Application of the Competitive Neural-Network Architecture to Single-Electron Circuit Systems

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Background: Information processing devices in the natural world; e.g., our central nervous systems, can operate correctly under a noisy environment even though the unit elements are sensitive to noises. Recently many researchers have reported noise tolerance on neural networks. Asai *et al.*, for example, reported the properties of the WSA competition on a network [1]. If we apply such tolerance of neural networks to single-electron circuits, we may design novel single-electron LSIs that have such tolerance for device failure or thermal noise. In this report, we propose a neuron circuit with a single-electron circuit, and a neural network with the circuit. We investigate noise and fault tolerance of the proposed network circuits by computer simulations.

Methods: We designed neuromorphic single-electron circuits for a soma, excitable dendrites and axons (Fig. 1). The single-electron dendrites and axons are bidirectional spike transmission devices that consist of a 1-D array of a pair of single-electron oscillators [2], while the soma is unidirectional one. We constructed an inhibitory neural network in which the single-electron neuron circuits are coupled to each other through all-to-all inhibitory connections of equal strength (Fig. 2). Note that the term “inhibition” used here is not a conventional meaning of inhibition. Actually, it is “excitation” to produce efferent spike trains that annihilate afferent-input spike trains.

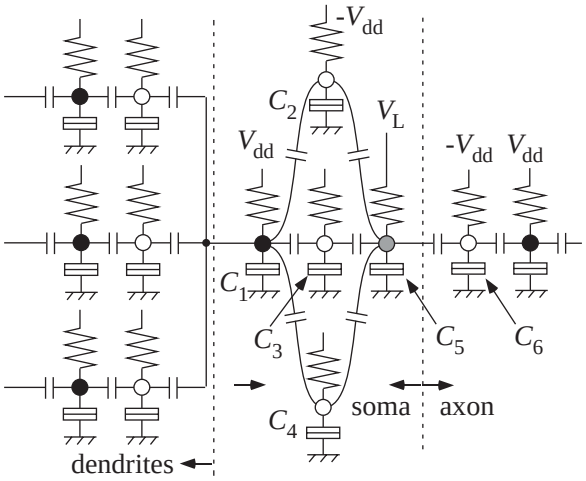

Figure 1 Single-electron neuron circuit

Results: We simulated the inhibitory neural networks with some numbers of neurons. In our networks, we divided the neurons into two groups to make the network operate as a network with the WSA competition. We provided two types of afferent inputs for our network. i) One was encoded as spike timing. ii) The other was encoded as spike frequency. Each neuron receives periodic spikes from the afferents regarding each type of inputs. When the temperature was set at 0 K, each network showed that one group of neurons was “winner” and the other was “loser.” Then, winner means the group reflects afferent inputs. In contrast, loser means the group cannot reflect afferent inputs (Fig. 3). These results indicate that the WTA competition in the time domain or frequency domain was achieved successfully. According to some simulation

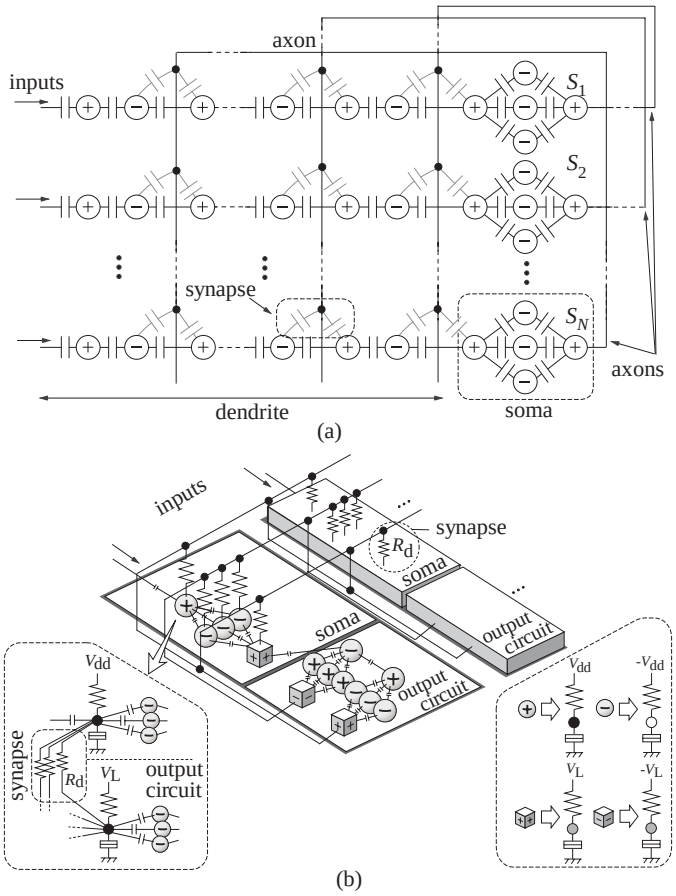

Figure 2 Single-electron inhibitory network for (a) the WSA competition with afferent input i) and (b) with afferent input ii).

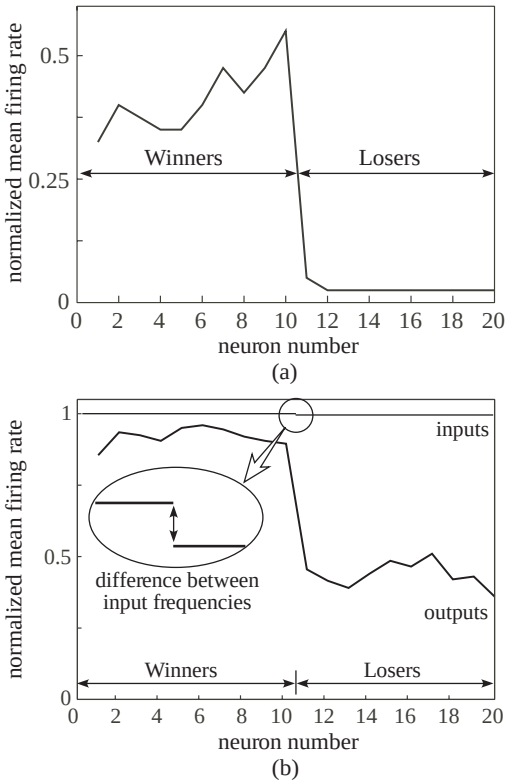

Figure 3 Simulation results: (a) normalized mean firing rate regarding neuron number with afferent input i) and the network shown in Fig. 2 (a), and (b) normalized mean firing rate regarding neuron number with afferent input ii) and the network shown in Fig. 2 (b).

results, our network shows the WSA competition under that the temperature is lower than 1 K.

Conclusions: We observed expected neural competition at quite low temperature (< 1 K). Our networks show tolerance for device failure or thermal noise because of the properties of the WSA competition. Furthermore the networks with the large number of neurons in a group are projected to show more tolerant than with the small number. That means actual single-electron neural networks may be a candidate for novel single-electron LSIs that have tolerance for device failure or thermal noise.

[1] T. Asai, M. Ohtani and H. Yonezu, *IEEE Trans. Neural Networks*, **10** (1999) 1222.

[2] T. Oya, T. Asai, T. Fukui and Y. Amemiya, *Int. J. Unconventional Computing*, **1**(2) (2005), in press.