Dynamics, correlations, and search optimization in active processes with distinct motility states

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Despite the broad range of stochastic transport processes with distinct motility states in nature (examples are active biological processes such as swimming of bacteria, migration of cells, and transport of motor proteins, or passive processes like chromatography and transport in amorphous materials), a comprehensive theoretical framework to identify their universal transport properties is lacking. To capture some of the specific features of these systems often simple mixtures of stochastic processes has been employed (e.g. run-and-tumble models for bacterial dynamics) but in general an arbitrary combination of two stochastic active processes with different activities is required, which is technically very challenging.

We develop a general theoretical framework to combine multi-state active processes with arbitrary self-propulsions and velocity distributions. This enables us to provide a quantitative link between the characteristics of particle dynamics to macroscopically observable transport properties. We derive exact analytical expressions for the time evolution of the transport quantities of interest, such as the velocity autocorrelation function, and identify several timescales for orientational correlations, set by the self-propulsions and the transition probabilities between the states. The variations of the correlation length by several orders of magnitude dramatically affects the ability of the active particle to efficiently explore the environment. Using Monte Carlo simulations we clarify how the sets of parameters that lead to the same mean-first-passage time are distributed in the phase space of the control parameters.