Review of: "Thermodynamics, Infodynamics and Emergence"

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Thermodynamics, information, emergence: these are three extremely wide and comprehensive concepts, as is complexity, which does not appear in the title but is amply featured in the text. The literature to each of them fills libraries. Presenting a review that covers all of them is a daring enterprise indeed. In the paper at hand, the author pretends moreover to unify these concepts under a common physical principle, a simple relationship between free energy and information. He did not succeed in convincing this reviewer.

The starting point and central thesis claims that "it takes free energy to acquire information, and it takes information to increase free energy". As plausible as it sounds, it falls short and is even misleading in its generality. Many contexts where information plays a basic role, e.g., in mathematics, logics, linguistics, physical concepts such as free energy just do not apply. Even in physical contexts, relating information directly to free energy is inadequate: Referring to the energy contained in macroscopic degrees of freedom (as distinguished from thermal energy, which refers to the motion in microscopic freedoms), it implicitly assumes a clear separation of scales. This may be the case in typical physical systems in thermal equilibrium. Precisely complex systems and systems far from equilibrium though, which are in the focus of this paper, are characterized by the presence of structures on most intermediate scales, so that free energy and thermal energy can no longer be unambiguously distinguished.

Beyond this basic criticism, I am concerned about the sometimes inaccurate way those general concepts are introduced. To mention a few particularly striking cases:

Energy: While mechanical, electromagnetic, chemical, ..., energies allow for a sound definition in physical terms, talking of biological, social, cognitive, ..., energies amounts to a merely metaphorical use of the term. Messing up these very distinct meanings will lead to confusion and misunderstanding.

Information: Similarly, the list of categories of information on page 7 mixes up completely different contexts and ways of use of this term. Fortunately, in this case, Shannon's definition provides us with a very versatile tool to unify what can be unified. It could help clarifying and systematizing the diverse meanings and uses of the concept of information, but it is only mentioned cursorily in the paper.

Usefulness: The author refers frequently to "useful energy" and "useful information". The term "useful energy" may be justified, at best, as a synonym for "work". Even here, and much more so in wider contexts, referring to usefulness evokes utilitarian connotations that are inadequate within a scientific account. Useful for whom? This criterion introduces an unacceptable subjective element.

Emergence: It is tempting to see emergence wherever new structures arise, as does the author of this essay. However, in this way the distinctiveness of this concept is weakened. It has been introduced to characterize and explain how in systems with a large number of in themselves simple components, properties appear that could not have been predicted, based on the features of the component systems alone. Like this, it applies to phenomena in physical many-body systems, such as phase transitions or lasing, in neuronal assemblies, such as consciousness, and even in technology, such as computing in electronic circuits (see my ref. [1]). Including all the structural levels from elementary particles through atoms, molecules, cells, through organisms and ecosystems as indicated in this paper, stresses that already broad definition too far.

Complexity: The way the term "complex" is used in this paper, it seems to insinuate that it is roughly equivalent to "comprising a high information content". That may well be a necessary condition for complexity, but it is not nearly sufficient. Another necessary

ondition is certainly that this information arises over an entire hierarchy of structural levels, but that's not enough, either. Additional properties are required, for example concerning scaling properties and the time dependence. Ref. [2] elucidates all this and has become a standard reference concerning complexity. It should not be missing in the bibliography.

No doubt, these concepts are intimately related to each other. Synoptic essays analyzing and illuminating their mutual relationships are welcome and necessary. At the same time, they should acknowledge their subtleties and even emphasize them, to stimulate their transparent and precise usage in the scientific discourse. Generally and on the whole, the present paper provides correct orientations. However, I am afraid that for the sake of drawing a clear picture, it tends to oversimplify important details and thereby to obscure the accuracy and delicacy of these notions. I think there remains much space for improvement.

I would like to conclude with a personal remark. On page 14, the author uses a paragraph on socioeconomics to comment on his present working conditions on the background of the general political and economic situation in Venezuela. As faculty member of the National University of Venezuela's western neighbour, I had the opportunity to observe the slow agony of science in this country during the last two decades at close range. It is all the more moving for me to see how even under the prevailing adverse conditions, efforts continue to produce scientific output for an international readership. The critical remarks in this review should therefore not discourage such work but inspire further advancement.

[1] Sophie Gibb, Robin Findlay Hendry, Tom Lancaster (eds.): “The Routledge Handbook of Emergence”, Routledge Handbooks in Philosophy (Abingdon, 2019).

[2] Remo Badii, Antonio Politi: “Complexity. Hierarchical Structures and Scaling in Physics”, Cambridge Nonlinear Science Series 6, Cambridge Univ. Press (Cambridge, UK, 1997).