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LETTER TO THE EDITOR

Operational impact of entropy concepts in genetics and medical practice

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Abstract

The general trend in medical practice is to integrate new knowledge and perspectives on human beings that help enrich our understanding of the mechanisms that enable their existence and help us combat diseases or other conditions that affect them. This refinement of understanding and this integrative vision come from the convergence of various areas of knowledge, such as biology and physics, since reality is a whole, which, due to the limitations of human capabilities and in order to study it better, we have had to divide into parts in order to assimilate all the information it contains. In this sense, the concepts of entropy and its role as a modeling force of the vital phenomenon are fundamental to substantially improve this vision. They provide us with an interesting perspective on evolutionary processes and could provide us with very useful tools for the specialized management of patients.

Understanding the most intimate foundations of vital processes is part of the ultimate objectives of the biological sciences. Comprehending life is a challenge that has remained relevant since antiquity and continues to be constantly renewed. However, when we reach the point of analyzing the fundamental principles of the vital phenomenon, biology inevitably encounters the principles of physics and other fields of knowledge that seek to understand the very essence of nature and are concerned with the basic structure of the Universe. To set these principles aside because of their complexity is to risk stubbornly remaining on the surface of understanding, without undertaking the integrative process of the sciences and of reality that is required to achieve true knowledge.

In this sense, for living beings the issue of biological energy and its organization is central. In fact, all aspects of survival and essential daily life revolve around this theme. Closely linked to it, and at the very foundation of the construction of this knowledge, lies the reality of entropy, a term that currently has several meanings or operational definitions, but which, when considered in its original classical sense under the Second Law of Thermodynamics, refers to what is also known as thermal entropy: a physical quantity designated by the letter S, which describes the tendency toward maximum disorder to which the entire universe is directed [1].

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From this perspective, the entire vital phenomenon—which clearly tends to move in the opposite direction of this tendency toward maximum disorder—is nothing more than the expression of a possibility implicit in the very physical magnitude we are analyzing. If we place this tendency toward disorder on a Cartesian plane along the X-axis, just as there is a tendency toward the positive side, that is, toward increasing disorder, we could also move in the opposite direction, toward negative values, implying a direction and tendency toward increasing order: negative entropy, or negentropy (neg-entropy).

This increasing order depends intimately on another fact: structure. Structure begins at subatomic levels, but for the existence of life, among all possible configurations of associations between these basic elements, certain specific arrangements have been selected over time—arrangements that are not random, but rather special because of their emergent qualities. In other words, all structures selected by "life," all molecules belonging to the four basic families and their combinations and resulting structures, depend on this other fact: order or organization. And order or organization is a direct consequence of information. These successful variabilities fall within the universe of "complexities" described by Boltzmann's entropy, which defines entropy as the number of possible microstates within a macrostate—another definition of entropy that is highly useful in this biological framework [2].

Negentropy is order, and order depends on information. The assertion that biological systems have been "informed," and that "what has enabled evolution is the establishment of patterns for the efficient use of energy," as noted by Freire [3], leads us to an inevitable conclusion supported by the evidence: for biological systems, information is itself a type of energy, just like other known forms such as kinetic, electrical, thermal, chemical, and nuclear energy, and as such must be treated accordingly—just as Vopson argues with his mass–energy–information equivalence [4]. Information, as manifested in biological systems, fulfills all the requirements to be considered a form of energy in its own right: it can be understood as the "capacity to perform work" (including self-organization), it is "intangible," it "is neither created nor destroyed, only transformed," it "exists as a possibility inherent in the very structure of the universe," and it can be "stored and transmitted." The fact that it depends on solar photons does not diminish its status, since no form of energy is infinite; rather, it is part of the continuum of universal energy, constantly moving, transforming, and transitioning from one state to another.

The vital phenomenon cannot be conceived without this indissoluble association between information and energy. This reality therefore goes beyond viewing information as a mere set of data and energy as a force that drives processes. In living beings, energy and information merge into a single, inseparable entity: infonergy, organized vital energy. It is a force of structural cohesion in specific patterns of increasing negentropic order, shaped by natural selection and exhibiting a tendency toward expansion.

Genetics is, par excellence, the science of biological information, where information is transmitted through the language of structures. DNA represents the most elaborate informational achievement of the negentropic tendency, emerging as an evolutionary accomplishment following the so-called primitive "RNA world." However, all structures are saturated with information. The molecular expressions of molecules that function in the vital phenomenon would not exist without the specific data that define them as what they are. Consequently, considering the "Thermodynamic Advantage Magnifying Glass" as the guiding mechanism or tool that natural selection has used—and continues to use—to shape life helps orient an integrative vision of all vital activity: its past, its present, and its future [5].

This "Thermodynamic Advantage Magnifying Glass" consists of evaluating all organic processes from

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this perspective—that is, structures and processes are assessed by their capacity to construct order, by the advantage they provide to the system's structure and energy, which even carries ethical implications. Therefore, quantifying order is a task that must be carried out meticulously and exhaustively at all levels, beginning at the molecular level—a task as detailed and vast as genome sequencing has been, and as proteomics and functional genomics currently are—with the purpose of identifying system viability. For all these systems, there exists a minimum threshold of organization that allows them to continue being what they are: an existence threshold that can be measured and quantified. Of course, the sheer volume of information required to achieve this makes it impossible to collect and use it effectively without the support of artificial intelligence. This, in itself, is an example of negentropic strategies in their process of expansion and must be acknowledged: the effect of technology and culture and their role as emergent elements, as unexpected qualities, in which order is capable of generating more order as part of the expression of the vital phenomenon.

This same framework will allow medical practice to be reoriented by using the entropy levels of bodily systems as a measure for evaluating health and disease, and by more firmly embracing the human aspiration to halt or reverse the seemingly inexorable "arrow of time."

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