Effect of Alzheimer's disease on the dynamical and computational characteristics of recurrent neural networks

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Recurrent circuits of simple model neurons can provide the substrate for cognitive functions such as perception, memory, association, classification or prediction of dynamical systems [1,2,3]. In Alzheimer's Disease (AD), the impairment of such functions is clearly correlated to synapse loss [4]. So far, the mechanisms underlying this correlation are only poorly understood. Here, we investigate how the loss of excitatory synapses in sparsely connected random networks of spiking excitatory and inhibitory neurons [5] alters their dynamical and computational characteristics. By means of simulations, we study the network response to noisy variations of multidimensional spike-train patterns. We find that the loss of excitatory synapses on excitatory neurons lowers the network's sensitivity to small perturbations of time-varying inputs, reduces its ability to discriminate and improves its generalization capability [6]. A full recovery of the network performance can be achieved by firing-rate homeostasis, implemented by an up-scaling of the remaining excitatory-excitatory synapses. By studying the stability of the linearized network dynamics, we show how homeostasis can simultaneously maintain the network's firing rate, sensitivity to small perturbations and its computational performance.

References:

1. JJ Hopfield: Neural networks and physical systems with emergent collective computational abilities. PNAS 1982, 79(8):2554-2558.
2. H Jaeger, H Haas: Harnessing nonlinearity: predicting chaotic systems and saving energy in wireless communication. Science 2004, 304:78-80.
3. W Maass, T Natschlaegel, H Markram: Real-time computing without stable states: a new framework for neural computation based on perturbations. Neural Comput 2002, 14(11):2531-2560.
4. RD Terry, E Masliah, DP Salmon, N Butters, R DeTeresa, R Hill, LA Hansen, R Katzman: Physical basis of cognitive alterations in Alzheimer's disease: synapse loss is the major correlate of cognitive impairment. Ann Neurol 1991, 30(4):572-80.
5. N Brunel: Dynamics of sparsely connected networks of excitatory and inhibitory spiking neurons. J Comput Neurosci 2000, 8(3):183-208.
6. R Legenstein, W Maass: Edge of chaos and prediction of computational performance for neural circuit models. Neural Netw 2007, 20(3):323-334.

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