

Is a whole insect brain connectome bilaterally symmetric?

A case study on comparing two networks

Benjamin D. Pedigo^{1*}, Mike Powell¹, Eric W. Bridgeford¹, Michael Winding², Carey E. Priebe¹, Joshua T. Vogelstein¹

1 - Johns Hopkins University, 2 - University of Cambridge, * - correspondence: [@bpedigo \(Github\)](mailto:bpedigo@jhu.edu) [@bpedigod \(Twitter\)](https://github.com/bdpedigo) bdpedigo.github.io

Summary

- Aimed to define bilateral symmetry for a connectome, and formally test this hypothesis.
- Hemispheres differ in a network-wide parameter under even the simplest model of a network pair.
- Hemispheres differ in neuron group connection probabilities, even when adjusting for the network-wide effect.
- Detect no differences in adjusted group connections after removing a cell type or when only considering strong edges.
- Provided a definition of bilateral symmetry exhibited by this connectome, tools for future connectome comparisons

Motivation

- Connectomes are rich sources of inspiration for architectures in artificial intelligence.
- Comparing connectomes could help elucidate which structural features are necessary for yielding the capabilities animal intelligences.
- Bilateral symmetry for connectomes has been investigated, but not clearly defined as a network hypothesis.

Larval *Drosophila* brain connectome

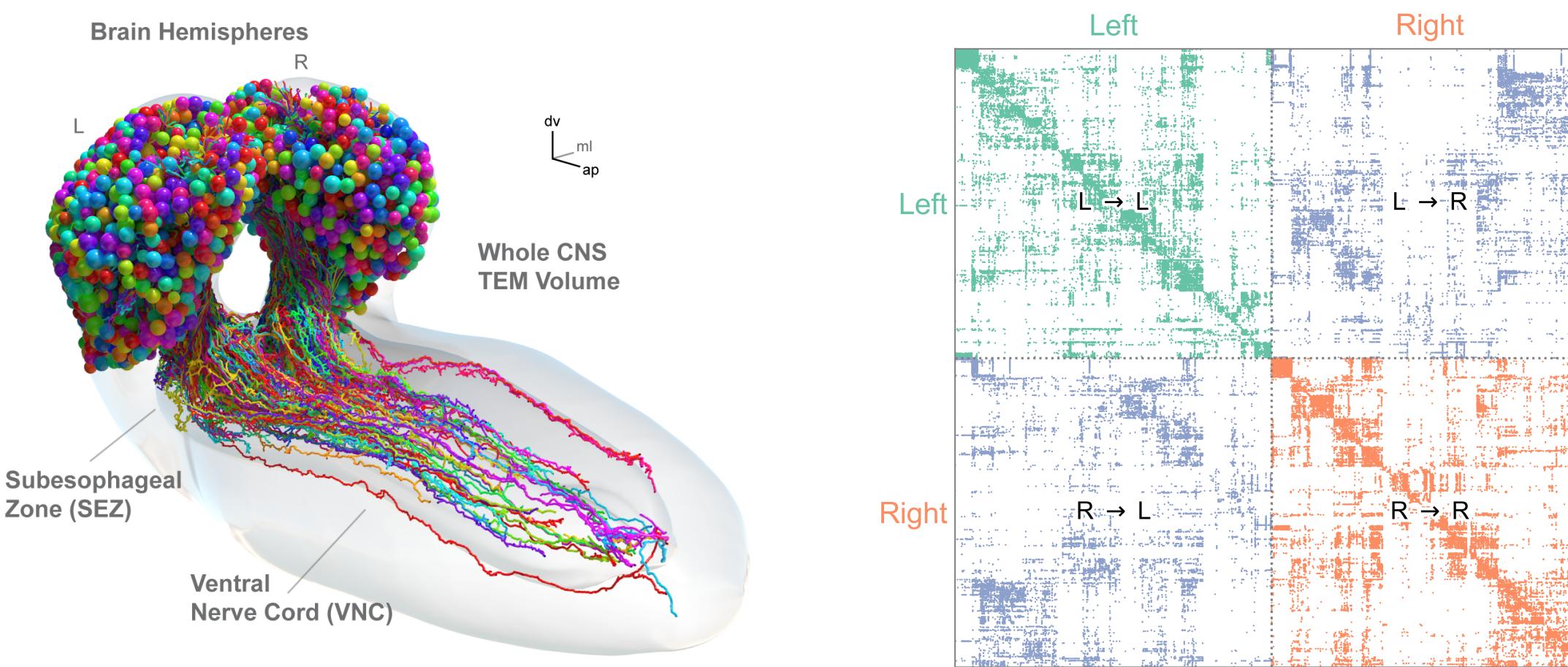


Fig 1A: 3D rendering of a larval *Drosophila* brain connectome [1] comprised of ~3k neurons and ~544k synapses.

Fig 1B: Directed, binary adjacency matrix sorted by brain hemisphere. We compare $L \rightarrow L$ vs. $R \rightarrow R$ subgraphs.

Are the left and right networks "different"?

Requires that we define what we could mean by "different" for a pair of networks, develop a test procedure for each definition.

Density test (Model 1)

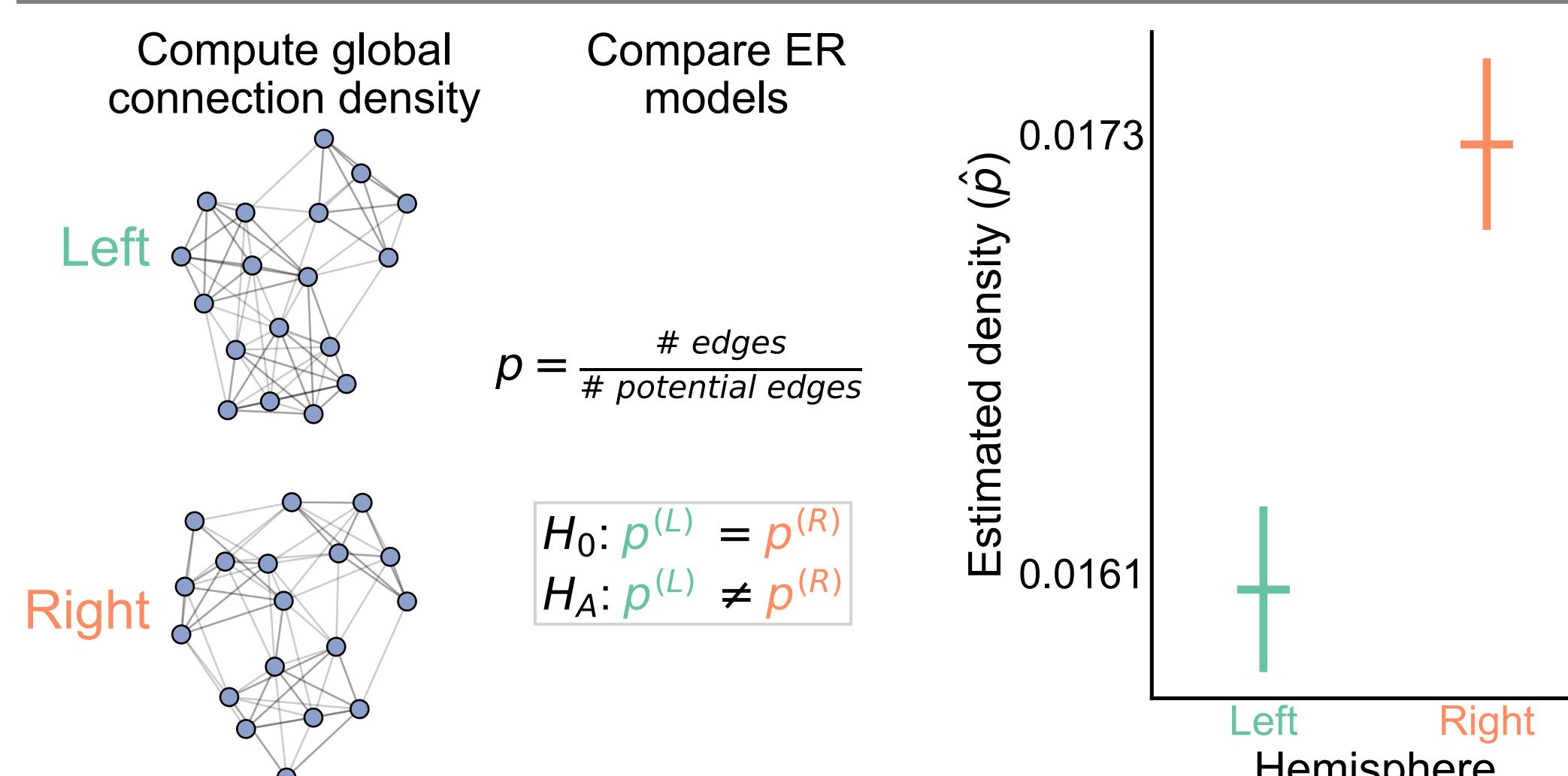


Fig 2A: Testing symmetry under Erdos-Renyi (ER) model [2] amounts to comparing densities (here via Fisher's exact test).

Fig 2B: Densities are significantly different between hemispheres ($p < 10^{-23}$).

Group connection test (Model 2)

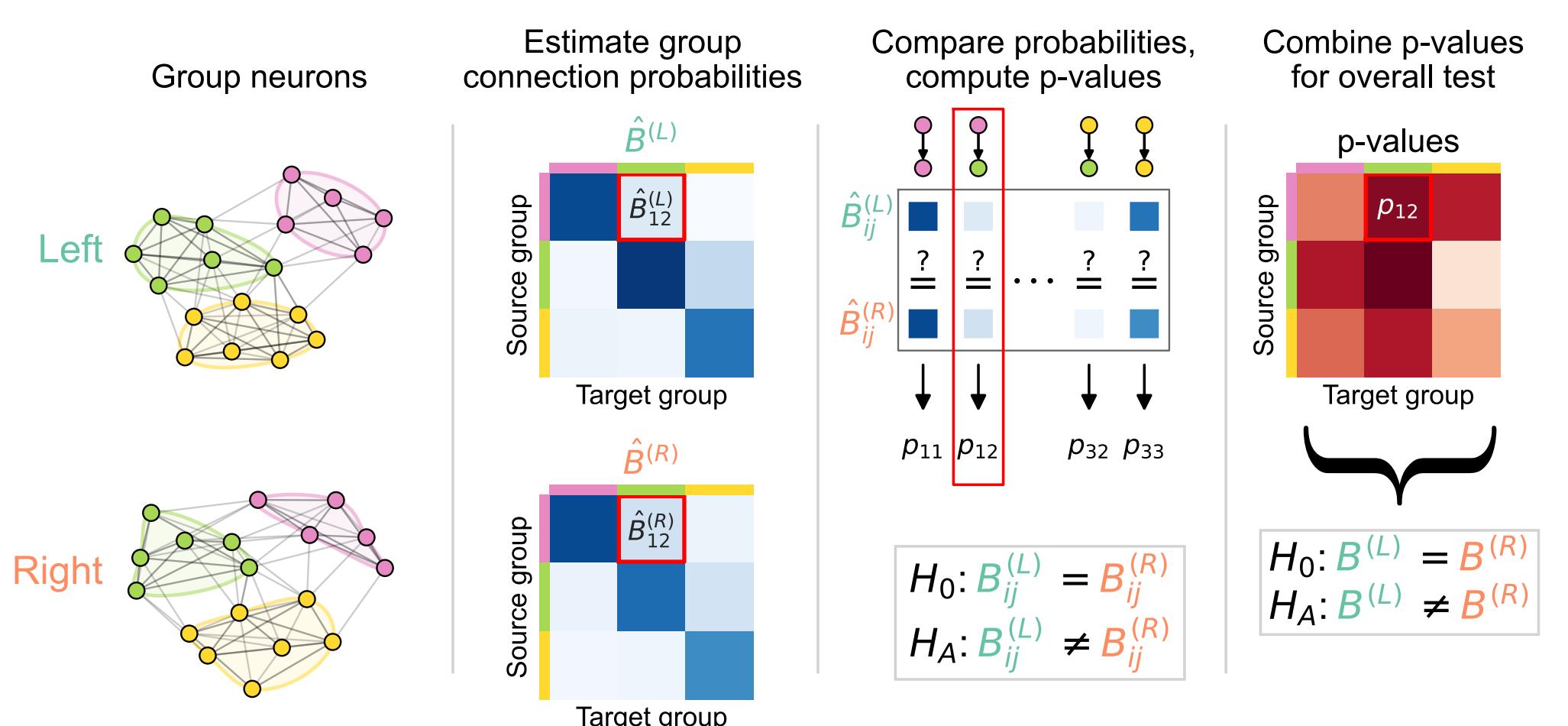


Fig 3A: Testing under stochastic block model (SBM) compares probabilities of connections between groups (here using cell types).

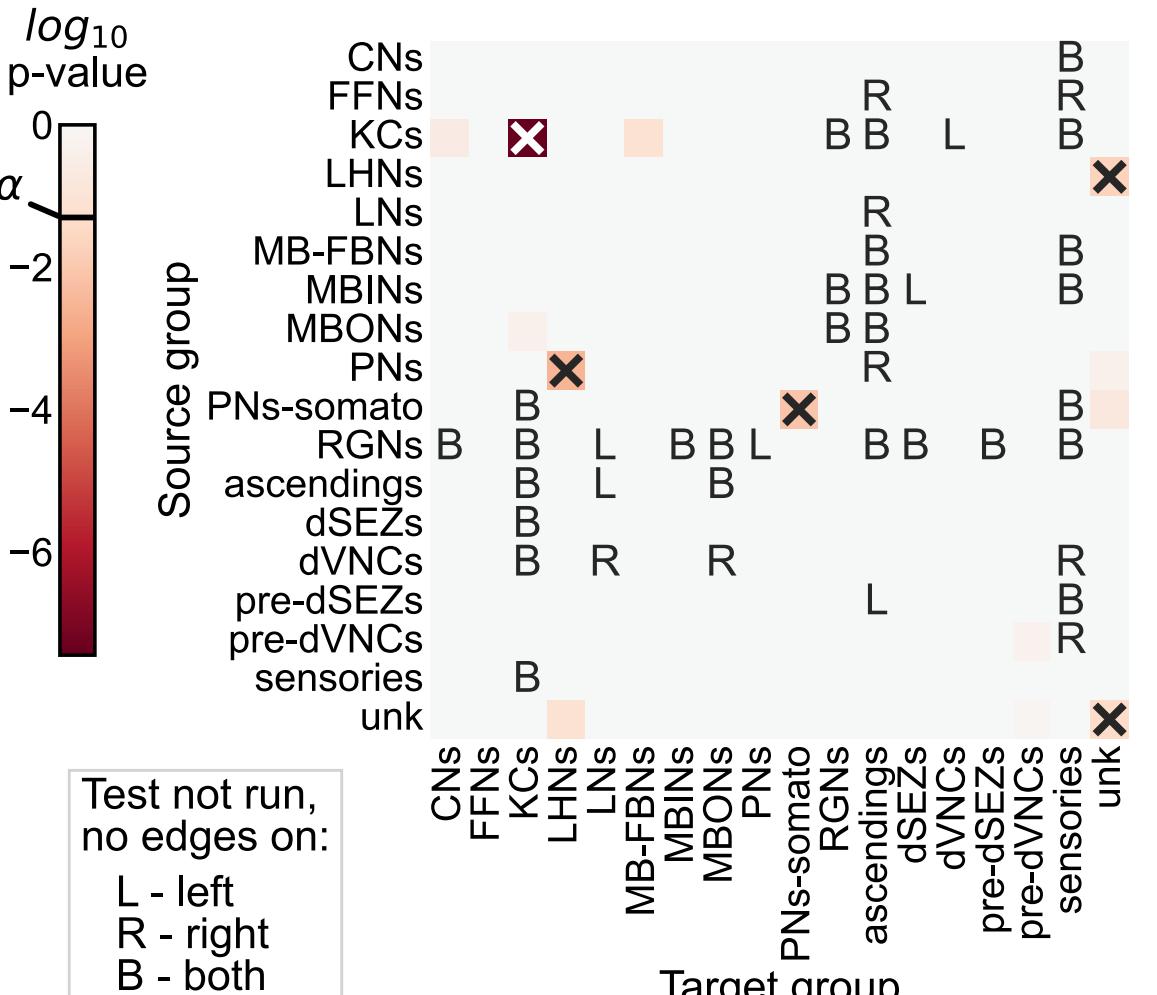


Fig 3B: Test comparing group connections rejects ($p < 10^{-7}$); five specific connections differ.

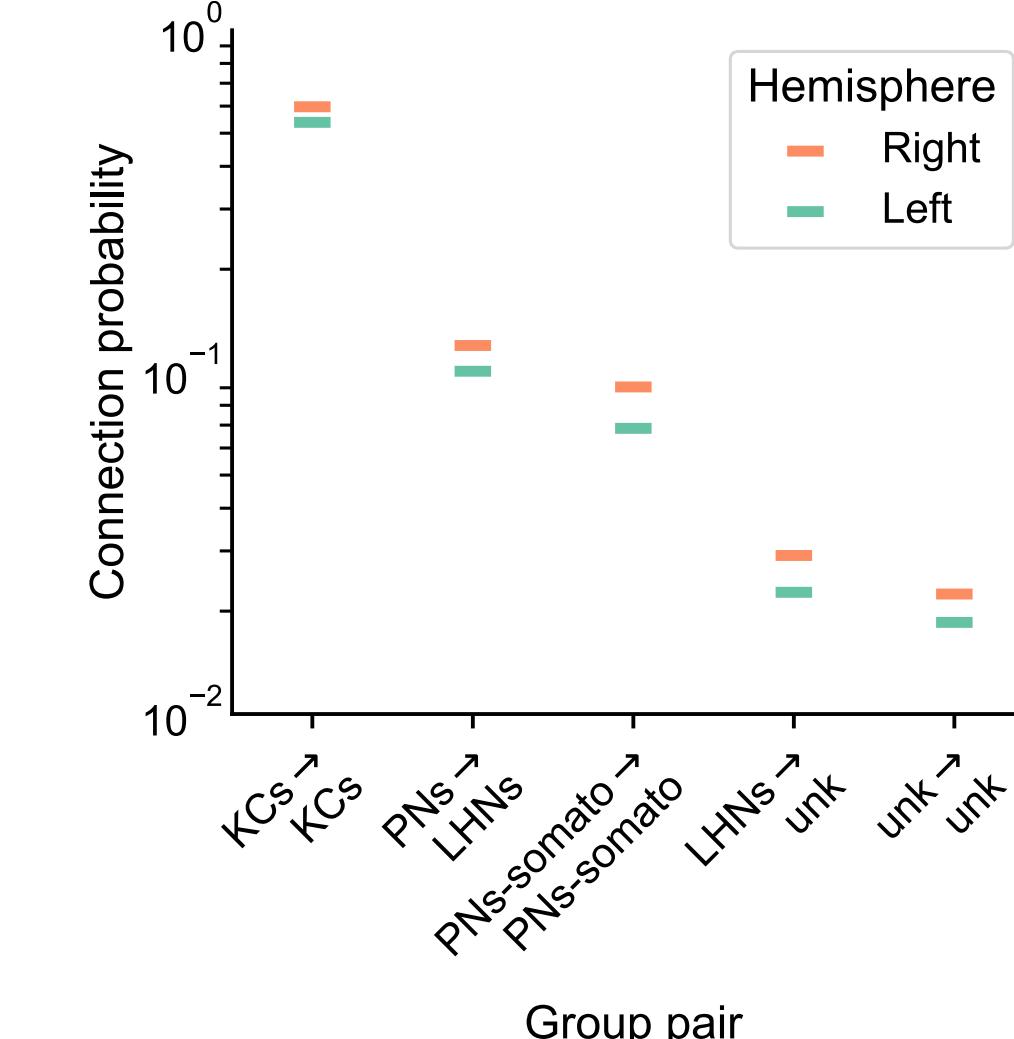


Fig 3C: For significant group connections, denser hemisphere probability is always higher.

Density-adjusted group connection test (Model 3)

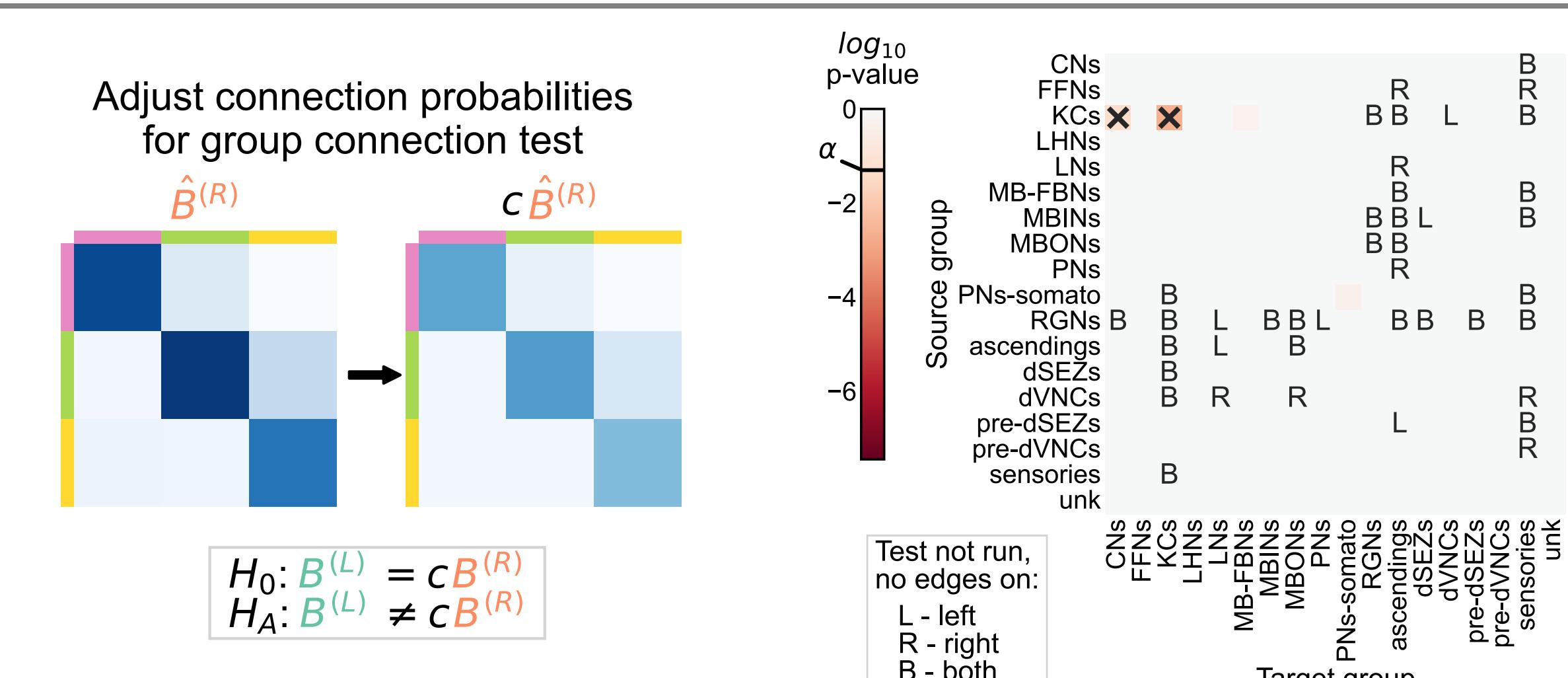


Fig 4A: Hypothesis from Fig 3 modified by a factor c set to make densities equal.

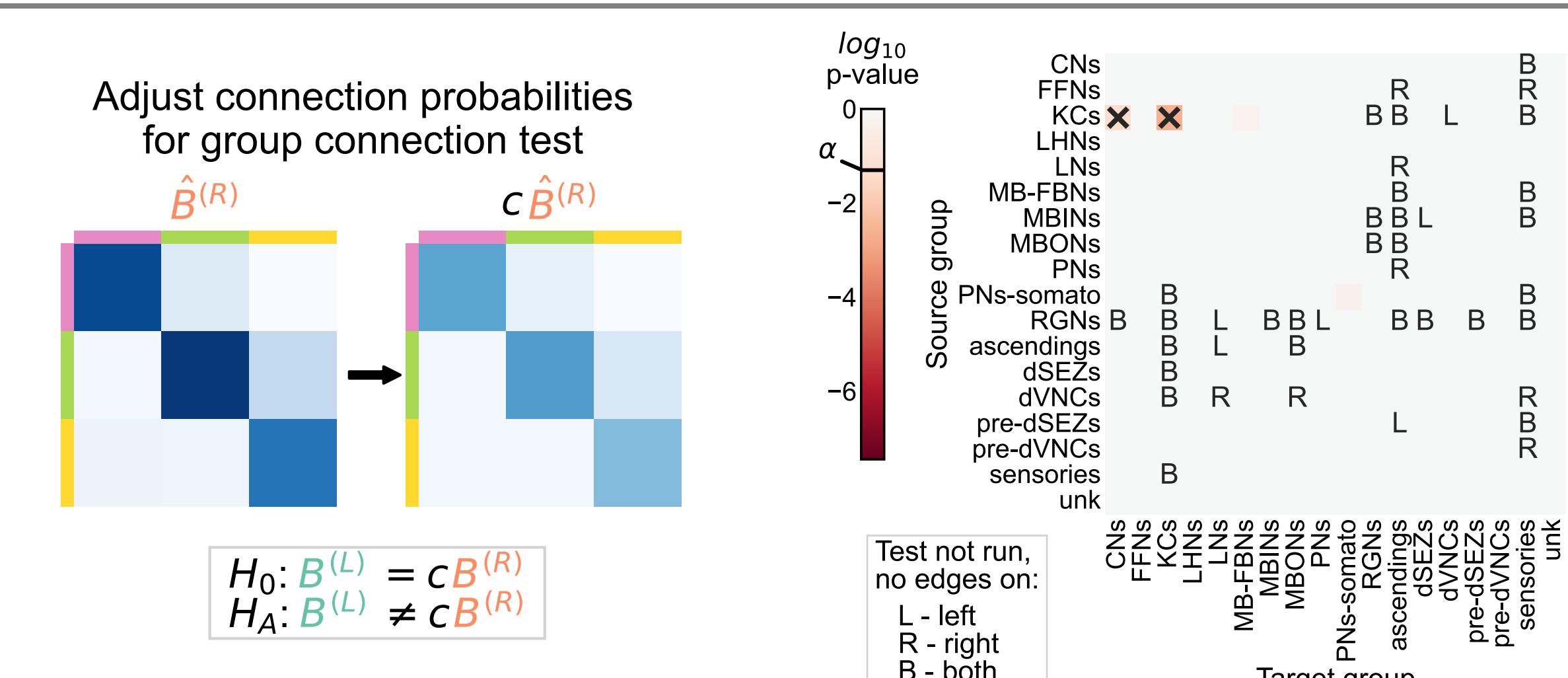


Fig 4B: Test comparing adjusted group connections rejects ($p < 10^{-2}$); two differing connections from KCs.

Notions of bilateral symmetry

With Kenyon cells

| Model | H_0 (vs. $H_A \neq$) | p-value |
|-------|-------------------------|--------------|
| 1 | $p^{(L)} = p^{(R)}$ | $< 10^{-23}$ |
| 2 | $B^{(L)} = B^{(R)}$ | $< 10^{-7}$ |
| 3 | $B^{(L)} = cB^{(R)}$ | $< 10^{-2}$ |

Without Kenyon cells

| Model | H_0 (vs. $H_A \neq$) | p-value |
|-------|-------------------------|--------------|
| 1 | $p^{(L)} = p^{(R)}$ | $< 10^{-26}$ |
| 2 | $B^{(L)} = B^{(R)}$ | $< 10^{-2}$ |
| 3 | $B^{(L)} = cB^{(R)}$ | 0.51 |

Edge weight thresholds

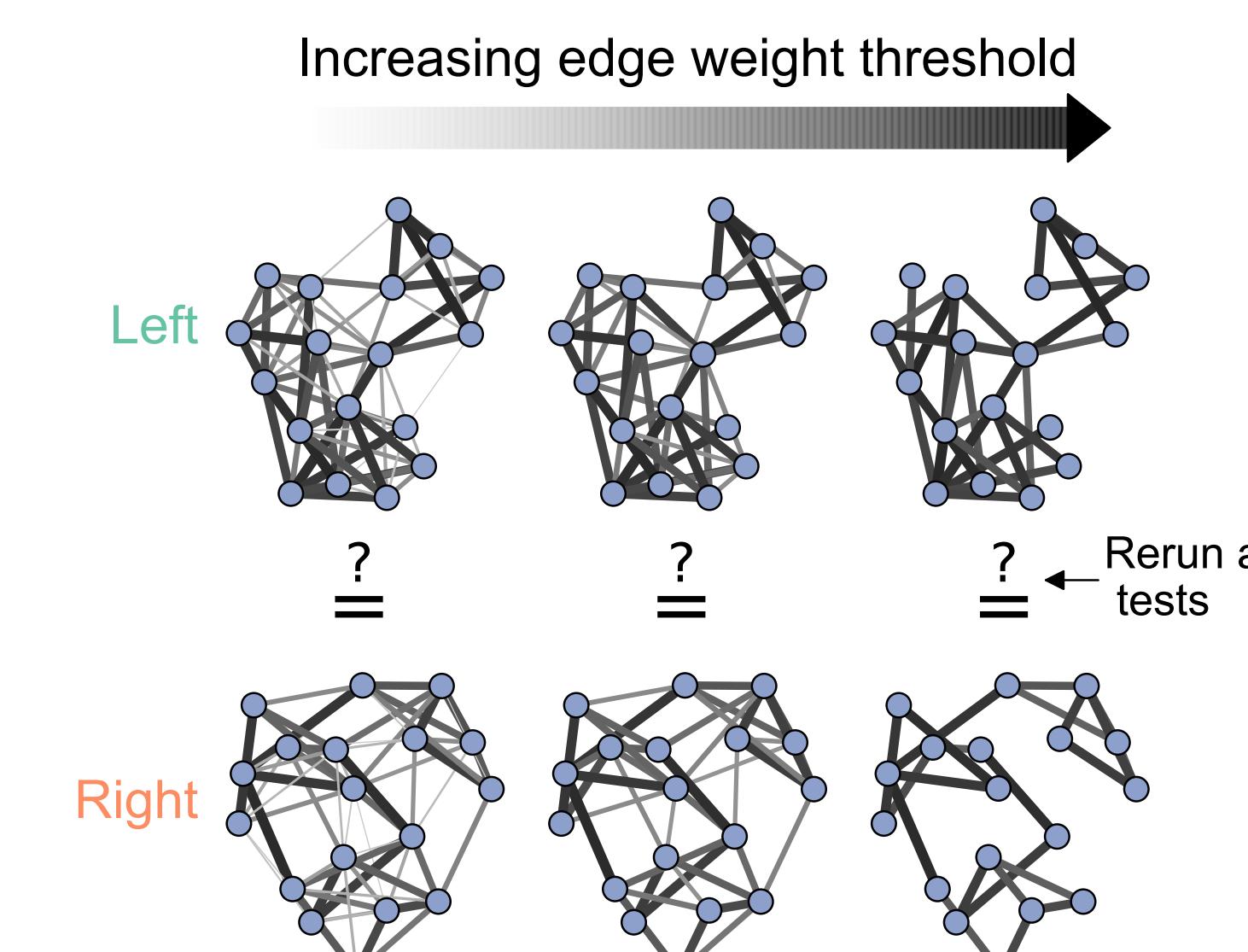


Fig 5A: Removed edges w/ weight (synapse count or percentage of input to downstream neuron) below some threshold, tested symmetry for each pair of networks.

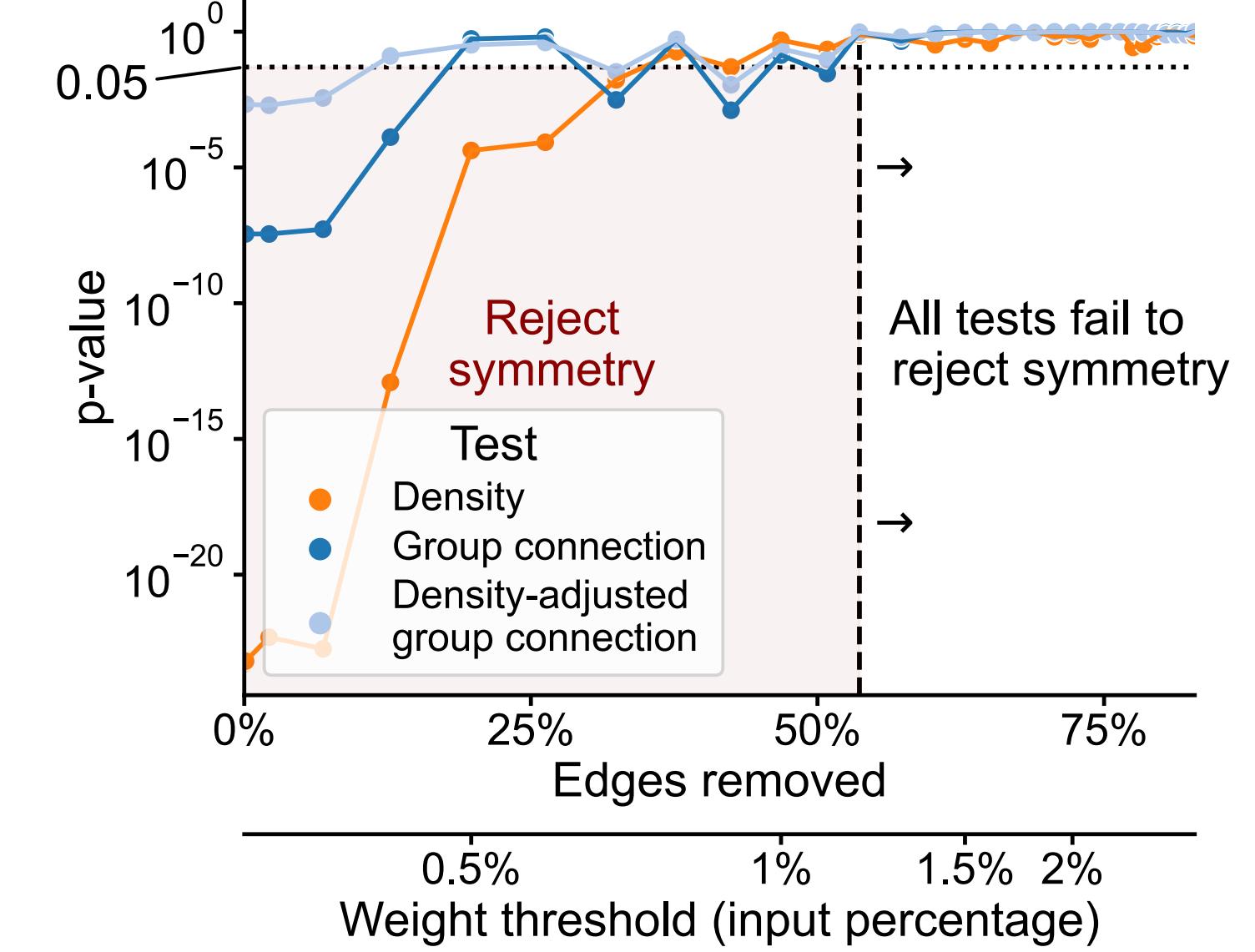


Fig 5B: Higher edge weight thresholds generally made networks more symmetric. Less apparent when using synapse counts as edge weights (not shown).

Limitations and extensions

- Other models to consider (e.g. random dot product graph [3])
- Other sensible neuron groupings for group connection test
- Matching nodes between networks - leads to different models, likely with more power

Code



downloads 116k
Stars 245



This work

jupyter book



References

- [1] Winding, Pedigo et al. "The complete connectome of an insect brain," In preparation (2022)
- [2] Chung et al. "Statistical connectomics," Ann. Rev. Statistics and its Application (2021)
- [3] Athreya et al. "Statistical inference on random dot product graphs: a survey," JMLR (2017)

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