Time-dependent study of bit reset

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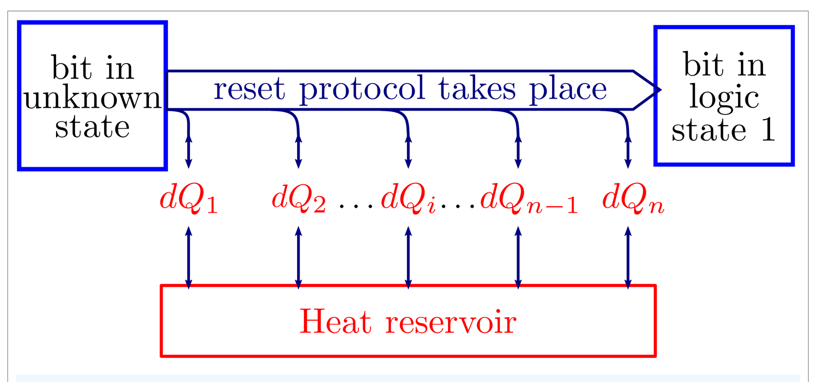
Introduction

Landauer principle states that at least $k_B T \ln 2$ of heat must be produced to reset one bit of information[1]. Derivations of this result for practical systems are complex[2]; additionally, real experiments are sophisticated and sensitive[3].

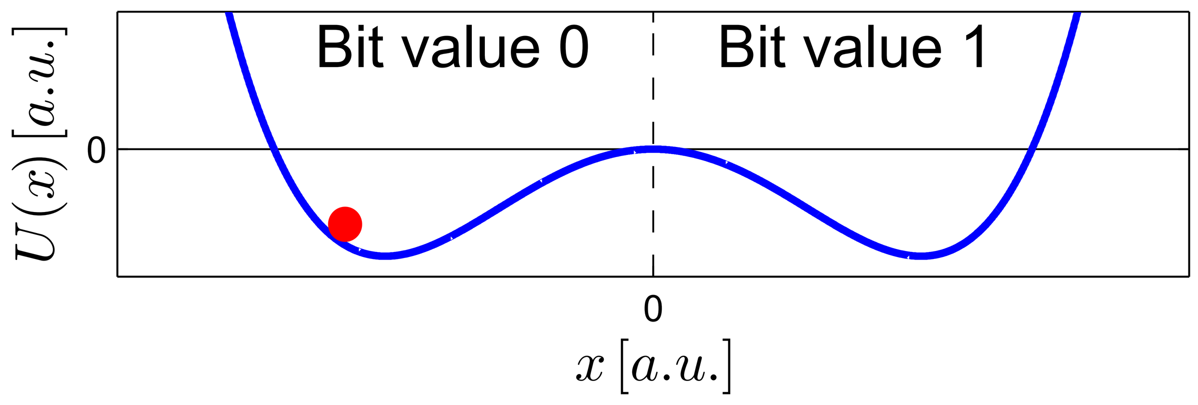
In the literature it's then common practice to look for a net heat production of $k_B T \ln 2$ while the detailed analysis of heat exchanges as the protocol takes place is neglected. This way interesting properties of the system are not considered. With the help of an example[4], we investigate and recover here some of them.



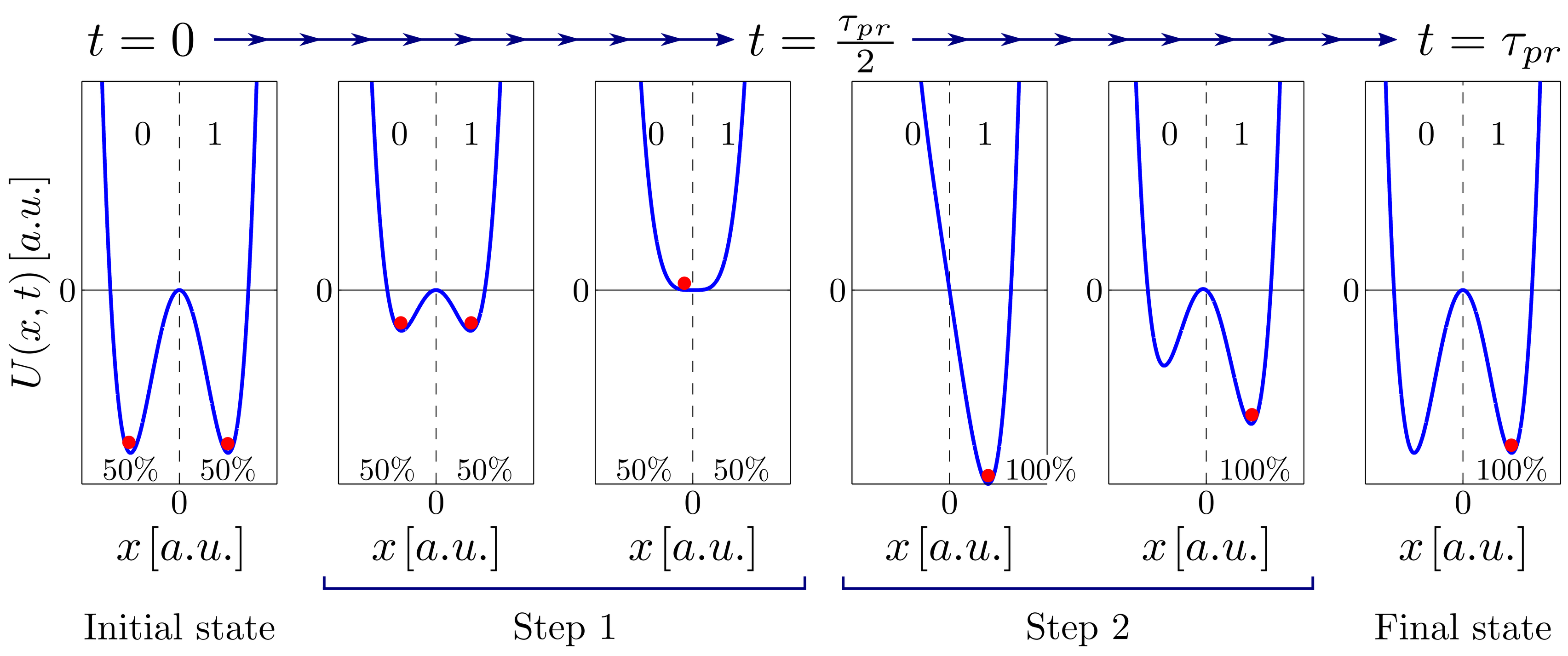
If $\sum_{i=i}^{n} dQ_i = k_B \ln 2$, what else does $\{dQ_i\}$ tells us?

Methods

Bit coding: Brownian particle in a bistable potential



Reset protocol structure



Observables

- Cumulative heat

$$Q(t) = -\left\langle \int_0^t \frac{\partial U(x,t')}{\partial x} \frac{\partial x}{\partial t'} \mathrm{d}t' \right\rangle$$

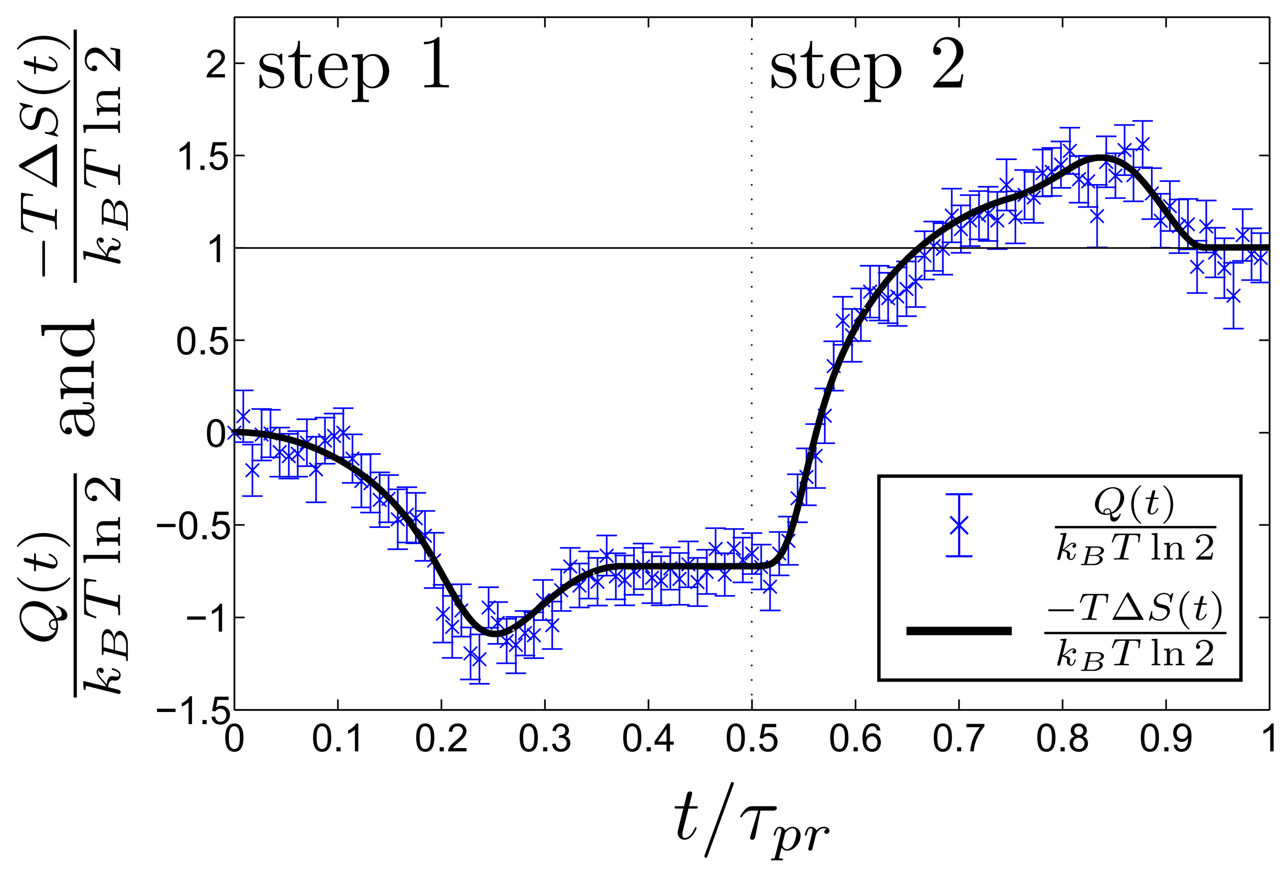
- Minimum cumulative heat

$$-T\Delta S(t) = -T\big(S(t) - S(0)\big)$$

- Entropy

$$S(t) = -k_B \int_{-\infty}^{\infty} P(x,t) \ln P(x,t) \mathrm{d}x$$

Results - Intermediate time analysis



For protocol duration τ_{pr} much longer than the system relaxation time:

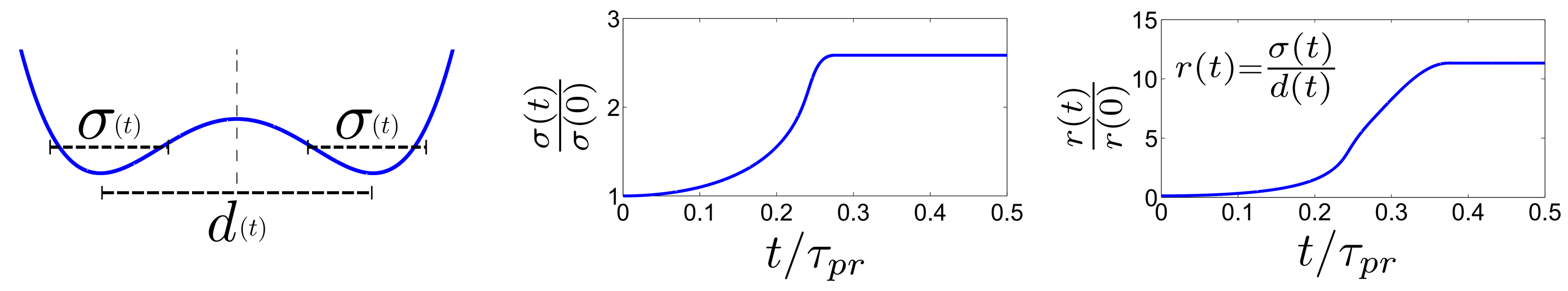
- $Q(\tau_{pr}) = k_B T \ln 2$
- $Q(t) = -T\Delta S(t)\ \forall t \in [0; \tau_{pr}]$
- $-T\Delta S(t)$ has a minimum in step 1
- $-T\Delta S(t)$ has a maximum in step 2

Results - Explanation of $-T\Delta S(t)$ minimum

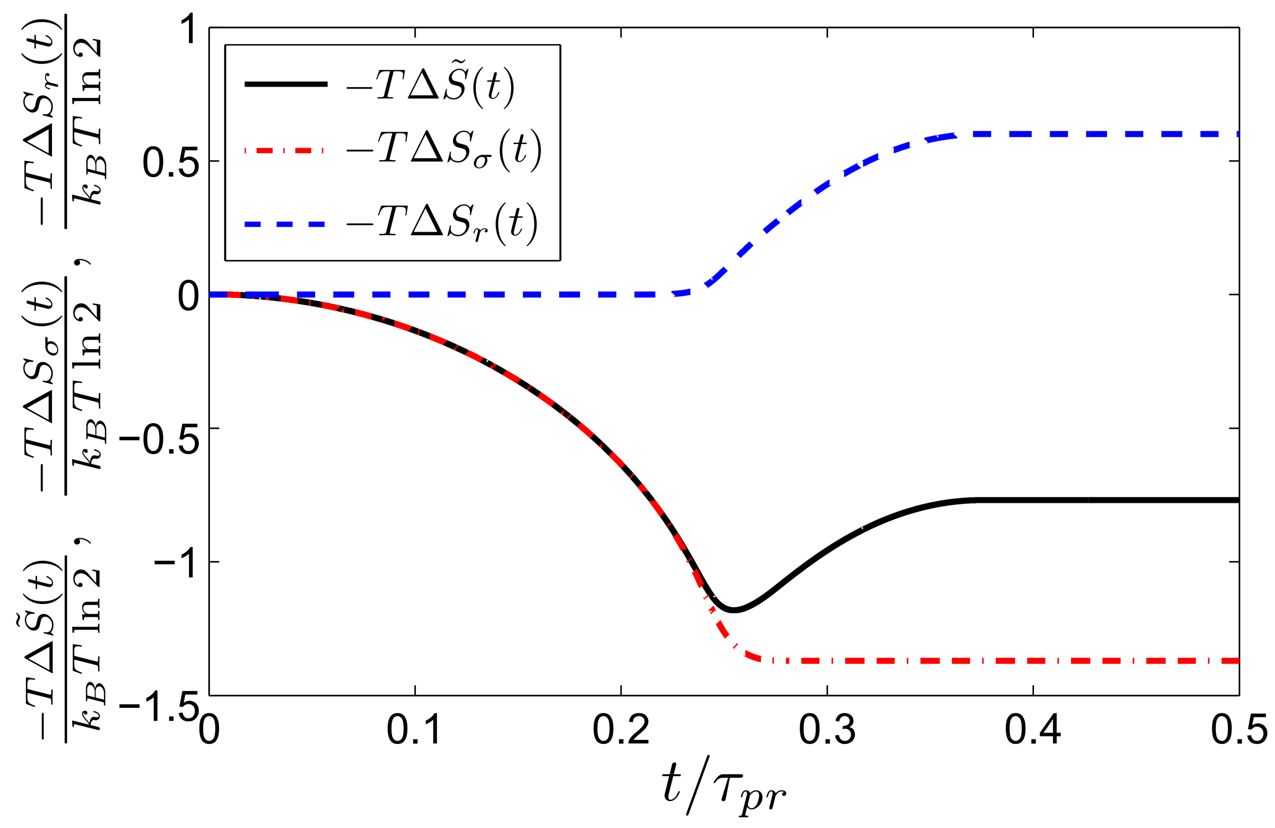
The effects of step 1 on $U(x,t)$ wells are:

1. Their width $\sigma(t)$ increase with time;
2. Their overlap $r(t)$ increase with time.

The minimum in $-T\Delta S(t)$ is explained as the interplay of the entropy increase $\Delta S_\sigma(t)$ required by wells widening, and the entropy decrease $\Delta S_r(t)$ due to wells overlap.

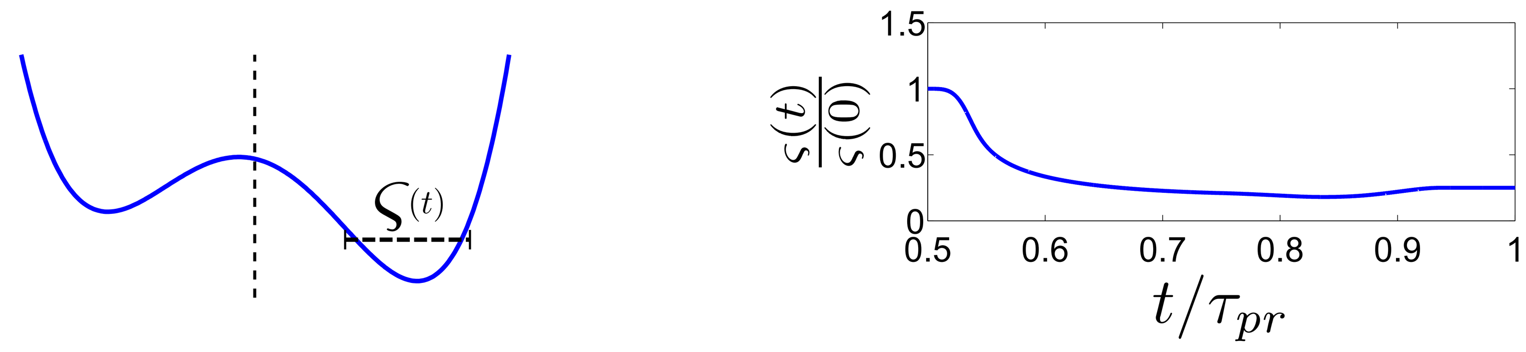


$$-T\Delta S(t) \approx -T\Delta \tilde{S}(t) = -T\Delta S_\sigma(t) - T\Delta S_r(t)$$

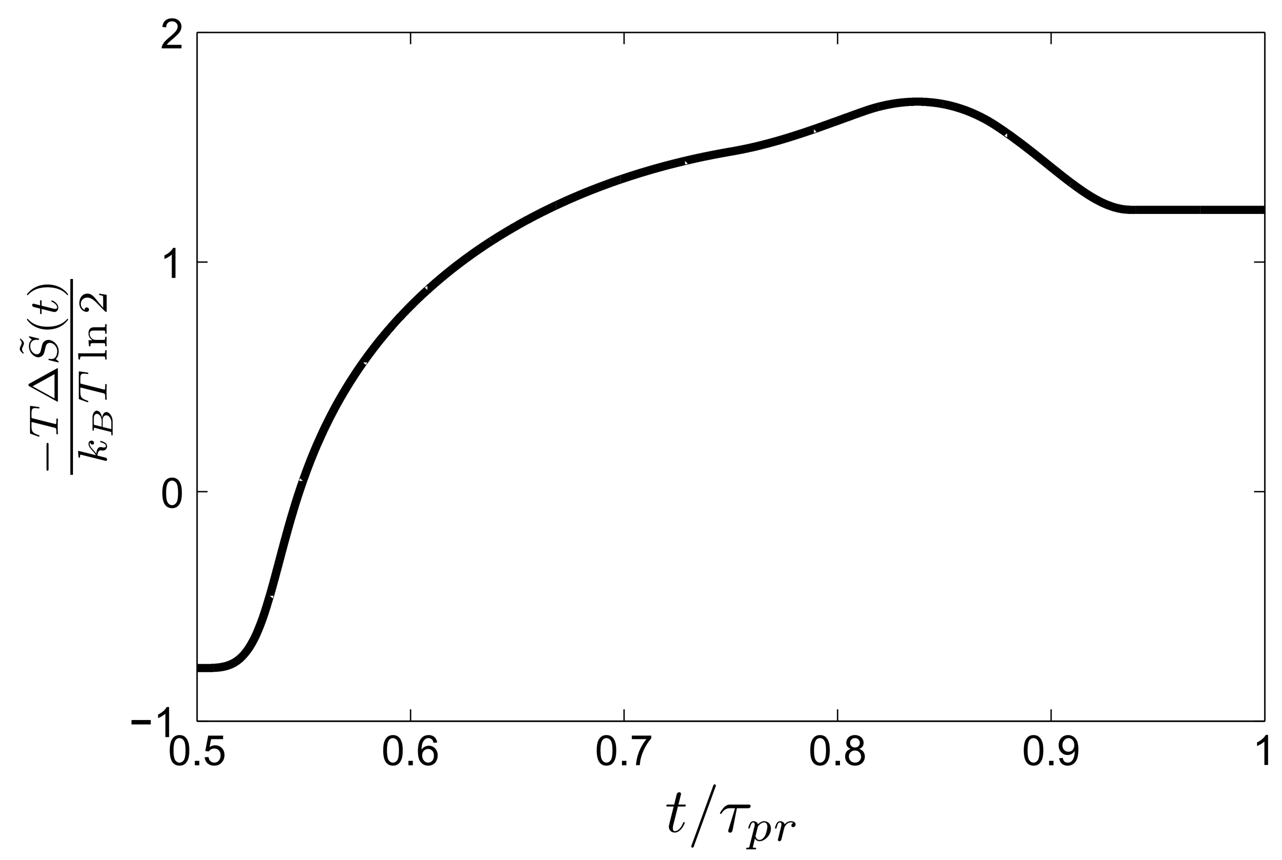


Results - Explanation of $-T\Delta S(t)$ maximum

In step 2, $-T\Delta S(t)$ depends only on the width $\varsigma(t)$ of the potential well relevant to the reset. The minimum in $\varsigma(t)$ implies a minimum in $\Delta S(t)$ and, thus, a maximum in $-T\Delta S(t)$.



$$-T\Delta S(t) \approx -T\Delta\tilde{S}(t) = -T\Delta S_\varsigma(t)$$



Conclusions

By studying heat exchanges occurring while a reset protocol takes places, it's possible to show that heat saturates to $k_B T \ln 2$ in a nontrivial manner. Such time evolution is a new accessible observable since it's already measurable in experiments and it can still be explained in terms of entropy changes. This shows that new observables aimed to test the linkage between information and thermodynamics can be defined starting from a time-dependent study of computation processes realized with simple physical systems.

Additional info

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References:

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2. R. Dillenschneider et al. *PRL* 102, 210601
3. A. Bérut et al. *Nature* 483, 187-189
4. D. Chiuchiù *EPL* 109, 30002

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