Modular organization of resting state functional connectivity networks: breaking the resolution limit by Surprise

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Background: The modular organization of resting state brain networks has been widely investigated using graph theoretical approaches. Recently, it has been demonstrated that graph partitioning methods based on the maximization of global fitness functions, like Newman’s Modularity, suffer from a resolution limit, as they fail to detect modules that are smaller than a scale determined by the size of the entire network. The resolution limit prevents detection of important details of the brain modular structure, thus hampering the ability to appreciate differences between networks and to assess the topological roles of nodes.

Methods: Here, we show that Surprise, a recently proposed binary fitness function based on probability theory behaves like a resolution-limit-free method [1]. We propose an extension of Surprise to weighted networks, and heuristics for its optimization [2]. We benchmark Surprise against widely applied algorithms, and quantitatively assess its performance in synthetic correlation networks with different levels of noise, and in human resting state functional connectivity data.

Results: In synthetic networks, Surprise shows better sensitivity and specificity in the detection of ground-truth structures, particularly in the presence of noise and variability such as those observed in experimental functional MRI data. Surprise maximization in human resting state networks reveals the presence of a rich structure of modules with heterogeneous size distribution undetectable by current methods. Moreover, Surprise leads to different, more accurate classification of the network’s connector hubs, the elements that integrate the brain modules into a cohesive structure.

Conclusions: Our results indicate that the resolution limit may have substantially affected previous analyses of brain connectivity networks. Surprise represents a promising alternative to current methods, and demonstrates the presence of functional modules of very different sizes in resting state networks. This calls for a revisitiation of some of the current models of brain modular organization.

[2] Nicolini C., Bordier C. and Bifone A. “Modular organization of weighted brain connectivity networks beyond the resolution limit” (submitted)