# Comparing Perturbation Models for Evaluating Stability of Neuroimaging Pipelines

Gregory Kiar, on behalf of

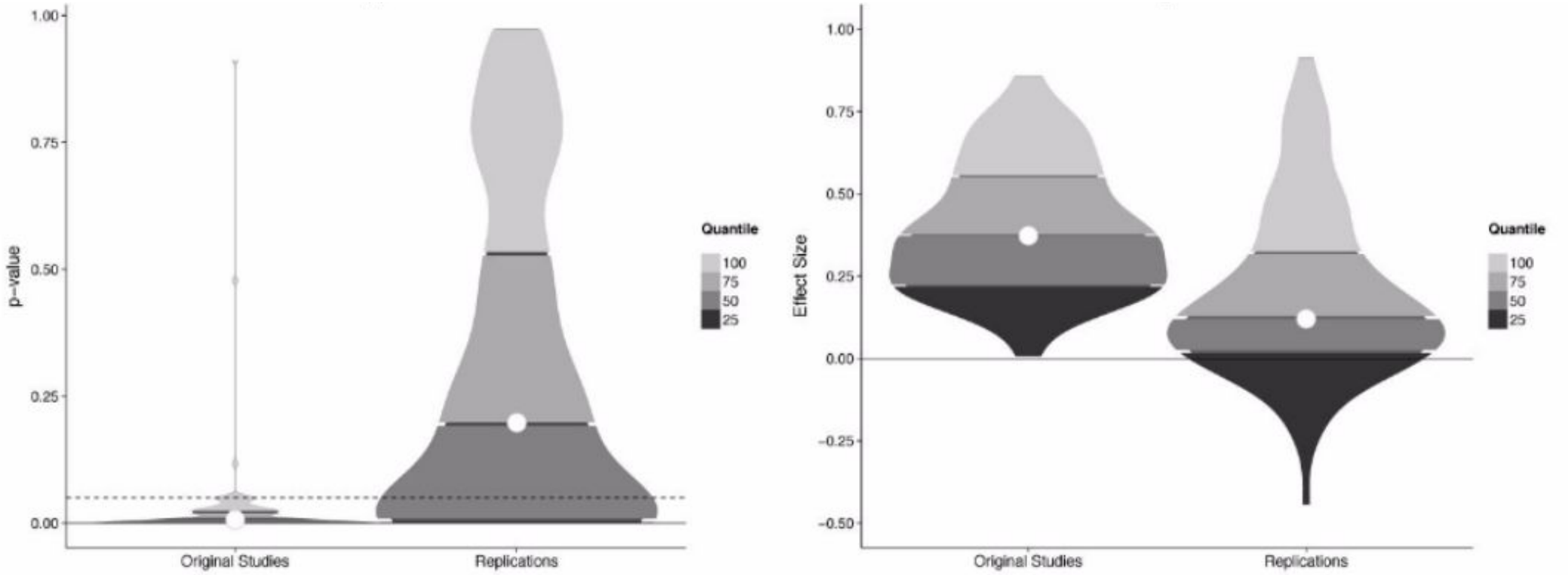
Pablo de Oliveira Castro, Pierre Rioux, Eric Petit, Shawn T. Brown, Alan C. Evans, Tristan Glatard




# Overview

- Topics in reproducibility
- Operationalizing Stability
- Evaluation of Neuroimaging Pipelines

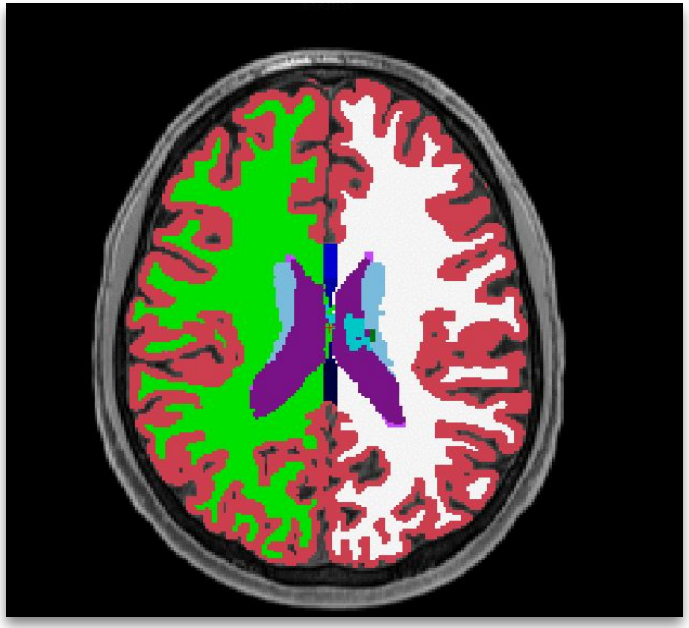
# Reproducibility is Measurable

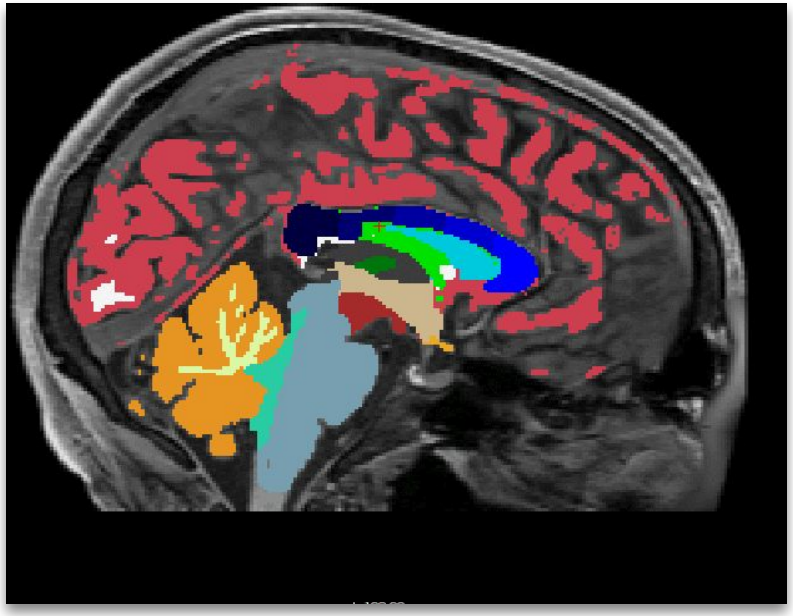


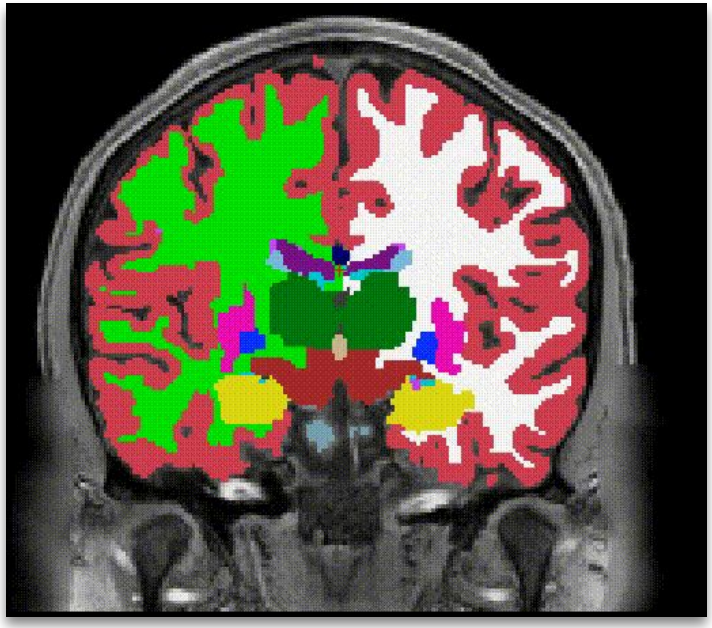

(Open Science Collaboration, 2015)

# Contributing Factor: OS

## CentOS 6 vs CentOS 7







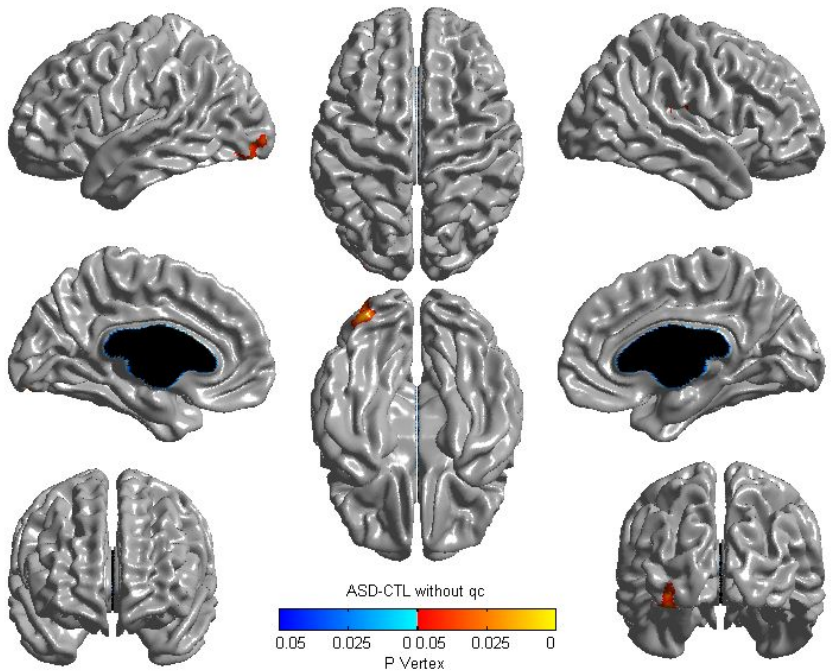
(Scaria, 2017)

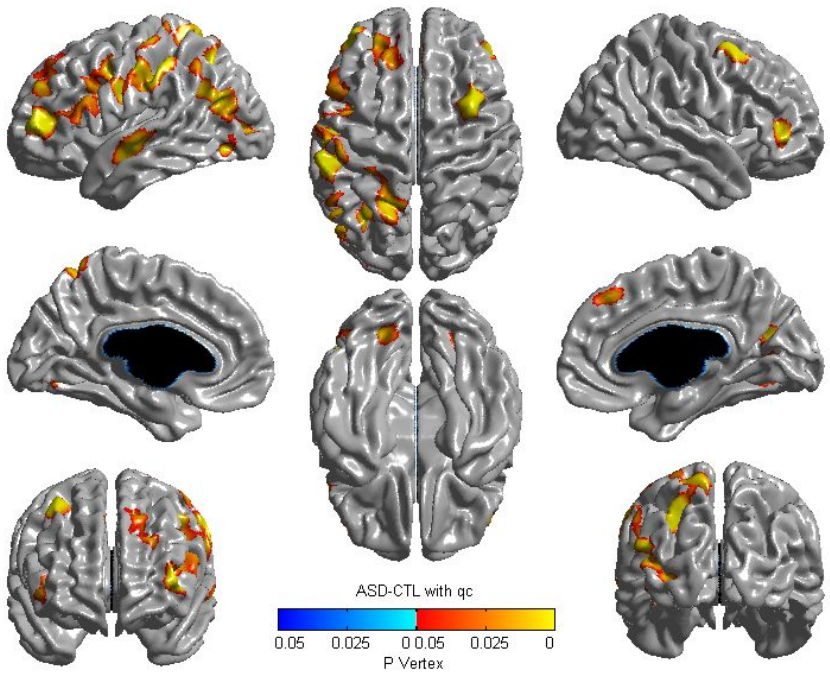
(Scaria et al., 2017)

(Lewis, 2017)

# Contributing Factor: Data Quality

## Full Dataset (N ~ 1100) vs QC'd Dataset (N ~ 400)



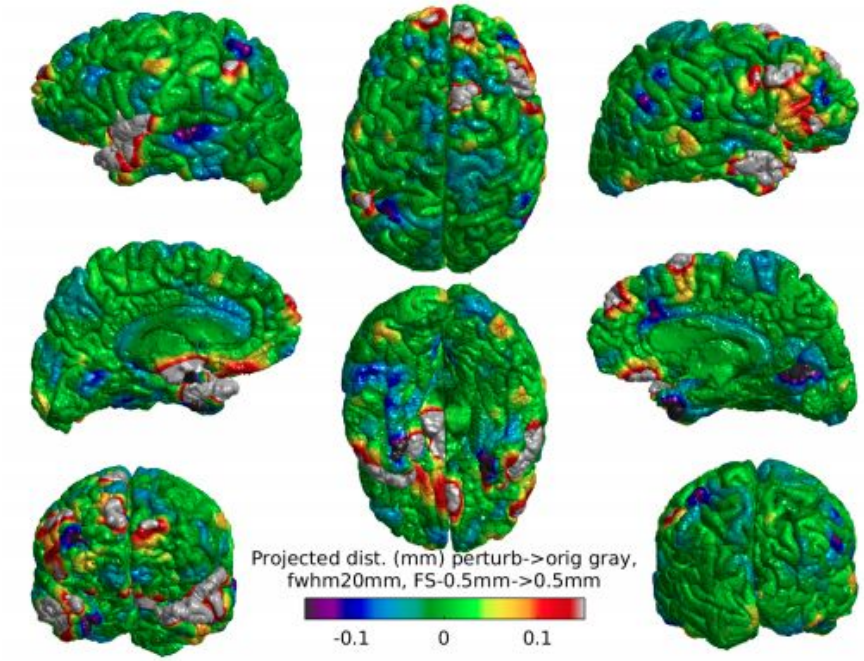

(Scaria, 2017)

(Khundrakpam et al., 2017)

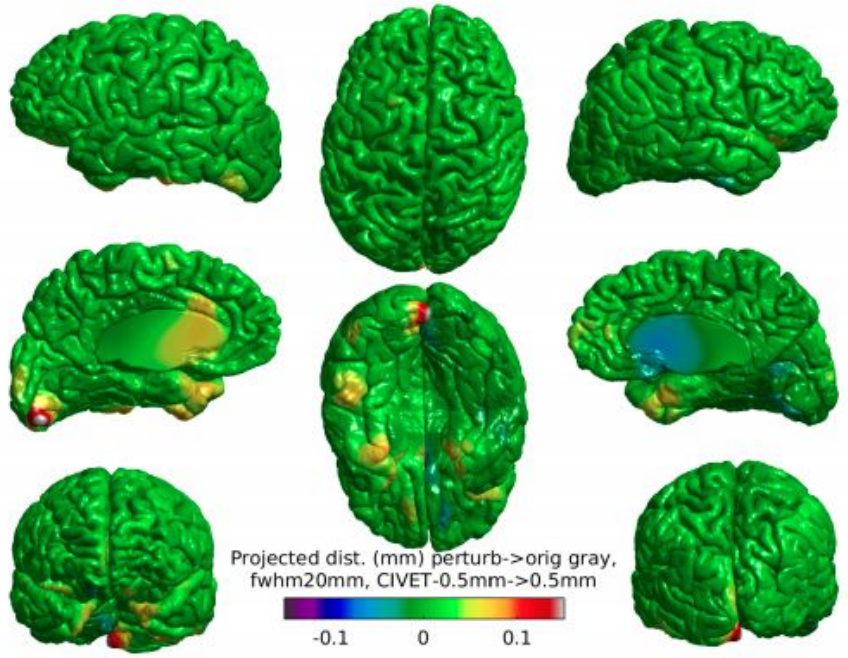
(Lewis, 2017)

# Contributing Factor: Instability

## 1-voxel noise injections at 1% intensity




Freesurfer

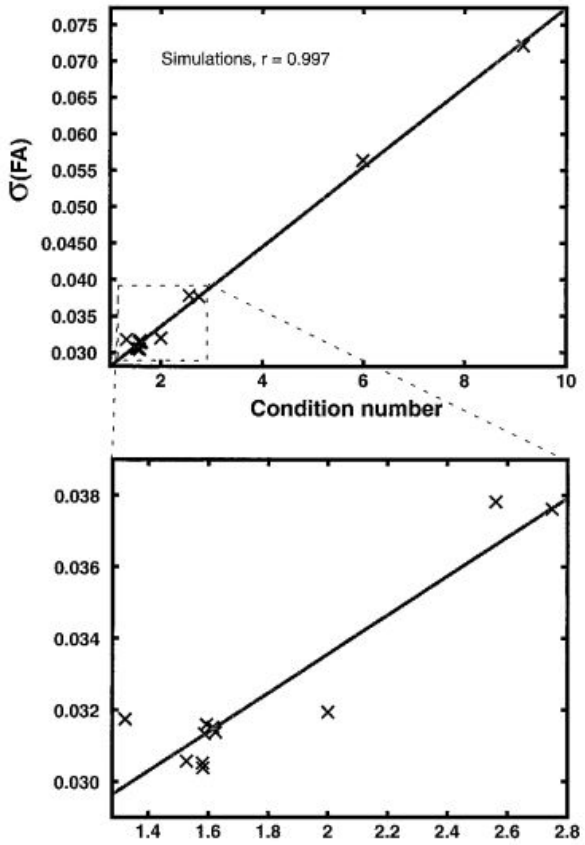


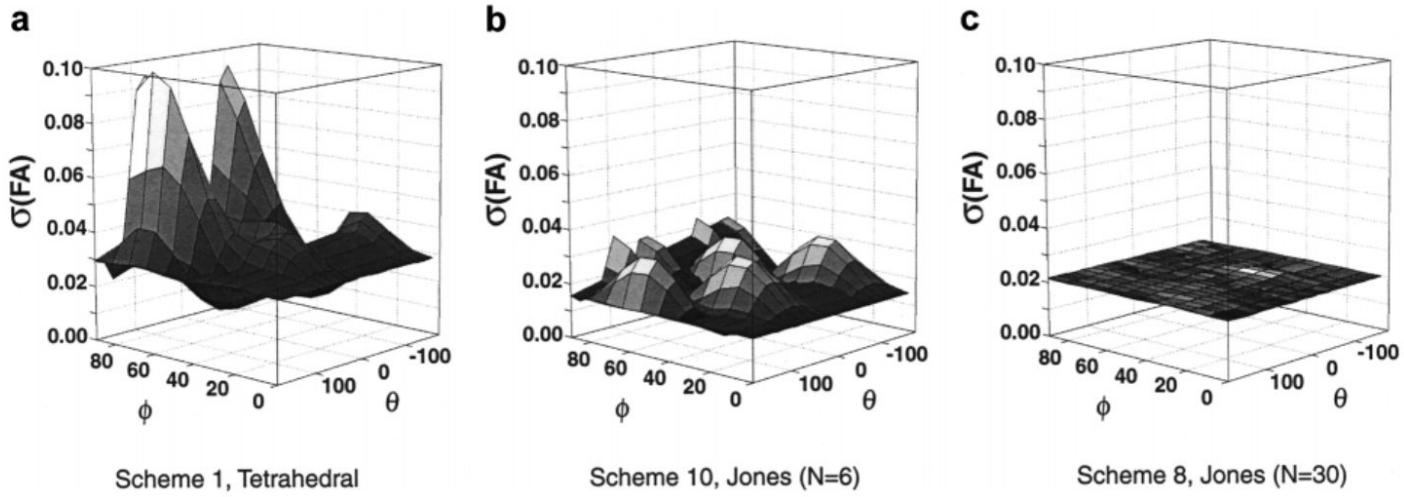

CIVET

(Lewis et al., 2017)

(Lewis, 2017)

# Instabilities can* be Anticipated




*sometimes

(Skare et al., 2000)

# What about the instabilities that we see *in practice*?

# Such as addition in Python...

In [1]:
```
def count_to_one(N):
    step = 1.0 / N
    return step, step*N, sum([step for _ in range(int(N))])
```

- The function above should return the number 1: we're adding N steps of size 1/N together

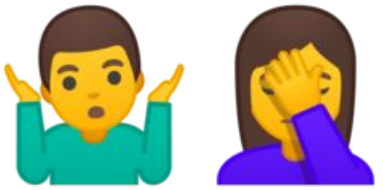
In [2]:
```
N = 5
print(count_to_one(N))
```

```
(0.2, 1.0, 1.0)
```

- great, it works, now let's try a slightly bigger number

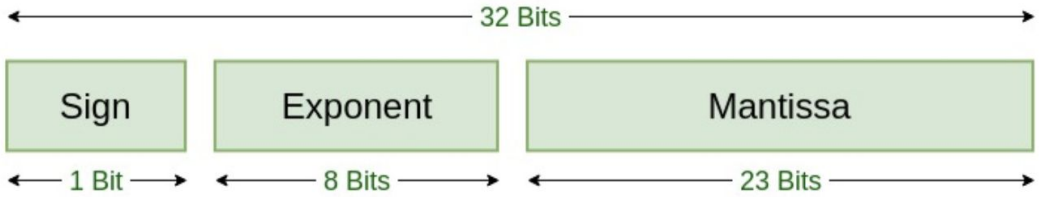
In [3]:
```
N = 1e3
print(count_to_one(N))
```

```
(0.001, 1.0, 1.0000000000000007)
```

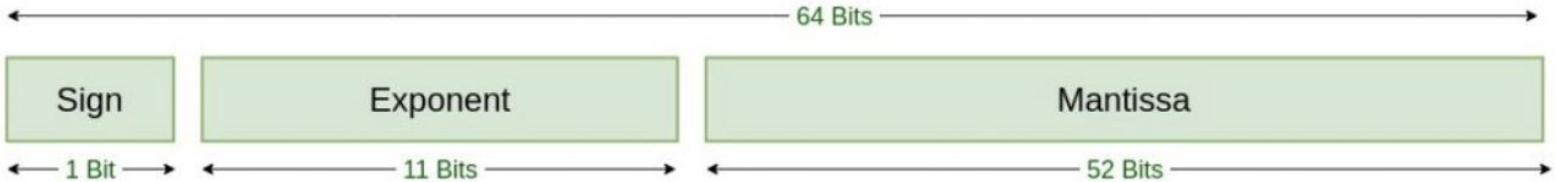
... 

https://github.com/gkiar/fuzzy/blob/master/fuzzy/tutorial/

# Floating Point Data are Finite




Single Precision
IEEE 754 Floating-Point Standard




Double Precision
IEEE 754 Floating-Point Standard

https://www.geeksforgeeks.org/ieee-standard-754-floating-point-numbers/

# Floating Point Arithmetic is Inexact

E.g. addition is non associative

$$(\ 2000. \oplus -1998.\ ) \oplus 1.333 = 2.000 \oplus 1.333 = 3.333$$
$$2000. \oplus (\ -1998. \oplus 1.333\ ) = 2000. \oplus -1997. = 3.000$$

(inspired by Parker et al., 1997)

# Monte Carlo Arithmetic (MCA)

## Inexact 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 (MCA)

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

# We Instrumented...

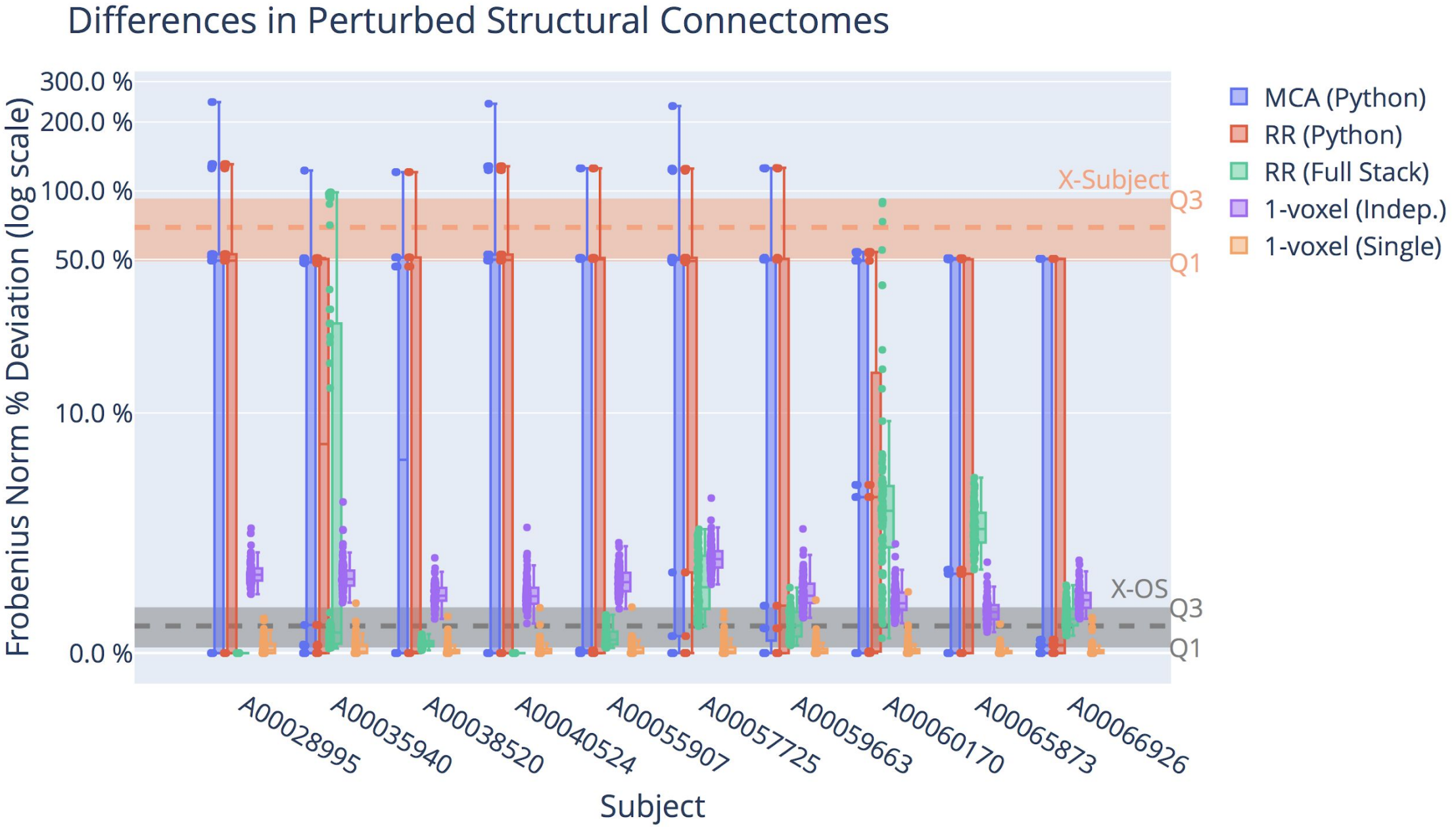
- Python
- Cython libs
- Numpy
- BLAS
- Lapack

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

# We ran a 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

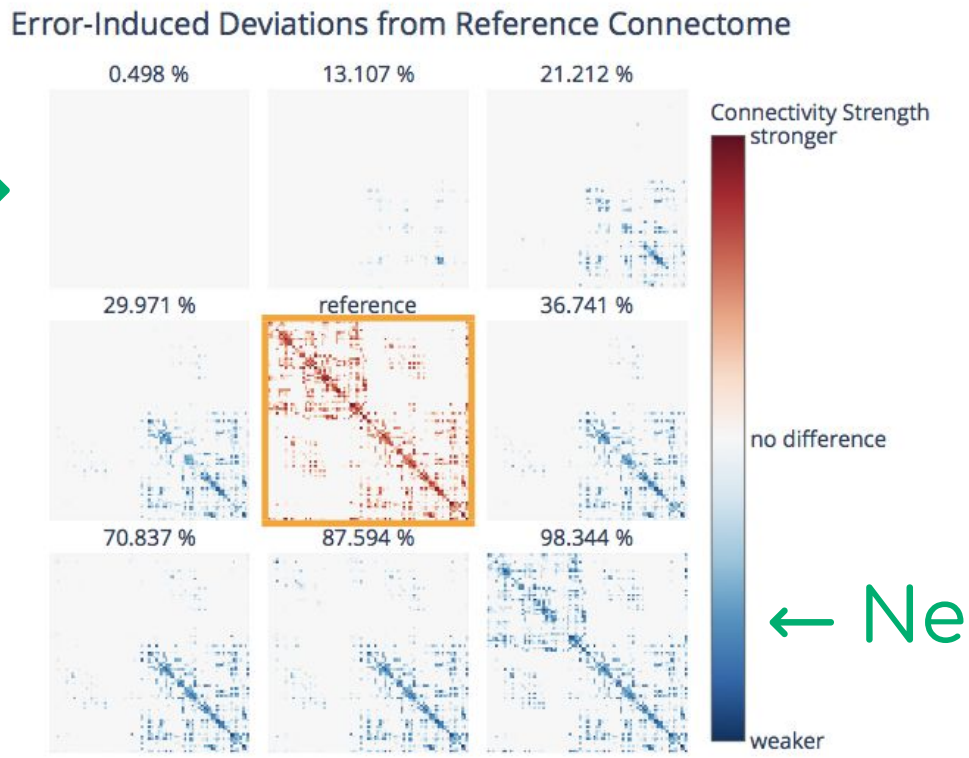

Differences in Perturbed Structural Connectomes
Frobenius Norm % Deviation (log scale)
300.0 %
200.0 %
100.0 %
50.0 %
10.0 %
0.0 %
X-Subject
Q3
Q1
X-OS
Q3
Q1
MCA (Python)
RR (Python)
RR (Full Stack)
1-voxel (Indep.)
1-voxel (Single)
A00028995
A00035940
A00038520
A00040524
A00055907
A00057725
A00059663
A00060170
A00065873
A00066926
Subject

Takeaway #1:

# A deterministic pipeline shows instabilities comparable to individual-level variation

# What do these changes look like?

No deviation →

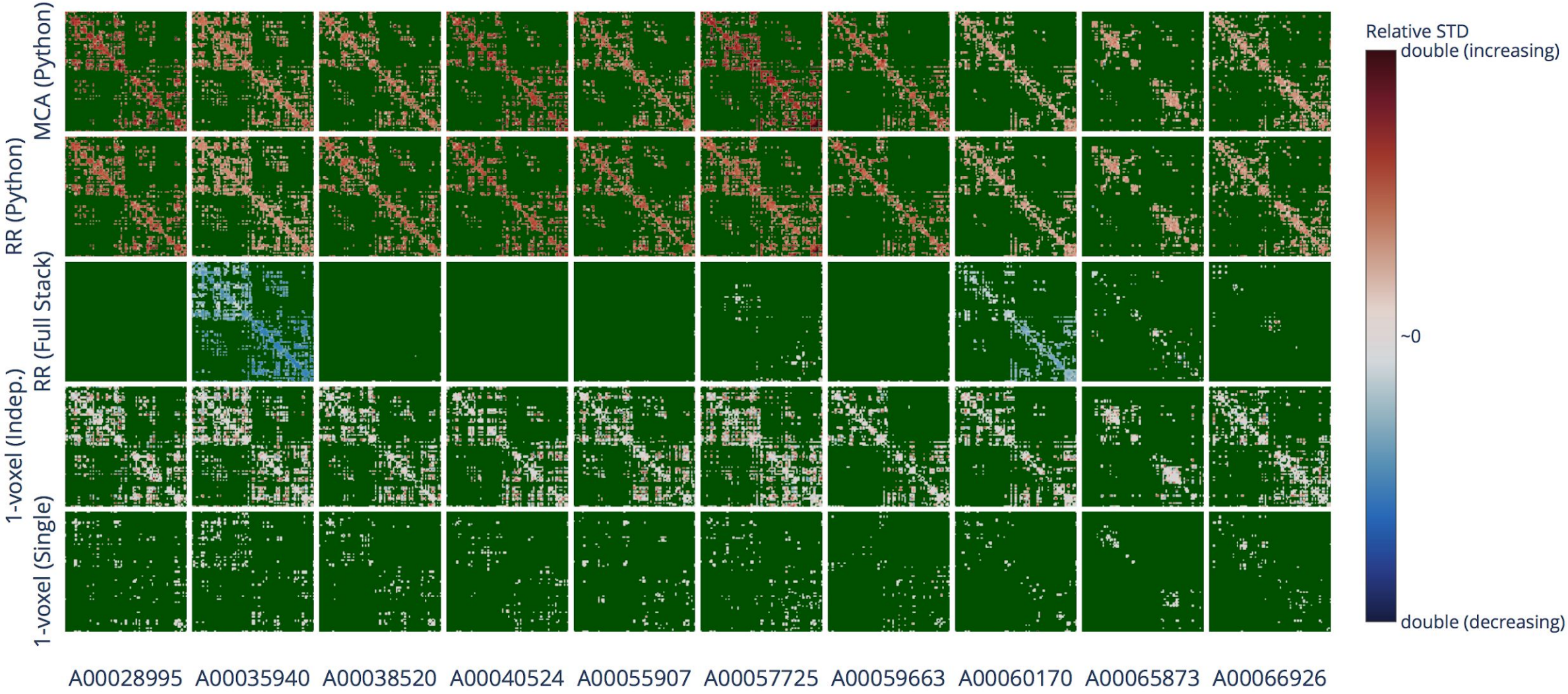



← Near full deviation

Takeaway #2:

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

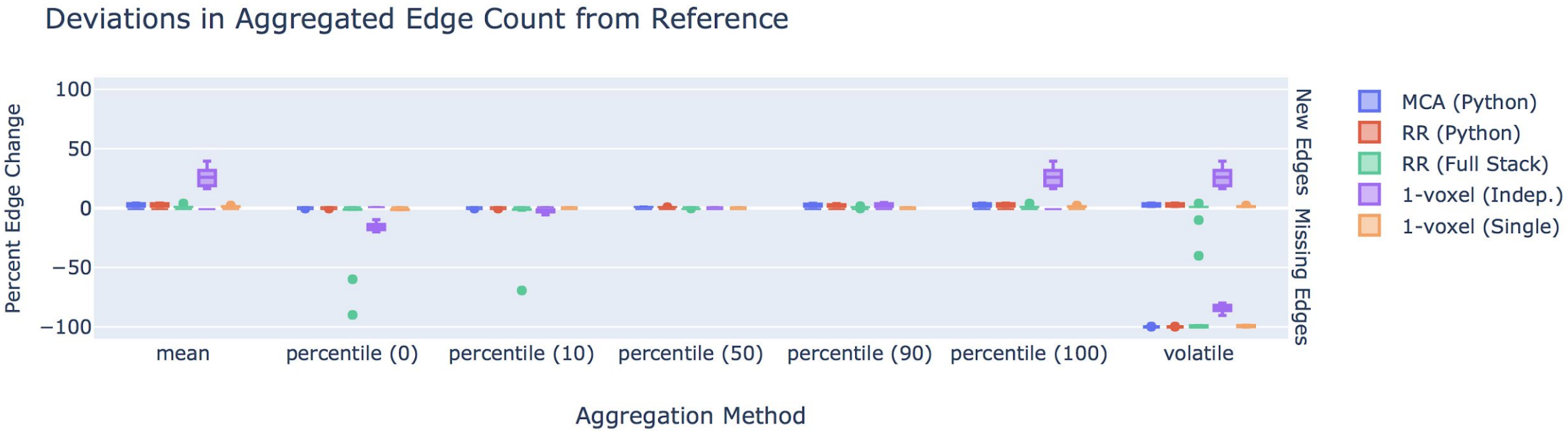
## Structural Differences Across Perturbation Modes and Subjects



Takeaway #3:

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

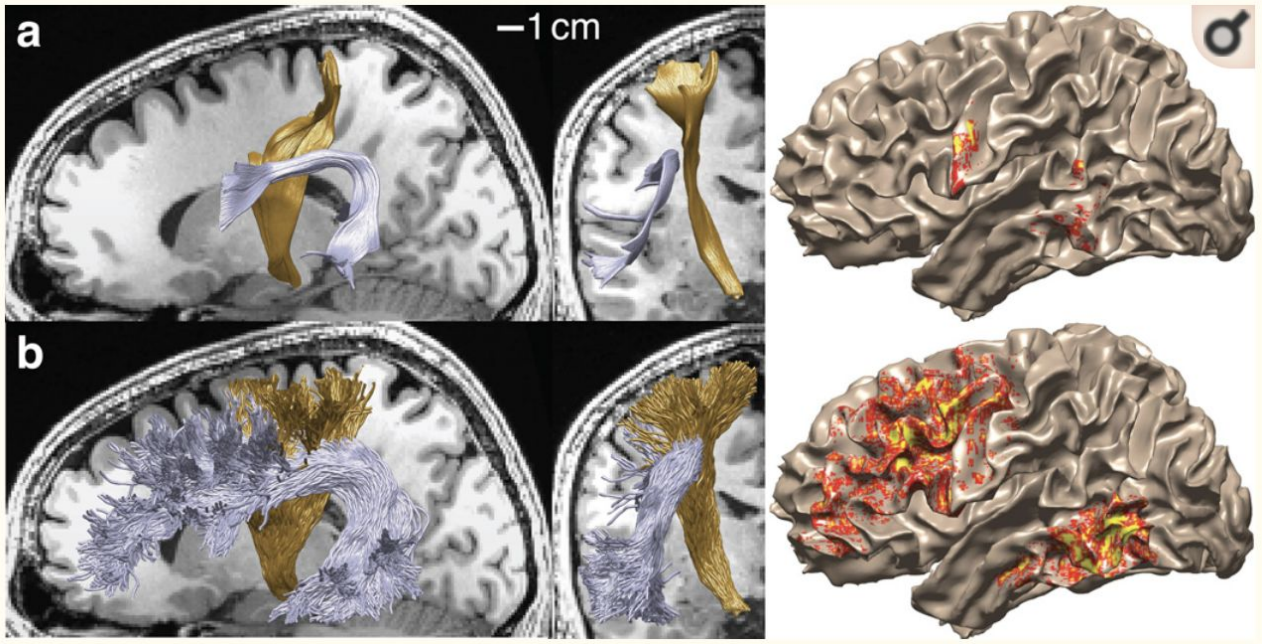
# Can aggregation help?



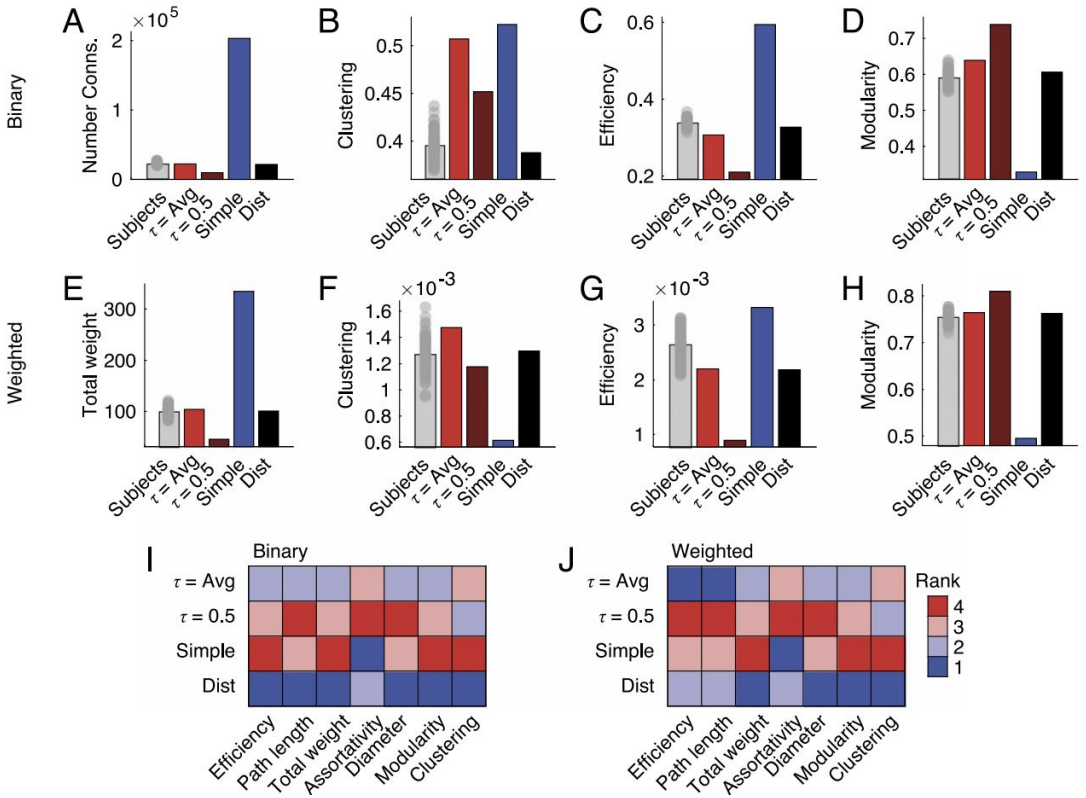
Takeaway #4:

# 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 @

 gkiar

 g_kiar

 greg.kiar@mail.mcgill.ca

# Acknowledgements

...

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MITACS Globalink
Inria inventeurs du monde numérique

# Questions?