Landauer's Erasure and Exorcism

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Goal

By the end of this talk, you'll appreciate the relationship between information theory and thermodynamics.

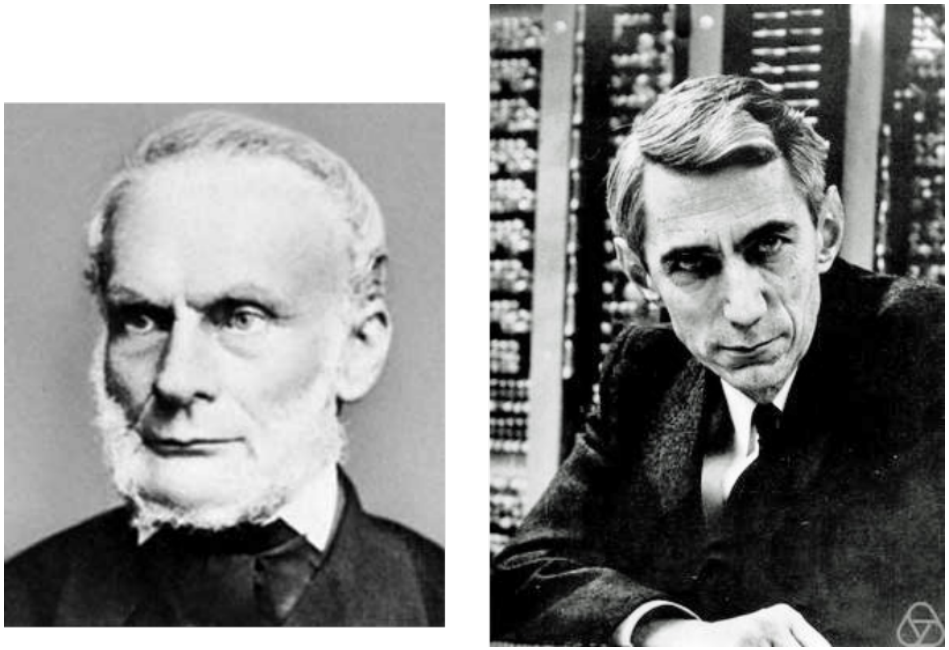

Figure: Rudolf Clausius (left) and Claude Shannon. Source: Wikipedia.

Outline

- State and motivate Landauer's Principle.
- Model a bit (fundamental unit of information).
- Verify Landauer's Principle experimentally.
- Exorcise Maxwell's demon.
- Summarize and take-home message.

What is Landauer's Principle?

Landauer

Irreversible logical operations increase entropy [2].

- In all computing devices, a physical system – subject to the laws of physics – performs logical operations.
- A logically irreversible operation translates to a physically irreversible one.

Information is Physical

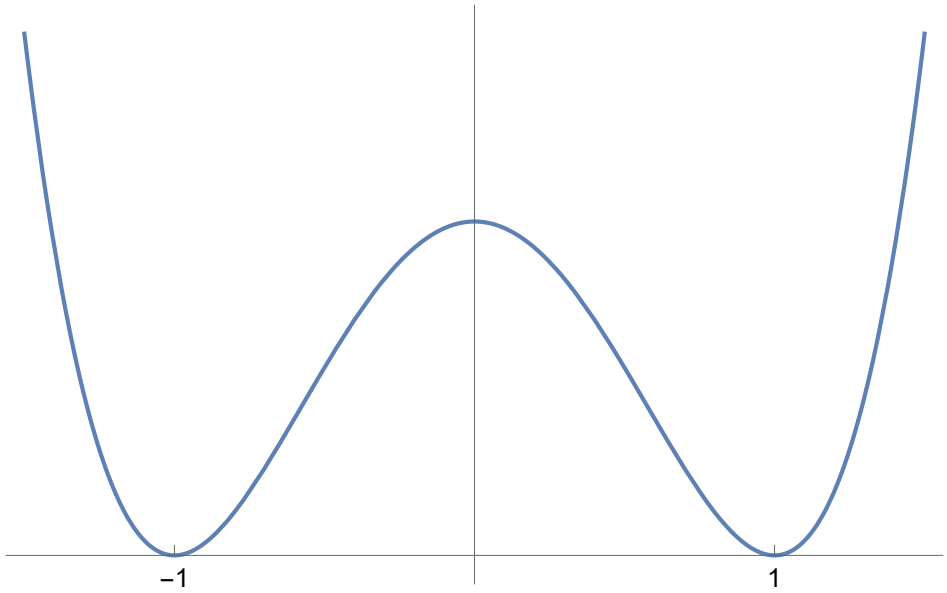

Figure: The two minima represent 0 and 1 of a bit.

- For the rest of the talk, a bit is modelled by a particle in a bi-stable double well.

Logical Irreversibility

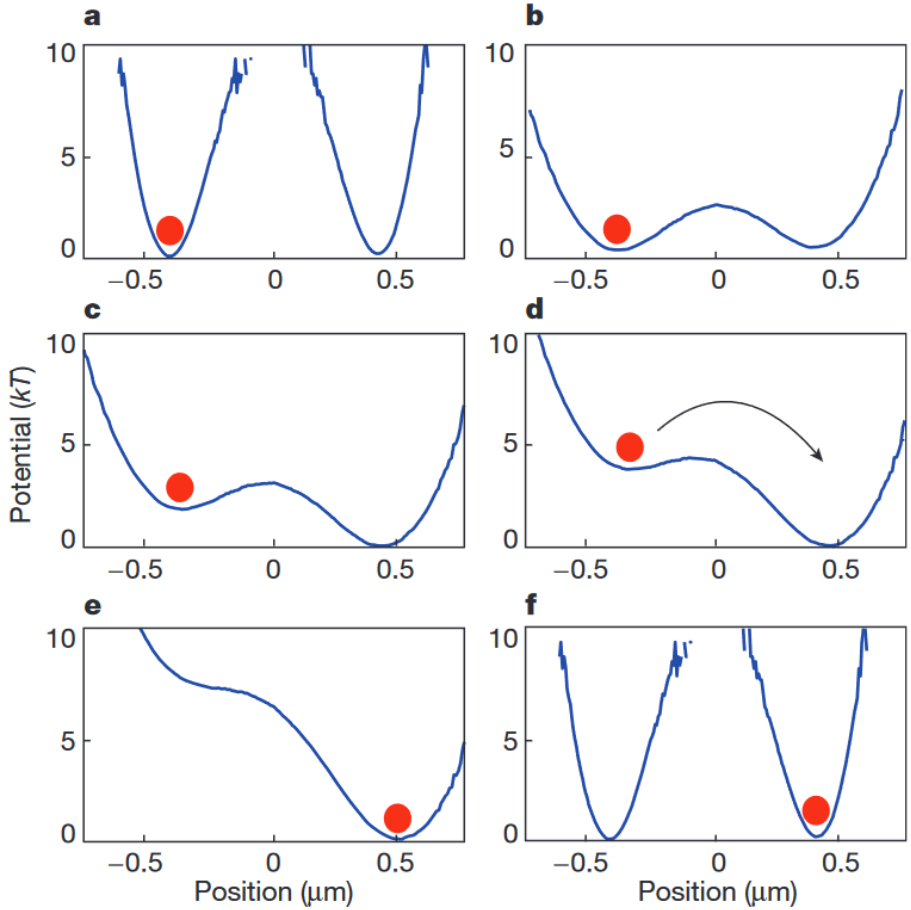

Figure: A logically irreversible operation. Figure from [1].

Landauer's Argument

- A spin chain, initially with all spins up, cools a reservoir when coupled to it.
- When viewed in reverse, can think of as a computer erasing information. Must dissipate heat to the reservoir.
- Erasing information necessarily generates heat

$$\Delta Q = k_B T \ln(2) \tag{1}$$

  per bit.
- Observed experimentally [1].

Exorcising Maxwell's Demon

- Landauer's Principle resolves the Maxwell's Demon paradox [3].
- After extracting work from the system, to begin a new cycle, the demon's memory must be erased!
- This costs at least $k_B T \ln(2)$ heat pet atom, thereby saving the second law.
- This resolution shows that information must be treated as physical. We must add the informational entropy to the second law to save it from Maxwell's Demon.

Summary

- Physical systems – obeying the laws of physics – operate on information.
- A logically irreversible operation increases entropy (Landauer's Principle).
- The Maxwell's Demon makes the message clear:

Take-Home Message

Information is Physical.

References

- Bérut, A., Arakelyan, A., Petrosyan, A. et al. Experimental verification of Landauer's principle linking information and thermodynamics. Nature 483, 187–189 (2012)
- R. Landauer, "Irreversibility and Heat Generation in the Computing Process," in IBM Journal of Research and Development, vol. 5, no. 3, pp. 183-191, July 1961.
- M. B. Plenio, V. Vitelli (2001) The physics of forgetting: Landauer's erasure principle and information theory, Contemporary Physics, 42:1, 25-60.