

Maurizio Mattia

Istituto Superiore di Sanità, Roma

Recurrent neural networks as digital twins of brain activity

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Brain networks are complex, heterogeneous systems, posing a significant challenge in understanding their organized complexity. Theoretical and computational neuroscience is a cutting-edge interdisciplinary field bridging neurobiology and quantitative sciences like statistical mechanics and the physics of nonlinear systems. Here, I will illustrate a key outcome of such an interplay, demonstrating how single-neuron activity at the microscale can be aggregated into low-dimensional rate-based dynamics. This enables the use of recurrent neural networks (RNNs) as plausible models of brain activity at the mesoscale of cortical areas. Under specific conditions, these RNNs can function as universal approximators of dynamical systems, a capability leveraged in the "reservoir computing" framework for machine learning applications. As a practical example, I will show how a linear RNN can be inferred from fMRI BOLD signals of healthy subjects in a resting state, effectively creating a personalized "digital twin" of the observed brain activity.

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