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Predicting spike activity in neuronal cultures

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Discovering the functional connectivity and modeling the dynamics of neuronal networks is essential to understand neural information processing. Here we focus on neuronal cultures of neocortical tissue, which are closed system in vitro neural networks. Recordings of spontaneous activity from neuronal cultures using multi-electrode array (MEA) technology have revealed that the activity is composed of irregular network-wide bursts of spikes, even in the absence of any external stimulation [1]. Although it is reasonable to think of 'spontaneous' fluctuations which start a burst in these cultures, the spatio-temporal spread of activity is nevertheless generated and shaped by the underlying network. It is then an interesting problem to characterize the underlying synaptic connectivity based on activity measurements. This knowledge will help us understanding how a given anatomical structure generates different activity patterns, and hence would be a significant step towards understanding structure-function relations in the neural networks of the brain.

Activity dynamics in neuronal cultures display both nonlinear and non-stationary characteristics. Noise is another innate property of those networks causing high variability of the activity. The combination of these properties suggests the use of automated adaptive methods, (i.e. machine learning algorithms) to infer appropriate models of the activity dynamics. Specifically, we propose an algorithm to learn a predictive computational model of spontaneous activity in neuronal cultures. The learned model may also be regarded as an abstraction of the underlying effective network connectivity, i.e. its functional connectivity. Although similar functional connectivity models have been described previously [2,3], we take a steepest descent approach to learn functional connectivity, which naturally allows for online learning and, hence, is able to capture network plasticity, i.e. changes in the structure. We use the log-likelihood of point processes as a criterion for optimization. This approach has previously been suggested to analyse neural receptive field plasticity [4]. Here we apply it to multi-channel recordings from neuronal cultures, and demonstrate its use for learning functional connectivity and predicting upcoming spike activity. A ROC curve analysis of our experiments shows that this online approach predicts upcoming spike activity very well.

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