Tuning competitive first-passage outcomes via stochastic resetting

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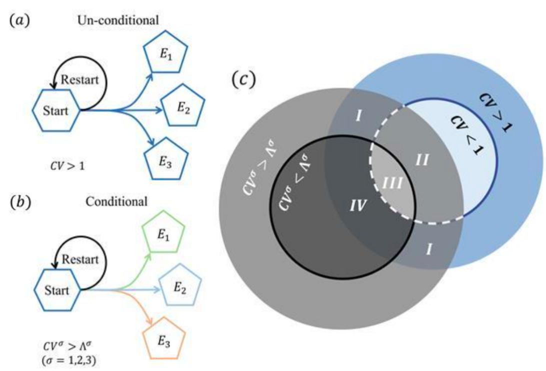
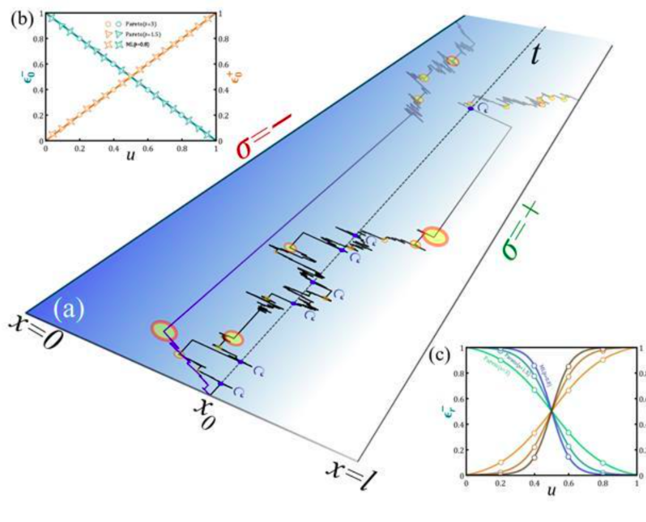
Target search is a ubiquitous phenomenon observed across diverse natural scales, ranging from the microscale dynamics of protein-DNA interactions to the macroscale foraging patterns of marine predators. Recently, stochastic resetting [1] has emerged as one of the most prominent mechanisms in optimizing mean search time. By abruptly returning a searcher to its initial location at random intervals, the system effectively discards errant or diverging trajectories, thereby minimizing the overall time to target. However, determining precisely when and how resetting facilitates such optimization remains a fundamental theoretical challenge. In classical single-target setups (or irrespective of targets), the coefficient of variation criterion [2], $CV > 1$ (where CV denotes the statistical dispersion of the underlying first-passage time distribution), serves as a foundational bound on system parameters. However, many complex systems involve multiple targets where this classical criterion fails to adequately capture the full dynamics due to the emergence of preferential and non-preferential outcomes. To address this limitation, we investigate the resetting-mediated stochastic process with multiple outcomes. We discover a generalized necessary criterion for optimization, $CV_\sigma > \Lambda_\sigma$ [3], where σ denotes the set of possible outcomes. This inequality puts a sharp bound on the system parameters when resetting becomes prominent in optimizing the conditional mean first-passage time. Building upon this multi-outcome framework, we extend our analysis to complex environments where reaction time statistics deviate significantly from classical Debye relaxation. Such systems are frequently governed by stochastic dynamics characterized by broadly distributed waiting times, which results in anomalous transport. Truncating these long pauses, intermittent restarts become profound in regulating the mean first-passage time. Considering a simple setup of continuous-time random walks (CTRW) in a confined one-dimensional line, we find that resetting becomes profound in reshaping the first-passage time statistics. Furthermore, we reveal the emergence of a universal optimal resetting rate that predictably minimizes the mean completion time. Crucially, we show that the universality condition, previously established exclusively for Markovian systems, persists robustly even in the non-Debye regime where reaction timescales play a dominant role.





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