

Brain Activity Mapper Graphs Link Task States, Personality, and Behavioral Symptoms

Chunyin Siu^a, Saad Pirzada^a, Cameron Glick^a, Richard Betzel^{b,c}, Giovanni Petri^d, Jeremy Manning^e, Leanne Williams^a, Manish Sagar^a



personal homepage



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^a Department of Psychiatry and Behavioral Sciences, Stanford University, Stanford, CA, USA

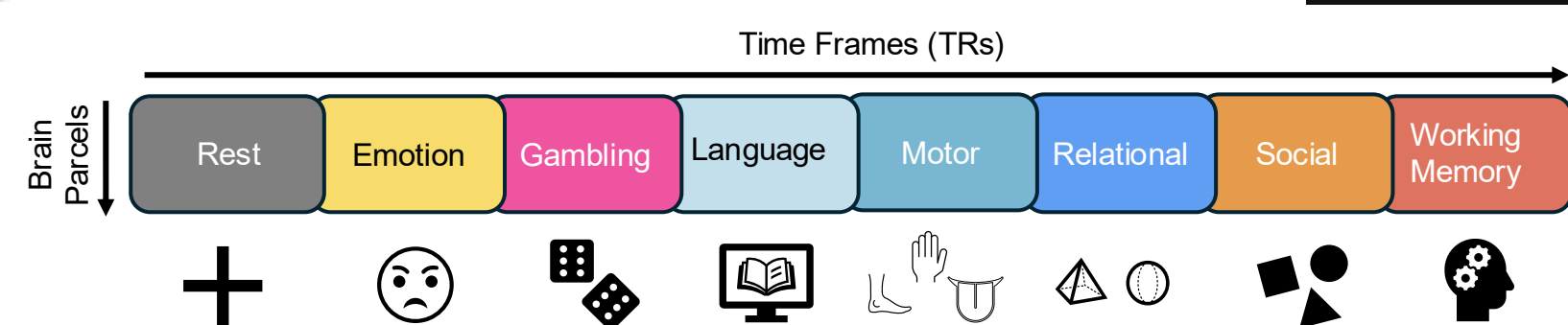
^b Department of Neuroscience, University of Minnesota, Minneapolis, MN, USA

^c Masonic Institute for the Developing Brain, University of Minnesota, Minneapolis, MN USA

^d Network Science Institute at Northeastern University, London, UK

^e Department of Psychological and Brain Sciences, Dartmouth College, Hanover, NH USA

1. Question and Setup



Questions

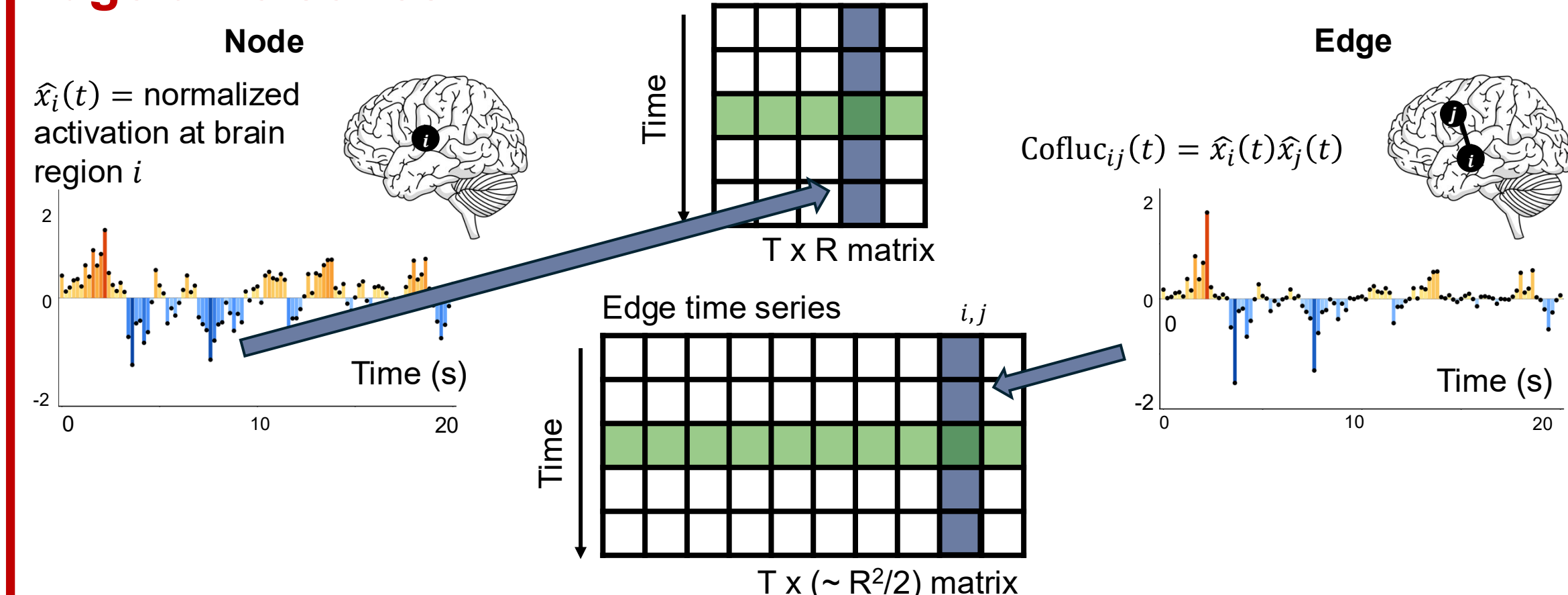
How to understand brain activity?
Across tasks?
Instantaneous interaction between brain regions?

Setup

Human Connectome Project¹
fMRI data of ~1000 subjects

2. Ingredients

Edge time series²

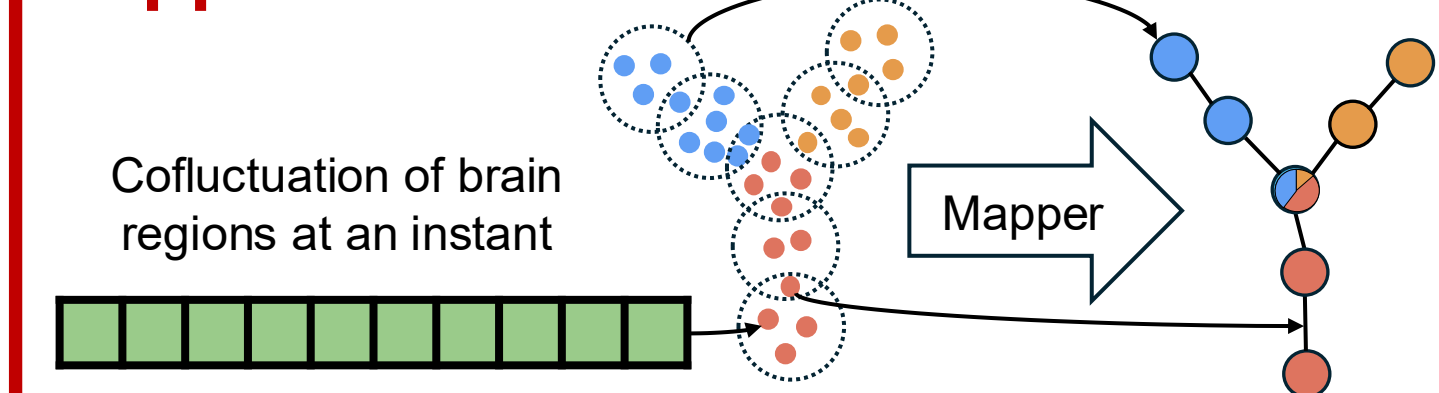


Let $x_i(t)$ be the activation level of brain region i at time t .
Let $\hat{x}_i(t)$ be the temporally z-scored activation.
Define $\text{Cofluc}_{ij}(t) = \hat{x}_i(t)\hat{x}_j(t)$

Why neuroscientists like this

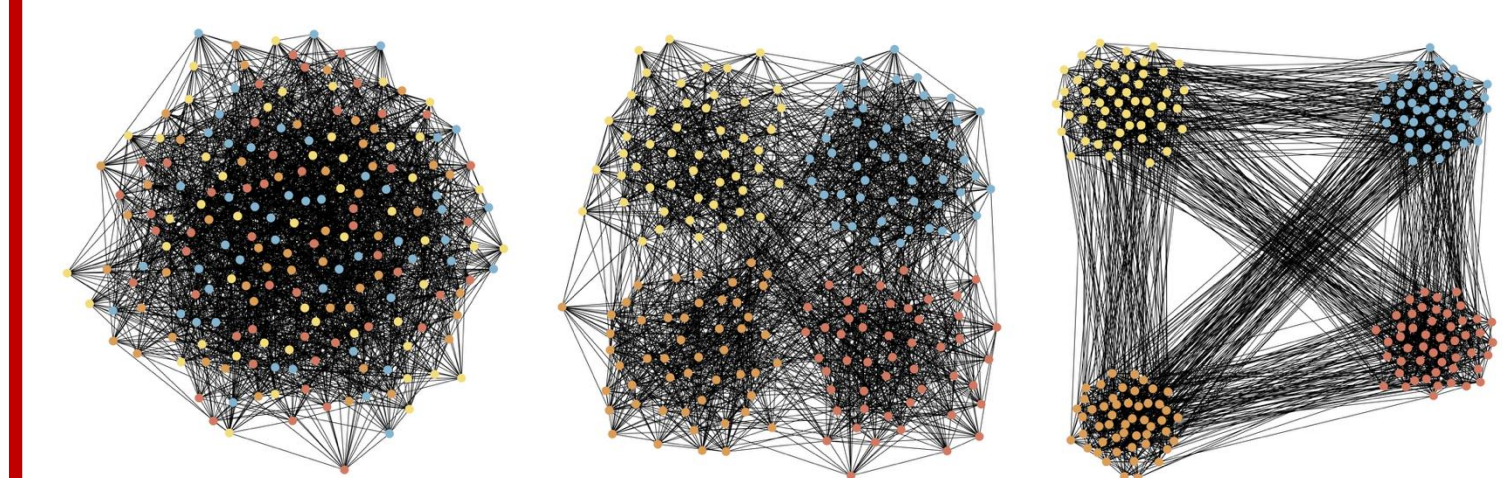
Probes instantaneous interaction between brain regions

Mapper³



Why neuroscientists like this
Visual representation of high-dimensional time series

Graph Modularity⁴



Why neuroscientists like this
Well established in network science

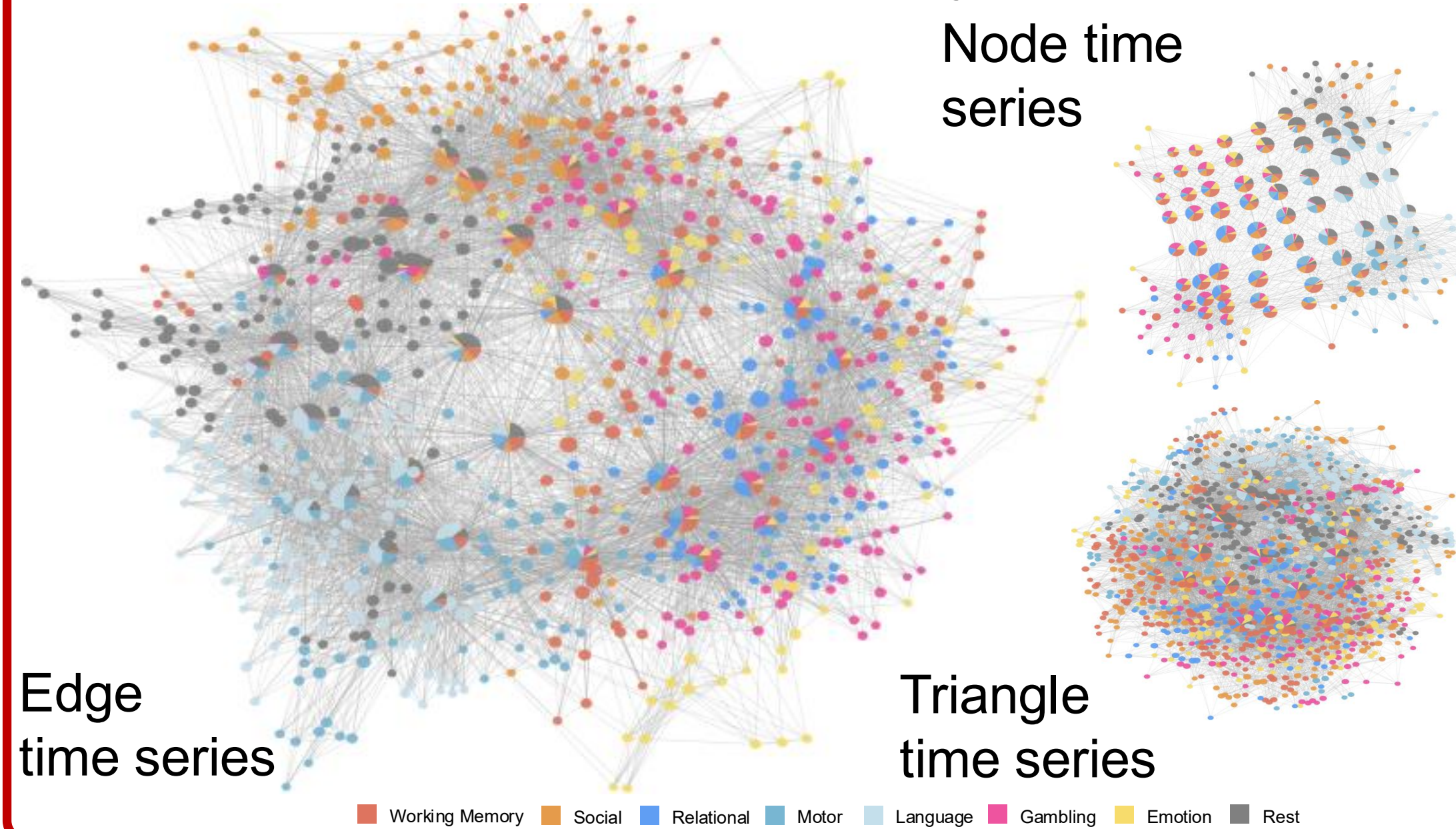
For a graph G with a partition P of its nodes, the **quality of modularity** of the the partitioned graph (G, P) measures the **discrepancy between the proportions of in-group edges and inter-group edges**.

Precisely, for nodes u and v , let $Q_{uv} = \mathbf{1}_{u \sim v} - \frac{\text{deg } u \text{ deg } v}{\text{num. nodes in } G}$.

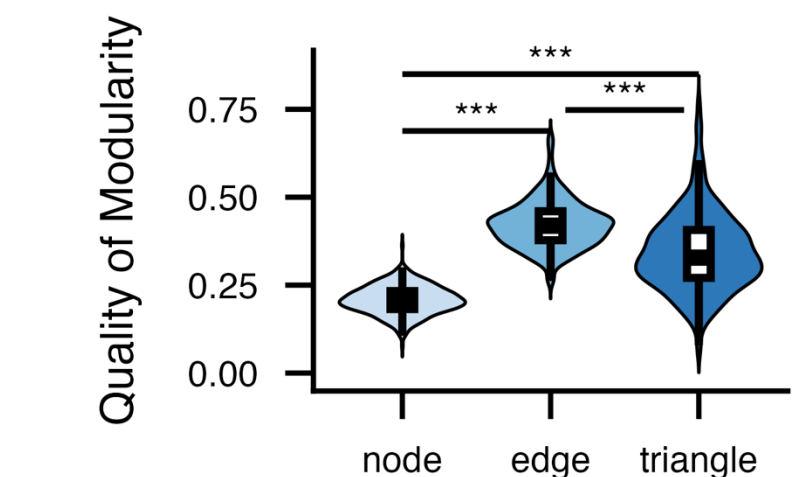
The quality of modularity Q of the partitioned graph is the sum of the Q_{ij} 's for all in-group node pairs.

3. Mapper and Modularity

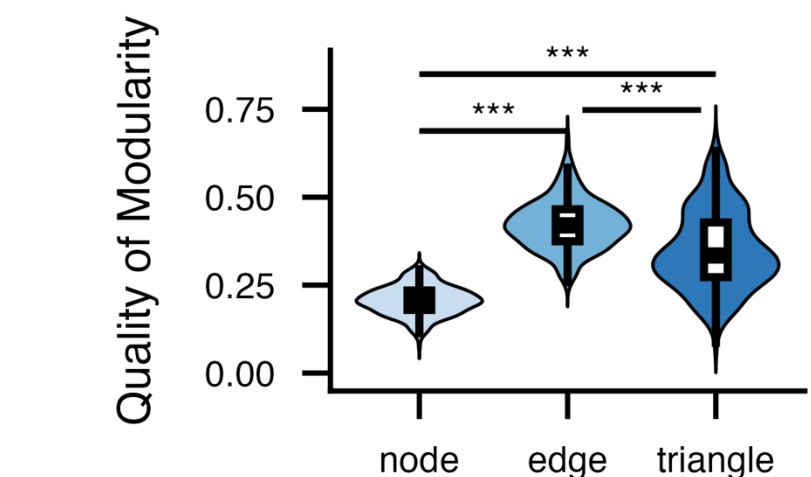
Representative Subject



Exploration Cohort

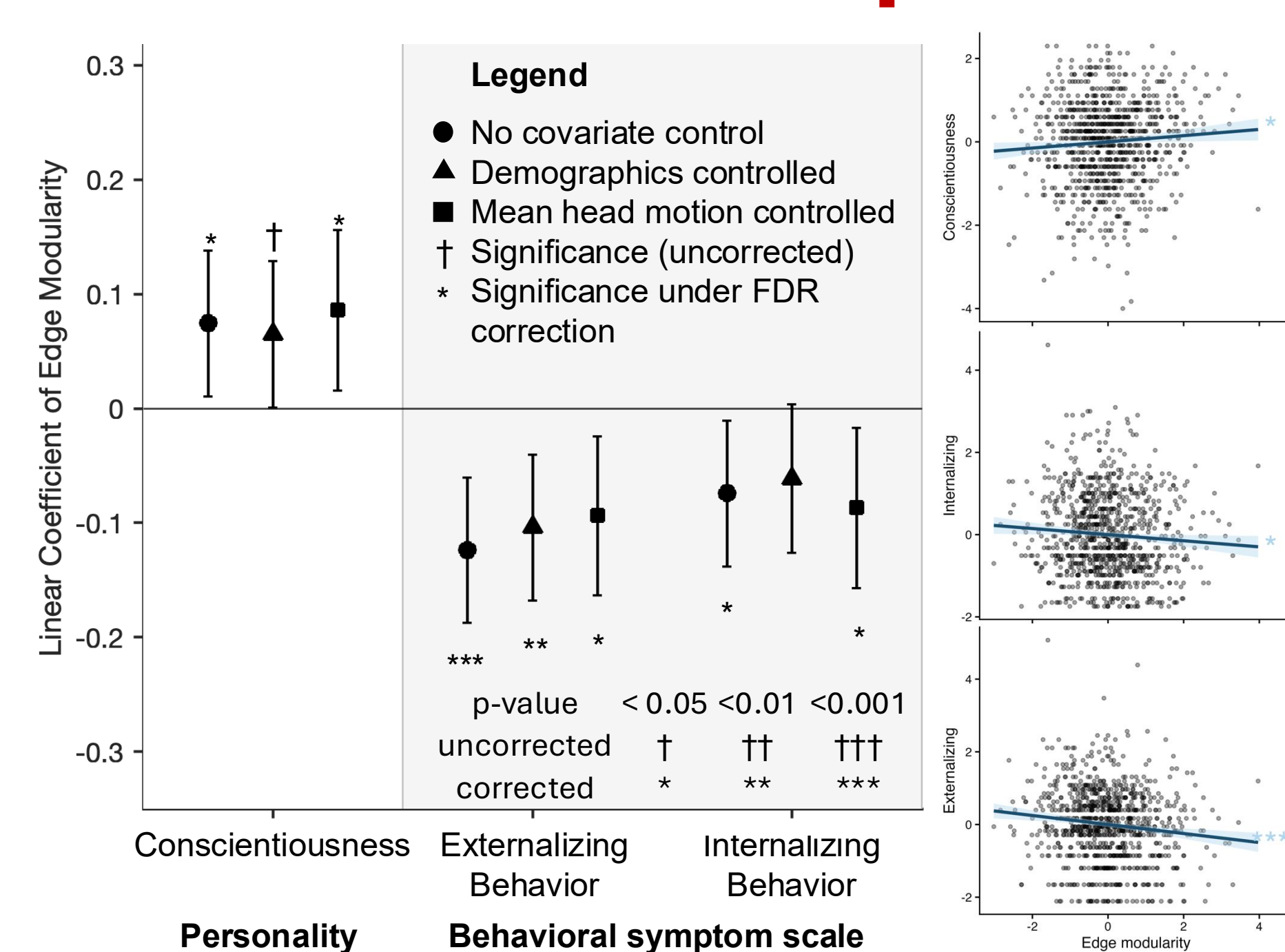


Replication Cohort



The edge time series-based Mapper graph shows the highest level of task segregation.
(Left) Mapper graphs of brain dynamics of a representative subject.
(Above) Distributions of Mapper graph quality of modularity

4. Behavioral Implications



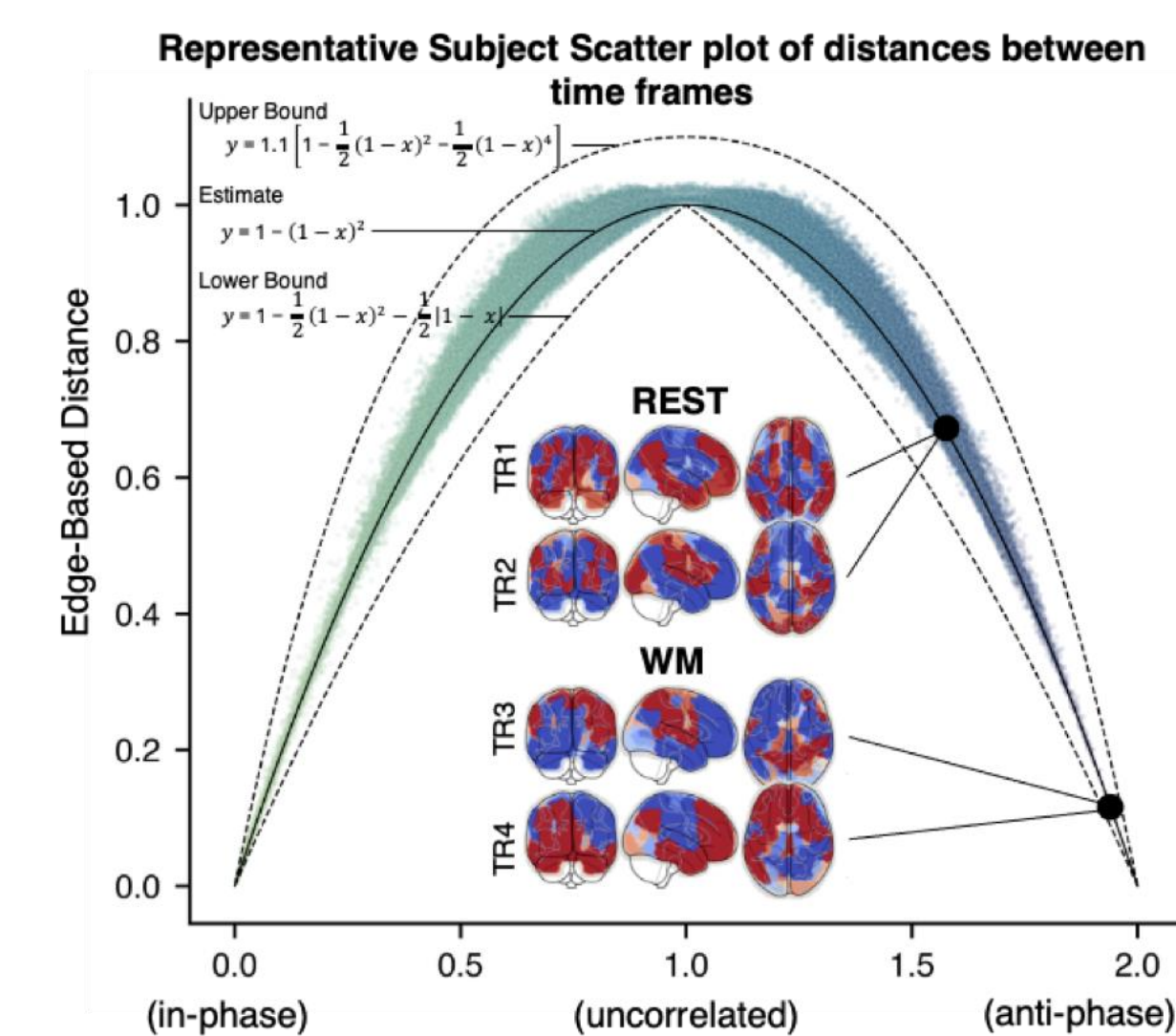
Edge Mapper modularity is associated with:
Conscientiousness tendency toward organization and self-discipline

Externalizing behavior outward-directed problem behavior such as aggression, rule-breaking

Internalizing behavior inward-directed problems such as anxiety, depression

We speculate they all correlate with the mind's "orderliness".

5. Why better task differentiation?



We speculate that the better topological organization arises from the the treatment of antiphase (antipodal) patterns as related states while ignoring sign reversals that may arise from oscillatory or context-dependent activity.

References

- Barch, D. M., Burgess, G. C., Harms, M. P., Petersen, S. E., Schlaggar, B. L., Corbetta, M., Glasser, M. F., Curtiss, S., Dixit, S., Feldt, C., Nolan, D., Bryant, E., Hartley, T., Footer, O., Bjork, J. M., Poldrack, R., Smith, S., Johansen-Berg, H., Snyder, A. Z., & Van Essen, D. C. (2013). Function in the human connectome: Task-fMRI and individual differences in behavior. *NeuroImage*, 80, 169–189.
- Faskowitz, J., Esfahlani, F. Z., Jo, Y., Sporns, O., & Betzel, R. F. (2020). Edge-centric functional network representations of human cerebral cortex reveal overlapping system-level architecture. *Nature Neuroscience*, 23(12), 1644–1654.
- Singh, G., Memoli, F., & Carlsson, G. (2007). Topological Methods for the Analysis of High Dimensional Data Sets and 3D Object Recognition. In M. Botsch, R. Pajarola, B. Chen, & M. Zwicker (Eds.), *Eurographics Symposium on Point-Based Graphics*. The Eurographics Association. <http://dx.doi.org/10.2312/SPBG/SPBG07/091-100>
- Newman, M. E. J. (2006). Modularity and community structure in networks. *Proceedings of the National Academy of Sciences*, 103(23), 8577–8582.

6. Next Step: from Mapper to Homology

Homology of evoked brain activity

