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Supra-threshold stochastic resonance in a population of stochastic Hogkin-Huxley neuron models with random ion channel gating

Hiroyuki Mino

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Supra-threshold stochastic resonance (SSR) refers to a phenomenon what an optimally added noise can enhance information transmission when a supra-threshold signal is driven into an array of non-linear systems with threshold [1]. The noise in neurons has been considered to come up from not only randomness of synaptic vesicle secretions (extrinsic fluctuations) but also stochasticity of ion channel gating (intrinsic fluctuations). However, it is still unclear whether and how those fluctuations help enhance information transmission in the case of supra-threshold input signals. The objective of this presentation was to see how randomness of ion channel gating could affect spike firing times and mutual information, and if SSR could be observed or not through computer simulations.

Methods and results

A supra-threshold filtered Poisson process with an intensity of 10 [s^{-1}] was applied into an array of 50 stochastic Hodgkin-Huxley (HH) neuron models possessing stochastic sodium and potassium channels with a patch area of 100, 200, ..., and 700 [um^2]. The stochastic ion channel gating was implemented by the channel-number tracking algorithm [2]. Each output spike train of neuron models was gathered and moving-averaged for calculating the rate of spike trains. Ten kinds of input realizations were applied repeatedly ten times to the array in order to estimate the total and noise entropies of the spike firing rate for calculating mutual information. Figures 1 and 2.

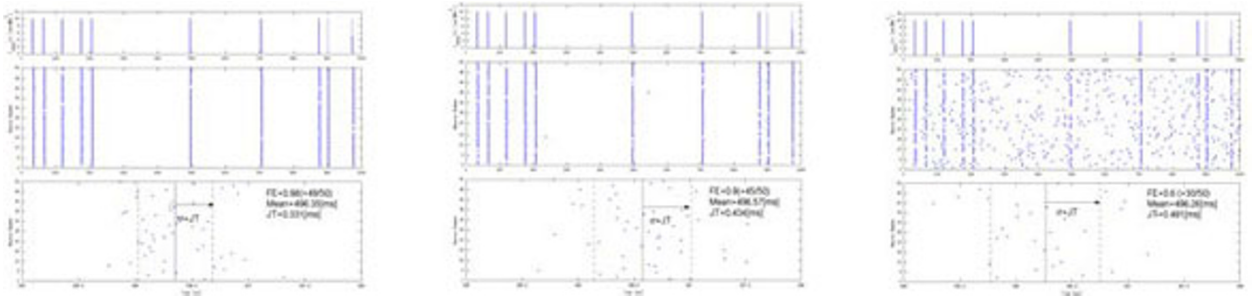

Figure 1 (left). A sample path of supra-threshold input signals (top column), raster plots of spike trains for 50 neuron models (middle column), and raster plots expanded temporally (bottom column) as a function of time at a patch area of 700 [um^2]. The standard deviation of spike firing times (Jitter: JT) was estimated to be 0.331[ms]. (middle). A patch area of 400 [um^2]. (JT=0.434[ms]). Figure 1 (right). A patch area of 100 [um^2]. Spontaneous spike firings are observed, suggesting information lost (JT=0.491[ms]). Decreasing patch areas tended to increase randomness of spike firing times, and eventually to generate spontaneous spike firings.

Correspondence: mino@ieee.org
Department of Electrical and Computer Engineering, Kanto Gakuin University, Yokohama 236-8501, Japan

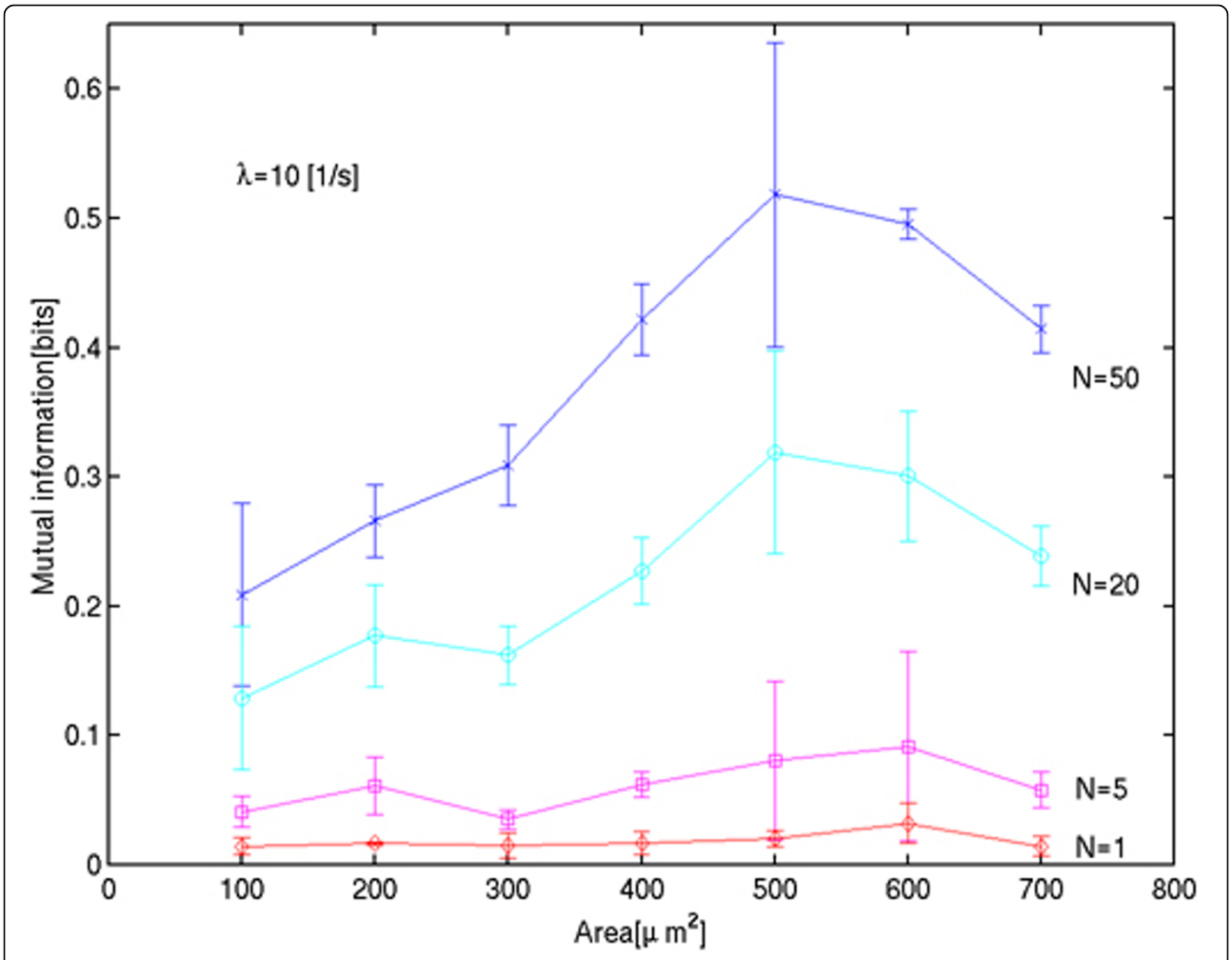

Figure 2 Mutual information as a function of patch area for the number of neuron models (N) being set at 1, 5, 20, and 50. SSR was observed remarkably for N greater than 20, while it did not so for N smaller than 5.

Conclusion

It follows that the mutual information was maximized at an optimal patch size in an array of stochastic HH neuron models, and therefore that SSR was observed in the presence of intrinsic fluctuations. This phenomenon may be aptly called ``intrinsic'' SSR (ISSR). ISSR could play a key role in processing excessive input signals into sensory nervous systems.

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