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

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# Outline

1. Classical Physics
   - Entropy and Information Entropy
   - Maxwell's Demon
   - Exorcising the Demon

2. Quantum Regime
   - Searching for a general Quantum Entropy Function
   - Conservation Laws

# Entropy and Information Entropy

### Information Entropy

Entropy is a measure of the average information content one is missing when one does not know the value of the random variable

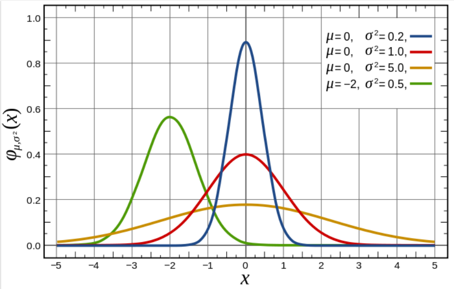
### Shannon Entropy

$H := -\sum_i p_i \log p_i$

### 1Bit of memory

$S := k_b H = k_b \ln 2$

# A closer look on Entropy and Second Law

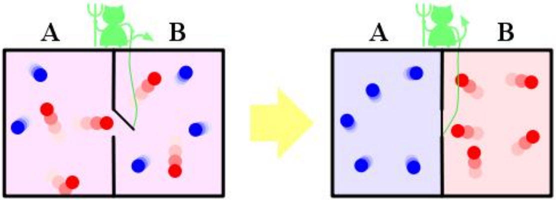



source by: wikipedia

- The more spread the distribution → high entropy.
- The sharper → low entropy.

# Maxwell's Demon

## Experiment outlook

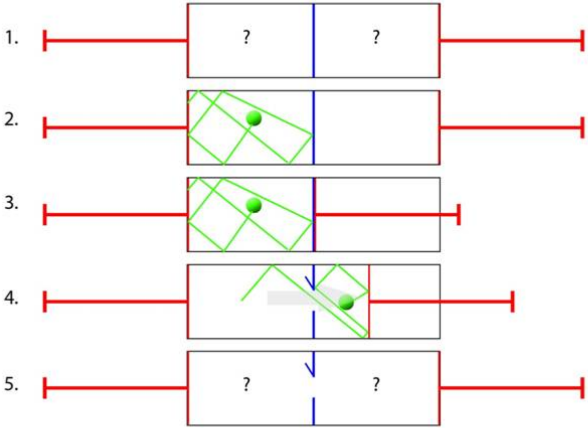



Maxwell:

- Proposed this gedanken(thought) Experiment in 1867
- Tought that the Second Law of Thermodynamics is valid only in the statistical limit.

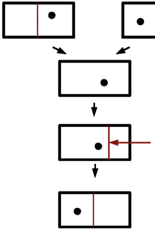
# Maxwell's Demon

## Szilard Engine




source by:http://splasho.com/blog/essays/maxwell-thermodynamics-meets-the-demon/

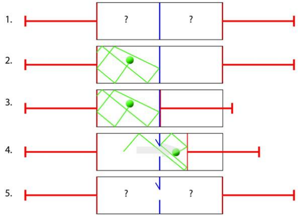
# Landauer's Principle



source by:http://plato.stanford.edu/entries/information-entropy

- Logically irreversible operations need dissipate heat to the environment to conserve entropy
- Reseting a bit costs $k_b T \ln 2$ of work

# Exorcising the Demon




- Now again with considering the memory the demon!
- Bennett: Demon has to store measurements but when it erases them it generates entropy.

# Outcomes

- The second law is a fundamental principle and not necessarily a statistical property
- Information and Energy are connected

# Is 2nd Law Really Fundamental?

### Quantum Entropy

Von Neumann, $S(\rho) = -tr(\rho log \rho)$, valid only in large systems and many uses

### Single-Shot

more complicated forms,

$$D_\alpha(\rho\|\sigma) = \begin{cases} \frac{1}{\alpha-1}\log(tr(\sigma^{(1-\alpha)/2\alpha}\rho\sigma^{(1-\alpha)/2\alpha})^\alpha) & \text{if } \alpha \in (0,1)\cup(1,\infty) \\ tr(\rho\log(\rho-\sigma)) & \text{if } \alpha = 1 \\ \log\|\sigma^{-1/2}\rho\sigma^{-1/2}\|_\infty & \text{if } \alpha = \infty \end{cases} \tag{1}$$

# Why we need it?

## Most Common Assumptions

1. Unitary evolution, $U$. Conserves any entropy function
2. Conservation of Energy, $[U, H] = 0$

## Can be replaced with

1. Conservation of Energy
2. Conservation of (Quantum)Information

# Summary

- Maxwell's Demon → 2nd Law is not fundamental, but statistical phenomena
- Landauer's Principle → Irreversible maps require work(energy), in particular memory erasure
- Bennett "Demon has to delete his/her memory" → 2nd Law is recovered

# Results

- In classical systems, information is what referred as entropy for in the last century.
- For quantum systems, there is no general form yet. But research goes on an results are found for certain systems.
- Outlook
    - Many interesting discussions exists, involving fancy names: Black hole information paradox, A black hole firewall

# For Further Reading I

O. Maroney
Information Processing and Thermodynamic Entropy
*http://plato.stanford.edu/entries/information-entropy/#LanPri*

Bennett, Charles H.
The thermodynamics of computationa review
*International Journal of Theoretical Physics volume 21, Issue 12, pp 905-94*