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Improving image segmentation quality through effective region merging using a hierarchical social metaheuristic

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Abstract

This paper proposes a new evolutionary region merging method in order to efficiently improve segmentation quality results. Our approach starts from an oversegmented image, which is obtained by applying a standard morphological watershed transformation on the original image. Next, each resulting region is represented by its centroid. The oversegmented image is described by a simplified undirected weighted graph, where each node represents one region and weighted edges measure the dissimilarity between pairs of regions (adjacent and non-adjacent) according to their intensities, spatial locations and original sizes. Finally, the resulting graph is iteratively partitioned in a hierarchical fashion into two subgraphs, corresponding to the two most significant components of the actual image, until a termination condition is met. This graph-partitioning task is solved by a variant of the min-cut problem (normalized cut) using a hierarchical social (HS) metaheuristic. We have efficiently applied the proposed approach to brightness segmentation on different standard test images, with good visual and objective segmentation quality results.

Keywords: Evolutionary metaheuristics; Image segmentation; Watershed; Region merging; Graph-based segmentation; Hierarchical social algorithm

1. Introduction

Image segmentation is one of the most complex stages in image analysis. It becomes essential for subsequent image description and recognition tasks. The problem consists of partitioning an image into its constituent regions, objects or labels (Gonzalez and Woods, 2002). The level of division depends on the specific problem being solved. This partition is accomplished in such a way that the pixels belonging to homogeneous regions, regarding to one or more features (i.e., brightness, texture or colour), share the same label, and regions of pixels with significantly different features have different labels. There must be considered four objectives for developing an efficient generalized segmentation algorithm (Ho and Lee, 2003): continuous closed contours, non-oversegmentation, independence of threshold setting and short computation time. In particular, the oversegmentation error, which occurs when a single semantic object is divided into several regions, is a tendency of some segmentation methods like watershed (Beucher and Lantuejoul, 1979; Haris et al., 1998; Hernández and Barner, 2000). Therefore, some subsequent region merging process is needed to improve the segmentation results.

Metaheuristic search algorithms are high-level general strategies for finding high quality solutions that have some mechanism for escaping from local optima (Glover and Kochenberger, 2002; Michalewicz and Fogel, 2000; Voss, 2001). The relevance of metaheuristics is reflected in their application to solve many different real-world complex

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problems, mainly combinatorial. Since the initial proposal of Glover about tabu search in 1986, many metaheuristics have emerged to design good general heuristics methods for solving different domain application problems. Genetic programming, GRASP, simulated annealing or ant colony optimization, are some other well-known examples of metaheuristics. Their relevance is reflected in the publication of many books and papers on this research area. There can be found a recent survey in (Glover and Kochenberger, 2002).

The applications of evolutionary techniques to Image Processing and Computer Vision problems have increased mainly due to the robustness of the approach (Parker, 1996). Many image analysis tasks like image enhancement, feature selection and image segmentation, have been effectively solved using genetic programming (Poli, 1996). Among these tasks, segmentation is one of the most difficult one. The standard linear segmentation methods are insufficient for a reliable object classification. The usage of some non-linear approaches like neural networks or mathematical morphology methods has usually provided better results (Sonka et al., 1999). However, the inherent complexity of many scenes (i.e., images with non-controlled illumination conditions or textured images) makes it very difficult to achieve an optimal pixel classification into regions, due to the combinatorial nature of the task. Evolutionary image segmentation (Ho and Lee, 2003; Poli, 1996; Yoshimura and Oe, 1999) has reported a good performance in relation to more classical segmentation methods.

Many segmentation approaches have been proposed in the literature (Gonzalez and Woods, 2002; Parker, 1996; Sarkar et al., 2000; Sonka et al., 1999). In this paper, we present a region merging method based on a new evolutionary metaheuristic called hierarchical social (HS) algorithms. This metaheuristic uses as evolutionary strategies the cooperation and competition mechanism, instead of classical crossover and mutation operators. Note that other well-known evolutionary metaheuristics present a similar type of cooperation and competition mechanism, like ant colony optimization (Dorigo et al., 1996), swarm intelligence (Kennedy et al., 2003) and cultural algorithms (Reynolds, 1999).

The proposed segmentation method can be considered as region-based, and it pursuits a high-level extraction of the image structures. After an oversegmentation of the initial image, our method produces a hierarchical top-down region-based decomposition. This way, the oversegmented image is represented by a weighted undirected graph, called modified region adjacency graph (MRAG). The MRAG structure is similar to the region adjacency graph (RAG) (Haris et al., 1998; Hernández and Barner, 2000; Sarkar et al., 2000) but MRAG also enables to add edges between pairs of non-adjacent regions (nodes).

In the MRAG model, nodes are represented by the centroid of each region as a result of the initial oversegmentation, and weighted edges are defined taking into account the spatial distance between nodes, their corresponding brightness mean value, and the corresponding region sizes. We consider that the minimum semantic information is given by each watershed region, so the mapping from the original oversegmented image to the MRAG can be made in a straight way (that is, each region mapped by one node).

Next, an optimal bipartition that minimizes the normalized cut value (Shi and Malik, 2000) for the image graph is computed. This process is successively repeated for each of the two resulting regions (image subgraphs) using a binary splitting scheme until a termination condition is achieved. An evident computational advantage is obtained when describing the image as a set of regions instead of pixel in the MRAG structure. It enables a faster region merging in oversegmented images with higher spatial resolution than reported in the literature (Haris et al., 1998; Hernández and Barner, 2000; Sarkar et al., 2000).

The definition of MRAG and the application of a hierarchical social (HS) metaheuristic to solve efficiently the normalized cut problem is the core of the proposed method. Our approach for modelling and solving image segmentation as a graph-partitioning problem is related to Shi and Malik's work (2000). They use a computational technique based on a generalized eigenvalue problem for computing the segmentation regions. Instead of that, we found that higher quality segmentation results can be obtained when applying HS Algorithms, through an iterative solution of a normalized cut problem.

2. Modified region adjacency graph

Several approaches have been proposed to decrease the effect of severe oversegmentation of watershed-based segmentation approaches (Haris et al., 1998; Hernández and Barner, 2000). These methods usually involve a preprocessing of the original image. Many of them are based on the region adjacency graph (RAG) which is a usual data structure used to represent region neighbourhood relations in a segmented image (Sonka et al., 1999). RAG is a weighted undirected graph $G = \{V, E, W\}$, where each node represents a region of the oversegmented image and each edge is a symmetric dissimilarity function between adjacent regions (nodes). Fig. 1a and b, respectively, shows a synthetic image and its corresponding RAG.

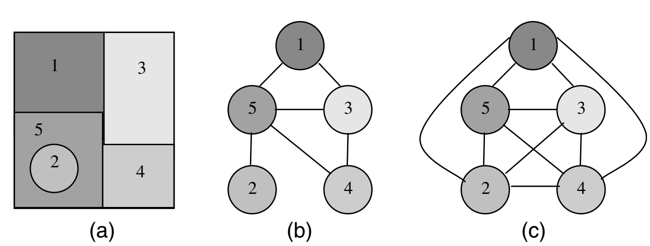

Fig. 1. (a) Original image. (b) Corresponding RAG. (c) A possible MRAG: enables adding edges between pairs of non-adjacent regions.