A spiking neural model of strategy shifting in a simple reaction time task

Trevor Bekolay, Benjamine Liu, Chris Eliasmith, and Mark Laubach

We present a spiking neural circuit model that shifts between two strategies for performing a simple reaction time task. The model is based on the known neuroanatomy of the medial prefrontal cortex (mPFC), and recent behavioural and neural evidence that leads to a strategy shifting hypothesis for response time variability in simple reaction-time (RT) performance. In a simple RT task with two or more foreperiods, subjects prepare the appropriate response and activate that action in response to the triggering cue when it is presented at a relatively short foreperiod. By contrast, when the foreperiod is relatively long or entirely predictable, subjects prepare the appropriate response at the time when they believe the cue will occur. Evidence for these performance strategies have been detected in rodents, primates and human beings.

A key brain region for implementing these control strategies over simple RT performance is the mPFC. Neurons in this brain region show changes in firing rates around the start of trials or fire persistently during the foreperiod of simple RT tasks (Narayanan & Laubach, 2009). mPFC exerts control over the motor system by influencing firing rates in the motor cortex during the foreperiod activity (Narayanan & Laubach, Neuron, 2006).

Here, we describe a neural circuit model that can reproduce the observed activity patterns in the mPFC–motor cortex system and that can exhibit adjustments in the behavioral strategy used on a given trial based on the subject's expected duration of the delay period and the subject's recent success in performing the simple RT task. A neural circuit based on Singh and Eliasmith (2005) is able to track the action state and the time elapsed in the action state. These neuronal ensembles inhibit the prepared action (e.g. lever release) until the predicted time of the trigger stimulus, thus limiting premature responding. Principal component analysis (PCA) on experimentally recorded population activity in the mPFC during the delay period (Narayanan & Laubach, 2009) suggests that the mechanism implementing the time tracking is a double neural integrator. Using this as part of a time-tracking strategy leads to a model that matches behavioral reaction times and neural firing rates in the rodent mPFC.

The mPFC has also been implicated in strategy shifting (e.g. Floresco et al., Behavioural Brain Research, 2008). Since we assume that the time-tracking strategy is also mediated by mPFC, we predict that the activation of this system modulates the cue-responding strategy. The sustained activity of the mPFC after error trials (e.g. Narayanan and Laubach, 2008) also suggests a strategy shift following poor performance.

We propose a neural control system that allows the two strategies to work cooperatively or competitively. This control system is similar to recent large-scale neural simulations requiring complex control (Eliasmith, in press). We show that this control system is general and can be scaled up to more complex tasks easily and within biological parameters.