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Connectivity analyses on self-organized neural competition networks

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Abstract—It was observed spike timing-dependent plasticity (STDP) induced competition among cells, that is called neural competition, when the network with axonal conduction delays exhibited oscillatory activity. Among such competitive cells, specific architecture might be constructed in the network even if uniform random connectivity was assumed under the initial condition. In the present study, it is demonstrated the STDP network organizes specific architecture by characterizing details of the network connectivity with the framework of the complex networks.

1. Introduction

Some theoretical studies reported STDP induced specific connectivity in recurrent networks [1–5]. In addition to these studies, it was shown a fraction of cells in a network obtained many strong connections (winners) and the others failed to do it (losers) by the interplay of three factors: oscillatory network activity, axonal conduction delays, and STDP [6]. This bias of in-coming and out-going connections might give alternative functional roles to the cells in the network. Based on this concept, in the present study, it is analyzed the connectivity among the cells in each population.

2. Materials and Methods

The network model, that was based on the simulator created by Izhikevich [7], used in simulations were same as in Ref. [6]. Since only connections between pairs of excitatory (E) cells were plastic, an E cell network was only focused on in this analysis. The cells were identified as winners (W) if its in-strength was larger than its out-strength and as losers (L) if vise versa (See Ref. [6]).

The network architecture was quantitatively evaluated with the synaptic strength matrix W. Additionally, the basic complex network statistics of the characteristic path length L and the clustering coefficient C were employed as the network quantifiers. There were two candidates of possible weight in the network in the network model: the axonal conduction delays and the synaptic strength. The analysis was, then, conducted with both types of weight. When the weight was the synaptic strength, the global efficiency E [8] was introduced instead of L as a quantifier. The definition of C in Ref. [9] was adopted since the evaluated networks were weighted and directional. For this analysis, connections with a positive value of synaptic weight were considered. The connectivity was evaluated from a network organized via STDP learning for 3,600 s.

3. Results

The following specific architecture emerged when neuron's index was sorted by the descending order of the in-strength within each population. The connections of the W-cell population (WCP) almost died out and the extremely sparse subnetwork was organized. In contrast, the L-cell population (LCP) was relatively dense but surviving connections were on average weak. Remarkably, the strong pathway was established from the WCP to the LCP established, whereas the alternative direction disappeared.

In order to quantify the connectivity, L (or E) and C were calculated. In this analysis, the network evaluation was two steps. In the first step, by treating the STDP network as a digraph, the classical small-world test was conducted. For this, 1,000 random networks were generated from the STDP network by rewiring connections. In the second step, 1,000 weight-shuffled networks were generated from the STDP network by shuffling the weight values among connections.

In all the cases of the digraph and the weighted digraph analyses, the normalized L (or E) and C of the LCP were both unity, indicating the potentiation and the depression of the connections were spatially balanced within the LCP. In contrast to the LCP, $C = 1$ but L was slightly larger then one in the digraph analysis of the WCP. This indicated spikes, on average, mediated via more cells to arrive at another cell.

When the axonal conduction delays were considered as the weight, $L \approx 1.2$ and $C \approx 1.05$. Then, this indicated, within the WCP, it took a long time for the spike transmission and three cells clusters were composed of relatively distant cells. For the weighted digraph, in which the weight was the synaptic strength, $E \approx 0.1$ and $C \approx 1$, indicating there were no pathway to reliably conduct spikes to the other cells and three cell clusters were not tightly linked.

4. Summery

In the present study, I characterized the network connectivity in the two populations organized by STDP. As a result, the winner cells organized a subnetwork that seemed to be inappropriate and inefficient for the information processing. It is unknown what functional roles exist in such a connectivity. Further analyses are needed to clarify this and this will be discussed anywhere else.

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