

Optimal synaptic strategies for different timescales of memory

Subhaneil Lahiri and Surya Ganguli

Systems consolidation suggests that different brain regions are specialized to store memories over different timescales. Similarly, synapses mediating memory have highly complex, diverse molecular signaling pathways, varying across brain regions. This suggests the possibility that synaptic diversity across brain regions may be adapted for different timescales of memory storage. We are left with the fundamental question: what type of molecular synaptic dynamics is suitable for storing memory over any given timescale?

To address this, we systematically analyze an extremely broad class of models where synaptic plasticity is implemented by stochastic transitions between internal functional states of a sub-synaptic molecular network. Such models are essential in navigating stringent tradeoffs between learning and remembering, known as the stability-plasticity dilemma. Previous work (e.g. [Fusi, Drew, Abbott, 2005]) analyzed this tradeoff in models with only one topological structure of transitions between sub-synaptic states. This leaves open the nature of this tradeoff over all possible sub-synaptic networks. Rather than analyze one model, we analyze the space of all possible models and elucidate principles that determine how sub-synaptic network structure can be ideally adapted to the time-scale over which memories are stored. We find that as this timescale increases, initially synapses are forced to grow a chain of internal states with rapid transitions, while at even longer timescales, synapses are further forced to exhibit slow stochastic transitions.

We also discuss the design of synaptic physiology experiments to test our theoretical predictions. We find conventional methods for probing synaptic plasticity cannot discern the relevant synaptic dynamics. Instead we propose new classes of experiments and data-analysis procedures in which more subtle protocols for probing plasticity can yield systems identification of the synaptic dynamics so crucial for storing memories at a particular time-scale.