Optimal Search Strategies for Active Particles in Complex Environments

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Active particles are biological or manmade particles that can self-propel. Examples range from the macroscopic world of animal foraging and robot swarming to the microscopic world of bacterial motility and artificial swimmers. Because of their activity, their behaviour can only be explained and understood within the framework of non-equilibrium physics. As a consequence, their dynamics are very sensitive to changes in environmental conditions, which for realistic natural systems are often highly heterogeneous and disordered. For active particles, this is also the case for the selection of an optimal search strategy. In environments with scarce resources, adopting the right search strategy can make the difference between succeeding and failing, even between life and death. When looking for sparse targets in a homogeneous environment, a combination of ballistic and diffusive steps is considered optimal; in particular, more ballistic Lévy flights are generally believed to optimize the search process. However, most search spaces present complex topographies, with boundaries, barriers and obstacles. What is the best search strategy in these more realistic scenarios? Here, I will discuss, with both theoretical and numerical arguments, how the topography of the environment significantly alters the optimal search strategy of an active particle towards less ballistic and more diffusive cases. I will also discuss the relevance of this result for search problems at different length scales, from animal and human foraging to microswimmers' taxis, to biochemical rates of reaction.