

TDA x Neuroscience

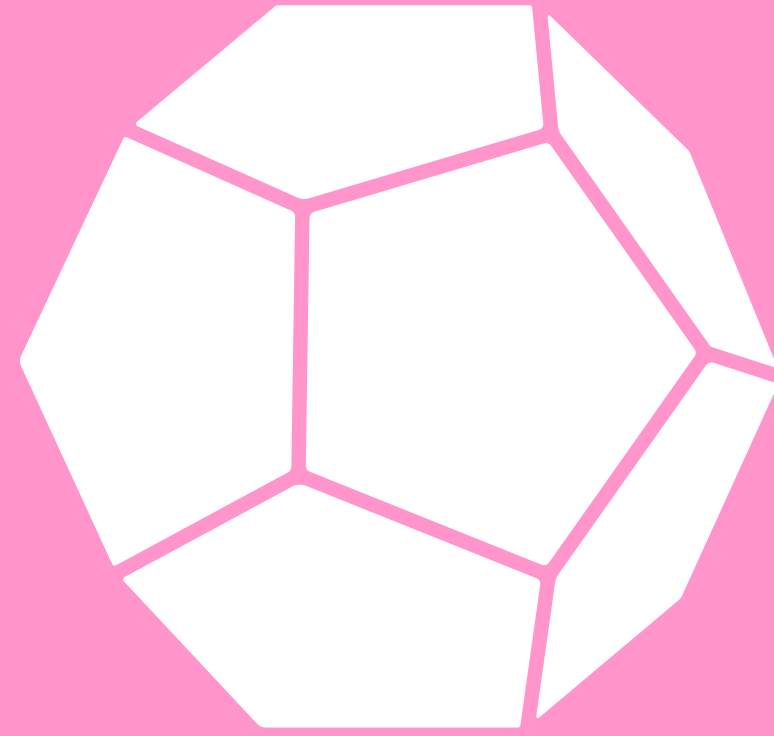
A novel topological characterization of brain-wide co-fluctuation patterns over time reveals brain-behavior links across spontaneous and evoked activity

**Chunyin Siu,
Saad Pirzada, Cameron Glick, Jeremy R. Manning (Dartmouth), Richard Betzel (U
Minnesota), Giovanni Petri (Northeastern @ London), Leanne Williams, Manish Sagar**

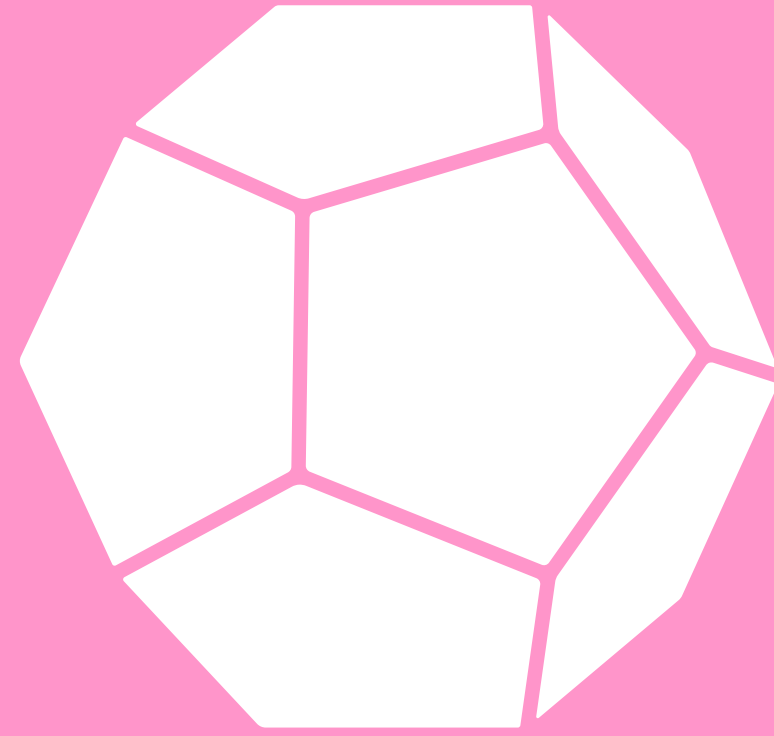


What is Topological Data Analysis?

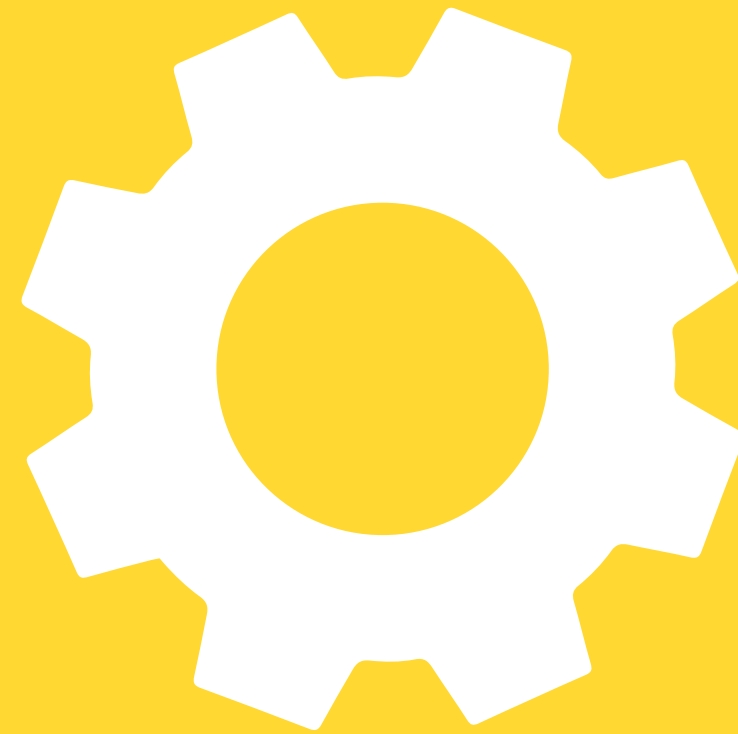
Topology



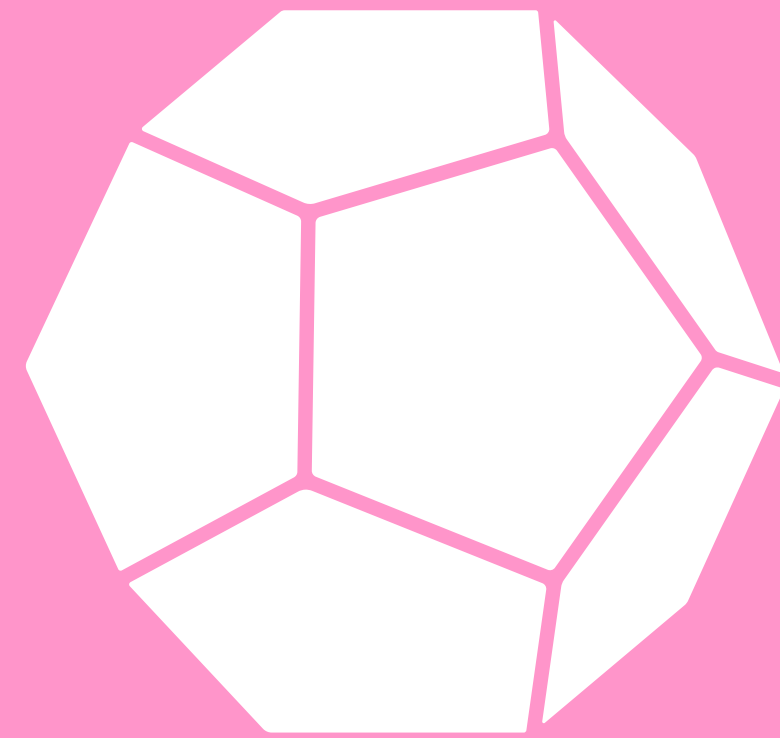
Topology



Computation



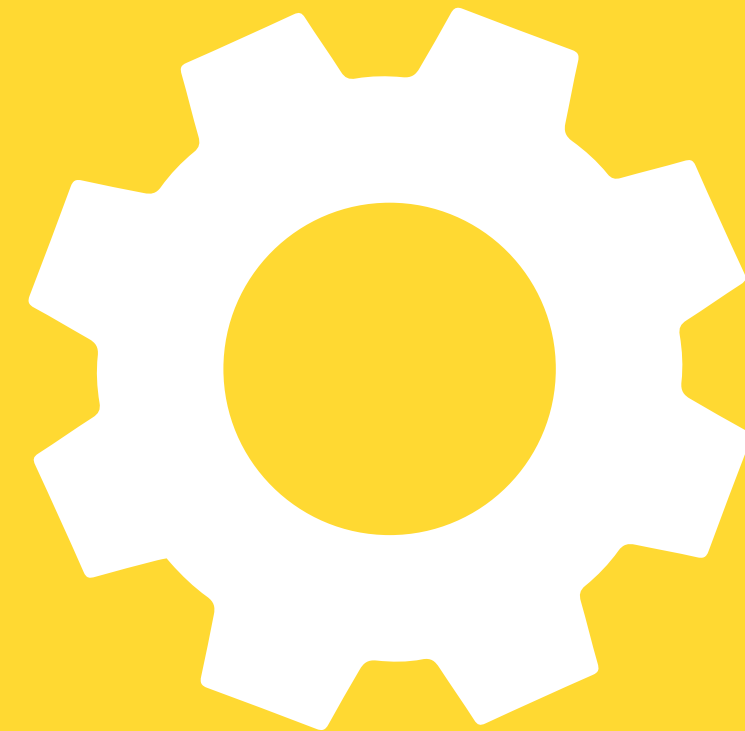
Topology



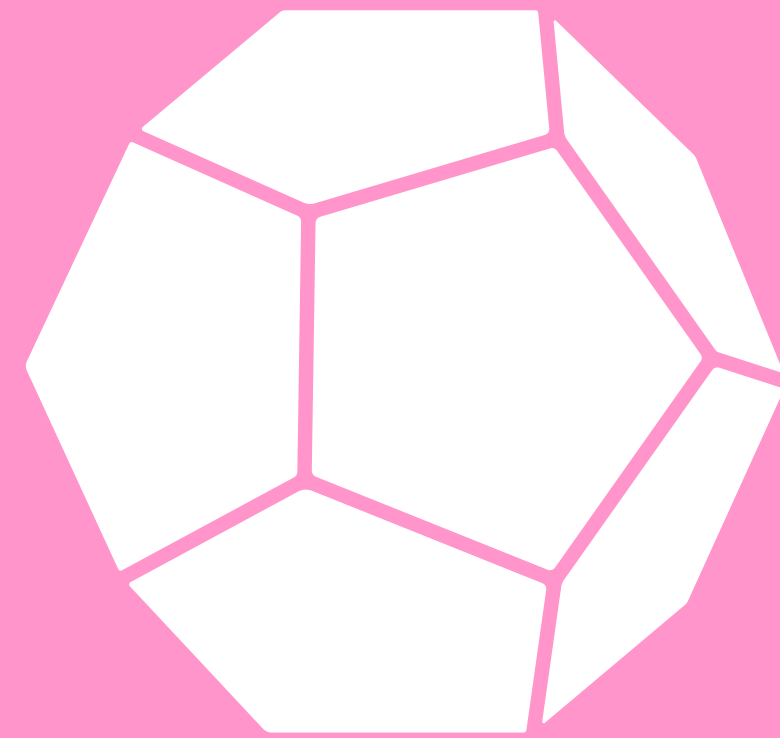
**Probability
and Statistics**



Computation



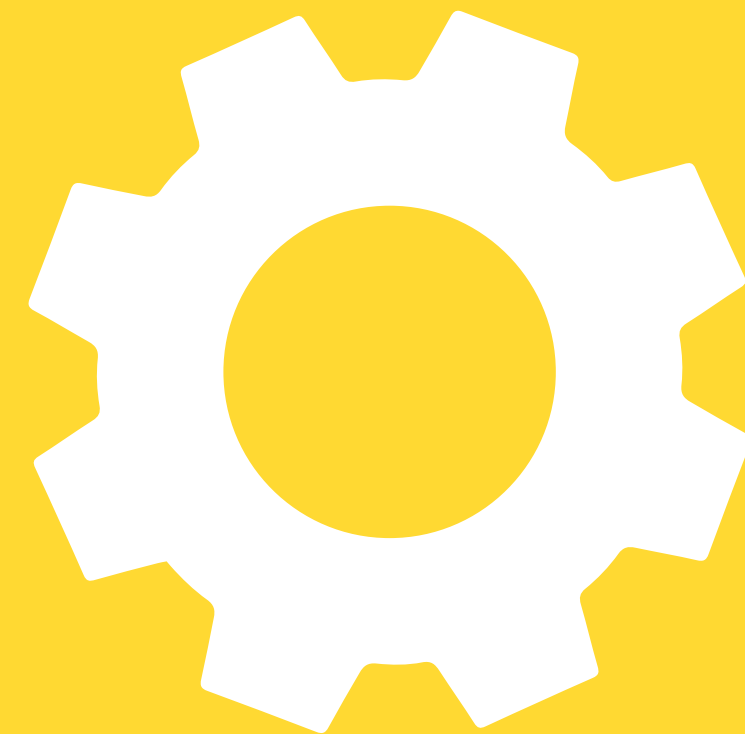
Topology



**Probability
and Statistics**



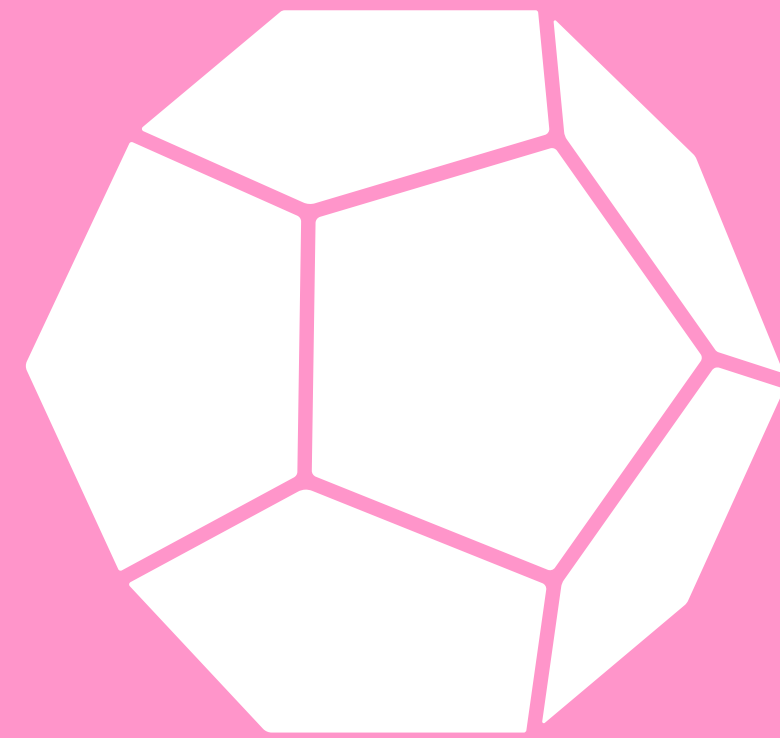
Computation



Data



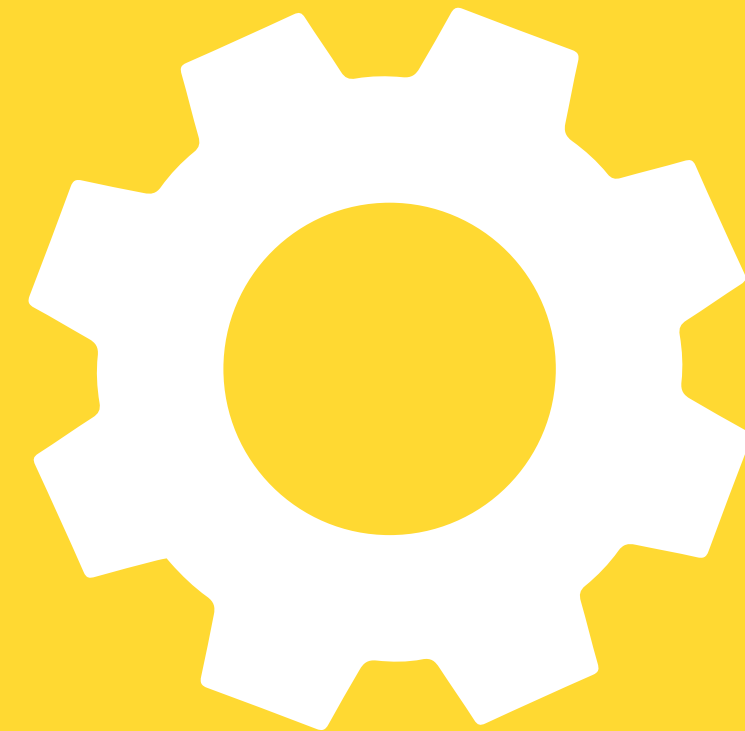
Topology



**Probability
and Statistics**



Computation



Data



Agenda

- Neuroscience — data, people, questions and techniques
- Our analysis



Neuroimaging Data



School of Medicine



CONNECTOME
COORDINATION FACILITY

Neuroimaging Data



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School of Medicine

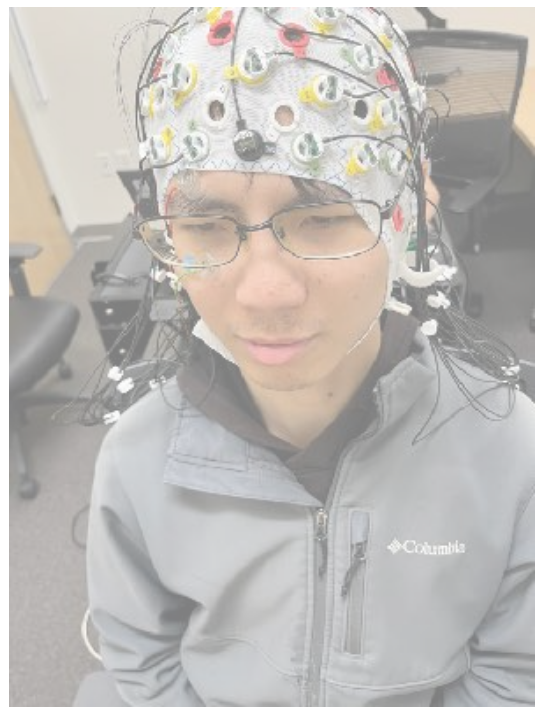


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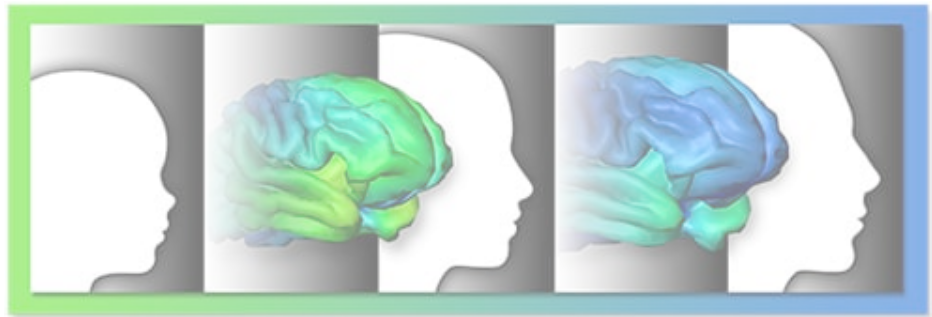
Neuroimaging Data



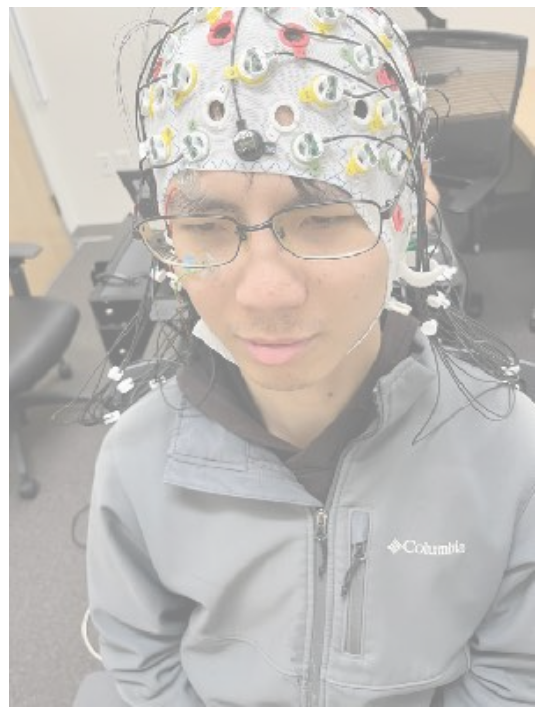
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Neuroimaging Data



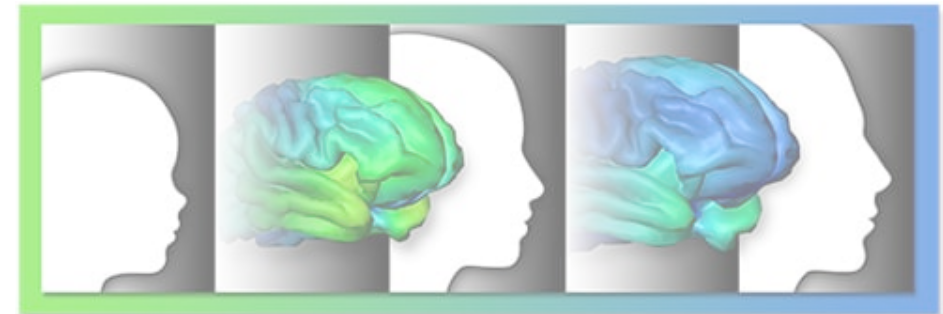
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Sampling noise

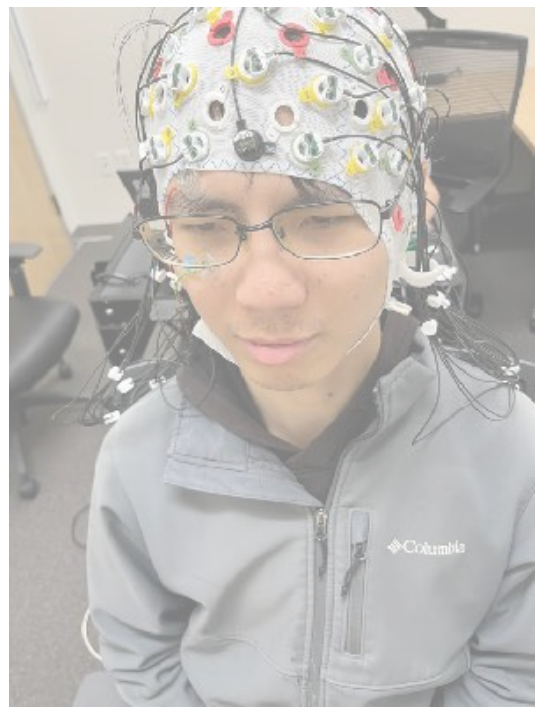
Small sample size

Low resolution



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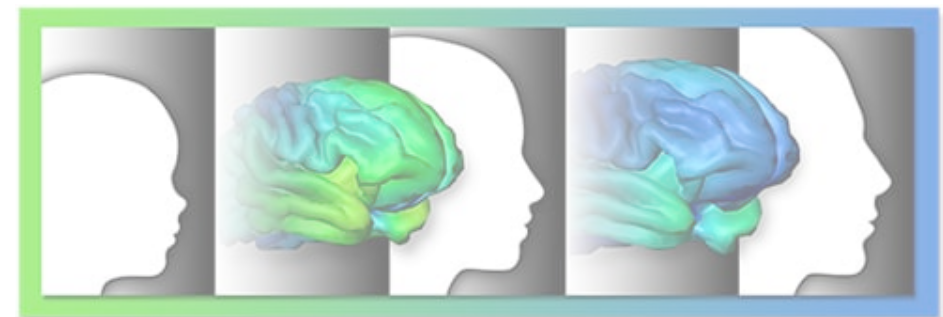
Neuroimaging Data



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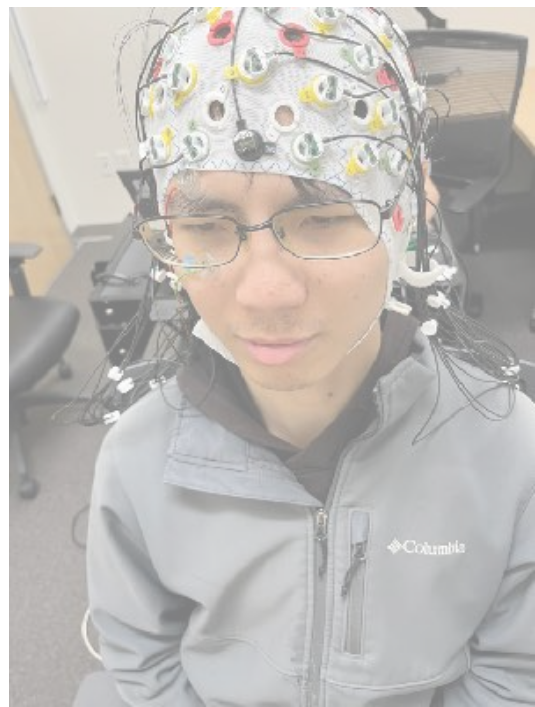
Neuroimaging Data

Love pictures

Care more about behavior than methodology



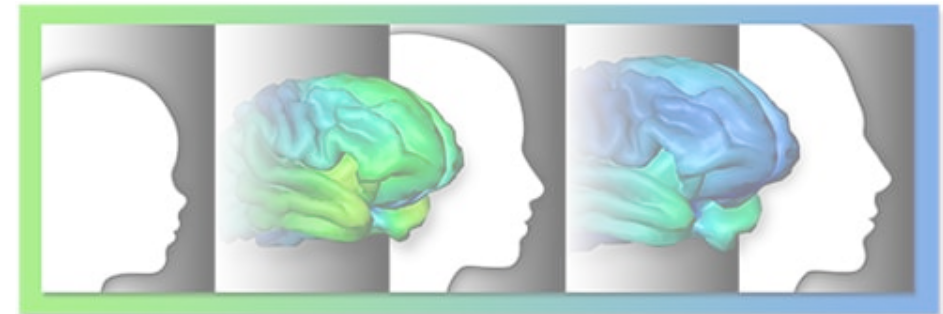
Mikael Häggström
https://commons.wikimedia.org/wiki/File:Radiologist_interpreting_MRI.jpg



Sampling noise
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Low resolution

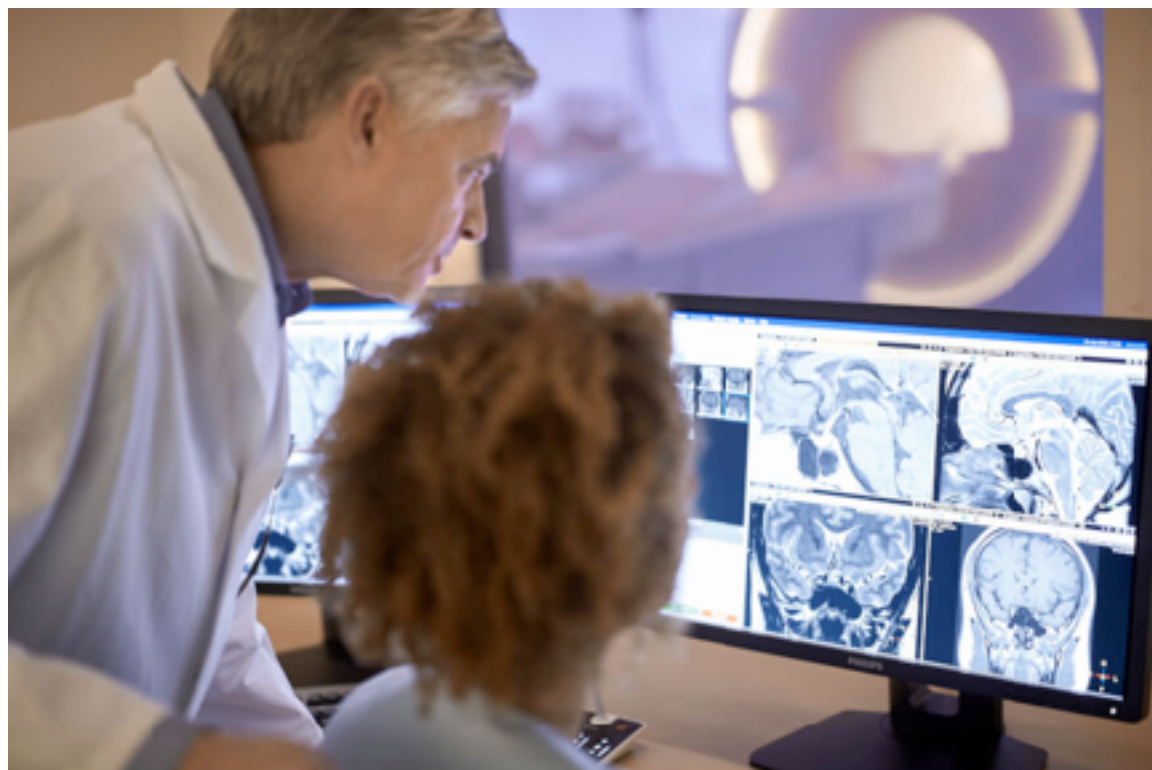


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Neuroimaging Data



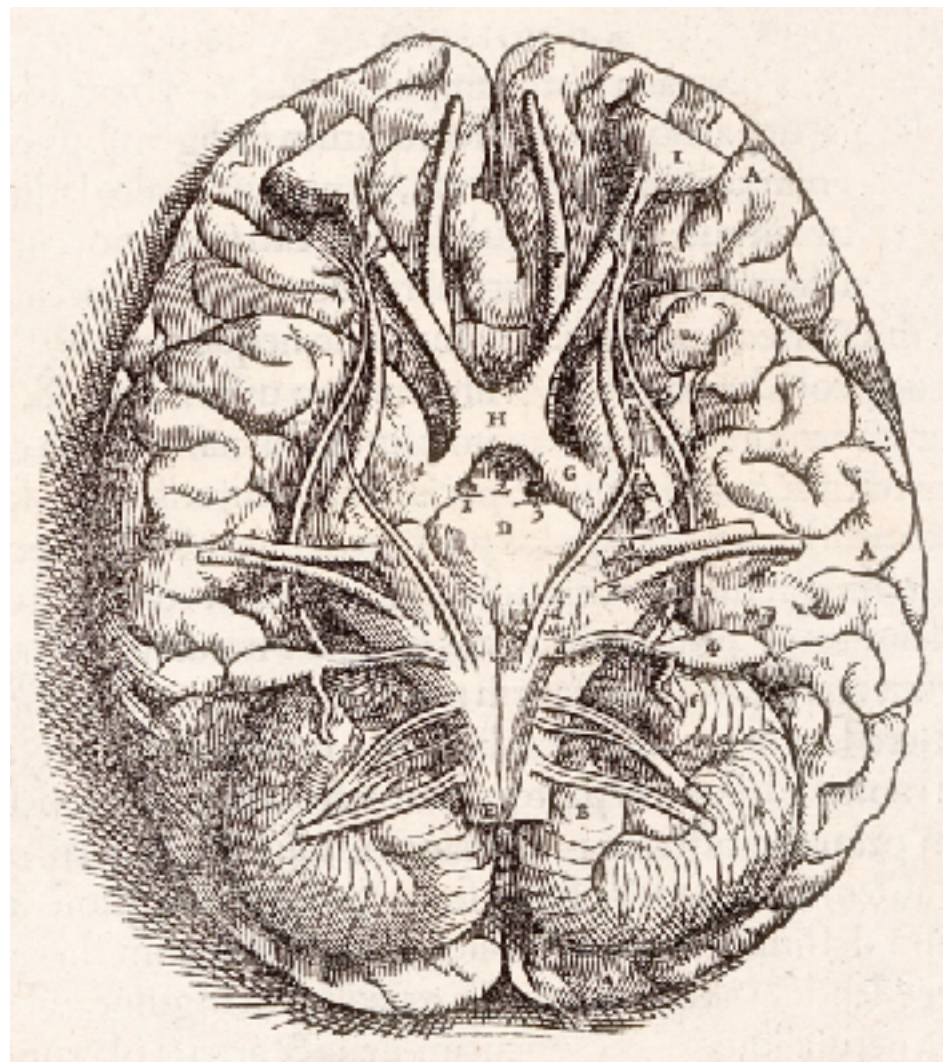
Mikael Häggström
https://commons.wikimedia.org/wiki/File:Radiologist_interpreting_MRI.jpg

Love pictures
Care more about behavior than methodology
Generally are rusty on math
Have preconceptions of math

Behavior?

Behavior?

How do different brain regions interact to give rise to complex mental activities?



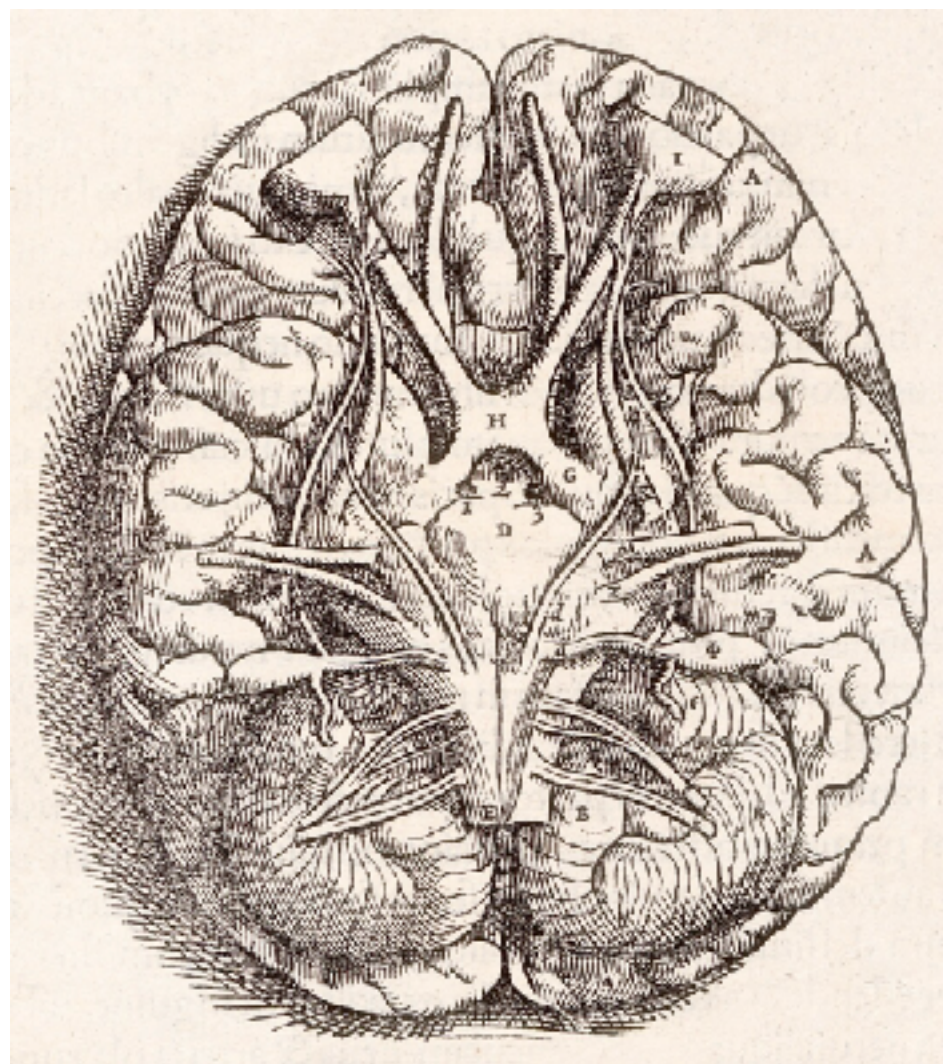
from Andreas Vesalius' *Fabrica*

[https://en.wikipedia.org/wiki/](https://en.wikipedia.org/wiki/File:1543,_Andreas_Vesalius%27_Fabrica,_Base_Of_The_Brain.jpg)

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Behavior?

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How can we understand psychopathology like depression and addiction?



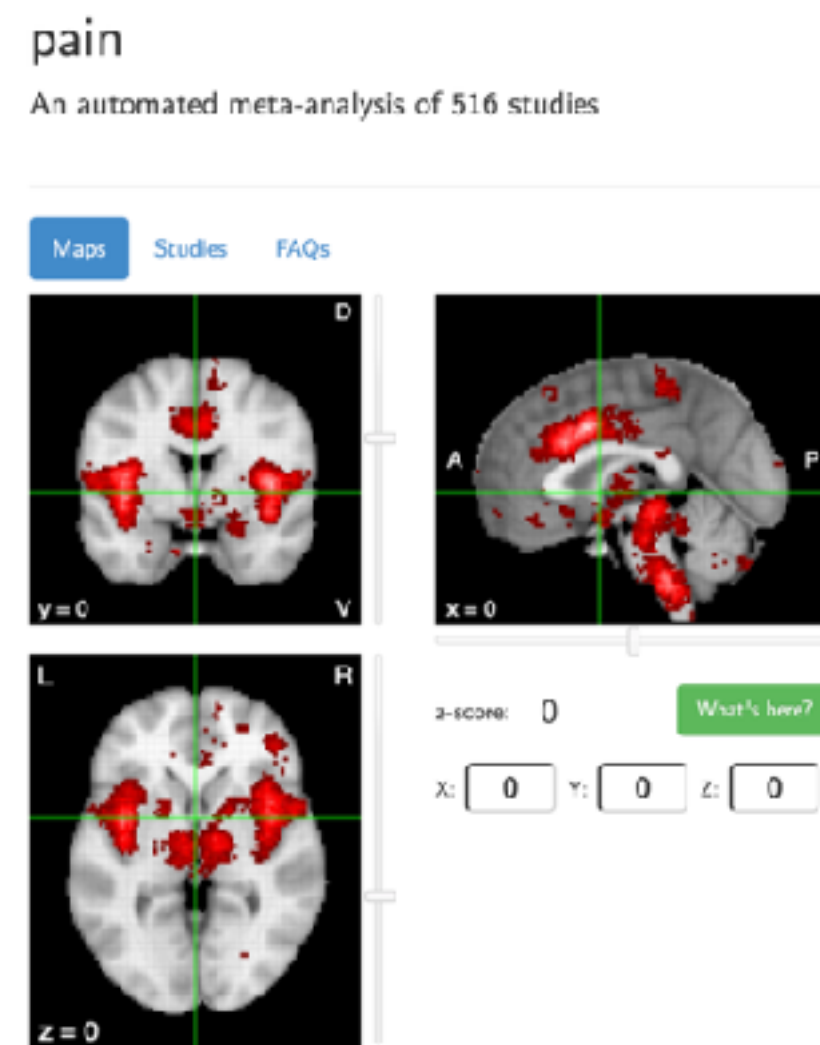
Edvard Munch, 1893

[https://en.wikipedia.org/wiki/The_Scream#/media/](https://en.wikipedia.org/wiki/The_Scream#/media/File:Edvard_Munch,_1893,_The_Scream,_oil,_tempera_and_pastel_on_cardboard,_91_x_73_cm,_National_Gallery_of_Norway.jpg)

File:Edvard_Munch,_1893,_The_Scream,_oil,_tempera_and_pastel_on_cardboard,_91_x_73_cm,_National_Gallery_of_Norway.jpg

Existing tools — classics

activation

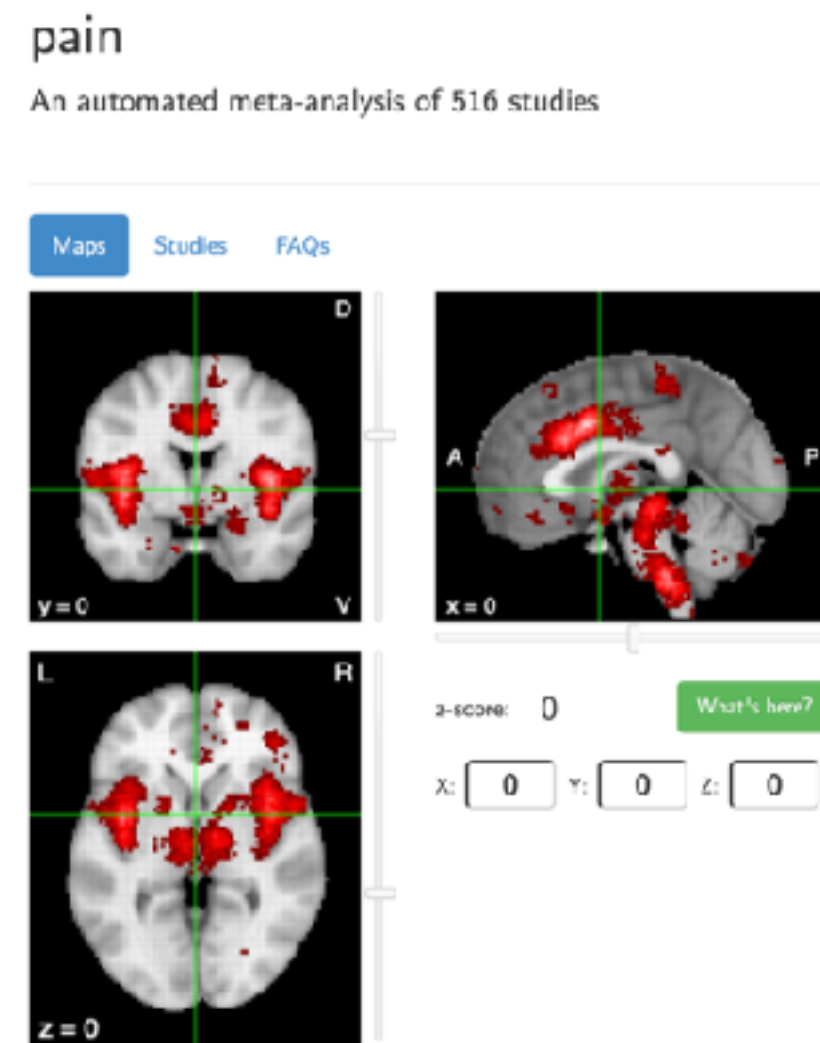


Neurosynth

<https://neurosynth.org/analyses/terms/pain/>

Existing tools — classics

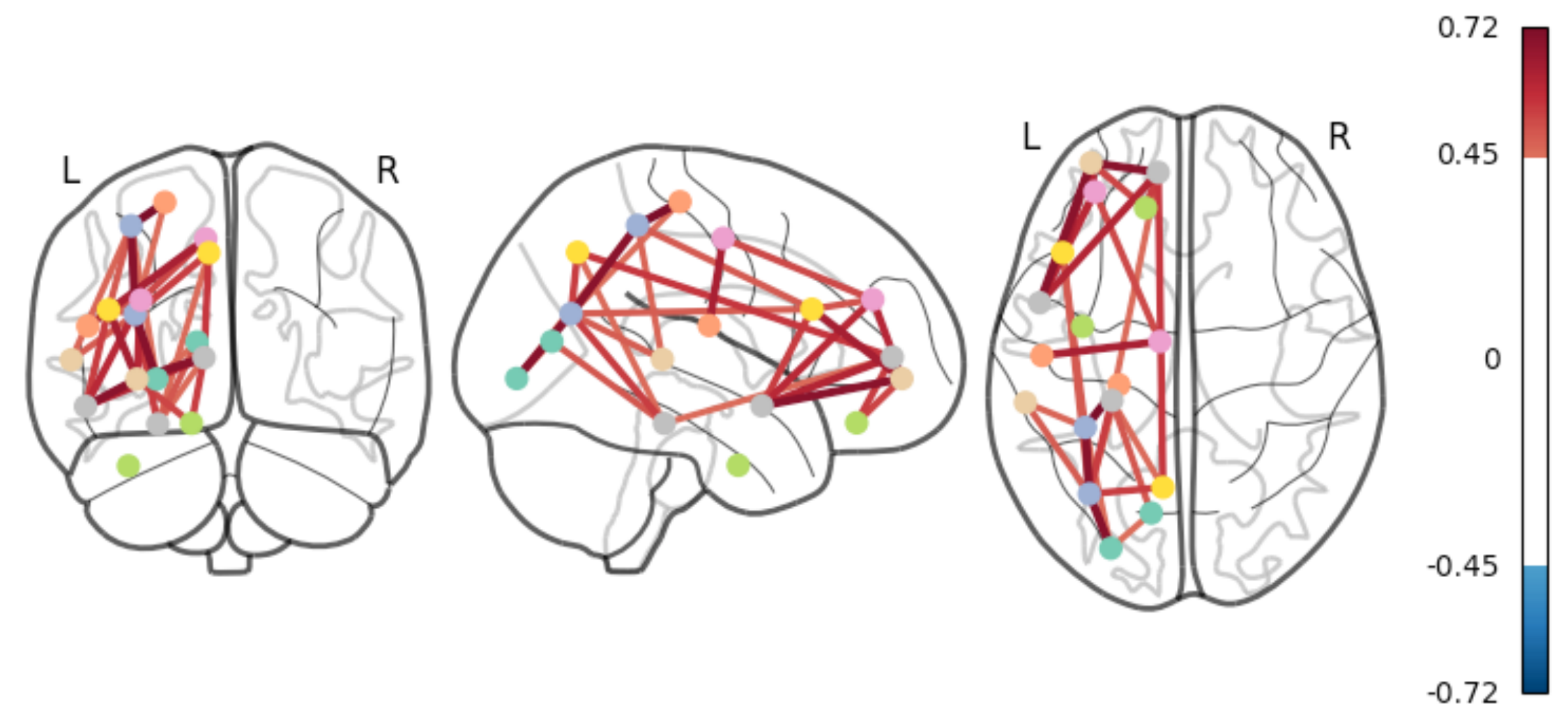
activation



Neurosynth

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temporal correlation (functional connectivity)



Nilearn plotting example

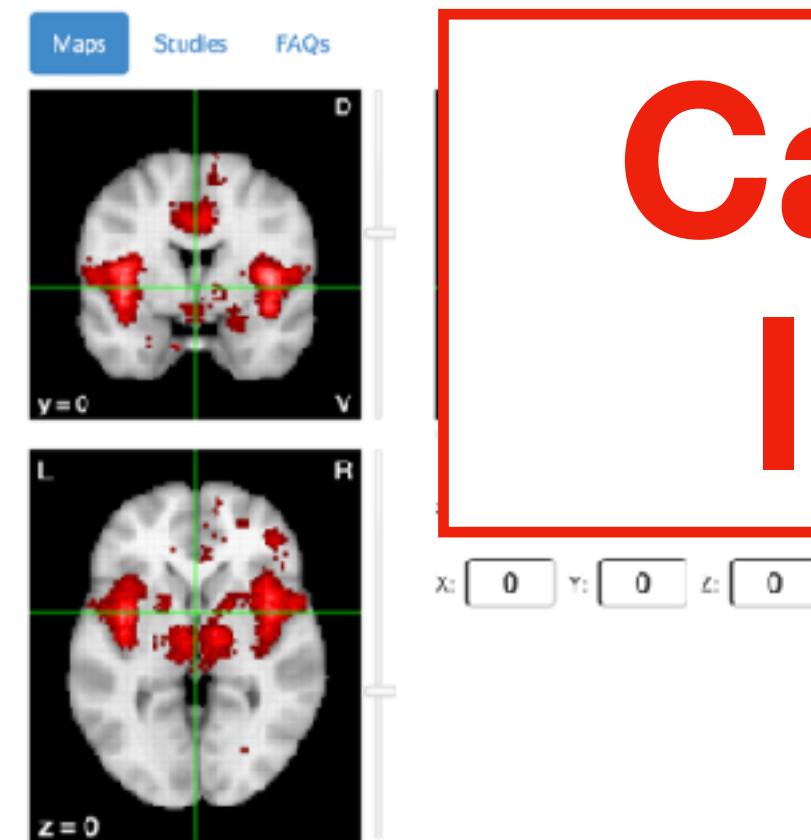
https://nilearn.github.io/stable/auto_examples/03_connectivity/plot_atlas_comparison.html#sphx-glr-auto-examples-03-connectivity-plot-atlas-comparison-py

Existing tools — classics

activation

temporal correlation (functional connectivity)

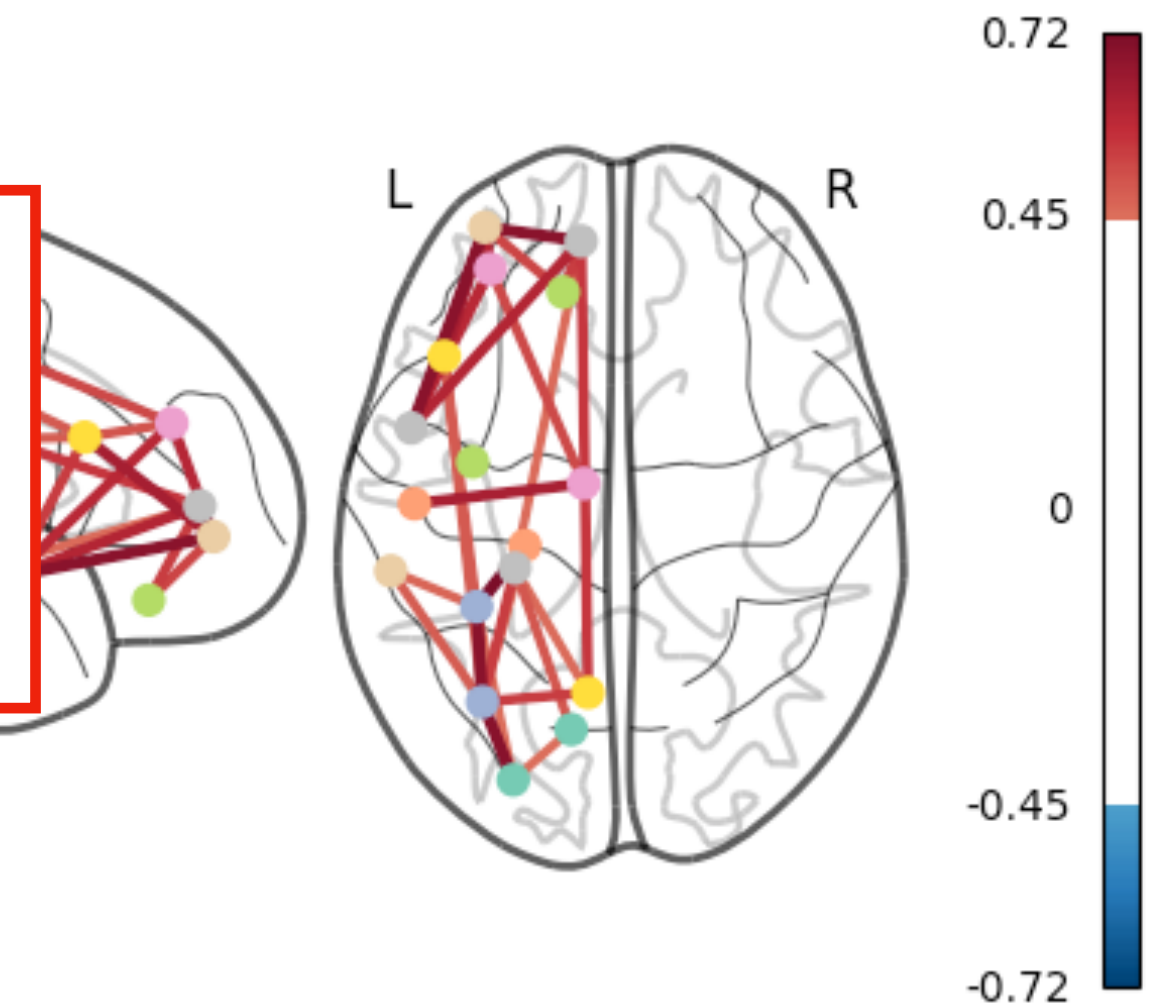
pain
An automated meta-analysis of 516 studies



Neurosynth

<https://neurosynth.org/analyses/terms/pain/>

Can we go beyond linear measure?



Nilearn plotting example

https://nilearn.github.io/stable/auto_examples/03_connectivity/plot_atlas_comparison.html#sphx-glr-auto-examples-03-connectivity-plot-atlas-comparison-py

Existing tools — edge time series

Faskowitz et al., 2020

- $\mathbf{x}(t) = [x_1(t), \dots, x_D(t)]$

Existing tools — edge time series

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- $\text{corr}(x_i, x_j) = \frac{1}{T} \sum_{1 \leq t \leq T} \hat{x}_i(t) \hat{x}_j(t)$, where hat means standardization over time

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- Consider $\mathbf{E}(t) = [E_{12}(t), E_{13}(t), \dots, E_{ij}(t), \dots, E_{D-1,D}]$,
where $E_{ij}(t) = \hat{x}_i(t) \hat{x}_j(t)$

Existing tools — edge time series

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E is the edge time series.

brain activation

functional connectivity

edge time series



Mapper

homology

sheaf theory



brain activation

functional connectivity

edge time series



Mapper

homology

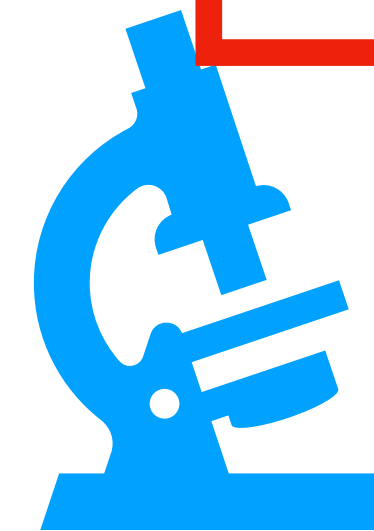
sheaf theory



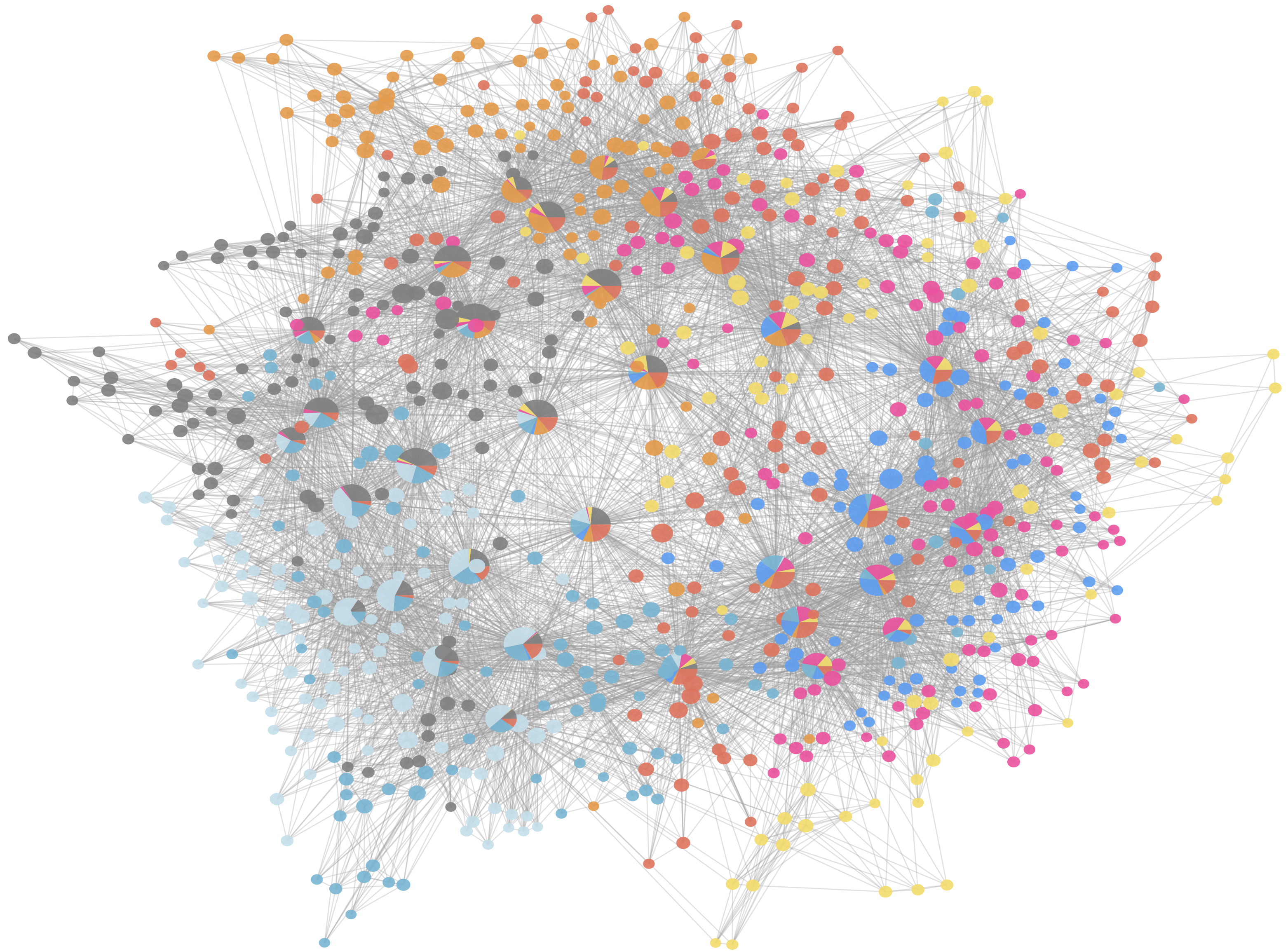
brain activation

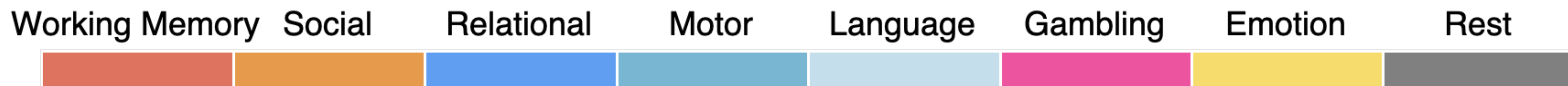
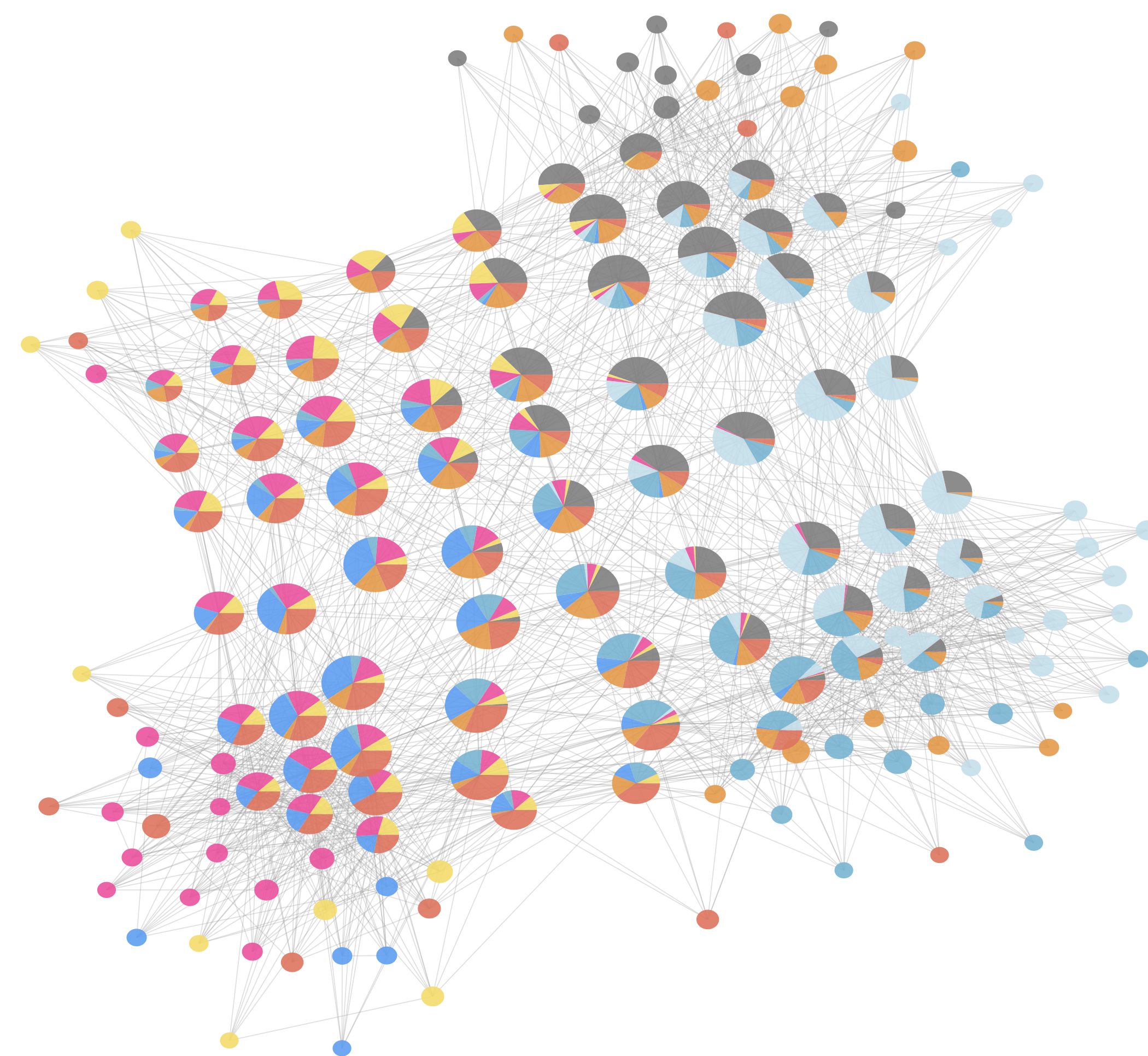
functional connectivity

edge time series



- one scan session of a subject
- Each node is a cluster of time points
- Pie charts indicate the proportion of tasks at time points in the clusters.



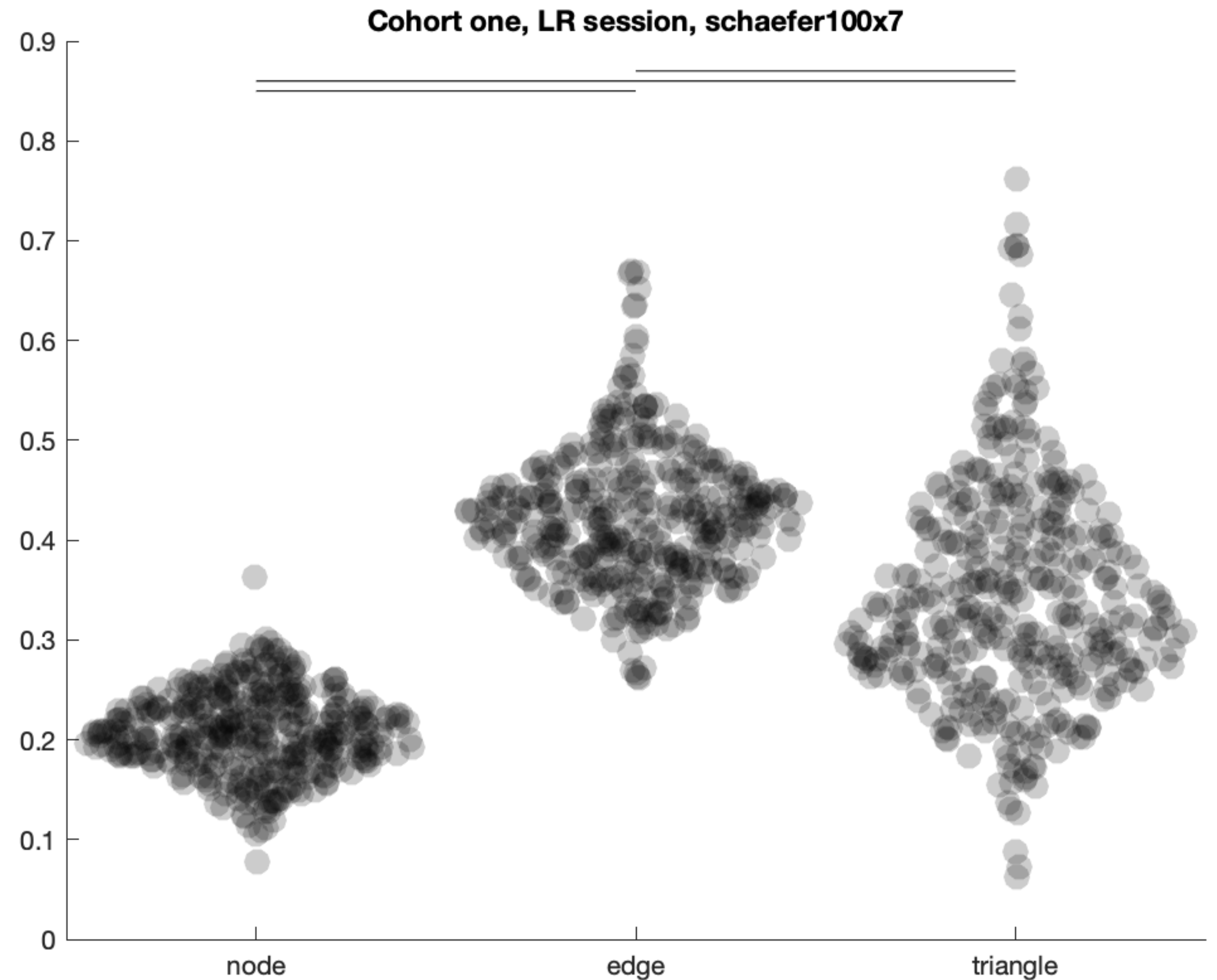


Quantification of Segregation by Task

- Consider a graph with n_V nodes.
- Denote by A the adjacency matrix. For every pair of nodes i and j , let
$$Q_{ij} = A_{ij} - \frac{(\deg i)(\deg j)}{n_V}.$$
- The modularity of the graph with respect to a partition of the nodes is the sum of the Q_{ij} 's for all in-group node pairs (i.e. i and j belong to the same subset in the partition).

Modularity across subjects

- Better metric (?)



Behavior?

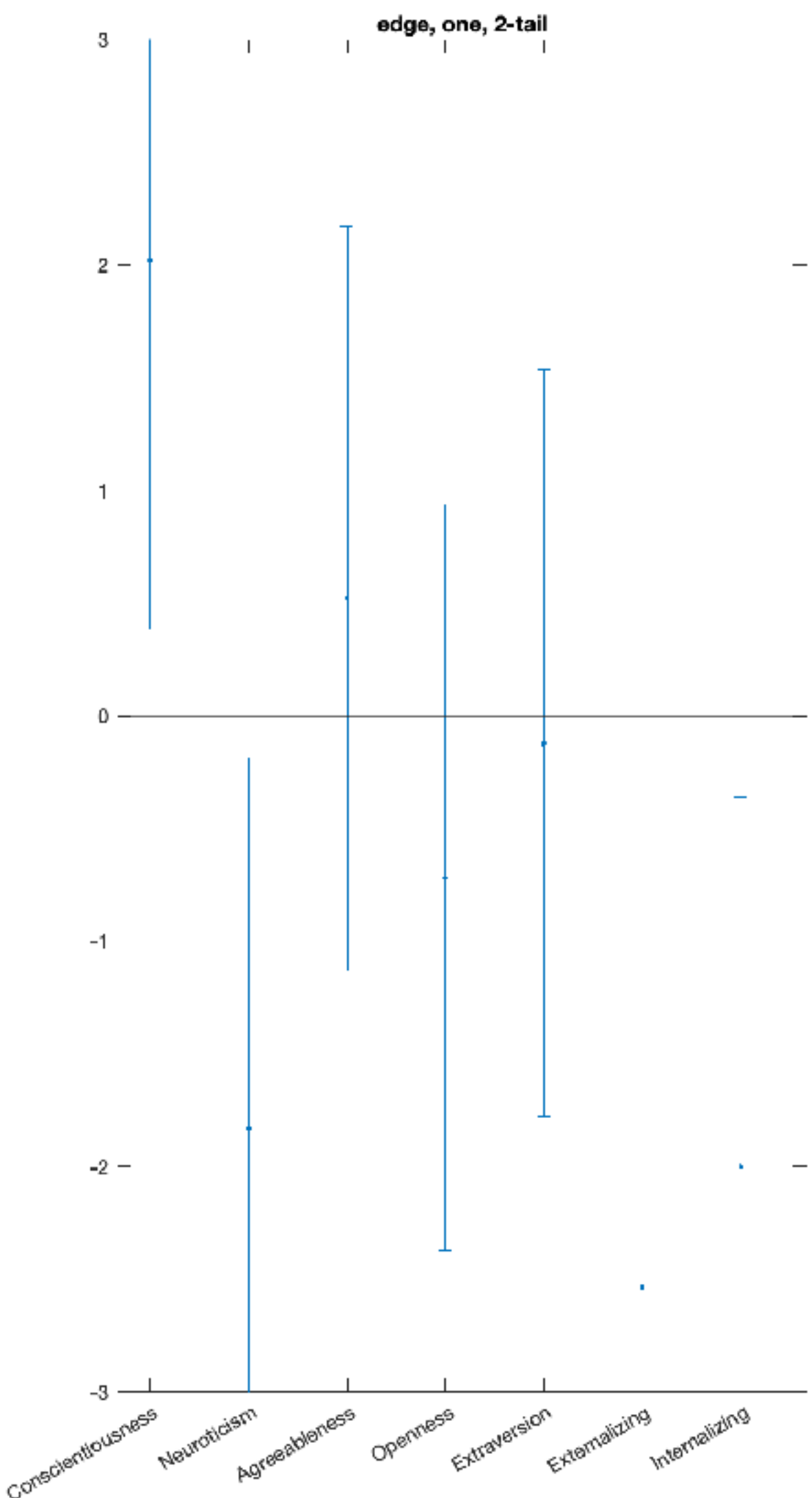
- personality
 - conscientiousness
 - neuroticism
 - agreeableness
 - openness
 - extraversion

Behavior?

- personality
 - conscientiousness
 - neuroticism
 - agreeableness
 - openness
 - extraversion
- pathology
 - internalizing behavior
 - externalizing behavior

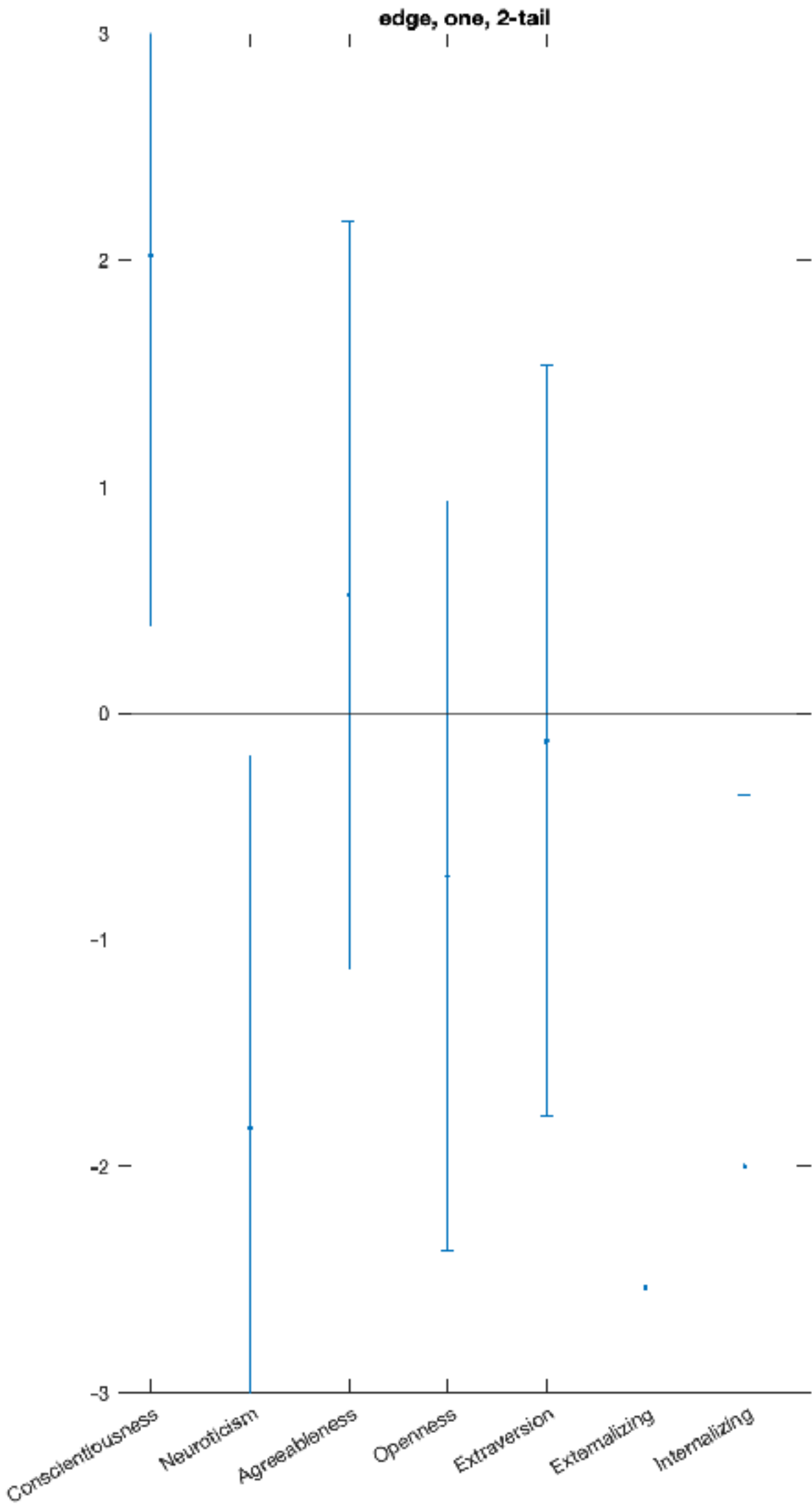
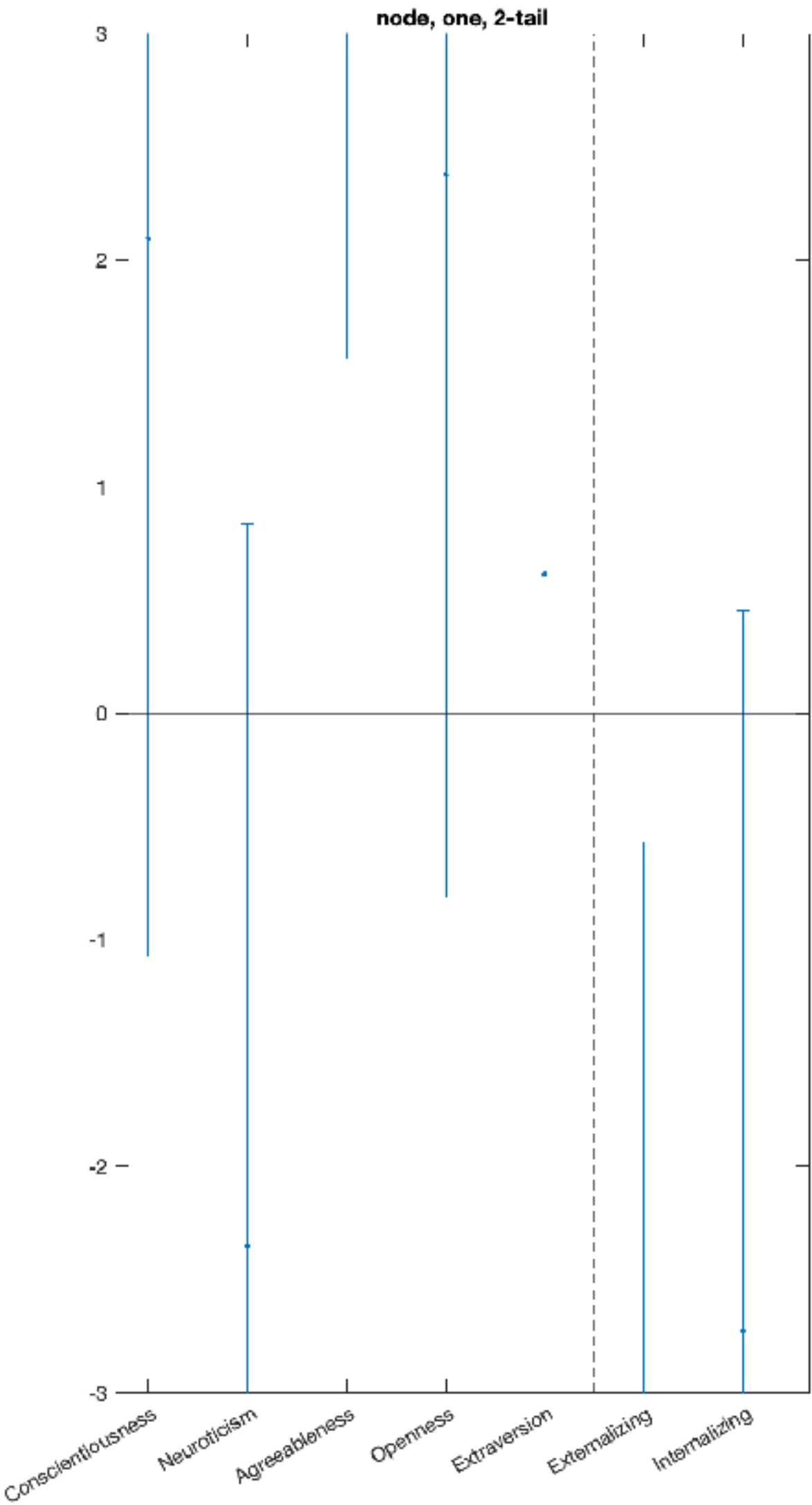
Behavior?

~400 subjects



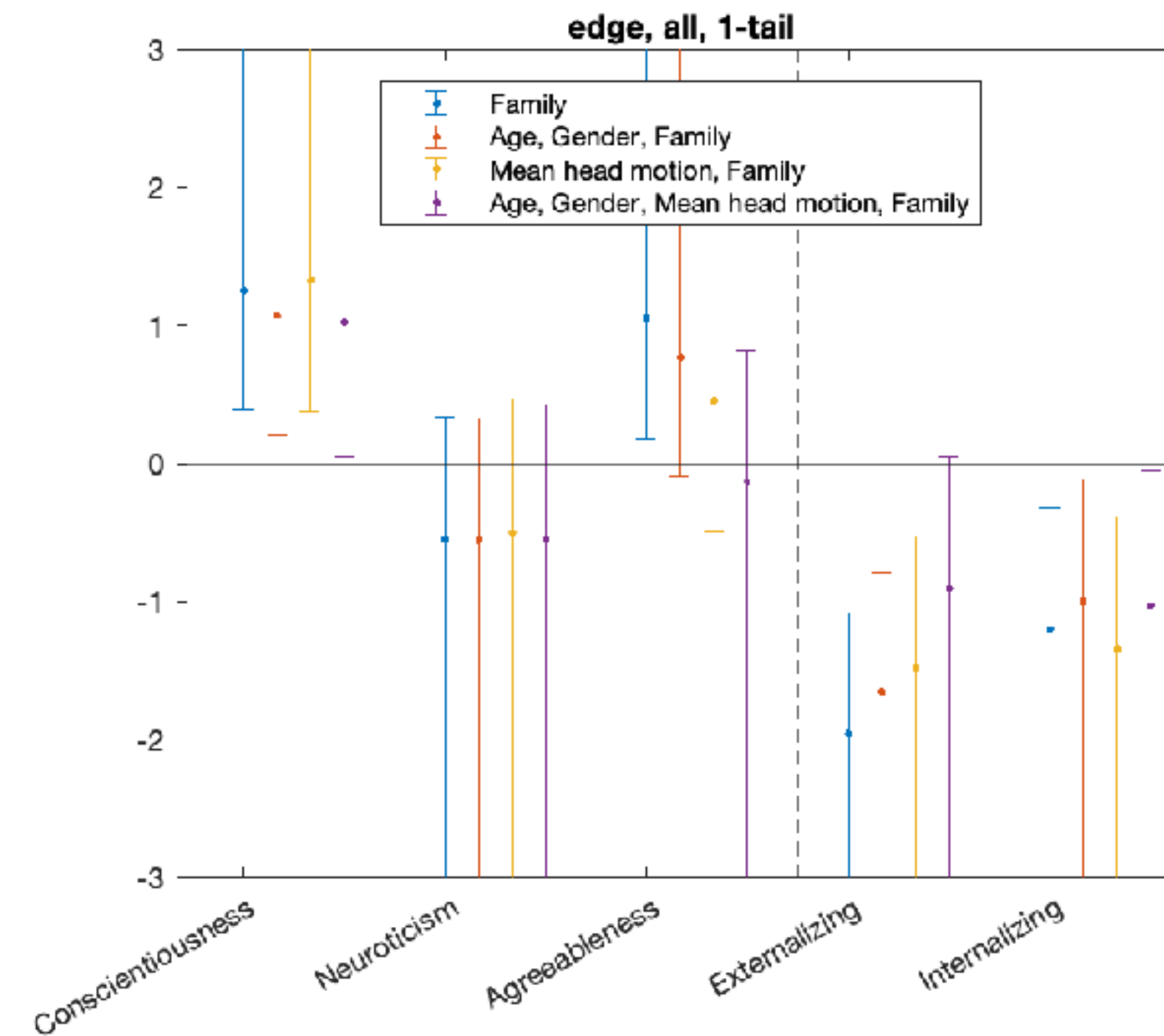
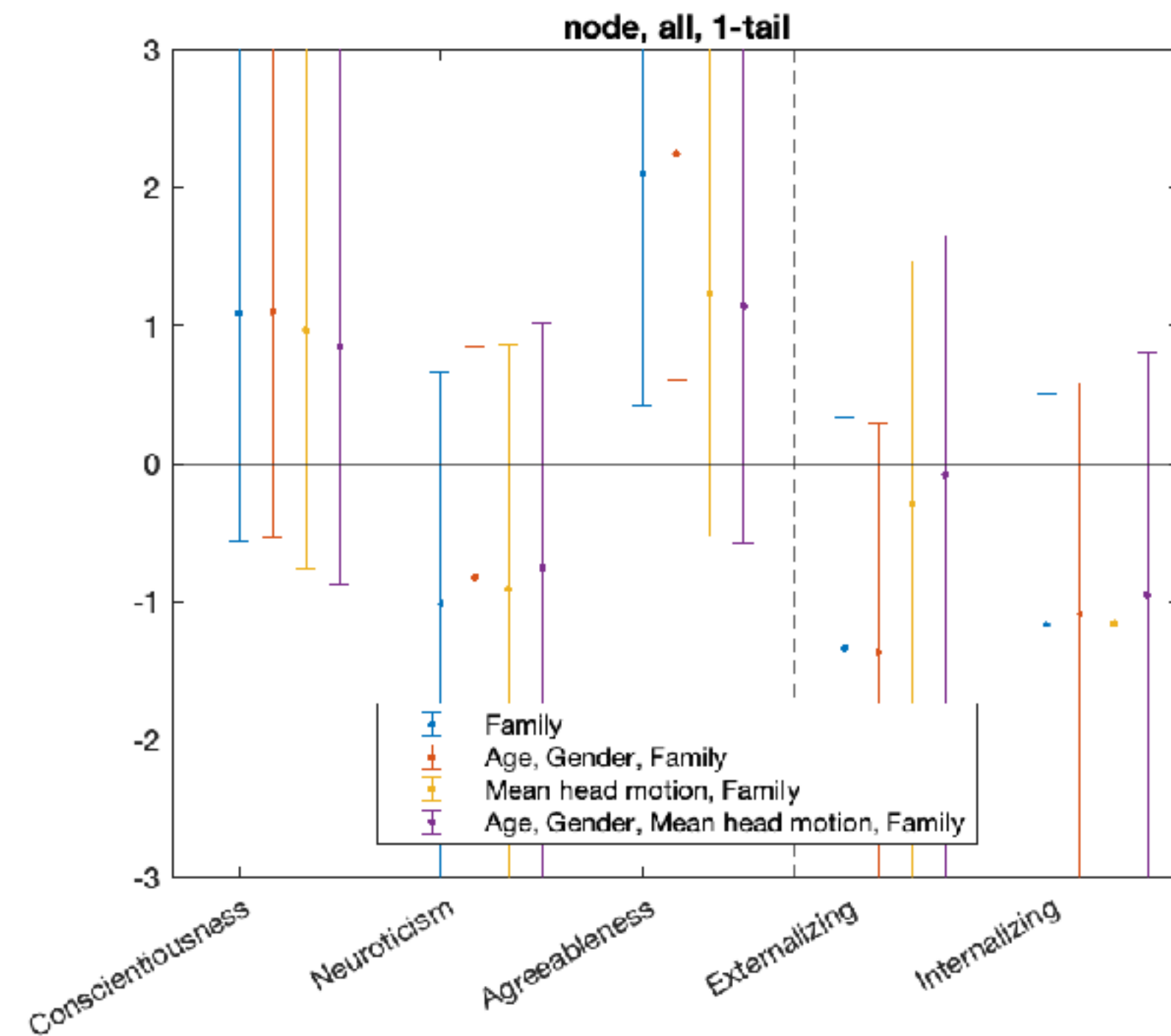
Behavior?

~400 subjects



Control for demographics and head motion

~1000 subjects



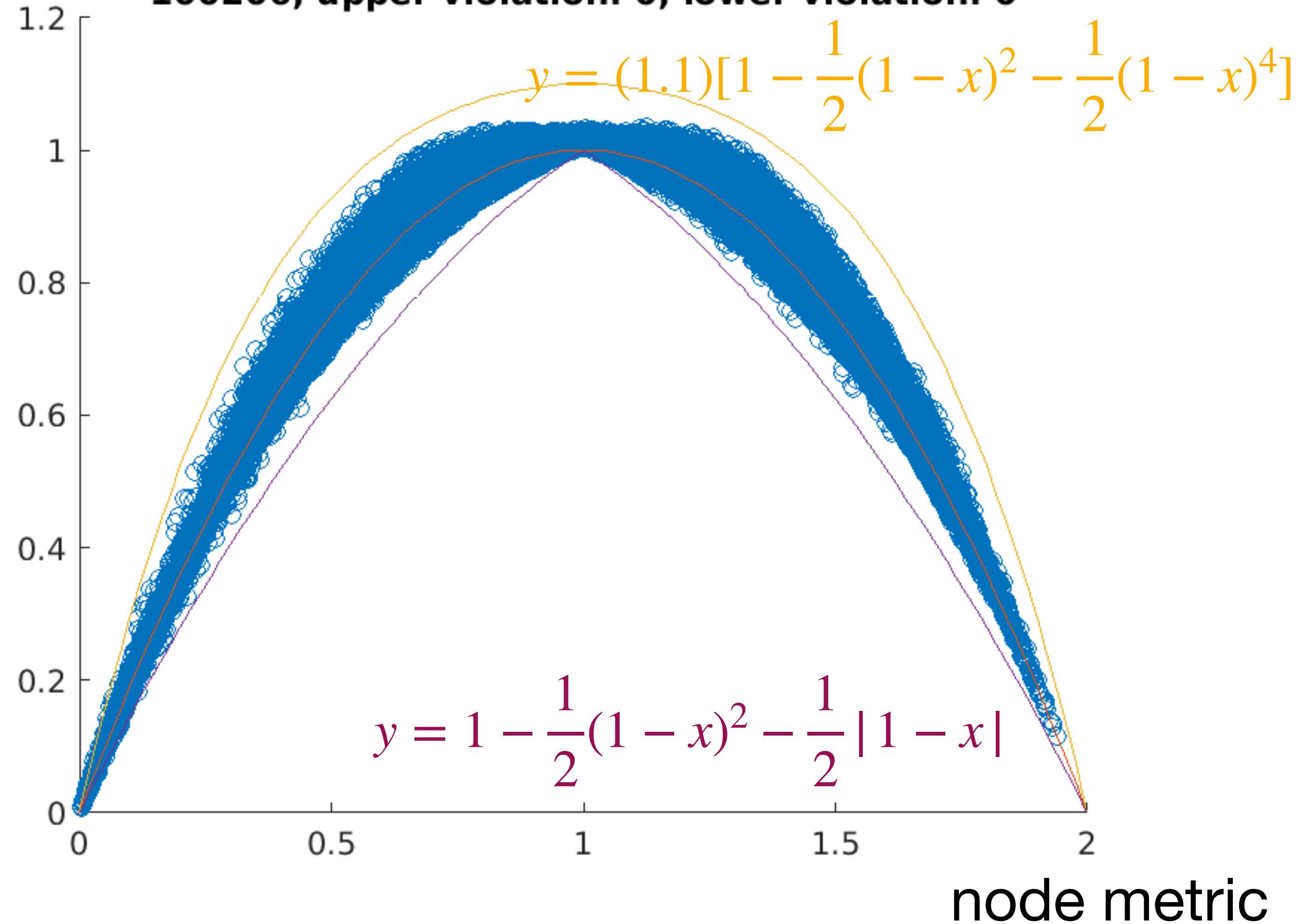
- Modularity increases with conscientiousness
- Modularity decreases with internalizing and externalizing behavior

What is with the edge time series metric?

- $y = 1 - (1 - x)^2$

edge metric

100206, upper violation: 0, lower violation: 0



The End... of the Beginning...

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- Mapper helps clinicians visualize fMRI data.

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- The resultant Mapper graph shows segregation by tasks.

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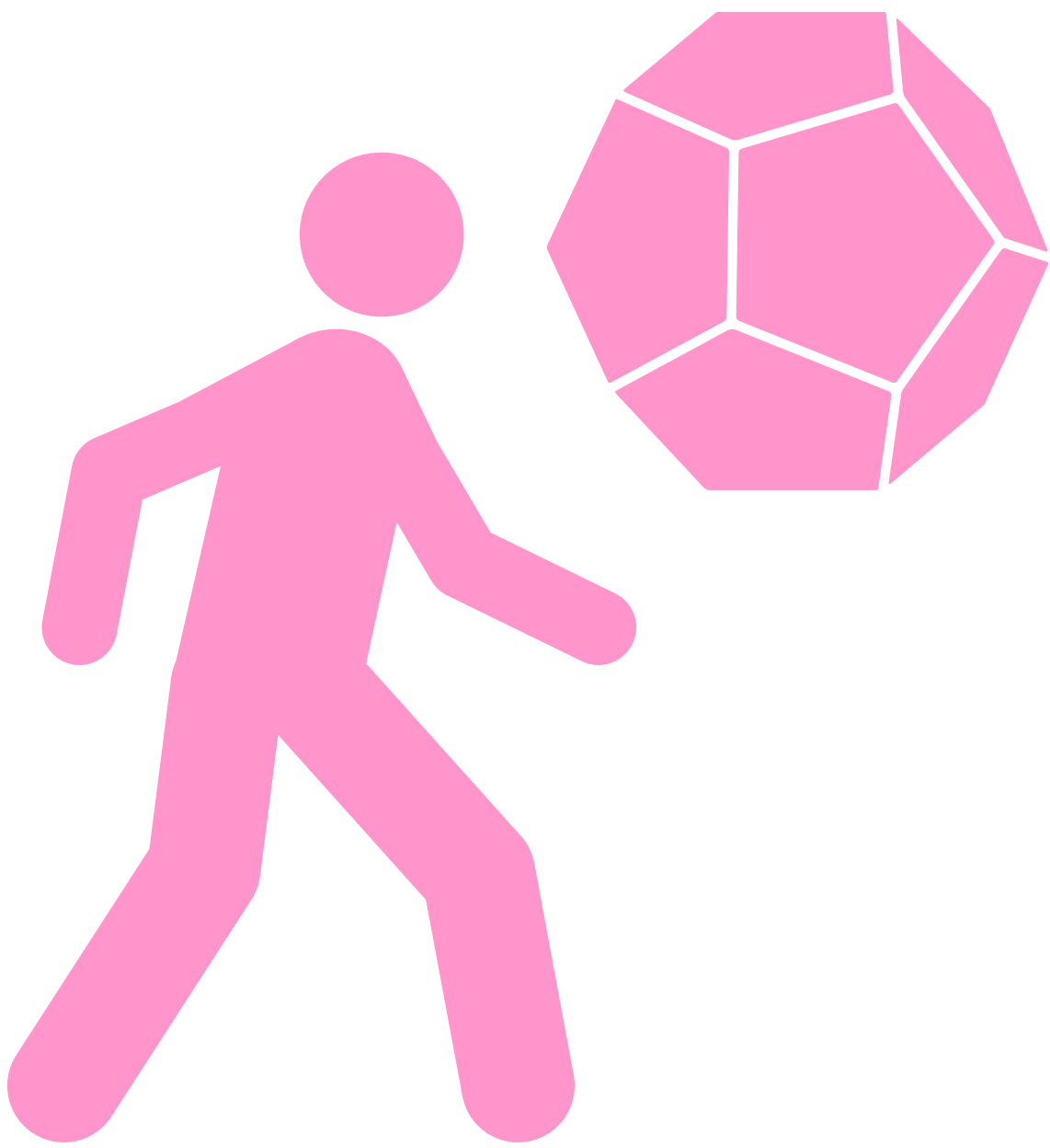
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The End... of the Beginning...

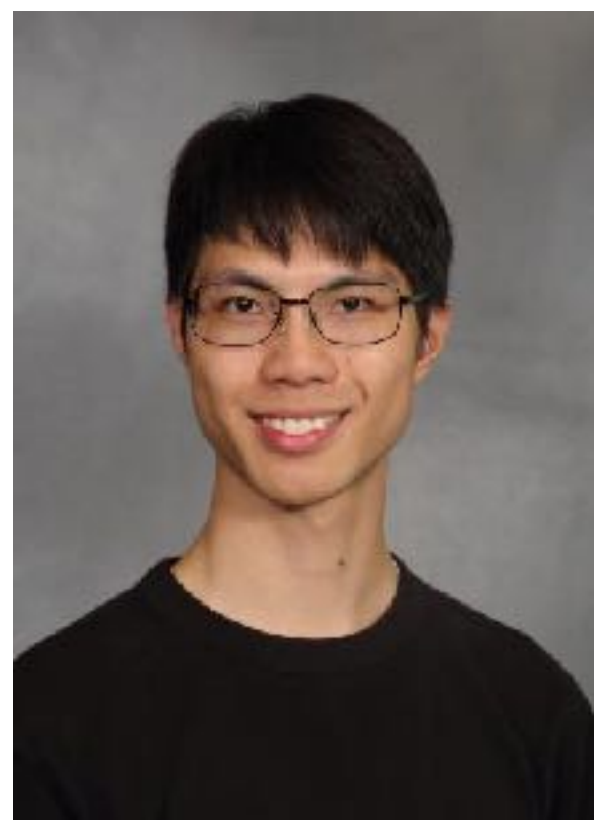
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- What is mental orderliness? How do we measure that?
- Is edge time series the right way to go beyond linear measures? How do we overcome noise?
- Can thought patterns of psychiatric patients be characterized? Topologically?



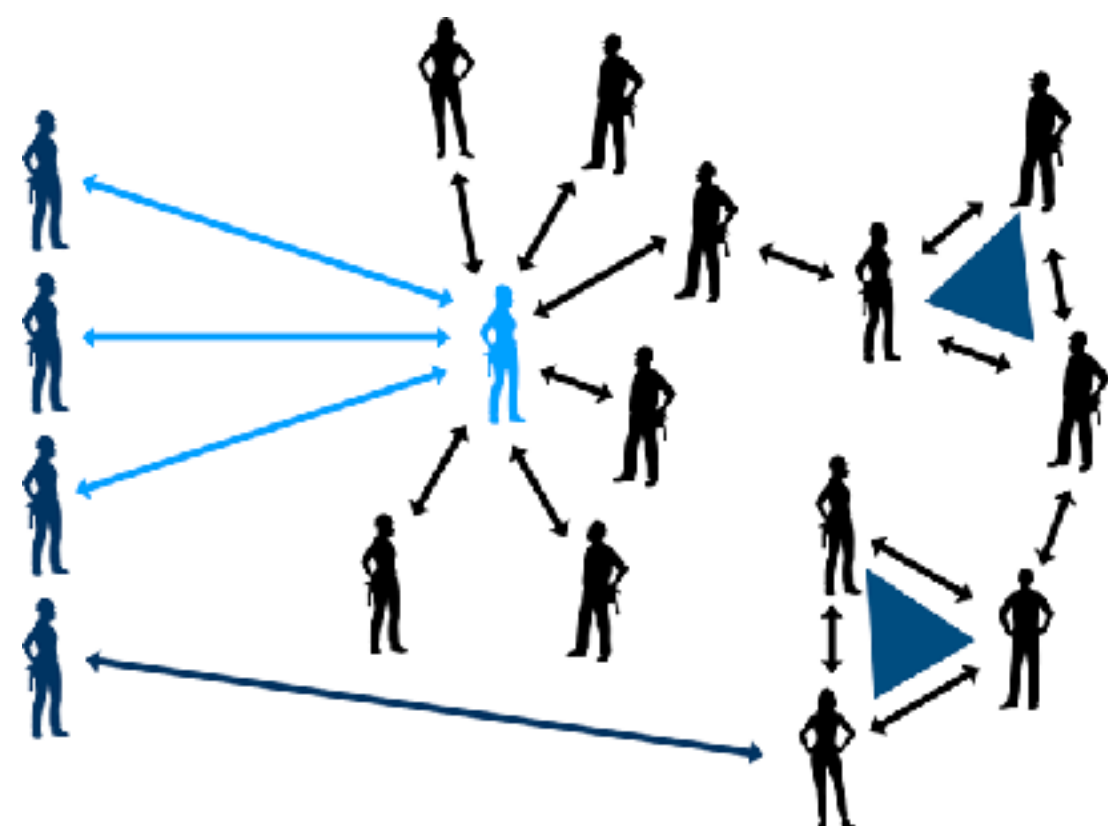
Preprint?

Preprint? — Not Yet

Preprint? — Not Yet, But...



my homepage



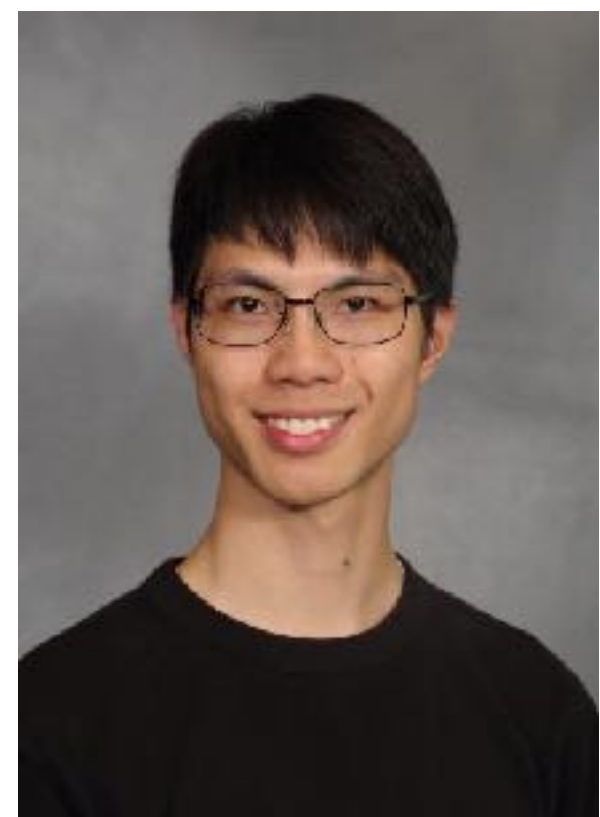
paper (homology, homotopy)



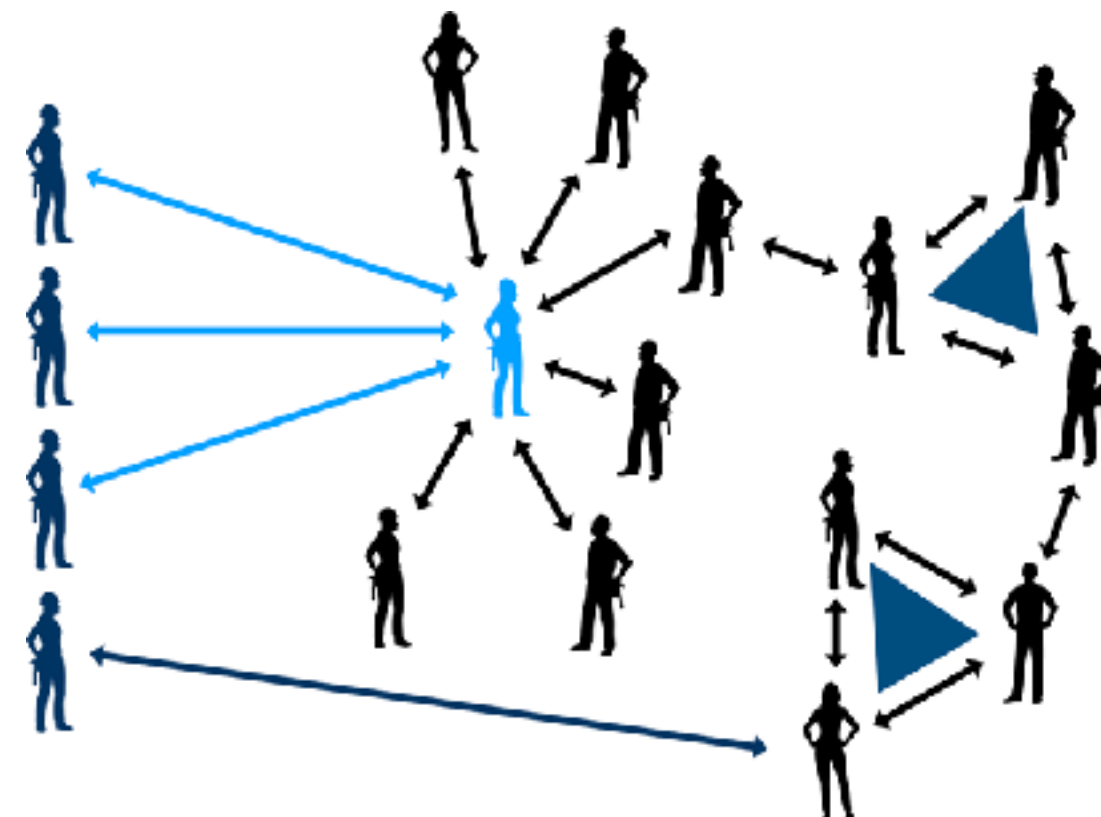
my video about small holes

Thank you!

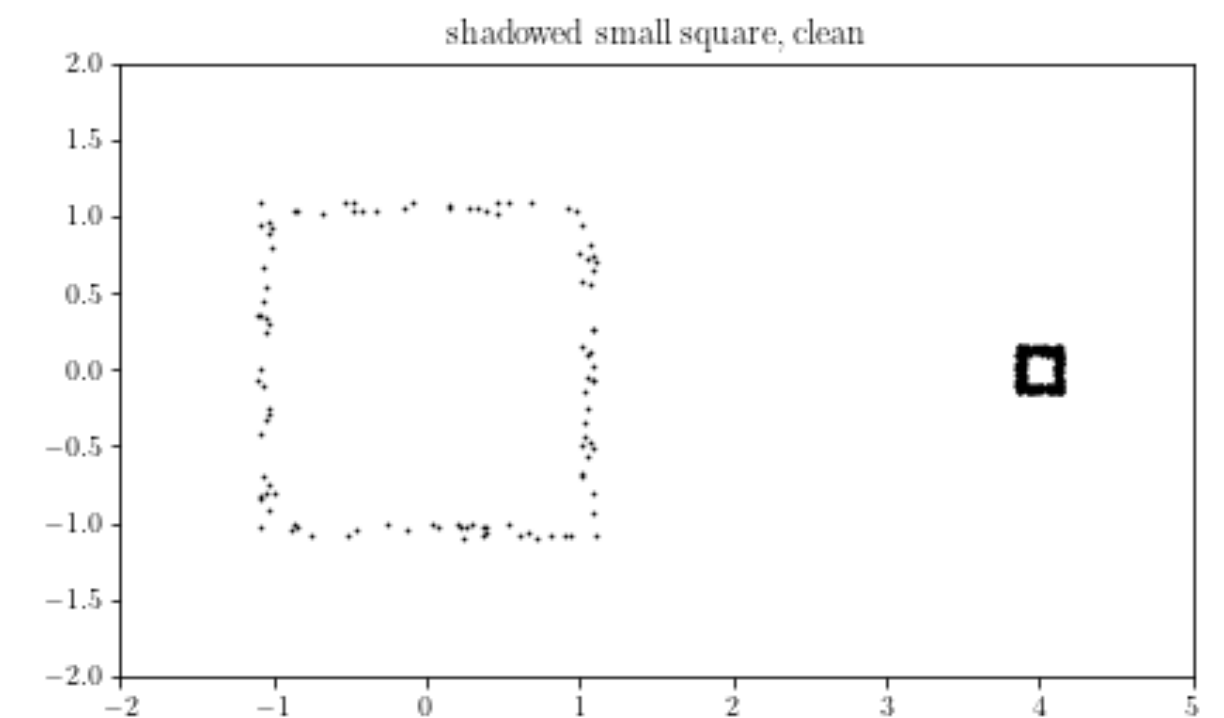
Chunyin Siu — siuc@stanford.edu



my homepage



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