Dynamical Similarity Analysis of primate cortical networks under targeted optogenetic stimulation

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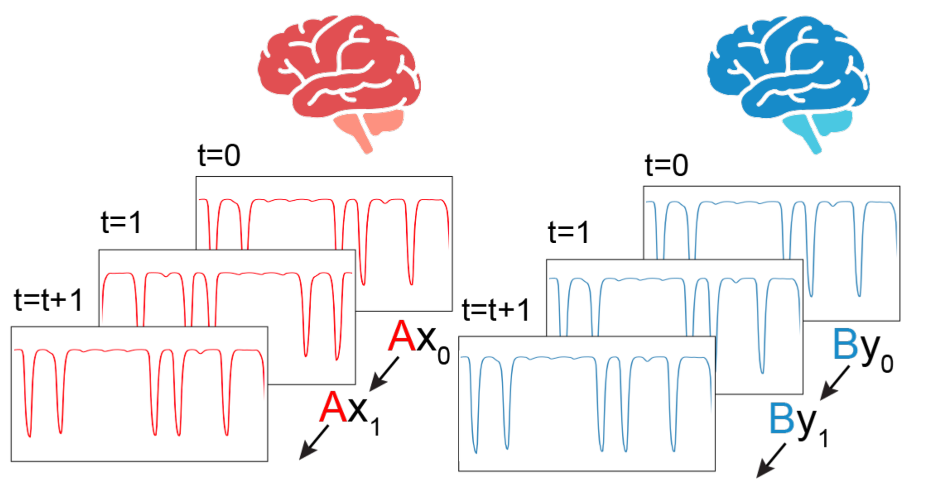
I. Introduction

Motivation

Neural plasticity, or the capacity of neural circuitry to adapt its functionality and structure over time, is fundamental to the versatile computational power of biological neural networks. However, the effects of plasticity-driven reorganization on large-scale neural circuits are unclear. Previous work in categorizing the behavior of neural networks has focused primarily on the organization of high-dimensional neural signals into low-dimensional manifold spaces, and relies on the geometric properties of these latent spaces to characterize distinct computational processes. While this approach may effectively identify differences in the neural ensembles that compose network responses, emerging data from the fields of machine learning and dynamical neuroscience suggest that key distinctions between computational processes lie in the features of their temporal dynamics, and may be largely independent from their latent space geometry.

Using the theoretical framework of **Dynamical Similarity Analysis** recently proposed by Ostrow et al., we examine linear approximations of the dynamical systems in primate cortical networks, as well as their topological distortion under targeted optogenetic stimulation. We demonstrate that the topological features of these dynamical systems are largely invariant to changes in network stimulation patterns, but remain consistently separable across different primate brains. Furthermore, we find that long-term stimulation conditioning is associated with an increasing distortion of these features over time. These findings clarify the behavioral dynamics of biological neural networks during stimulation-induced cortical reorganization, and provide insights into the topological landscape of neural plasticity adaptations.

What is Dynamical Similarity Analysis (DSA)?



$Ax_t = x_{t+1}$ $\quad$ $By_t = y_{t+1}$

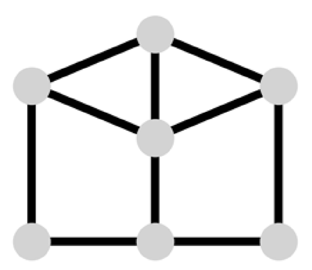
$$\mathrm{DSA}(A, B) = \min_{C \in O(n)} | A - CBC^{-1}|_F$$

BioRender. See Ostrow et al. (2023)

DSA is a method of comparing the temporal dynamics of two different systems, using linear approximations of their evolution over time. It provides a similarity metric based on the topological features of these approximate linear systems.

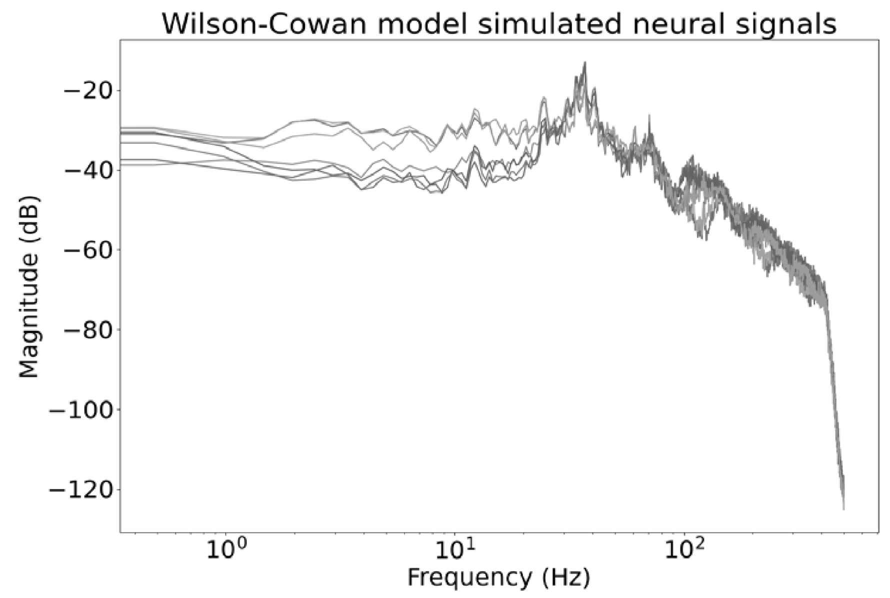
II. By applying DSA to simulated Wilson-Cowan models of neural activity, we can verify that the overall connectivity strength of a cortical circuit is a defining feature of its approximate dynamics.

Network of Wilson-Cowan Oscillators with varied connectivity strengths

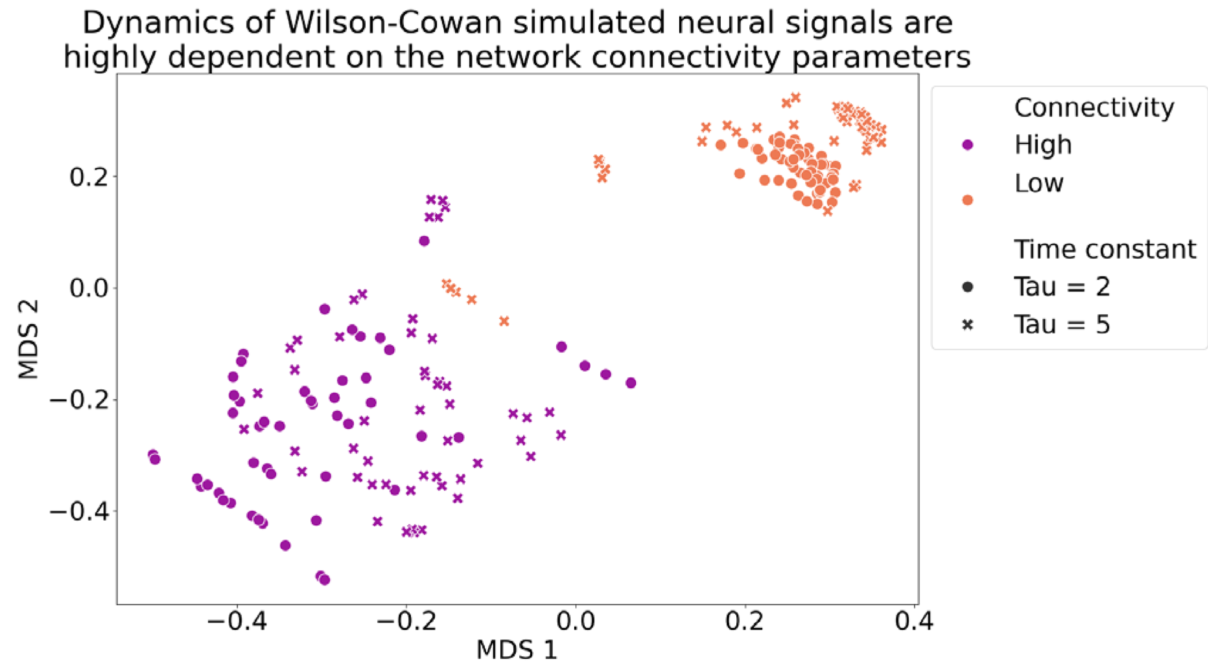


$$\tau_e \frac{de_i(t)}{dt} = -e_i(t) + S\left(c_{ee}e_k(t) + c_{ie}i_k(t) + P + \xi(t) + \sum_{j\in\mathcal{N}(i)} w_{j\to i}e_j(t-\tau_{jk})\right)$$

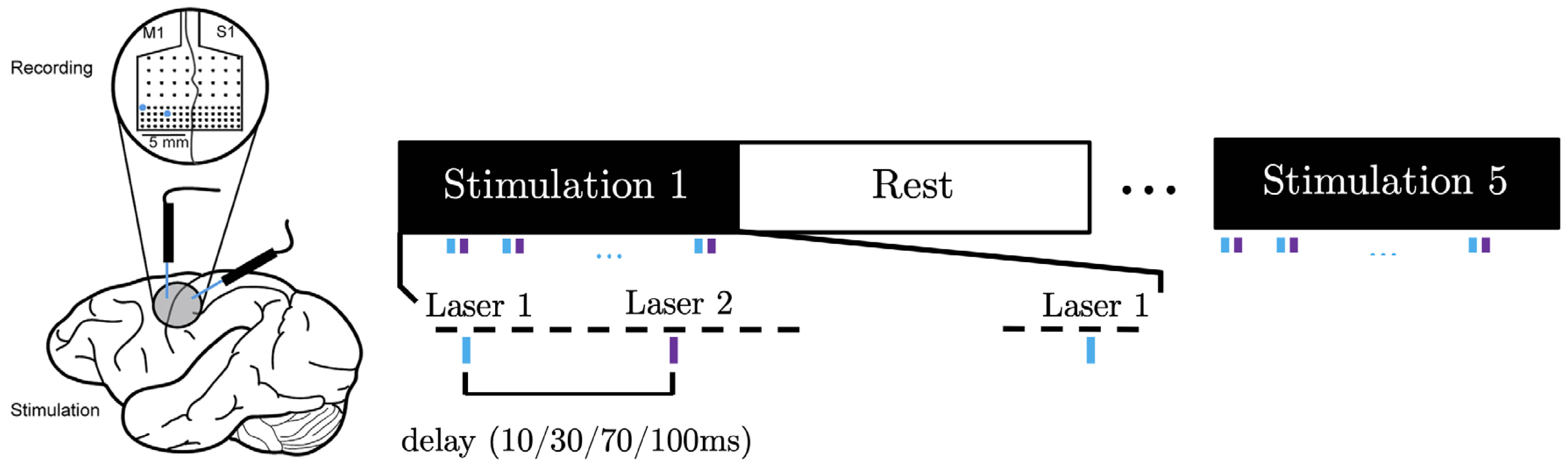
$$\tau_i \frac{di_i(t)}{dt} = -i_i(t) + S\left(c_{ei}e_i(t) + \xi(t)\right)$$



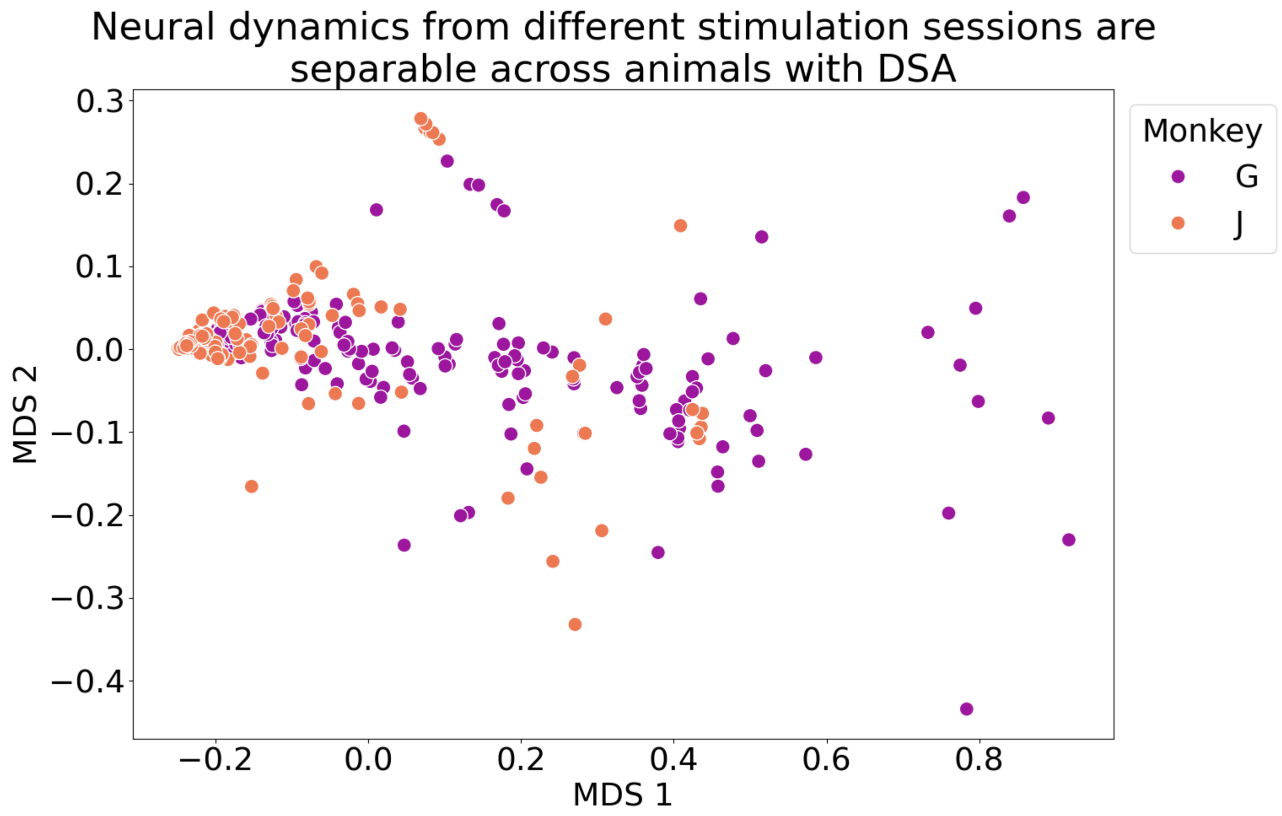
Multidimensional scaling (MDS)

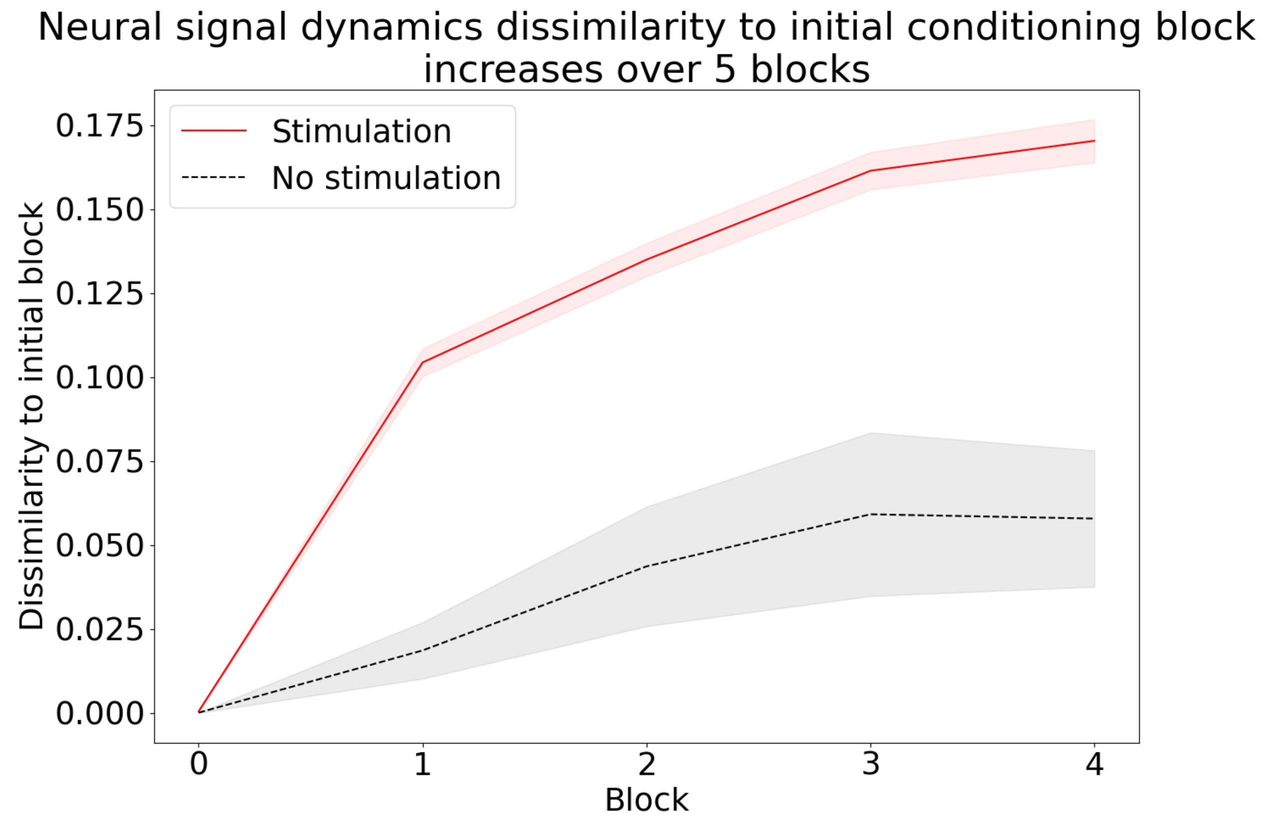


III. We record local field potential (LFP) signals from primate cortical networks during stimulation via microelectrode ECoG array. The electrode placement, stimulation location, number of stimulation sites, and delay varies between sessions.



IV. DSA distinguishes neural signals recorded from different primate brains, but differences in stimulation site location and inter-stimulation delay values are not well-separated. Long-term stimulation is associated with an increasing shift in dynamics, supporting the theory that this procedure sustainably enhances circuit connectivity and induces lasting plasticity adaptations.





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