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Extraction of Image Regions Using Oscillatory Responses in Chaotic Neuronal Network

Mio Musashi† , Ken'ichi Fujimoto‡ and Tetsuya Yoshinaga‡

†Graduate School of Health Sciences and ‡Institute of Health Biosciences
The University of Tokushima
3-18-15, Kuramoto, Tokushima 770-8509, Japan
Email: musashi@anan-nct.ac.jp, {fujimoto | yosinaga}@medsci.tokushima-u.ac.jp

Abstract—For dynamic image segmentation, which is used to extract connected components in an image and to exhibit them in a time series, we have developed a network model consisting of discrete-time chaotic neurons. According to an n-phase oscillatory response of neurons, the network model can segment n image regions within one processing. Based on the bifurcation analysis of periodic points in a reduced model of the network, we propose a successive algorithm for dynamic image segmentation of a gray-level image with an arbitrary number of isolated image regions, using our network model with two- and three-phase oscillatory responses.

1. Introduction

For dynamic image segmentation, which is used to extract connected components between pixels, i.e., isolated regions or blobs, in an image and to exhibit them in time series, we have developed a network model [1] consisting of discrete-time chaotic neurons [2,3]. A neuron can generate a similar oscillatory response formed by a periodic point with high order of period to an oscillation as observed in a continuous-time dynamical system. According to an n-phase oscillatory response of neurons, the network model can segment n image regions within one processing. In our previous studies [4–6], we derived reduced models, which are two- and three-coupled neuron systems, and analyzed the bifurcations of various kinds of synchronized oscillatory responses observed in the models.

This paper presents a successive algorithm for dynamic image segmentation of a gray-level image with an arbitrary number of isolated image regions, using our network model with two- and three-phase oscillatory responses. In our algorithm, the values of system parameters and initial values were determined based on the results of bifurcation analysis [4–7] so that two- and three-phase oscillatory responses can appear. Although the maximum number of image regions to be segmented is three in one processing, all image regions can be segmented by repeating the process. We demonstrate that the algorithm for dynamic image segmentation works for a gray-level image with six isolated image regions.

2. Scheme of Dynamic Image Segmentation

We need a network model consisting of N chaotic neurons and a global inhibitor for an N-pixel input image. As shown in Fig. 1, the N neurons are arranged in a grid so that neurons correspond to pixels in an input image and can connect to neurons in its neighborhood including itself; the global inhibitor connects to all neurons.

The dynamics of the ith neuron with two state variables (x_i, y_i), $i = 1, 2, \ldots, N$ is described as

$$x_i(t+1) = k_f x_i(t) + d_i + C_i(t) \quad (1)$$

$$y_i(t+1) = k_r y_i(t) - \alpha \cdot g\left(x_i(t) + y_i(t), 0\right) + a \quad (2)$$

where t denotes the discrete time. d_i denotes a direct-current input value (DC input value) corresponding to the ith pixel value. C_i represents the sum of excitatory couplings from neurons in its neighborhood including itself and an inhibitory coupling from the global inhibitor. It is described as

$$C_i(t) = \sum_{k \in L_i} \frac{W}{M_i} g(x_k(t) + y_k(t), 0) - W \cdot g(z(t), 0.5), \quad (3)$$

where L_i denotes a set of neurons corresponding to pixels with similar gray levels at the ith pixel and its four-neighborhood. M_i is the number of elements in L_i. The $g(\cdot,\cdot)$ represents the output function of a neuron or a global inhibitor and is described by

$$g(u, \theta) = 1/\left(1 + \exp(-(u-\theta)/\varepsilon)\right). \quad (4)$$

The dynamics of a global inhibitor is described as

$$z(t+1) = \phi \left\{ g\left(\sum_{k=1}^{N} g(x_k(t) + y_k(t), W), 0 \right) - z(t) \right\}. \quad (5)$$

The system parameters except for k_r, ϕ, and d_i, $i = 1, 2, \ldots, N$ were set to $k_f = 0.5$, $\alpha = 4$, $a = 0.5$, $W = 15$, and $\varepsilon = 0.1$ according to Ref. [8].

Neurons corresponding to only pixels with high pixel values can generate oscillatory responses. Therefore, as seen in Fig. 1, segmented images can be outputted based on responses of neurons in a time series.

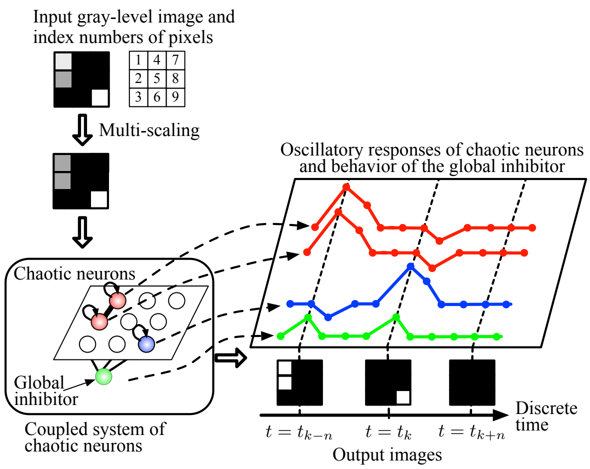

Figure 1: Architecture of our system and scheme of dynamic image segmentation.

To segment an image with n isolated image regions, it requires an n-phase oscillatory response. However, only two- or three-phase oscillatory responses could be generally observed in our system from our preliminary experiments. This indicates that the number of image regions to be segmented using an oscillatory response is up to three.

3. Successive Algorithm

Since the number of image regions to be segmented by an oscillatory response is up to three, we need a successive algorithm using our system to extract all image regions from an image with many image regions. Figure 2 illustrates the flow chart of a successive algorithm we proposed to extract all image regions from an image with n isolated image regions. In a routine of the algorithm, the generation of two- or three-phase oscillatory responses is needed. Our previous studies [5, 6] showed a parameter region in which in-phase oscillatory responses do not occur and two- or three-phase oscillatory responses are always generated for appropriate initial values.

Let us consider the dynamic extraction of image regions from a gray-level image with five isolated image regions in Fig. 3(a). We assumed that the gray levels of pixels in an image region are same. At first, for the input image, the DC-input values of all neurons are assigned according to the values of all pixels. Based on a three-phase oscillatory response, the three segmented images in Fig. 3(b)–(d) are obtained in the first step. The each segmented image becomes an input image for our system in the next step.

In the second step, Figs. 3(e) and 3(f) are made from Fig. 3(b); subsequently, Figs. 3(g) and 3(h) are made from Fig. 3(c). The each segmentation was achieved according to a two-phase oscillatory response. The respective images in Figs. 3(d)–(h) have only one isolated image region. Since a non-oscillatory response, which corresponds to a fixed point, always occurs at the parameter values we set for an image with only one image region, we can obtain black images in Figs. 3(i)–(m). When we have black images in all flows, our algorithm is terminated.

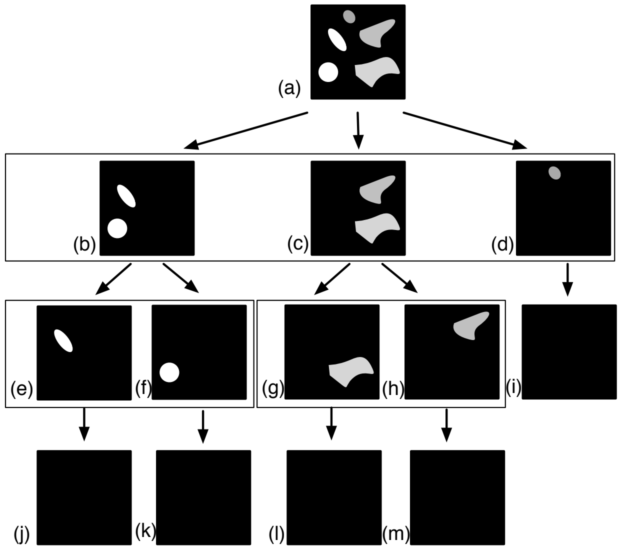

Figure 3: Schematic diagram of dynamic image-region extraction using our algorithm.

4. Experimental Result of Image-Region Extraction

We considered dynamic image-region extraction for (6×6)-pixel a gray-level image with six isolated regions in Fig. 4(a). Based on the results of bifurcation analysis [4–6], we set the unfixed system parameters as $(k_r, \phi) = (0.885, 0.8)$ in which a fixed point or two- or three-phase periodic point appears for appropriate initial values to all chaotic neurons and the global inhibitor. The gray levels of pixels in each image region correspond to DC input values from 1.9 to 2.0 with the intervals of 0.02. In the first step, as seen in Fig. 4(b), the output images were obtained based on a three-phase oscillatory response. In the figure, the images sequentially appeared from the top-left to the bottom-right; their appearances in each line also started from the left. Subsequently, by removing redundant images from the output images in a time series, we picked out the three images in Fig. 4(c). In addition, because the output images were generated based on a three-phase 54-periodic point observed in a reduced model consisting of three neurons and a global inhibitor, the appearance period of each image region was also 54.

In the second step, each picked out image was inputted to our dynamic image segmentation system again. Based on two-phase periodic points, two segmented images were outputted as shown in Fig. 4(d) for every input images in Fig. 4(c). As the results, we finally obtained the six images. Therefore, it was demonstrated that our successive algorithm could dynamically extract all the image regions

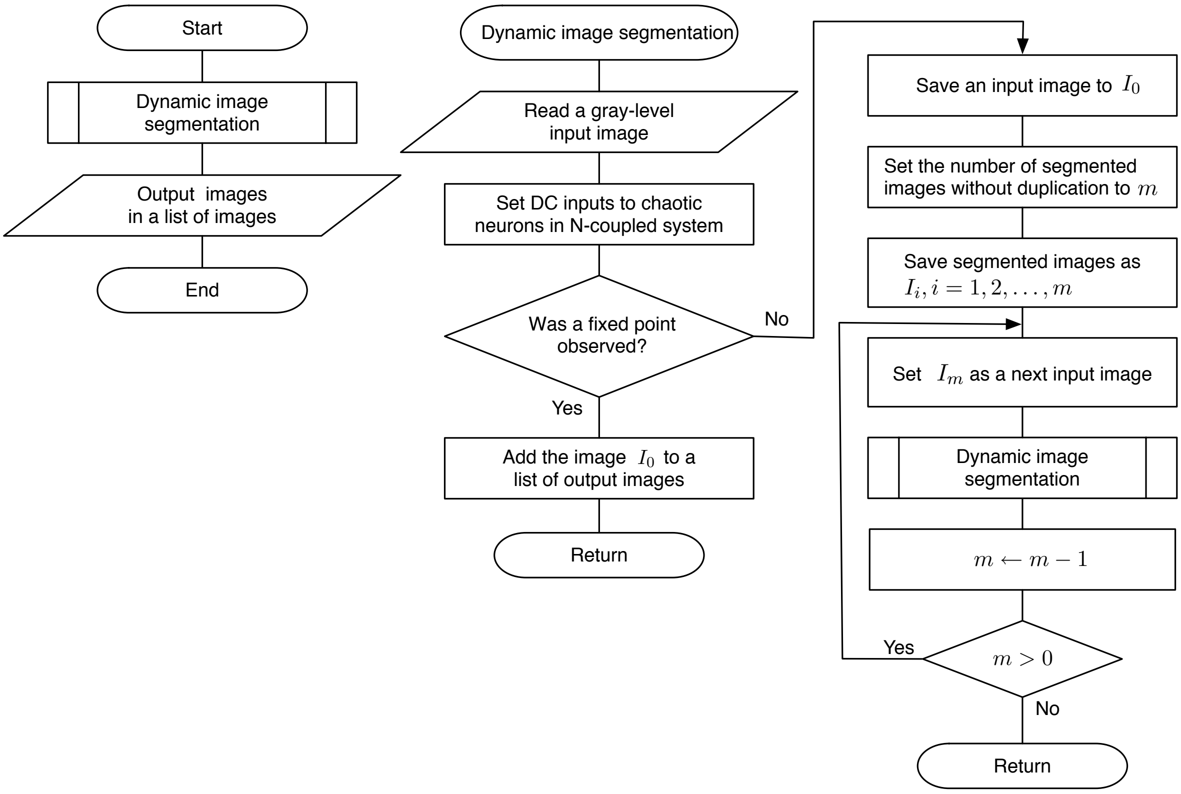

Figure 2: Flow chart of our successive algorithm.

from a gray-level image with six isolated image regions.

5. Concluding Remarks

We presented a successive algorithm using our dynamic image segmentation system to extract all image regions from a gray-level image with any number of isolated regions. We demonstrated that all the image regions in a gray-level image with six isolated image regions were extracted using our algorithm. In this paper, we dealt with the case that the gray levels of pixels in an image region were same. Since the assumption is not satisfied for general gray-level images, we will investigate synchronization phenomena in the responses of neurons corresponding to pixels in a gradational image region.

References

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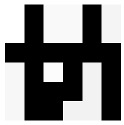
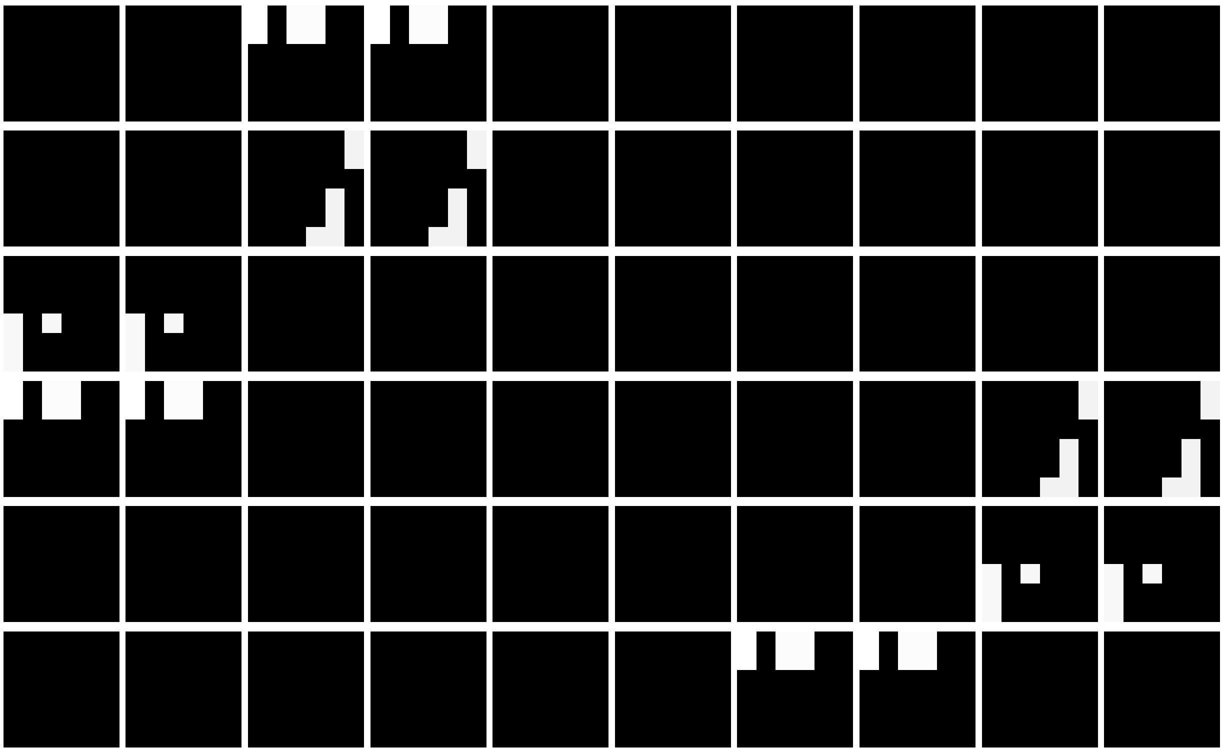
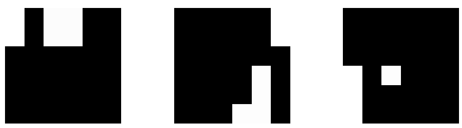


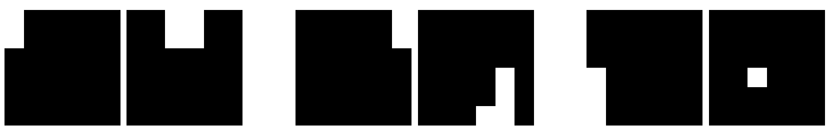
(a) (6×6)-pixel gray-level input image with six isolated regions.



(b) Output images performed by dynamic image segmentation in the first step.



(c) Picked out images from output images in Fig. 4(b).



(d) Picked out images from output images for input images shown in Fig. 4(c) in the second step.

Figure 4: Results of dynamic image-region extraction based on our successive algorithm using our network model.