## Neural Signal Prediction and Demixing via Multi-Time Delay Reservoir Computing | Kamyar Tavakoli

Brains process information through large-scale networks of interconnected neurons. Their collective activity offers a high-dimensional space for flexible input processing—a principle used in reservoir computing. In classical reservoir computing, a randomly connected network of nonlinear units is employed, and only the readout layer is trained—an approach that is well-suited for classification and prediction tasks due to the reservoir's inherent memory and high-dimensional properties. Inspired by these properties, time-delay reservoir computing was developed as an alternative approach that replaces large-scale networks with a single nonlinear delay differential equation, which can be implemented in various physical and computational systems. Time delays are inherent components of the dynamics of brain feedback circuits that constitute its multiple networks. In this sense, time-delay RC explores the signal processing potential of such brain networks. In this work, we specifically study how introducing multiple delays influences prediction performance for tasks of varying complexity and involving signals with different levels of correlation (1). The properties of this supervised learning depends on the eigenvalue spectrum at the fixed point around which the input to be learned induces high-dimensional transients. We furthermore exploit time-delay reservoirs for signal demixing, where a single channel input to the RC is presented with a mixture of two chaotic signals (2). This scenario is akin to challenges in the auditory system that require speech separation, as well as to the cancellation of redundant (i.e. predictable) signals, such as self-generated motion or the superposition of rhythms that occur when weakly electric fish are in each other's proximity. Our findings reveal that tuning the delay distribution parameters and the feedback gain can improve signal separation, providing insight into the broader applicability of delay-based reservoir models. We furthermore employed a multi-layer reservoir architecture, as described in the literature, to improve the demixing of chaotic signals, thereby demonstrating the potential of deeper reservoir designs for more complex separation tasks.


1.

Tavakoli S Kamyar, Longtin A (2024) Boosting reservoir computing performance with multiple delays. Phys. Rev. E 109, 054203. (DOI: 10.1103/PhysRevE.109.054203) (see viewpoint in the APS Physics Magazine)

2.

Tavakoli S Kamyar, Longtin A (2025) Signal de-mixing using multi-delay multi-layer reservoir computing. PLoS Complexity (in press)