STOCHASTIC RESONANCE AS AN EMERGENT PROPERTY OF NEURAL NETWORKS

M. Lopes, A. Goltsev, K.-E. Lee, J. Mendes

Department of Physics & I3N, University of Aveiro, 3810-193 Aveiro, Portugal

In biological sensory systems, a presence of noise can actually enhance the detection of weak signals [1]. This phenomenon is called stochastic resonance (SR). It can explain sensitivity of some animals to weak signals in a noisy environment. Sensory neurons are noisy and operate as non-linear, threshold systems. Several models based on non-linear dynamics of single neurons were proposed to explain SR in the brain. However, they neglect interactions between neurons. Here, in contrast to these models, we show that SR can emerge as a collective phenomenon in neural networks. We consider a treatable cortical circuit model composed by stochastic excitatory and inhibitory neurons that form a sparsely connected network. Neurons are bombarded by random spikes representing synaptic noise and random spikes arriving from other areas of the brain. These random spikes are the driving force of collective neural activity in our model. We find that threshold SR appears due to non-linear dynamics near the critical point of a dynamical phase transition to network oscillations. The critical point is actually an emergent threshold in the collective dynamics. It is determined by the noise level, single neuron dynamics, and network parameters. We model experiments of Gluckman et al [2] that observed threshold stochastic resonance in a response of CA1 networks from mammalian brain on periodic electric stimuli. Our numerical results agree with the experiments. Furthermore, we discuss a role of modular structure of sensory systems and show that if modules (represented by large groups of neurons) are in the regime with SR, this kind of network structure strongly enhances reliability of signal detection because it enables to use divergence and averaging that are the key principles used by the central nervous system to reduce irregular fluctuations and detect a signal [3].

[1] K. Wiesenfeld and F. Moss Nature **373**, 33–36 (1995).

[2] B. Gluckman et al. Phys. Rev. Lett. **77**, 4098–4101 (1996).

[3] A. Faisal et al. Nat. Rev. Neurosci. **9**, 292–303 (2008).