Information is physical?

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The big picture

All automatic digital computing activities are made with elementary devices that we call combinational binary switches.
These devices can be combined together to make logic gates and memories, that are the basic components of modern computers, according to the von Neumann architecture.
We have shown that all the computing activity with these devices can be performed without spending any energy.

The fundamental limits in the physics of computing, regarding energy consumption

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- These devices can be combined together to make logic gates and memories, that are the basic components of modern computers, according to the von Neumann architecture.
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The fundamental limits in the physics of computing, regarding energy consumption

- We have shown that digital memories can be made with sequential binary switches. The operation of these devices can be performed without spending any energy, with the exception of the reset operation that can be necessary once the device has relaxed at thermal equilibrium.
- We have shown that maintaining the status of a digital memory can be performed by spending and arbitrarily small amount of energy, if the refresh operation is performed often enough or arbitrarily close to its local equilibrium.
- We have also shown that, no matter what we do, there is no way to keep the memory status forever, due to unavoidable growth of the memorization error over time.

The fundamental limits in the physics of computing, regarding energy consumption

These limits have been established on the base of the laws of physics as developed within statistical classical and quantum mechanics, with specific refer- ence to the set of tools developed within the so-called stochastic thermodynamics approach.

Is this the end of the story?

No. In 1961, Ralf Landauer published an article where he claimed a physics interpretation of the notion of information.

Landauer’s take on the issue

Landauer introduces the notion of «logic irreversibility».

«We shall call a device logically irreversible if the output of a device does not uniquely define the inputs. »

Accordingly an OR logic gate (e.g.) is a logically irreversible device, while a NOT gate is logically reversible.

Landauer’s take on the issue

Landauer writes:

«Logical irreversibility, we believe, in turn implies physical irreversibility, and the latter is accompanied by dissipative effects.»

According to this statement, a logically irreversible device cannot be physically operated without spending energy, because dissipative effects are unavoidable. Landauer’s belief originates from the idea that the decrease of information between input and output, an operation that is sometime addressed as “information erasure”, is necessarily connected to a decrease of physical entropy in the physical system that embodies such a device.

Landauer’s take on the issue

Such a connection between logical irreversibility and physical irreversibility has been at the centre of a very long and controversial debate.

It is our opinion that, in this respect, Landauer was wrong: logical irreversibility does not imply physical irreversibility, and to make this point clear, we made an experiment, whose results have been published in M.López-Suárez,I.Neri,L.Gammaitoni,Sub-kBTmicro-electromechanicalirreversiblelogic gate. Nature Commun. 7, 12068 (2016).


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Sub-$k_B T$ micro-electromechanical irreversible logic gate

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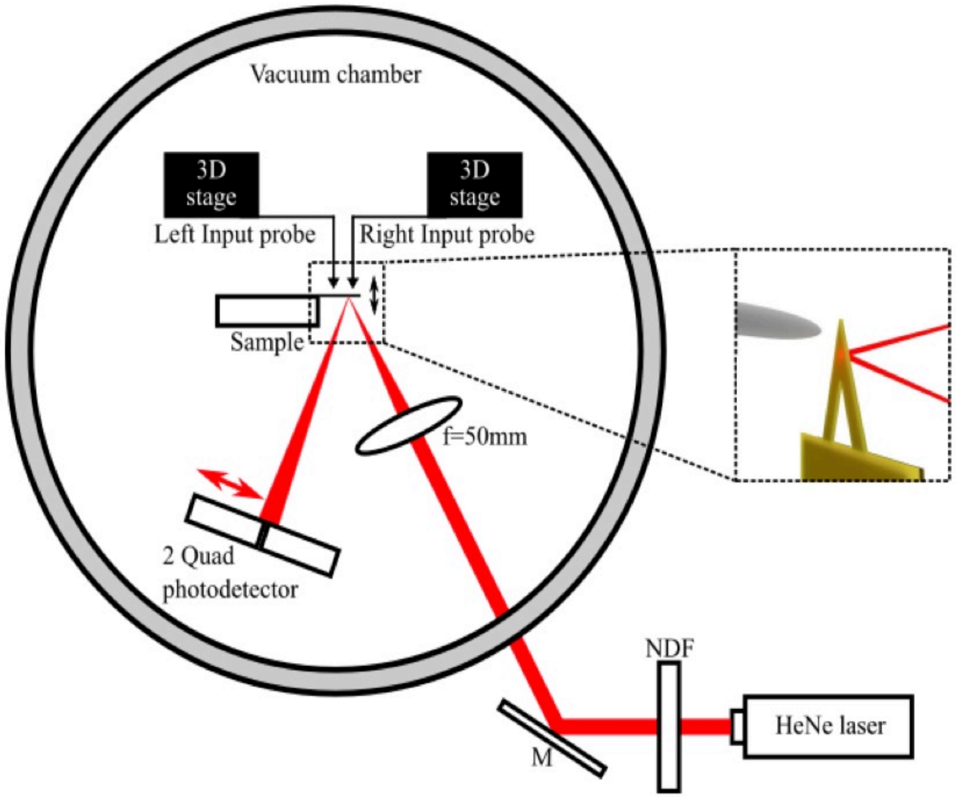
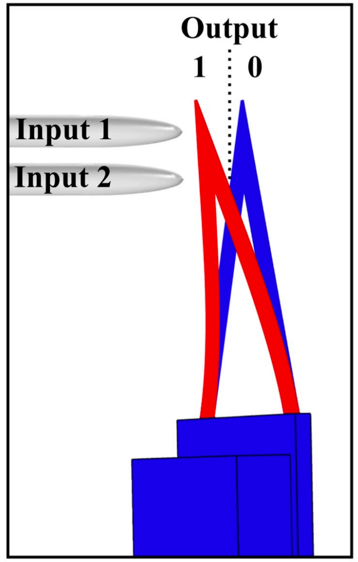
The experiment





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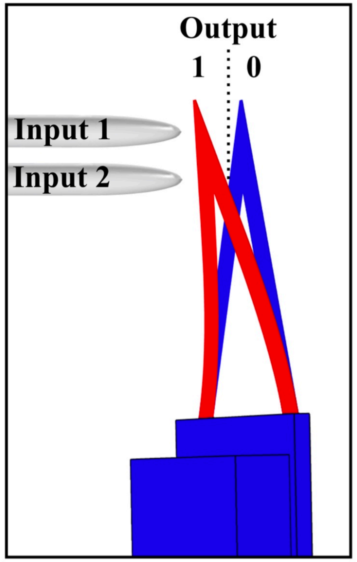

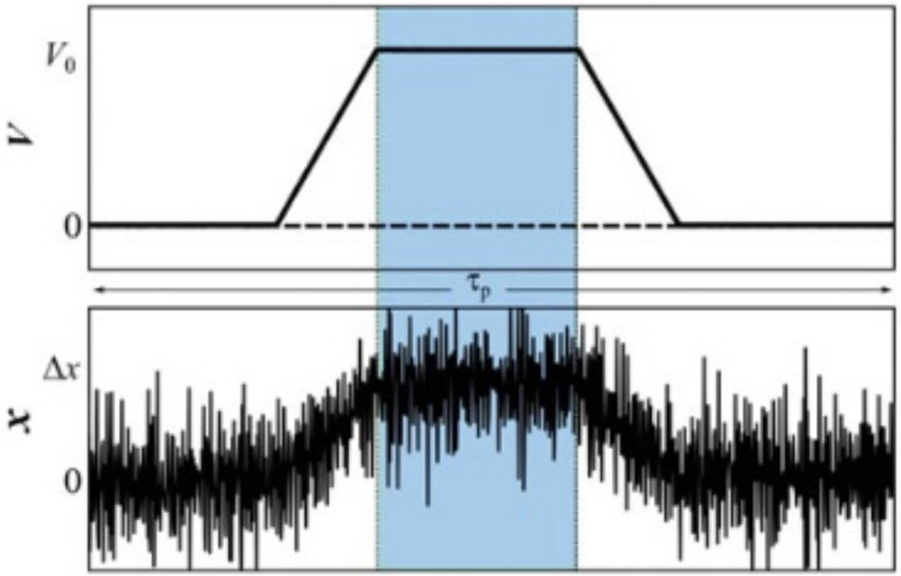

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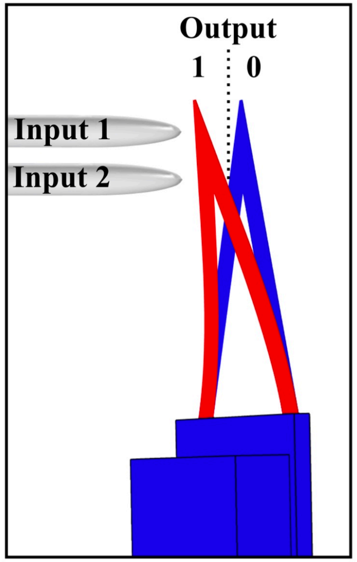

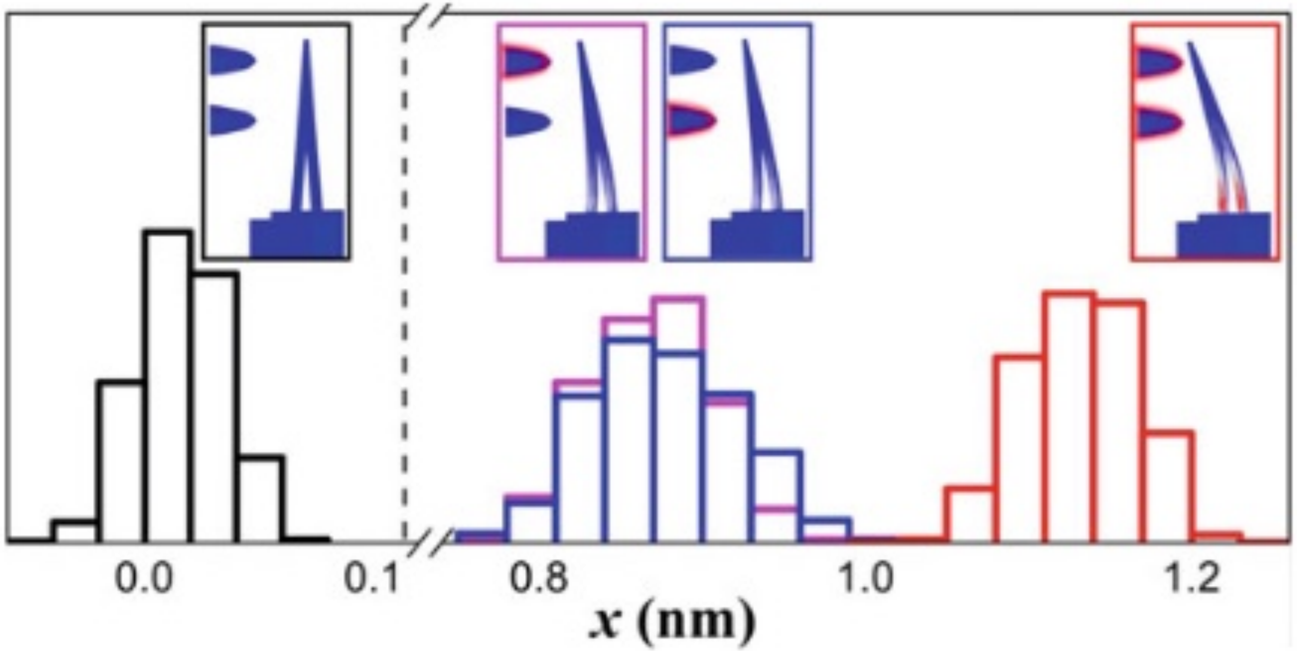

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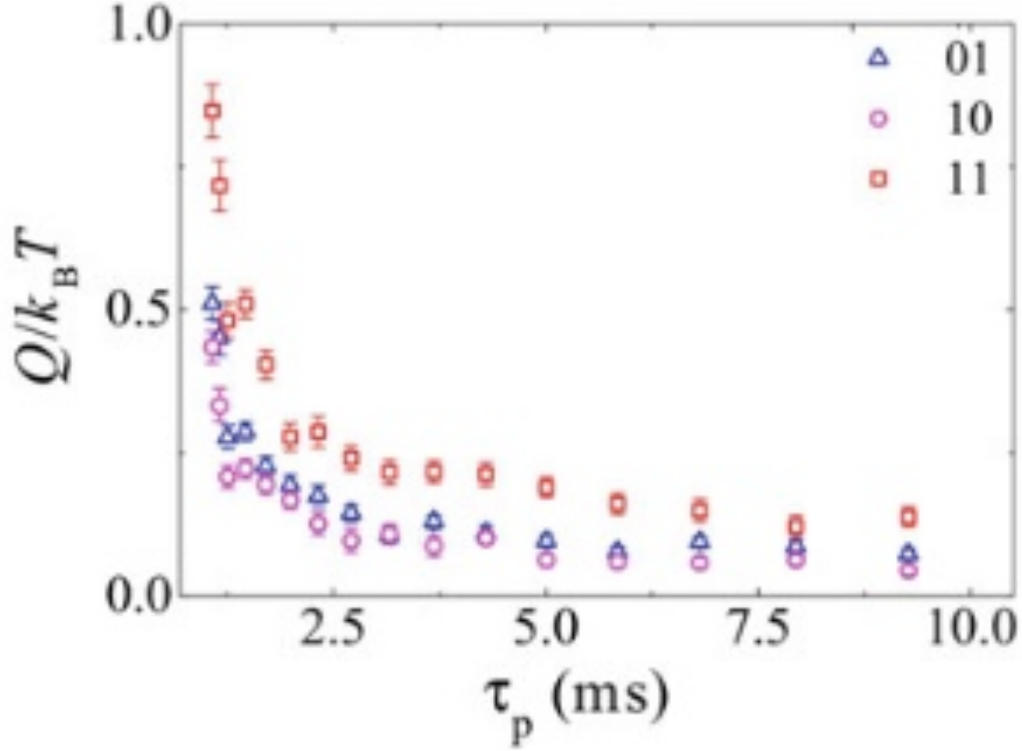
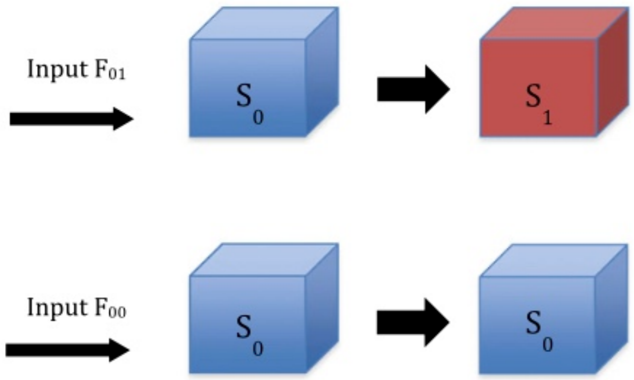


Conclusion



A computation is the result of a **change of state** of a given physical system, under the action of an external force.

According to Landauer, the dof bearing information is represented by the status Si of the system and by the input forces, while in a thermodynamic picture the change in entropy (that is a state variable) is uniquely related to the system itself and the forces are not accounting for any entropic contribution.

Although Shannon information and Gibbs entropy have the same formal aspect, they are not the same. The first is a mathematical quantity associated with the probability of a message, while the second is related to the probability of a microstate in a physical system.

While the first has no connection with the physical nature of the message, the second is a direct consequence of the nature of the physical system itself. Thus, it seems natural to conclude that while Gibbs entropy is associated with the way the energy is exchanged according to the second principle of thermodynamics, Shannon information is not.