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Review Article

Wrestling Maxwell's Demon

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Abstract

Maxwell's Demon is a thought experiment proposed by James Clerk Maxwell in 1867 to challenge the second law of thermodynamics. It has been used by physicists to extract an energy value for information. We question the various thermodynamic descriptions of the demon's ability to separate atoms without considering the energy requirements for "recognition," which involves the parameters "awareness" and "memory". We argue that "information" is distinct from "data" and involves these critical parameters. In contrast to the "demotive" information processing of computers, the emotive qualities of cognitive information (cog-info) is crucial in biological systems. The chemographic description of the tripartite mechanism of neural memory recognizes the emotive factors as embodied by neurotransmitters (NTs). Without an energy-dependent mental apparatus, the demon's putative ability to discern and act on information presents an energy paradox. Thus, we conclude that Maxwell's Demon is a non-existent phantom arising from mathematical manipulations of physicists that do not reflect the energetic and cognitive realities of biology.

Keywords: Maxwell's Demon; Thermodynamics; Information; Tripartite Mechanism Of Memory; Cognitive Information; Consciousness; Neurotransmitter

Background

"Mentality" is the "big mystery" of Neuroscience. Notwithstanding the efforts of some scientists, "mentality" cannot be measured by the metrics of physics nor coded for by the algorithms of the Information theorists [1-12]. Only the theologians have the courage to address "mentality", by proposing spirits and souls rationalized by "faith". Of course, there is no objective evidence to buttress any particular "faith". Thus, we scientists slog on in our quest to employ the scientific method to comprehend the mentality achieved by the neural net.

Maxwell's Demon

Our readings about Maxwell's Demon [13-17] stimulated us to consider the Demon and its circumstances in the context of a neural memory mechanism. The Demon has been linked to "Information theory", as an aspect of thermodynamics with constraints related to information processing [13,14]. The Demon is putatively capable of transferring heat from a cold region to a hotter one without exerting any work, violating the second Law of Thermodynamics. Maxwell's Demon could choose between fast and slow atoms to form separate volumes with high and low energy atoms with corresponding high and low temperatures evaluated as "information" (Figure 1).

In 1929, Szilard analyzed Maxwell's Demon as an idealized heat engine thereby merging Information Theory with thermodynamics [13-17]. Though he described the energy of the basic unit of information ("bit") as kTln2, he did not specify the role of memory in the capability of the Demon. These days, it is generally accepted that information processing must be performed by a physical system [18,19]. The exorcism of the Demon was finalized by considering that the erasure of memory entails an entropy increase [20]. Thus, theoretical physicists conjured up an entity that would defy the normal rules of thermodynamics as well as psychodynamics.

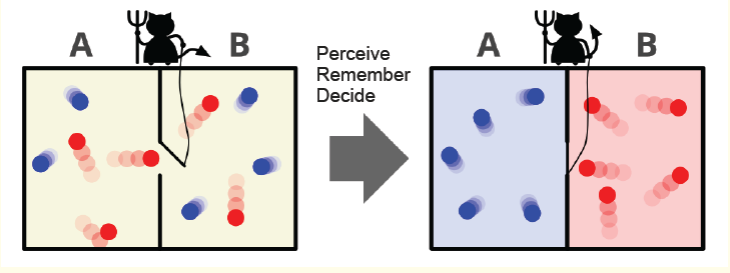

Figure 1: Schematic drawing of Maxwell's Demon selecting atoms from a random mixture and separate them into a confined high and low velocity compartments.

Thermodynamic calculations aside, one is asked to suspend belief that the Demon is governed by the same rules that apply to all sensate creatures. That is, the Demon must recognize and remember info, to be able to act on it. More on this below.

Memory

Our attempt to decipher these enigmas focused on molecular mechanisms. In particular, we considered how psychic states are encoded in the conscious memory of neural entities. The workings of the human brain consume ~20% of total body caloric energy. Thus, the mentality of the brain requires energy. How did the Demon remember without such an energy-dependent apparatus? To that end, we needed some definitions and clarification of processes, as follows:

Data, Information and Recognition

As a general rule, one could state that without "*Recognition*", data and information are nothing, equivalent to the thermal vibrations of any inanimate collection of atoms kept above absolute 0° K (i.e. thermal noise). Without a sensate entity to comprehend, they convey no insight or "meaning". Thus, we question the Demon's ability to remember without a neural apparatus and without using energy.

We distinguish between "*data*" and "*information*". Data is a single sensate point, a quantal of energy described by the term "bit" which however has no inherent meaning. In binary format, its energy equivalent is

Equation 1

Data (bit) $E_{bit} = kT \ln 2$ ------> Meaningless

Thus as in equation 1, the data ("*bit*") processing by computers is described in terms of energy where k = Boltzmann constant (1.3801×10^{-23} joule/Kelvin or 1.3801×10^{-16} erg / Kelvin) [20]. But the *bit* has no inherent meaning.

"*Information*" could be considered as a collection of data bits. In our opinion, the "*bit*" was misunderstood as "*information*" by Landauer and other thermodynamicists [19-21]. The description of "*bit*" is lacking a critical parameter involved in converting "*data*" to "*information*". That is, its missing the parameter termed "*Recognition*" (Rec). Without Rec, "*information*" is meaningless, it does not really exist or impact. Note that Rec is comprised of two parameters which both require energy, namely *consciousness* (E_C) and *memory* (E_M).

Equation2

Information

$E_{info} = kT \ln 2 + E_C + E_M$ -------> Meaning

E_C = energy of consciousness (awareness)
E_M = energy of memory

Though the Demon is hypothesized to be both conscious and to remember, it is not supposed to require energy (21). Thus, Maxwell's Demon presents an energy paradox.

Information (Info) and Cognitive Information (Cog-info)

"*Information*" requires recognition of a pattern of data, processed by a computer algorithm. In the computer, the "*recognition*" is embedded by the human programmer who wrote the processing algorithm. Without *recognition*, data is just noise. Moreover, cog-info, characteristic only of sensate beings, is comprised of an additional parameter, namely emotions.

Tripartite mechanism of neural memory [22-30]

A confounding aspect of both "*information*" and " *cognitive information*" is that they both require memory as a basis for assigning "*meaning*" or *"value*". Note that the info of the computer and of Maxwell's Demon is totally "*demotive"*, devoid of affective quality. By contrast, cog-info of sensate biologic beings is "chock full" of emotive qualities. More on this in our previous publications on the tripartite mechanism of memory (Marx and Gilon, 2012-2025, figure 1). In short, the neural system of memory is modulated by neurotransmitters (NTs) which render "*meaning*" with emotive context.

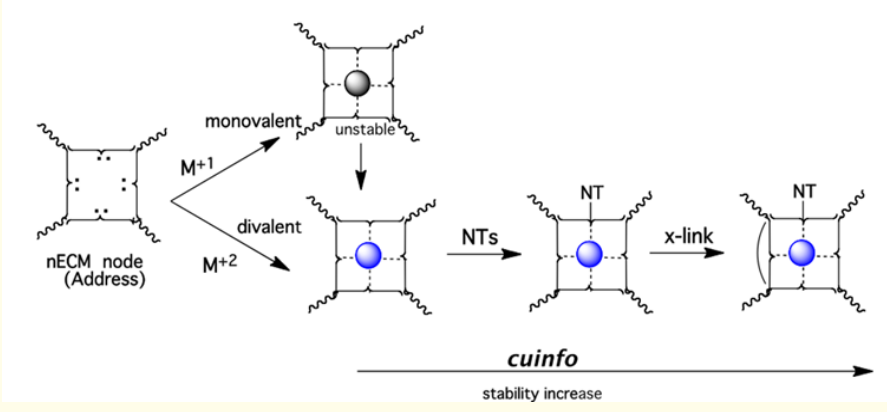

Figure 2: Tripartite mechanism of the encoding of memory in the nECM.

Chemographic representation of the formation of *cuinfo* complexes with different monovalent and polyvalent metal cations, as well as with different neurotransmitters (NTs), rendered more stable (persistent) by crosslinking. The NTs confer emotive quality to the *cuinfo*.

The chemographic notation in Figure 1, encapsulates the general encoding features of the *tripartite* mechanism. It remains cryptic in that it does not specify how individual NTs elicit specific emotions from the neural net. But it identifies the salient components of the neural memory system that entangles psychic states with physiologic reactions.

Interim conclusion

The Demon inspired by Maxwell is a supposed thermodynamic being that could distinguish between the fast and slow atoms to effect a separation based on the "information" (info) gleaned from the speed of the atoms. The energetic cost of every bit of info could be calculated.

All well and good for thermodynamics. But what of mentality? What of the energy requirements of the Demon? He/she requires a memory function and a psychic capability to evaluate the speed of each atom....fast....slow, and to select accordingly, and to remember. Without delving into the minutia of the thermodynamic states of the atoms, such a Demon cannot exist in the absence of energy-dependent mental functions. To be clear, Mentality requires an apparatus capable of transcending caloric energy into a mental state capable of recognizing the relative speeds of the atoms. This requires a function called "memory" and a desire to affect a separation of atoms.

Energy

Many physical forces of Nature can be analytically described by the laws of thermodynamics, by mass conversion as per Einstein's equation $E= mc^2$, or by the laws of gravity or Newtons laws of force and motion, or by Maxwell's laws of electricity and magnetism .

However, the conversion of biochemical events into psychic states remains opaque. We subjectively experience the transcendence of caloric energy into mental states. Notwithstanding Freudian psychoanalysis, we are incapable of analytically describing such transcendence. The best we could do is to suggest a tripartite mechanism which identifies the components of the biologic system (i.e. neurons, extracellular matrix (nECM) and dopants (metal cations and NTs)) that together achieve the realm of mentality, experienced as emotive memory.

Characterizing maxwell's demon

In the context of the tripartite mechanism of memory, we summarize our view of Maxwell's Demon as follows

- **Energy:** The Demon is presented as analogous to Cajal's "naked neuron". That is, just as Cajal ignored the extracellular matrix (nECM) around the neuron as having no relevance to neural activity, so do the proponents of Maxwell's Demon ignore the energy requirements to effect recognition of "info" and decision making (i.e. distinguishing between high and low velocity atoms). Effectively, Maxwell's Demon has been presented as "naked" in terms of energetics and mentality.
- **Memory**: Maxwell's Demon requires a function called "memory" to distinguish between the moving atoms. But without an apparatus to function as "memory", it cannot recognize or decide anything.
- **Consciousness:** Without awareness, Maxwell's Demon is a non-entity, a ghost to frighten scientists. The only beings that we know of that exhibit awareness are biologic creatures. As Maxwell's Demon is incorporate, it does not require energy and cannot function without memory to render decisions. It is just a phantom "slip of the tongue".

Mental power

Though it is generally accepted that the brain does not function like a computer, it is worthwhile to contemplate their energy requirements (Table 1).

Supercomputer: ~17,208,413 calories/hour	Binary (n = 2)
Laptop: ~26 calories/hour	Binary (n = 2)
Human Brain: ~17 calories/hour	Multinary (n > 100)

Table 1: Power usage Mode.

Note that both computers process info as memory with binary (n = 2) effectors (i.e. 110011000110011...) with a code formalized by Information Theory [31,32].

By contrast, we suggest that the neural net of the brain processes cog-info as memory with much greater energy efficiency, employing many more effectors comprising >10 metal cations and >90 neurotransmitters (NTs), the latter which endow memory with affective qualities. At this time, we are not aware of any theory of cog-info coding. We have identified the effectors of the neural code but we may never achieve such knowledge, having reached the "event horizen" of the black hole of our mentality.

Wrestling

Much like the biblical Patriarch Jacob (renamed "Israel") who engaged with an angel/man to wrest a blessing from him (Genesis, Vayishlach, 32: 23-30), we wrestle with Maxwell's Demon to comprehend its limitations and extract the blessing of *Understanding*.

But we cannot ignore the Demon's requirement for energy to drive memory as well as energy to recognize and decide. We know that such a Demon cannot exist in an "energy vacuum". The equations dealing with the thermodynamics of atom separation based on "*information*" derived from atomic speed imply the energy needs of the Demon for a function called "*recognition*" which involves "*consiousness*" and "*memory*".

Our expanded tripartite mechanism of memory goes a long way to addressing this issue for neural systems. It involves neurons/glial cells surrounded by nECM/PNN which performs as a "*memory material*". Neural memory is encoded with metal cations and neurotransmitters (NTs) ejected into the nECM/PNN by stimulated cells. The dopants generate the physiologic and psychic states which generate the mentality of recalled in memory. The neural

circuits are capable of reading the *cuinfo* distributed throughout the brain's nECM/PNN [29] and integrating (consolidating) them into the seamless experience of memory.

This is quite a complicated process for a simple Demon. It requires caloric energy not spoken of in the thermodynamic models. Descarte's truism " *Je pense, donc je suis*" ("I think, therefore I am" or in Latin "*Cogito, ergo sum*") does not apply to Maxwell's Demon. Thus, we view Maxwell's Demon as a non-existent phantom conjured up by the mathematical manipulations of physicists that do not reflect the true logic of information thermodynamics or the energy realities of biologic mentation.

Acknowledgment

(GM) To the memory of my late wife, the artist Georgette Batlle (1940-2009), whose graphic skills helped me refine graphic models of blood coagulation which I generalized to mentation. My daughter Danae and son Jonathan continue their mother's approach, by helping their father cope. Thanks also to Karine Ahouva Leopold (Paris, Nice, Jerusalem) for warm companionship. Tango and many discussions on emotions. Thanks to my brother Rabbi Dr. Tzvi Marx (Amsterdam, Jerusalem) for being a sounding board.

(CG and GM): Our collaboration exemplifies the sage proverb: *"Iron sharpens iron, and one man sharpens the face of his neighbor"* Mishlei, Proverbs 27:17

It means that in a good collaboration, one mind sharpens the abilities of the other.

We appreciate Zoom meetings with Prof. Orly Shenker (Hebrew University, Dept. Philosophy) for discussions on Maxwell's Demon.

Conflict of Interest

GM is a founder of MX Biotech Ltd., with a commercial goal to develop biomaterials for wound healing and biomimetic sensors.

CG is an Emeritus Professor at the Hebrew University, Jerusalem, Israel, but is active in developing and patenting peptide and protein-based drugs.

Notwithstanding, the ideas forwarded here are scientifically genuine and presented in good faith, without commercial clouding of the concepts expressed here. The text was written by the authors and not generated by an AI program.

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