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Influence of topology on neural networks based on the recognition of neural signatures

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Abstract. We study the emerging collective dynamics of a neural network model that emits and recognizes neural signatures with different network topologies in order to assess the capacity of a neural network to implement a signature-based information processing strategy. Complex collective dynamics emerge in the proposed model in the presence of stimuli, i.e. specific incoming signatures. Results presented in this paper point out that neural information processing based on the recognition of signal sources is a plausible, flexible and powerful strategy for neural coding.

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1. Introduction

Advances in the study of the nervous system have provided a wealth of new results on the mechanisms of neural information encoding, processing, coordination, generation, execution and learning in different types of biological neural networks [1]. One of these interesting experimental findings is the presence of neural fingerprints in the activity of different neurons [2, 3]. These *neural signatures* are robust and cell-specific interspike interval distributions found in the activity of some bursting neurons. Although still it is unknown if they have any functional meaning, these precise temporal structures may play a critical role in neural information encoding since they allow to identify the signal source. Modeling results show that neural fingerprints identifying each individual cell can be part of a multicoding strategy where the neuron identity ("who") could be transmitted together with the circumstantial message ("what") [4, 5]. Information processing based on the recognition of the origin of individual signals could be a powerful strategy for neural systems that greatly enhances the capacity of these networks.

Theoretical efforts can largely contribute to the understanding of the possible mechanisms used by neural systems to encode and process information based on the recognition of specific neural fingerprints. Nevertheless, from a theoretical point of view, few works study the information processing mechanisms based on the emission and recognition of specific neural signatures. In this work, we investigate (i) the emerging collective dynamics of a neural network model that emits and recognizes signatures and (ii) the influence of the network topology on these dynamics.

2. Neuron and Network models

To model the individual behavior of each network node, we have used a simple binary neuron model with the ability to emit and recognize neural signatures arriving thought its input channels in the form of specific sequences of zeros and ones. The model is based on a preliminary work by Tristán et. al. [6]. Each neuron within the network is connected to other neurons according to different network topologies. These connections (synapses) define the input of the neuron. In addition to these synaptic channels, each neuron has an additional channel to introduce an external stimulus (external signature) in the network. Similarly to the local informational context defined in [7], each neuron in the network has a local transient memory to keep track of the prior inputs received through the different channels and implements the recognition of the incoming signatures by using a set of history-dependent processing rules. When a signature is recognized, the neuron emits the same signature to all its neighbors with probability p_r. If no signature is recognized in a time step, the neuron emits automatically a "spontaneous signature" with probability p_e ($p_e <<< p_r$). After emitting a signature, neurons have a refractory period of t time units during which neither emission nor recognition are made.

In our simulations, we have built two-dimensional networks of $50x50$ such as neurons. Each node is always bidirectionally connected to other eight neurons. Since we are interested in the effect of different network topologies on the self-organizing properties of the network, we study three different kinds of connectivity patterns: regular topologies, random topologies and small-world topologies.

3. Results

The simple neural network model proposed here is able to generate many different complex dynamics.

In the absence of external stimuli, the network evolves to a stationary state, displaying intrinsic dynamics related to the emission of the spontaneous signature. No dependence in the intrinsic dynamics is found on the pattern of connectivity. As expected, the level of spontaneous activity in autonomous networks only depends on the probability p_e.

The collective dynamics of the network changes drastically in the presence of specific neural fingerprints. When external stimuli are injected into the network (both in series and in parallel), this is able to show a fast collective response to the stimuli and new dynamics associated to the incoming signatures emerge. These responses are organized as localized patterns of activity with different spatial organization that coexist and compete during and after the stimulation. The competition among the intrinsic network dynamics (promoted by the probability p_e) and/or the different dynamics induced by incoming stimuli (driven by the probability p_r) is the basis of the signature-based information encoding mechanism. However, we observe that the type of competition (ranging from a winner take-all competition to a winnerless competition) has a strong dependence on the connectivity pattern among neurons. Stimuli induced spatio-temporal patterns can survive for long periods after the end of the stimulation, providing both short-term and long-term memory mechanisms to the network. Figure 1 illustrates some of the different behaviors the network can exhibit depending on the network parameters and the network topology. It shows the evolution of the number of neurons that emit the spontaneous signature (blue traces) and an injected signature (red traces) in two simulations, first without stimuli, then during the stimulation of a randomly chosen neuron with a 5-bit signature (grayed area), and finally without any stimulation again. Top panel is an example of short-term memory network in which the global activity is nearly constant. Bottom panel is an example of long-term memory network in which the external stimulus increases the global activity in the network.

4. Conclusions

In this communication we show that a simple neural network model consisting of neurons/nodes whose main property is its ability to emit and recognize neural signatures can generate different complex collective dynamics in response to external stimuli, i.e. specific incoming fingerprints. The different dynamics generated in response to external stimuli depend on the combination of the

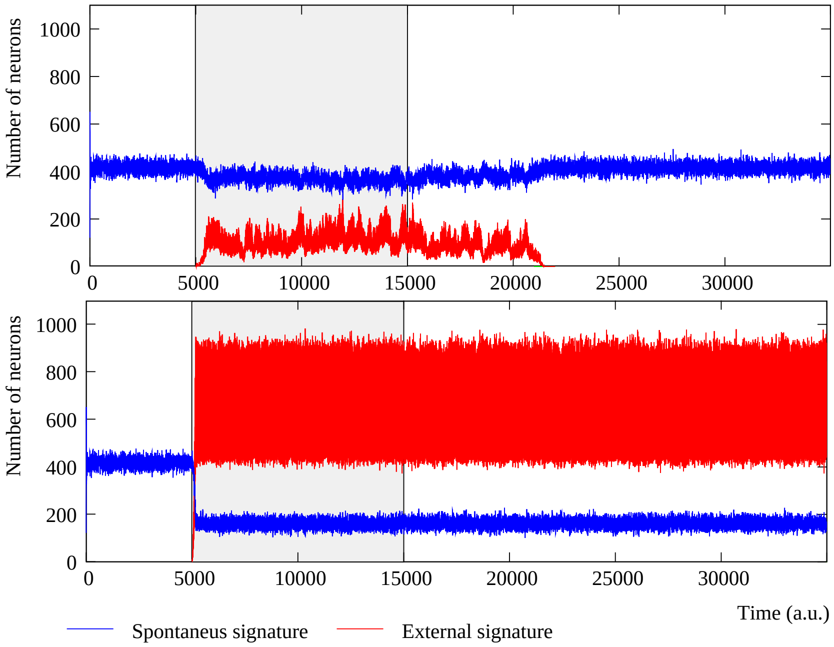

Figure 1: Examples of competing dynamics in the network. More complex dynamics appear in simulations with a greater number of external stimuli.

values of the neuron parameters and on the organization of the connections between neurons. Stimuli are encoded into coexisting patterns of activity that propagates through the network with different spatial organization. Signatures can survive after the stimulation is over, which provides memory mechanisms to the network. The presence of random connections enhances the signature processing and potentiates long-term memory mechanisms. Conversely, regular patterns of connectivity promote short-term memory mechanisms and increase the encoding/storage capacity. These results point out that neural systems could process and encode information efficiently by using neural fingerprints.

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References

[1] M I Rabinovich, P Varona, A I Selverston, and H D I Abarbanel. Dynamical principles in neuroscience. *Reviews of Modern Physics*, 78:1213–1265, 2006.

[2] Attila Szücs, Reynaldo D Pinto, Michail I Rabinovich, Henry D I Abarbanel, and Allen I Selverston. Synaptic modulation of the interspike interval signatures of bursting pyloric neurons. *J Neurophysiol*, 89(3):1363–1377, Mar 2003.

[3] Attila Szücs, Henry D I Abarbanel, Michail I Rabinovich, and Allen I Selverston. Dopamine modulation of spike dynamics in bursting neurons. *Eur J Neurosci*, 21(3):763–772, Feb 2005.

[4] Roberto Latorre, Francisco de Borja Rodríguez, and Pablo Varona. Neural signatures: multiple coding in spiking-bursting cells. *Biol Cybern*, 95(2):169–183, Aug 2006.

[5] R. Latorre, F. de Borja Rodríguez, and P. Varona. Reaction to neural signatures through excitatory synapses in central pattern generator models. *Neurocomputing*, 70(10):1797–1801, 2007.

[6] Antonio Tristán, Francisco de Borja Rodríguez, Eduardo Serrano, and Pablo Varona. Networks of neurons that emit and recognize signatures. *Neurocomputing*, 58-60(0):41 – 46, 2004.

[7] Roberto Latorre, Francisco de Borja Rodríguez, and Pablo Varona. Signature neural networks: definition and application to multidimensional sorting problems. *IEEE Trans Neural Netw*, 22(1):8–23, Jan 2011.