Mathematical Biosciences and Engineering

http://www.aimspress.com/journal/MBE

MBE, 16(6): 8214–8216.
DOI: 10.3934/mbe.2019415
Received: 10 September 2019
Accepted: 10 September 2019
Published: 12 September 2019

Preface

Special Issue: Neural Coding 2018

The research in computational neuroscience has a tradition of more than 100 years, marked by the now-classical Lapicque, McCulloch-Pitts or Hodgkin-Huxley neuronal models. During the last three decades the field has experienced a dramatic increase, attracting a number of scientists from different disciplines. New topics have emerged alongside the traditional neuronal modeling approaches and the long-standing problem of neuronal coding is receiving substantial attention. The approach to the problem relies on a wide scope of mathematical and statistical methods applied within the context of individual neurons or their populations, e.g., analysing the crucial role of the stochastic components in neural systems or improving our understanding and inference based on real experimental data.

This Special Issue of *Mathematical Biosciences and Engineering* contains six selected papers based on the contributions presented at the *Neural Coding Workshop 2018* held in Torino, Italy, between September 9 and September 14, 2018. This was the 13th of the successful biennial Neural Coding conference series, after the previous workshops in Prague (1995), Versailles (1997), Osaka (1999), Plymouth (2001), Aulla (2003), Marburg (2005), Montevideo (2007), Tainan (2009), Limassol (2010), Prague (2012), Versailles (2014) and Cologne (2016). Further information on the 2018 workshop, including the book of abstracts and the list of participants, can be found at `http://www.neuralcoding2018.unito.it/`. The selected articles illustrate well the broad methodological scope used in the field and also show how different theoretical models and concepts may relate to each other.

In *"On a stochastic neuronal model integrating correlated inputs"* [1], Ascione and Pirozzi introduce a two-component stochastic differential equation model for a neuron, modeling the membrane potential dynamics through an Ornstein-Uhlenbeck process with colored noise. The interest of introducing a colored noise is motivated as a way to account for the presence of gating variables or by the possibility of injecting colored currents. They distinguish two cases, depending on whether both neuron potential and input are reset after a spike or only the neuron potential is reset. They derive expressions for statistics such as mean, variance and covariance for the unrestricted processes while they resort to obtain some insights into the firing time densities.

Motivated by the recent interest for dichotomous noise in biological systems, and in particular in neuroscience, Di Crescenzo and Travaglino construct a simple stochastic model describing alternating systems driven by state-dependent noise. In *"Probabilistic analysis of systems alternating for state-dependent dichotomous noise"* [2], the authors introduce the generalized telegraph process, i.e. a telegraph process characterized by state-dependent intensity of velocity changes. According to their assumptions, passages through zero state separate consecutive velocity changes. The authors determine formal expressions of forward and backward transition densities resorting to the renewal property of the considered process and obtain analytical expressions for such densities in a special instance. Furthermore, the paper presents some results for the first passage time problem of this process.

Often, mathematical models of information transmission in neural networks resort to diffusion fields where an assembly of a large number of diffusion-coupled systems describes the totality. The most peculiar property of this dynamics is the emerging of oscillations, a well-known phenomenon in the brain. In addition, also damped oscillations sustained by noise (quasi-cyclic systems) give rise to global oscillations. In *"Rapidly forming, slowly evolving, quasi-patterns of quasi-cycle phase synchronization"* [3], Greenwood and Ward investigate a similar system but they introduce a local coupling rather than global. Specifically, their system is such that nearby sub-systems excite each other whereas sub-systems farther away inhibit each other following the so-called Mexican Hat coupling. The paper considers the joint phase and amplitude behavior of the stochastic reaction-coupling system. The authors prove that this type of coupling, if strong enough, gives rise to quasi-cycle phase synchronization and the system exhibits a corresponding spatial pattern. However, for weak coupling, the phase synchronization does not imply a corresponding spatial pattern.

Development of statistical methods for finding spike bursts and other salient features in experimental recordings is required in order to understand neurophysiological data better. In their paper *"Detection and evaluation of bursts in terms of novelty and surprise"* [4], Ito, Lucrezia, Palm and Grün propose a burst-detection method, based on Poisson and gamma-surprise measures, to include a strict significance test which has been missing in previously proposed approaches. They show an application of their method on real interspike-interval data from macaque motor cortex.

The paper *"Mathematical studies of the dynamics of finite-size binary neural networks: A review of recent progress"* [5] by Fasoli and Panzeri reviews existing analytical solutions of the dynamics of small-size neural networks. The paper specializes on networks composed by binary units and focuses on bifurcations of the network dynamics due to the coexistence of mathematical tractability and rich dynamics behavior of these networks. The paper includes both the study of deterministic networks and the case with the noise. The review includes the presentation of specific mathematical techniques developed for the study in presence of noise.

Determining the time when a process crosses a certain time-varying threshold corresponds to the so-called first passage time (FPT) problem. In neuroscience, FPTs are used to model spikes for Leaky Integrate-and-Fire neuronal models. When both the FPT distribution and the underlying process are known, it is of interest to determine the corresponding time-dependent threshold. This is the so-called inverse FPT problem. In *"The Inverse First Passage time method for a two dimensional Ornstein Uhlenbeck process with neuronal application"* [6], Civallero and Zucca propose a numerical method to tackle the inverse FPT problem in the case of a two-dimensional Ornstein-Uhlenbeck process which corresponds to a two compartment model of Leaky Integrate-and-Fire type. The performance of the algorithm is illustrated on inverse Gaussian and gamma FPT distributions (due to their role in neuroscience), together with a discussion on the differences between the two cases and an explanation on how the (heavy or light) tails influence the threshold behavior.

We would like to thank the authors for their invaluable contributions and the anonymous referees who accepted to take their time and share their expertise. Finally, we would like to thank Yang Kuang for supporting us and making this Special Issue possible.

September, 2019

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