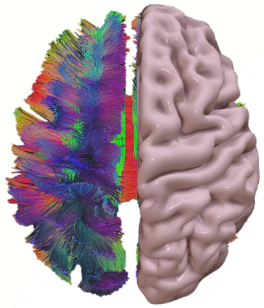
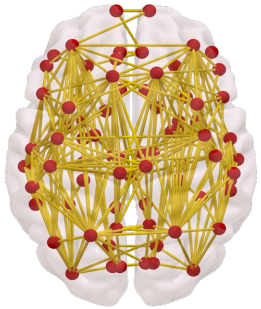
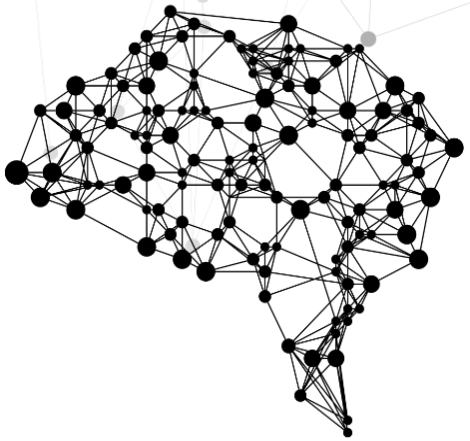
Competitive interactions shape brain dynamics and computation across species



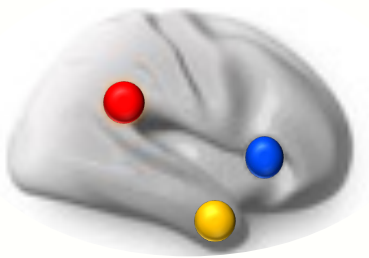


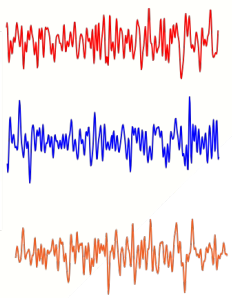


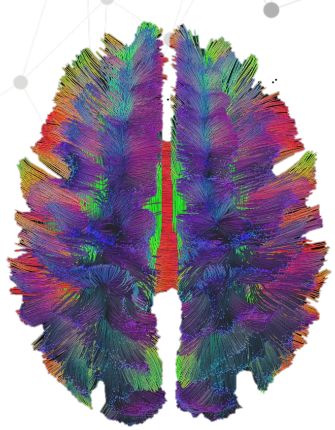
Division F Conference
October 7th 2025

Dr Andrea Luppi
Research Fellow, St John's College Cambridge

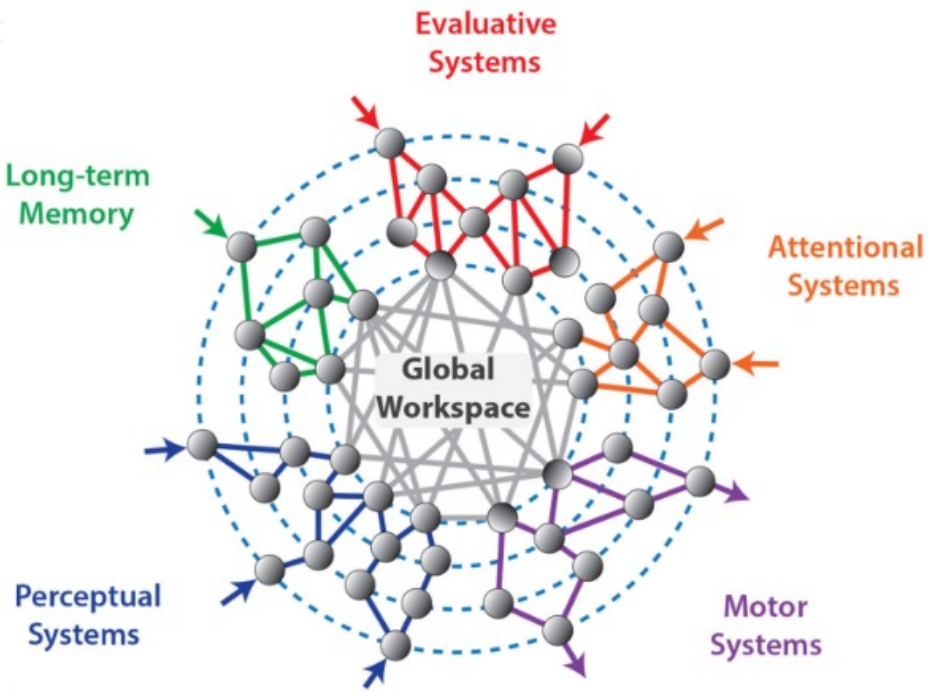
Neural information-routing architecture

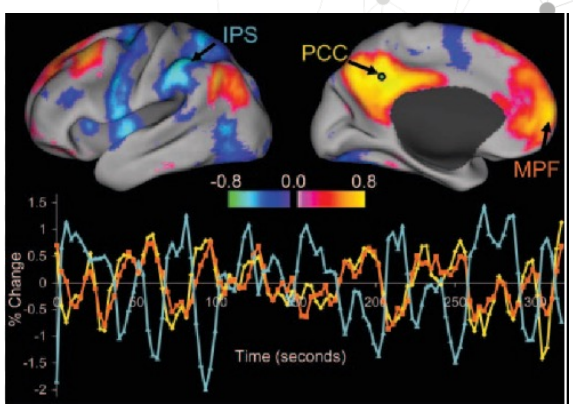






Cooperation and competition

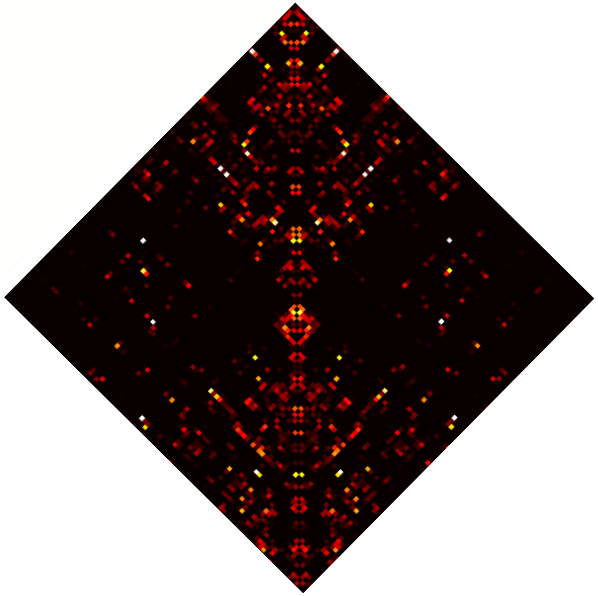




Mesulam 1998 *Brain*
Fox *et al.* 2005 *PNAS*
Dehaene and Changeaux 2011 *Neuron*
Cocchi *et al.* 2013 *TICS*

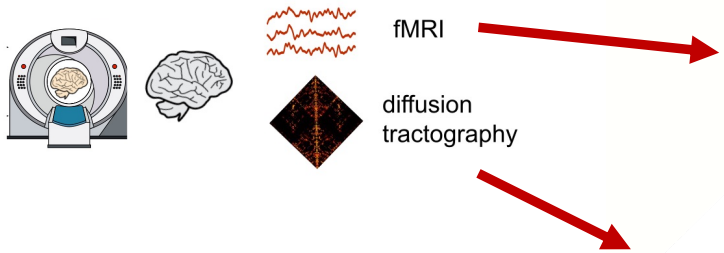
Cooperation and competition

Does the brain's network architecture include competition?

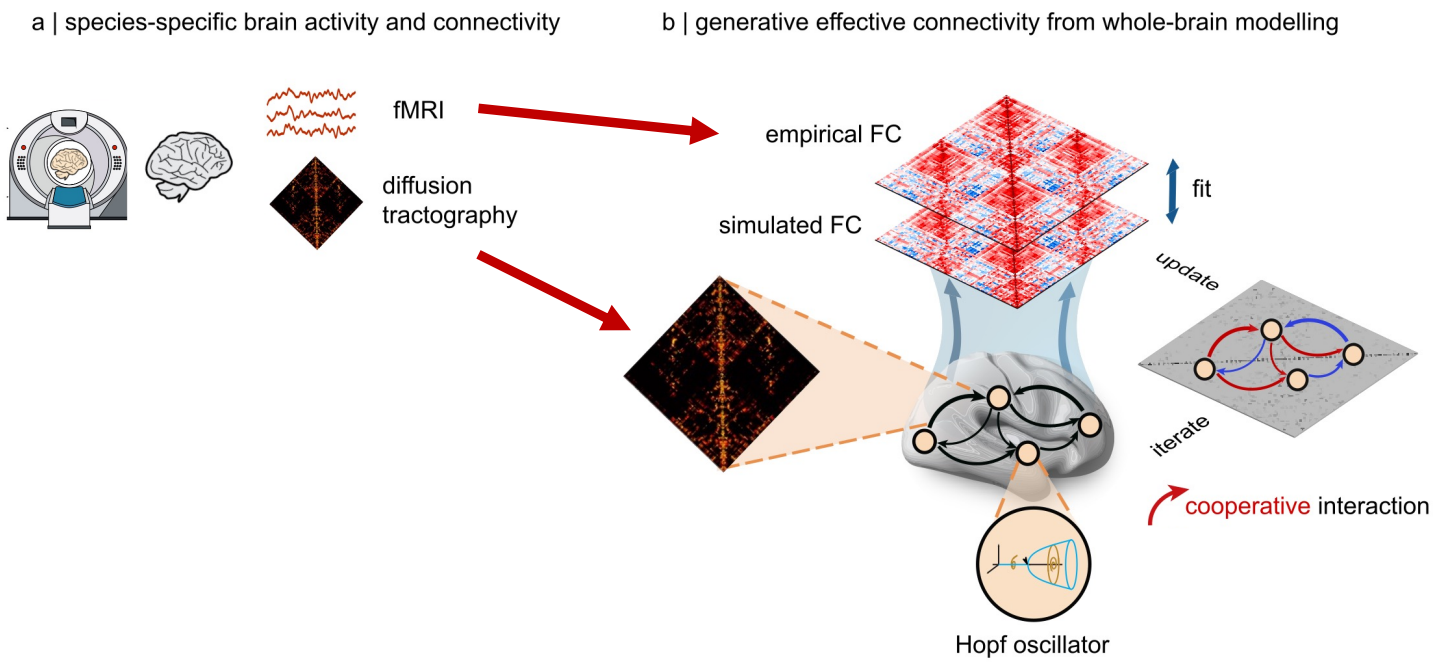


How do competitive interactions shape brain dynamics?

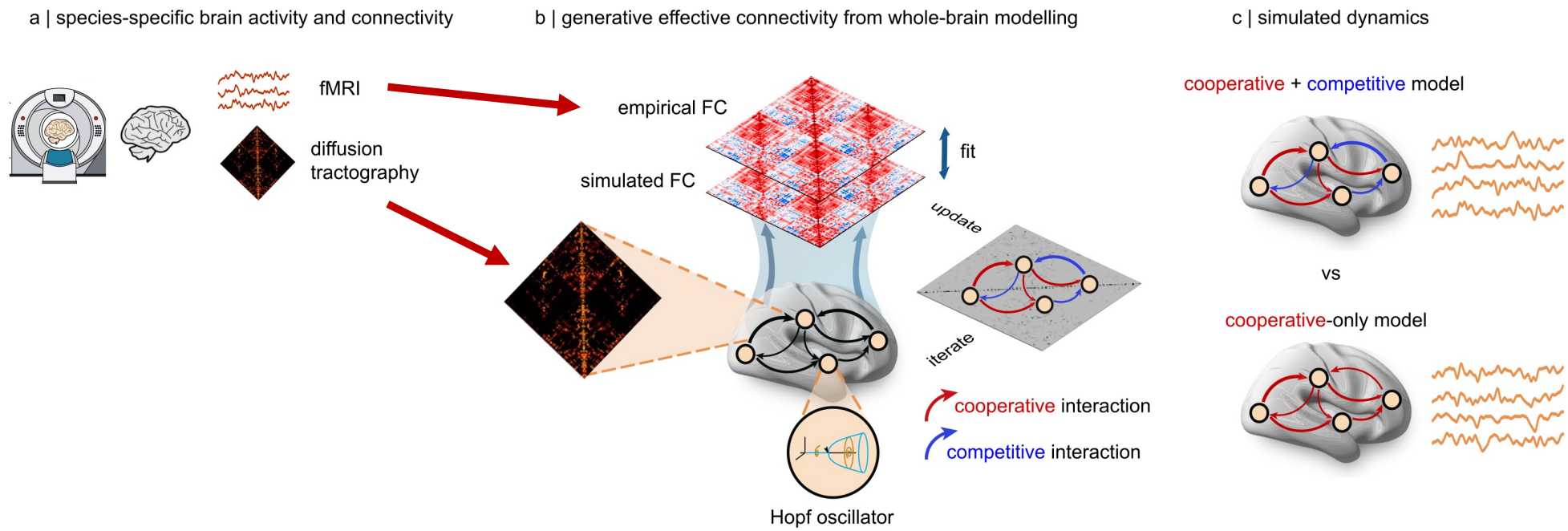
Modelling competitive interactions



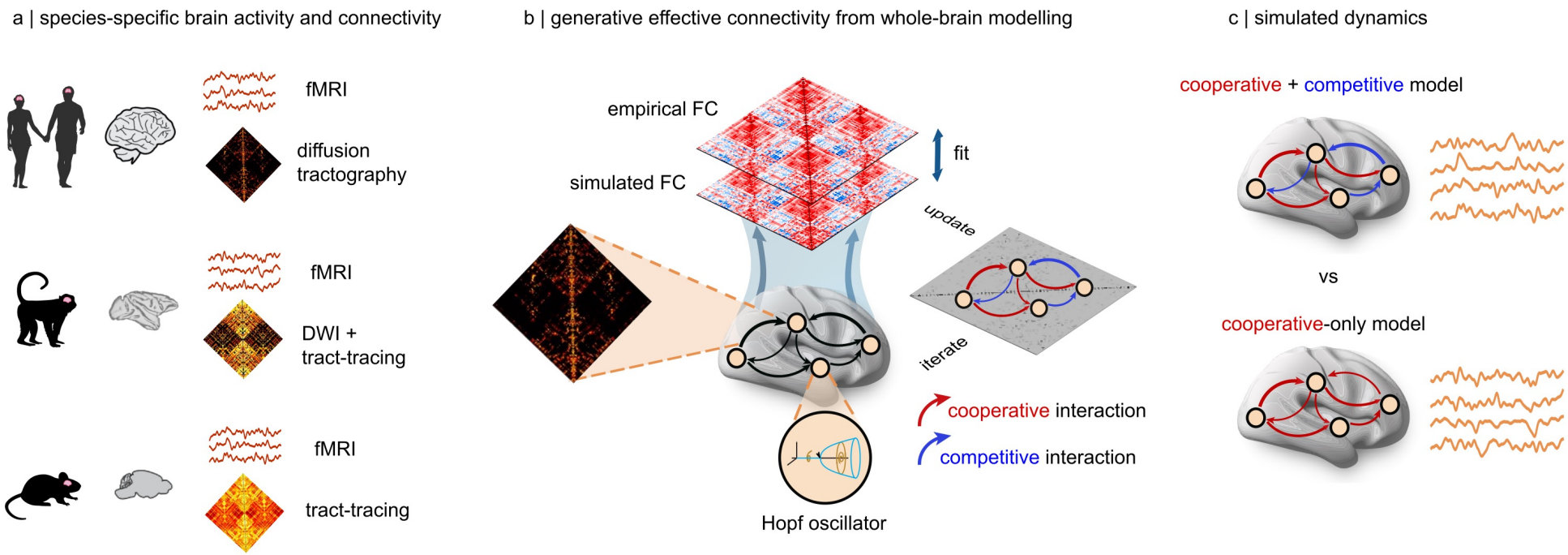
Modelling competitive interactions



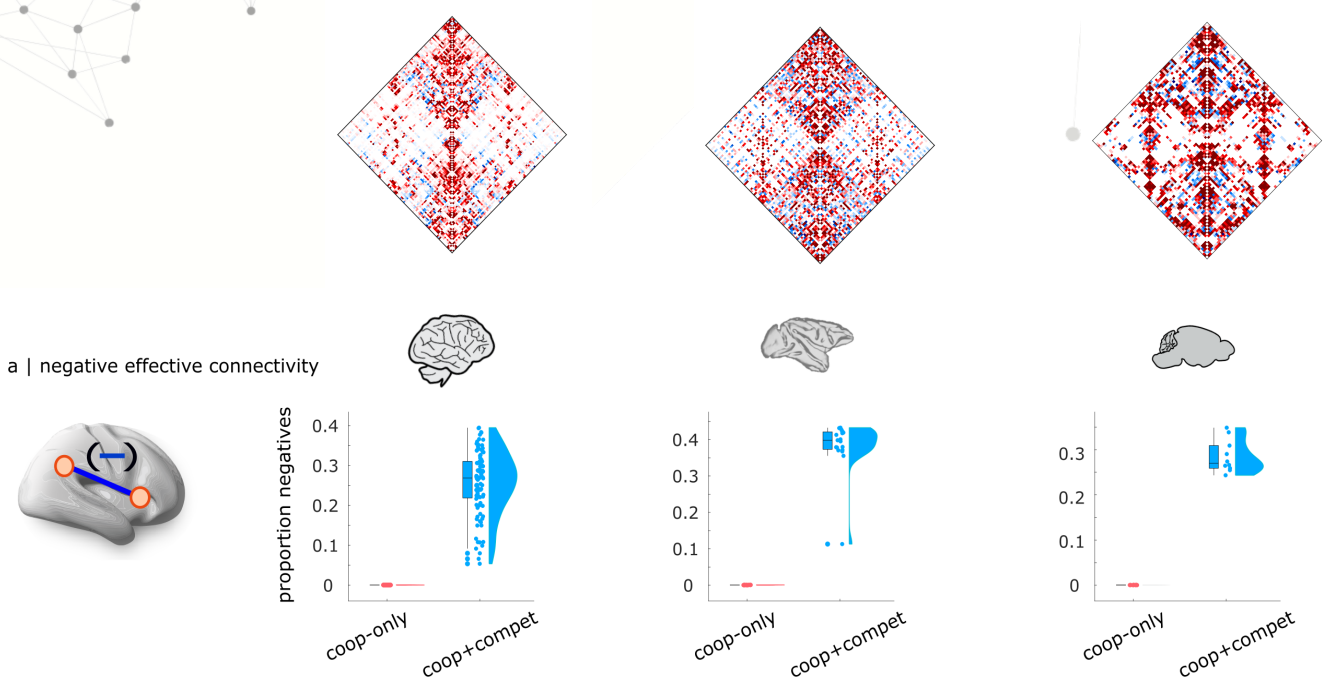
Modelling competitive interactions



Modelling competitive interactions across species

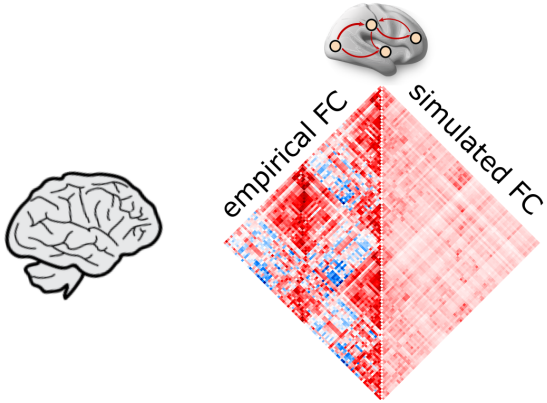


Widespread competitive interactions across species



Superior group-level fit to empirical FC

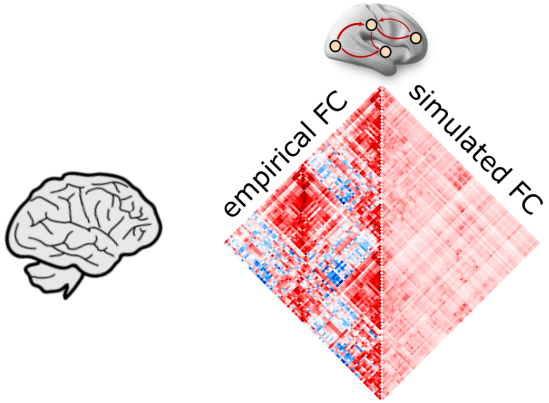
a | group FC fit cooperative-only



r = 0.42

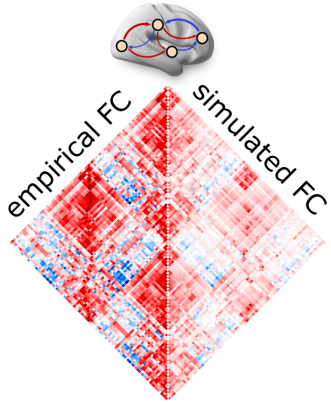
Superior group-level fit to empirical FC

a | group FC fit cooperative-only



r = 0.42

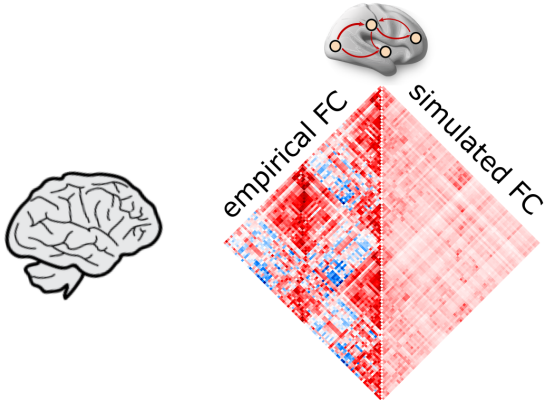
b | group FC fit with competition



r = 0.87

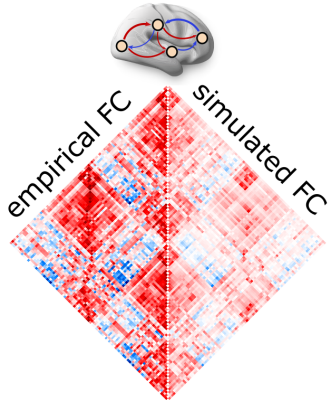
Superior subject-wise fit to empirical FC

a | group FC fit cooperative-only



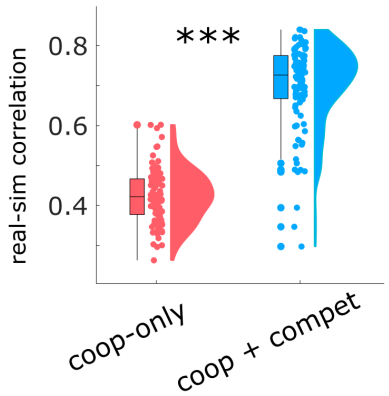
r = 0.42

b | group FC fit with competition

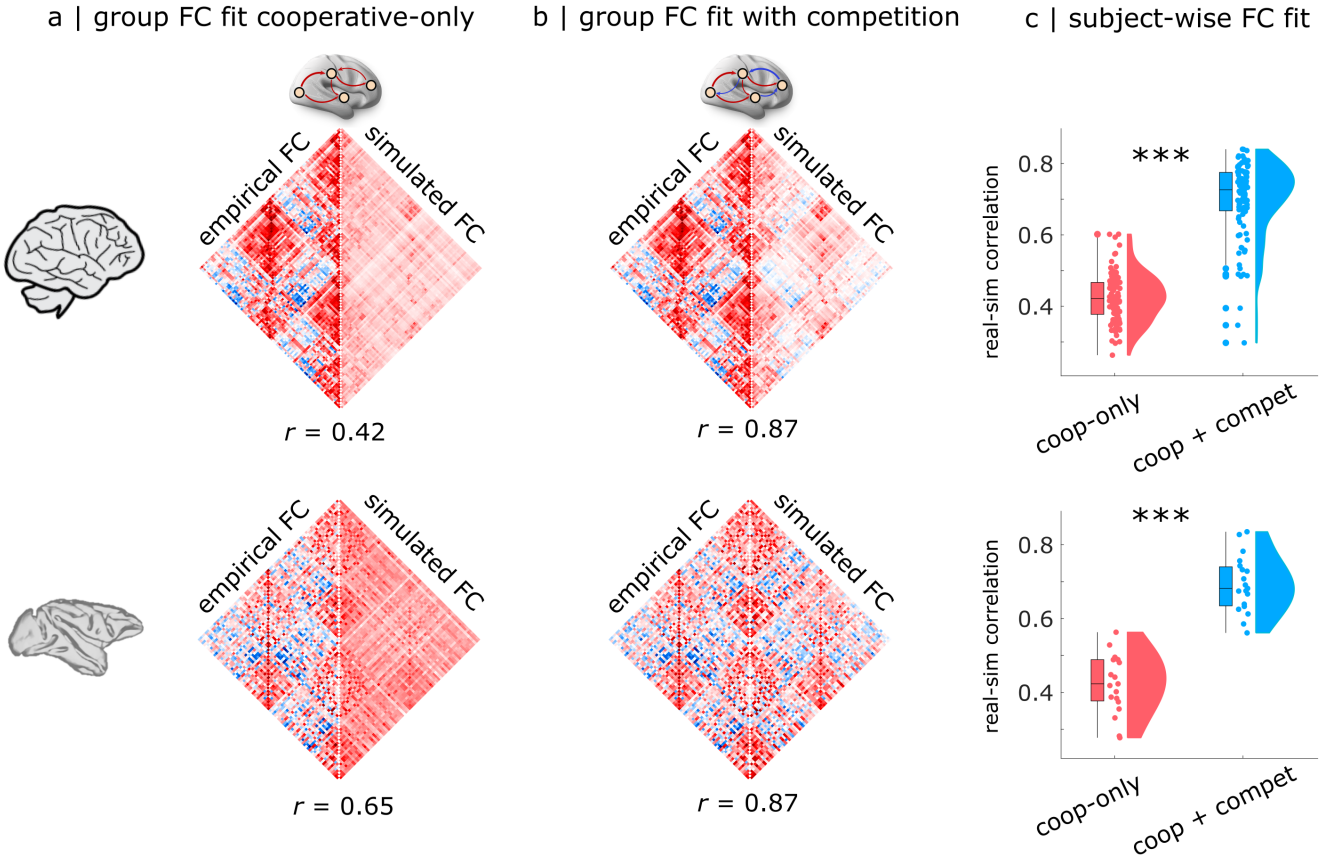


r = 0.87

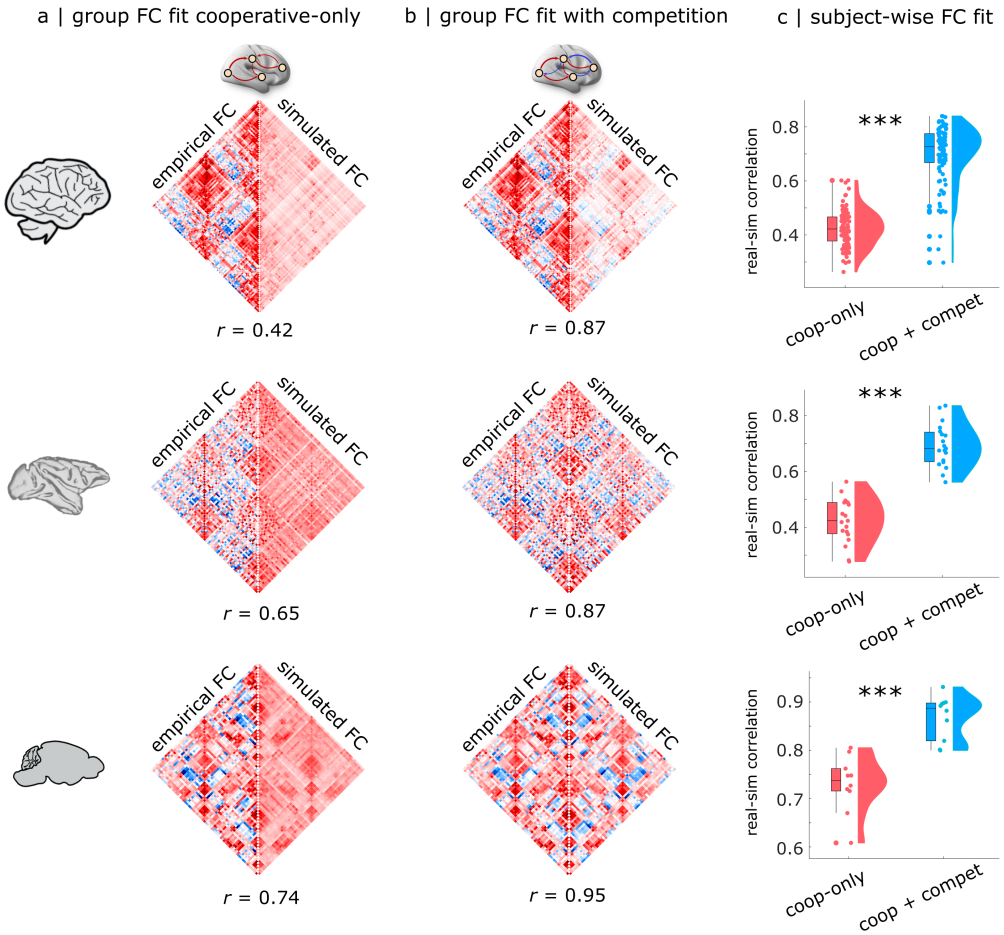
c | subject-wise FC fit



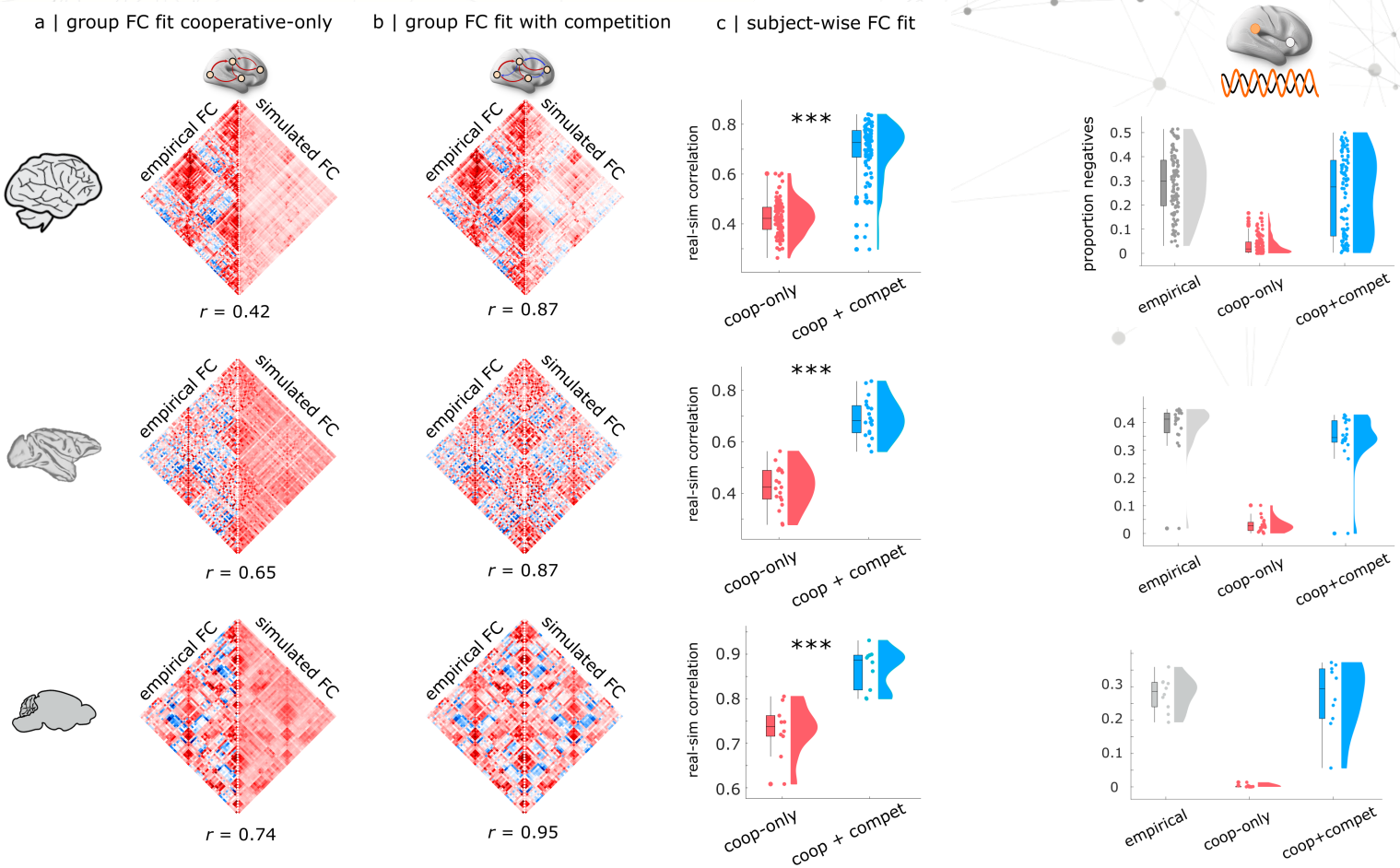
Superior FC fit across species



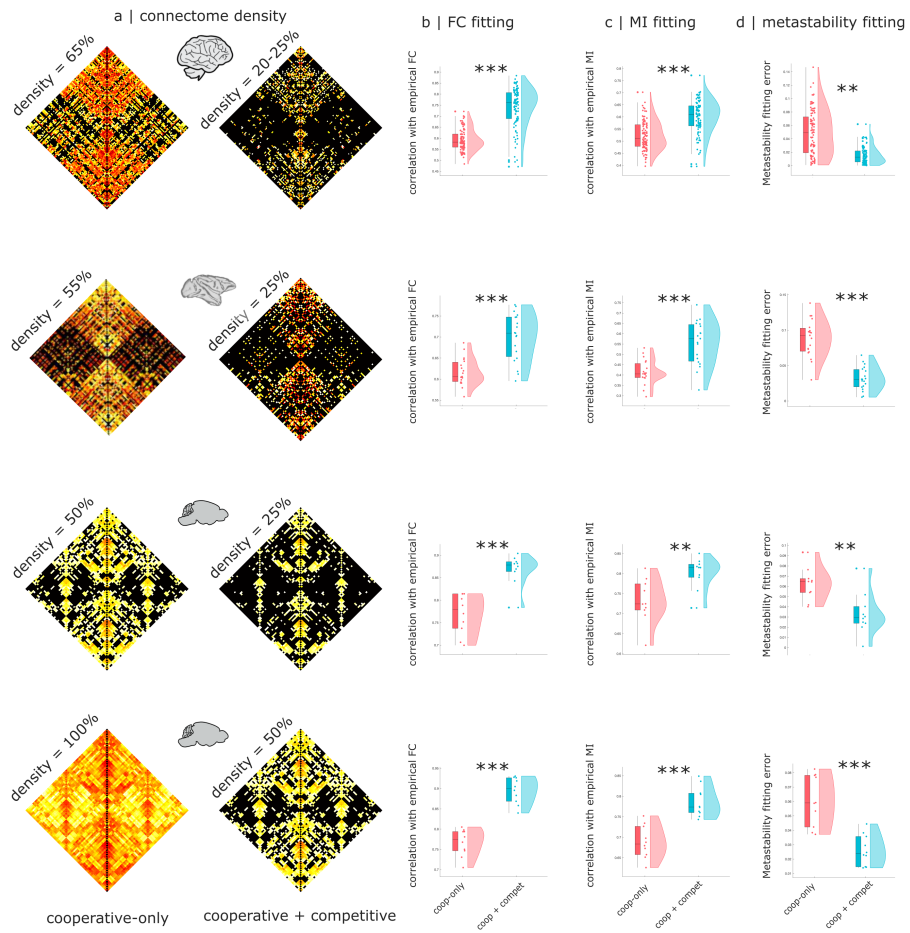
Superior FC fit across species



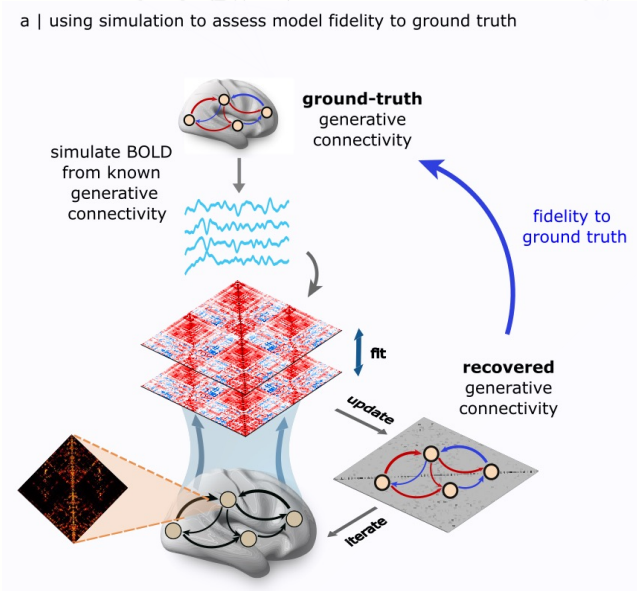
Matching anticorrelations

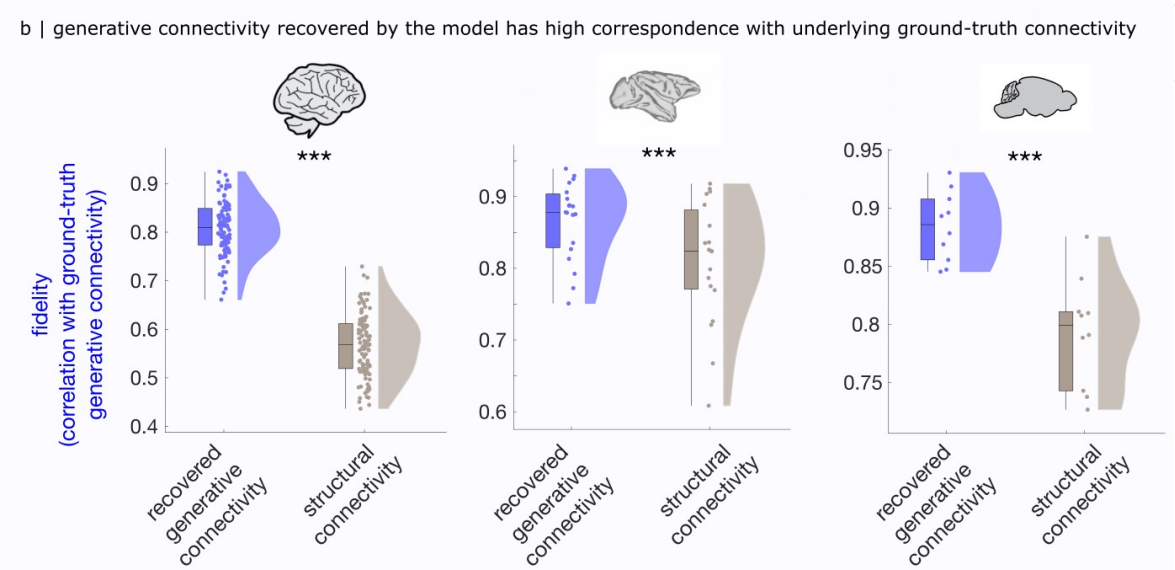


Competitive interactions: better than 2X parameters



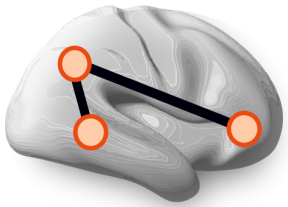
Recovering ground truth

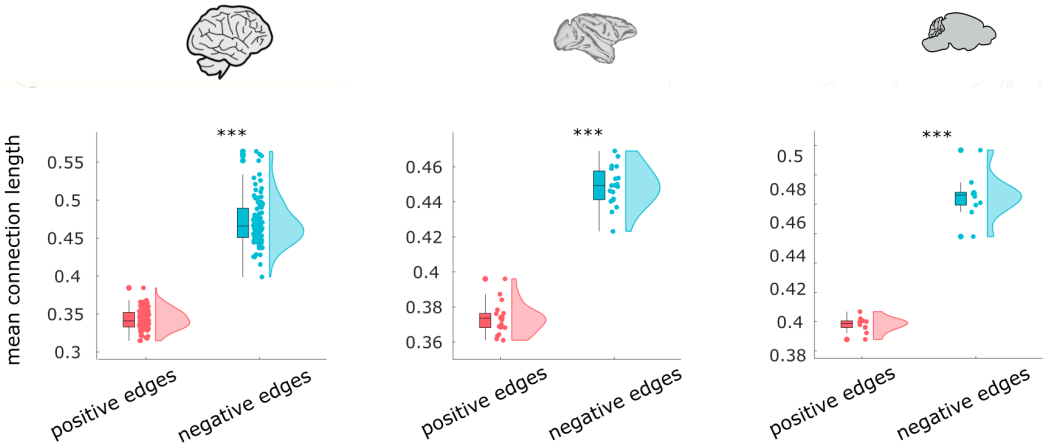




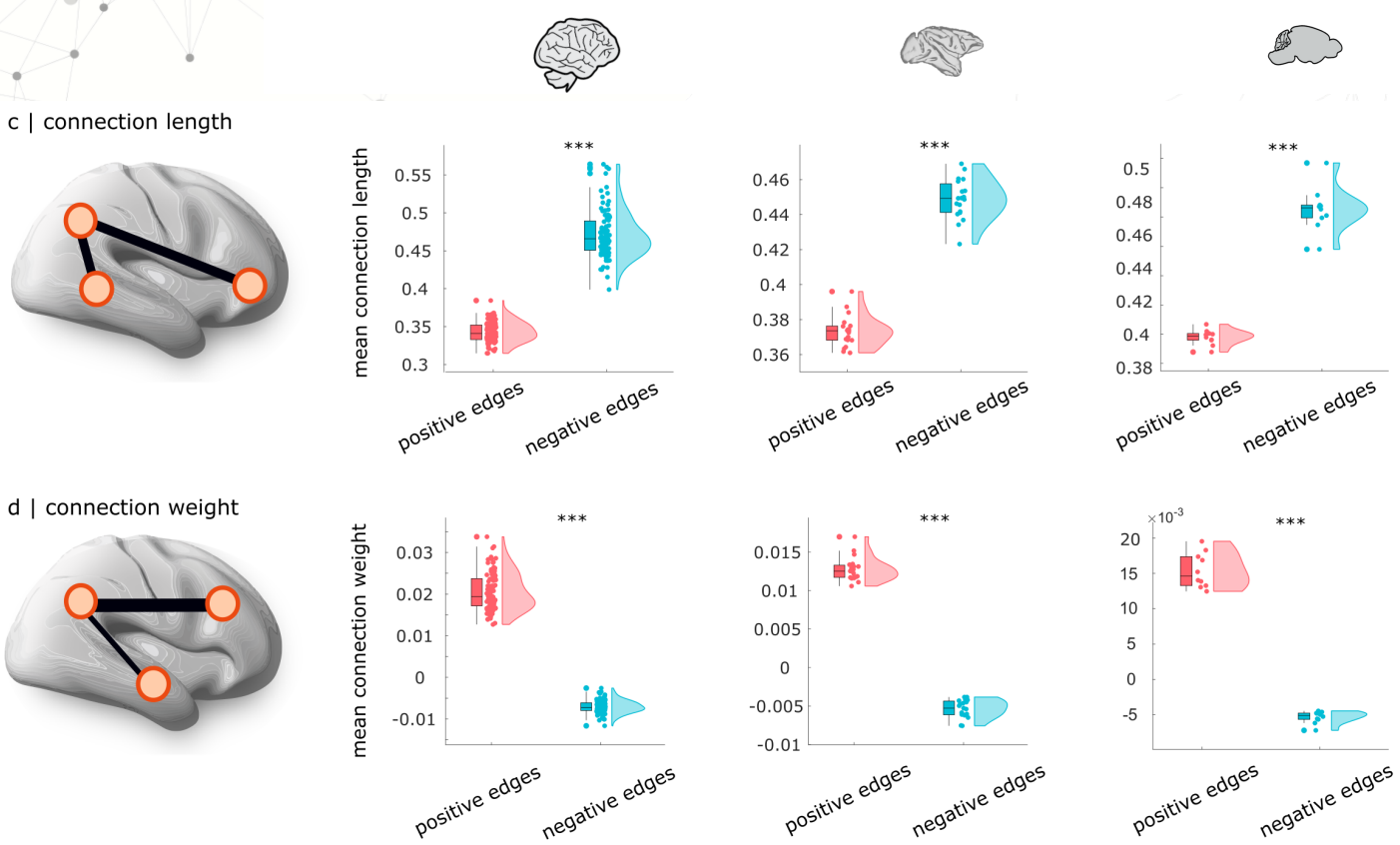
Systematic organisation of competitive connections

c | connection length

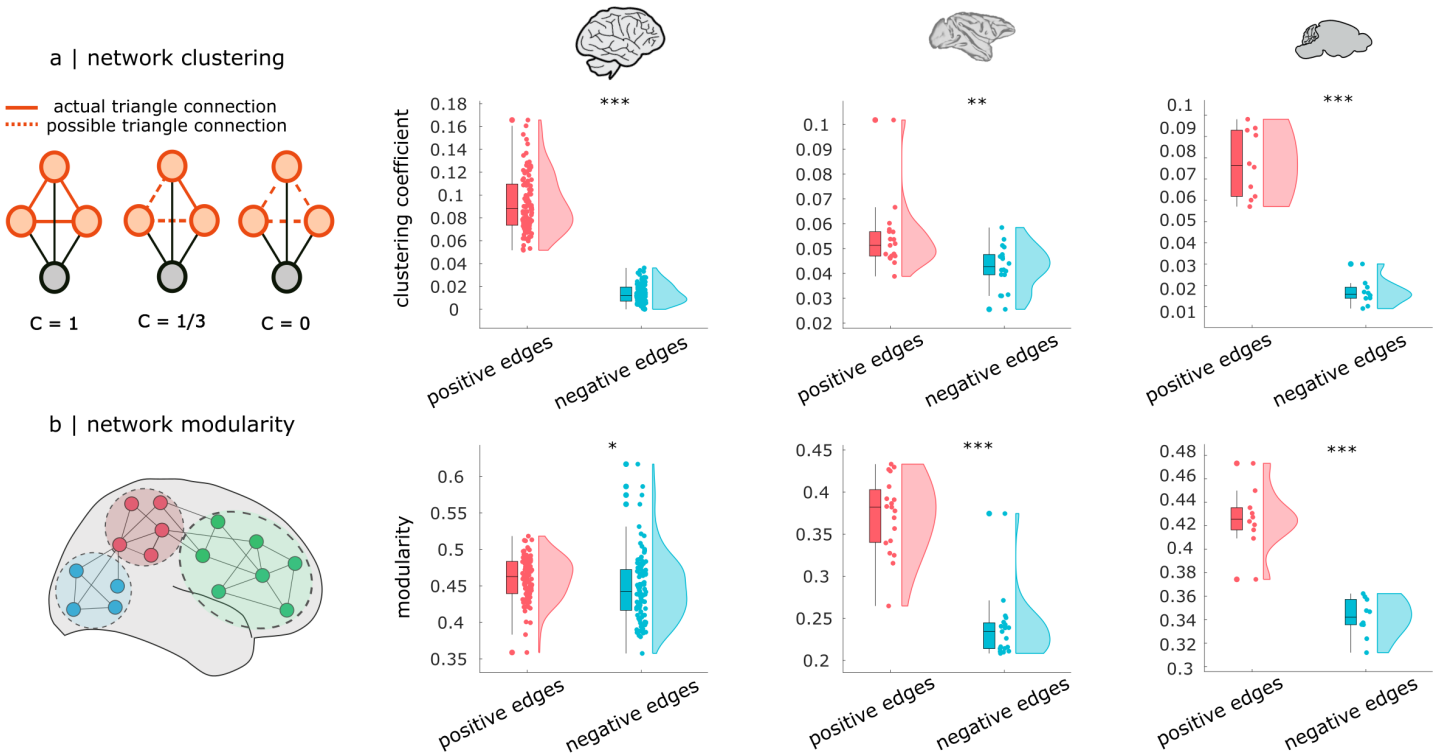




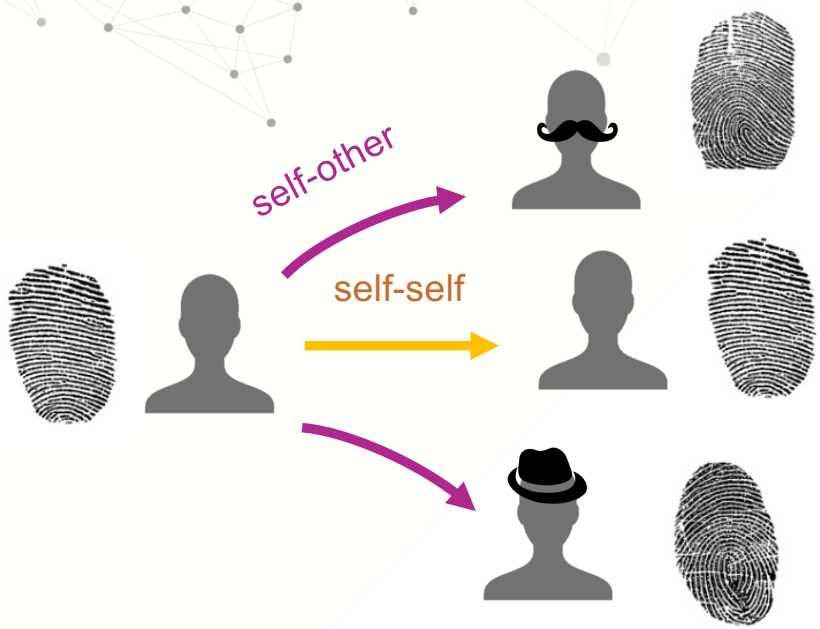
Systematic organisation of competitive connections



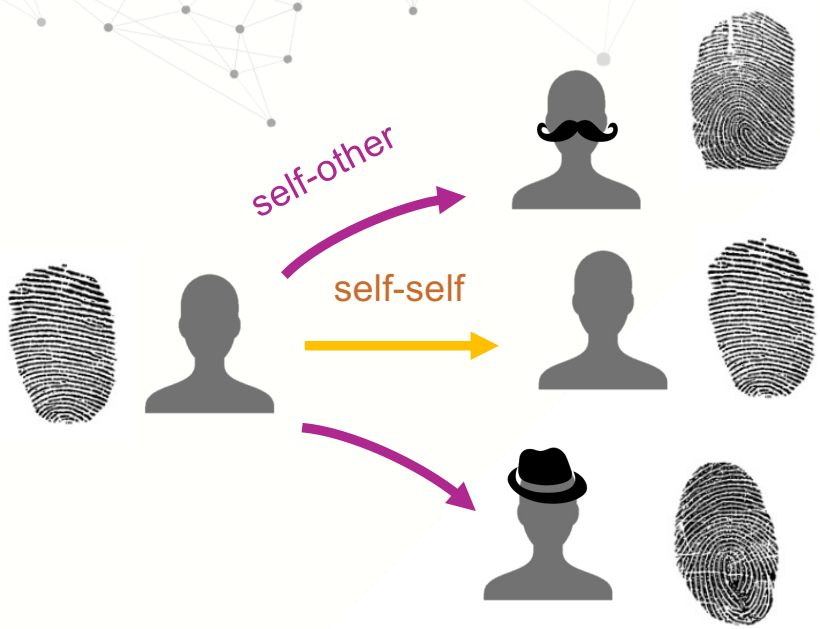
Systematic organisation of competitive connections

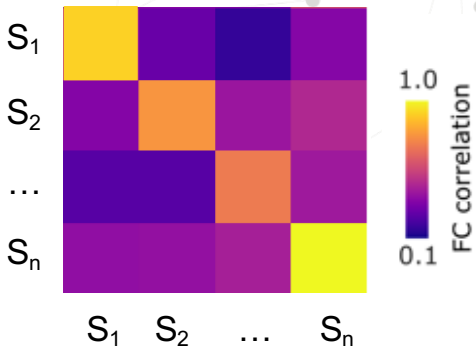


Subject-specificity



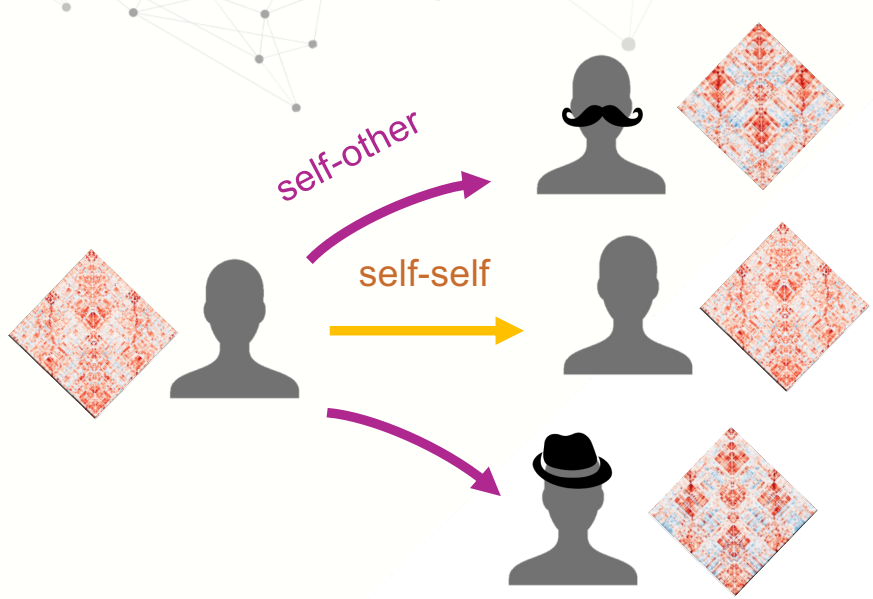
Subject-specificity

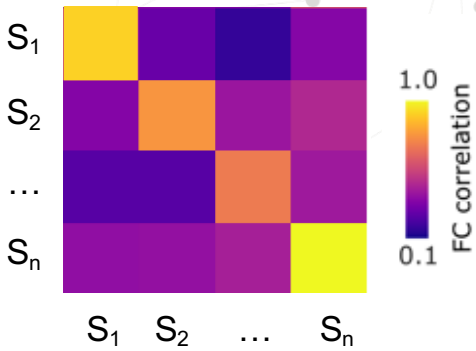




Differential identifiability
=
self-self (diagonal)
minus
self-other (off-diagonal)

Subject-specificity

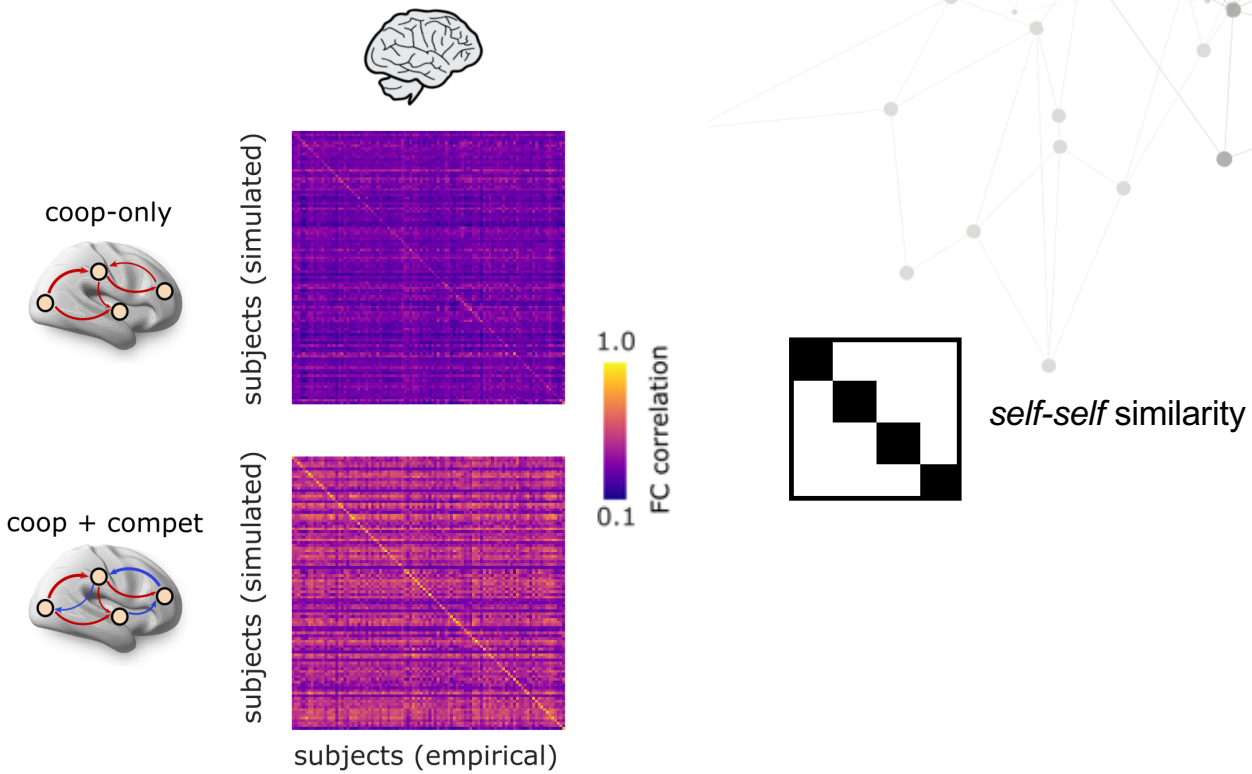




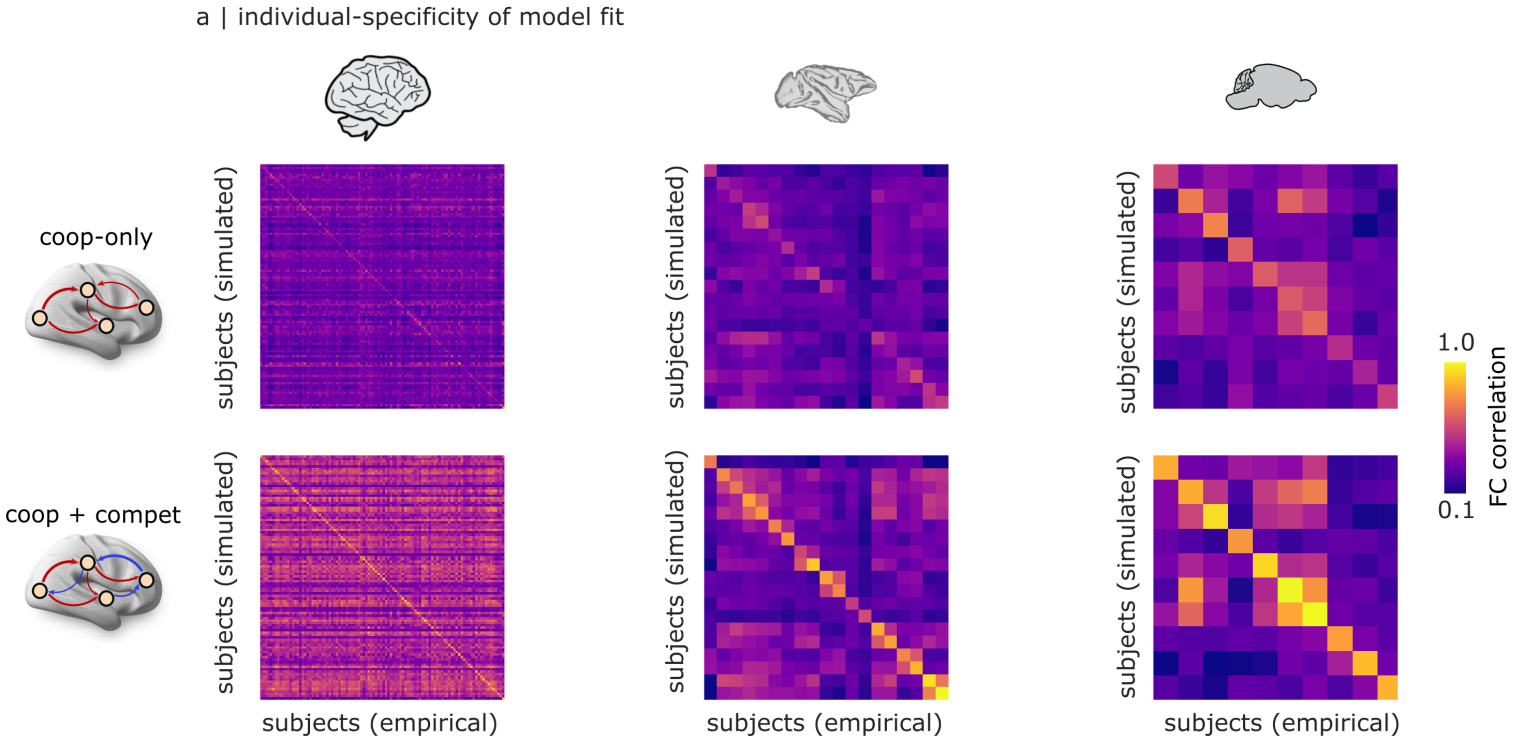
Differential identifiability
=
self-self (diagonal)
minus
self-other (off-diagonal)

Enhanced subject-specificity

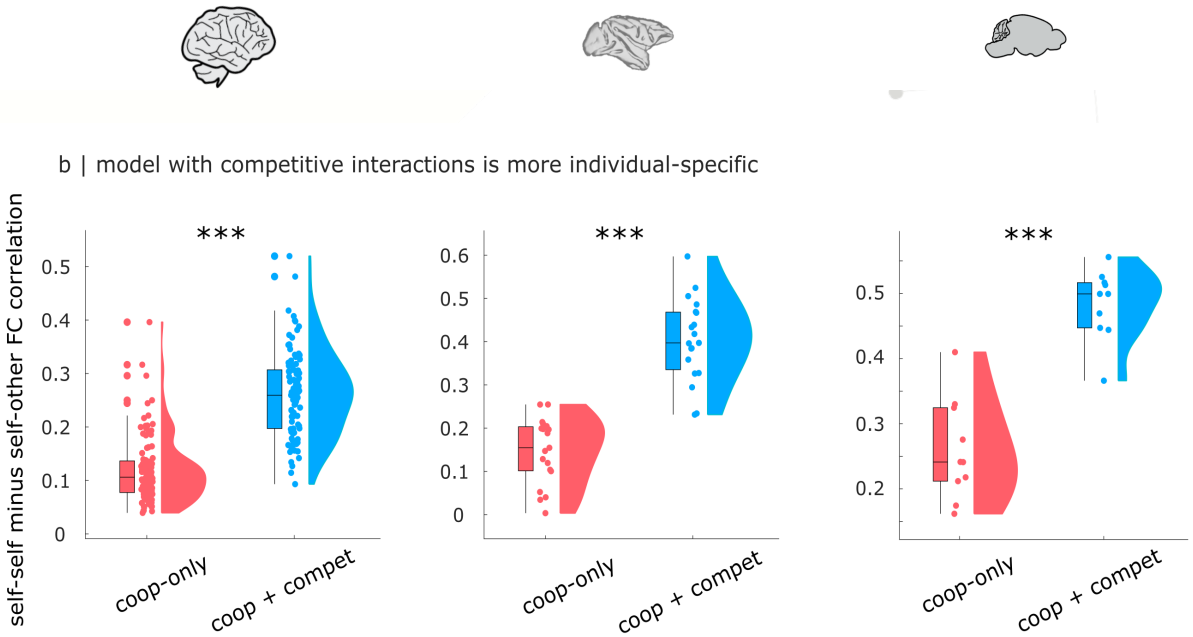
a | individual-specificity of model fit



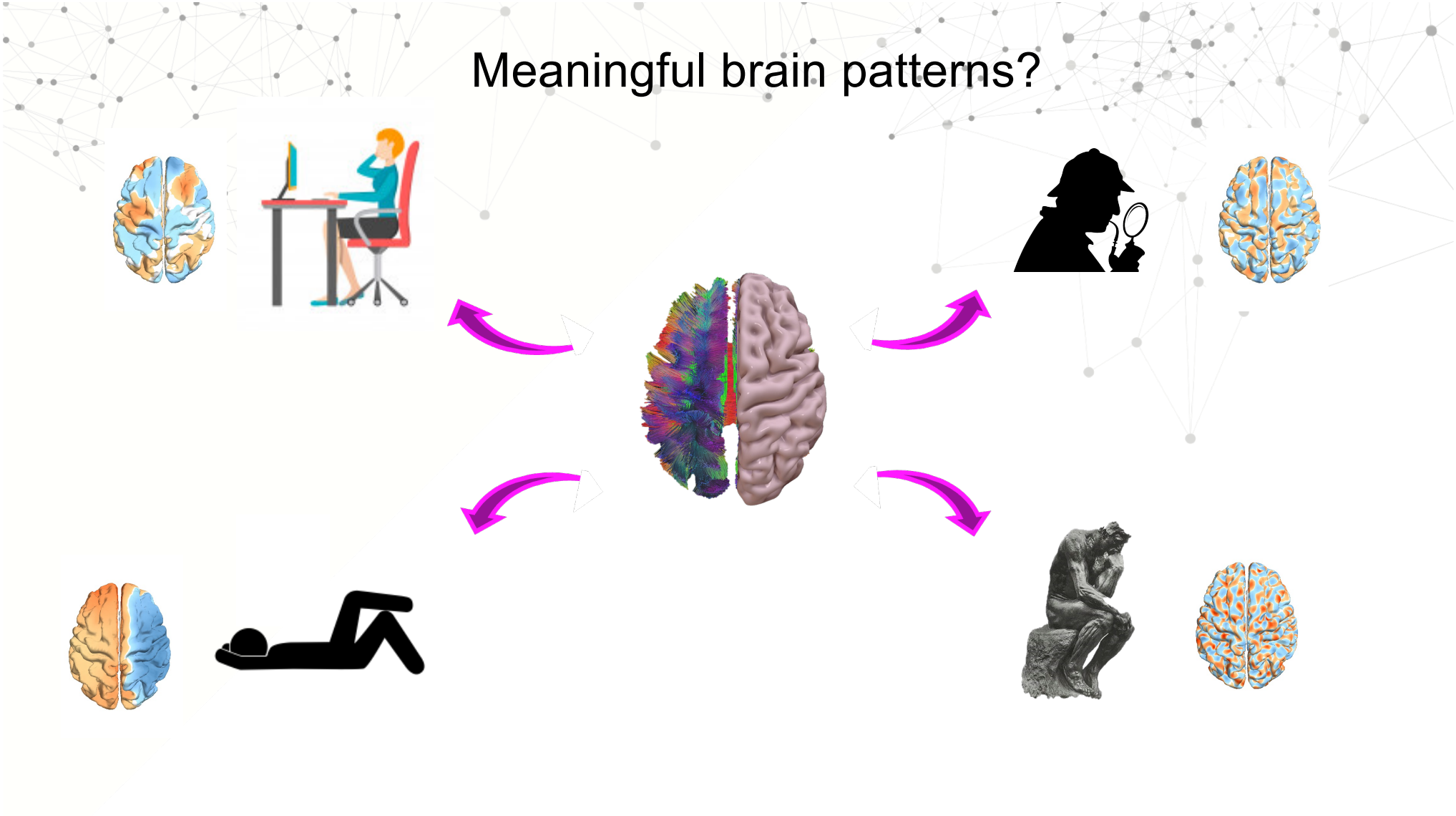
Enhanced subject-specificity



Enhanced subject-specificity

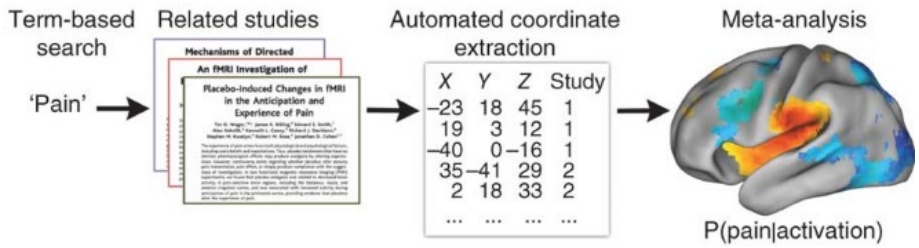


Meaningful brain patterns?

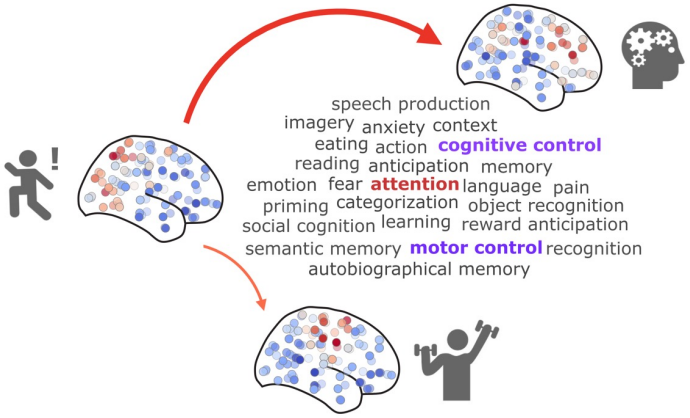


Meaningful brain patterns from NeuroSynth

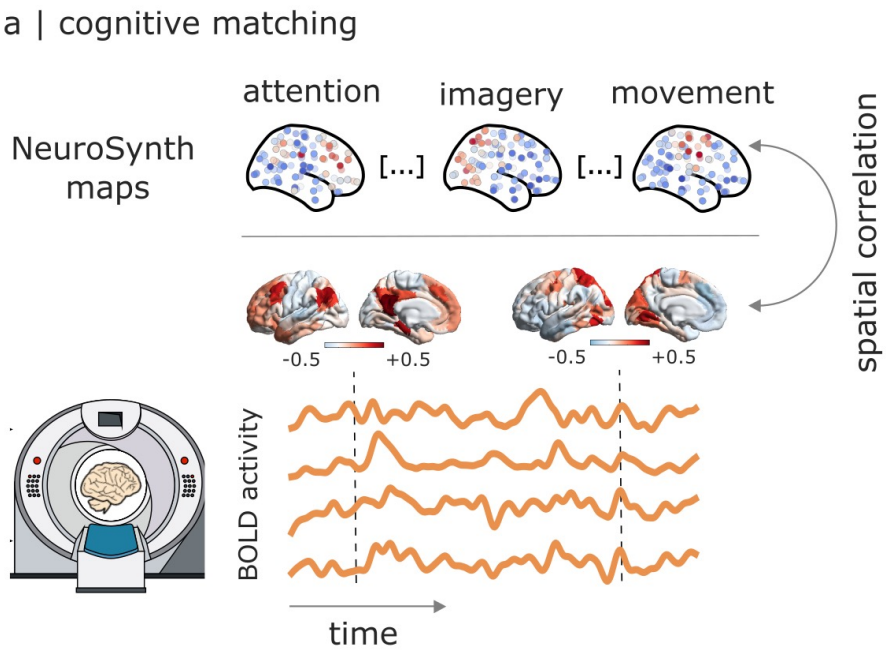
neurosynth.org



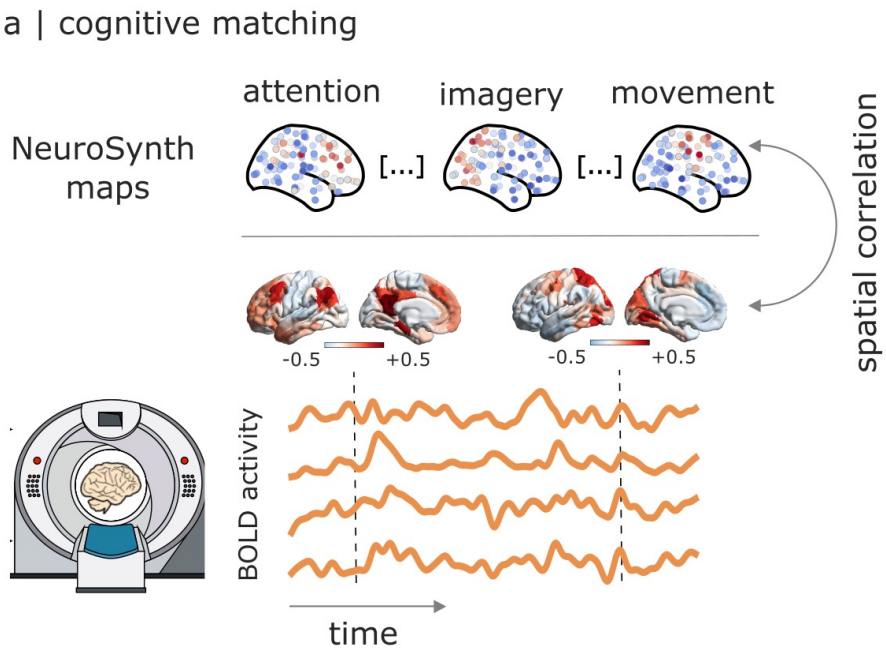
summary of >14,000 neuroimaging experiments

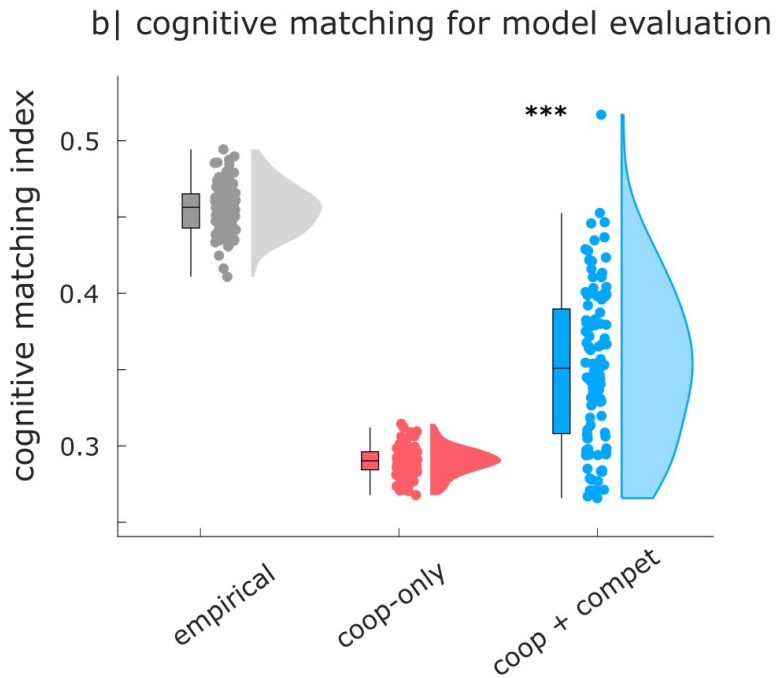


Matching cognitive brain patterns



Matching cognitive brain patterns

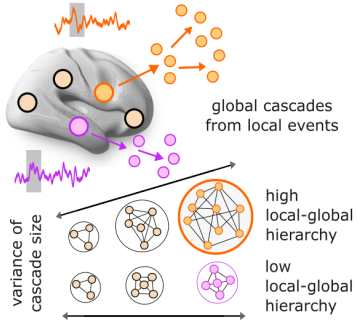


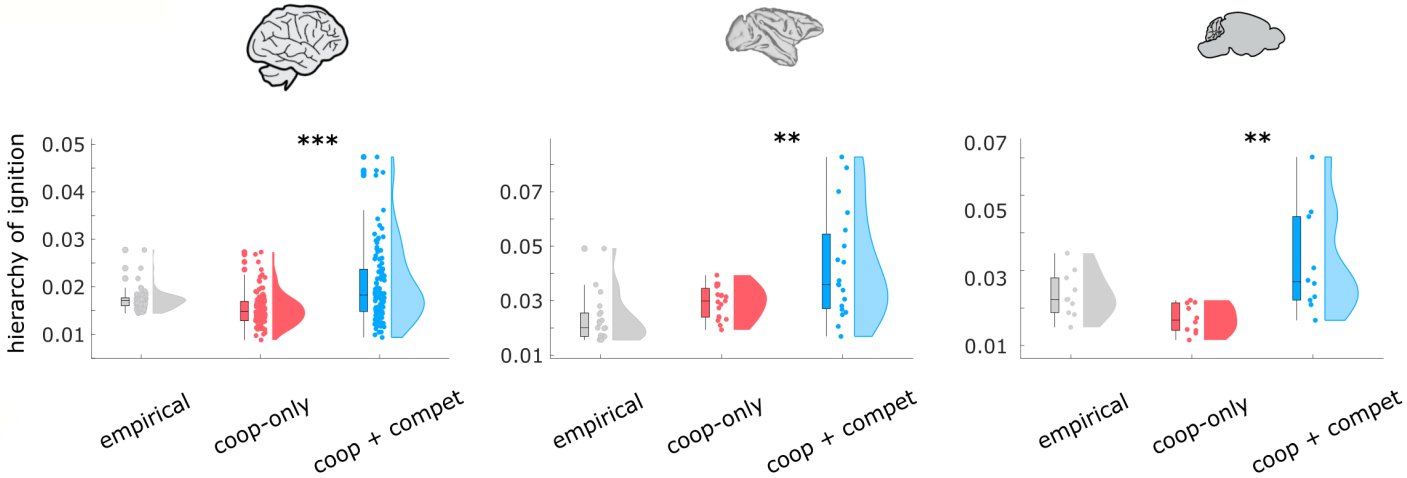


Luppi *et al. Nature Human Behaviour* (2025)

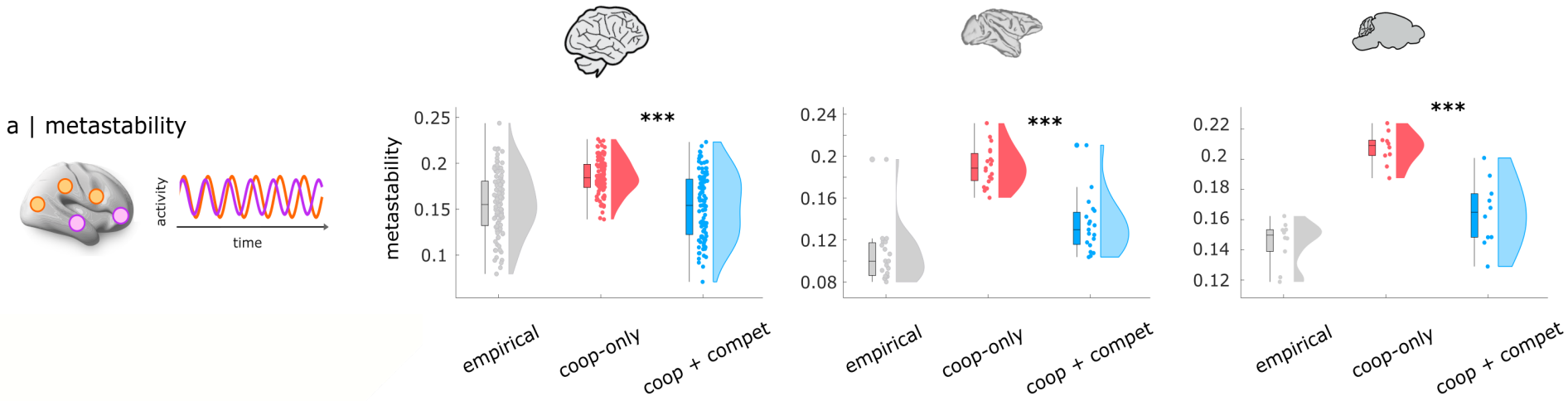
More hierarchical character

b | local-global hierarchy



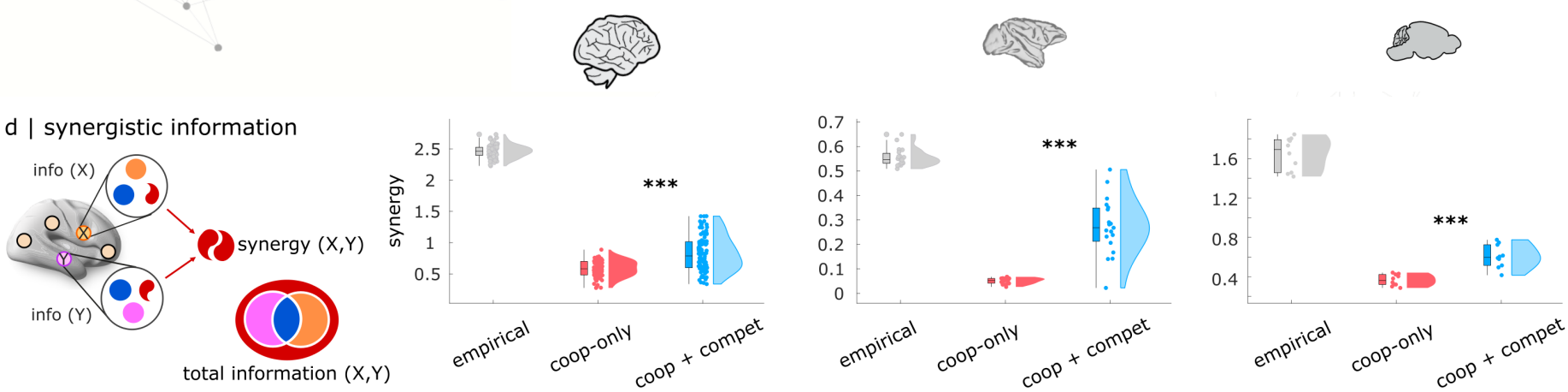


Competitive interactions stabilise metastability*



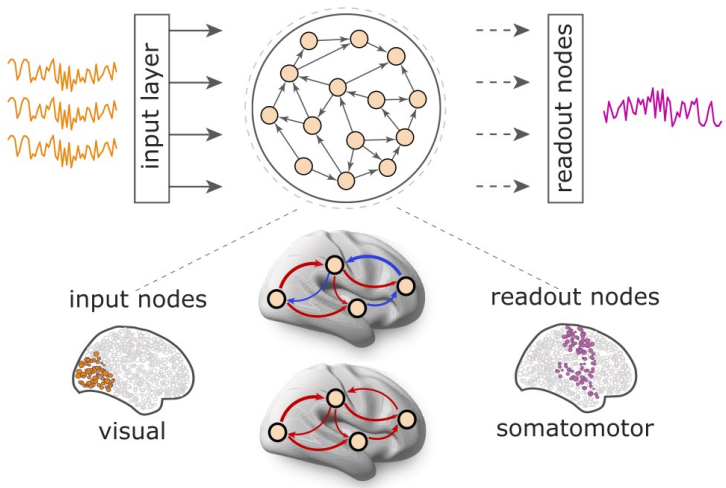
*see Hancock, Rosas *et* (many) *al.*
Nature Reviews Neuroscience (in press)

Increased synergistic information

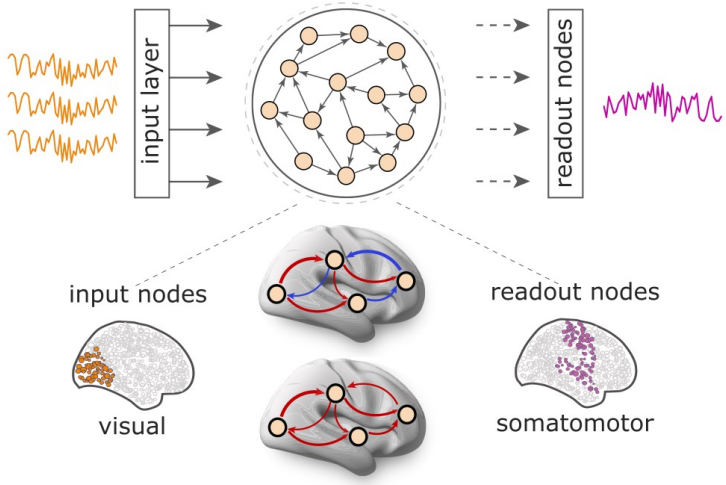


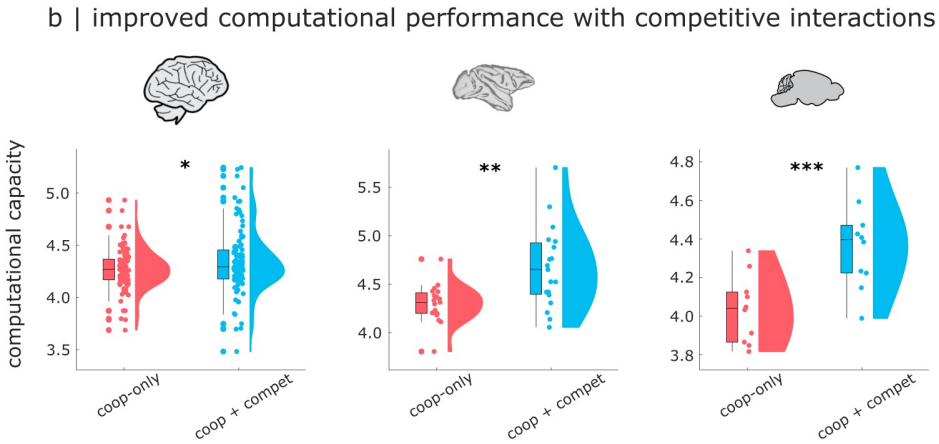
Luppi *et al. Nature Neuroscience* (2022)

Improved computational capacity

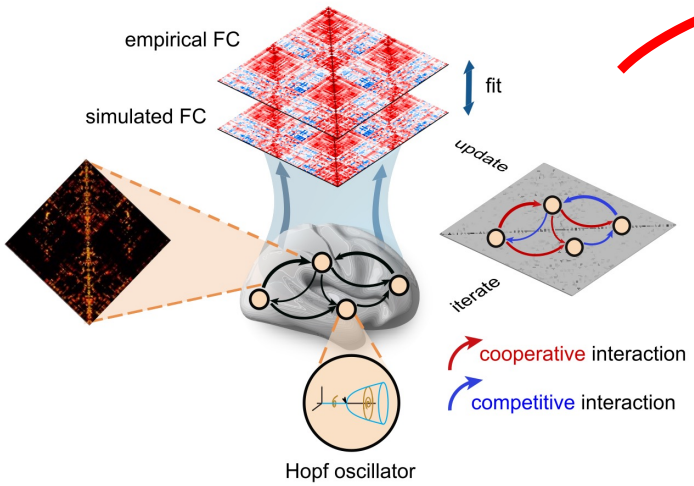


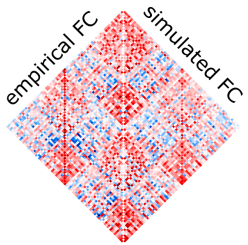
Improved computational capacity



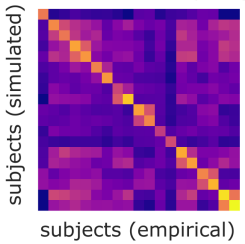


Improving models along multiple dimensions

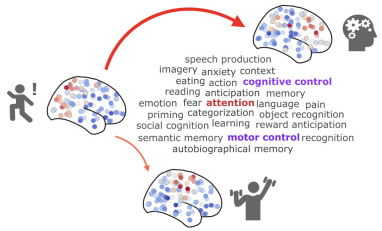




matching the emergence of function from structure

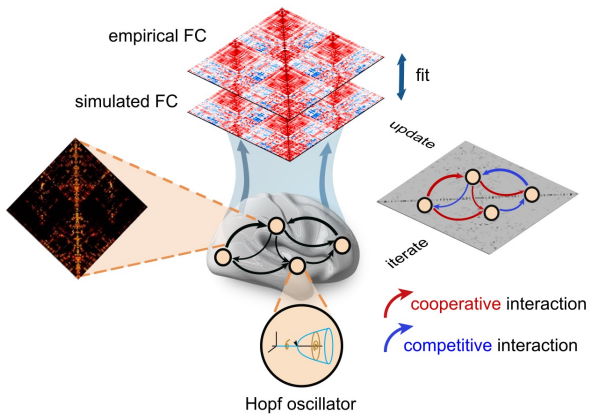


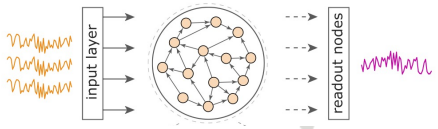
enhanced subject-specificity



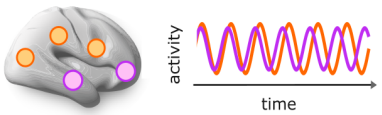
generating cognitively relevant patterns

Dynamical consequences of competitive interactions

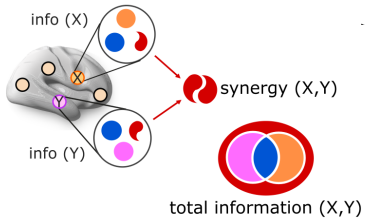




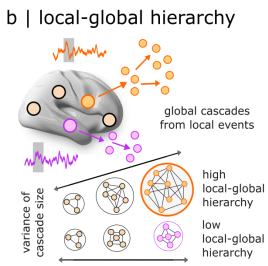
computational capacity



metastability

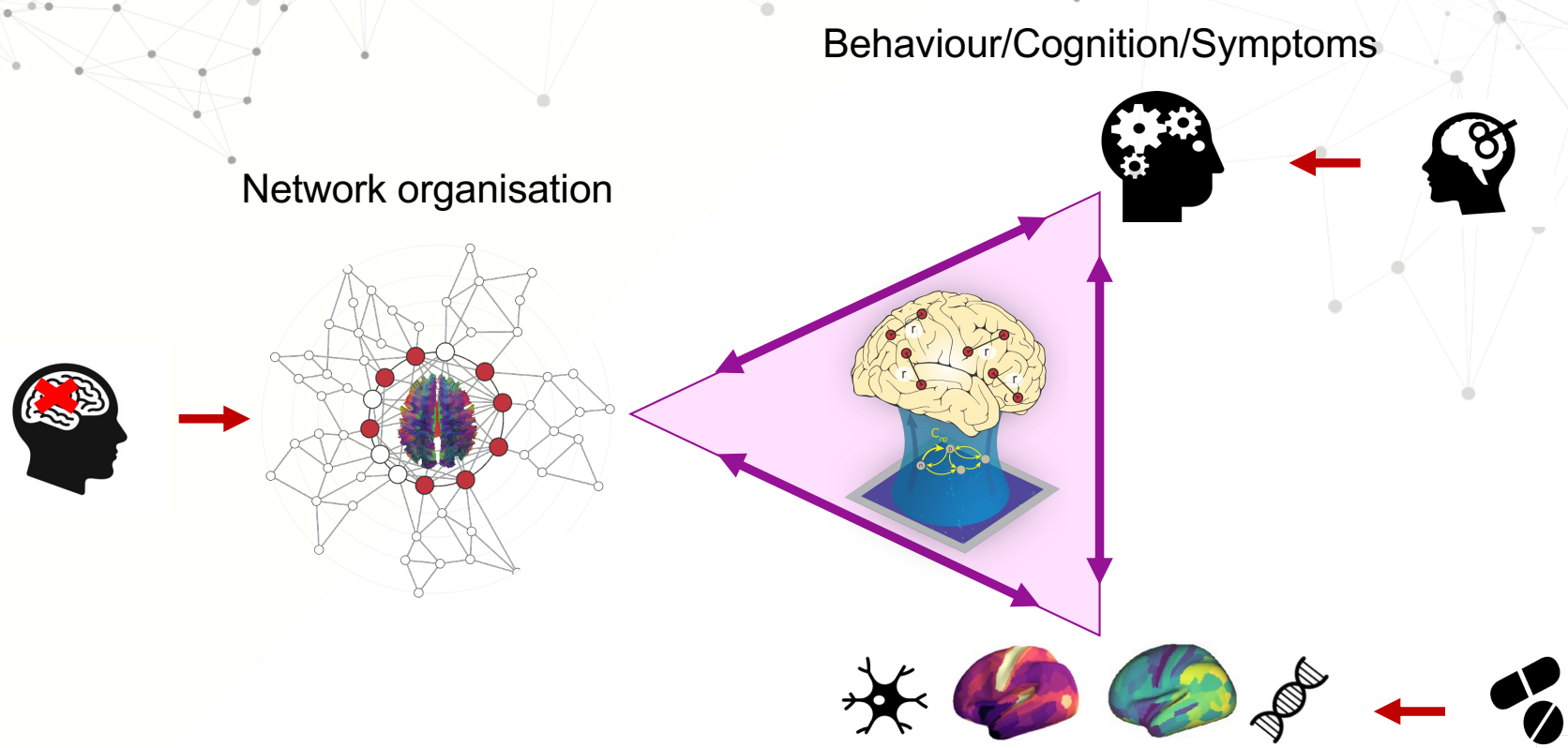


synergistic information



local-global hierarchy

Long-term goal: Modelling as Rosetta Stone



A Synergistic Effort

Competitive interactions shape brain dynamics and computation across species

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doi: https://doi.org/10.1101/2024.10.19.619194

wellcome

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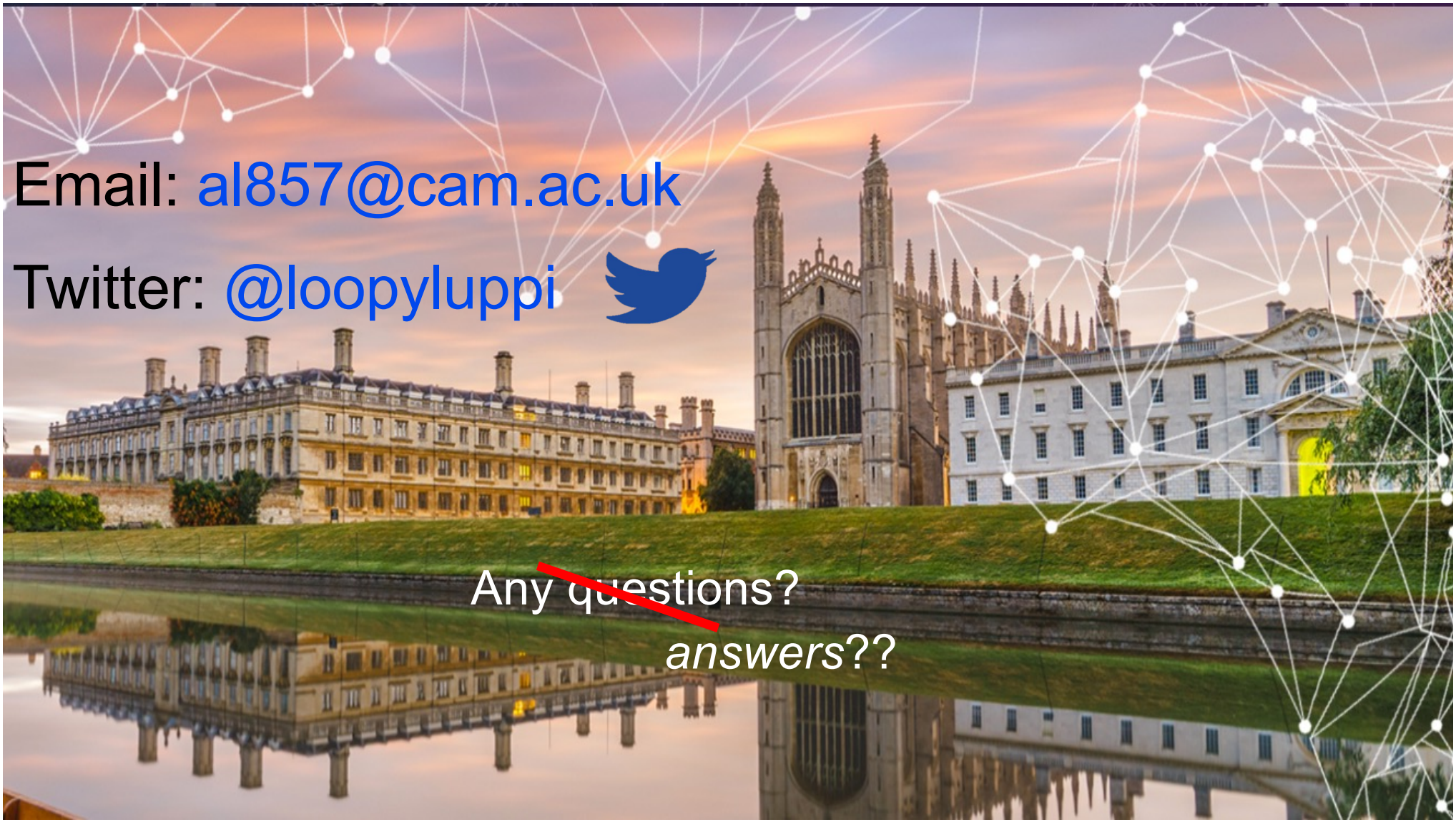
Any questions?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answers??