Nonequilibrium thermodynamic stability: the apparent teleology of living beings

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Abstract

Among physical systems, living beings are usually thought of as the only genuinely teleological natural systems. In this paper, I argue that the alleged teleology of living beings is not a real property but only an appearance, behind which what really exists is a complex version of stability. The complexity of living beings as stable systems has to do mainly, though not exclusively, so I argue, with the fact that living beings are dissipative structures which obey the thermodynamic principle of maximum entropy production.

Living beings: stability or teleology?

Living beings remain alive to the extent that a set of metabolic or physiological variables (usually called critical or essential variables) maintain their values within certain specific ranges (called physiological or metabolic ranges) (Ashby, 1960). Living beings' ability to maintain, in spite of disturbances, their physiological or metabolic condition within these ranges is what is usually known as homeostasis. Living beings' homeostasis is a particular version of stability, which is a relatively common property among physical systems.

All stable systems, when disturbed, generate to greater or lesser degree a characteristic behavioral pattern that appears to be teleological (Ashby, 1960). They exhibit a typically convergent behavioral pattern; i.e., no matter which way they are displaced from their steady state (the variability of the disturbances), they always return to the same steady state. A pendulum, for example, regardless of the angle of the displacement, will always return to the same state of equilibrium (the resting position). It is the combination of variability (by the side of the behavior) with invariance (by the side of the steady state), that gives the idea of 'flexibility' in the system. The system, somehow, seems to have a fixed goal around which it is able to vary and 'accommodate' its behavior according to the different circumstances. However, the system, e.g., the pendulum, does not really move according to goals or purposes; it just follows physical laws.

Living beings, as highly complex stable systems, are not the exception to this rule but rather the most representative and strongest case (Villalobos, 2015). When dealing with pendulums, most of us do not find a teleological explanation terribly attractive, as simple physical variables are enough to explain their behavior. When dealing with living systems, however, the situation seems to change. Why is this so? Why are we so prone to attribute some kind of teleology to living beings?

One might say that we humans simply tend to project features of our subjective experience to entities which are close to our genus, and that living beings, without any doubt, are closer to us than pendulums. But that comment, even if true, does not explain the apparent teleology of living beings *as a function of living beings themselves*; it just expresses, at most, a human bias. What I want to do here, instead, is to explain the teleological appearance of living beings taking as *explanans* the very constitution and functioning of living beings themselves. The question is "What is peculiar about living beings, i.e., their constitution and functioning, such that their behavior appears to be teleological?" The answer, I argue, has to do with the complexity of living beings as stable systems.

The relative simplicity or complexity of a stable system has to do, mainly, though not exclusively, with the following factors: a) its dimensionality (the number of variables in which the system exhibits stability), b) its thermodynamic regime, c) the presence or absence of feedback mechanisms, and d) its order of stability (e.g., first-order stability, second-order stability). Living beings have high dimensionality, exist in far-from-thermodynamic equilibrium conditions (i.e., they are dissipative structures), have feedback mechanisms, and (at least in the case of animals) exhibit second-order stability (i.e., they are ultrastable systems). All these factors, I argue, enrich or complicate the way in which living beings generate their behavior as stable systems, but do not introduce any ontological exceptionality in terms of teleology. That is, although much more complex, living beings remain as purposeless as pendulums.

In previous works, I have addressed all the aforementioned factors in some detail (Villalobos 2015; Abramova and Villalobos, 2015). Here I will focus only on the thermodynamic nature of living beings. The thermodynamic nature of living beings and its connection with teleology has been addressed by ecological theorists of perception, especially in the line of what they call "physical intelligence" (Turvey and Carello, 2012; Kondepudi, 2012; Shaw and Kinsella-Shaw, 2012). Typically, these theorists see thermodynamics as a scientific ground to naturalize teleology.

My interpretation takes a different path. I argue that thermodynamics, instead of giving us a scientific base to naturalize teleology, provides us with good reasons to eliminate it from biology.

Nonequilibrium thermodynamic stability

From a thermodynamic point of view, living beings belong to a special group of physicochemical systems called dissipative structures (Prigogine and Stengers, 1984). Examples of these structures include Benard cells, flames, hurricanes, and whirlpools (Ji, 2012; Ulanowicz and Hannon, 1987). The peculiarity of these systems, as opposed to the so called equilibrium structures (or near-equilibrium structures), is that they are constituted in far-from-thermodynamic equilibrium conditions, and maintain integrity through the constant exchange of energy (and matter in the case of open systems) with the environment. In other words, they disintegrate if this exchange is cut off. Living beings, like any other dissipative structure, are systems whose region of physicochemical stability is far-from-thermodynamic equilibrium. This means that, when disturbed, they move *not to equilibrium* but to the specific far-from-equilibrium region in which they conserve integrity.

Every dissipative structure, at different scales, exhibits the same behavioral pattern of stability. If we disturb a candle flame in different ways (without being destructive, of course), we see how the flame reconstitutes as such. The same occurs with a maelstrom in the sea; it recovers its dynamics and conserves its integrity. Once a nonequilibrium steady state stabilizes as such, it is able to exhibit a considerable degree of stability (Kondepudi, 2012). Sure, the stability that a physical volume X can reach in far-from-equilibrium conditions is weaker than the stability that it may reach in equilibrium conditions (sooner or later, hurricanes disintegrate and living beings die), yet it is still a quite robust stability. As in any case of stability, dissipative structures seem to 'insist,' despite disturbances, in retaining their organization, and so are susceptible to teleological descriptions. But why do dissipative structures exhibit stability?

According to a relatively established hypothesis in thermodynamics, dissipative structures, living or not, originate, exist, behave and evolve following what is known as the 'maximum entropy production principle' (MEPP) (Kondepudi, 2012; Martyushev and Seleznev, 2006; Michaelian, 2011; Swenson, 2009; Swenson and Turvey, 1991). MEPP, roughly, states that given a thermodynamic gradient through a system, structured subsystems tend to organize and behave so as to maximize the production of entropy (Martyushev and Seleznev, 2006; Swenson, 2009). This phenomenon, in England's view (2015), can be interpreted as an instance of 'dissipative adaptation,' and understood as a general condition of nonequilibrium spontaneously organized systems. According to this hypothesis, dissipative structures, living or not, would exhibit stability as a result of MEPP (Kondepudi, 2012).

Although this hypothesis is still in need of more substantive empirical support, it is theoretically consistent with the general laws of thermodynamics (Martyushev and Seleznev, 2006). If correct, the idea that MEPP is behind the behavior of every dissipative structure would explain away, rather than retain, the teleological conception of living beings (or so I want to hold in the next and final section).

Discussion

Living beings face a continuous flow of disturbances, both internal and external, and their behavior as dissipative structures is a constant return to the far-from-equilibrium condition where they exist. We see them constantly renewing the exchange of energy and matter with the environment, and tend to interpret this behavior as indicative of purposes or intrinsic teleology. However, as some studies have recently showed, 'energy-seeking' and adaptive behavior can equally appear in inert simple dissipative structures such as voltage-driven conducting beads in a viscous medium (Kondepudi, Kay and Dixon, 2015). The same thermodynamic principle, namely MEPP, applies to both nonliving and living dissipative structures and seems to account for what we take to be purposeful behaviors. These systems' behavior, however, according to the argument presented here, represents just a different version, namely a nonequilibrium version, of a fundamental and ordinary physical phenomenon; stability. From pendulums to beads, from flames to living beings there seems to be a considerable and undeniable distance. Yet the distance, significant as it may be, seems to be a matter of (thermodynamic) degree, and not a matter of teleology.

Acknowledgments. This work was partially supported by Performance Agreement UTA-MINEDUC.

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