Comparing Perturbation Models for Evaluating Stability of Neuroimaging Pipelines

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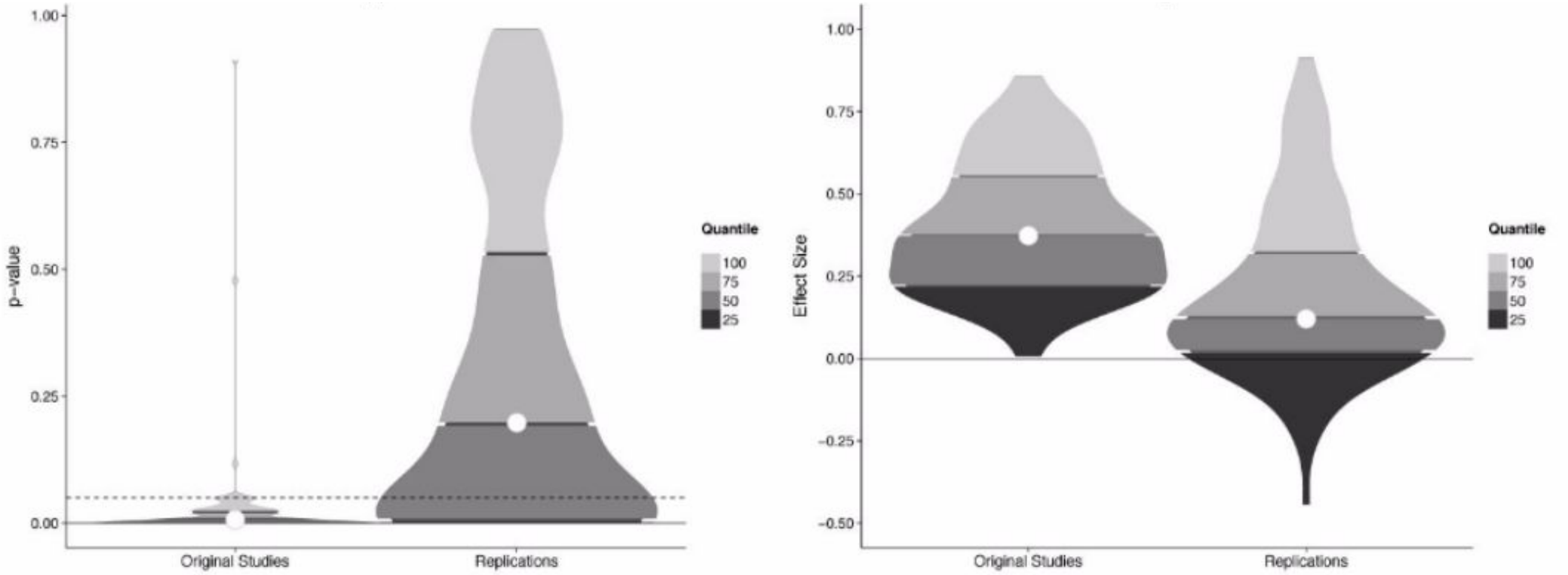
Overview

- Topics in reproducibility
- Operationalizing Stability
- Evaluation of a Neuroimaging Pipeline

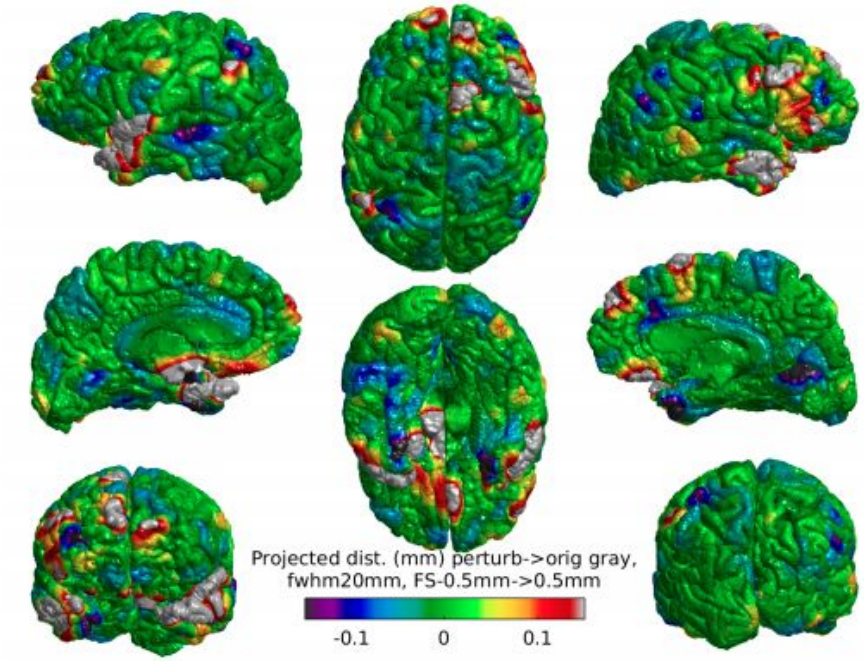
Reproducibility is Measurable



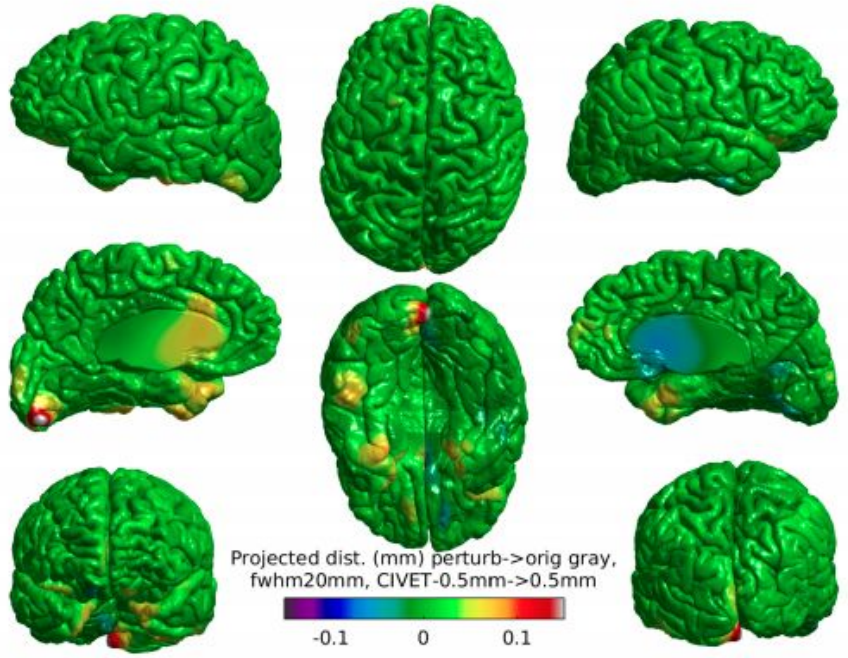
(Open Science Collaboration, 2015)

Contributing Factor: Instability

1-voxel noise injections at 1% intensity



Freesurfer

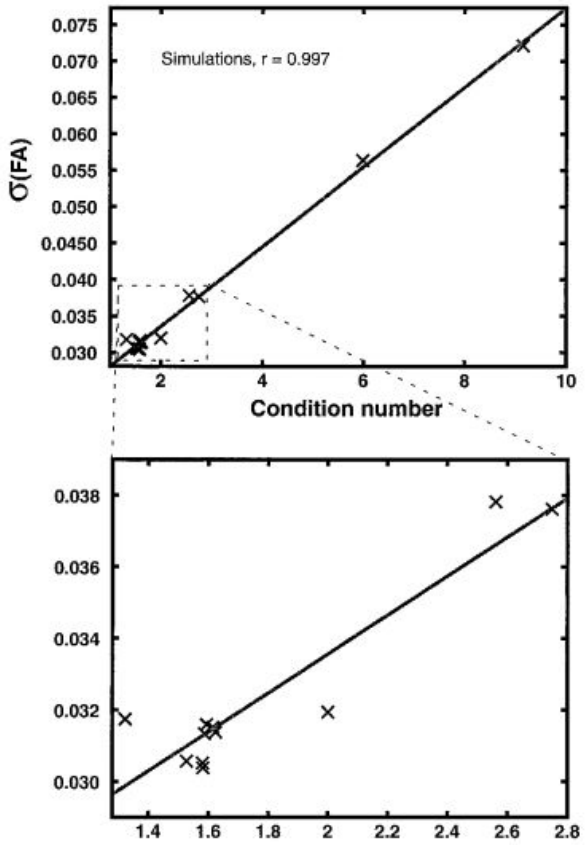


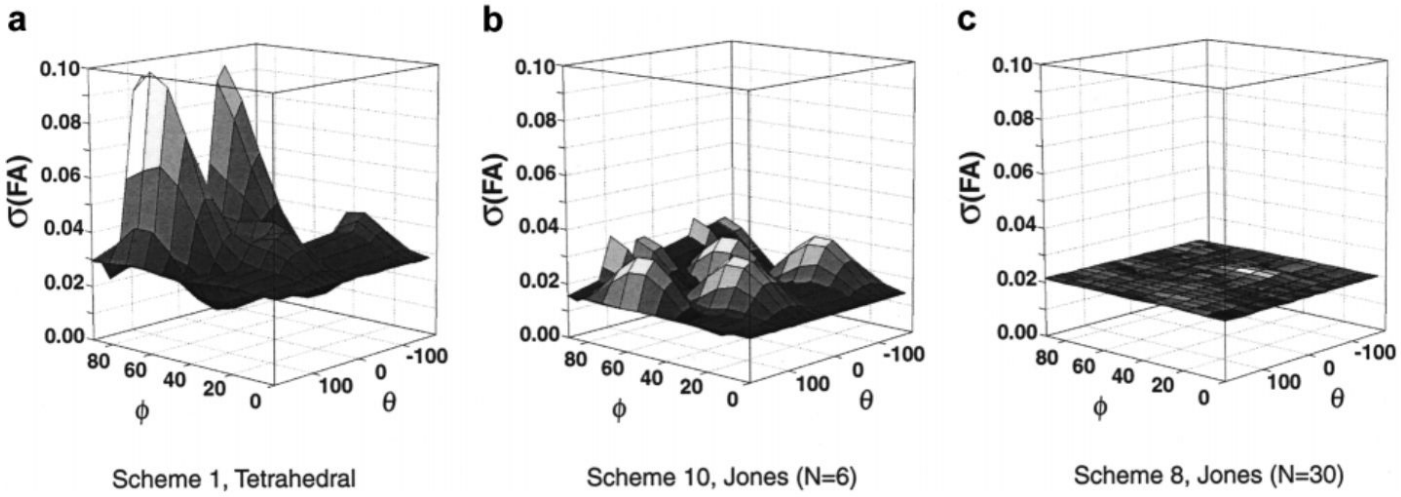
CIVET

(Lewis et al., 2017)

(Lewis, 2017)

Instabilities can* be Anticipated





*sometimes

(Skare et al., 2000)

Monte Carlo Arithmetic (MCA)

Inexact FP quantities become random variables

$$\widetilde{x} \quad = \quad \mathsf{inexact}\,(x,\, s,\, \xi) \quad = \quad x \;+\; 2^{e-s}\,\xi \qquad \text{where } e \text{ is the order of magnitude of } x$$

$$t\_\mathsf{digit\_precision}\,(x) \quad = \quad \begin{cases} x & \text{if } x \text{ can be expressed exactly with } t \text{ digits} \\ \mathsf{inexact}\,(x,\, t,\, \xi) & \text{otherwise.} \end{cases}$$

(Parker et al., 1997)

Setup

Compile C/C++/Fortran lib with Verificarlo

Instrumentation

1. if floating point operation:
2. {float, double} -> {double, quad}
3. (PB) simulate unrounding
4. perform operation
5. (RR) simulate rounding
6. {double, quad} -> {float, double}
7. endif

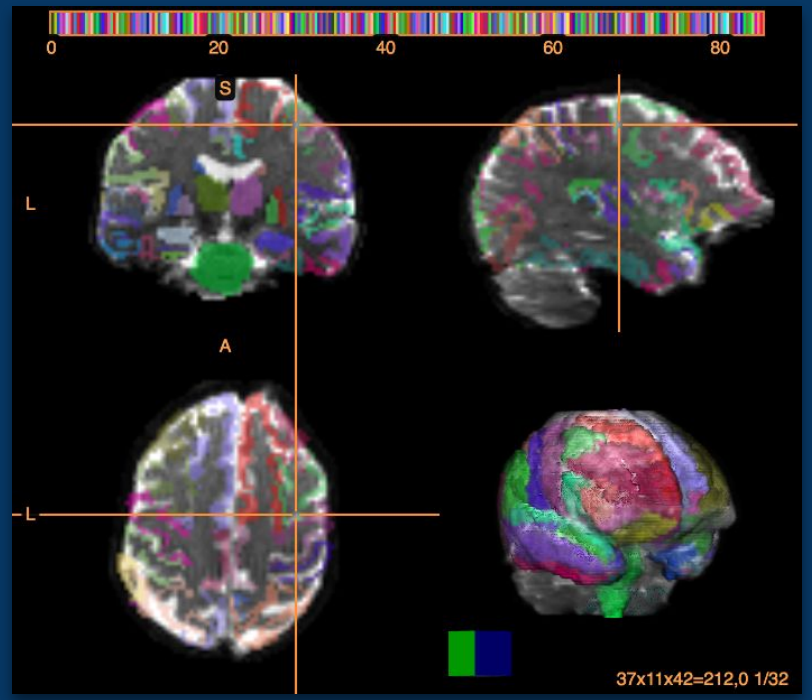
} MCA

Objective:

Perturb a neuroimaging pipeline and observe induced instabilities

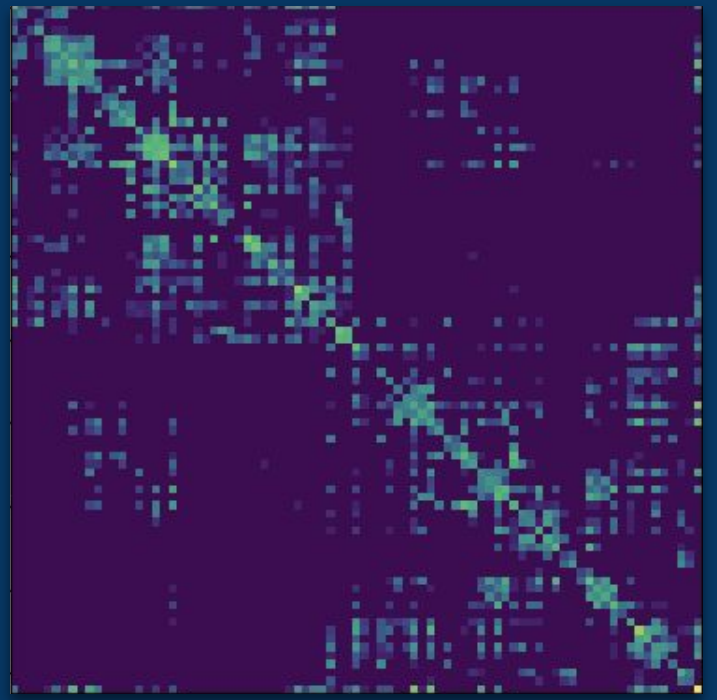
Data in Structural Connectomics

Diffusion MRI Volumes + Labels



(X, Y, Z, D) ~ O(10M voxels)

Connectivity Matrix



(83, 83) = 3403 edges

Perturbation Models

MCA

Instrument all FLOPs with...

- Full MCA
- RR only (less aggressive)

1-voxel noise

Double image intensity in...

- Single (1 vox / (X, Y, Z, D))
- Independent (1 vox / (X, Y, Z))

We Instrumented...

- Python
- Cython libs
- Numpy
- BLAS
- Lapack

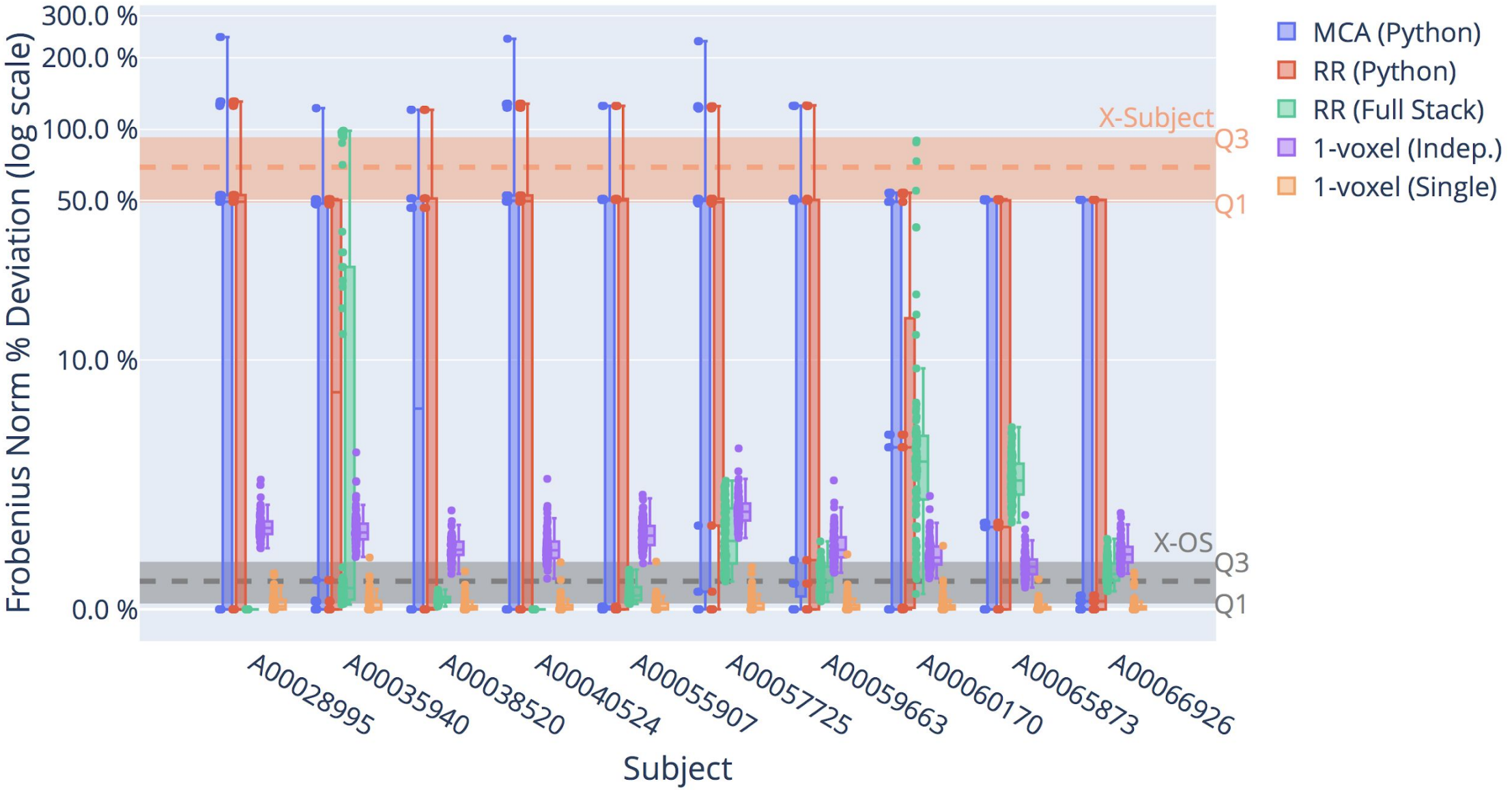
https://hub.docker.com/gkiar/fuzzy/

We ran our Pipeline with...

- MCA (Python/Cython only)
- RR (Python/Cython only)
- RR (Full Stack)
- 1-Voxel noise (per 3D volume)
- 1-Voxel noise (per 4D volume)

... 100 x each, for 10 subjects

Differences in Perturbed Structural Connectomes

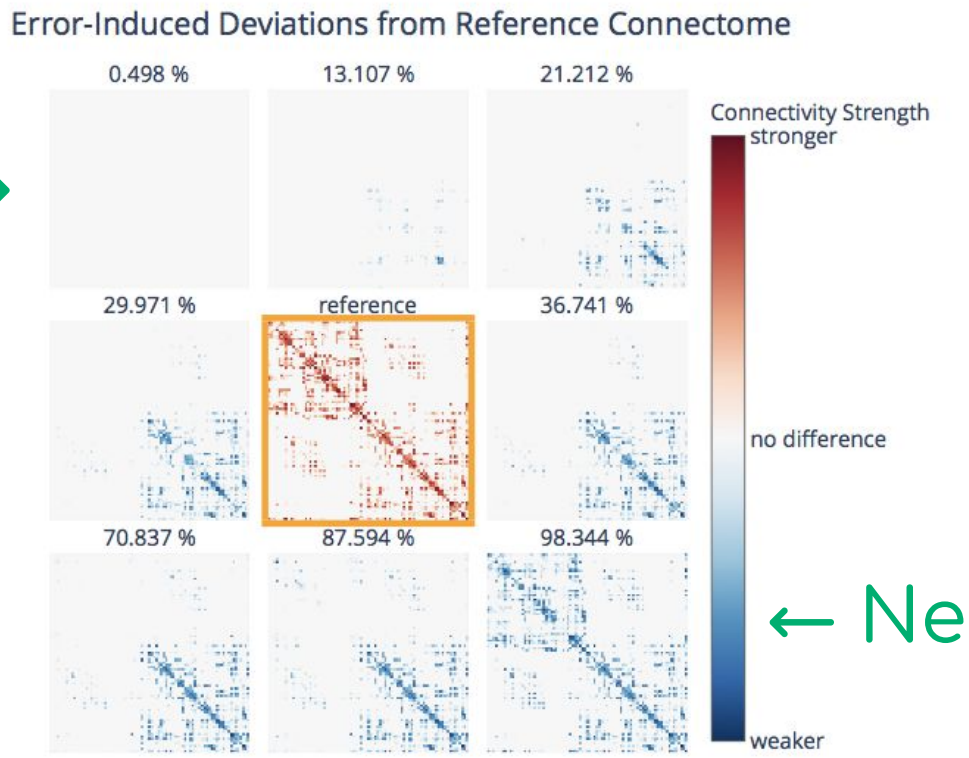


Takeaway #1:

A deterministic pipeline shows instabilities comparable to individual-level variation

What do these changes look like?

No deviation →

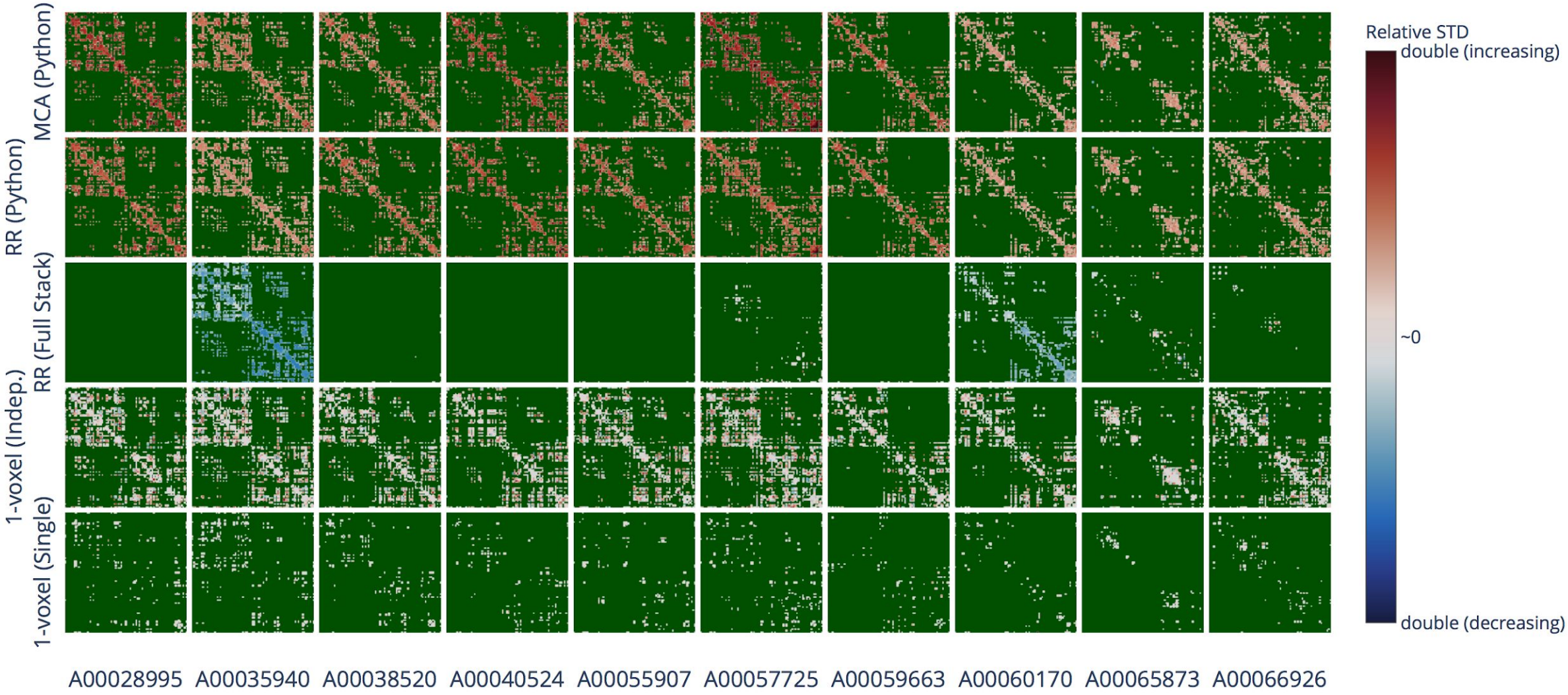


← Near full deviation

Takeaway #2:

The perturbation-induced instabilities are, at least in some cases, structured

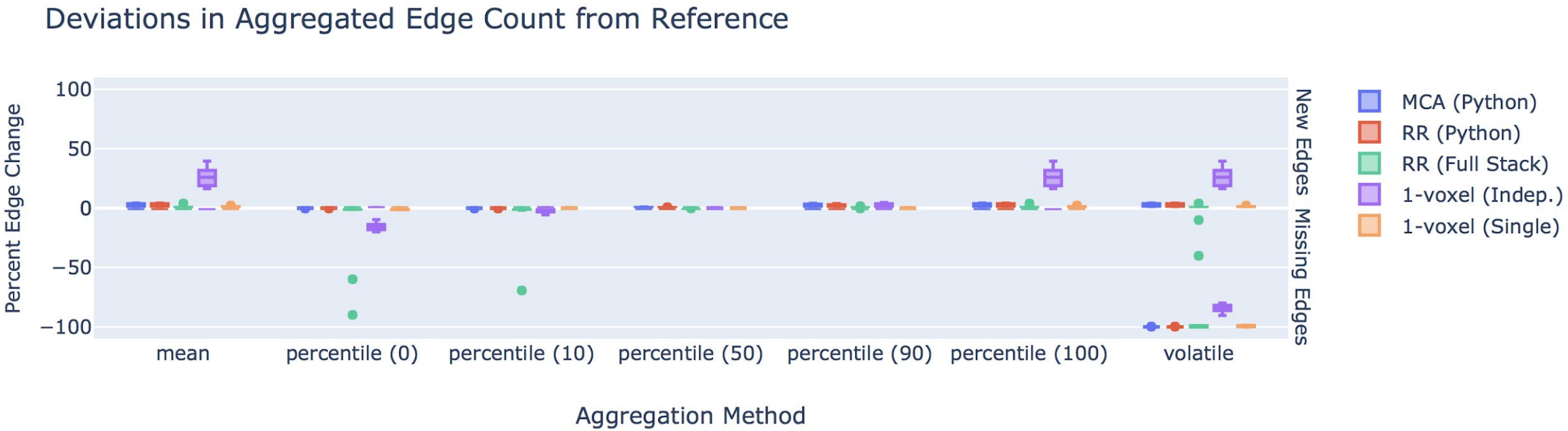
Structural Differences Across Perturbation Modes and Subjects



Takeaway #3:

Instabilities have a bi-directional effect and are highly data-dependent

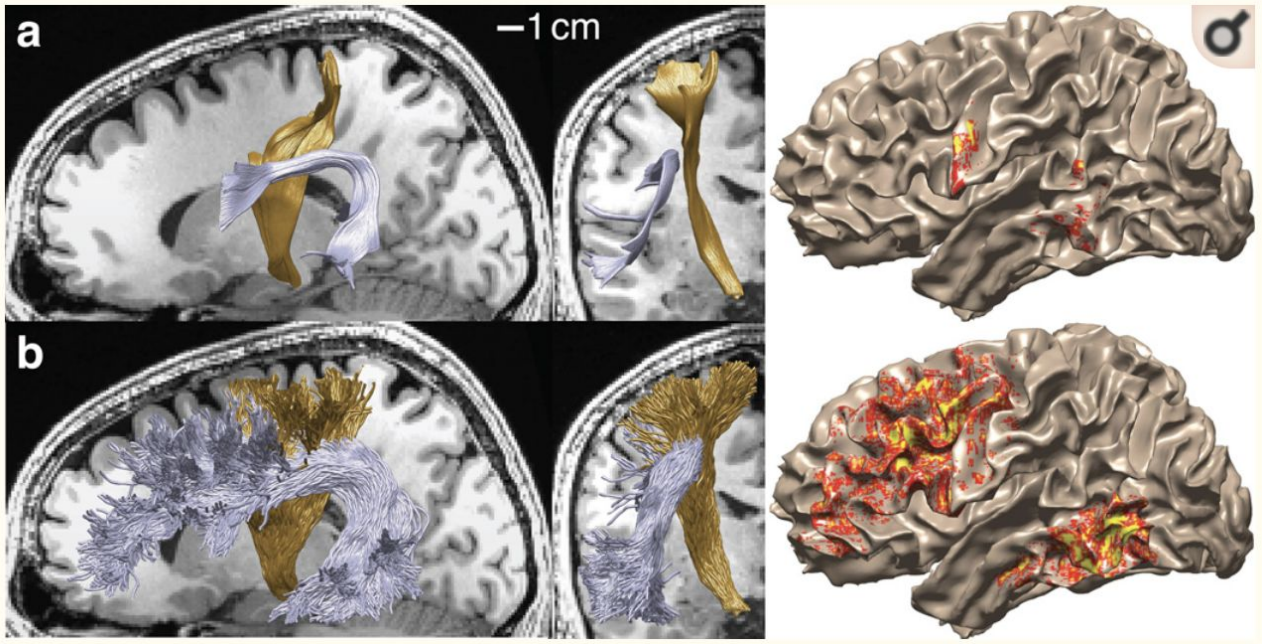
Can aggregation help?



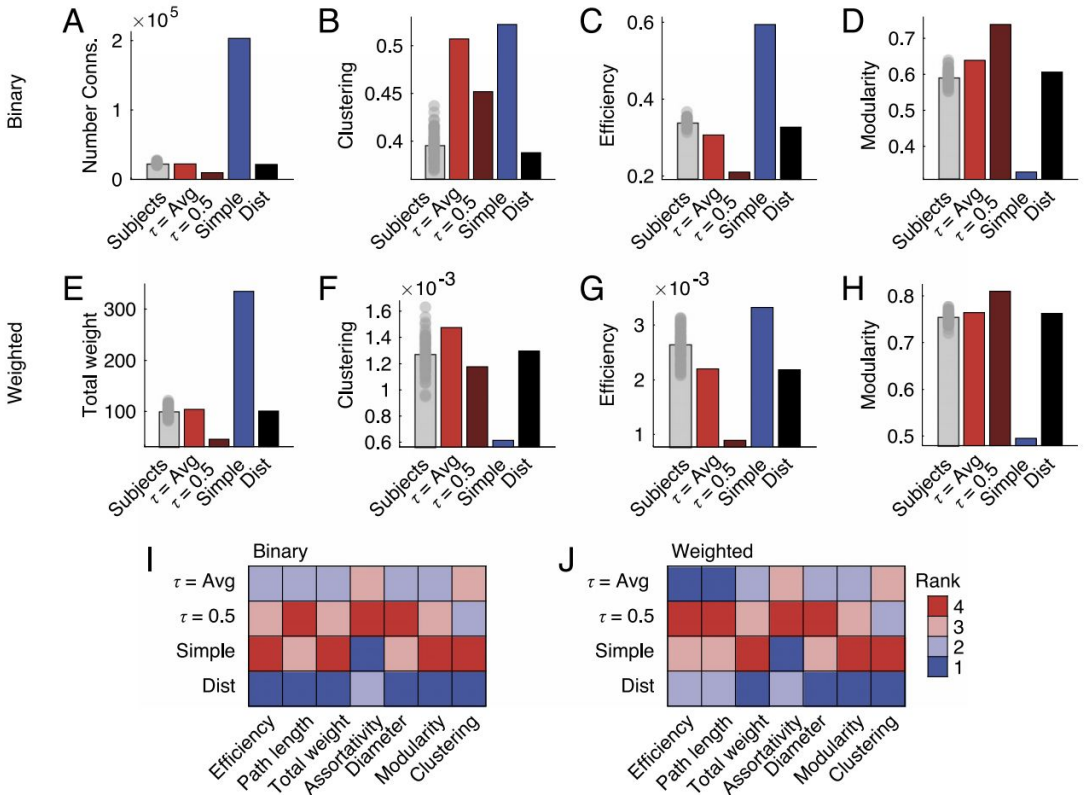
Takeaway #4:

Aggregation may create stable derivatives alongside estimates of their variance

Evaluation of "Validity" Still Needed



(Pestilli, 2015)



(Betzel, 2019)

Summary

- Minor perturbations can induce severe instabilities in neuroimaging pipelines
- Stability analyses inseparably evaluate tool-dataset pairs, rather than either in isolation
- Analytical impact of instabilities is in progress

All code mentioned in this presentation is publicly available on GitHub.

Thanks!

Find me @

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Acknowledgements

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Questions?