Chapter 9: Entropy And Its Demons

What is entropy?

- Shannon's discussion of entropy has concerned specifically his theory of information, but the broader concept originally owes its origin to thermodynamics. As introduced by Gleick, the first to encounter this convoluted topic was the German physicist and father of thermodynamics Rudolf Clausius who initially described it as "its uselessness for work"(Gleick 270). This ultimately allows for the creation of the laws of thermodynamics; the first two of which are stated in a tongue and cheek manner as

    1. **You can't win** (energy can be neither created nor destroyed)
    2. **You can't break even either** (entropy of an isolated system always increases)

    Are such laws decidedly dystopian as remarked by writers of the time?

- Entropy is traditionally given the definition of 'a measure of disorder', this is a notion first expressed by James Maxwell in relation to the dissipation of energy, but it is somewhat of an oversimplification of the subject. How does one measure disorder? What entropy specifically refers to is a probabilistic function of order as indicated by microstates within a given structure. This video provides a concise and clear description of entropy at the quantum level and explains why reactions are governed by entropic favorability.

    How is the physical understanding of entropy similar to Shannon's entropy of information? How is it different?

- Maxwell then gives an analogy to describe the second law of thermodynamics and *why* the world tends towards disorder:

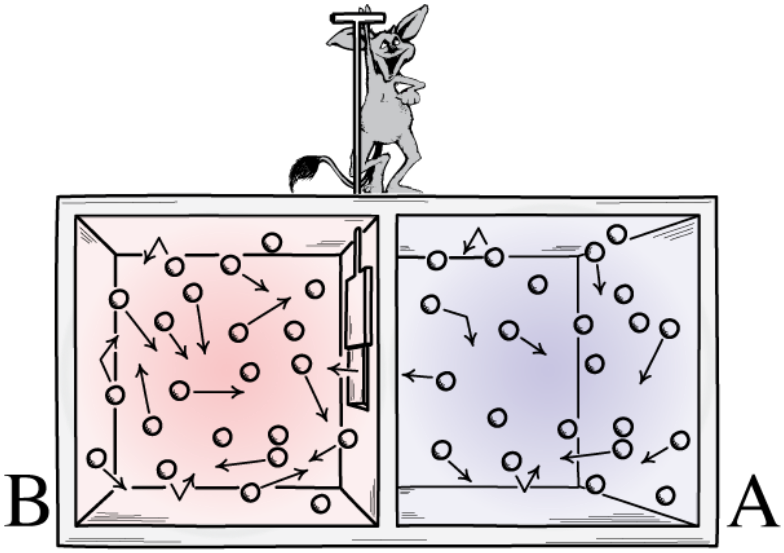
    The 2nd law of thermodynamics has the same degree of truth as the statement that if you throw a tumblerful of water into the sea, you cannot get the same tumblerful of water out again.

This analogy, in addition to being helpful for understanding the second law, reminds me of a thought experiment that is occasionally seen online. How long would it take a monkey, or a handful of monkeys, to reproduce Hamlet word for word? While our monkeys, given typewriters, would certainly chunk away, it is unlikely that they would produce anything sensible. It is even more unlikely that they would reproduce word for word a piece of literature from the western canon. **Not impossible.** But very unlikely. This is the notion of the second law of thermodynamics.

Can you think of another analogous example?

Maxwell's Demon

- Maxwell, unnerved by the idea that probability decided all reactions in the universe, conceived of a thought experiment to challenge Clausius and his own finding. He imagined a being that could systematically sort a mixed system into a hot and cold component; this would ultimately become referred to as Maxwell's sorting demon.



- The mixing of two gasses, due to its high entropic favorability is universally considered a spontaneous reaction which means it occurs without the input of energy. In order to measure whether a reaction occurs spontaneously or not, physicists and chemists alike utilize Gibbs free energy equation where a -ΔG value indicates a spontaneous reaction.

$$\Delta G = \Delta H - T \cdot \Delta S$$

ΔG = Gibbs free energy
ΔH = Change in enthalpy
ΔS = Change in entropy
T = Temperature in K

This equation illustrates that, if a change in entropy is high enough, any reaction becomes spontaneous regardless of heat or temperature factors. Free mixing is one such reaction with a very high ΔS value. Maxwell's proposed demon can bypass this phenomenon: to not allow uniform mixing to occur by reducing the entropic change. Physicist Leo Szilard challenged this idea. In order for the demon to sort the particles it must decide which particles are hot and which particles are cold. It is making a choice from a set of two hence *n*log2. As put by Szilard, information is not free. Maxwell's demon is not possible.

How does the refutation of Maxwell's demon corroborate the idea of 'information as entropy'?

Entropy and living organisms

It appears that living organisms organize the world, propagating structure and reducing entropy, while non-living things reduce to a stable state. Schrödinger claims that life is when matter goes on doing something for a much longer period than we would expect an inanimate piece of matter to keep going in those circumstances, demonstrating remarkable permanence. This is a bold biological claim to stem from the world's premier quantum physicist that rings of physics, biology, and above all, philosophy.

"To put it less paradoxically," he added paradoxically, "the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive" (Gleick 283)

As such, living creatures seem to evade the second law, freeing themselves from the entropy created. The organism sucks order, or negative entropy, from its surroundings. This is seen in how animals break down the structure of their food, or plants use sunlight. Like crystals, organisms seem to have a self-repairing property and for that reason have been termed as *aperiodic crystals* – permanent, yet complex.

1) What do you think is meant by "negative entropy"?

2) Does it make sense to define life as the prolonging of doing?