Is the Brain a Resource Discovery Network?

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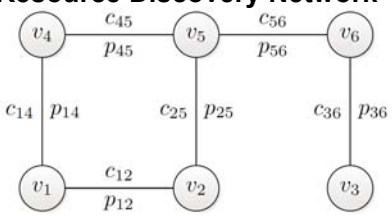
Summary

The objective of this work is to test the hypothesis that the brain network statics and dynamics, namely the structural and functional connectomes, are consistent with a Resource Discovery Network (RDN). A RDN is a probabilistic network in which agents follow paths in the graph, searching for resources. Practically, a RDN can be viewed as the road network along with searching agents, e.g. taxi/Uber-drivers searching for customers. Each edge in the network has a traversal cost, and a probability of finding the resource on, or close to it. The objective of an agent is to find a resource at minimum (expected) cost. In the brain, the agents are communication signals, and a resource may be a subgraph of the connectome with a certain level/pattern of activity, or a similar object.

If the brain is a RDN, it will contribute to the understanding of neural coding. Specifically, this will indicate that codes are formed by a process of search and discovery on the structural connectome (SC).

To test our hypothesis, we use the structural connectome to construct the network, and then take the probability of each edge from the FC. Then we evaluate the error of four increasingly accurate search algorithms, starting with a Random Walk and ending with the decision-theory ([2]) based Expected Cost Minimization algorithm introduced in [1]. The error of a search algorithm SA is computed as follows. For each pair of nodes v and w that are not necessarily neighbors, we compute f(v,w) which is the probability that a search using SA and starting from v, ends at w. Then the error of SA is the sum of $|f(v,w) - |FC(v,w)||$ over all pairs of nodes v and w. In other words, the FC serves as the ground truth. The hypothesis is verified if algorithm error decreases as its expected cost decreases.

Resource Discovery Network

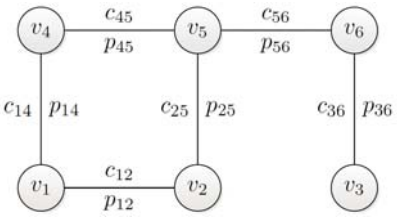


Each edge has a cost and a probability

Cost of traversing the edge e_{ij}: c_{ij}

Probability of finding a resource on e_{ij}: p_{ij}

Taxi driver search for a customer modeled as Resource Discovery Network



Cost of traversing the edge e_{ij}: Time to traverse the edge

Probability of finding a resource on e_{ij}: Probability of finding a customer on e_{ij}

Taxi driver should search along a **path of minimum expected cost**

Could neural coding be explained by a RDN Search?

Resources: neuronal configurations with some properties

Signals search for resources in the brain network

Plan to test hypothesis that brain is a RDN

Based on Structural Connectome (and part of Functional Connectome) generate an RDN

Check if increasingly sophisticated RDN search algorithms get closer to ground truth (remaining part of Functional connectome)

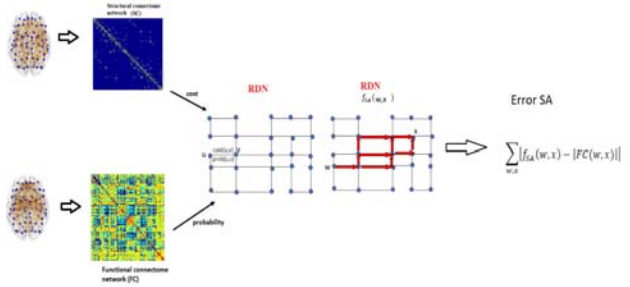


Figure: Verifying whether the brain corresponds to a Resource Discovery Network. First, the structural connectome and selected entries in the functional connectome are mapped as a graph with costs and probabilities on the edges. Then the error of a Search Algorithm SA is calculated as follows: 1. for each pair of nodes compute the error as the difference between the ground truth represented by the FC, and the SA probability for the node-pair; 2. Sum the error over all possible pairs. The hypothesis is verified if the error of a search algorithm decreases as the algorithm gets closer to computing a search of minimum expected cost.

Algorithms evaluated: Demonstration of move at a vertex

Single step look-ahead:

Random Walk

Greedy

Smart Greedy

Multistep look-ahead:

Expected Cost Minimization :

Find a path of minimum expected cost;

Move at an intersection depends on rest of network

Proximity of algorithm SA to ground truth

For each pair of nodes v and w: Compute f(v,w)= the probability that a search using SA starting from v ends at w.

$$ErrorSA = \frac{2\left(\sum_{v,w}\left|f(v,w) - |FC(v,w)|\right|\right)}{\mathrm{n}(\mathrm{n}-1)}$$

Hypothesis verification

- SA_1 Random Walk
- SA_2 Greedy
- SA_3 Smart Greedy
- SA_4 Expected Cost Minimization

Hypothesis is refuted if some $ErrorSA_i - ErrorSA_{i-1}$ is positive

Experimental verification: in progress

Data used is the 2514 node parcellation in [3].

References

1. Q. Guo, O. Wolfson, "Probabilistic spatio-temporal resource search", Geoinformatica, Springer, Nov. 2016, pp. 1-29.
2. S. Russell, P. Norvig, Artificial Intelligence: A Modern Approach, 3rd edn. Prentice Hall, 2010.
3. Diez. Ibai, Bonifazi. Paolo, Escudero. Iñaki, Mateos. Beatriz, Muñoz. Miguel A, Stramaglia. Sebastiano, Cortes. Jesus M ; A novel brain partition highlights the modular skeleton shared by structure and function, Scientific Reports **5**, Article number: 10532 (2015)