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A primal sketch based framework for bean-shape contour extraction

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ABSTRACT

Contour extraction and object detection is one of fundamental problems in computer vision. Contour extraction can be guided by either global or local constraints. In this paper, we propose a local constraint based framework for bean-shape contour extraction. We propose a criterion to construct primal sketches based on connected components of Canny edge points in a channel-scale space. When a targeting object is surrounded by a complex background, a sketch token may be deficient (not closed), and it may also contain some faulty part (not on the boundary of a targeting object). We propose algorithms to detect and restore deficiencies and faults of primal sketch tokens. We present two case studies for the proposed framework: (i) embryo localization and (ii) face localization. The case studies demonstrate the potential of the proposed framework.

1. Introduction

Contour extraction and object detection is one of fundamental problems in computer vision and image understanding [34,1,33]. Contour extraction can be guided by either global constraints, such as internal and external energy used in active contour models or level set models [14,8,11,20], or "cut energy" used in graph cut approaches, such as minimum cut [6,18,4,13,33], and normalized cut [34,38]. Contour extraction can also be achieved by configuring local constraints on low-level tokens, such as edge/ridge pixels, to group or link small/short tokens in order to construct complete contours [17,22,39,24,43].

The contour fragmentation issue [17] (e.g., a closed contour is broken into multiple fragments) is one of main challenges in contour extraction and object detection [22,39,24,17]. The contour fragmentation issue leads to a circumstance that different tokens may be extracted from similar images [17]. Analyzing, splitting, and merging line segments is a popular strategy to address the fragmentation issue [22,39,24,17].

Primal sketch [26] is an important methodology for object detection and image structure analysis. A *primal sketch* of a scene, simply speaking, is a collection of significant low-level tokens (such as line segments and blobs) of the scene [26,16,17]. Lindeburg [23] proposed a multi-scale representation of grey-level shape called *the scale-space primal sketch*. Furthermore, he proposed a methodology for extracting significant blob-like image structures from this representation. Kokkinos et al. [16] proposed a bottom-up and top-down object detection method based on primal sketch features (including edge features, ridge features and blob features) and graphical models. Fig. 1 shows examples of different types of sketch tokens extracted in a Drosophila embryonic image by state-of-the-art methods. Blue (dark) regions in an embryonic image (see Fig. 1(a)) are gene expression regions that are valuable information to reveal gene–gene interaction during the development of a Drosophila embryo [9]. However, different gene expression patterns also lead to significant variations of the appearances of embryos, and thus become a challenge to embryo localization. Fig. 1(b) shows salient tokens extracted by the method of Kennedy et al. [15]. The tokens have been grouped (illustrated by different colors) the contour cut criterion. Fig. 1(c) shows edge tokens extracted by the scale-invariant method of Kokkinos et al. [16]. Fig. 1(d) shows ridge tokens extracted by the scale-invariant method of Kokkinos et al. [16]. Fig. 1(e) shows blob tokens extracted by the scale-invariant method of Lindeberg [16]. It is easy to see that the last two types of tokens are not helpful for the problem of embryo contour extraction. Although salient tokens extracted by the methods of Kennedy et al. and edge tokens by Kokkinos et al. are more promising than the last two, they do not provide sufficient tokens to construct the complete contour of the embryo shown in Fig. 1(a).

In this paper, we propose a primal sketch based framework for contour extraction based on two *assumptions*:

1. *Assumption 1:* The object of interest in an image dominates the image plane.
2. *Assumption 2:* The object of interest is "bean"-shaped [31], e.g., embryo, face, and car.

The primal sketch used in our framework is constructed by connected components (in terms of 8-connectivity) of Canny edge points of a given image in a scale space. An image that contains a

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0925-2312/

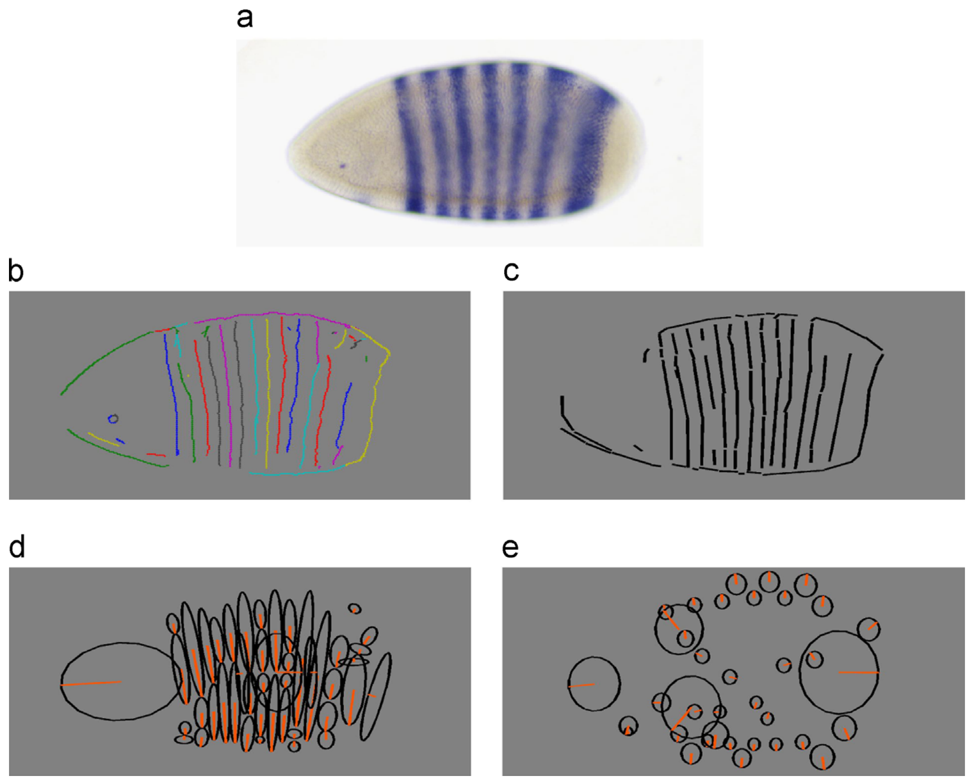

Fig. 1. Primal sketches extracted by existing methods do not contain enough sketch tokens to build the contour (boundary) of a targeting embryo object. (a) Input image. (b) Salient tokens by Kennedy et al. [15]. (c) Edge tokens by Kokkinos et al. [16]. (d) Ridge tokens by Kokkinos et al. [16]. (e) Blob tokens by Lindeberg [23].

complex background likely causes the contour fragmentation issue and deficient sketch tokens. Thus, it is not reliable to allow a single sketch token extracted from an edge image for an image with a complex background. Moreover, a sketch token extracted in complex background may also contain some faulty part (not on the contour of the targeting object).

Note that a bean-shape sketch token contains a certain degree of symmetry. Intuitively, a bean-shape token has to be approximated by a polygon with a large number of vertices because of densely distributed non-zero curvatures in the bean-shape token. Based on this assumption, we propose a *high curvature oriented criterion* that maximizes the number of vertex points of the convex hull of a sketch token. To address deficiencies and faults of sketch tokens, we follow a three-step processing strategy. We start from processing a single sketch token, and propose basic operations (algorithms) to address deficiencies and faults. Then we propose methods to address two sketch tokens, where the focus is on the detection of mergeability of two sketch tokens and the procedure of merging two mergeable sketch tokens. Last, we propose methods to process multiple sketch tokens.

We test the proposed framework on two case studies: (i) embryo localization, and (ii) face localization. Drosophila embryonic images provide detailed spatial and temporal information of gene expression, which becomes an important tool for micro-biologists to study gene–gene interaction [9]. Localization of a targeting embryo in an embryonic image is the first step of an automatic computational system for the exploration of gene–gene interaction on Drosophila. Embryonic images usually contain significant amount of variations: (i) imaging conditions, such as the contrast, scale, orientation, and neighboring embryos, (ii) gene expression patterns, and (iii) developmental stages [10,25,32,21]. Face localization is an important prerequisite of statistical appearance-based methods for face recognition [2,41]. Common variations of face images include (i) appearances of face objects, (ii) poses and facial expressions of faces, (iii) clutter backgrounds, and (iv) illuminations [41]. Our case studies will demonstrate the potential of the proposed framework.

The main contributions of the paper include

- a proposed criterion to construct primal sketches based on connected components of Canny edge points in a channel-scale space;
- a proposed algorithm to group sketch tokens, and a proposed algorithm to restore a sketch token, which can be integrated with other segmentation methods.

The rest of the paper is organized as follows: we describe related work in Section 2; we introduce a channel-scale primal sketch in Section 3; methods for processing a single deficient and faulty sketch token are proposed in Section 4; methods for processing two sketch tokens are proposed in Section 5; methods for processing multiple sketch tokens are proposed in Section 6; two case studies are given in Section 7; conclusion and future work are presented in Section 8.

2. Related work

Recall that contour extraction can be achieved by configuring global constraints [14,8,11,20,1,4,13,33,34,38]. In terms of internal and external energy, an active contour approach can incorporate generic shape constraints, such as smoothness, and elastic and image contrast in order to drive an initialized contour to the boundary of an object [14]. Chan and Vese [8] proposed an active contour method without edge, which is essentially a level set method. Fussenegger et al. [11] integrated shape priors of objects in a level set in an incremental manner to improve the performance of image segmentation and tracking. A level set function