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Fast Rare Events in Exit-Time Statistics of Jump Processes

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Rare events in first-passage and exit-time statistics of jump processes can play a decisive role in triggering anomalous reactions and extreme responses in a wide range of systems. This is particularly relevant when jump lengths or waiting times follow broad, heavy-tailed distributions, for which rare events are not exponentially suppressed and can significantly affect macroscopic observables. Quantifying the contribution of such fast, atypical events to exit probabilities therefore poses a fundamental challenge. In the presence of heavy-tailed distributions, large fluctuations follow the Big Jump Principle, a counterintuitive mechanism according to which rare events arise not from the accumulation of many small deviations, but from a single, dominant fluctuation.

In this talk, we present a general framework for estimating the contribution of fast rare events to exit probabilities in jump processes with fat-tailed distributions. We apply this approach to three paradigmatic models—discrete-time random walks, Lévy walks, and the Lévy–Lorentz gas—which are widely used to describe transport in biological systems, disordered media, ecology, and finance. We derive the exact scaling form of the probability distribution associated with fast exit events, in which the process leaves a finite interval over distances much larger than the typical scale and on timescales orders of magnitude shorter than the characteristic timescale of the dynamics.

Our results show that these fast rare events can provide a non-negligible, and in some cases dominant, contribution to the total exit probability, despite being far outside the typical regime of the process. We also discuss extensions to systems of N independent walkers, where collective effects can further enhance the contribution of fast rare events to exit statistics.

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