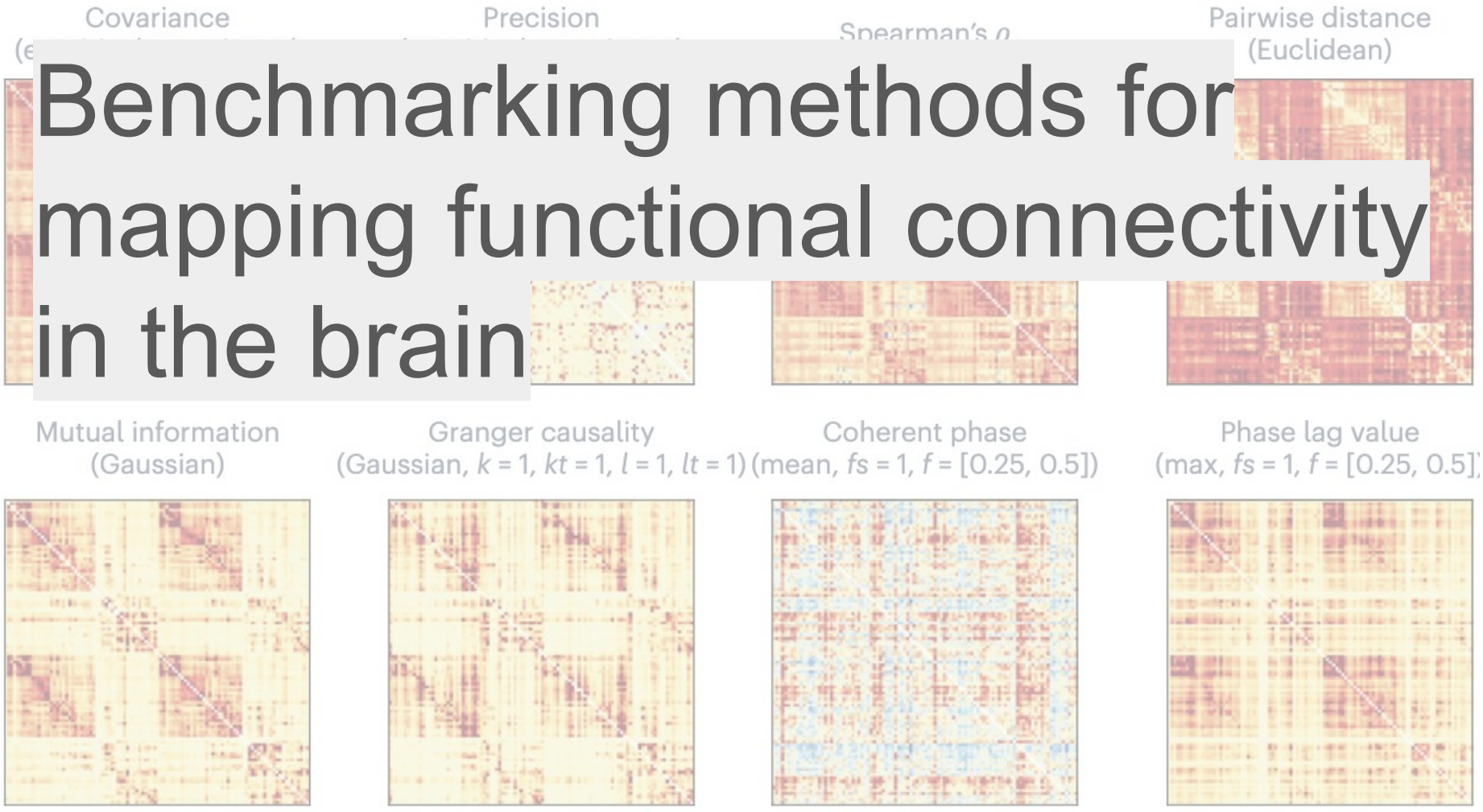
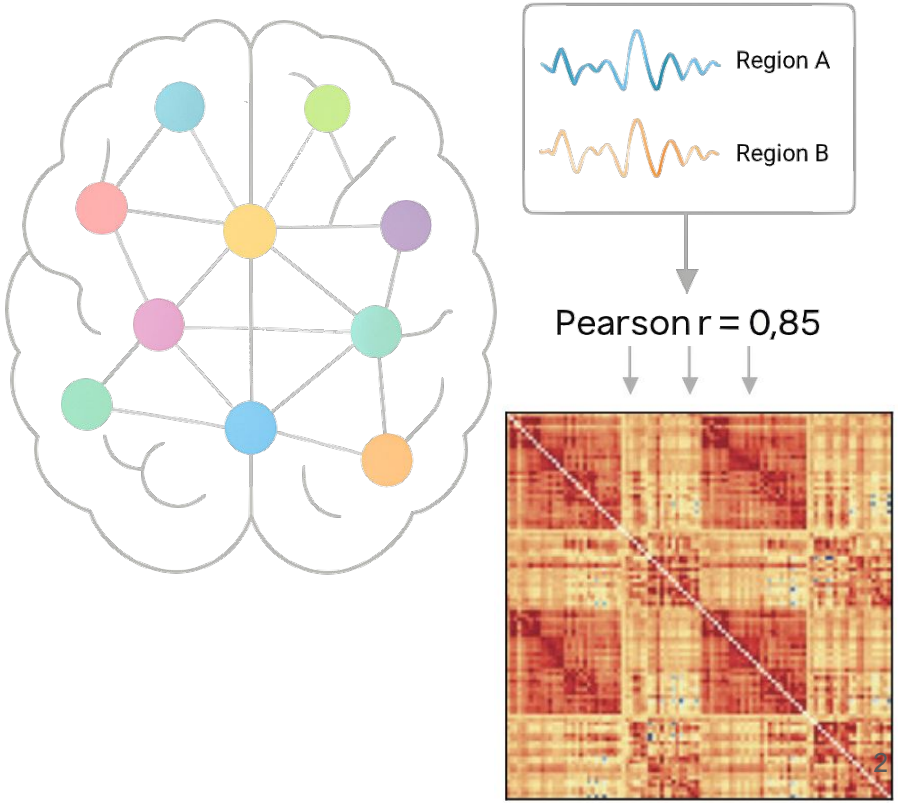
Benchmarking methods for mapping functional connectivity in the brain



What is functional connectivity

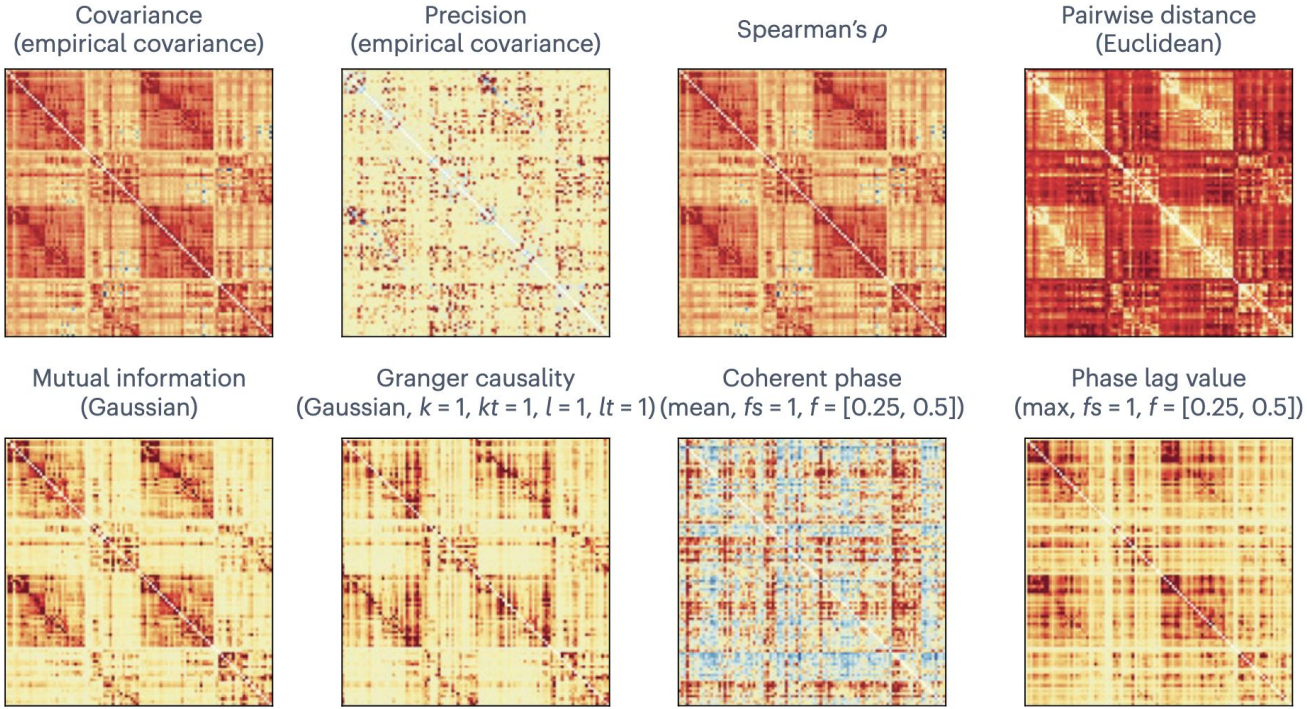
- Brain connectivity describes how brain regions are linked and communicate.
- Functional connectivity (FC) describes it using pairwise statistical tests on the signals from different brain regions.
- FC is typically estimated as Pearson correlation coefficients (PCC), which reflect the covariance between signals.



What this paper did

There is more to pairwise statistics than PCC, different tests can highlight different things.

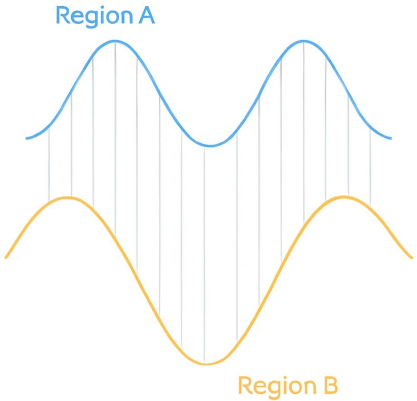
This paper compared lots of these tests on a couple of connectivity benchmarks.



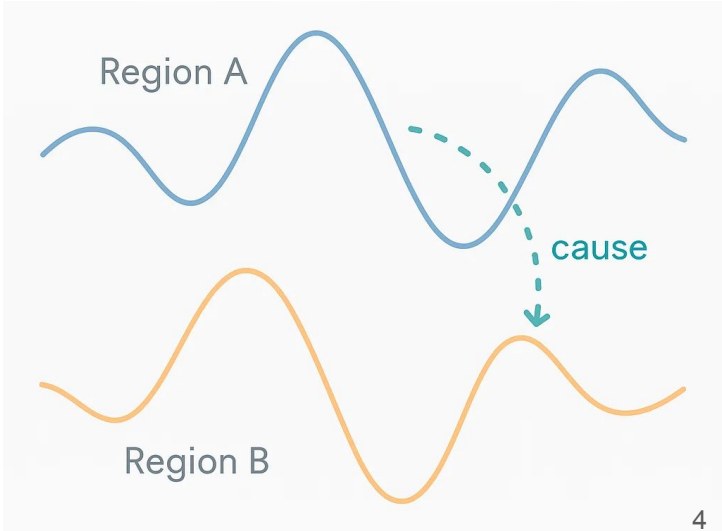
Families of pairwise statistics

Covariance
(‘Basic’ in paper)
Pearson
Precision

Distance
Pairwise distance
Dynamic Time Warping



Causal
Additive Noise Model
Conditional-Distribution Similarity

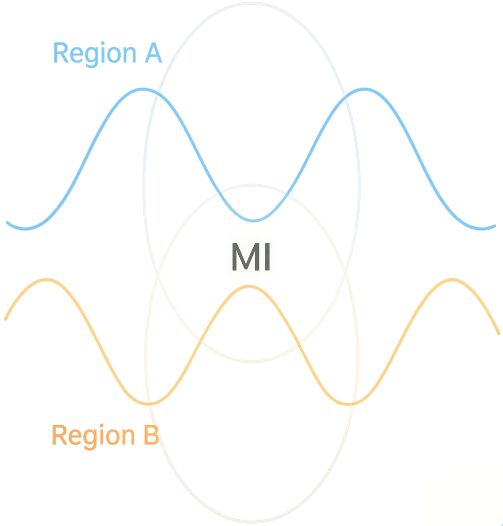


Families of pairwise statistics

Info theory

Mutual Information

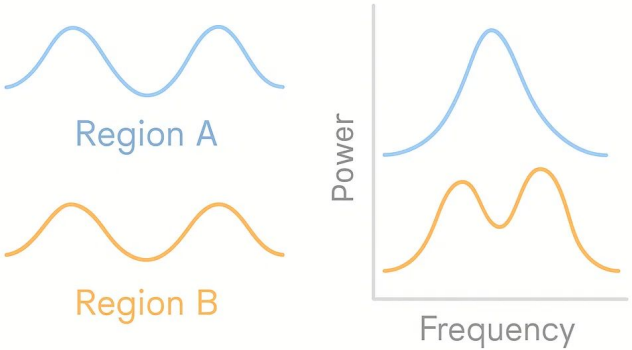
Joint entropy

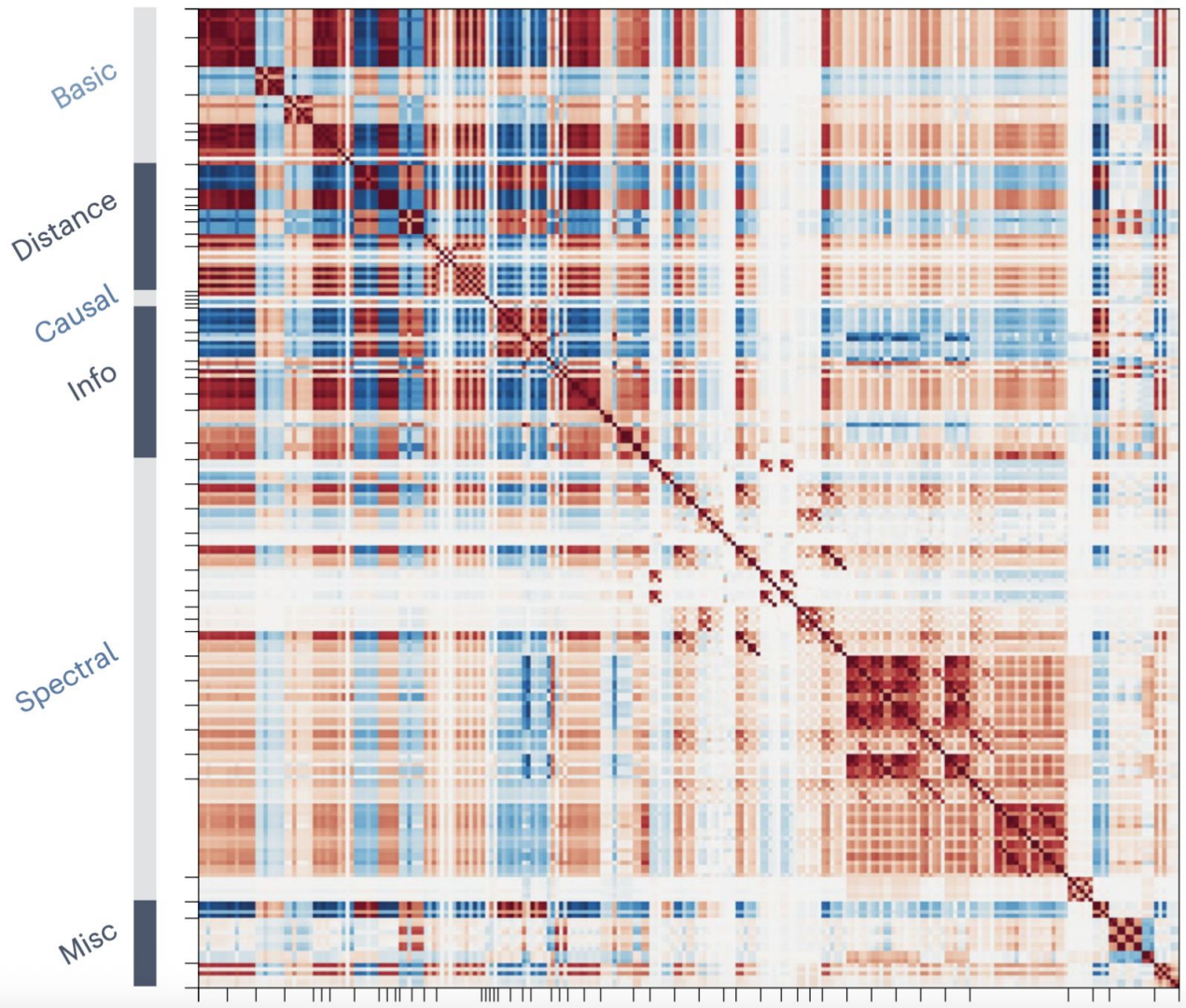


Spectral

Coherence

Phase Locking Value





Average similarity between all pairs of 239 pairwise statistics.

Spearman ρ

−1 1

Basic
Covariance (7)
Covariance sq. (7)
Precision (7)
Precision sq. (7)
Spearman's ρ (2)
Kendall's τ (2)
Cross-correlation (6)

Distance
Pairwise distance (6)
Distance correlation (2)
Hilbert–Schmidt indep. crit. (2)
Cross-distance correlation (1)
Dynamic time warping (3)
Soft dynamic time warping (3)
Longest common subseq. (3)
Barycenter (11)

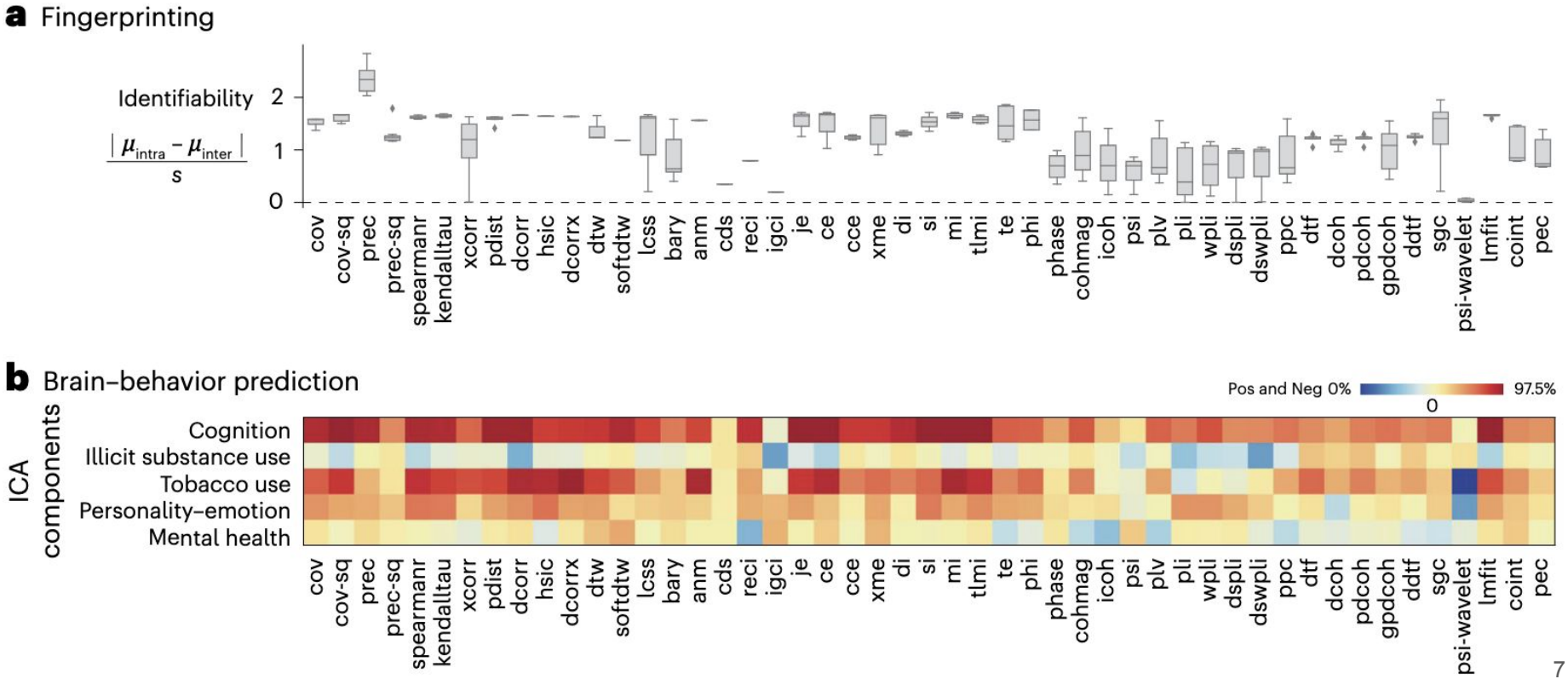
Causal
Additive noise model (1)
Cond. distrib. similarity fit (1)
Reg. error-based causal inf. (1)
Info.-geometric causal inf. (1)

Info theory
Joint entropy (3)
Conditional entropy (3)
Causally cond. entropy (2)
Cross-map entropy (5)
Directed information (2)
Stochastic interaction (2)
Mutual information (MI) (4)
Time-lagged MI (4)
Transfer entropy (8)
Integrated information (4)

Spectral
Coherence phase (6)
Coherence magnitude (6)
Imaginary coherence (6)
Phase slope index (3)
Phase locking value (PLV) (6)
Phase lag index (PLI) (5)
Weighted PLI (4)
Debiased squared PLI (3)
Debiased sq. weighted PLI (3)
Pairwise phase consistency (6)
Directed transfer function (6)
Directed coherence (6)
Partial directed coh. (6)
Generalized partial dir. coh. (6)
Direct directed transfer func. (6)
Spectral Granger causality (24)
Phase slope index (wavelet) (6)

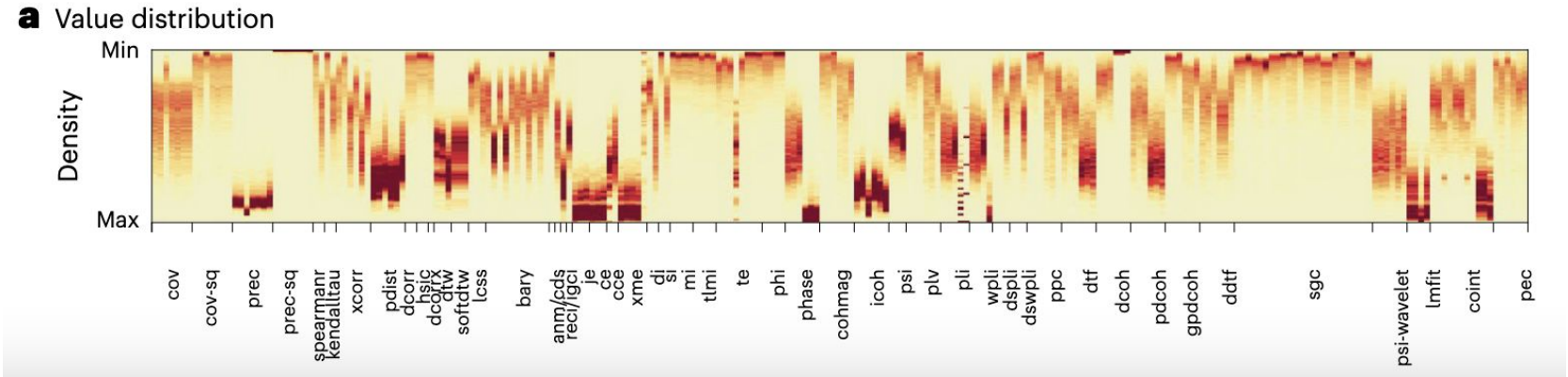
Misc
Linear model fit (4)
Cointegration (11)
Power envelope correlation (6)

Subject identifiability and behavior prediction



Connectivity benchmarks

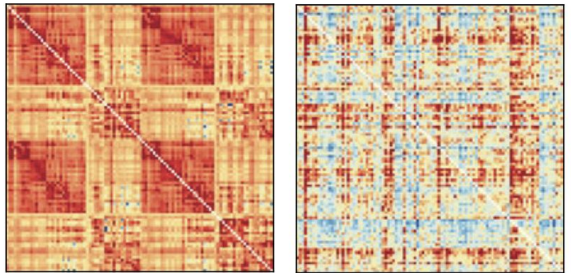
Connectivity strength variation

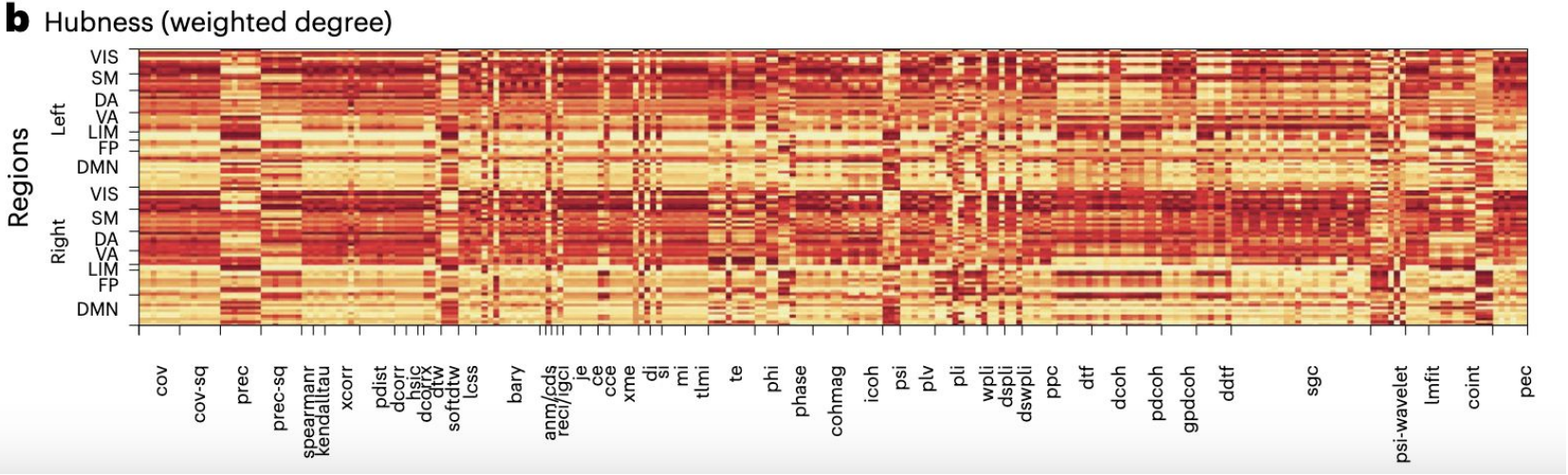


Connectivity benchmarks

Hubness. Good hub region has many connections to other regions.

Degrees of hubness

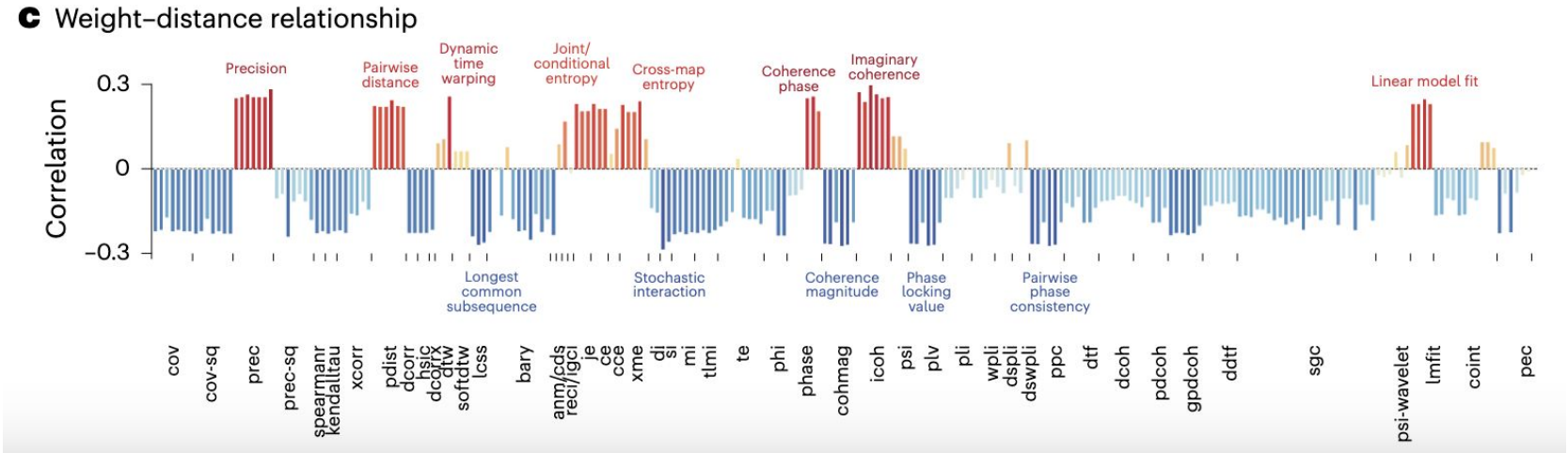




Connectivity benchmarks

Weight-distance relationship.

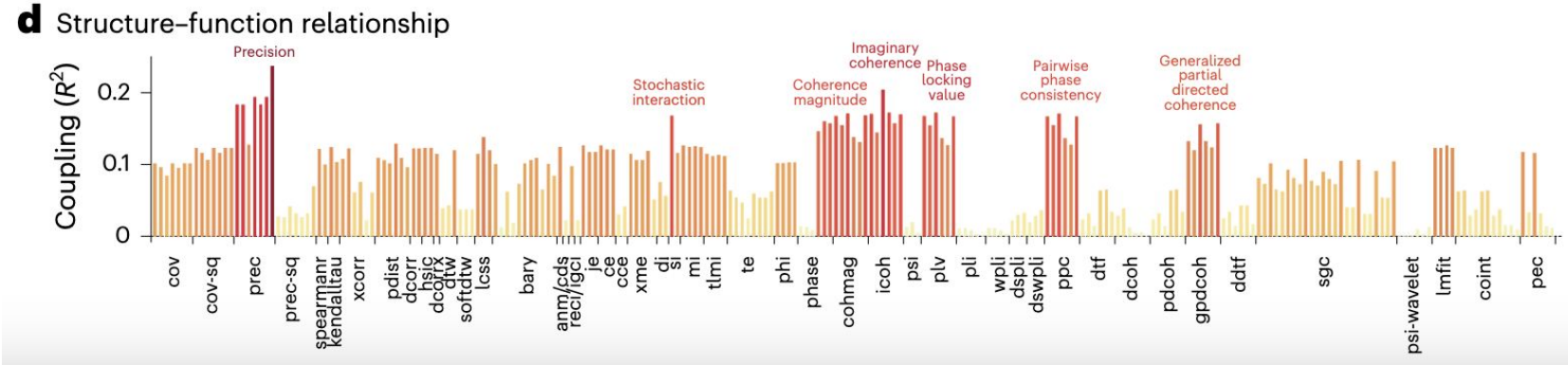
Distant brain regions tend to have weaker connections.



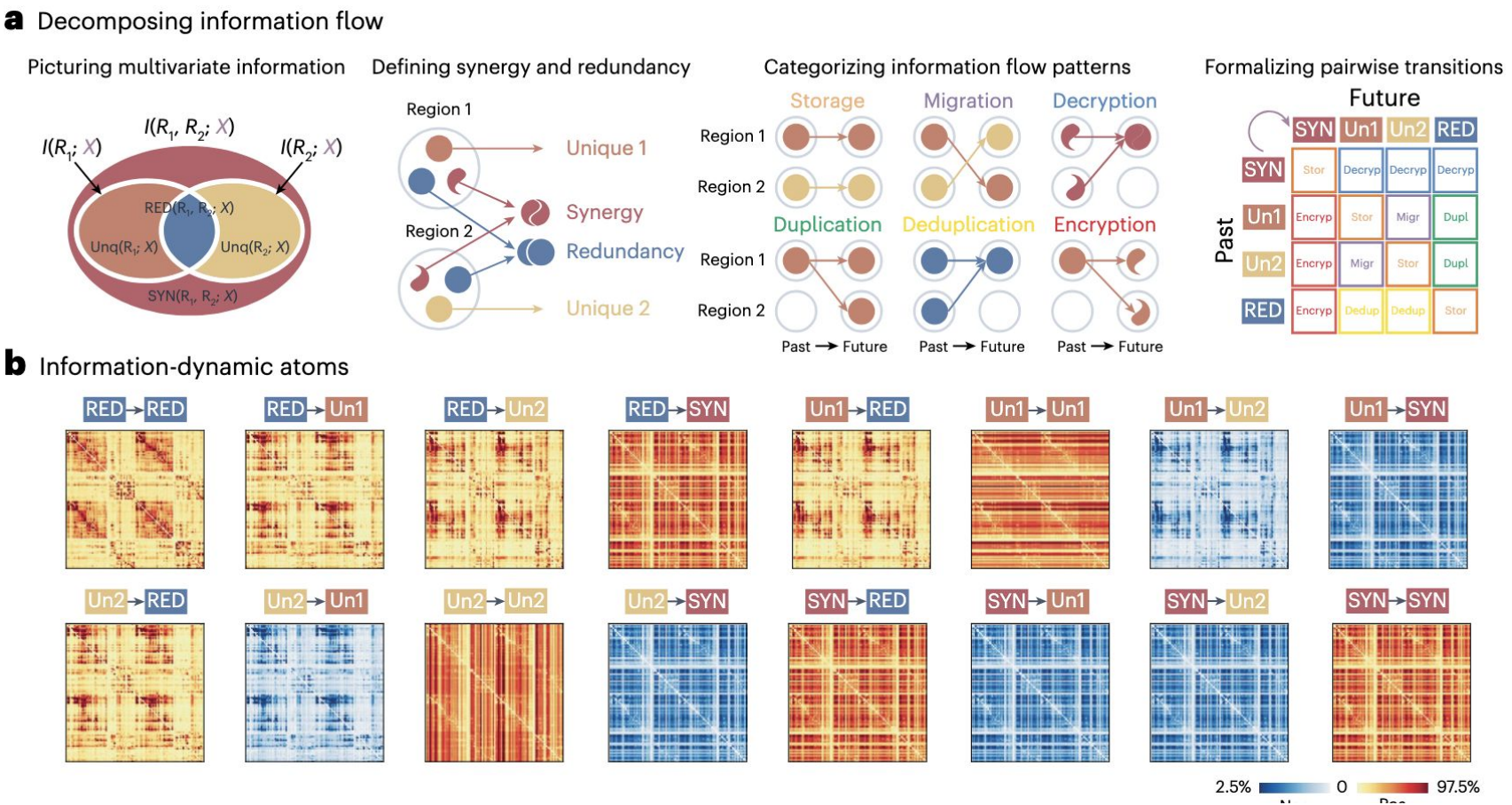
Connectivity benchmarks

Structure-function relationship.

FC should be similar to the anatomy-based structural connectivity derived from diffusion MRI.



Integrated Information Decomposition



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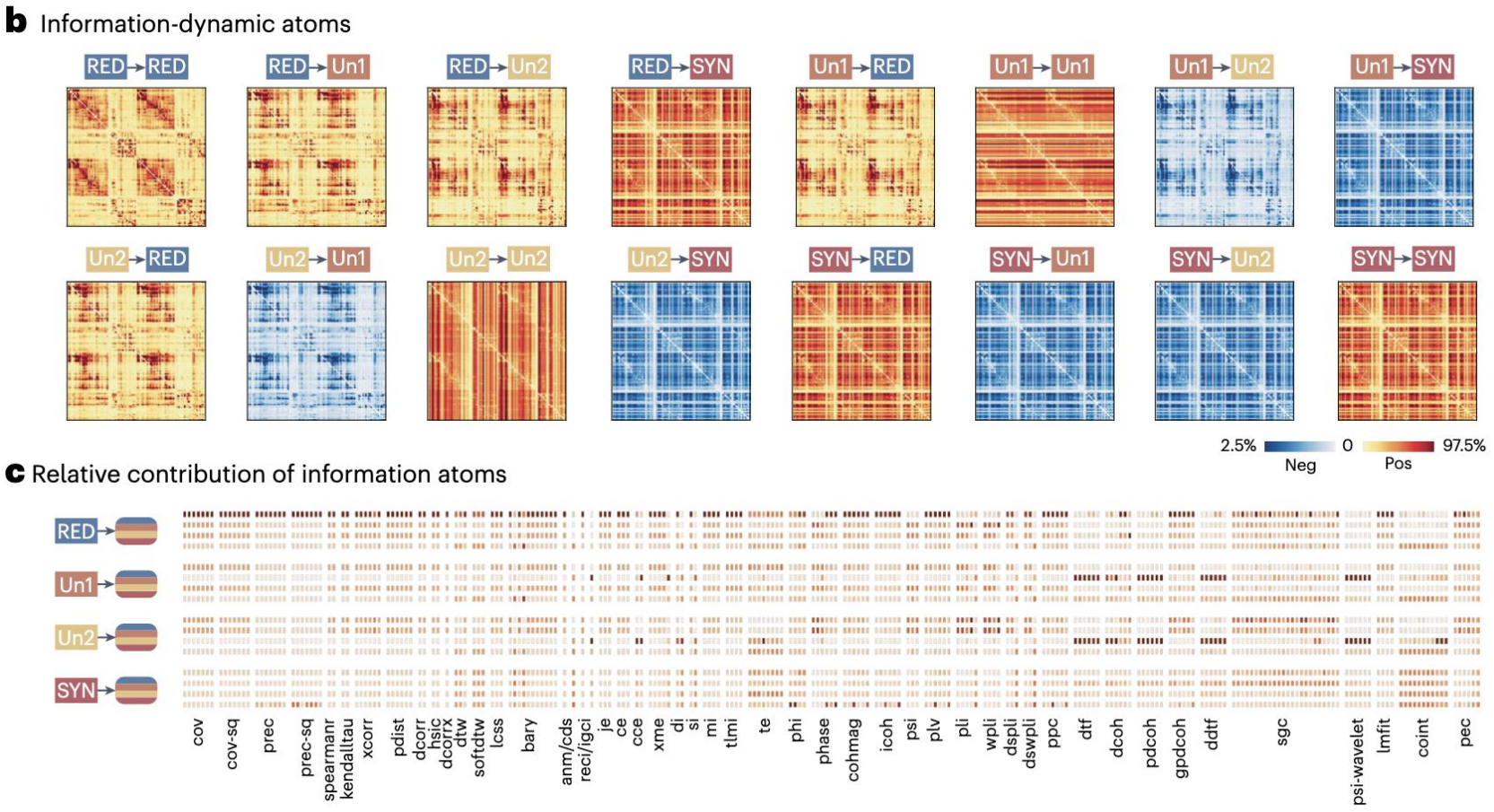
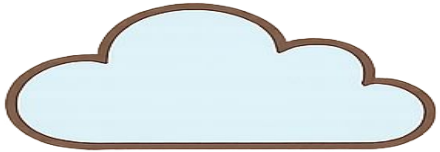
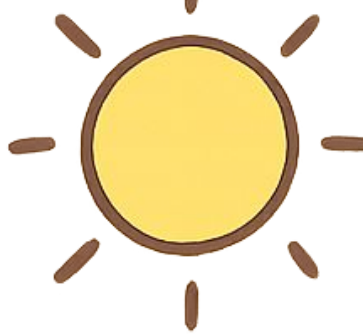
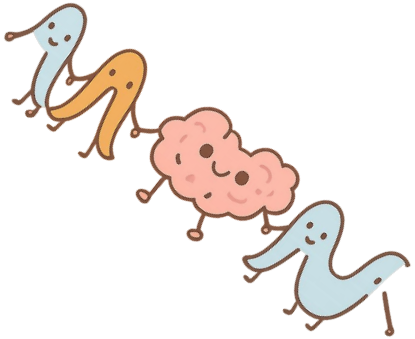


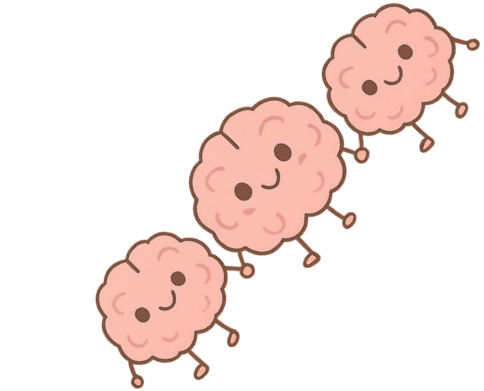
Discussion

- FCs derived with different statistics look very different and have different hubs.
- They all show expected *weight-distance* and *structure-function* correlations, but with variable magnitude.
- Variability rises from pairwise statistics being sensitive to different underlying mechanisms of interregional signaling.
    - Pairwise statistic should be matched to the experimental question.
    - For fMRI, covariance based methods seem to be most balanced.
    - Precision (i.e., inverse covariance) is surprisingly good for fingerprinting.









The end