Optimal navigability of weighted human brain connectomes in physical space

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Historically, brain network communication has focused on optimal routing, which proposes that information travels through topological shortest paths. However, this approach requires each element of the system to have full knowledge of the network [1]. Alternatively, more decentralized routing protocols have been proposed. One of these methods is greedy routing, which is guided by a local rule that sends information to the connected region closest in distance to a desired destination [2,3].

In this work, we introduce a framework to explore decentralized routing protocols that combine the weighted topology of the human connectome and its spatial embedding. We explored a continuous spectrum of stochastic routing protocols, having the greedy routing strategy and a weight-biased random walk at the opposite extremes, on two cohorts of real human connectome networks.

In our framework, messages are preferentially sent along paths with larger connection weights and to nodes closer in space to the target node. We studied two standard metrics widely employed to assess the efficiency of greedy routing navigation: the success rate –proportion of paths that reach the target successfully– and the average stretch –ratio between the number of links in the path and the number of links in the topological shortest path, averaged over all successful paths.

We found that there is an intermediate region in this spectrum in which connectomes become maximally navigable, achieving full communication efficiency. Moreover, we found that in this region weights, topology and distances are coupled in such a way that information transmission not only is maximally efficient but also robust even under severe perturbation.

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