Bridging Neural Dynamics Across Scales: On Averaging and How It Transforms Large Multi-Scale Dynamics

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Abstract: One of the greatest challenges in understanding the neural code and its generative mechanisms is the broad span of neural dynamics across spatial and temporal scales: macroscopic dynamics (e.g. those measured via EEG) are radically different from microscopic dynamics of a single neuron, and so are ultra-slow dynamics (e.g. those measured via fMRI) compared to sub-millisecond dynamics of spiking. For the most part, neuroscience studies are limited to one scale or another, with limited understanding of how the dynamics at one scale relate to those at another. In this talk, I focus on one key process that connects dynamics across spatial and temporal scales: averaging. I present empirical, numerical, and analytical evidence demonstrating how averaging enforces linear dynamics on macroscopic variables, such as those measured by EEG and fMRI. I will then discuss some of the implications of this linearity for our understanding of the neural code. First, these results provide rigorous, yet unconventional, empirical guidelines for what set of computational methods are most suitable for each scale of analysis. Second, the strong relationship between averaging and linearity provides a normative computational theory for the spatial and temporal scales at which information is encoded in neural activity. I will show an instance of the former in the context of causal connectome discovery and provide a computational framework for the latter using hyper-dimensional computing. Finally, I will highlight the limitations of this linearity, including its reliance on temporal stationarity, and suggest switched-linear dynamics as a powerful generalization.

Bio: Erfan Nozari is an Assistant Professor at the University of California, Riverside Department of Mechanical Engineering. He received his B.Sc. degree in Electrical Engineering-Control in 2013 from Isfahan University of Technology, Iran, and his Ph.D. in Mechanical Engineering and Cognitive Science in 2019 from University of California San Diego. He was subsequently a postdoctoral researcher at the University of Pennsylvania Department of Electrical and Systems Engineering. His main research interests lie at the intersection of computational neuroscience, dynamical systems, and machine learning and his lab’s recent focus has been on understanding the neural code and its generative mechanisms across spatial and temporal scales using the unique perspective of dynamical systems and controls. He is a Hellman Fellow and has been the recipient of the NSF CAREER Award, the IEEE Transactions on Control of Network Systems Outstanding Paper Award, and Best Student Paper Awards from the IEEE Conference on Decision and Control and the American Control Conference.