# A state space model for bursting neurons

Jacob Østergaard, University of Copenhagen, ostergaard@math.ku.dk
Uri Eden, Boston University, tzvi@math.bu.edu
Mark Kramer, Boston University, mak@math.bu.edu
Susanne Ditlevsen, University of Copenhagen, susanne@math.ku.dk

Bursting is a complex behavior observed in neural spike dynamics that is characterized by a cluster of rapid successive spikes followed by a longer period of quiescence. It is well known that some classical neuron models such as the FitzHugh-Nagumo model [1] and the Morris-Lecar model [2] among others, cannot produce this behavior [3]. The duality of this behavior requires a model that can account for dual time scales to handle a fast and slow subsystem such as the Izhikevich model, [3]. However, while the Izhikevich model is capable of producing bursting behavior in simulations, it is cumbersome to fit model parameters to observed data. In contrast, a statistical model class such as the Generalized Linear Model (GLM) is capable of capturing the features of a variety of spike train behaviors as shown in [6]. The flexibility of the GLM has been illustrated previously by the broad applications of this model class (see [4, 5]). However, the interpretation of a GLM is not always intuitive and in [6] this was indeed the case for a bursting neuron. Although the model was capable of capturing bursting, evident from the estimated intensity, the model itself had a more complex interpretation. In this paper, we show how the GLM can be extended to a State Space GLM (SSGLM) to explicitly account for the dual behavior observed for a bursting neuron. We demonstrate how the model can be fitted to an observed spike train by utilizing a marginalized particle filter to simultaneously decode the state of the neuron (bursting/resting) and estimate history dependent kernels that modulate the baseline firing rate, dependent on the behavior. This leads to a simple statistical model that captures the bursting behavior very well when evaluated by a goodness-of-fit analysis based on the Kolmogorov-Smirnov statistic as in [6].

## References

[1] R. Fitzhugh Impulses and Physiological States in Theoretical Models of Nerve Membrane, *Biophysical Journal* 1 (6) pp. 445-466, 1961.

[2] C. Morris, H. Lecar Voltage oscillations in the barnacle giant muscle fiber, *Biophysical Journal* 35 (1) pp. 193-213, 1981.

[3] E. Izhikevich Which Model to Use for Cortical Spiking Neurons?, *Trans. Neur. Netw.* 15 (5) pp. 1063-1070, 2004.

[4] E. Kass, U.T. Eden, E.N. Brown *Analysis of Neural Data,* Springer, 2014.

[5] P. McCullagh, J.A. Nelder *Generalized Linear Models, Second Edition,* Chapman and Hall/CRC, 1989.

[6] J. Østergaard, M.A. Kramer, U.T. Eden Capturing Spike Variability in Noisy Izhikevich Neurons Using Point Process Generalized Linear Models, *Neural Computation* 30 (1) pp. 125-148, 2018.

[7] O. Cappé E. Moulines, T. Ryden *Inference in Hidden Markov Models,* Springer, 2005.