Energy can be measured as a bitrate

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Background

- Particle and Molecular Dynamics Simulations at LLNL allow rethinking classical definitions of physics.
- Should lead to insights and more efficient simulations.

Summary

- Joule -> bit/s
- bits/s -> Joule
- Conclusion

Joule -> bits/s

- Definition: Joule

$$J = kg \cdot \frac{m^2}{s^2}$$

- Representation of a classical Hamiltonian state in computer:

```
double m; // in kg
double v; // in m/s
double d; // in m
```

Joule -> bits/s

$$E = \frac{\log_2(d) + \log_2(v) + \log_2(m)}{t}$$

$$[J] = \frac{\log_2([m]) + \log_2([ms^{-1}]) + \log_2([kg])}{[s]} = \frac{[bits]}{[s]}$$

- Maximum amount of bits needed to represent one Joule. QED for this direction.
- Minimum amount of bits needed depends on structure. Needs Entropy definition. See following slides.

bits/s -> Joule

- Conceptual idea: A vinyl record defines a set amount of mechanical energy per second (rotation speed) measurable by the needle oscillations.
- bits/s -> Nyquist Theorem

Photo: Wikimedia Commons

bits/s -> Joule

- How much energy is needed to erase one bit (in Joules)?

$$E_{erase} = kT \ln 2$$

k=Boltzmann constant
T=Temperature
ln(2) = 0.69314718056…

- Landauer Limit (1961), confirmed experimentally 2013.

bits/s -> Joule

- How much energy is needed to erase n bits (in Joules)?

$$n \cdot E_{erase} = nkT \ln(2)$$

- But how many bits are erased?

bits/s -> Joule

- Shannon Entropy:

$$S = -\sum_{i=1}^{n} p_i \log_2(p_i)$$

How many bits expected to represent characters with normalized frequency (probability) pi?

- Proportional to number of bits to be set to 0.
- Already available in physics as Boltzmann-Gibbs Entropy:

$$S_B = -k_B \sum_{i=1}^{n} p_i \log_2(p_i)$$

- kB is 1.44*Boltzmann constant. See previous slide.

Problem with Shannon Entropy

s=10000111010100010101011 -> H(s)=1 (random)

s=10101010101010101010101010 -> H(s)=1 (random)

Shannon and Boltzmann-Gibbs Entropy assume well-known alphabet.

What's the alphabet in physics? What's the alphabet of the universe?

We don't know.

What we know

s=1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
H(s)=1 (random)

s=10 10 10 10 10 10 10 10 10 10 10 10 10 10
H(s)=0 (repeating character)

s=101 010 101 010 101 010 101 010 101 0
H(s)=1.0165

s=1010 1010 1010 1010 1010 1010 1010
H(s) = 0 (repeating character)

- Shannon capacity depends on block length. Generalization?

Kolmogorov-Sinai Entropy

Generalization of Shannon Entropy:

$$h_{KS} = Sup_{\mathcal{P}}\ lim\ _{n\to\infty} - \frac{1}{n\Delta t} \sum_{\omega_1,\omega_2,\ldots,\omega_n} P_{\omega_1,\omega_2,\ldots,\omega_n} log_2 P_{\omega_1,\omega_2,\ldots,\omega_n}$$

Intuition: KS Entropy is the supremum (least upper bound) of the Shannon entropy per unit time with respect to all possible partitions *P* of the phase space into cells Ω_{ij}.

bits/s -> Joule

- Dzugutov et al. (2003) showed, in fact, that this measure is applicable as there is a universal relation between the Kolmogorov-Sinai Entropy and the thermodynamic Entropy in simple liquids.
- This concludes the second direction. QED

Note

- KS Entropy complex to compute but approximations available as:
  - Approximante Entropy (ApEn)
  - Sample Entropy (SampEn)
  - LZW (zip) distance

Conclusion

- Energy can be measured in bits/s.
- This allows to connect classical and statistical mechanics to information theory, in addition to thermodynamics.
- Work in progress (under review):
  - Universal definition of equilibrium
  - Closed-form definition and very efficient approximation of free energy
  - Explanation for phase transition

Stay tuned! (pun totally intended)

Thank you for your kind attention!