Theoretical study of bit-switching and bit-resetting

L. Gammaitoni[1], D. Chiuchiú[1], M. Madami[2], G. Carlotti [2]

[1]NiPS Laboratory - UNIPG [2]Ghost Laboratory - UNIPG

ICT-Energy Community Workshop — Barcelona 23-24/04/14

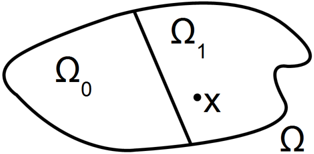
ICTenergy

NiPS Laboratory
Noise in Physical Systems

Outline

1. Bit-Switching
2. Numerical Simulations and Bit-Resetting

Encoding a Bit in a Physical System



x is the physical microstate

Logical states coding:

$\mathbf{x} \in \Omega_0 \equiv 0; \;\; \mathbf{x} \in \Omega_1 \equiv 1$

$$P_0(t) = \int_{\Omega_0} P(\mathbf{x}, t) d\mathbf{x} \quad P_1(t) = \int_{\Omega_1} P(\mathbf{x}, t) d\mathbf{x}$$

$$\langle \mathbf{x} \rangle = \int_{\Omega} \mathbf{x} P(\mathbf{x}, t) d\mathbf{x} \quad -\frac{S_G(t)}{K_b} = \int_{\Omega} P(\mathbf{x}, t) \log P(\mathbf{x}, t) d\mathbf{x}$$

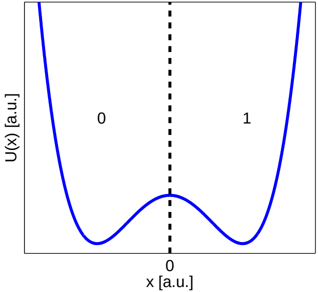
Fokker-Planck equation

$$\frac{\partial}{\partial t} P(\mathbf{x}, t) = -\frac{\partial}{\partial x_i} \left(D_i^1 P(\mathbf{x}, t) \right) + \frac{1}{2} \frac{\partial^2}{\partial x_i \partial x_j} \left(D_{ij}^2 P(\mathbf{x}, t) \right)$$

Bit-coding: 1-Dimensional System

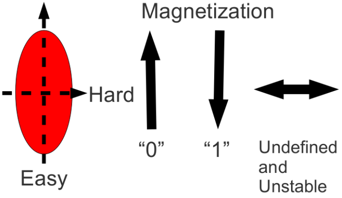
Hypothesis

- 1-Dim system, i.e. only one significative degree of freedom, namely x;
- Heat bath at fixed temperature T;
- Symmetric and bistable potential $U(x)$ in the absence of external forces or fields.



Relevant examples:

- Colloidal particle.
  $x =$ particle position.
- Anisotropic nanomagnet.
  $x =$ magnetization angle.



Zero Power Switching

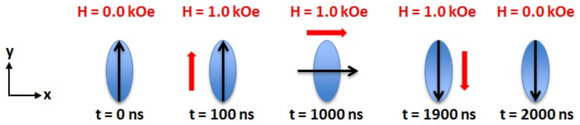
Landauer limit for $0 \to 1$ switch

$$Q_{min} = -T\Delta S_G = 0$$

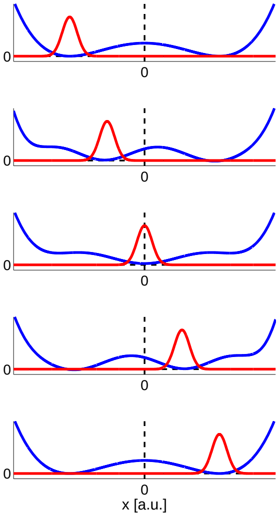
Aim: reach zero dissipation in practice

Transformation Properties

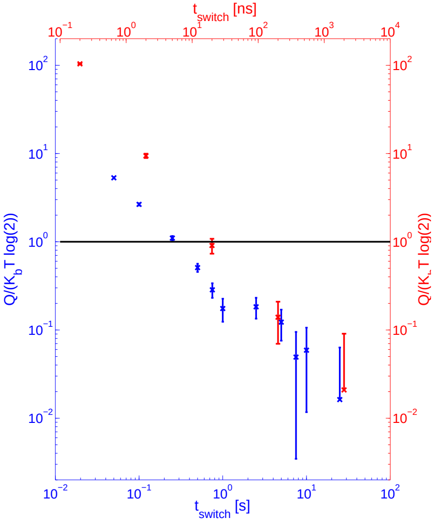
- Isothermal.
- Arbitrarily slow.(zero friction, reversible)
- **Constant** S_G at each instant
- $U(x)$ recovered at the end.



$0 \to 1$ switch



Numerical Simulations: $0 \rightarrow 1$ Switching Q vs. t_{switch}

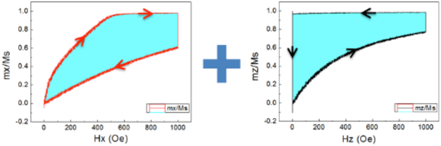


Blue Micrometric colloidal particle in a duffing potential $U(x) = -\frac{a}{2}x^2 + \frac{b}{4}x^4$.

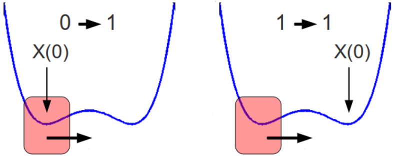
$$Q = \left\langle \int_0^{t_{switch}} \mathbf{F}(x,t) \cdot d\mathbf{x} - \int_0^{t_{switch}} m\mathbf{v} \cdot d\mathbf{v} \right\rangle$$

$$r = 0.984 \quad Q \propto t^{-0.886} \xrightarrow{t \to \infty} 0$$

Red Anisotropic magnetic nanodot.
Q is given by hysteresis areas



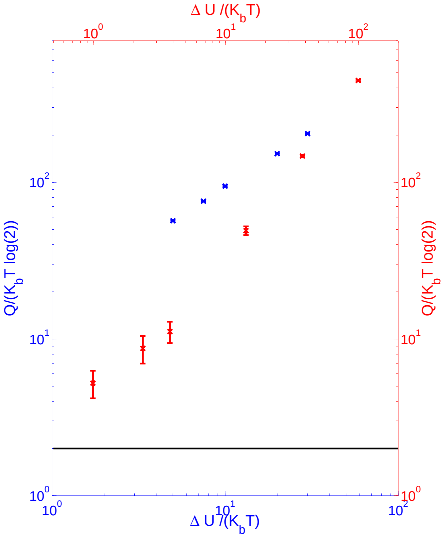
Numerical Simulations: $1 \to 1$ Switching Q vs. ΔU



$$\{0 \to 1\} \cup \{1 \to 1\} \equiv \text{bit reset}$$

$$Q_{min}^{reset} = K_b T \log 2 = \frac{Q_{0\to1} + Q_{1\to1}}{2}$$

If $Q_{0\to1} \to 0 \Rightarrow Q_{1\to1} \to 2K_b T \log 2$



Conclusions

Conclusions:

- Bit-switching can be performed with $Q = Q_{min}^{switch} = 0$.
- Bit-resetting is consistent with $Q^{reset} \geq K_b T \log 2$ but non-conclusive.

Questions for the audeince:

- Why $\Delta S_G = 0$ for bit-switching?
- **Information** or **thermodynamics**. Which one is more fundamental?

Question from the auidience: