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Inferring spike trains, neural filters, and network circuits from in vivo calcium imaging

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Abstract:
Calcium imaging using two-photon microscopy is quickly gaining traction as the experimental modality of choice for simultaneously observing the activity of a population of in vivo neurons. Unfortunately, even in "ideal" experimental conditions, observations of each neuron are both noisy and intermittent. From this data, one would like the ability to both (i) infer the underlying spike trains or time-varying firing rates, and (ii) fit a model that explains the data. We describe a computational approach based on Sequential Monte Carlo Expectation Maximization (SMC-EM) to solve both these problems in tandem.
Each neuron is modeled as a point process whose firing rate is a function of: (i) a bias current, (ii) a linearly filtered, time-varying, (multidimensional) stimulus, and (iii) a weighted sum of spike history terms from itself and other neurons. The spike histories account for both refractory effects and cross-neural coupling terms. The calcium concentration of the neuron jumps at spike times and then slowly decays. Observations are a noisy and intermittent function of the calcium. Collectively, these dynamics can be described as a discrete-time, continuous-valued, state-space model; an EM framework is natural here, since the spike times are not observed directly and therefore may be treated as "hidden" data. Because the model dynamics are nonlinear, analytic propagation of these distributions is intractable, so SMC algorithms are invoked to approximate these quantities. We demonstrate that for a single model neuron, the parameter estimates converge to the true estimates with a reasonable amount of data. We further show that this approach scales reasonably with increasing number of neurons. Experimental verification is currently in progress. These tools are sufficiently general to apply, potentially, to a wide variety of systems and neural substrates.
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