Harnessing higher-dimensional fluctuations in an information engine

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We study the theoretical performance of an information engine consisting of an overdamped Brownian particle in multiple dimensions, confined in a controllable harmonic trap and additionally subjected to gravity. The trap's center is updated dynamically via a feedback protocol designed such that no external work is done by the trap on the bead while maximizing the extraction of gravitational potential energy and achieving directed motion against gravity. We show that performance significantly improves when thermal fluctuations in directions perpendicular to gravity are harnessed. This improvement arises from feedback cooling of these transverse degrees of freedom, along which heat extraction is maximal. Remarkably, even a single transverse degree of freedom yields better performance than relying solely on vertical measurements. Our engine design modularizes the functions of harnessing fluctuations and storing free energy, drawing a close analogy to the Szilard engine.