A Competitive Neural Network with Neuromorphic Single-Electron Circuits

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Background: The winner-take-all (WTA) competition provides a way to select the input of upmost importance, however, it does not suit for device implementation since the selection of a single winner may easily suffer from noises. The winners-share-all (WSA) competition, on the other hand, gives multiple winners in the order of magnitudes of external inputs [1], which can be used to reduce the influence of the noise when multiple winners select the external signal. We here apply this idea to develop robust and fault-tolerant neural architectures for nano-electronic devices, i.e., single-electron quantum devices.

Methods: We designed neuromorphic single-electron circuits for a soma, excitable dendrites and axons. 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. 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.

Results: We simulated the inhibitory neural network with three neurons. Afferent inputs were encoded as spike timing and each neuron receives periodic spikes from the afferents. When the temperature was set at 0 K, only one neuron that received the first afferent input produced output spikes and resting neurons did not produce output spikes, which indicated that WTA competition in the time domain was achieved successfully by having inputs that carried encoding in the form of the spike timing. When the temperature was lower than 1 K and optimal values of supply voltages were used, the circuit exhibited perfect neural competition. As the voltage decreased, the rate decreased as well because low supply voltage prevented spike trains on dendrites.

Conclusions: We observed expected neural competition at quite low temperature (< 1 K). A possible solution to further increase the operation temperature is to leave several winners (WSA competition, not one winner) to represent a wining “cluster”. Although a large number of neurons are required, it will be an appropriate method for constructing fault-tolerant nano-electronics systems.

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

[2] T. Oya, T. Ueno, T. Asai and Amemiya Y.: Proc. Silicon Nanoelectronics Workshop (2003) p. 82-83.