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Processing visual stimuli using hierarchical spiking neural networks

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Abstract

Based on spiking neuron models and different receptive field models, hierarchical networks are proposed to process visual stimuli, in which multiple overlapped objects are represented by different orientation bars. The main purpose of this paper is to show that hierarchical spiking neural networks are able to segment the objects and bind their pixels to form shapes of objects using local excitatory lateral connections. The presented architecture is based on biologically inspired hierarchical structures. Segmentation is achieved through temporal correlation of neuron activities. The properties of these networks are demonstrated using a series of visual scenes representing different stimuli settings.

Keywords: Hierarchical spiking neural network; Receptive field; Lateral connection; Segmentation

1. Introduction

Biological experimental evidence shows that the primate visual system can achieve high-level visual processing tasks in a very short time of 100–150 ms [11,15,21]. However, it is still unclear how a high-level representation of objects is achieved by neurons in the human brain [22,23,31]. Various neural network models have been proposed to explain how the visual system is able to solve this problem. Knoblauch and Palm [16,17] have proposed a network of three areas (retina, primary visual cortex, and central visual area). Each area is composed of several neuron populations reciprocally connected. The network has been applied to scene segmentation by means of spike synchronization mechanism. A dynamically coupled neural oscillator networks are proposed to segment images in Refs. [2,4,19,26,36]. By means of attention-guided object selection and novelty detection [1], an oscillatory model is proposed to recognize objects by combining consecutive selection of objects and discrimination between new and familiar objects.

A model of self-organizing maps of spiking neurons has been applied in computational modelling of the pattern interaction and orientation maps in the primary visual cortex [5,6,9,18]. Spiking neurons with leaky integrator synapses have been used to model image segmentation and binding by synchronization and desynchronization of neuronal group activity. The model, which is called RF-SLISSOM [5], integrates the spiking leaky integrator model with the RF-LISSOM structure, modelling self-organization and functional dynamics of the visual cortex at a more accurate level than earlier models.

These neural network models can be applied to explain some behaviours of the visual system in the human brain. The spike synchronization network in Refs. [16,17] can be applied to explain how the visual system can perform high-level visual processing tasks. The spiking neural network in Ref. [32] can be applied to explain why the visual system can perform high-level processing tasks in a limited time of 100–150 ms. This model is based on a firing order encoding scheme which is called spike wave, in which neurons are allowed to fire only once during a period. The model can explain how this information embedded in the first wave of spikes generated in the retina can be decoded by post-synaptic neurons, and how it can propagate in a feed-forward way through a simple hierarchical model of the visual system, to implement fast and reliable object recognition. Although to date there has been no

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experimental observation to directly confirm the model, there is also no direct experimental evidence of the contrary. Literature shows that many experimental results tend to favour the hypothesis in the model. Currently most spiking neural network models for segmentation and recognition of objects are based on leaky integrate-and-fire neuron models and the principle of segmentation is based on neural oscillators. In this paper, a conductance-based integrate-and-fire neuron model is employed so that the more biological neuronal behaviours can be reflected in the network models. The receptive field models described in neuroscience [10,15,25] are used to construct spiking neural network model. A new parallel hierarchical network is proposed to simulate visual cortex for segmentation of objects so that the computational efficiency is better than neural oscillators. Another advantage is that the obtained segmentation are stable patterns instead of instantaneous patterns. The simulation results show that not only the network model is able to segment objects with vague stimuli, but also the processing time is consistent with biological system.

Remainder of this paper is organized as follows. In Section 2, the architecture of the hierarchical network is presented. The different receptive field models are used to connect neurons between different levels in the hierarchical spiking neural network. The calculations for the used neuron model and receptive fields are described in detail. Firing rate maps for different neuron arrays are recorded from simulations using a calculation method given in the section. In Section 3, an approach for generation of visual stimuli is described and the stimuli are applied to test the network. The experimental results show that the network is able to segment the objects represented by different orientation bars. In Section 4, lateral connections between neighbouring neurons are introduced in the network. The simulation results show that the network with lateral connections is able to combine pixels to form an object shape more efficiently than the network without lateral connections. In Section 5, a two-neuron structure is proposed to make a decision to determine where is an object and which object overlaps over another object. The STDP learning mechanism is introduced to train neurons in the network. A set of visual stimuli is applied to test this decision-making mechanism. Results are comparable to psychological experiments. Discussions and further study topics are presented in Section 6.

2. Spiking neuron models and hierarchical networks

Visual processing in the cortex is often considered to be a hierarchical building up of various receptive fields [15,18]. Inspired by the hierarchical nature of the primate visual cortex, a hierarchical network of integrate-and-fire neurons (see Fig. 1) is proposed for segmentation of visual stimulus images which consists of two-overlapped objects with different textures represented by orientated bars.

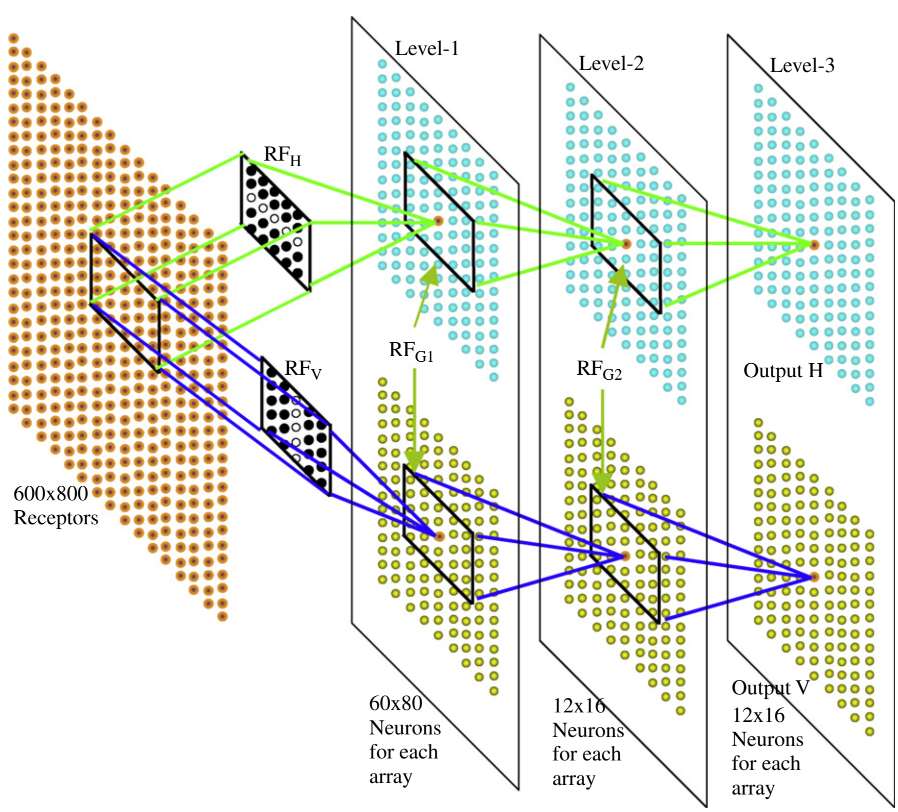

Fig. 1. Architecture of hierarchical spiking neural network: (○) in receptive fields RF_v and RF_H represents excitatory synapses and (●) in receptive fields RF_v and RF_H represents inhibitory synapses.