Stochastic Resonance in an Ensemble of Single-Electron Neuromorphic Devices

Ryo Kagaya, Takahide Oya, Tetsuya Asai, and Yoshihito Amemiya

Graduate School of Information Science and Technology, Hokkaido University,
Kita 14, Nishi 9, Kita-ku, Sapporo 060-0814, Japan.
E-mail: kagaya@sapiens-ei.eng.hokudai.ac.jp

Neuromorphic computing based on single-electron circuit technology is gaining prominence because of recent claims about its massively increased computational efficiency and its increasing relevance between computer technology and nanotechnology [1], [2]. Its impact will be strongly felt maximum when single-electron circuits can operate at room temperature, based on fault- and noise-tolerant neural structures. In this paper, inspired by stochastic resonance (SR) in an ensemble of spiking neurons [3], we designed a basic single-electron neural component and examined its statistical results on the network.

A single-electron box, in which a quantum dot lies between a nanoscale tunnel junction with capacitance C and a gate capacitance C_{G} whose order of magnitude is close to that of C, is the simplest tunnel junction circuit [4]. We see a significant similarity between single-electron boxes and conductance-based neuron models, that is the tunnel junction and C_{G} in a single-electron box correspond to a voltage-controlled gate and membrane capacitance in the neuron model, respectively. Furthermore, electron tunneling at the junction results in a sudden voltage change on the quantum dot (therefore it corresponds to a spike generation in neurons) and is easily perturbed by thermal fluctuations, as in real neurons.

Our primary interest here is whether single-electron box neurons can overcome (or utilize) thermal fluctuations, based on the SR described in [3]. In the experiments, the subthreshold spike inputs given at each quantum dot resulted in no electron tunneling (firing) without external noises. We calculated the correlation values (c) between the input and output spikes for the increasing temperature T (increasing magnitude of noise). The results showed characteristic signatures of SR-type behavior: a rapid rise to a peak, and then a decrease at high temperatures. As the number of single-electron neurons (N) increased, the peak value of c increased; e.g., it approached 1.0 when $N = 50$ and $T = 20$ K, even with a given signal-to-threshold distance (not optimized). This implies that a neuromorphic approach based on the SR model is one possible way to construct fault-tolerant computing systems on nanodevices.

References

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