Robust Short-Term Memory without Synaptic Learning

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Whenever an image is flashed briefly before your eyes, or you hear a sudden sound, you are usually able to recall the information presented for a few seconds thereafter.[1] In fact, it is most vivid at first but fades gradually. According to our current understanding of neural networks, memories are stored by strengthening and weakening the appropriate connections (synapses) between neurons.[2] But these biochemical processes take place on a timescale of minutes.[3] Most models of short-term memory get round this problem by assuming that the information in the stimulus is (sometimes inexplicably) already in the brain, which therefore has only to activate the correct pattern.[5] However, this clashes with everyday experience as well as with more rigorous observation.[4] Mechanisms of cellular bistability have also been proposed, such that each neuron has an individual memory.[6] But considering how noisy real neurons are, it seems difficult for these to be robust enough.[7]

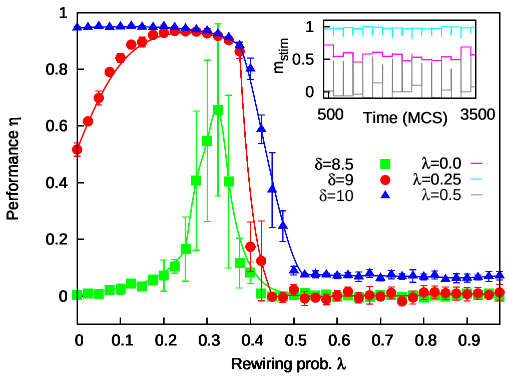

FIG. 1. Performance η against probability of rewiring λ for modular networks, from Monte Carlo (MC) simulations; patterns are "shown" to the system with different intensities δ. For intensities similar to the input the average neuron receives from its neighbours, there is an optimal value of λ (a measure of network modularity). Inset: Typical time series for $\lambda = 0.5$ (bad performance), 0 (intermediate), and 0.25 (near optimal).

Here we suggest an entirely different mechanism – Cluster Reverberation – whereby simple model neurons can store novel information for a short time (a few seconds) without previous learning or individual cellular memory[8] (Fig. 1). This is achieved thanks to metastable states of activity that arise from the clustered nature of the underlying network topology. We show that this mechanism is robust to the kind of model neuron used (which can be very noisy) and to network structure. Furthermore, we predict that forgetting will occur according to quasi-power laws (Fig. 2), in the same way as happens for nonequilibrium magnetic systems or Griffiths phases on networks; and that there will be local synchronization of synaptic inputs.[9] Both these results fit in with experimental findings from psychology[10] and neurobiology.[11]

We conclude by suggesting some *in vitro* and *in vivo* experiments that could be done to test whether the brain does indeed make use of this mechanism.

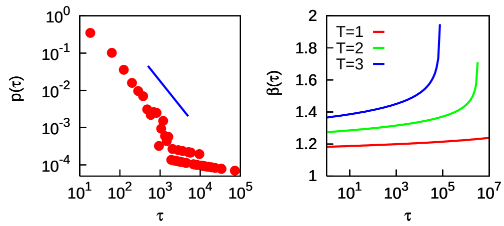

FIG. 2. Left panel: Distribution of escape times τ for $\lambda = 0.25$ and noise $T = 2$, from MC simulations. Slope is for the theoretical prediction at $\tau = 10^3$ ($\beta \simeq 1.35$). Other parameters as in Fig. 1. Right panel: Exponent β of the quasi-power-law distribution $p(\tau)$ as obtained analytically, for noise $T = 1$, 2 and 3.

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