Reversible feedback confinement

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Micro-manipulation techniques introduced in the last decades —optical and magnetic tweezers, monitored quantum dots, or atomic force microscopy— call for a theoretical framework to analyze driven systems at the micro-scale. An important element in such a framework is feedback control, where the system is monitored or measured at certain stages of a process, and the driving protocol depends on the outcomes of the measurements. Feedback control can be used to increase the performance of Brownian motors or to diminish thermal fluctuations, confining the system to a small region of phase space, as in feedback cooling for instance.

Now, it is well established that for any feedback protocol the information itself is a thermodynamic resource, which is quantified within the framework of information thermodynamics [1]. In particular, the work W needed to perform an isothermal feedback process at temperature T is bounded by [2]

$$W \geq \Delta F - kTI, \qquad (1)$$

where k is Boltzmann's constant, ΔF is the difference in free energy between the final and initial states of the system, and I is the amount of information gained by the measurement.As a consequence of (1), the work W performed in a feedback process might be lower than the variation in the free energy of the system ΔF.

In particular, we present a feedback protocol that is able to confine a system to a single micro-state with neither heat dissipation nor performed work. The protocol adjusts the Hamiltonian of the system in such a way that the Bayesian posterior distribution after measurement is in equilibrium. As a result, the whole process satisfies feedback reversibility [3] —the process is indistinguishable from its time reversal— and assures the lowest possible dissipation for confinement. In spite of the whole process being reversible it can surprisingly be implemented in finite time. We illustrate the idea with a Brownian particle in a harmonic trap with increasing stiffness κ (see Figure 1) and present a general theory of reversible feedback confinement for systems with discrete states[4].

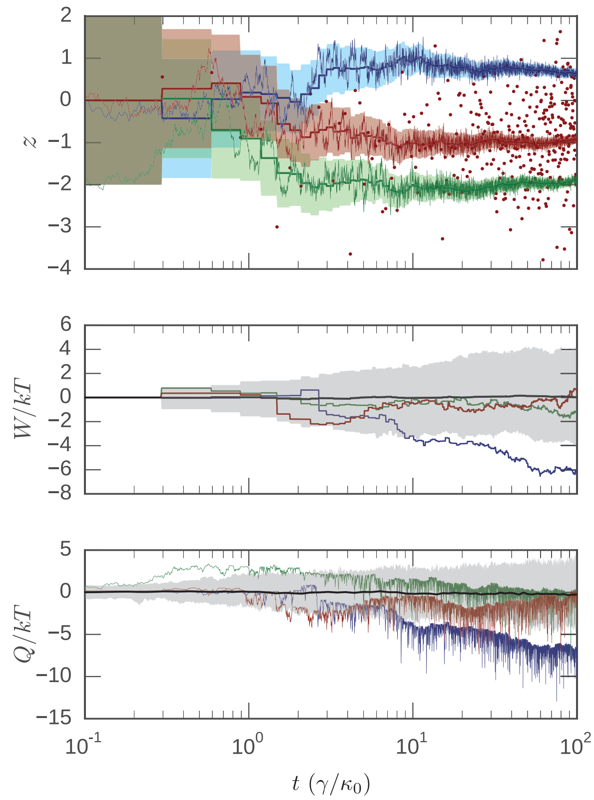

Figure 1: Top panel: Three realizations of the confinement process, each color corresponding to a different realization. The strongly fluctuating thin lines represent the position z_t of the particle. The thick lines represent the position y_t of the trap and the shaded area correspond to $y_t \pm 2\sigma_t$, where $\sigma_t = kT/\kappa_t$ is the equilibrium variance. The red dots are the outcomes of the measurements for the trajectory depicted in red, ending in the middle. Time is given in units of $\tau_0 = \gamma/\kappa_0$, with γ the friction coefficient, and is given on a logarithmic scale. The unit of length is $\sqrt{kT/\kappa_0}$. Measurements are performed every $\Delta t = 0.3\tau_0$. Middle panel: Work performed during the confinement process. The black line represents the average over 100 realizations of te process and the gray shaded area to 90% of the realizations. The colored lines correspond to the realizations depicted on the top panel. Bottom panel: Same as the middle panel but for the heat released to the environment.

[1] J.M.R. Parrondo, J.M. Horowitz,T. Sagawa, Nature Phys.**11**, 131 (2015)

[2] T. Sagawa, M. Ueda, Phys. Rev. Lett. **100**, 080403 (2008)

[3] J.M. Horowitz, J.M.R. Parrondo, EPL **95**, 10005 (2011)

[4] L.Granger, L.Dinis, J.M.Horowitz, J.M.R.Parrondo, EPL **115**, 50007 (2016)