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On Norton's "…Shook…" and Myrvold's "Shakin' …"

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Norton's and Myrvold's recent analyses of fluctuations and Landauer's principle are compatible.

Norton's (2013) "All Shook Up: Fluctuations, Maxwell's Demon and the Thermodynamics of Computation" and elsewhere argues that there is a thermodynamic cost in suppressing fluctuations on molecular scales. It follows that the minimal thermodynamic cost of completing any process is set by the number of steps to be completed, in contradiction with the Landauer principle literature that relates the minimal cost to the logic of the process, independently of the number and details of the steps of the implementation.

While not committing to Norton's above "no-go" result, Myrvold's (2021) "Shakin' All Over: Proving Landauer's Principle without Neglect of Fluctuations" seeks to place the thermodynamic cost computed in Landauer's principle on a firmer theoretical foundation by deriving it within statistical physics, without assuming as a primitive the precarious notion of a thermodynamically reversible process. The analysis deals with systems subjected to external manipulations, represented as changes to the system's Hamiltonian, and focuses on dissipation within those systems, setting aside entropy generated by the external systems driving the changes. It is argued that, in addition to any entropy generated by the external drivers, there is entropy generated within the manipulated system that is subject to the Landauer bound.

The juxtaposition of Norton's and Myrvold's colorful titles can lead to the misunderstanding that Myrvold's results refute Norton's "no-go" result. That is not the case, since Norton's and Myrvold's analyses proceed under different background assumptions.

Briefly, Norton's no-go result requires that the thermodynamic properties of all processes must be considered, whereas Myrvold's analysis leaves out of consideration the thermodynamic processes in the systems driving the changes in the system under consideration.

Norton's no-go result follows from the consideration that all real thermal processes only advance if the total system entropy increases. It is assumed that minimal entropy production obtains in processes in which the total system passes slowly through a sequence of close-to-equilibrium states. A process that takes some initial state "*init*" to a final state "*fin*" will only advance if the respective entropies are such that $S_{fin} > S_{init}$. Boltzmann's principle $S = k \log P$ relates these entropies to the equilibrium probability P of the corresponding state. Combining and inverting the logarithm, we recover that

$$P_{fin}/P_{init} = \exp((S_{fin} - S_{init})/k)$$

where P_{fin} is the probability of successful completion of the process and P_{init} is the probability that the process fails to complete because a fluctuation restores it to its initial state. If we seek just a modest probabilistic assurance that the process completes with $P_{fin}/P_{init} = 20$, the entropy increase must be at least $S_{fin} - S_{init} = k \log 20 = 3k$. This entropy cost is independent of the logic implemented by the process and applies to each step individually of a compound process.

This has potential relevance to the literature surround Landauer's principle in two ways. First, the result implies that, even if the Landauer bound on entropy production is satisfied, the minimal entropy production is actually higher than that provided by the Landauer bound. Second, insofar as arguments for Landauer's principle rely on the assumption of the availability of processes that are thermodynamically reversible (or close to it), it threatens the cogency of those arguments. Myrvold's tactic is, first, to provide a proof of the Landauer principle that does not assume the availability of processes that are even close to reversible. Then, in section 4, he argues, via consideration of a system that is heated by thermal contact with a heat reservoir, whose temperature slowly rises, that thermodynamic reversibility can be approached as nearly as one would like. It should be emphasized that this result concerns the thermodynamic properties of the system and the heat reservoir; systems controlling the process are left out of the analysis. An analysis of this sort enables an isolation of those parts of the processes whose thermodynamic cost derives from the many-to-one mappings of states considered in Landauer's principle.

An application of Norton's no-go result to these systems requires consideration of the thermodynamics of the processes that lead to the slow alteration of the parameters. These must also be thermal processes that can only advance if their entropies increase. The no-go result applies. The temperature of a heat reservoir might increase since heat is passed to it from a warmer reservoir. There must be enough of an entropy-creating temperature difference between the two reservoirs to preclude fluctuations probabilistically reversing the direction of heat transfer. Similarly, there must be enough of an entropy-creating imbalance of forces to suppress fluctuations in the one particle gas that would reverse the compression. Devising suitable mechanisms for this last case is challenging. Norton (2011, §7.5; 2017, §IV) gives detailed calculations for particular mechanisms that enable gas expansion and recover results compatible with the no go result.

References

Myrvold, Wayne C. (2021) “Shakin’ All Over: Proving Landauer’s Principle without Neglect of Fluctuations,” *British Journal for the Philosophy of Science*, accepted online.

Norton, John D. (2005) “Eaters of the Lotus: Landauer's Principle and the Return of Maxwell's Demon.” *Studies in History and Philosophy of Modern Physics*, **36**, pp. 375-411.

Norton, John D. (2103) “All Shook Up: Fluctuations, Maxwell's Demon and the Thermodynamics of Computation,” *Entropy* 2013, 15, 4432-4483

Norton, John D. (2017) “Thermodynamically Reversible Processes in Statistical Physics,” *American Journal of Physics*, **85**, pp. 135-145.