SYNCHRONOUS CHAOS AND ERGODICITY BREAKING IN RANDOM NEURAL NETWORKS

Carles Martorell,[1,*] Rubén Calvo,[2] Adrián Roig,[2] Alessia Annibale,[3] and Miguel A. Muñoz[2]

[1]*Department of Electromagnetim and Physics of the Matter, Universidad de Granada, Spain*
[2]*Universidad de Granada, Spain*
[3]*King's College London, UK*

The Sompolinsky–Crisanti–Sommers (SCS) model is a paradigmatic framework for studying chaos in random recurrent neural networks [1]. In its classical form, with perfectly balanced synaptic couplings, it displays only two dynamical regimes: a quiescent state and asynchronous chaos (AC), where activity fluctuates strongly but averages to zero at the population level. We analyze an extended version of the model that breaks this balance [2], revealing a much richer phase diagram. Alongside the classical phases, two novel regimes emerge: a persistent-activity (PA) phase, where neurons freeze into stable states, and a synchronous chaotic (SC) phase, where activity remains chaotic but develops a non-zero mean and long-lasting correlations. This SC phase is characterized by spontaneous symmetry breaking and ergodicity loss, features that parallel the behavior of spin glasses. Remarkably, the resulting phase diagram mirrors that of the Sherrington–Kirkpatrick model, with the SC phase corresponding to the onset of replica-symmetry breaking [3, 4]. These findings highlight a deep analogy between disordered neural networks and glassy systems, offering a unified perspective on complexity in dynamical and disordered systems.

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* carlesma@ugr.es