Memory and recall of information in neural networks with dynamic synapses

Jorge F. Mejías* and Joaquín J. Torres
Departamento de Electromagnetismo y Física de la Materia
Avda. Fuente Nueva s/n, Universidad de Granada
18071 Granada

In classical neural network models, information is assumed to travel through links between neurons, or synapses. The complex configuration of these links allows the system to exhibit a rich phenomenology. For example, the system can retrieve P previously stored patterns of neural activity, mimicking the associative memory processes which occur in several brain areas, as the hippocampus[1]. The activity patterns are stored in the network via a learning rule, which modifies the strengh of the synapses in a proper way. This modification is slow compared with the dynamics for generation of electrical signals or action potentials (APs) in the individual neurons, thus synapses are considered to have "static"values in these models. However, in the last years much attention has been paid to fast synaptic dynamics and its role in the processing and coding of information in the brain[3,5,6]. In particular, synapses often present fast activity-dependent dynamics, as for example short-term depression (STD) and short-term facilitation (STF), which notably modifies the behaviour of the system when compared with the case of static synapses. While STD implies a temporal reduction of the synaptic strengh for high frequency signals (in order to save synaptic resources needed for information transmission), STF has the opposite effect, since it reflects the increase of calcium ions which occurs after an presynaptic AP, and these ions favours future transmissions. Therefore, the interplay between these two effects may have nontrivial consequences in the system behaviour. Indeed, the inclusion of activity-dependent synapses, or *dynamic synapses*, is responsible of the appearance of switching between activity patterns in neural networks[2], the gain control of signals with different frequencies[3], and improvements on the detection of input correlated APs[4].

In this work, we study the influence of the competition of STD and STF in the capacity of the network to store and retrieve information. We consider a network of N fully connected binary neurons which follow a probabilistic dynamics $\mathrm{Prob}[s_i(t+1)=+1]=\frac{1}{2}(1+\tanh[2\beta(h_i(t)-\theta_i)])$ where s_i represents the state of the neuron i, β takes into account the termal noise in the network, h_i is the local field or the total synaptic current to the neuron i, and θ_i is the neuron firing threshold. To include the dynamic synapses, we consider the following phenomenological model[5]:

$$x_i(t+1)=x_i(t)+\frac{1-x_i(t)}{\tau_{rec}}-u_i(t)x_i(t)s_i(t) \quad (1)$$

$$u_i(t+1)=u_i(t)+\frac{U_{SE}-u_i(t)}{\tau_{fac}}+U_{SE}(1-u_i(t))s_i(t) \quad (2)$$

where x_i is the synaptic resources molar fraction in the presynaptic neuron i, u_i is related to calcium concentration near the synapse, U_{SE} is the minimal release probability of synaptic resources after an AP, and τ_{rec}, τ_{fac} represent time constant for STD and STF processes, respectively. Then, the synaptic current is given by $h_i=\sum_j \omega_{ij}x_j\frac{u_j}{U_{SE}}s_j$, where ω_{ij} represents the static synaptic weights.

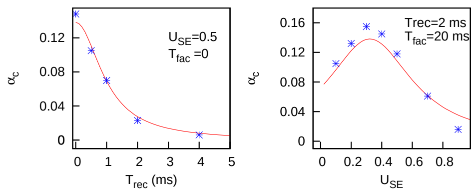

Figura 1. Storage capacity of a neural network with dynamic synapses with STD and STF mechanisms. STD decreases the storage capacity with τ_{rec} whereas STF can enhance it for intermediate values of U_{SE}. The figure also shows how an standard mean-field theory (lines) agrees qualitatively with simulations (data points).

Figure 1 shows the effect of include STD and STF in the storage capacity of the network. This is measured by the maximun number of patterns (relative to the network size, i.e., $\alpha_c=P/N$) which is able to memorize and retrieve eficiently. Our study reflects that STD makes α_c to decrease for large τ_{rec}, while STF allows to restore this number to eventually its maximum value ($\alpha\simeq 0.138$) for relatively small U_{SE}. This results would lead us to think in the positive role of synaptic facilitation in optimal and fast memory retrieval whereas synaptic depression could be more oriented to other tasks concerning, for instance, the dynamical processing of data.

---

* jmejias@onsager.ugr.es

[1] J. J. Hopfield, *Proc. Nat. Acad. Sci. USA* 79 2554-2558 (1982).
[2] J. J. Torres et al., *Neural Comp.* 19 (10) 2739-2755 (2007).
[3] L. F. Abbott et al., *Science* 275 (5297) 220-224 (1997).
[4] J. F. Mejias and J. J. Torres, *J. Comp. Neurosci.*, in press, (2007).
[5] M. V. Tsodyks, *Proc. Nat. Acad. Sci. USA* 94 719-723 (1997).
[6] N. Matsumoto et al., *Neurocomputing* 65-66 571-577 (2005).