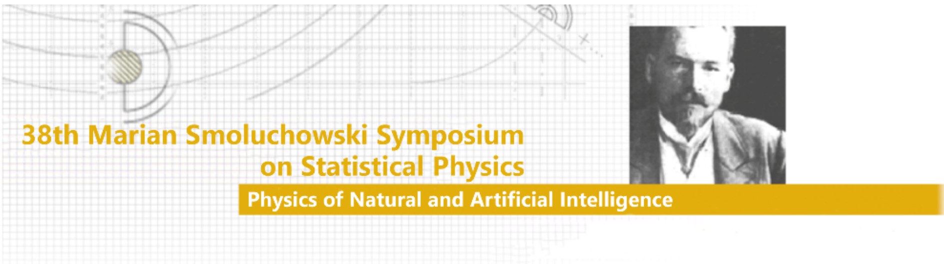

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Hierarchy of chaotic dynamics in random modular neural networks

Monday, 15 September 2025 12:00 (30 minutes)

Despite wide recognition of the modular and hierarchical organization of neural circuits in the brain, our understanding of its influence on neural dynamics and information processing remains incomplete. To address this gap, we introduced a model of randomly connected neural populations (modules) and studied its dynamics by means of the mean-field theory and simulations. Our analysis uncovered a rich phase diagram: High-dimensional chaotic activity (microscopic chaos), common in homogeneous networks, is separated from the low-dimensional chaotic activity of strongly coherent modules (macroscopic chaos) by a crossover region (multiscale chaos). In the crossover region, macroscopic and microscopic chaotic activities coexist and the dimension of activity can be interpreted as either high (according to the Lyapunov dimension) or low (according to the participation ratio dimension). Counterintuitively, chaos can be attenuated, as measured by the maximal Lyapunov exponent, by either adding quenched noise to strongly modular connectivity or by introducing modularity into random connectivity. Thus, for a given level of network activity, the network exhibits longest memory (slowest time scales) at intermediate values of modularity. We confirmed the utility of the modularity-dependent slow manifold in a simple reservoir computing task (delayed XOR), where the introduction of strong-enough modularity was required to solve the task when the encoding of inputs was noisy. Altogether, our results indicate that modular connectivity strongly affects neural dynamics and may play important roles in neural computations.

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