Beyond equilibrium: revealing non-equilibrium dynamics of brain states

Tomas Berjaga-Buisan [1], Juan Manuel-Monti [2,3], Yonatan Sanz-Perl [1,4] and Gustavo Deco [1,5]

[1] Center for Brain and Cognition (CBC), Department of Information Technologies and Communications (DTIC), Pompeu Fabra University, Barcelona, Spain
[2] Instituto de Fisica Rosario CONICET-UNR, Rosario, Argentina
[3] Laboratorio de Colisiones Atomicas, FCEIA, Universidad Nacional de Rosario, Rosario, Argentina
[4] Physics Department, University of Buenos Aires, and Buenos Aires Physics Institute, Argentina
[5] Institucio Catalana de la Recerca i Estudis Avançats (ICREA), Barcelona, Spain

Abstract: Consciousness assessment in the clinics still relies mainly on the patient's ability to interact with the environment and motor functioning. However, as an absence of behavioral signs cannot be considered proof of the absence of consciousness, clinical consciousness evaluation represents a fundamental shortcoming. The search for reliable and objective methods that do not depend on the lack of responsiveness has been increasing. The Perturbational Complexity Index (PCI) is the most promising method developed to date, but, despite its promising and accurate results, it is associated with many technical and clinical problems. In fact, it needs transcranial magnetic stimulation (TMS) for its calculation. Hence, there are notable ethical concerns as it interferes with brain excitability and could even lead to seizure induction or syncope. Moreover, despite being a promising index, there is no mechanistic explanation of its functioning. To address this issues, as the brain is a nonequilibrium system whose dynamics change in different states, we introduce a thermodynamic formalism based on the off-equilibrium extension of the fluctuation-dissipation theorem (FDT) in combination with a whole-brain model fitted to empirical neuroimaging data. Results show that the violations of the FDT could capture the deviations from equilibrium and correlate with the PCI metric, therefore, explaining that system dissipation implies the emergence of complexity patterns due to the asymmetry in brain connectivity. Overall, this framework seems promising for consciousness assessment as it discriminates different brain states without the need for in vivo perturbations and provides a mechanistic explanation based on thermodynamics for those previously successful and promising indexes of consciousness.