Functional couplings for information propagation in multiscale interacting systems

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The presence of interconnected fluctuating processes occurring across multiple temporal scales is a fundamental characteristic of neural networks, ecological communities, biochemical architectures, and many other complex systems. A key feature of these systems is that such processes can interact both directly and indirectly, with interactions across timescales often exhibiting intricate internal properties. This complexity makes understanding the relationships between their components a formidable challenge.

In this talk, I will begin by exploring how the distinct timescales associated with each process influence their effective couplings. By examining the probabilistic structure of a general multiscale system, I will uncover the underlying principles that govern information propagation across different timescales. In doing so, I will clarify the interplay between mutual information and coupling structure, revealing the origin of the critical distinction between causal and functional interactions in complex stochastic systems. Furthermore, by analyzing the rate of mutual information, I will then demonstrate that the tree-structured backbone of the multiscale interaction network can be exactly reconstructed in linearized dynamics, opening the avenue to refined numerical approches for more complex systems.

The ideas presented in this talk provide novel insights into the processing capabilities of complex multiscale systems.