BANISHING THE PESKY DEMON: THE FINAL WORD

Laurence Daw

Thomas Pynchon's work is well known for its concern with the subject of entropy. in The Crying of Lot 49, for example, the idea of entropy in thermodynamics is linked to the idea of entropy in information theory. As Oedipa Maas succinctly puts it: "there were two distinct kinds of this entropy. One having to do with heat- engines, the other to do with communication. The equation for one, back in the '30's, had looked very like the equation for the other. It was a coincidence. The two fields were entirely unconnected, except at one point: Maxwell's Demon" (105). Oedipa is correct. Until recently, however, no one knew why. But in a recent Scientific American article, "Demons, Engines and the Second Law" (November, 1987, 108-16), Charles H. Bennett takes pains to make a distinction between the thermodynamics of the physical world and the so-called thermodynamics of information theory, to have, as it were, the last word on the failure of Clerk Maxwell's gnome-like mythological sorter that could supposedly cheat the second law of thermodynamics.

In 1871, Maxwell conceived the demon as a type of information-processor that could sort individual molecules to create and sustain differences in temperature without itself doing any work. These differences in temperature would be a source of usable energy, and, in effect, the work the demon did not do would be the work a heat engine could do. Scientists saw that such a demon would violate the second law of thermodynamics, which holds that the entropy of a closed system always increases. Yet, it remained difficult to prove exactly why the demon would not be able to violate the second law. As Bennett puts it: "To protect the second law, physicists have proposed various reasons the demon cannot function as Maxwell described. . . . The correct answer--the real reason Maxwell's demon cannot violate the second law--has been uncovered only recently. It is the unexpected result of a very different line of research: research on the energy requirements of computers" (108).

In a 1929 article entitled "On the Decrease of Entropy in a Thermodynamic System by the Intervention of Intelligent Beings," the physicist Leo Szilard argued that the measurements the demon needed to make could not be done without the performing of work, which, in turn, would cause an increase in entropy; thus, the demon could not violate the second law. Szilard's work was carried forward in the 1950s by Leon Brillouin and Denis Gabor, whose main aim was to prove what Szilard had vaguely defined as "The irreversibility of measurement." They understood that the demon functioned primarily as an information processor and that its acts of sorting were thermodynamically costly, but not necessarily in a mechanical way. Yet, they finally had to attribute the probable failure of the demon to the quantum theory of radiation: the energy of the photons contained in the electromagnetic radiation the demon would use to observe the molecules of gas it sorted would have to come from somewhere, to be taken from another system, thereby increasing that system's entropy; thus, again, the demon could not violate the second law.

The next major advance in the effort to banish the pesky demon was made by Rolf Landauer of IBM in the 1950s as a side effect of research he was doing on what was becoming known as "the thermodynamics of data processing." In computers, certain data-processing operations, such as copying data from one device to another, are analogous to measurements, in that one device acquires information about the state of another. These processes, like the measurements made by the demon, are thermodynamically costly. In the 1950s, data processing operations were believed to be intrinsically irreversible (in the thermodynamic sense of the word) because any kind of data operation was thought to require the generation and removal of at least one bit's worth of heat energy for every bit of data being processed within a computer's electronic circuitry. The process of data transfer would therefore always be irreversible because it would always be thermodynamically costly. Yet, once again, though perhaps for the last time, physicists were on the wrong track. In later work, Landauer discovered that some data operations are, for one reason or another, free of any fundamental thermodynamic limit. But it was not until around 1982 that Bennett and others finally determined exactly why Maxwell's demon could never do what it was supposed to do.

The key to the failure of the demon lies in the surprising fact that forgetting or discarding information, not gaining it, is what is actually thermodynamically costly. In order to decrease the entropy of its environment, the demon has to increase the entropy of its memory. When the demon forgets information, its memory actually becomes less organized than when it remembers information; it is, therefore, more entropic. In order to cause this change of state, the demon needs energy. Recall that the demon is really nothing more than a supernatural type of information-processing computer. If a computer's memory, which can exist in any number of possible electromagnetic states, is reset or cleared, the value of each location of the memory must be set to the same value, regardless of its previous value. Before the operation, the memory could have been in *n* number of states; after the clearing operation, the register can be in only one state. As Bennett puts it: "the operation has therefore compressed many logical states into one, much as a piston might compress a gas" (116). This process of logical compression is irreversible; therefore, and most importantly, it is thermodynamically costly. The increase in entropy which occurs in accordance with the second law of thermodynamics takes place during the resetting of the memory.

Thus, after more than a century of hypothesizing, we have found the real reason Maxwell's demon cannot violate the second law: in order to observe a molecule, it must first forget the results of previous operations. Forgetting results, or discarding information, is thermodynamically costly, and the demon is forced to increase the entropy of its memory in order to decrease the entropy of the heat engine. In the world of information processing, the process of making measurements is thermodynamically costly. The demon cannot work. Physicists have finally banished it forever.

--The University of Western Ontario