Sliding-window channel capacity

an information-theoretic measure of time-resolved effective connectivity and neural noise

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INTRODUCTION

Background

A fundamental part of understanding brain function is characterizing how distributed neural circuits interact to support cognition[1,2]. Functional neuroimaging provides rich data for studying brain connectivity; however, existing connectivity measures are often limited in their ability to capture both causal and dynamic interactions[2–4], and they often rely on the assumption of Gaussian noise.

Contributions

We propose and validate a novel connectivity measure based on sliding-window channel capacity that quantifies both **causal** and **dynamic** interactions among brain regions, enabling time-resolved characterization of **non-Gaussian** information flow in functional neuroimaging data.

METHODS

Communication channel model

Each directed pair of regions of interest (ROIs) within a fixed-length sliding window is modeled as a communication channel with a finite impulse response (FIR) and an additive white Gaussian noise (AWGN).

Model parameters are estimated from the recorded signals using linear regression with model order selected using the Bayesian information criterion (BIC) or corrected Akaike information criterion (AICc)[5].

Channel capacity is then computed using the water-filling algorithm[6].

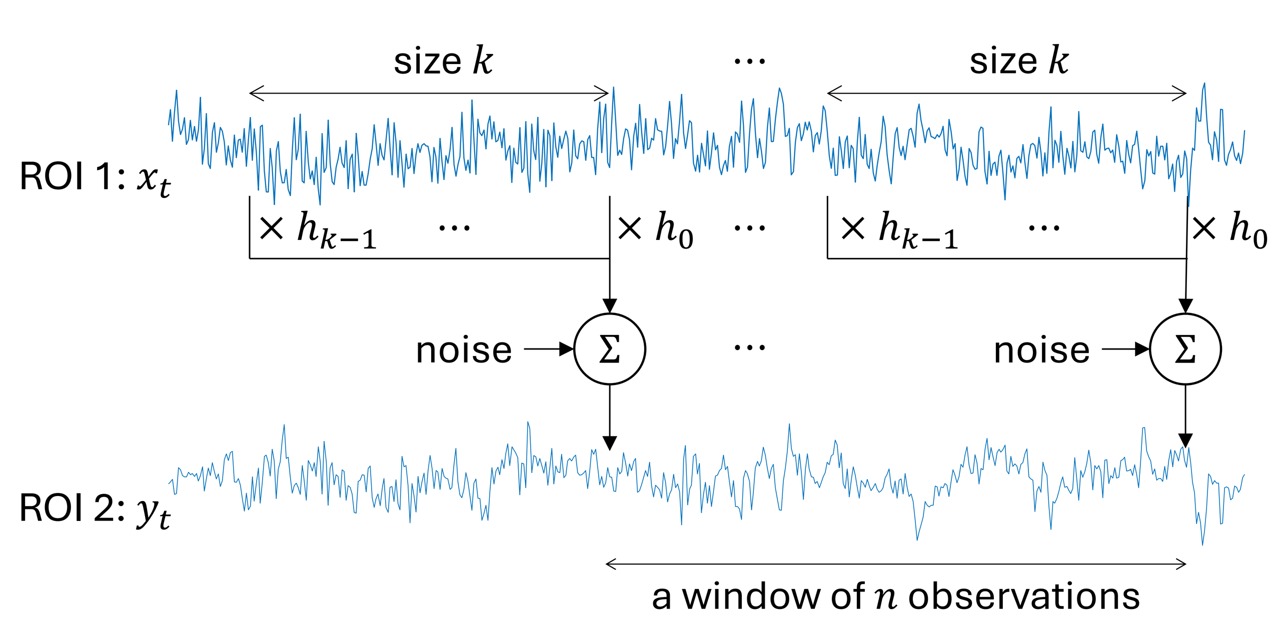

Figure 1. Channel model applied to a directed pair of signals in a window.

VALIDATION ON MULTI-MODAL DATA

Dataset	Targeted evaluation
Human motor-task fMRI	**Sensitivity** to task-evoked directed interactions
Concurrent resting-state rat bilateral LFP-fMRI	**Specificity** against spurious directionality and time-resolved **cross-modal correspondence**
Concurrent resting-state mouse wide field Ca^{2+}-fMRI[7]	**Brain-wide connectivity** and **cross-modal correspondence**

Sensitivity

Channel capacity can serve as an indicator of causal interactions.

In foot and hand movements, channel capacity exhibits mirror-symmetric left- and right-sided patterns consistent with contralateral sensorimotor organization.

In tongue movement, channel capacity shows a bilateral pattern.

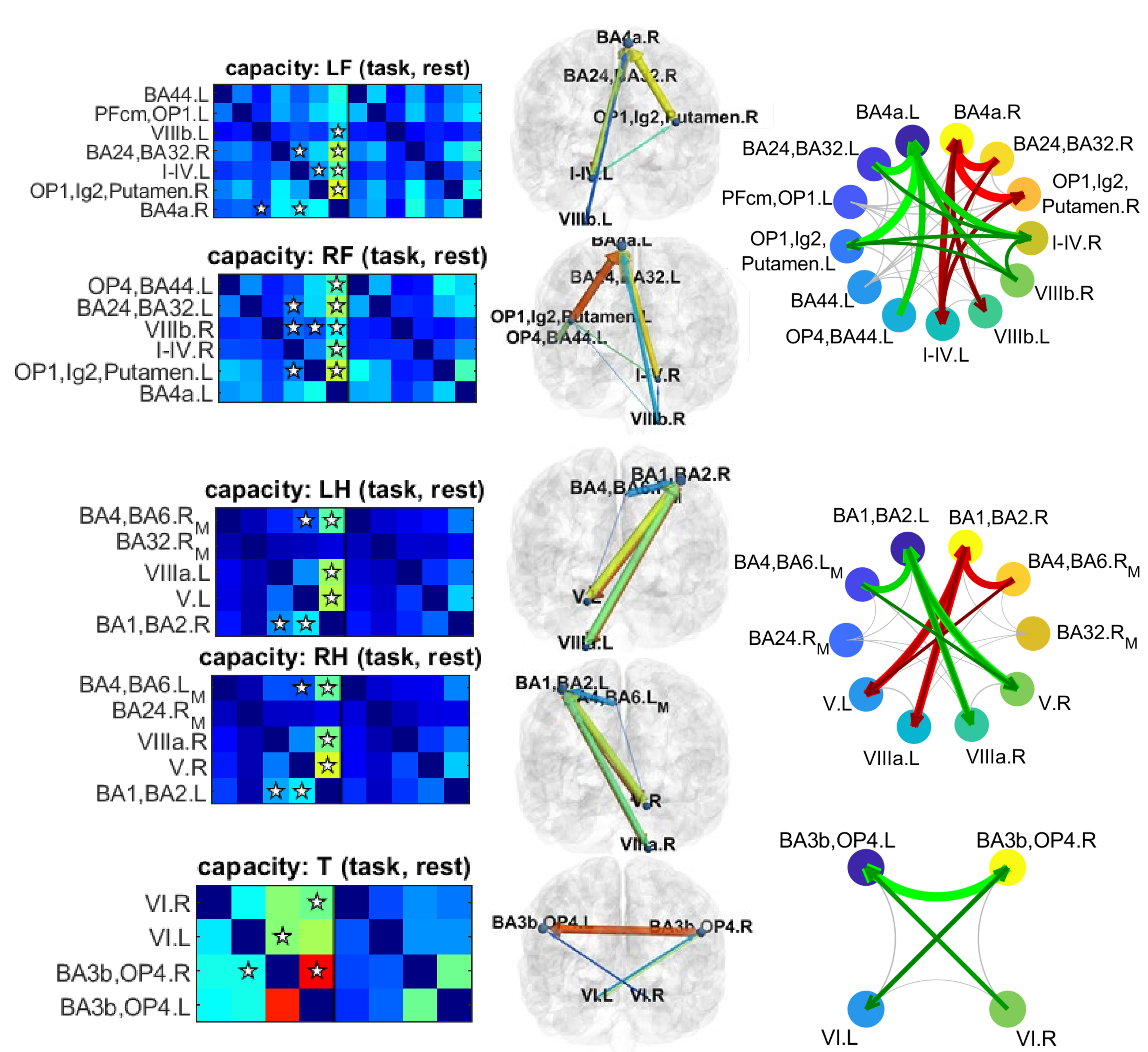

Figure 3. Task-evoked connectivity in Human motor-task fMRI. LF: left foot; RF: right foot; LF: left hand; RH: right hand; T: tongue.

Specificity

Channel capacity is a reliable measure.

No spurious directed connectivity between bilateral S1 areas was detected during rest.

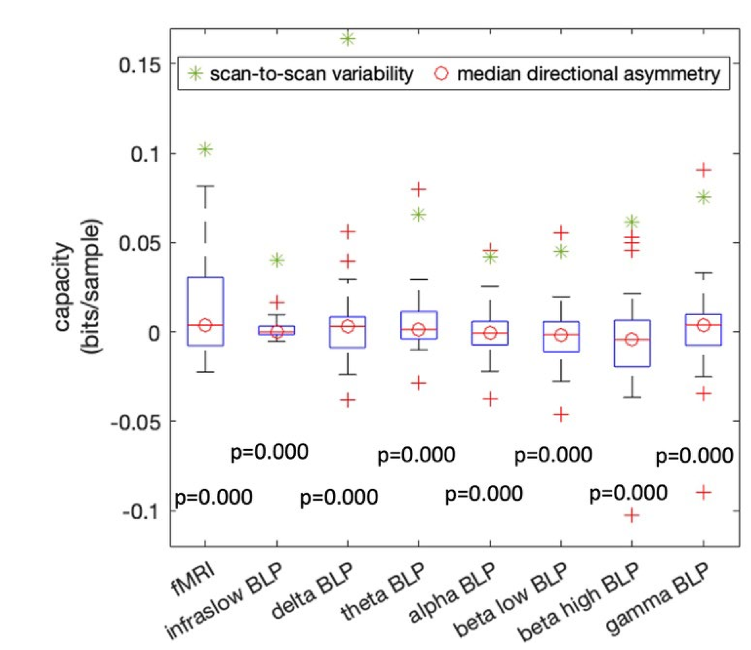

Figure 4. Directional asymmetry of channel capacity in resting-state LFP-BOLD

Cross-modal correspondence

Channel capacity can serve as a measure of cross-modality association.

Brain-wide connectivity

Channel capacity can be effectively computed for large cortical networks.

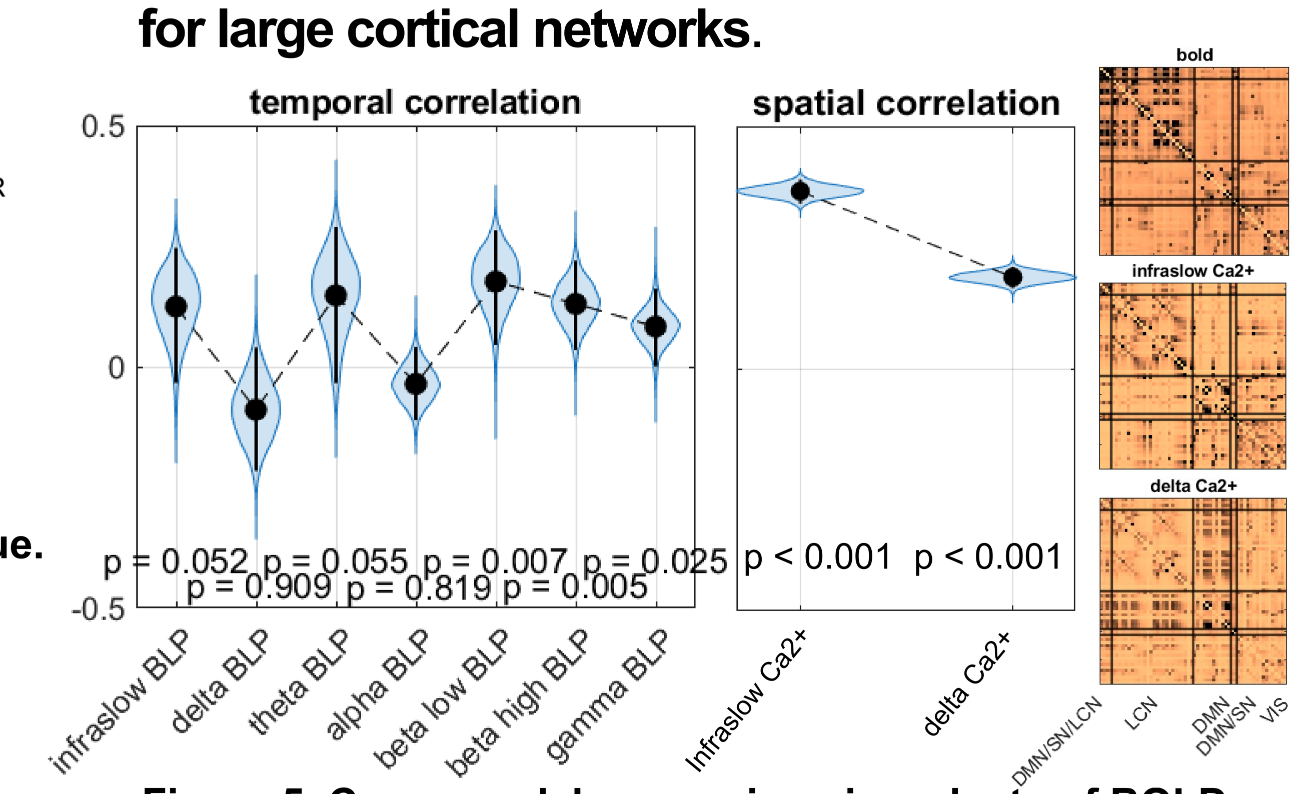

Figure 5. Cross-modal comparison in rodents of BOLD-derived and neural (LFP/Ca^{2+}) -derived channel capacity.

CONCLUSIONS

We proposed an information-theoretical model-based connectivity measure, capturing the directed interactions among brain regions over time.

Experimental data showed that the measure is reliable, sensitive to changes during motor tasks, captures cross-modal correspondence, and scales effectively to large networks.

It can be applied to more complex channel model of the brain connectivity in future work.

tinyurl.com/biorxiv-capacity

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REFERENCES

1. Hutchison et al. (2013). Dynamic functional connectivity: Promise, issues, and interpretations. *NeuroImage.*
2. Xu et al. (2021). Spatiotemporal functional interactivity among large-scale brain networks. *NeuroImage.*
3. Friston (2011). Functional and effective connectivity: a review. *Brain connectivity.*
4. Mitra et al. (2015). Lag threads organize the brain's intrinsic activity. *Proc Natl Acad Sci USA*
5. Xu et al. (2026). Time-Varying Directed Interactions in Functional Brain Networks: Modeling and Validation. *ArXiv.*
6. Gallager (1968). *Information Theory and Reliable Communication.* John Wiley & Sons.
7. Mandino et al. (2025). Multimodal identification of the mouse brain using simultaneous Ca2+ imaging and fMRI. *Communications Biology.*