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Contrast-dependent surround suppression models for contour detection

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ABSTRACT

The goal of this work is to present a computational model for contour detection, based on the surround suppression mechanisms of the primary visual cortex, in which the strength of surround suppression can adaptively vary with contrast—the surround modulation tends to be clearly suppressive at high contrast and less suppressive at low contrast, which may help to achieve the tradeoff between reducing cluttered edges and retaining object structures with weak responses, thus improving performance of contour detection under different circumstances; on the other hand, for similar texels can engender stronger suppression effects, more than orientation feature, texton is introduced to homogeneity measurement, which can well character multiple properties of texture regions, thereby yielding better contour detection results than other suppression models. The study can provide useful suggestions for contour detection algorithm in computer vision, but may also contribute to understanding contrast influence and feature representation in non-classical receptive field inhibition.

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1. Introduction

Contours that contain rich structure information about the contents of scenes are an important feature in many visual tasks such as object recognition, geometric reconstruction, and motion analysis. At early stages of visual processing, however, many important shape contours are often submerged in the abundance of local oriented edges arising from texture fields or cluttered backgrounds. The traditional edge detectors are mainly based on a measure of discontinuity in some low-level image features. For example, the Canny operator [1] measures oriented brightness gradients. Many of the edges obtained with these detectors are meaningless distractor elements, but are not part of any significant or relevant physical structures. For contour detection, one major difficulty is to eliminate trivial texture edges and selectively preserve important shape structures in the scene, especially in the case of low contrast, which is a contradiction.

The physiological results of Levitt and Lund [2] showed that the neuron responses to the stimuli placed within receptive field can be either increased or decreased by adding the stimuli in the region surrounding the receptive field. Many evidences demonstrated that the stimuli beyond classical receptive field (CRF) can modulate the activities of neurons in the primary visual cortex (V1) [3–6]. This surrounding region outside CRF is called non-classical receptive field (non-CRF). The modulatory effect of contextual information from the surround is desirable for contour perception, which can selectively enhance relevant edges and selectively suppress texture edges.

The response reduction originating from the introduction of a surround to a visual target, called surround suppression, makes V1 neuron weak or no response to broad field homogenous textures but respond vigorously to various textural contrasts [7–9]. Surround suppression has been interpreted as the neural substrate for a variety of perceptual pop-out phenomena, such as figure-ground segregation and visual attention. The inhibitory mechanisms have inspired many efforts to deal with computer vision problems such as contour detection [10,11], edge enhancement [12], and object detection [13,14]. A lateral inhibition pyramidal neural network has recently been proposed to perform image segmentation and classification [15].

Surround suppression seems to be a common property of biological edge detection mechanism. Many computational models have been developed to aim explicitly at better detection of object contours and region boundaries bases on surround suppression in V1 neurons. Grigorescu et al. [10] introduced the surround suppression mechanism to local oriented edge detectors, and thus proposed two models – isotropic and anisotropic inhibition models. They regarded isolated lines and edges as non-texture features,

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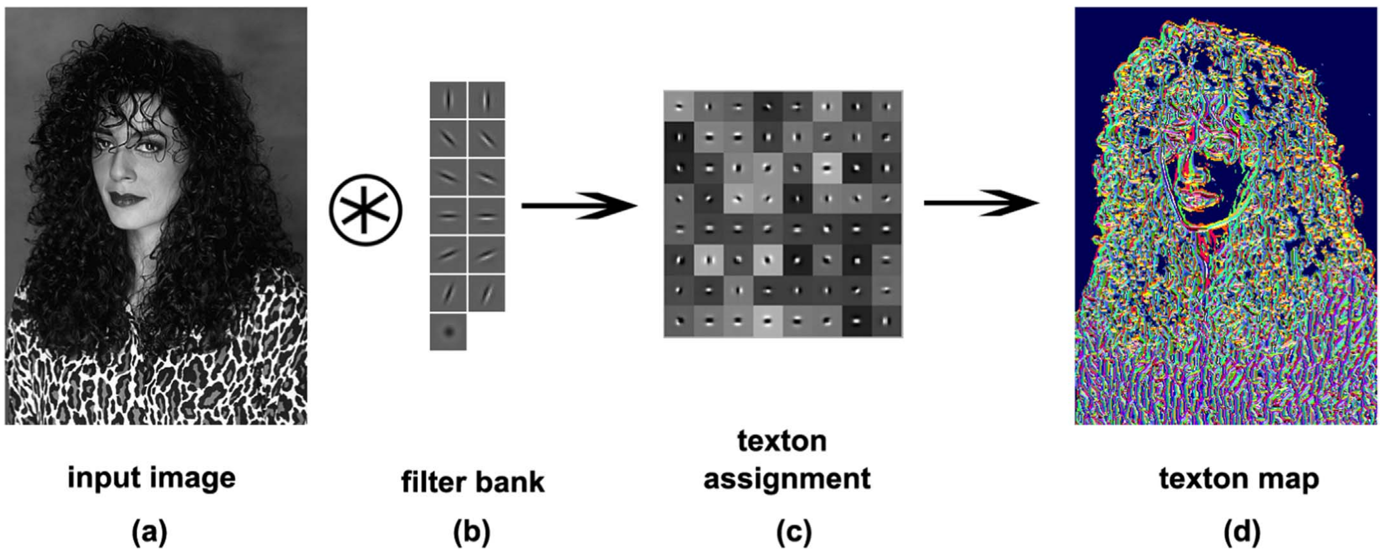

Fig. 1. Schematic illustration of texton assignment process. (a) Input image. (b) Filter bank: the filter bank consists of six oriented even and odd symmetric Gaussian derivative filters and a difference of Gaussians (DoG) filter. The corresponding pattern is produced by convolving the input image with the filter bank, and thus each pixel obtains a vector of responses to the filter bank. (c) Texton assignment. Each pixel is labeled with the texton which lies closest to it in filter response space. In the clustering stage, 64 universal textons are learned using K-means approach from the 200 training images [49]. (d) Texton map. Colors map uniquely to texton indices. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

which are not affected by the inhibition, while groups of lines and edges viewed as texture features are suppressed. Ursino et al. [16] combined feed-forward and feedback inhibition mechanisms to present a model of contour extraction, in which the feed-forward input plays a major role to suppress non-optimal stimuli and to ensure contrast invariance, and long-range feedback inhibition is essential to suppress noise. Li and colleagues [17–19] have developed biologically-inspired contour perception models over many years, especially in non-CRF inhibition modeling. They applied multi-resolution techniques to surround suppression models in which an adaptive end inhibition is realized based on the information extracted at two different spatial scales – Gabor energy information at a coarse scale and the side inhibition information at a fine scale [17]. They have also recently proposed a multiple-cue inhibition method in which the multi-feature combined weights are used to modulate the final inhibitory responses of the neurons [18]. These models can dramatically reduce trivial edges from texture regions and thus improve the performance of contour detection in comparison to traditional local operators.

For non-CRF modulation, in addition to the inhibitory effects, facilitatory influences have also been demonstrated for V1 neurons [20–23], and is applied to the task of perceptually salient contour detection [24–26]. Tang et al. [27] built a unified contour model by combining inhibitory and facilitatory interactions, in which inhibitory and facilitatory regions are located at both sides of and along the axis of the receptive field respectively. The advantage of the proposal is that it can effectively suppress distractor edges, and meanwhile retain salient structures in real images. Recently, Spratling [28] proposed a contour model of PC/BC-V1 + lateral + texture by integrating recurrent lateral excitatory connections and other special lateral connections (which is equivalent to the inhibitory effects) into the PC/BC (i.e., predictive coding/biased competition) model of V1. This method can obtain good results of contour detection from single intensity information.

Despite these recent important contributions, there are still two problems that are not addressed in these biologically-inspired models mentioned above:

Influence of contrast on surround suppression effects: Perceived contrast is a basic perceptual attribute of an image. The nature of center–surround interactions in the visual cortex is often dependent on contrast [29–31], moreover, surround suppression effects are stronger at high contrast than at low contrast. Complex images derived from natural scenes usually contain a broad range of luminance and contrast. The contrast-dependent property of surround modulation may contribute to maximizing the performance of the visual system under various stimulus conditions, and thus surround suppression models should take into account the influence of contrast.

Reasonable measure for texture homogeneity: V1 neuron responses to stimuli are modulated by texture information outside the receptive field, and homogeneous texture surrounds often produce larger inhibitory strength [32]. The test of texture modulation indicated stronger suppression from similar texels (the fundamental unit of texture space) and a nearly linear relationship between the strength of suppression and the number of similar texels in the nearby surround [33]. Texture homogeneity is measured based mainly on orientation similarity in the previous suppression models. It is well known that, besides orientation, texture contain various properties, such as spatial frequency, spatial phase and luminance [34–37]. Reasonable measurement of texture homogeneity can more effectively model suppression behavior.

This study focuses on surround suppression modeling. Aiming at the two problems presented above, we present a contour detection model, in which (I) the strength of surround suppression would vary with contrast, which can be beneficial to reduce texture edges and retain object structures at low contrast regions, and consequently improve performance of contour detection for different stimulus conditions; (II) more than orientation feature, texton is introduced to homogeneity measurement, which can better implement suppression of the responses to texture elements and stand out region boundaries. This work may contribute to understand contrast influence on inhibitory behavior and feature representation of surround suppression, and may provide useful suggestions for contour detection algorithm in computer vision. A preliminary version of measuring homogeneity through combining the multiple attributes of surround regions appeared in a conference proceedings [38].

One closely related work is the weighted KPCA degree of homogeneity amended non-CRF inhibition model of Zhang et al.

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