Efficient methods for sampling spike trains in networks of coupled neurons

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A central goal of neuroscience is to understand the connectivity of neural circuits. ``Functional'' approaches to this connectivity problem rely on statistical analyses of neural activity observed via multielectrode recording or calcium imaging. The biggest challenge for this functional approach is that we can not yet observe the spike trains of all the neurons in any complete neural circuit. Standard functional approaches for connectivity estimation are based on the likelihood of the observed activity given an estimate of the underlying connectivity. Computing this likelihood, however, requires us to integrate out the probability distribution over the activity of all hidden neurons. The very high dimensionality of this latent distribution makes direct integration infeasible.

Monte Carlo approaches have recently been proposed to perform this integration numerically. The key problem is to sample from the conditional distribution of a single spike train, given the activity of the other neurons in the network. Dependencies between neurons are usually relatively weak; however, temporal dependencies within single spike trains are typically strong. We develop several specialized Metropolis-Hastings samplers which take advantage of this dependency structure. These samplers are based on two ideas: 1) an adaptation of fast forward-backward algorithms from the theory of hidden Markov models to take advantage of the local dependencies inherent in spike trains, and 2) a first-order expansion of the conditional likelihood which allows for efficient exact sampling in the limit of weak coupling between neurons. We also demonstrate that these samplers can effectively incorporate noisy fluorescence observations in the context of calcium-sensitive imaging experiments. We quantify the sampling efficiency in a variety of simulated experiments in which the network parameters match data measured in real cortical networks, and also demonstrate that the sampler may be used to deconvolve real calcium imaging data to obtain estimates of underlying spiking activity.