Prediction of EMG based on neural firing rates using stochastic dynamical operators

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Our goal is to provide a new framework with the theory of stochastic dynamical operators (SDOs) that allows quantitative prediction of the relationship between any two scales of the nervous system during movement. The premise of the SDO theory is that it facilitates analyzing the nonlinear dynamics of neural populations in motor control by providing a mathematical framework where the dynamic effect of populations of neurons can be linearly superimposed to predict motion at a larger scale. The theory is capable of describing the sensory-motor effects of neurons, which is inherently difficult due to the nonlinearity of their dynamics.

As an initial step, we aim to link the firing patterns of interneurons to overt motor behavior in a spinal rhythmic movement. We present preliminary results for validation of this theory with the simulations of a Hodgkin-Huxley spinal network. We use a simulated two-level central pattern generator (CPG) model of a known neural circuit, with 27 populations, which generates locomotor rhythmic activity simulating control of four muscles (Shevtsova et al. 2015). We first generate simulated electromyographic (EMG) signals by filtering the spike trains of motoneuron pools and estimate their individual SDOs using their spiking event times and the changes in the EMG. An SDO stochastically maps the current state of the system into a change in the state. When a neuron fires, its activated SDO updates the probability distribution of EMG, which represents an internal belief of the system about EMG. When multiple neurons fire together and they are only coupled via the system dynamics, we can linearly superimpose their SDOs. Initially, we estimate the SDOs of individual neurons offline and hold them constant during the dynamics. We use the spike count of each neuron in a 40ms time interval before the current time point to scale the strength of its SDO in the prediction of EMG in the next time step.

Using the SDO framework, we are able to predict the time-course of the EMG signal extracted from the extensor motoneuron pool. For prediction generation, we use the superposition of the SDOs of four populations of pattern formation and rhythm generators, primary afferents and Renshaw cells. We are able to regenerate the extensor EMG trajectory for 1000ms, which is the period of the rhythmic movement. The correlation coefficient between the estimated EMG trajectory and the simulated EMG is obtained as 0.996±0.001 (95% CI).

This result is an initial step that demonstrates SDO theory has the potential to describe nonlinear network dynamics that are generated by a simulated neural network with realistic Hodgkin-Huxley models for the neurons. Ongoing research is using this mathematical framework to link between neural dynamics and behavioral variables in frog spinal cord and human basal ganglia.