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# A new method of morphological hierarchical segmentation

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## Abstract

In this paper, we propose a novel method for morphological hierarchical segmentation. First, we review two state of the art methods: the quasi-flat-zones and the non parametric hierarchical watershed (waterfall algorithm). Then, we propose a novel method which is referred to as the nested homogeneous connections. All three methods have been applied and evaluated on the dataset of one hundred color images from the “Berkeley Segmentation Dataset and Benchmark (BSDB)”. The segmentation results have been evaluated using NCD and MSE techniques. The method that we proposed offers better segmentation results than the two above mentioned. This algorithm can be used to simplify the image without the major loss of the image quality.

## 1 Introduction

Image segmentation consists in partitioning an image in more or less regular or coherent zones according to a given criterion. Thus, one usually seeks an image partition in zones whose values follow a given model of organization. Automatic segmentation of images is a central problem in image processing since the partition of an image in regions makes the extraction of the primary visual components from an image possible; these latter being used to identify and recognize objects of interest. However, there is a gap between the image itself and its description as a sole partition of the image into several regions. A way of circumventing this gap is to concentrate on region segmentation on one hand and on perceptual groupings extracted by a hierarchical vision of images on the other hand. The union of regions is a group of elements which is also a region at a given level, with local inner properties and global ones according to its neighborhood. Most of the time, low level image segmentation algorithms cannot directly cope with this semantic gap since it is very difficult to directly construct the best image partition (if there is one). Thus, it is necessary to deal with hierarchical methods which produce a multi-scale image segmentation. In this paper, we take a morphological point of view of hierarchical segmentation. However, when considering morphological segmentation, one needs to work on complete lattices and the problems aspects of the classical gray-scale morphological algorithms to color ones arises.

That is why, we propose to define a new method of hierarchical segmentation which offers very good results.

The paper is organized as follows. In section 2, we detail the principles of morphological hierarchical segmentation and review two state of the art methods: the quasi-flat-zones and the non parametric hierarchical watershed (waterfall algorithm). A novel method which is referred to as the nested homogeneous connections and which produces a hierarchy of partitions is also proposed. To finish, we illustrate the three mentioned methods of morphological hierarchical segmentation and conclude on their performances.

## 2 Hierarchical segmentation of color images

In this section, the principles of morphological hierarchical segmentation are recalled [12]. We then focus on the definition of connective criterion and present two connections: threshold connections (quasi-flat-zones) [3, 10, 13] and pathwise connections (non parametric hierarchical watershed also called waterfall [1, 2]). Finally, we propose a new connective criterion which extracts the homogeneous zones of an image and produces with an extension, a hierarchy of partitions.

### 2.1 Partition of image

The traditional problem of the automatic segmentation of images is generally considered like a division of the image in disjointed areas, the result being a partition of the image domain. An image  $I$  is a set of pixels  $I = \{p_1, p_2, \dots, p_n\}$  and a region  $R$  is a subset of the image pixels composed of  $|R|$  pixels. Regions are therefore sets of pixels which usually fulfill a given homogeneity criterion.

#### Definition 1 (Partition - S.W. Zucker [16])

A partition  $P$  is a set of regions  $P = \{R_1, R_2, \dots, R_k\}$  so that:

The union of the partition regions provides the initial set:

$$I = \bigcup_{i=1}^k R_i \text{ and regions are disjointed: } \forall i, j, i \neq j, R_i \cap R_j = \emptyset$$

Several algorithms can be used to segment an image and thus to create a partition. But these algorithms can also define, while exploiting their parameters, a stacking of partitions of increasing levels called a hierarchy of partitions. In mathematical morphology, it is important to define an ordering relation between two partitions to have a complete lattice of partitions: a partition  $P$  is included in a partition  $Q$  if every region  $R_j^P$  is completely included in a region  $R_i^Q$ . With

this property, we can define a hierarchy of nested partitions for an image. Let  $H$  be a set of partitions associated to an image,  $H$  is a hierarchy of nested partitions if it is possible to establish an inclusion order between any pair of  $H$  elements. It means that two regions from two different partitions of a hierarchy are either disjointed or included one in to the other.

**Definition 2 (Hierarchy of nested partitions - S.L. Horowitz [5])**

A hierarchy of nested partitions is a set of partitions  $H = \{P_1, P_2, \dots, P_i\}$  so that the regions of the partition  $P_i = \{R_1^i, R_2^i, \dots, R_k^i\}$  are all included in the regions of the partition  $P_j = \{R_1^j, R_2^j, \dots, R_{k'}^j\}$  with  $j > i$ ,  $k > k'$  and  $R_m^i \subseteq R_p^j$  or  $R_m^i \cap R_p^j = \emptyset$

$P_i$  is called the  $i^{\text{th}}$  level of the hierarchy,  $P_0$  if the lowest one and is the finest partition,  $P_1$  is the highest level of the hierarchy and is the coarsest partition. The regions of the lowest level being always included in higher level regions, the regions of the  $(i+1)^{\text{th}}$  partition can be obtained by merging ones of the  $i^{\text{th}}$  partition. Therefore, a hierarchy of partitions is naturally represented by a stack of Region Adjacency Graphs (RAG) also called an irregular pyramid [6]. Links between regions that merge from one level to the next one are contained in a so-called contraction kernel [7].

In mathematical morphology, to have an ordering relation between successive levels of the hierarchy implies that the latter forms a complete lattice. The main morphological criteria that define hierarchies of partitions are based on connections (connective criteria) [14, 15]. This enables to divide an image into zones according to a given criterion. In the following subsections, we present two main morphological connective criteria for segmentation: the quasi-flat-zones and the non parametric hierarchical watershed (waterfall algorithm). A third connective criterion called nested homogeneous connections is proposed and whose behavior is in between the two above mentioned.

**2.2 The flat-zones and quasi-flat-zones**

The flat-zones of an image  $I$  are the maximal connected components having a constant value and were introduced by SALEMBIER and SERRA [3, 13]. The flat zone concept relies therefore on a threshold connective criterion. Using directly the partition of an image in flat-zones is not very interesting because an over segmented partition is obtained. The extraction of the flat-zones of an image is generally accompanied with the use of a preliminary filtering which increases the flat-zones to reduce the over segmentation effect. This is the purpose of levelings, proposed by MEYER [10], which enlarges flat-zones according to a marker image. However, even with the use of levelings to simplify the image, small variations still occur (this is even true with color images) and MEYER [10] has proposed to extend the principle of flat-zones to quasi-flat-zones.

**Definition 3 (The quasi-flat-zones - F. Meyer [10])**

Two points  $p$  and  $q$  belong to the same quasi flat zone of an image  $I$  if there is a connected path  $(p_1, p_2, \dots, p_n)$  between those two points so that  $p_1 = p$  and  $p_n = q$  and for each  $i$ :  $\|I(p_i) - I(p_{i+1})\| < \lambda$

$\|\dots\|$  is a  $L_2$ -norm and increasing values of  $\lambda$  create a hierarchy of partitions. Quasi-flat-zones are strict flat-zones for a threshold criterion equal to zero ( $\lambda = 0$ ). Increasing values of  $\lambda$  defines a hierarchy of partitions. The progression in the hierarchy levels is strongly correlated with the number of regions and the loss of information. It is therefore important to be careful on the determination of this threshold criterion for obtaining a single efficient segmentation.

**2.3 Non parametric hierarchical watershed**

The watershed is a region growing algorithm which defines a pathwise connection. The watershed lines associate a catchment basin to each minimum of a function. Typically, the function to flood is a gradient function which catches the transitions between the regions. Region seeds of the watershed are therefore the gradient minima. Working with color images, the definition of an appropriate color gradient is the core part of the watershed. In this paper, we consider the classical one which was originally proposed by DI ZENZO [4]. The watershed is extensively used for the segmentation of images but its major drawback relies on the production of over segmented partitions mainly because of the presence of a high number of significant gradient minima. As for flat-zones, one can try to overcome this problem by filtering the image, but this comes to report the problem on an appropriate tuning of a given filtering operation. Another solution to disguise these disadvantages consists in using specific markers instead of gradient minima. Whatever the technique used to overcome over segmentation, it introduces an *a-priori* information and therefore techniques of hierarchical segmentation are of interest for the production of a non parametric hierarchical watershed also called waterfall. The waterfall algorithm [1, 2] enables to construct a non parametric hierarchy of watersheds (a hierarchy of partitions) which performs region merging between adjacent catchment basins. It is based on an iterative process which computes the gradient on a specific image called the mosaic image (obtained by associating its color mean value to the catchment basins). By carrying out several times this operation, we obtain a cascade of watersheds i.e. a hierarchy of partitions.

**2.4 A novel method: Nested homogeneous connections**

Flat-zones hierarchies are usually too fine and waterfall ones too coarse; thus, we propose a new connective criterion which is an intermediate one between pathwise connections (watersheds) and threshold connections (quasi-flat-zones). This new criterion is referred to as homogeneous connections and was introduced by LEZORAY and MEURIE [8, 9].

**Definition 4 (Homogeneous connections – C. Meurie [9])**

Two points  $p$  and  $q$  belong to a same homogeneous zone of an image  $I$  if:  $\|I(p) - I(q)\| \leq k \times \lambda(\text{Seed}(p))$

with  $\text{Seed}(p)$  the initial seed of the region of  $p$  and

$$\lambda(p) = \frac{1}{n_v} \sum_{p_v \in V(p)} \|I(p) - I(p_v)\|$$

$V(p)$  denotes the neighbors of  $p$  and  $n_v$  the cardinal of this set,  $\|\dots\|$  is a  $L_2$ -norm and  $k$  is a real number which sets the fineness of the partition.  $\lambda(p)$  being close to a gradient computation, pixels in homogeneous regions (the color variation among the considered neighborhood is small) will be considered first as candidate region seeds. Each pixel is a candidate region seed which grows by aggregating adjacent pixels according to the previous rule. This implies that a pixel  $q$  is aggregated to a region  $R$  if the distance between a pixel  $p$  of  $R$ , neighbor of  $q$ , is  $k$  times lower than the initial homogeneity of the seed pixel of  $R$ .  $k$  is the accepted homogeneity jump and states if two pixels belong to the same region. Homogeneous zones therefore produce partitions, the fineness whose decreases while  $k$  increases (the homogeneity constraint is slackened). Obviously, a hierarchy of partitions obtained for increasing values of  $k$  is not nested since it lowers the number of initial seeds while slackening the homogeneity constraint. This is the same problem as producing nested partitions with the watershed: one has to consider the output of the  $i^{\text{th}}$  level as an input for the  $(i+1)^{\text{th}}$  level. Therefore, it is possible to produce hierarchical partitions using homogeneous connections by applying the same principle on the partition obtained at the previous level (an efficient implementation uses graphs). For that, we apply the principle of homogeneous connections on a Region Adjacency Graph (RAG) obtained by a fine partition of homogeneous connections. Each region of this RAG being described by its average, one can apply the same growth rule to the graph. We, therefore, obtain the principle of nested homogeneous connections described below.

**Definition 5 (Nested homogeneous connections - Meurie [9])**

Two nodes  $p$  and  $q$  of a Region Adjacency Graph (RAG)  $G$  belong to same homogeneous zone of an image  $I$  if:

$$\|I(N_p) - I(N_q)\| \leq k \times \lambda(\text{Seed}(N_p))$$

with  $\text{Seed}(N_p)$  the seed node of the region of  $N_p$ ,

$$\lambda(N_p) = \frac{1}{n_v} \sum_{N_{p_v} \in V(N_p)} \|I(N_p) - I(N_{p_v})\|$$

$I(N_p)$  denotes the average color of the pixels corresponding to the node  $N_p$ ,  $V(N_p)$  the neighbors of  $N_p$  and  $n_v$  the cardinal of this set. Each node  $N_p$  of the graph is threaded in a hierarchical queue with the value of  $\lambda(N_p)$  as priority. The algorithm (cf. Algorithm 1) for the construction of nested homogeneous connections builds a hierarchy of partitions and needs two parameters  $k$  and  $k'$ .  $k$  is a number which sets the fineness of the base partition and  $k'$  the fineness of the next partitions of the hierarchy.

The adjustment of  $k$  and  $k'$  has a real importance in the performance of the algorithm. In this paper, we have fixed  $k=0.5$  and  $k'=1$ .

```

λ: integer; λ_end : integer; k and k': double
λ ← 1; Define λ_end
P_λ ← Homogeneous zones (fineness k) of initial image
G_λ = (N_λ, A_λ) for an initial partition P_λ
While (λ ≤ λ_end) do
    G_{λ+1} ← Homogeneous zones (fineness k') of G_λ
    λ ← λ+1
Done

```

Algorithm 1: Hierarchy of partitions by homogeneous connections.

**3 Results and discussions**

In this paper, we present a novel approach for morphological hierarchical segmentation and compare it with the two classical state of the art approaches on one hundred images of the “Berkeley Segmentation Dataset and Benchmark” (BSDB). To evaluate the achieved results, objective criteria such as the mean square error (MSE) and the normalized color difference (NCD) have been considered. For this experimentation, only the RGB color space is considered.

Figure 1 shows the evaluation of segmented images obtained by different methods of hierarchical segmentation (segmentation obtained by quasi-flat-zones, non parametric hierarchical watershed with Di Zenzo gradient and nested homogeneous connections). A quantitative evaluation with MSE and NCD is given for one hundred images of the BSDB. MSE increases as the hierarchy of partitions increases. This is inherent to the principle of hierarchical segmentation since progressing in the hierarchy means merging regions which results in a coarse segmentation. For low hierarchy levels (ie. levels lower than 10), we can notice that for the quasi-flat-zones MSE increases quickly while for the hierarchical watershed and the proposed method it increases only slightly. Nevertheless, the nested homogeneous connections algorithm offers a good compromise. For the high hierarchy levels (ie. levels between 10 and 20), the quasi-flat-zones MSE increases strongly and the quality of the segmentation becomes poor. On the contrary, the two other methods give satisfactory results.

Figure 2 illustrates several levels of the hierarchy of partitions produced by the quasi-flat-zones method, the non parametric hierarchical watershed (waterfall algorithm) and the proposed nested homogeneous connections algorithm. For a given low hierarchy level (ie. level 1), the differences between the colorized (mosaic) images produces by the three above mentioned methods are not significant. The number of regions is huge and the quality of segmentation is very good.

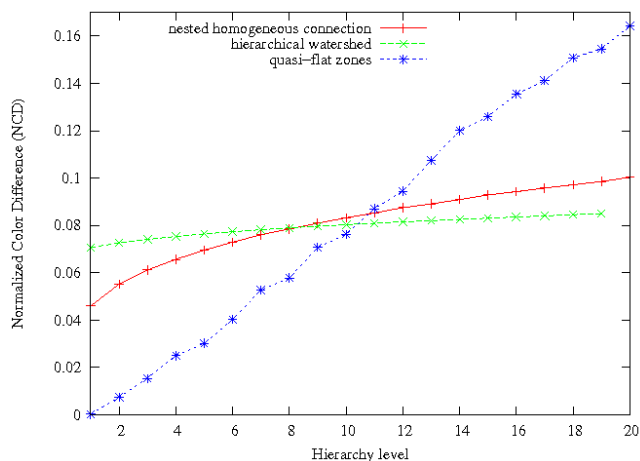
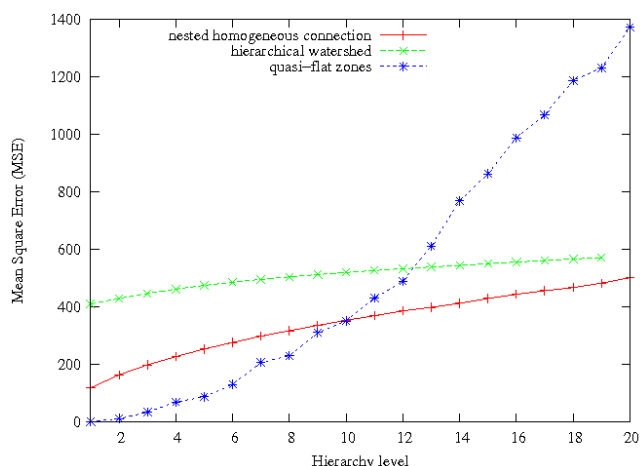


Figure 1: Evaluation of segmented images obtained by different methods of hierarchical segmentation in RGB color space (segmentation obtained by quasi-flat-zones, non parametric hierarchical watershed and nested homogeneous connections), all evaluated with MSE and NCD.

But these differences increase as the hierarchy increases. For high hierarchy levels (i.e. level 15), the nested homogeneous connections algorithm preserves better the important visual components of the image such as the person’s face than the quasi-flat-zones method. The segmentation results obtained by the non parametric hierarchical watershed with the Di ZENZO gradient are less satisfying than the other two methods. In fact, the number of regions decreases only slightly as the hierarchy increases. A high number of hierarchy levels must be achieved to extract the important visual components and it is not computationally cost-effective. Nested homogeneous connections algorithm produces hierarchical partitions which are finer than the ones produced by the waterfall algorithm and coarser than those of quasi-flat-zones method. However, nested homogeneous connections algorithm are better suited in the case of automatic segmentation since they do not need a definition of seeds for a given gradient.



Figure 2: Hierarchies of partition produced at the levels 1, 5, 10 by the quasi-flat-zones (lines 1-2), the non parametric hierarchical watershed (line 3-4) and the nested homogeneous connections (lines 5-6). Segmented images (lines 1-3-5) and their colorized (i.e. mosaic) images (lines 2-4-6).

This method locally adapts its behavior to the image content since the threshold which determines if a pixel belongs to a region depends on the local homogeneity at this pixel.

To conclude, the proposed method offers better results than the two other methods with regard to the quality of the segmentation obtained. The algorithm can be used to segment the image at high levels to extract the important visual components and to simplify it at low levels i.e. to be used as markers for connective filters such as levelings. Figure 3 illustrates two initial images and their segmentations produced by the nested homogeneous connections algorithm at low levels (i.e. level 1) and high levels (i.e. level 20). At the level 1, we show that the quality of the two images is very good. The produced images can be used as simplified images for other treatments. At the level 20, the quality of the two images obtained is less satisfactory but the produced images can be used to extract the important visual components.

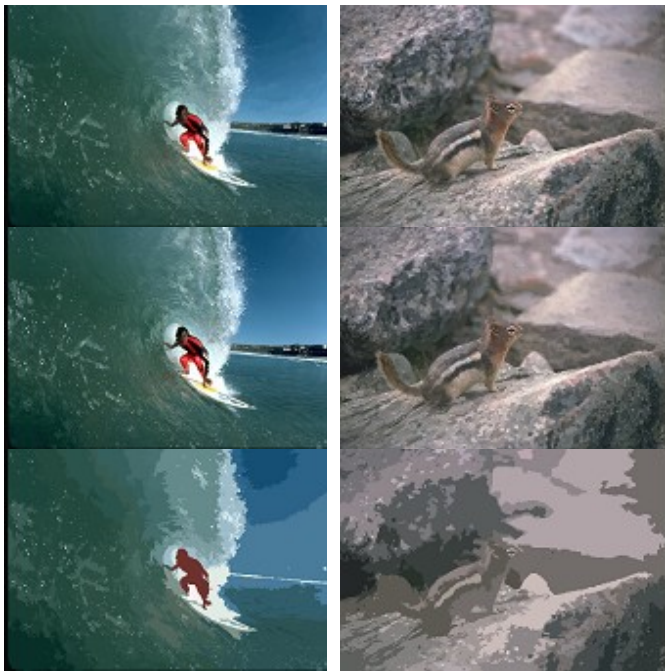


Figure 3: Initial images (top) and their segmentations (colorized images) produced by the nested homogeneous connections algorithm at level 1 (middle) and level 20 (bottom).

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