MULTIMODALITY OF THE INTERSPIKE INTERVAL DISTRIBUTION OF A LEAKY INTEGRATE-AND-FIRE MODEL WITH JUMPS

Laura Sacerdote
Dipartimento di Matematica, Università di Torino
V. Carlo Alberto 10, Torino, Italy
laura.sacerdote@unito.it

Roberta Sirovich
Dipartimento di Matematica, Università di Torino
V. Carlo Alberto 10, Torino, Italy
sirovich@dm.unito.it

Alessandro E.P. Villa
Inserm U318 & Laboratory of Neurobiophysics, University Joseph-Fourier, Grenoble, France
Neuroheuristic Research Group, I.S.I. Foundation, Villa Gualino, 10133 Torino, Italy
Alessandro.Villa@ujf-grenoble.fr - http://www.neuroheuristic.org

ABSTRACT

The time series of neuronal discharges–the spike trains–are generally assumed to carry information about the process that generates the spikes. In Leaky Integrate-and-Fire (LIF) neuromimes the spikes occur whenever the value of the membrane potential is greater than a threshold value. Then, it appears that the dynamics of the membrane potential plays a key-role in determining the dynamics of the spike train. The Ornstein-Uhlenbeck diffusion process is often used to describe the dynamics of the membrane potential. However, a realistic implementation of this model should consider the diffusion limits [1] that turn the Stein's model into the Ornstein-Uhlenbeck one. This could be due to the nonlinear combination of the synaptic inputs deriving from the remote synapses located in the dendritic tree and the inputs from the synapses located in the vicinity of the trigger zone.

A model based on the overlapping of a diffusion process by two jump processes overcomes some of these limitations [2]. Recent works ([3, 4]) show that this model gives rise, with particular tuning of the parameters, to multimodal interspike interval (ISI) distributions. These distributions represent the first-order statistics of the spike trains in the time domain and are often used to describe single unit discharges recorded during extracellular electrophysiological recordings. An alternative interpretation for multimodal ISI distributions is based on the response of a stochastic LIF neuromime to subthreshold periodic stimulus [5, 6] giving rise to Stochastic Resonance.

The current study is aimed to investigate the comparison and the limitations of the two alternative models mentioned above. The subthreshold dynamics of the membrane potential is described by the stochastic process $X = \{X_t; t \geq 0\}$ defined as

$$\begin{aligned} X(t) &= Y(t) + aN^+(t) + iN^-(t) \\ X(0) &= x_0 \end{aligned} \tag{1}$$

where $Y = \{Y(t), t \geq 0\}$ is an Ornstein-Uhlenbeck process and $N^+ = \{N^+(t), t \geq 0\}$ and $N^- = \{N^-(t), t \geq 0\}$ are counting processes independent from each other and from Y, characterized by constant amplitude jump sizes $a > 0$ and $i < 0$ respectively. We consider here Inverse Gaussian (IG) and Exponentially (EXP) interarrival times distributions. The comparison of the influence of noise intensity on the peak heights of the ISI distributionof the jump-diffusion model with ISI distributions based on periodically modulated input raises important questions about the exact role that periodicity could play in a realistic situation.

Keywords: Ornstein-Uhlenbeck diffusion process, jump processes, Interspike interval, subthreshold periodic input.

References

[1] Capocelli, R.M. and Ricciardi, L.M. (1971) Diffusion approximation and first passage time problem for a model neuron, *Kybernetik*, **8**: 214-223.

[2] Musila, M. and Lánský, P. (1991) Genaralized Stein's model for anatomically complex neurons, *BioSystems*, **25**: 179-191.

[3] Sacerdote, L. and Sirovich R. (2003) Multimodality of the interspike interval distribution in a simple jump-diffusion model, to appear on *Scientiae Mathematicae Japonicae*.

[4] Sacerdote, L. and Sirovich R. (2003) A Wiener process with Inverse Gaussian time distributed jumps as a model for neuronal activity, to appear on *5th ECMTB Conference Proceedings*, V. Capasso Editor.

[5] Bulsara, A.R., Elston T.C., Doering C.R., Lowen, S.B. and Lindenberg, K. (1996) Cooperative behavior in periodically driven noisy integrate-fire models of neuronal dynamics, *Physical Rev. E*, **53(4)**: 3958-69.

[6] Shimokawa, T., Pakdaman K. and Sato, S.(1999) Time-scale matching in the response of a leaky integrate-and-fire neuron model to periodic stimulus with additive noise, *Physical Rev. E*, **59(3)**: 3427-43.