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Comment

Nonlinear effects for the reinforcement of small neural ensembles in high dimensional brain
Comment on "The unreasonable effectiveness of small neural ensembles in high-dimensional brain" by A.N. Gorban, V.A. Makarov, I.Y. Tyukin

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Physics of life requires innovative methods and a global system point of view to establish new strategies to develop appropriate mathematical models for living systems and in particular for brain studies. This principle has been widely expressed since 1944 by Erwin Schrödinger, in his book *What is Life?* [1]. Some key points outlined by Erwin Schrödinger prelude the DNA discover by Crick and Watson.

The considerations that arise reading and studying the communication on "The unreasonable effectiveness of small neural ensembles in high dimensional brain", leads to consider more items that have been the core of a wide discussion in the topic of neuroscience modeling proposed in the last 25 years. Indeed the pioneering studies of Norbert Wiener [2] were aimed at establishing a significant address to the study of brain also taking into account the incoming principles of the information science and of the statistic thermodynamics, thanks to the Williams Gibbs principles [3]. The paper "The unreasonable effectiveness of small neural ensembles in high dimensional brain", strongly and timely remarks some important points regarding a new view of approaching the complexity of the brain signals and modeling taking into account the stochastic separation principles [4] inspiring the study to the approach of simultaneous separation of several uncorrelated information. This allows to get suitable neuronal ensemble in order to improve the possibility for an appropriate and rigorous investigation method of the brain functions.

In this comment, even if the following items are not related to statistics and to the methods of the discussed paper, they are strictly correlated to the efforts that the authors remark in order to make the study of the brain more accessible

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and direct, moreover the problem of ensemble of neurons with reduced order dimension has been approached taking into account some topics of nonlinear dynamics theory. Indeed the problem of model order reduction is a key point in the study of the brain. It is not suitable to consider the brain like a classical high order system, like a complex network or an aggregate of dynamical subsystems that must be controlled where appropriate model order reduction techniques based on optimization algorithm does work in a successful manner to get simplified low order models of the original one. In the case of brain networks or signals the approach must be quite different. The authors look at the Gibbs statistic theory and develop a successful theory based on the principle that “a random point can be separated from a random set by Fisher’s linear discriminants with high probability” this leads from a practical point of view to the “extreme selectivity of single neurons to the information content of high dimensional data”. Indeed the Fisher’s theory is usually adopted in the analysis of EEG data for advanced study and applications [5].

Moreover even if the theory of measure concentration phenomena is considered a quite outstanding approach for brain model complexity approaching, in the following comments some key points items are proposed that allow to collect important information and to look at the network brain model reduction under a particular perspective based on some nonlinear dynamics facts.

The first one regards viewing the ensemble of neurons like resonators. This means that the selectivity of a large amount of units can be simplified to simple macro cells like grandmother cells taking the new idea of considering particular dynamical systems working in a multi jump resonance behavior [6]. This concept is based on the selectivity of nonlinear circuits that respond to sinusoidal inputs in a very appealing manner. In fact complex circuits with more cells have been recently proposed with the aim to emphasize only a set of frequency signals with different response both in frequency increasing behavior and in frequency decreasing behavior. The behavior of that a circuit establishes a frequency hysteresis behavior. Is this new paradigm suitable for studying new memory brain devices based on ensemble of nonlinear resonance units?

The second remark regards the behavior of neurons that is strongly affected by the presence of spontaneous activity that can be considered noise [7,8]. The noise level it has been proved to be related to the organisms evolution [9]. Indeed the role of neuron noise, even if it represents a problem in detecting the correct information, it is considered an important presence in the brain behavior [10]. Indeed it has been proved that stochastic resonance does appear in group of neurons. This means that the signal to noise ratio at the output of the neuron ensemble is greater with respect the input signal to noise ratio. This validated behavior emphasizes that noise in the brain network does not compromise the information, moreover makes ensemble of neurons more robust with respect to the information detection [11]. From a model reduction point of view this means that groups of neurons do work like a unique neuron from a behavior point of view. In fact it has been well proved that stochastic resonance is a feature of the single neuron model.

The third consideration regards the synchronization aspects of the networks in the brain [12]. Synchronization allows us to dealt with high dimensional ensemble of neurons or dynamical units considering the behavior of one only. This means to recollect big ensembles in a one only unit, it is an intrinsic model order reduction method. A trivial example of hidden synchronization that does appear is in the ensemble of signals that are detected by EEG techniques.

Moreover when synchronization does occur? The synchronization condition is very hard to establish, moreover also two real facts must be taken into account. In neuronal networks, synchronization is in some sense encouraged by diversity [13] also in devices with chaotic behavior like many neurons. In more experiments it has been proved both experimentally and numerically that the phenomenon is achieved also thanks to the noise and to the high number of units. More units more easy does appear to achieve the synchronization. Therefore very high number of ensemble thanks to the synchronization principle can be view as a one only particular ensemble. The wide generalization of this aspect is related to the particular capabilities of the brain to create patterns [14] and to generate self organization phenomena. Indeed this last aspect reinforces a new principle that is related to the imperfection concept. Indeed an ideal system does not work well as not ideal ones. Therefore in the brain ensemble the role of imperfection [15] can be view as an added value instead of a negative ingredient in the system behavior.

The model order reduction for brain networks is an appealing problem moreover it must be considered taking into account more strategies. In my opinion the statistic techniques based on Gibbs ideas and the stochastic separation theory coupled to advanced experimental based nonlinear dynamics techniques can give further important answers both to deal with brain signals data processing and to design innovative learning algorithms.

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