Information and thermodynamics: optimizing information processing using underdamped systems

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The energetic cost to perform basic operations on a 1-bit logic gate is bounded by a fundamental theoretical limit: the Landauer principle states that at least $k_B T \ln 2$ of energy is required to erase a 1-bit memory ([RESET] operation), with $k_B T$ the thermal energy of the system. Practical erasures implementations require an overhead to the Landauer's bound, observed to scale as $k_B T \times B/\tau$, with τ the protocol duration and B close to the system position response time. Most experiments use over-damped systems, for which minimizing the overhead means minimizing the dissipation. Underdamped systems thus sounds appealing to reduce this energetic cost. That is why we use an underdamped system to build an optimized logic-gate in terms of processing speed and energetic cost. The one-bit memory consists in an underdamped micro-mechanical oscillator confined in a double-well potential created by a feedback loop [1]. The resulting virtual potential can be shaped within the few $k_B T$ range with high precision and can follow elaborate procedures.

We demonstrate that, using this underdamped system, the Landauer bound is reached with a 1% uncertainty, with protocols as short as 100 ms [2], several of magnitude faster than the state-of-the-art using over-damped memories. Nevertheless, we show experimentally and theoretically that in the underdamped regime, fast erasures induce a heating of the memory [3]: the work influx is not instantaneously compensated by the inefficient heat transfert to the thermostat. This temperature rise results in a kinetic and potential energy contribution superseding the viscous dissipation term. Our model covering all damping regimes allows new optimisation strategies in information processing, based on the thorough understanding of the energy exchanges [4]. We illustrate such perspectives with applications to several logical operations of the 1-bit logic gate: repeated [RESET] operations and [NOT] operations [5]. Besides, we elaborate optimal procedures to lower even further the information processing cost. We finally pave the way to shortcut procedures to create faster protocols designed for a continuous use of the memory.

References

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