Search for Second Laws and Landauer's principle: connecting information and physics

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The purpose of this talk is to introduce the previous attempts and show the recent developments in understanding the second law of thermodynamics for classical and quantum systems.

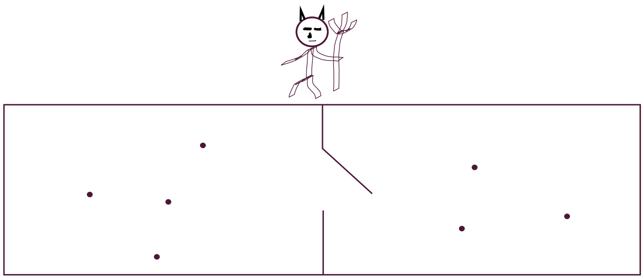

Fig. 1. Maxwell's Demon is a gate keeper who has the ability to open and close the door that seperates the two compartments without spending energy (this should be achievable since demon can regain the energy it has spent to open the door initially). By measuring the energy of the incoming particles demon can put all of the hot particles to one compartment and cold ones to the other, which is a lower entropy state compared to the initial states; therefore violates the '2$^{\text{nd}}$ Law'. Problem is solved by Bennett who recognized that in order to return to the initial state demon has to reset his memory, which basically records from which side the hot (or cold) particle is coming.

Our discussion starts by stating the famous Maxwell's demon problem, which initially proposed by James Clerk Maxwell in order to demonstrate that '2$^{\text{nd}}$ Law' is just a statistical outcome not a fundamental law of physics, roughly in '70s, See Fig. 1. In this famous problem, a 'demon' is allowed to put colder particles in one compartment, thus violating the 2$^{\text{nd}}$ Law; since this operation can be done without spending energy. 'Exorcise'ing the demon via Landauer's principle, which paved the way of connecting information theory and thermodynamics, is done by Bennett in '82. He explicitly showed how the total system (compartments + demon) obeys '2$^{\text{nd}}$ Law' in his famous paper [1].

Using the ideas above we argue that information is physical by understanding that Shannon Entropy (known as Von Neumann in quantum systems), for a probability distribution $p = \{p_i\}$

$$S(p) = -\sum_i p_i \log p_i, \tag{1}$$

can be connected to the classical definition of thermodynamical entropy using the ideas of irreversible processes.

Lastly we presents some recent attempts to define a second law for quantum systems. So far there is no general result for quantum systems but some results for specific cases, all of which approaches to the known results at classical limits. [2]

The importance of these arguments is twofold. First, they propose a way to give a physical meaning to information theory, which is used to be thought as pure mathematical area and have applied conseuences in physics. On the contrary, today we know that information itself can be considered as a physical quantity. Secondly, they give a chance to research on the concept of 'entropy' on fundamental level, instead of studying it as a statistical law.

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[1] CharlesH. Bennett. The thermodynamics of computationa review. International Journal of Theoretical Physics, 21(12):905–940, 1982.

[2] F. G. S. L. Brandao, M. Horodecki, N. H. Y. Ng, J. Oppenheim, and S. Wehner. The second laws of quantum thermodynamics. ArXiv e-prints, May 2013.