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Moving with minimum effort –Optimal work protocols for systems with memory and activity

Tuesday, 9 December 2025 13:30 (50 minutes)

We discuss thermodynamically optimal driving protocols for systems with hidden degrees of freedom. As a paradigmatic case, we consider the finite-time transport of a particle in a harmonic trap through a medium with minimum average work input. For passive particles in viscous fluids, the optimal protocol features two symmetric jumps at the beginning and end of the trajectory [1]. We analytically show—and experimentally confirm using colloids in optical tweezers—that this structure originates from an intrinsic time-reversal symmetry of the optimal control problem [2]. Remarkably, this symmetry is universal for systems governed by a linear generalized Langevin equation, independent of the specific memory kernel or noise correlations, and thus also applies to glassy, granular, or active systems. Our findings establish a general criterion for identifying thermodynamically optimal protocols and provide a practical framework for constructing them. We further address the role of information thermodynamics in closed-loop control of active particles [3].
[1] Schmiedl, Seifert, PRL 98, 108301 (2007).
[2] Loos, Monter, Ginot, and Bechinger, PRX 14, 021032 (2024).
[3] Garcia-Millan, Schüttler, Cates, and Loos, PRL 135, 088301 (2025); PRE 112, 024119 (2025).

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