Temporal integration in a network has been identified as an essential computation for motor control, working memory, and decision making. When presented with a transient input, integrating networks accumulate the information over time and output persistent changes in neuronal firing. Classically, it has been hypothesized that these networks use synaptic feedback to give rise to persistent firing. We recently tested this hypothesis in the oculomotor integrator through inactivation experiments that perturbed feedback. We found deficits in persistent firing, suggesting a critical role for feedback, but these deficits appeared only at times when the inactivated cells would have fired at elevated rates. Thus, we suggested that the traditional model of feedback-based integration should be modified to include the principle that firing rates of integrator neurons must exceed a threshold level before they affect their postsynaptic targets. One way in which thresholds on synaptic inputs may be realized is through the presence of bistable postsynaptic functions. Such bistable elements could arise from active dendritic properties that permit two stable levels of membrane voltage, a depolarized ‘on’ state and a resting ‘off’ state.

To understand how neurons with bistability in the dendrites could be incorporated into a realistic network capable of temporal integration, we have begun to develop a conductance-based network of spiking neurons in which each cell has multiple bistable dendritic compartments. Each compartment contains leak and voltage-gated conductances which combine to yield a N-shaped current-voltage relationship; in the presence of synaptic current, two stable fixed points are present. The soma is modeled as an integrate-and-fire compartment with leak, saccadic, and noise currents, as well as input from the dendrites. Parameters are tuned to yield a threshold-linear relationship between injected current and firing rate as seen experimentally. The connectivity matrix for the network is chosen to be rank one; that is, each dendrite receives input from a particular presynaptic neuron, and each weight equals the product of a unique dendritic gain times a global somatic gain scaling all inputs. Somatic gains and compartmental impedances were constrained by experimental measurements. This procedure leaves, for a system of N dendrites, N free parameters in the determination of the weights. To enable the model to integrate, we implement a tuning procedure for balancing the leak with network and intrinsic feedback. Two key approximations are made. First, we treat the current from a dendritic compartment to the soma as arising from a single effective conductance. Second, we describe somatic responses as rate functions. These two approximations allow us to establish a self-consistency relationship between ideal and realized feedback; minimization of the difference with a constrained least squares fit determines the N free parameters.

The tuned model exhibits multiple fixed points that lie on a line in firing rate state space, with fixation rates in the spiking model close to those predicted from the reduced model. Further, the network shows an insensitivity to small inputs, as indicated by the existence of a threshold value below which external input cannot activate plateau potentials in the dendrites; thus the network remains at a fixed point unless it is perturbed by a sufficiently large input. Ongoing work is focused on making the network fully bilateral, incorporating realistic morphological data, and testing the model with smooth inputs that drive the vestibuloocular reflex. The completed model will match many experimental features and may help explain common mechanisms underlying diverse processes such as motor control, working memory, and decision making.