Signal Processing: Image Communication 65 (2018) 231–239

Contents lists available at ScienceDirect

Signal Processing: Image Communication

journal homepage: www.elsevier.com/locate/image

# Weak boundary preserved superpixel segmentation based on directed graph clustering

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ARTICLE INFO

*Keywords:*
Superpixel segmentation
Directed graph clustering
K-NN graph
Integer programming

ABSTRACT

Weak boundary preservation is a challenge for superpixel segmentation. Existing methods that measure pixels' similarity based on pairwise distance could not efficiently describe relationship among high-dimensional image data, which plays key roles in extraction for image boundaries. In this paper, we present a new directed graph clustering (DGC)-based superpixel segmentation method via K-nearest-neighbor (K-NN) graph and distance information. It can efficiently deal with segmentation for the weak boundary of complex and irregular object. The basic idea is motivated by following observations: compared with smooth region, image boundary points have much lower pixel density and directed connectivity in local region. Based on K-NN directed graph, we introduce indegree and outdegree to describe above observation, which are the foundation to evaluate pixels' similarity. Then, a patch-based segmentation generates superpixel borders by even overlapping regions. Finally, we solve an integer programming to stitch small noise regions into final superpixels. Experimental results on two benchmarks demonstrate that our method outperforms the state-of-the-arts.

## 1. Introduction

Superpixel segmentation has been widely used in image and video segmentation [1,2], saliency detection [3,4], object proposal extraction [5], biomedical image analysis [6], object recognition [7] and target tracking [8], which benefits from the region consistency, cluster perceptibility and computation efficiency.

Generally, superpixel segmentation can be coarsely divided into two classes: (1) cut edge searching on graph structure and (2) seed region growing. The first class models image pixels as graph structure and seeks cut edges with minimum cost to disjoint the graph into subgraph as individual superpixel, such as Ncut [9], FH [10], LatticCut [11,12] and RegularSeg [13]. Those methods introduce adaptive similarity predicate [10] or regularity constraint [9,11–13] to produce consistent superpixel segmentation. The second class grows superpixel from some initial seeds. For example, SLIC [14] and HOSup [15] assign pixels' label of adjacent region by their nearest seeds. TP [16] expands the superpixel region from initial seeds until satisfies some stop conditions. Seed expansion-based superpixel segmentation obtain efficient computation performance due to their sophistical energy models. Although those two class superpixel segmentation methods produce simple and efficient calculation, they all calculate the affinity based on pairwise distance of pixels in feature space.

Pairwise distance-based measure can easily describe the dissimilarity of two pixels from obviously difference regions. However, it is difficult to reflect the fundamental difference for two pixels in image weak boundary. Intuitively, image boundary points have lower density distribution compared with smooth regions. Meanwhile, boundary points have different connectivity with non-boundary points based on K-NN directed graph. Existing methods for graph-based superpixel segmentation ignore these two key cues to describe pixels' similarity, which result into low boundary adherence rate, such as results of FH [10] and NC [9] for fish image in Fig. 1. Seed expansion-based methods, i.e., TP [16], SNIC [17] will yield large region leakage for some long and narrow regions due to lack of seed location on fine structure by regular grids location, such as segmentation for branch in crow image as shown in Fig. 1.

In this paper, we focus on the preservation for image weak boundary by combining pixels' density distribution and its local connectivity in K-NN directed graph, inspired by DGC [18]. Weak boundary preservation is the ability to extract the object boundary with low contrast, which

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https://doi.org/10.1016/j.image.2018.04.008
Received 6 September 2017; Received in revised form 9 April 2018; Accepted 9 April 2018
Available online 22 April 2018
0923-5965/

is due to the similarity of foreground and background, illumination and blur. For example, the fish's lip in Fig. 1 has the similar appearance with the surroundings and its border is blur. The state-of-the-art methods use the pairwise distance to depict the pixel similarity, which results into the inaccurate weak boundary extraction. In contrast, the proposed method define the similarity by some corresponding neighbor pixels based on the K-NN adjacent graph. It is more accurate to distinguish the boundary pixels, such as our segmentation result of fish in Fig. 1. Although the fish's lip has the similar appearance with background, our method is more robust to extract the weak boundary by considering the similarity of pixel to some its neighbor pixels.

In DGC [18], Zhang et al. introduce indegree and outdegree to describe the spatial structure of irregular cluster, which is suitable to segment irregular and low contrast object boundary in complex and noise background. We utilize indegree and outdegree to construct graph structure to describe the relationship between pixel and its neighbors. Intuitively, the external points of object boundary have lower indegree compared with object smooth regions, which reflects much lower density distribution than its nearest pixels. Meanwhile, those boundary points have difference local connectivity with smooth region points, which can be captured by pixel's outdegree. That is to say, pixels with lower indegree tend to locate in image boundary. Moreover, those points tend to be some region boundary if they are with higher outdegree. Utilizing these two indications, it is easy to discriminate those points and capture the topology structure of fine object.

Specifically, we firstly introduce DGC-based boundary extraction. Then patch-based superpixel segmentation has been proposed to partition the image pixel into consistent regions. Finally, we model region stitching process as an integer programming problem. We compare our method with several state-of-the-arts on BSD500 benchmark and shows that it outperforms other methods. The result proves that our method can more efficiently preserves the image weak boundary.

Our main contributions are:

- We first analysis the relationship between image boundary extraction and pixel K-NN graph.
- Then we propose superpixel segmentation methods via directed graph clustering.
- We construct the problem of stitching trivial regions by an integer programming-based region merging.

## 2. Related work

This section reviews two class superpixel segmentation mentioned above. The first class constructs image pixels as a graph structure and model segmentation problem as cut edge searching with minimum cost. For example, Shi et al. [9] introduce a normalized cut to balance the size of different partition and relax the cost function as a Rayleigh quotient to obtain the analytic solution. However, this method heavily constrains the size balance for cluster groups, which reduces segmentation performance for the weak boundary of irregular shape objects. Felzenszwalb [10] proposes a minimum spanning tree (MST)-based superpixel segmentation, which calculates the region's similarity by minimum internal difference. This measure not only results into irregularity superpixel regions, but also reduces the weak boundary adherence rate due to considering the minimum internal difference and maximum intra difference, especially for image with complex noise background. Then Moore et al. propose two regular superpixel segmentation methods based on vertical and horizon seam-like paths [12] and overlap region binary graph cut [11], respectively. In order to avoid multiple paths crossing, they add some regularity constraints into their models, which results into not only many narrow superpixel regions but also with higher under segmentation error. Hence, Fu [13] proposes a regular superpixel segmentation by finding minimum cost links of two junctions which lying on object boundary. Although this method could more directly obtain superpixel borders to fit with object boundary, it

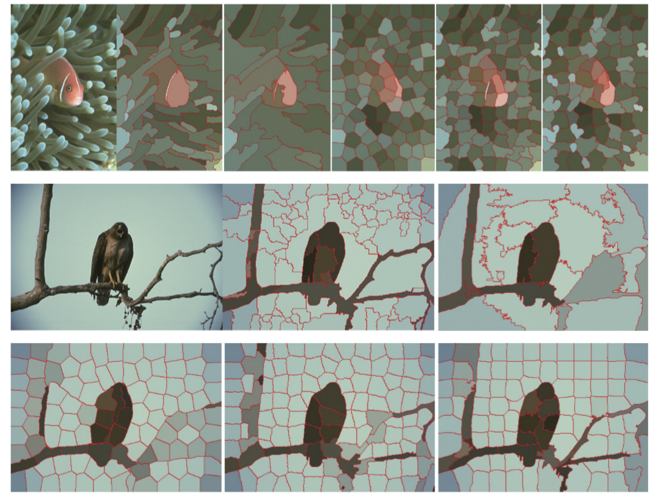

**Fig. 1.** Weak boundary and fine structure preserving for different methods. From top to bottom and left to right: input image, our DGC-based method, FH [10], NC [9], TP [16] and SNIC [17]. More results are shown in Fig. 6.

limits the link pairwise for vertical and horizon junctions to preserve the superpixel regularity, which makes lower object boundary adherence rate.

The second class grows superpixel regions from some initial seeds. For instance, TP [16] locates initial seeds and expands superpixel border towards gradient flows until reaching a much larger image gradient. Due to introduce a curvature cost to maintain regular superpixels, TP obtains poor segmentation performance under the condition of irregular object and complex background. The most popular superpixel segmentation method, i.e., SLIC [14], uses fast kmeans algorithm to formulate superpixel efficiently. However, pairwise distance-based kmeans on color and position space not always performs well for image boundary. Hence, Peng et al. [15] optimize an higher order energy term to refine the initial result obtained by SLIC. The performance incremental depends on the sufficient edges and segment regions for presegments, which limits the further promotion for segmentation performance.

Most of existing superpixel methods calculate pixel similarity based on pairwise distance, which are difficult to capture the change of local density and connectivity of pixels from the smooth region to object boundary. Therefore, the proposed method constructs a directed graph for adjacent pixels and introduce indegree and outdegree to describe those two indications. This benefits our superpixel segmentation to further exploit the density change and connectivity of image boundary pixels. To our best knowledge, this is the first time that directed graph is used to extract image superpixels.

## 3. The proposed method

In this section, we introduce a novel superpixel segmentation method via directed graph clustering and integer programming. We first explain the boundary extraction based on DGC and analysis initial boundary generation based on two directed graph terms, i.e., indegree and outdegree. Then, a detailed description of superpixel segmentation is introduced. The method is consisted of two main steps: (1) patch-based superpixel segmentation via directed graph clustering (DGC); (2) stitching by integer programming-based region merging. The flowchart of our method is shown in Fig. 2.

### *3.1. DGC boundary extraction*

There are some limitations in existing superpixel segmentation methods, such as: