Linking memories across time via neuronal and dendritic overlaps in model neurons with active dendrites

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Associative memories are believed to be stored in distributed neuronal assemblies through synaptic and intrinsic plasticity. The long-term plasticity of synapses involves the long-term potentiation/depression of synaptic responses, spine growth/elimination, protein synthesis and capture, homeostatic plasticity etc. Synaptic plasticity in excitatory neurons in the cortex, however, takes place primarily in their dendritic regions. The evidence suggests that dendrites can function as autonomous computational[1,2] and plasticity units[2,3]. In addition, dendritic phenomena such as synaptic clustering [1], synaptic tagging and capture [4] and local protein synthesis [3] contribute to different aspects of memory storage.

Based on experimental evidence, we developed a simplified computational model of plasticity that examines the role of dendrites during neuronal and synaptic memory allocation [4]. We use multi-scale modeling to model synaptic processes which span different temporal and spatial scales, such as calcium influx, protein synthesis and delivery, synaptic tagging and homeostasis in order to assess how distinct memories are encoded in a cortical population of neurons. Using the model, we show that memory storage increases the sparsity of population firing, and that this depends on whether the plasticity-related protein synthesis takes place in the soma or at the dendrites. We show that local protein synthesis promotes dendritic synaptic clustering.

We use the model to simulate the behavioral tagging experimental paradigm, in which a strong memory is paired with a weak one. We show that the rescue of the weak memory is dependent on the co-allocation of the two memories in highly overlapping populations of neurons and dendrites, creating clusters of synapses. We additionally show that intrinsic excitability can enhance this co-allocation when the strong memory precedes the weak. Generalizing, we show that increased excitability and synaptic capture both contribute to the co-allocation of related memories, in different ways. Our model suggests that the temporal proximity of memories translates to co-allocation in overlapping neuronal and dendritic populations, indicating the possible roles of synaptic tagging and intrinsic excitability in linking together memories. These neuronal and dendritic overlaps underlie memory linking even in the absence of dendritic spikes, albeit at a very high cost of increased afferent connections, indicating that active dendrites serve as a means for resource savings. Finally, we propose that the same mechanisms can bind together sequential memories, creating memory episodes [5].

References

1. Poirazi, P. & Mel, B.W., 2001. Impact of Active Dendrites and Structural Plasticity on the Memory Capacity of Neural Tissue. , 29, pp.779–796.
2. Branco, T. & Häusser, M., 2010. The single dendritic branch as a fundamental functional unit in the nervous system. Current Opinion in Neurobiology, 20(4), pp.494–502
3. Sutton, M.A. & Schuman, E.M., 2006. Dendritic protein synthesis, synaptic plasticity, and memory. Cell, 127(1), pp.49–58
4. Rogerson, T. et al., 2014. Synaptic tagging during memory allocation. Nature Reviews Neuroscience, 15, pp.157–169
5. Kastellakis G., Silva, A.J., Poirazi, P. Linking memories across time via neuronal and dendritic overlaps in model neurons with active dendrites. Accepted, Cell Reports, Sept.

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