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Reservoir computing methods for functional identification of biological networks

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The complexity of biological neural networks (BNN) necessitates automated methods for investigating their stimulus-response and structure-dynamics relations. In the present work, we aim at building a functionally equivalent network to a reference BNN. The response signal of the BNN to various input streams is regarded as a characterization of its function. Therefore, we train an artificial system that imitates the input-output relation of the reference BNN under the applied stimulus range. In other words, we take a system identification approach for biological neural networks. Generic network models with fixed random connectivity, recurrent dynamics and fading memory, *reservoirs*, were shown to have a strong separation property on various input streams. Equipped with additional simple readout units, such systems have been successfully applied to several nonlinear modeling and engineering tasks [1].

Here we take a reservoir computing approach for functional identification of simulated random BNNs and neuronal cell cultures [2]. More specifically, we utilize an Echo State Network (ESN) of leaky integrator (non-spiking) neurons with sigmoid activation functions to identify a BNN. We propose algorithms to adapt the ESN parameters for modeling the relations between continuous input streams and multi-unit recordings in BNNs. Our findings indicate that the trained ESNs can imitate the response signal of a reference biological network for several tasks. For instance, we trained an ESN to estimate the instantaneous firing rate (conditional intensity) of a randomly selected neuron in a simulated BNN. Receiver Operating Characteristic (ROC) curve analysis showed that the ESN

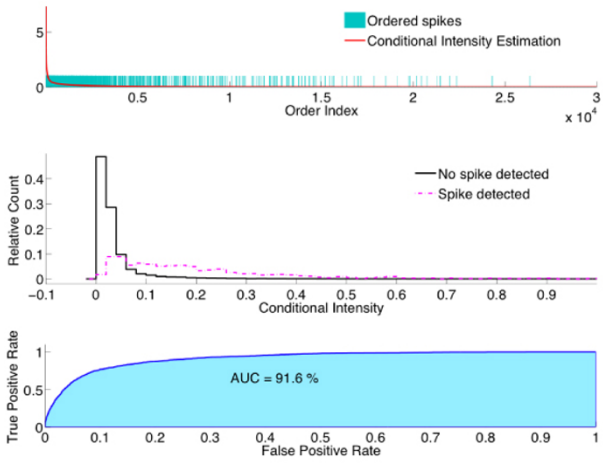

Figure 1
Estimated conditional intensity for a selected biological neural network. Conditional intensity estimations, λ, for all time steps in the testing period are shown in decreasing order (top). A bar is shown if there was indeed a spike observed in the corresponding time step (top). Distributions of conditional intensity for time steps with observed spikes and without spikes (middle). By a varying threshold on λ, true positive rates vs. false positive rates can be calculated (bottom).

can estimate the conditional intensity of this selected neuron (see Figure 1).

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