Edge functional connectivity reveals overlapping community structure

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Introduction

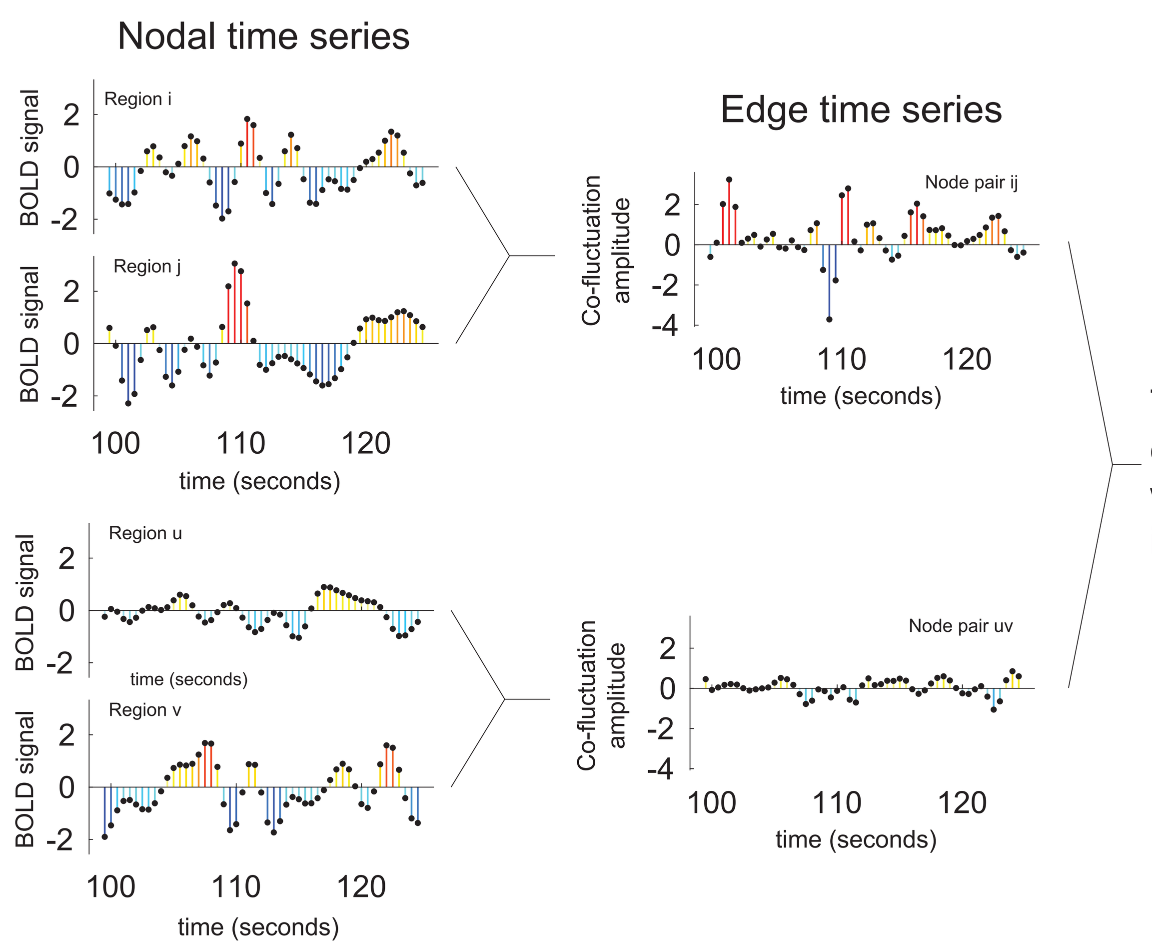
To date, the principal approach in network neuroscience has been node-centric, treating cortical areas as the irreducible units of our network model[1]. Here, we present a novel modeling framework that is edge-centric, focusing on the statistical relationships between edges of functional brain networks—a representation we call edge functional connectivity (eFC)[2].

- We present **edge time series**, which track frame-wise co-fluctuation[3]
- The similarity of edge time series is edge functional connectivity (**eFC**)
- Clustering the eFC matrix yields **overlapping community structure**
  - This structure spans systems, identifies areas of community overlap, highlights diverse systems, and is modulated by task
- eFC is a new method that can be applied to neural time series broadly

Methods

Edge time series and eFC.

- FC is time-averaged co-activation between two time courses
- Omit the averaging step → time course of co-fluctuation, edge time series
- Measure the similarity of edge time series to create eFC

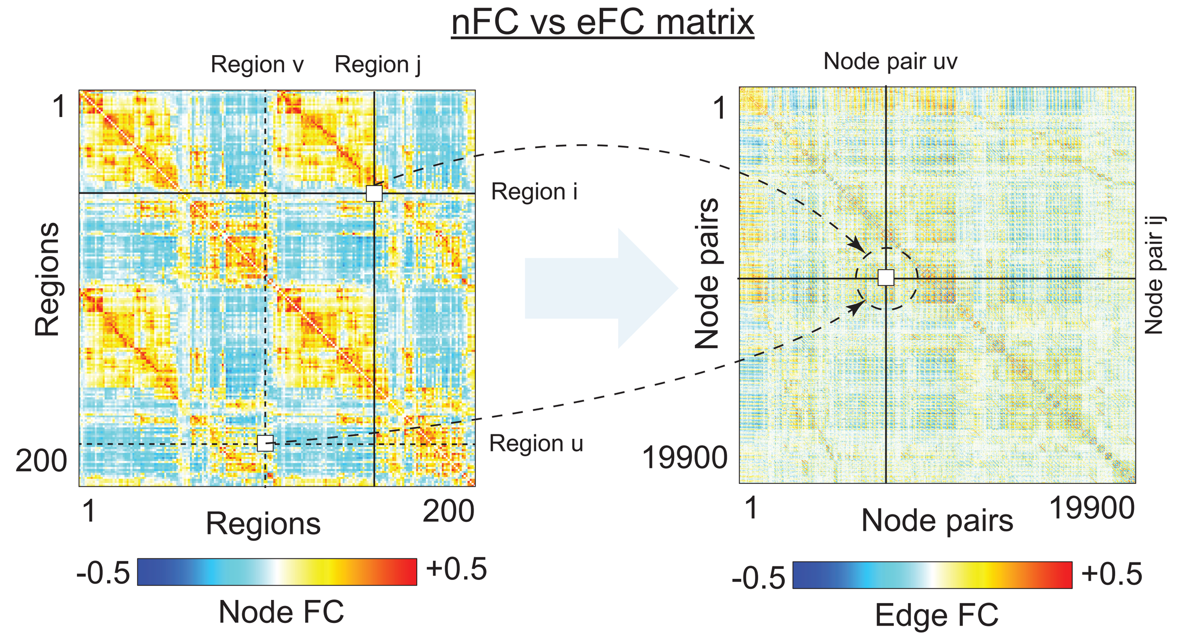


eFC

To measure similarity of edge time series, we take the normalized dot product

nFC vs eFC matrix

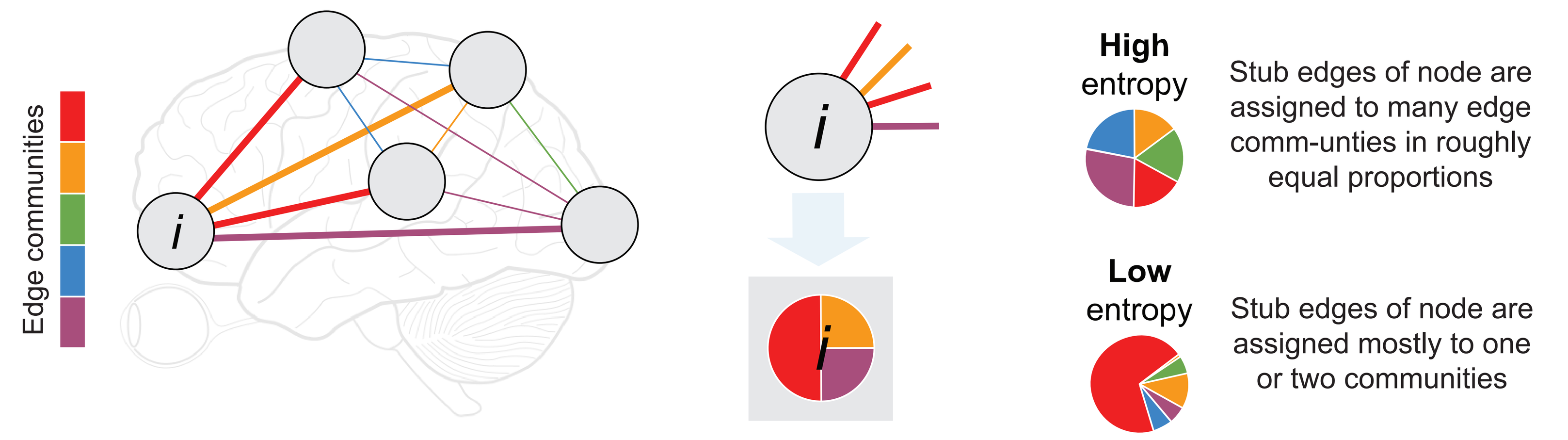
- Whereas traditional nFC is size NxN, the eFC matrix is ExE
- Each entry of the eFC matrix records the similarity of co-fluctuation
- "When nodes ij are fluctuating together, are nodes uv also fluctuating together?



Preprint: https://www.biorxiv.org/content/10.1101/799924v1

Community detection on eFC

- For each node, its N-1 edges are assigned to various edge communities
  - Nodes associated with multiple communities
- Distribution of edge communities at each node provides notion of overlap

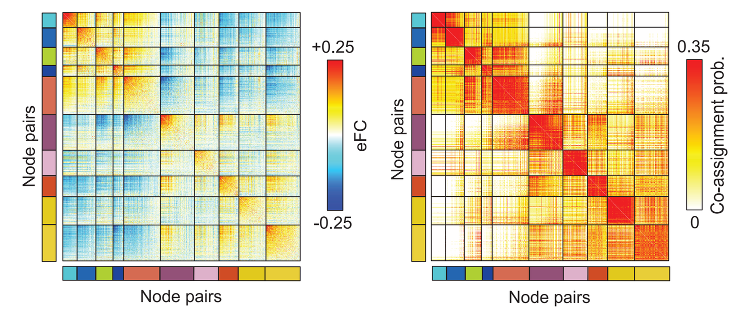


Application to fMRI data

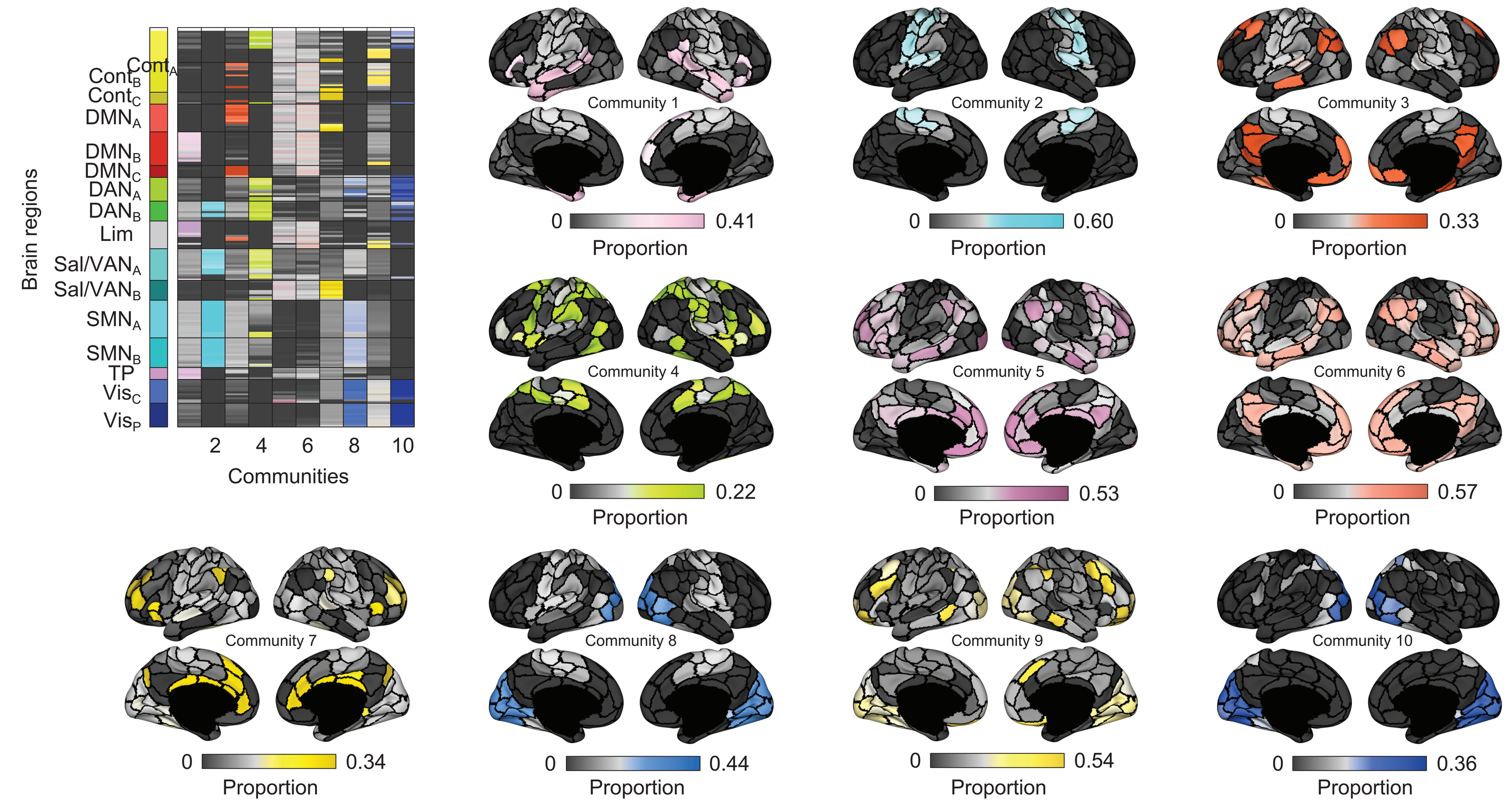
- Human Connectome Project (HCP) unrelated 100, Midnight Scan Club (MSC), Healthy Brain Network Serial Scanning Initiative (HBN)

Results

Edge Communities

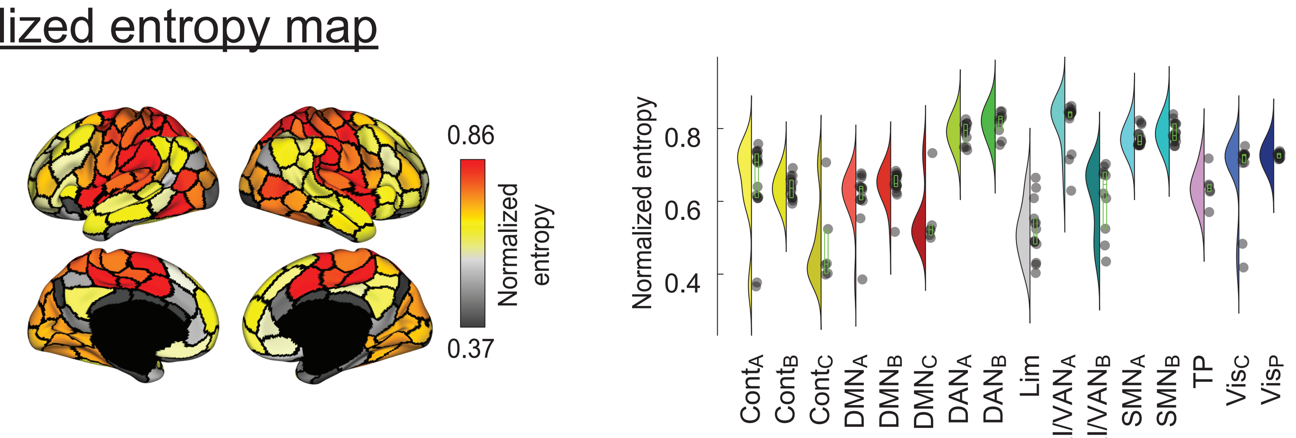


- We clustered the eFC matrix into 10 communities using k-means applied to PCA decomposition of eFC matrix
- Clustering on the eFC matrix creates communities of edges with similar co-fluctuation patterns across time



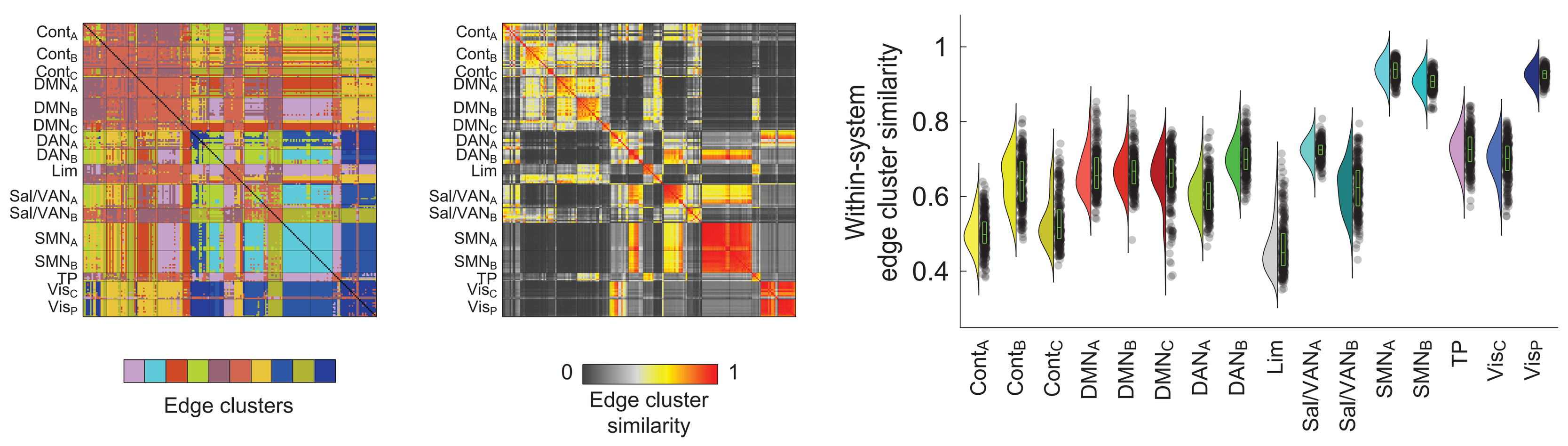
- Nodes are saturated by proportion of edges participating in each community and colored by weighted combination of canonical system[4]

Normalized entropy map



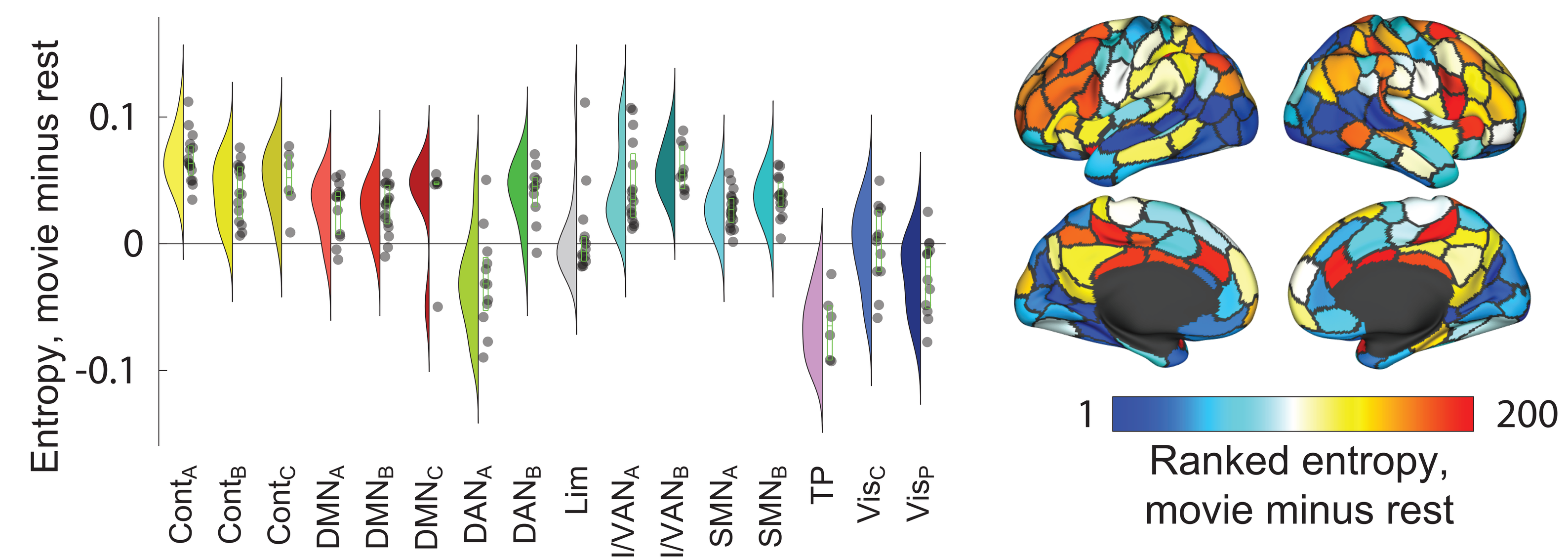
- Normalized entropy is highest dorsal-attention, somato-motor, and visual nodes, indicating that stub edges to these nodes are distributed across a variety of communities

Edge cluster similarity



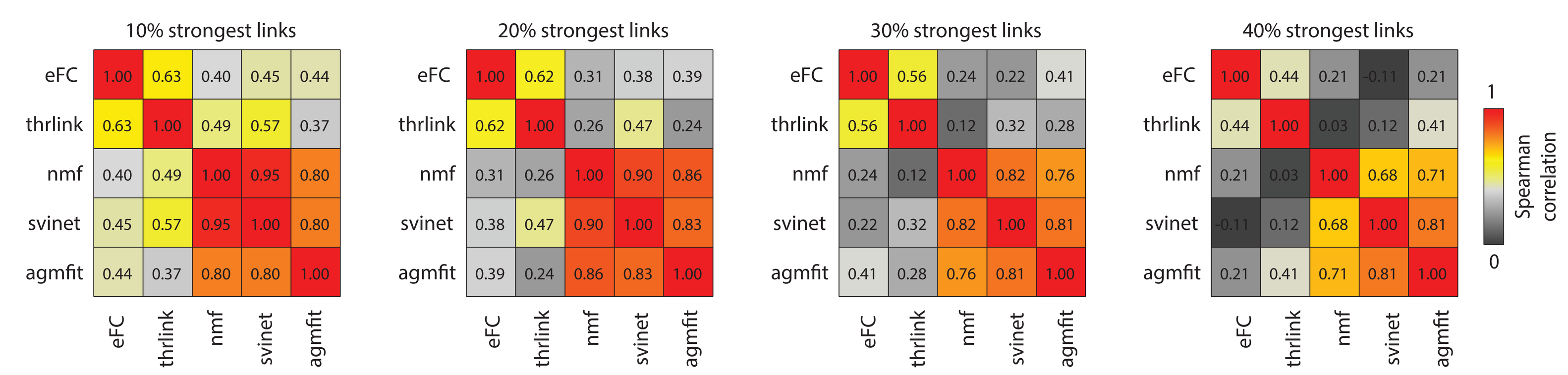
- As each edge is assigned to a cluster, we can project communities into the space of adjacency matrix
- Similarity of edge community assignment illustrates node-level systems with varying diversity[5]; control network → diverse edge community patterns

Entropy differences in rest vs. task



- Visual, dorsal attention, and temporal parietal nodes display greatest relative decreases in entropy during movie condition

Comparison to alternative overlapping algorithms



- Comparison of entropy patterns across methods and thresholds show eFC yields dissimilar overlap patterns; most similar is *thrlink*, which is based on line graphs; *nmf*: non-negative matrix factorization[6], *svinet*: an overlapping blockmodel[7]; *agmfit*: tiled overlapping algorithm[8]

Conclusion

The edge-centric approach allows us to uncover a pervasively overlapping[9] community structure by assigning communities to functional brain network ***edges***. In fact, all nodes are associated with multiple edge communities. We demonstrate that this structure is modulated by task-based input. These patterns of overlap provide a different, yet complementary, account of functional brain network organization.

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