The Spike Response Model: A Framework to Predict Neuronal Spike Trains

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Abstract. We propose a simple method to map a generic threshold model, namely the Spike Response Model, to artificial data of neuronal activity using a minimal amount of a priori information. Here, data are generated by a detailed mathematical model of neuronal activity. The model neuron is driven with *in-vivo*-like current injected, and we test to which extent it is possible to predict the spike train of the detailed neuron model from that of the Spike Response Model. In particular, we look at the number of spikes correctly predicted within a biologically relevant time window. We find that the Spike Response Model achieves prediction of up to 80% of the spikes with correct timing ($\pm$2ms). Other characteristics of activity, such as mean rate and coefficient of variation of spike trains, are predicted in the correct range as well.

1 Introduction

The successful mathematical description of action potentials by Hodgkin and Huxley has led to a whole series of papers that try to describe in detail the dynamics of various ionic currents. However, precise description of neuronal activity involves an extensive number of variables, which often prevents a clear understanding of the underlying dynamics. Hence, a simplified description is desirable and has been subject to numerous works. The most popular simplified models include the Integrate-and-Fire (IF) model, the FitzHugh-Nagumo model and the Morris-Lecar model (for a review, see [1]).

In this paper, we make use of the Spike Response Model (SRM), a generic threshold model of the IF type. Similar to earlier work [2], we map the SRM to a detailed mathematical model of neuronal activity. But, in contrast of what has been done in [2], we go beyond the classic Hodgkin-Huxley neuron model of the squid axon and use instead a model of a cortical interneuron. Moreover, we use a different mapping technique that could also be applied to real neurons. We show that such a simple technique allows reliable prediction of the spike train of

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a fast-spiking interneuron. Prediction of up to 80% of spikes with correct timing is achieved. The model also quantitatively reproduces the subthreshold behavior of the membrane voltage (see Fig. 1) as well as other characteristics of neuronal activity including mean rate and coefficient of variation (C_V).

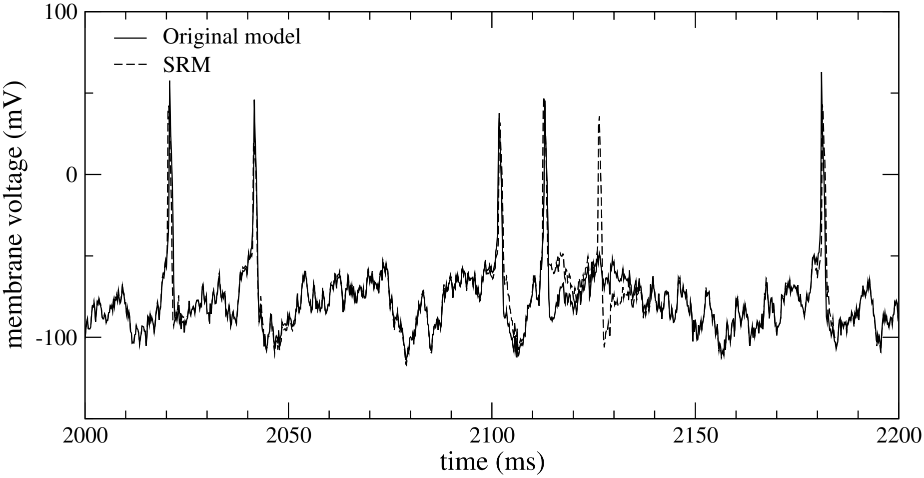

Fig. 1. The prediction of the SRM (dotted line) is compared to the target data (solid line). The model achieves very good prediction of the subthreshold behavior of the membrane voltage. The timing of all the spikes is predicted correctly, except that one extra spike is added at around 2125ms.

2 Model

In this section, we describe the SRM in detail. The state of a neuron is characterized by a single variable u, the membrane voltage of the cell. Let us suppose that the neuron has fired its last spike at time $\hat{t}$. At each time $t > \hat{t}$, the state of the cell is written:

$$u(t) = \eta(t - \hat{t}) + \int_{-\infty}^{+\infty} \kappa(t - \hat{t}, s) I(t - s) ds, \tag{1}$$

The last term accounts for the effect of an external current $I(t)$. The integration process is characterized by the kernel κ (additional external current). The kernel η includes the form of the spike itself as well as the after-hyperpolarization potential (AHP), if needed. As always, we have a threshold condition to account for spike generation:

$$\text{if } u(t) \geq \theta \text{ and } \dot{u}(t) > 0, \text{ then } \hat{t} = t. \tag{2}$$