Scale-free dynamics of brain networks: from self-organization to synchronization, oscillations and neutral theory.

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The brain of mammalians, including humans, have the remarkable property of being endogenously active even in the absence of tasks or stimuli. In vivo and in vitro experiments at different resolution scales –employing diverse experimental techniques– consistently reveal the existence of intermittent outbursts of electro-chemical activity that propagate through neural networks in the form of "avalanches". Such neuronal avalanches have sizes and durations distributed as power laws, obey finite size scaling, exhibit long-range correlations and other characteristic features of critical dynamics. These observations have elicited enthusiasm and attracted much interest among theoreticians, who took them as possible empirical evidence that some aspects of living systems (or parts or groups of them) could extract important functional benefits from operating at the edge of a continuous phase transition between two radically different phases, order and disorder. Criticality has been claimed to provided such systems with large susceptibility, huge dynamics ranges, large information processing and storing power, optimal computational capabilities, etc.

In this talk I will briefly review the state of the art in this research area and discuss possible alternative and/or complementary explanations to criticality for the empirically observed scale-free avalanches of neuronal activity. In particular, I will introduce two novel concepts in the field: self-organized bistability (SOB) which naturally extends the idea of self-organized criticality (SOC) to discontinuous phase transitions, and the neutral theory of neural dynamics – that borrows from important developments in molecular and population genetics– which explains the marginal stability of coexisting patterns of activity. Both of these concepts shed light on the nature of neural dynamics and open new perspectives and novel research lines in this fascinating field, whose ultimate goal is to undertand how the amazingly complex collective behavior of the brain can possibly emerge from its underlying network of neurons and plastic synapses, constituting an archetypical statmech problem.