoted by $\pi_1 \cdot \pi_2$. A path from u to v with minimum cost according to a cost function f_C is represented by $\pi^*(u, v)$. $\pi^*(M, v)$ denotes a minimum cost path from a set M, $M \subseteq V$, to the vertex v, that is, $f_C(\pi^*(M, v)) = f_C(\pi^*(m_i, v))$, for some $m_i \in M$, and $f_C(\pi^*(m_i, v)) \le f_C(\pi^*(m_j, v)), \forall m_j \in M$. A graph $G' = (V', E', w)$ is a subgraph of $G = (V, E, w)$, denoted by $G' \subseteq G$, if $V' \subseteq V$, $E' \subseteq V' \times V'$ and $E' \subseteq E$. A graph $G' = (V', E')$ spans a graph $G = (V, E)$ if $G' \subseteq G$ and $V' = V$. A forest of G is an acyclic subgraph of G. A tree is a connected component of a forest. A tree T is a minimum spanning tree (MST) of a graph G if $T \subseteq G$, T spans G, and the sum of its edges weights is minimum (considering all possible spanning trees of G).

2.2.1 Images as Graphs

Digital images can be modeled as graphs with different precision levels: pixels and regions.

Pixel Adjacency Graph (PAG). An image I is viewed as a weighted graph $G_I = (V, E, w)$, where V is the set of the image pixels, E is derived from V and a connectivity relation (usually 4-connectivity or 8-connectivity), and w is a dissimilarity function (in our case, $w(u,v) = \max\{\nabla(u), \nabla(v)\}$, where $\nabla(p)$ is the intensity of the pixel p in the gradient image).

Region Adjacency Graph (RAG). An image I is viewed as a weighted graph, whose vertices represent the primitive catchment basins (CB) associated to each regional minimum of I. An edge is created for each pair of adjacent CBs, weighted by the minimum pass value between them, that is:

$$w(CB_i, CB_j) = \min_{\substack{p_i \in CB_i,\\ p_j \in CB_j,\\ p_j \in N(p_i)}} \{w(p_i, p_j)\}. \quad (1)$$

2.3 Image Foresting Transform

Under the image foresting transform (IFT) framework (Falcão et al., 2004), the watershed transform is formulated as a graph optimization problem: it corresponds to the creation of a shortest-path forest (SPF), in which exists a minimum cost path from each vertex to the set of markers, or seeds. The cost function considered is the max-arc path-cost f_{max}:

$$f_{max}(\langle v_1, \ldots, v_n \rangle) \quad = \quad \max_{1 \le i < n} \{w(v_i, v_{i+1})\} \quad (2)$$

The resulting SPF defines a partition (each set of trees with same label in the forest corresponds to a catchment basin). We denote this partition by $IFT\text{-}WS(G,M)$, where G is the input graph and M is the set of markers (distinct marker vertices can have the same label associated to them).

2.4 Hierarchical Watershed

The nested set of partitions of the hierarchical watershed approach is derived from an MST of the RAG, suppressing some of its edges: if the edge between two vertices is not suppressed, they belong to the same region of interest (ROI). The coarser partition of the hierarchy is given by the MST without any edge being suppressed, corresponding to only one ROI. The finest partition is obtained when all the edges are suppressed, corresponding to the classical watershed partition. The other partitions of the hierarchy can be obtained suppressing all the edges whose weights are greater than a threshold value or through local operations (merge and refine) over the hierarchy, as described in (Zanoguera et al., 1999).

The navigation through the hierarchy of partitions in user real time is possible using a data structure known as the tree of critical lakes (TCL) (Meyer, 1996). It is derived from an MST of the RAG and it makes it possible to run through the MST edges ordered by their weights.

Other hierarchies can be derived from the MST of the RAG assigning different weights to its edges through synchronous flooding, as described in (Meyer, 2001a). The synchronous flooding can rank regions according to their contrast and/or size, generating hierarchies with partitions that are usually more interesting than the one obtained by uniform flooding.

2.5 Tie-zone Watershed

As the watershed transform can have distinct optimal solutions, the tie-zone watershed (Audigier et al., 2005) aims to provide a unique and optimal solution associated to a graph G and a set of seeds M: it assigns each vertex of G to a CB if in all possible solutions it belongs to this CB. Otherwise, the vertex is said to belong to a tie-zone, denoted by $TZ\text{-}WS(G,M)$.

3 SWITCHING BACK AND FORTH BETWEEN THE WATERSHED APPROACHES

In this section we investigate how to switch between the watershed from markers and the hierarchical watershed approaches. More specifically, given a partition P selected in the hierarchical set of partitions of an image I, we would like to find a set of markers M such that $IFT\text{-}WS(G,M) = P$, where G can be a PAG or a RAG, depending on the desired precision level. Conversely, given a set of markers M and its corresponding partition $P = IFT\text{-}WS(G,M)$, we would like to find a hierarchical set of partitions that includes P.

3.1 From Hierarchical to Markers Approach

This problem is addressed using the concept of minimal seed set (MSS). The MSS problem is the inverse of the segmentation by watershed problem: given a partition obtained by watershed, it consists in finding a minimal set of seeds that is enough to obtain the same partition by the watershed (Lotufo and Silva, 2002). The MSS is built by first computing the so called *non-redundant receptive regions* (NRRR) of each ROI and then choosing one seed in each NRRR. Each seed receives the same label of the ROI to which it belongs. The MSS can be computed either in a RAG or in a PAG (Audigier and Lotufo, 2007).

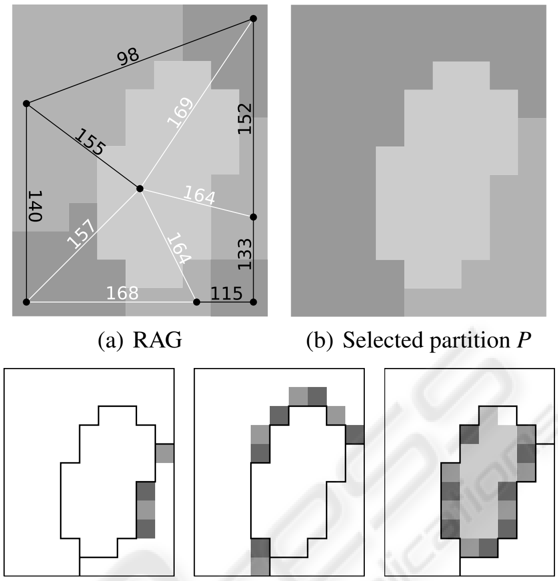
Given a partition P selected in the hierarchy, the MSS in the corresponding RAG can be computed straightforwardly because the hierarchy is constructed based on the RAG. Let M denote the resulting set of markers. If watershed is applied on the RAG with markers M, partition P can be recovered exactly. Similarly, if we compute the MSS of P in G_I, the resulting set of markers M' exactly recovers P, i.e., $IFT\text{-}WS(G_I,M') = P$, as M' guarantees that $TZ\text{-}WS(G_I,M') = \varnothing$.

These observations suggest computing markers either on the RAG or in the PAG: on the RAG if region level precision suffices and on the PAG if pixel level precision is required. However, the markers M' computed on the PAG tend to be located at the borders of the ROIs as shown in Figure 1. This figure shows the NRRRs of each ROI. Recall that M' must include at least one pixel of each NRRR.

In contrast, the markers M computed on the RAG tend to be compact and located more at the center of each ROI, making them more suitable for user edition. In Figure 2(a) we show the markers computed on the RAG for the same partition of Figure 1(b). However, if markers M computed on the RAG are considered on the PAG G_I, the resulting partition $P' = IFT\text{-}WS(G_I,M)$ may differ from the original partition P, as shown in Figure 2(b).

Experimentally, we have observed that the differences between the original partition P and the recovered one P' are located close to the borders. This evidence made us to conjecture that differences are located in the tie-zone. In fact, it can be show that P (the partition selected in the hierarchy) is also an optimal solution of $IFT\text{-}WS(G_I,M)$. This implies that the differences between P and P' necessarily belongs to the tie-zone $TZ\text{-}WS(G_I,M)$. The proof is presented in the following proposition.

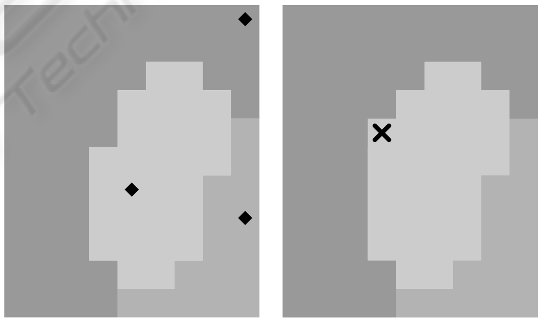
Lemma 1. *For any path $\pi_{RAG} = \langle CB_1, CB_2, \ldots, CB_n\rangle$ in the RAG of I there is a path $\pi_{PAG} = \langle r_1, \ldots, r_2, \ldots, r_n\rangle$ with same cost (according to f_{max}) in G_I, where r_i is an arbitrary pixel of the regional minimum of the catchment basin CB_i.*



(a) RAG (b) Selected partition P

(c) 4 NRRRs (d) 9 NRRRs (e) 14 NRRRs

Figure 1: NRRRs computed in G_I are located close to the border of the ROIs: (a) RAG edges superimposed on the primitive CBs, where the MST edges are in black. (b) A partition P, selected on the hierarchy suppressing the edges with weight greater than 150. (c)-(e) NRRRs of each ROI of P, computed in G_I.



(a) Marker set M (b) Obtained partition P'

Figure 2: Markers computed in the RAG: (a) Markers of the MSS of P (each ROI has one NRRR, containing all of its pixels). (b) Partition P' obtained by applying the watershed on the PAG. The difference between P and P' is marked with an x.

Proof. For each pair (CB_i, CB_{i+1}) in π_{RAG}, consider $(p_i, p_i{}')$, $p_i \in CB_i$ and $p_i{}' \in CB_{i+1}$, as the pair of pixels that determined the weight of the edge that connects CB_i to CB_{i+1} on the RAG of I (see (1)).

The path π_{PAG} is constructed by linking r_i to r_{i+1}, for $1 \leq i < n$, by connecting r_i to p_i and r_{i+1} to $p_i{}'$ by the non-decreasing paths contained in the SPF obtained by the IFT-WS when all regional minima are used as markers (classical watershed). □

Proposition 1. *Let $P = \{P_1, P_2, \ldots, P_n\}$ be a partition of the image I obtained from the hierarchical watershed. Consider a set of markers $M = \{M_1, M_2, \ldots, M_n\}$, computed on the RAG of I, where M_i is the marker associated to P_i, that is, for $i = 1, \ldots, n$:*

$$M_i \subseteq P_i \text{ and } M_i \cap R \neq \varnothing, \forall R \in NRRR(P_i) \tag{3}$$

where $NRRR(P_i)$ denotes the set of non-redundant receptive regions of P_i, computed on the RAG of I. Then, P is an optimal solution of $IFT\text{-}WS(G_I, M)$.

Proof. Let $P' = \{P'_1, P'_2, \ldots, P'_n\}$ be an arbitrary optimal solution of $IFT\text{-}WS(G_I, M)$. If $\exists p$ such that $\lambda_\alpha = L_P(p) \neq L_{P'}(p) = \lambda_\beta$, then it suffices to show that $f_{max}(\pi^*(M_\alpha, p)) = f_{max}(\pi^*(M_\beta, p))$, where M_α and M_β are the markers with labels λ_α and λ_β, respectively.

Without loss of generality, suppose that $\alpha = 1$ and $\beta = 2$. From the optimality of P',

$$f_{max}(\pi^*(M_2, p)) \leq f_{max}(\pi^*(M_1, p)). \tag{4}$$

The MSS is computed in such a way that there is no tie-zone, which implies that:

$$f_{max}(\pi^*(M_i, CB)) < f_{max}(\pi^*(M_j, CB)), \quad i \neq j, \forall CB \in P_i \tag{5}$$

In particular, denoting by V the CB to which p belongs,

$$f_{max}(\pi^*(M_1, V)) < f_{max}(\pi^*(M_2, V)). \tag{6}$$

From Lemma 1 it follows that:

$$f_{max}(\pi^*(M_i, V)) = f_{max}(\pi^*(M_i, r_V)) \tag{7}$$

From (7) and (6), we have that:

$$f_{max}(\pi^*(M_1, r_V)) < f_{max}(\pi^*(M_2, r_V)) \tag{8}$$

Let v_1 be the first pixel of V in $\pi^*(M_2, p)$ (see Figure 3). By the choice of v_1:

$$\begin{aligned} & f_{max}(\pi^*(M_2, p)) \\ = \;& f_{max}(\pi^*(M_2, v_1) \cdot \pi^*(v_1, p)) \\ = \;& \max\{f_{max}(\pi^*(M_2, v_1)), f_{max}(\pi^*(v_1, p))\} \\ = \;& \max\{f_{max}(\pi^*(M_2, v_1)), f_{max}(\pi^*(v_1, r_V)), \\ & f_{max}(\pi^*(r_V, p))\} \\ = \;& \max\{f_{max}(\pi^*(M_2, v_1)), f_{max}(\pi^*(v_1, r_V)), \nabla(p)\} \\ = \;& \max\{f_{max}(\pi^*(M_2, r_V)), \nabla(p)\} \end{aligned} \tag{9}$$

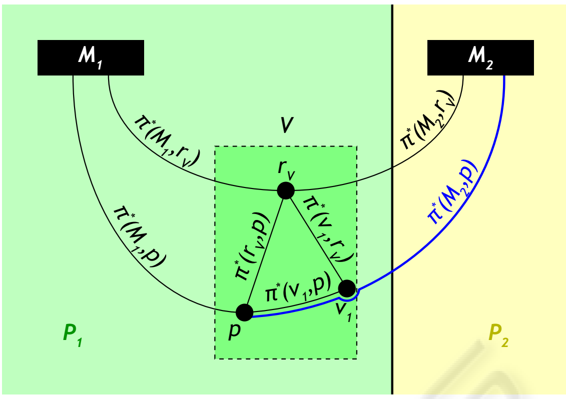


Figure 3: Proof scheme.

As $\pi^*(M_1, p)$ is an optimum cost path, it follows that:

$$\begin{aligned} & f_{max}(\pi^*(M_1, p)) \\ \leq \;& f_{max}(\pi^*(M_1, r_V) \cdot \pi^*(r_V, p)) \\ = \;& \max\{f_{max}(\pi^*(M_1, r_V)), f_{max}(\pi^*(r_V, p))\} \\ = \;& \max\{f_{max}(\pi^*(M_1, r_V)), \nabla(p)\} \end{aligned} \tag{10}$$

Replacing 8 and 9 in 10:

$$\begin{aligned} & f_{max}(\pi^*(M_1, p)) \\ \leq \;& \max\{f_{max}(\pi^*(M_1, r_V)), \nabla(p)\} \\ \leq \;& \max\{f_{max}(\pi^*(M_2, r_V)), \nabla(p)\} \\ = \;& f_{max}(\pi^*(M_2, p)) \end{aligned} \tag{11}$$

Then,

$$f_{max}(\pi^*(M_1, p)) \leq f_{max}(\pi^*(M_2, p)) \tag{12}$$

From 12 and 4, we conclude that

$$f_{max}(\pi^*(M_1, p)) = f_{max}(\pi^*(M_2, p)). \tag{13}$$

□

3.2 From Markers to Hierarchical Approach

Given a partition P obtained from a set of markers M, we would like to build an hierarchy that includes P. In order to do that, two issues need to be considered.

First, as the primitive CBs are considered atomic in the hierarchy, no partition of the hierarchy contains borders beyond those located at the border of the primitive CBs. When working with pixel level precision, if P contains borders that crosses some primitive CB, then P can not be represented in the hierarchy. If there are such borders, a possible approach is to set the same label for all the pixels within each CB, for example, the most frequent label among them.

Furthermore, it is also necessary that each set of primitive CBs with same label (that actually make up a ROI) is a connected set considering the edges of the spanning tree of the RAG from which the hierarchy is constructed. If this is not true, an hierarchy that includes the desired partition cannot be built. In order to accomplish this, instead of considering an arbitrary MST of the RAG, we derive a spanning tree (not necessarily an MST) of the RAG in the following manner:

1. consider an MST for each ROI (set of primitive CBs with same label), obtaining a spanning forest of the RAG;
2. complete the spanning forest with edges of minimum weight among the edges of the RAG not yet used, obtaining a spanning tree of the RAG.

When constructing the TCL, instead of using all the edges of the spanning tree ordered by their weights, the edges of the spanning forest obtained at the first step must be used before the edges added at the second step.

4 INTERACTIVE SEGMENTATION TOOL

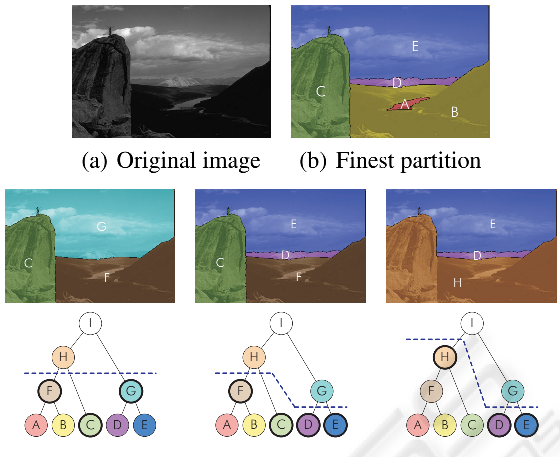
In this section we describe an interactive segmentation tool that allows switching back and forth between the two watershed approaches based on the transitions described in the previous section. Examples illustrating the use of these transitions in conjunction with interaction possibilities from both approaches are presented.

4.1 Interaction Possibilities

1. **Construction of hierarchy of partitions** using uniform flooding or synchronous flooding, with the following criteria:
   - depth (ranking regions by their contrast)
   - area (ranking regions by their size)
   - volume (ranking regions by their contrast and size)

   The user can navigate through the hierarchy using a slider control that selects a threshold value for the weight of the edges to be suppressed in the hierarchy.

   As the selection of a threshold value affects the entire partition, two local operations (merge and refine) can be used on the hierarchy to affect only a desired region of the current partition, as illustrated in a simplified hierarchy in Figure 4.



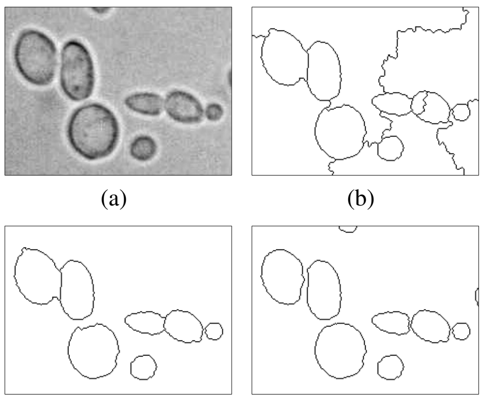
(a) Original image (b) Finest partition

(c) (d) (e)

Figure 4: Obtaining partitions navigating through the TCL: (c) 3 regions (F, C e G) selected by a threshold value. (d) Region G split in D and E. (e) Regions F and C merged in H.

   Note that the selection of the threshold value and the local operations are done on the RAG. Once the hierarchy is constructed, these operations are executed in user real time.

2. **Automatic generation of markers to partitions selected from the hierarchy**, as described in Figure 3.1. After switching from the hierarchy to the markers approach, the user can refine the partition at a pixel level precision. For example, to separate cells as shown in Figure 5(d).



(a) (b)

(c) (d)

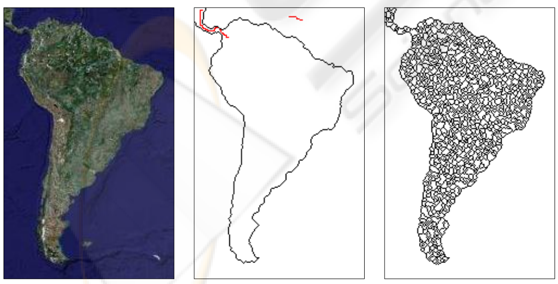
Figure 5: Segmenting using hierarchy and markers: (a) Original image. (b) Partition selected on the hierarchy. (c) Partition after welding regions. (d) Partition with refinements at pixel level precision.

3. **Edition of markers using a brush/erase tool**. The labeling function for the markers is derived associating a unique label for each connected

component drawn (for this reason, the user does not need to change the brush color when marking each ROI). If markers for distinct ROIs need to be placed adjacently, the user can use different colors in order to make the markers receive different labels. The brush and the erase tool are available selecting only one icon, so the user can edit (draw and erase) markers just using different mouse buttons.

4. **Merging of adjacent regions with a welding brush**. This is more flexible than the local merge operation over the hierarchy, since it can weld regions using edges that are not in an MST of the RAG, as described in Section 3.2. To accomplish this, a partition with the selected regions welded is derived (associating the same label to them) and this partition is utilized to compute markers or to derive a hierarchy that contains it (depending on the approach being used). This operation was used to obtain the partition shown in Figure 5(c), as it cannot be found in the original hierarchies (from the uniform and synchronous floodings).

5. **Use of the hierarchy in a selected region**. This enables the user to refine a region obtained from a previous use of the hierarchical watershed, or from manually created/edited markers. For instance, to obtain the primitive CBs of the land in a satellite image like the one shown in Figure 6, one could first design markers by hand in order to separate land from water, and then select the finest partition after applying the hierarchy in the land region. This is a more straightforward way to achieve the desired partition, instead of first obtaining the classical watershed partition for the entire image and them merging all the regions that are not located at land.



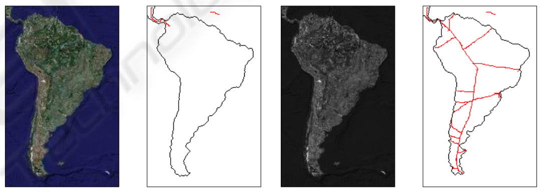
(a) Original image with markers (b) Intermediary step (c) Desired partition

Figure 6: Using the hierarchy restricted to a region: (a) Original image. (b) Partition (with markers) separating land from water. (c) Primitive CBs of the land region.

4.2 Additional Features

The implemented tool also includes additional features:

- *Segment automatically* option, that executes the algorithm at each edition of the markers (it can be disabled to improve performance when designing markers to segment large images, for instance);
- save the markers image for posterior refinements;
- control over the output image (the user can choose which images will be superimposed: original image, gradient image, catchment basins, markers and watershed lines).
- support for segmentation of color images using the weighted gradient, as described in (Flores et al., 2004). The user can use either the automatically computed weights or arbitrary weights for each gradient considered (the weighted gradient consists in a weighted sum of gradients defined on each band of the image: hue, saturation and brightness). The color information can be a key factor in reducing the interaction effort to obtain a desired partition, as can be observed in Figure 7.



(a) (b) (c) (d)

Figure 7: Color information reducing the interaction effort (markers in red, watershed lines in black): (a)-(b) Simple markers are enough to divide land from water using the weighted gradient. (c)-(d) Complex markers are needed when using the morphological gradient of the image obtained without color information.

4.3 A Coarse to Fine Approach

Since markers obtained by computing the MSS on G_I tend to be located at the borders of the ROIs, they are not interesting for user edition. Thus, we choose markers from the MSS computed on the RAG, independently of the precision level of the graph being utilized in the markers approach. With this choice, the partition obtained by switching from the hierarchy to markers over a PAG may differ slightly from the partition before the switching. Similarly, as noted in Section 3.2, there may be differences in the inverse mapping.

Since fine refinements done at a pixel level precision may be undone by a transition to the hierarchical approach or to the region level precision, segmentation process should follow a coarse to fine approach: first the user can work with both approaches to obtain a partition as close as possible to the desired partition, using only the RAG (which implies efficient processing time); then, using only markers (i.e., editing markers) over the PAG, he/she can refine the partition at a pixel level precision.

5 CONCLUSIONS

We investigated how to perform transitions between the hierarchical and the watershed from markers approaches. In particular, we discussed the effects observed when these transitions involve changes in the precision level of the partitions (pixels or regions). These transitions have been implemented in conjunction with several interaction possibilities from both watershed approaches as an interactive segmentation tool. The implemented tool allows one to take advantage of the best features of each approach and it is expected that the interaction effort necessary to produce a desired result may be reduced.

An interesting characteristic of the proposed approach is that it allows producing partitions with precisions at pixel or region levels. As a consequence, the tool may be used for different segmentation purposes.

We plan some use case studies, in order to evaluate and improve the usability of the developed tool. This study should take into consideration not only the available functionalities but also aspects related to the interaction process. For example, in applications in which a precise segmentation is important, the interaction effort necessary to draw the markers can still be very intense. It would be interesting if the tool could provide means to easily place markers, on both sides of the borders of interest. As an another example, support for color image segmentation is currently rather limited. These aspects, together with others to be found in the use case studies, will guide our future investigations.

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REFERENCES

Audigier, R. and Lotufo, R. A. (2007). Seed-relative segmentation robustness of watershed and fuzzy connectedness approaches. In *SIBGRAPI '07: Proceedings of the XX Brazilian Symposium on Computer Graphics and Image Processing*, pages 61–70, Washington, DC, USA. IEEE Computer Society.

Audigier, R., Lotufo, R. A., and Couprie, M. (2005). The tie-zone watershed: Definition, algorithm and applications. In *Proceedings of IEEE International Conference on Image Processing (ICIP'05)*, pages 654–657.

Beucher, S. and Meyer, F. (1993). The morphological approach to segmentation: the watershed transformation. In Dougherty, E., editor, *Mathematical morphology in image processing*, chapter 12, pages 433–481. M. Dekker.

Falcão, A. X., Stolfi, J., and Lotufo, R. A. (2004). The image foresting transform: Theory, algorithms, and applications. *IEEE Trans. Pattern Anal. Mach. Intell.*, 26(1):19–29.

Flores, F. C., Polidorio, A. M., and Lotufo, R. A. (2004). Color image gradients for morphological segmentation: The weighted gradient improved by automatic imposition of weights. In *SIBGRAPI '04: Proceedings of the Computer Graphics and Image Processing, XVII Brazilian Symposium*, pages 146–153, Washington, DC, USA. IEEE Computer Society.

Hahn, H. K. and Peitgen, H.-O. (2003). IWT - interactive watershed transform: A hierarchical method for efficient interactive and automated segmentation of multidimensional gray-scale images. In *Medical Imaging 2003: Image Processing. Proceedings of the SPIE*, volume 5032, pages 643–653.

Lotufo, R. A. and Silva, W. (2002). Minimal set of markers for the watershed. In Talbot, H. and Beare, R., editors, *6th International Symposium on Mathematical Morphology*, pages 359–368. CSIRO Publications.

Marcotegui, B. and Zanoguera, F. (2002). Image editing tools based on multi-scale segmentation. In Talbot, H. and Beare, R., editors, *Proceedings of ISMM 2002*, pages 127–135.

Meyer, F. (1996). The dynamics of minima and contours. In Maragos, P., Schafer, R. W., and Butt, M. A., editors, *Mathematical Morphology and its Applications to Image and Signal Processing*, pages 329–336. Kluwer Academic Publishers.

Meyer, F. (2001a). Hierarchies of partitions and morphological segmentation. In *Scale-Space '01: Proceedings of the Third International Conference on Scale-Space and Morphology in Computer Vision*, pages 161–182, London, UK. Springer-Verlag.

Meyer, F. (2001b). An overview of morphological segmentation. *International Journal of Pattern Recognition and Artificial Intelligence*, 15(7):1089–1118.

Zanoguera, F., Marcotegui, B., and Meyer, F. (1999). A toolbox for interactive segmentation based on nested partitions. In *Proceedings of the International Conference on Image Processing*, volume 1, pages 21–25.