Context-dependent representation in recurrent neural networks

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Numerous experimental studies (*e.g.* [1]) investigate how neural representations of a signal depend on its past context. Although synaptic plasticity and adaptation may play a crucial role to shape this dependence, we study here the hypothesis that this dependence upon past context may be also explained by dynamical network effects, in particular due to the recurrent nature of neural networks connectivity. The first step in our study is to introduce and discuss a measure to quantify the dependence of a neural representation upon the past context. This measure is constructed as a ratio between the context sensitivity and the intrinsic variability of the representation. We study this measure in the frawework of random recurrent neural networks driven by external stimuli $u(t)$ [2] :

$$x_i(t+1) = S\left(\sum_{j \to i} W_{ij}\, x_j\,(t) + u_i(t) + \epsilon_i(t)\right)$$

where the variable $x_i(t)$ represents the state of neuron *i* at time *t* In this model, we consider a directed graph *G = (v,E)* with *n* nodes, and an in-degree distribution *P*. On each edge j → i, one assigns a synaptic weight W_{ij} , which are independent centered random variables with finite variances. Developing upon the mean-field theory for such systems, we are able to derive an analytical formula for the measure of context dependence we introduced. In particular, we focus on the impact the level of heterogeneity in the network, by considering the variance of the synaptic weights and the variance of the degree-distribution. This analysis reveals the existence of optimal network heterogenity configurations that maximize the dependence of the neural representation upon past context. For instance, in Figure 1, the dependence on past context displays a maximum as a function of the synaptic weights variance. We further discuss the relationship between this optimality with the concepts of criticality and working memory.

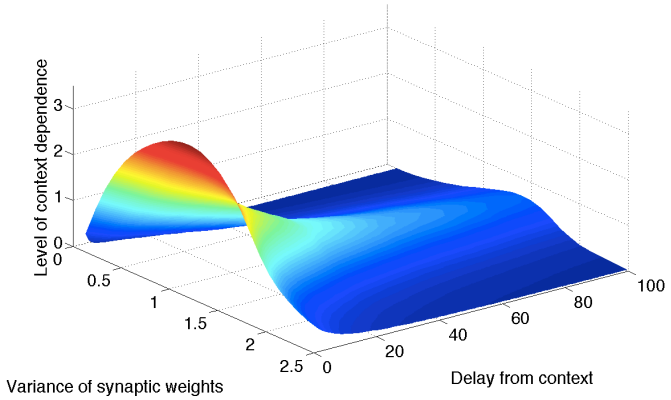

Figure 1 Context-dependent representation capacity, function of the variance of the synaptic weights and the delay since presentation of the context.

References :

[1] Wills, T. J., Lever, C., Cacucci, F., Burgess, N., & O'Keefe, J. (2005). Attractor dynamics in the hippocampal representation of the local environment. *Science*, *308*(5723), 873-876.

[2] Massar, M., & Massar, S. (2013). Mean-field theory of echo state networks.*Physical Review E*, *87*(4), 042809.