Object Segmentation by Oriented Image Foresting Transform with Connectivity Constraints

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Abstract

In this work, we introduce a new method called Connected Oriented Image Foresting Transform (COIFT), which provides global optimum solutions according to a graph-cut measure, subject to the connectivity constraint in Oriented Image Foresting Transform (OIFT), ensuring the generation of connected objects, as well as allowing the simultaneous control of the boundary polarity. While the use of connectivity constraints in other frameworks, such as in the min-cut/max-flow algorithm, leads to an NP-Hard problem, COIFT conserves the low complexity of the OIFT algorithm. Experiments show that COIFT can considerably improve the segmentation of objects with thin and elongated parts, for the same number of seeds in segmentation based on markers.

1 Introduction

Object segmentation is one of the most fundamental and challenging problems in image processing and computer vision. One important class of interactive image segmentation comprises seed-based methods, which can be roughly described in a unified manner according to a common framework, sometimes referred to as, Generalized Graph Cut (GGC). Within this framework, there are two important classes of energy formulations, the ε_1- and ε_∞-minimization problems, the former including the *min-cut/max-flow* algorithm, whereas the latter class encompasses methods, such as *watersheds* (1), *fuzzy connectedness* (2), and *image foresting transform* (IFT) (3).

Connectedness is an important global topology property, which can be used as a high-level prior for object segmentation. For a given binary image that represents the segmentation result, in this work, we consider a connected component as a maximal set of pixels, such that there are paths composed by adjacent pixels interconnecting all its elements and passing exclusively within the object.

In this context, the seed-based methods can be classified into three groups, according to their level of Connectedness:

1. In the first group, we have methods that do not guarantee any level of connectedness (Figures 1a-b). In the graph cut (GC) community, this is usually referred to as the disconnection problem of GC, when the source and sink nodes are connected to all image pixels (4).
2. In the second group, we have methods that guarantee that object's pixels are connected to some internal seed. However, note that the object could be composed by several disconnected components, as long as we have some object's seeds in each component (Figure 1c). The majority of methods belong to this class, including fuzzy connectedness and watershed from markers (2; 1).

Submitted to 33rd Conference on Neural Information Processing Systems (NeurIPS 2019). Do not distribute.

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

Figure 1: (a) Input image with user selected seeds. (b) Segmentation by Graph Cut showing the disconnection problem of an object region that is not marked by any seed on the right. (c) Segmentation by IFT resulting in disconnected components that are all marked by some object seed. (d) Segmentation by the proposed method producing a single connected component.

3. In the third group, we have methods that guarantee that the segmented object forms a single connected component in the image domain (5; 6; 7; 8) This is especially important when the target is a single object (Figure 1d).

In this work, we use the term connectivity constraint to indicate methods from the third group. The ε_1-minimization among all objects satisfying the connectivity constraint was proved to be NP-Hard (5; 6). Vicente et al. (5) propose a heuristic algorithm, named *DijkstraGC*, which merges the Dijkstra algorithm and graph cut. DijkstraGC is still slow, since it requires many calls to the maxflow algorithm. Other method, named *Topology cuts*, by Zeng et al. (6) also finds only an approximate solution to incorporate topology priors in the min-cut/max-flow algorithm. Nowozin and Lampert adopted a different approach solving a related optimization problem, which forces the output labeling to be connected in the framework of recent maximum a posteriori (MAP)-MRF linear program (LP) relaxations (7; 8).

2 Objective

In this work, our main goal was to develop a new seed-based segmentation method that guarantees optimal results subject to the connectivity constraint in the ε_∞-minimization problem of the GGC framework.

3 Contributions

In this work, we had as main results:

1. A novel method called *Connected Oriented Image Foresting Transform* (COIFT), that support a user-controllable minimum width of the connectivity constraint. The new method, successfully incorporates connectivity constraints on OIFT, preserving its low time complexity $O(N)$ (3), since it requires only four executions of the IFT algorithm.
2. The design of three new ground truth datasets from 280 public images [1], which contain objects with thin and elongated parts, available to the community.

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