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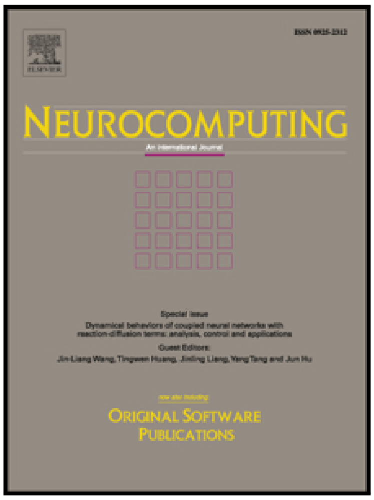

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Updating Initial Labels from Spectral Graph by Manifold Regularization for Saliency Detection

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Abstract
This paper presents a novel saliency detection method via updating initial labels from spectral graph in a semi-supervised learning (SSL) framework. For updating labels efficiently with graph-based SSL, two principles generally should be considered. The first one is that the updated labels should not change too much from their initial assignment. The second one is that the updated labels should not change too much between similar samples. To follow the first principle, the biggest eigenvector of Laplacian matrix, which contains rich contrast between background regions and salient regions, is employed to obtain the initial label vector. To follow the second principle, a new graph construction scheme, in which only boundary samples with similar features can be connected with each other, is proposed to reduce the geodesic distance in graph. Then a graph-based manifold regularization framework is exploited to update the label vector for separating salient samples from non-salient samples. A refinement function cooperating with an activation function is further presented for saliency optimization. Experimental results show that the proposed method achieves competitive performance against some recent state-of-the-art algorithms for saliency detection.

Keywords
Saliency detection; Spectral graph; Label updating; Manifold regularization

1. Introduction

Visual attention is one of the dominant characteristics of human vision system. Visual saliency is often used to measure the visual attention that human vision system perceives [1]. To estimate visual saliency, many approaches have been proposed in the past few decades, which can be categorized as either top-down [2, 3] or bottom-up [4]–[10] approaches. Generally, bottom-up methods are inspired by the mechanism of the human neural system [11], while top-down methods incorporate the prior knowledge derived from the human recognition system [12].

Efficient saliency detection plays an important role in many computer vision tasks, including automatic object detection [13], image retrieval [14], tracking and video surveillance [15], image/video resizing [16], video summarization [17], adaptive image compression [18], and defect detection [19]. In order to achieve such abilities, extensive research efforts have been conducted on bottom-up visual saliency analysis for years. Early works [11, 20] in this field are mostly based on biologically inspired models and are evaluated on human eye fixation data [21]. Many follow-up works are along this direction [22]–[24]. Recent years have witnessed more interest in object level saliency detection. In this direction, the salient objects are automatically detected and assigned consistently high saliency values.

The basic concept for semi-supervised learning (SSL) is to formulate an objective function that can use both labeled and unlabeled data. Recently, the graph-based semi-supervised learning approach has been widely used in various real-world data classification and saliency detection since it gives an elegant bridge for label propagation between labeled and unlabeled data [25]–[29]. Two principles referred to as label fitness and manifold smoothness are often concerned for label propagation [30]. When labels are propagated from the labeled nodes to the unlabeled nodes, label fitness ensures the updated labels of labeled nodes can be consistent with their original labels, while manifold smoothness ensures the neighboring samples in a high density region can share similar decision values.

The label fitness is determined by the manner of initial label assignment. Based on the hypothesis that the nodes along image boundaries have a big probability to be non-salient, the labels of these nodes are initialized strongly as “1” in [25]. However, this empirical manner can not provide the label fitness very well when the salient objects are partially cropped by image boundaries. To address this issue, Wang *et al.* use the nodes with weak image texture as background seeds [31]. Li *et al.* compute the color distinctiveness of each boundary node from other boundary regions and drop the top 30% with high color difference to obtain the background seeds, which are further assigned with “1” as their initial labels [26]. However, these schemes are limited by the decision accuracy of boundary seeds. Therefore, it is unreasonable to label strongly the boundary nodes with “1” from the point of label fitness and visual attention. Qin *et al*. integrate different distinction maps via k-means algorithm on image boundaries to generate initial labels and propagate those labels by cellular automata to enforce saliency consistency [32]. Because the distinction maps are mainly derived from contrast calculation, in some cases it fails to provide usable initial labels. Fortunately, Ng *et al.* find the spectral graph has the ability to detect important content in an image [33]. Herein, this paper presents a novel initial label assignment to provide the label fitness based on classical spectral graph analysis.

The manifold smoothness is determined by the connection manner of nodes in a graph. Based on the connectivity and boundary priors proposed by [10], many of the existing graph-based saliency detection methods consider all boundary nodes to be adjacent to each other to reduce the geodesic distance in a sparsely connected graph [25, 26, 34, 35]. However, this can cause significant errors due

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