Modeling the influence of non-local connectomic projections on geometrically constrained cortical dynamics

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Background

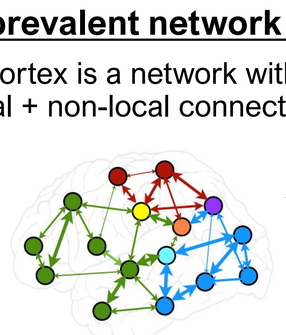
Despite the role of non-local long-range connections (LRCs) in integrating information across remote neural systems, many key properties of macroscale cortical dynamics can be accurately captured by simple geometric models that neglect the specific positions of LRCs[1,2,3]. Using a novel mathematical model, **we aim to investigate why the cortex's local geometry alone can sufficiently capture many properties of macroscale cortical dynamics**.

Phenomenological Model

In our novel mathematical model of cortical dynamics, local connections propagate activity between any two populations as waves; whereas LRCs propagate activity rapidly between specific pairs of distant populations.

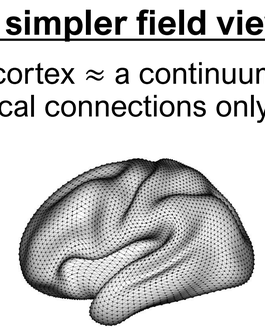
The prevalent network view

The cortex is a network with both local + non-local connections

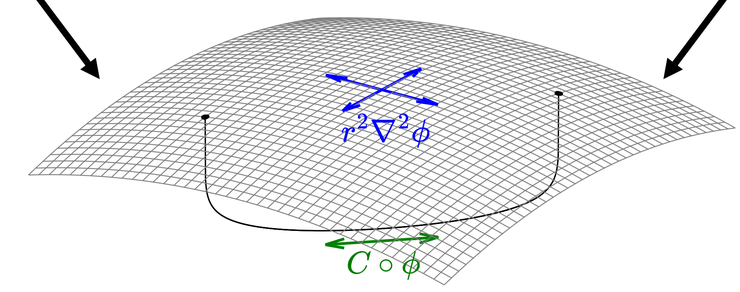


A simpler field view

The cortex ≈ a continuum of local connections only

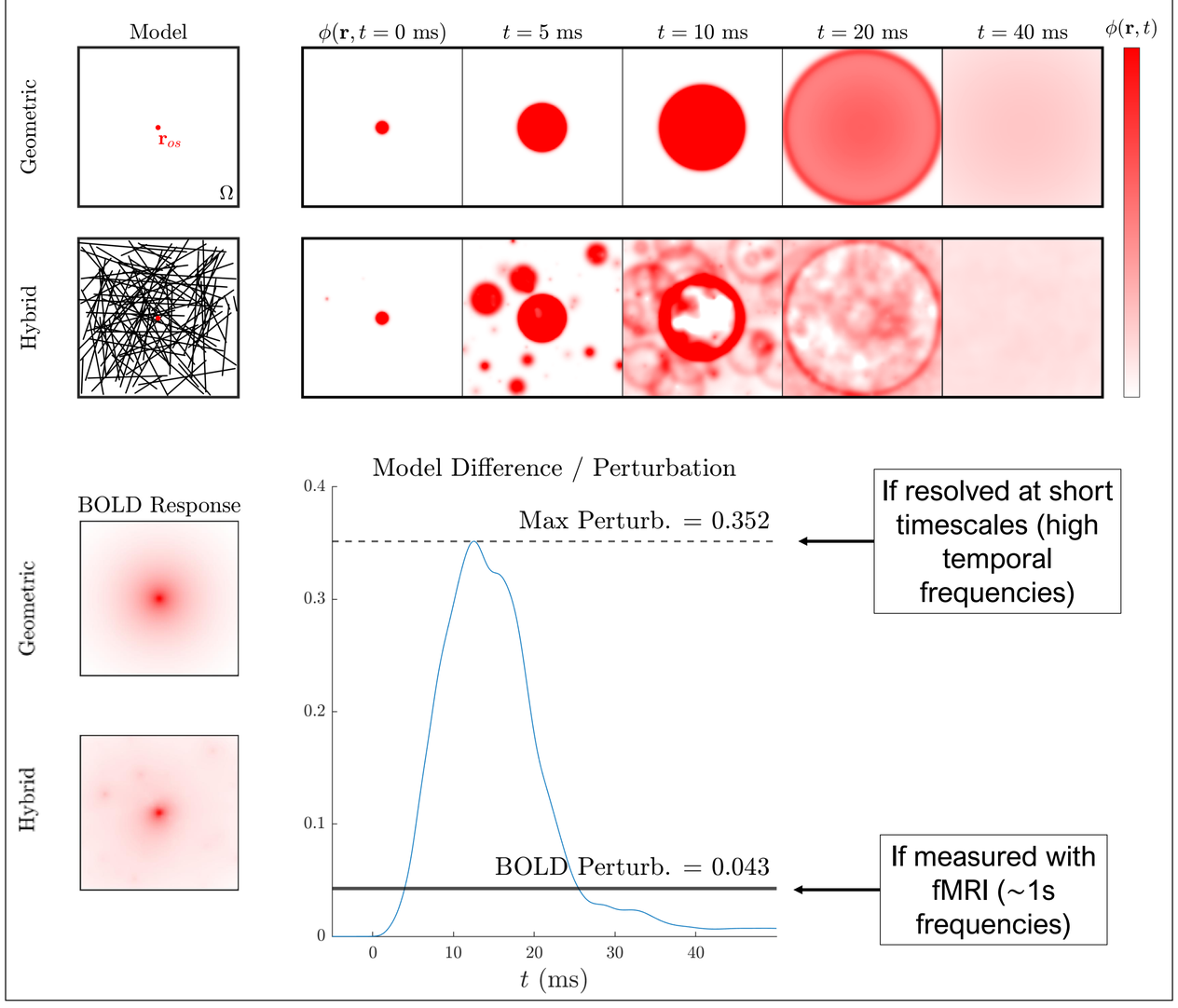


$$\mathcal{D}_t\phi - r^2\nabla^2\phi - C \circ \phi = f$$

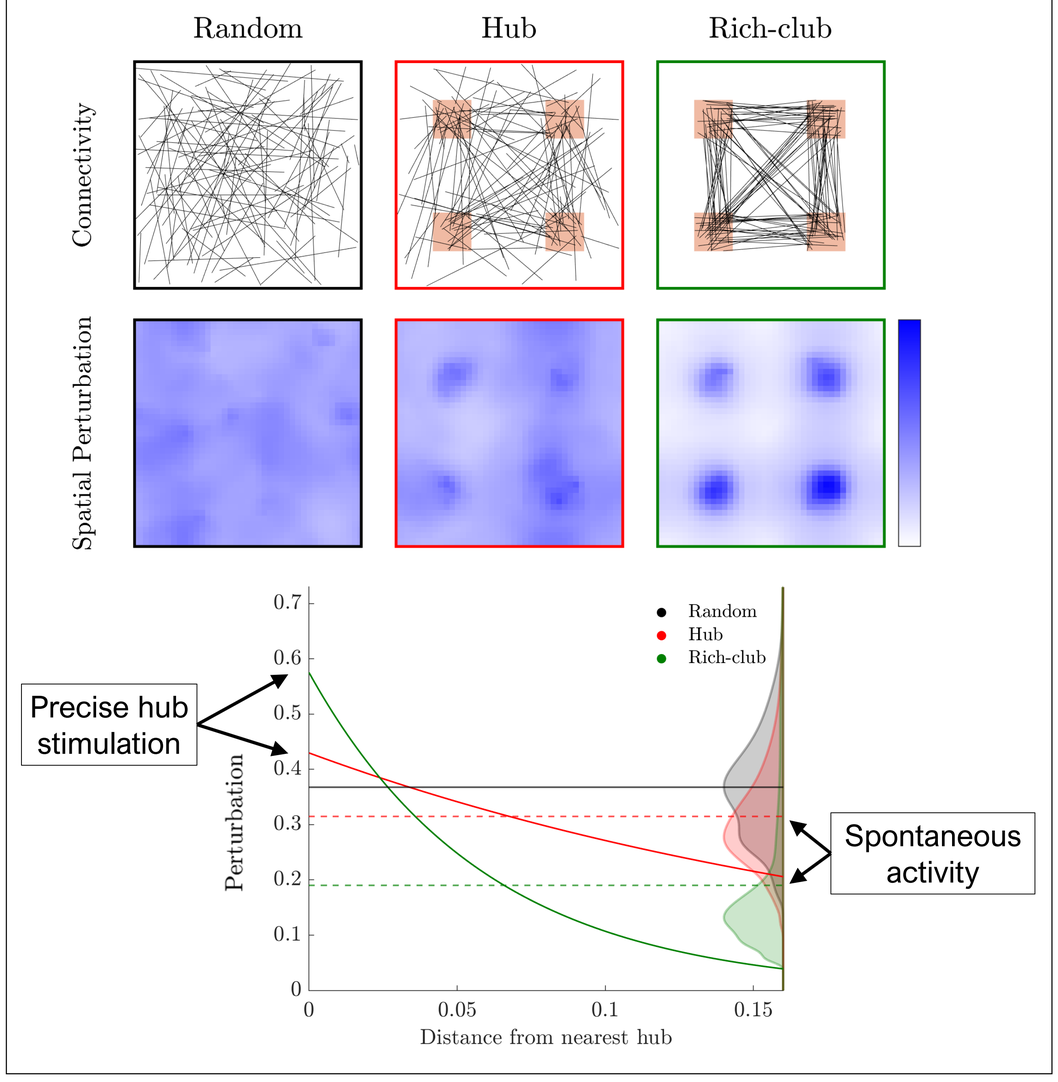


Simulation Results

1. LRCs perturb cortical dynamics **strongest over short millisecond timescales (< 30 ms)**



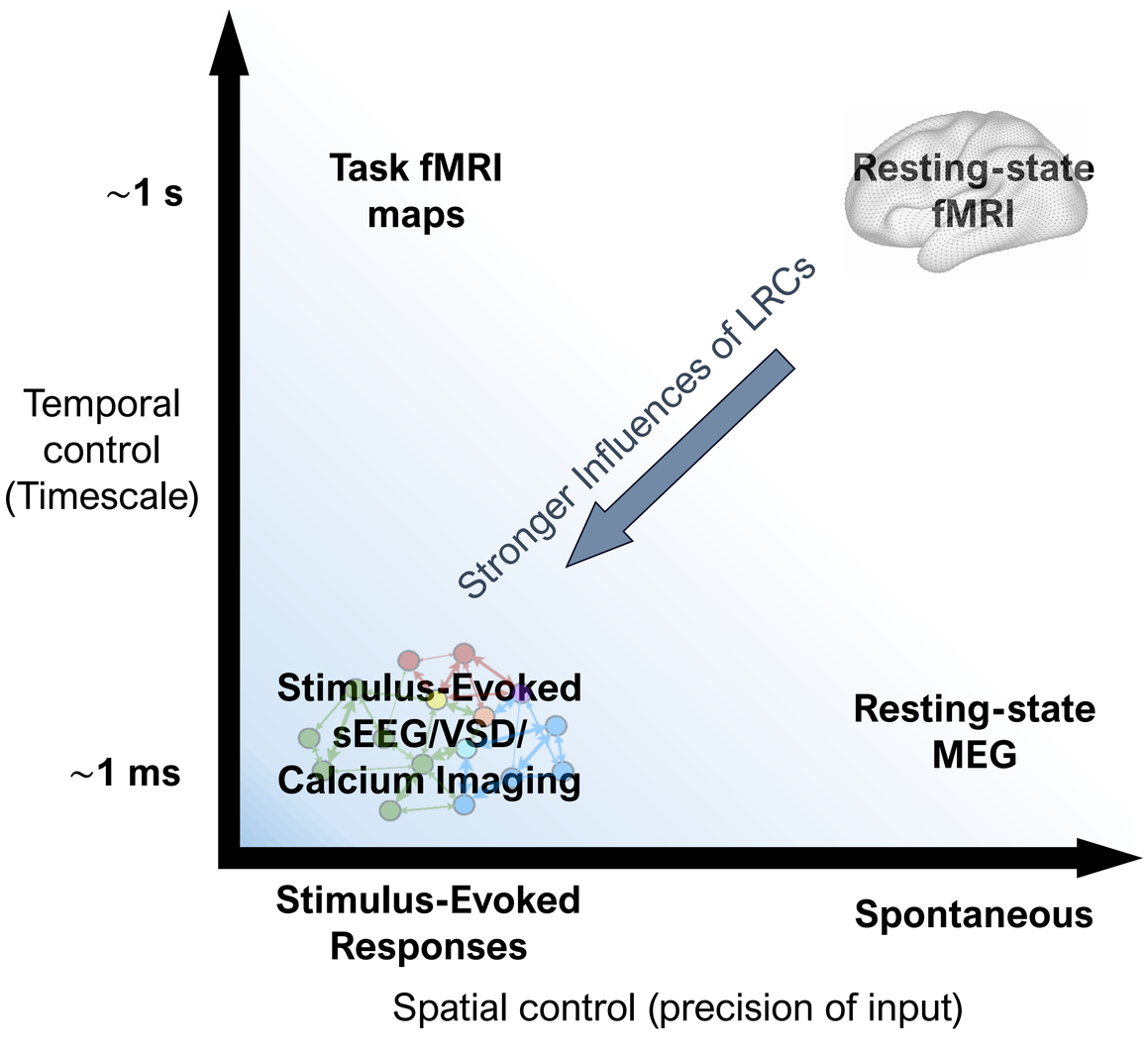
2. Networks of LRCs perturb cortical dynamics **strongest when driven by spatially precise inputs**



Take-away Messages

Our results provide an exciting resolution to the problem of why the geometric mean-field approximation to connectivity (that neglects connectome topology) can provide such accurate results for paradigms such as resting-state fMRI:

1. The effect of long-range connections on cortical dynamics is substantial only on short timescales (~10 ms), but on longer timescales the dynamics increasingly resemble that of geometric connectivity.
2. Spatially diffuse inputs also decrease the effect of long-range connections on cortical dynamics, being relatively negligible in spontaneous settings modeled as spatially uniform.
3. Long-range connections thus predominantly shape the fast information processing of spatially precise stimuli, but play a relatively minor role in shaping spontaneous fluctuations over longer timescales, which are well-captured by cortical geometry alone.



References

1. Robinson et al., *Determination of dynamic brain connectivity via spectral analysis,* Front. hum. neurosci. (2021).
2. Henderson et al., *Empirical estimation of the eigenmodes of macroscale cortical dynamics: Reconciling neural field eigenmodes and resting-state networks,* Neuroimage: Reports (2022).
3. Pang et al., *Geometric constrains on human brain function,* Nature (2023).

Acknowledgements

This work was supported by the RTP Scholarship.

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