Stochastic Resonance in an Ensemble of Single-Electron Neuromorphic Devices

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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