Inferring structure from firing patterns of cortical neural networks

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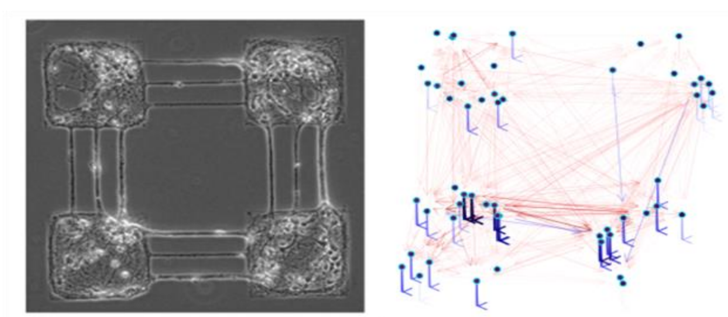
There has been growing interest recently in biological machine learning, specifically the use of cortical brain organoids as processing units for non-linear curve prediction [1], and in using cortical neural networks for playing in a simulated gaming environment [2]. These research activities rely on the assumption that plasticity takes place in cortical neural networks and that, with appropriate stimulation of neurons, the neural network will evolve to a structure capable of performing specific tasks. Revealing the emerging effective cortical network structure is crucial for understanding the mechanism behind these biological learning devices. However, there are few studies using principled methods for inferring the effective structure of cortical neural networks from their spiking patterns. Common techniques in the neuroscience community for identifying effective connections, such as measuring transfer entropy [3], are heavily affected by the sparsity of firing rate, and on setting the appropriate threshold for identifying the existence of connections; both are somewhat heuristic. Techniques for inferring the underlying interaction strengths between neurons have been developed in the statistical physics community, such as mapping neural activities onto the kinetic Ising model with inference using mean-field approximation [4]; however, these approaches are based on unrealistic assumptions, such as that the network is fully connected, and synaptic strengths are homogeneously and Gaussian distributed with small variance. More importantly, a principled technique for identifying excitatory and inhibitory connections, the existence of links between neurons, and take structural considerations into account, is still lacking. In this study, we developed an algorithm for inferring the effective structure of biological neural network using Bayesian techniques, principled machine learning methods and models from statistical physics. Based on binary spiking activity data and the prior distribution we impose, the algorithm allows one to obtain effective directional connectivity, the nature of the neurons (inhibitory or excitatory) as well as the synaptic strength between them. Moreover, based on the inferred structure, one can predict the neural activities using the probabilistic model we developed. We tested our method on both in-silico experiments using neural activity emulator data that fits realistic scenarios, and in-vitro experimental data of mouse cortical neural activities with specific structures. We extracted effective connectivity and the predictions of neural activity show good similarity with the original data. By obtaining reliable in-silico predictions of activities, we can greatly reduce the waiting time for results and improve the efficiency of in-vitro experiments by understanding the physical properties. Additionally, we expect the approach to provide insight and quantitative understanding of learning properties in cortical tissues.



References

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