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A region segmentation method for region-oriented image compression

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ABSTRACT

In order to obtain homogeneous regions and smooth contours for region-oriented image compression, gradient-coupled spiking cortex model is designed and applied to digital image segmentation. Inspired by the knowledge of visual cortex, the model is composed of neurons with spike coupling and gradient enhancement, and it is same as the one in the visual cortex which can distinguish some objects in real scene through capturing boundary information. The model smoothes pixels within regions and enhances pixels at boundaries by creating a fitting function. Outputs of the model are the desired segmented image after connection components label. Experiments show that the method not only detects regions of original image, but also remains succinct effective contours, so it is suitable for region-oriented image compression.

1. Introduction

Digital image processing is a subject about 2D discrete signal processing in which a digital image is represented as a matrix and the value is called as gray intensity. Image segmentation is to divide an image into some connected components based on the location and its gray intensities. While image compression is to represent images with the shorter bits and the more information. Region-oriented image compression technique handles images based on regions as contours of objects but regular rectangles as processing units.

Segmented image coding (SIC) is considered as one of region-oriented image compression technology [1], which divides an input image into two parts: contours and regions with slowly varying image intensity. The contours are coded with a method while the homogeneous regions are represented by linear combination of orthogonal basis functions. Here, segmentation of regions is one of key problems to be solved. The actual performance of image compression depends highly on the segmentation algorithm. As proposed by Christopoulos et al. [2], the segmented image is expected as the one that has the controlled number of regions, perfect homogeneity within a region, less small-region and smooth contours.

In order to represent images effectively, segmented regions are expected as homogeneous as possible, and the number of small regions should be limited [3]. Furthermore, many experiments show that quite a few of bits are spent for coding contours in SIC. Hence, the number of contour pixels is essential for compression ratio of the image compression method [4]. The segmented algorithm should not only classify similar neighbor pixels into same regions, but also contour objects with the least pixels. Those properties are essential but no existing methods could meet.

Generally, there are two approaches [5] to partition an image into regions: region-based segmentation and edge detection. For region-based segmentation, all pixels with similar attributes are grouped together and marked as a region. Pixels are selected based on the similarity of some attributes, for a gray image, the basic attributes are gray intensity and spatial distance. Pixels may be partitioned into the same region if they have similar gray intensity and adjacent space distance. Edges are crucial local information of regions and they generally occur at the common border of two or more regions. Edge detection aims to form a boundary to separate different regions and it implements through looking for the discontinuity of the image intensity. There are many edge detection algorithms such as Canny, Sobel, Prewitt, Laplace and so on [5], but edges detected by this method always are not closed.

Splitting and merging technology [6] is a region-based method, which starts with a unit in an image, and then the units split and/or merge together with some criteria until the desired result. This approach could obtain preferable segmented image but the process of splitting or merging is difficult to control. For region-oriented

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image compression, Christopoulos et al. [2] proposed a segmented method based on splitting and merging technology. The method produces an over-segmented image firstly by splitting, and then merges some regions based on the difference of their gray mean intensity and a cost function. The cost function is founded on the gradient information, the size of the segments and the shared contour length of adjacent segments. The over-segmented image is to reduce the risk of losing important edges and the merging is to classify some small segments into its neighboring regions, but the merging is unruly, and the optimal segmented image can be obtained by trial and error. Furthermore, the segmented image contains many unconsidered tiny texture or noise and it is a contradiction because if the over-segmented image is excessive, the important edge is captured but more useless textures are contained. Contrarily, the important edge information is lost. The clustering method [7–9] is another region-based approach and it regards image segmentation as common data classification to process through feature extraction and decision [10,11], and the decision step provides final segmented images, therefore, the definition of feature space is significant and difficult for different kinds of images.

Active contour model is an effective edge detection method, which is based on variational method and be widely applied to SAR, medical image segmentation and so on. At present, depending on the curve expression, active contour model can be classified as parametric active contour model and geometric active contour model. Those models achieve its segmentation through minimizing the objective energy function and evolving the initial curve toward the edges of objects. The C-V model [12] is a classical geometric active contour model based on level set and curve evolution and it takes full advantage of global gray intensity, but the result is not good because the edge positioning accuracy is not high. In recent years, various models have been proposed, for example, active contour with shape prior [13], fast global minimization of active contour model [14], GVF snake [15] and methods based on level set [16].

Furthermore, a variety of hybrid methods appear; for example, watershed method [17] which considers the border of local minima as watershed and segments the regions into catchment basins. It is better at the weak border, so the over-segmentation may emerge where there is noise. Graph cut [18], which considers an image as graph with nodes and edges, received considerable attention as a method for image segmentation. It could separate the object from a scene but the background is not homogeneous because some textures still hide in. Further, contours are not smooth enough. In [19], minimum description length principle is introduced into image segmentation. Images are modeled as Gaussian random fields with piece-wise homogeneous mean and variance. Based on the changes in the mean and/or variance, the edges can be detected.

For the past few years, artificial neural network has already became a well-known technology used in computer vision, of course, it is widely used in image segmentation. Motivated by a histogram clustering approach to image segmentation, Buhmann et al. [20] proposed a network of leaky integrate-and-fire neurons to segment gray image. The firing rate of class neurons is employed to encode image segmentation because the connection between neighboring neurons can smooth adjacent similar neighbors. Meftah et al. [21] applied spiking neural network model for image segmentation and edge detection, and addressed the issue of parameter selection by an unsupervised learning method.

In this paper, gradient-coupled spiking cortex model is proposed to segment gray images into homogeneous regions and smooth contours for SIC. The model is composed of neurons with spike coupling and gradient enhancement, and neurons imitate the ones in the visual cortex which can capture boundary information of the scene. Compared with others, the model smoothes pixels within regions and enhances pixels at boundaries by creating a fitting function, so it could eliminate some noise or disturbances and emphasize functions of the similar neighbors on finding discontinuous of stimulus. Then, the stimulus is segmented by a series of dynamic thresholds and fitting curved-surfaces. The stimuli coupled with the spikes of neighbors turn into the internal state, those make a curved-surface and the dynamic threshold forms another curved-surface. At different times, transection of the multilayer curved-surfaces produces a series of binary matrixes which contain the information of edge, region and texture. The time matrix of the neuronal spikes records object and boundary information of image. Outputs of the model are the desired segmented image after connection components label. Connected components labeling is implemented on those spike images to obtain regions and contours through fusing all the object information recorded in the spike images.

Considering a digital image as network, the network can achieve image segmentation through encoding the firing rate of similar neighboring neurons because of the local coupling among neighbors and decaying exponential. The method ensures that the results meet segmented image coding based on uniformity within a region and effectivity of contour pixels.

In the model, an activated neuron may result in the synchronous excitation of its neighbors with approximate intensity. So, similar neighbors affect each other and could capture local information. It is called as spiking coupling. Another, the transition between stimulus is sharpened by gradient coupling and it is easy to find the discontinuous. In short, the model is convenient for showing the local discontinuous and smoothness of the network.

The organization of this paper is as follows: In Section 2, gradient coupling spiking cortex model and its properties for image processing is demonstrated. Section 3 is the segmentation method based on the proposed model. The experimental results will be shown in Sections 4 and 5 is conclusion.

2. Gradient-coupled spiking cortex model and its properties

Inspired by firing rate encoding of neuron network and the threshold segmentation method, a novel model is constructed to find the discontinuous of stimuli. In this section, we formulate the model and its properties when it is applied to image processing especially segmentation.

2.1. Gradient-coupled spiking cortex model

Based on the visual cortical model [22–24], gradient-coupled spiking cortex model is proposed as follows.

The fundamental component of the model also is leaky integrator. The basic form of the response is

$$I(t) = V e^{-t/\tau}$$

where V is the amplification factor, τ is the decay time constant of the leaky integrator and $I(t)$ is of exponential decay with time t.

Each neuron is denoted with indices (i, j), and its neighbors are denoted with indices (k, l). Feeding and linking are combined together as internal activity. Neuron receives input signals from the stimuli and feedback synapse of its neighbors such that the output signal of a neuron modulates the activity of its neighbors. The internal activity $U_{ij}[n]$ of neuron in the model is modulated nonlinearly by feeding input and linking input as

$$U_{ij}[n] = U_{ij}[n-1]e^{-t/\tau_U} + S_{ij}[n] + S_{ij}[n]\sum W_{ijkl}Y_{kl}[n-1] + S_{ij}[n]GRAD_{ij}[n] \tag{1}$$