Global control of attractor switches in large-scale brain dynamics

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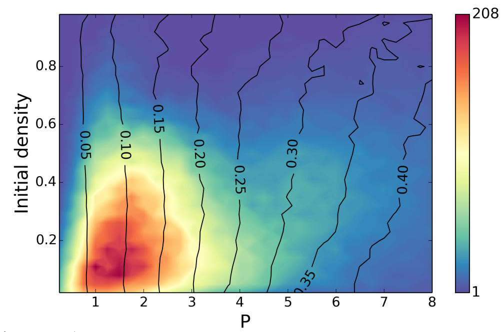

Figure 1: Example attractors count in function of the scaling factor P and the initial density f_0. The black lines are isodensity lines corresponding to the attractors average densities.

Diffusion Tensor Imaging allows to reconstruct the brain connectivity at large-scale, forming a network of interactions named the "Connectome" [1]. Dynamical models of brain activity use the connectome couplings to unveil the determinants of the large-scale brain dynamics, as observed in electro-physiology or functional imagery signals. They rely on simplifying assumptions that reduce the populations activity in few "neural mass" state variables. The Fokker-Planck equation allows to represent the stationary distribution of activities at the network level, depending on a noise ("temperature") parameter that can be adjusted to fit the data. However, the many non-stationary behaviors observed in the physiological signals are difficult to handle in such models. One question at stake is for instance the anomalous scaling of the signal variance when passing from short (100-500 ms) to long (10-20 minutes) temporal ranges [2]. Those anomalies are interpreted as a signature of criticality, as observed in spin-glass systems near the critical temperature for instance [3].

Our approach to nonstationarity relies on a thorough evaluation of fixed-point multistability in Connectome-based deterministic dynamical systems. Several variants of a deterministic neural mass model, including a local or global threshold adaptation, inspired from the "graded-response" Hopfield model [4], are used. The resulting multistability maps show non-monotonous transitions from single stability to multiple stability (see Figure 1). Consistently with [5], regions of maximal entropy are identified near the bifurcation line. The number of attractors however exceeds by several orders the numbers reported so far in previous studies. A clustering analysis of the attractors empirical distributions moreover identifies spatially-segregated components, sharing similarities with the fMRI independent components observed in the "resting state" condition [6].

When noise in introduced in the dynamics, a temporally multistable behavior is obtained (with alternating metastable attractors visited along the same time course) in a wide range of the parameter space. Noise however causes a large proportion of attractors to vanish and become invisible, leaving space to a much smaller attractor sets, including trivial attractors like the "Up" (full brain activation) and "Down" (full brain deactivation) sets. Only the model with a central adaptive threshold, imposing stable density across time, provides a condition where no tendency toward overactivation or extinction is observed. The multistable behavior is obtained on a large parameter range, but the best fit with the ultra-slow functional connectivity dynamics, as observed in the BOLD time courses, is obtained at the edge of multistability, a parameter region that also corresponds to the highest entropy of the attractors distribution. The general conclusion is the importance of the noise-free dynamics in analyzing the attractors landscape, for identifying high-multistability/high entropy parameter regions that both fit with the most physiological distributions of activity, and the most relevant time courses in the noisy condition.

References

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