Dynamics and Control Out of Equilibrium: From Active to Learning Systems

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Nonequilibrium systems are ubiquitous, from swarms of living organisms to machine learning algorithms. While much of statistical physics has focused on predicting emergent behavior from microscopic rules, a growing question is the inverse problem: how can we guide a nonequilibrium system toward a desired state? This challenge becomes particularly daunting in high-dimensional or complex systems, where classical control approaches often break down. In this talk, I will integrate methods from optimal control theory with techniques from statistical physics to tackle this problem in two broad classes of nonequilibrium systems: active matter, focusing on multimodal strategies in animal navigation and mechanical confinement of active fluids, and learning systems, where I will apply control theory to identify optimal learning principles for neural networks. Together, these approaches point toward a general framework for controlling nonequilibrium dynamics across systems and scales.