A control-theoretic framework to understand how structural brain networks can flexibly support various functional states

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ABSTRACT

Understanding the interplay between the anatomical structure and the functional activity of the human brain is a central challenge in neuroscience. In particular, how a single anatomical architecture can support multiple activity patterns corresponding to different cognitive states remains poorly understood. Here, we adopt a network approach combined with a dynamical framework to address this question.

First, we define a linear dynamics on the structural brain network and we introduce the concept of "dynamical signature" of a node in this network. Then, we demonstrate how the associated controllability Gramian, computed with respect to a particular set of input nodes, encodes the pairwise similarity between the dynamical signatures of the nodes. Next, we show that this controllability Gramian is positively correlated with functional brain networks, indicating that nodes having similar dynamical signatures are likely to be functionally connected.

We employed MRI data from the Human Connectome Project to build one structural brain network, one resting-state functional network and seven task-based functional networks corresponding to different cognitive states. Using a genetic algorithm, we identified the "optimal" set of input nodes associated to each functional network. Our preliminary results show that 1) different input sets are associated with different tasks, 2) some nodes are selected as inputs across all states, thereby forming a "core" control structure and 3) these nodes display a high modal controllability, a topological property identifying nodes that are able to steer the system towards hard-to-reach states. For some tasks, we also draw a parallel between the identified input nodes and results previously reported in the literature on cognitive control. We finish by discussing the limitations of this approach, and the potential future extensions.