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The S-Lagrangian and a theory of homeostasis in living systems

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HIGHLIGHTS

- Dynamic theory of homeostasis based on a generalized Lagrangian approach (S-Lagrangian).
- A living organism, capable of "feeling distress" should exhibit homeostasis.
- The approach can also be extended to social systems.

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ABSTRACT

A major paradox of living things is their ability to actively counteract degradation in a continuously changing environment or being injured through homeostatic protection. In this study, we propose a dynamic theory of homeostasis based on a generalized Lagrangian approach (*S-Lagrangian*), which can be equally applied to physical and nonphysical systems. Following discoverer of homeostasis Cannon (1935), we assume that homeostasis results from tendency of the organisms to decrease of the stress and avoid of death. We show that the universality of homeostasis is a consequence of analytical properties of the *S-Lagrangian*, while peculiarities of the biochemical and physiological mechanisms of homeostasis determine phenomenological parameters of the *S-Lagrangian*. Additionally, we reveal that plausible assumptions about *S-Lagrangian* features lead to good agreement between theoretical descriptions and observed homeostatic behavior. Here, we have focused on homeostasis of living systems, however, the proposed theory is also capable of being extended to social systems.

Introduction

A primary difference between living creatures and non-living things is the capacity for reproduction. However, if one considers only individual life rather than the existence of species, the major paradox is that living things actively counteract degradation in a continuously changing environment or being injured through homeostatic protection. By homeostasis, we refer to the ability of living organisms to maintain viability and stability of physiological functions in a changing external environment. The system remains alive as a consequence of homeostasis maintaining system integrity in the presence of perturbing influences. Cessation of homeostasis leads to inevitable death. In living systems, the relationship between cause and effect is paradoxical: organisms are characterized by poorly predictable motility, which is supposedly managed by their internal motives. Homeostatic motivation transforms an object into a subject by virtue of its own behavior. Thus,

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the mystery of arbitrary actions may be disclosed by exploring homeostasis [1]. It should be noted that homeostasis may evidently produce both maintenance of life and the will to act [2].

Although homeostasis is present in all living systems and relates to large numbers of different biochemical and physiological mechanisms, it reveals amazingly similar features and behavior. Such universality is not unique in the physical world. For example, physical systems, from crystals to large biomolecules, demonstrate universal behavior near critical points in spite of considerable differences in its structures and intermolecular interactions. This occurs due to the critical behavior of the systems being determined by the analytical properties of free energy near critical points, while the peculiarities of system structure and intermolecular interactions are "hidden" within the phenomenological parameters of the free energy.

We assume that the universality of homeostasis is a consequence of the analytical properties of the *S-Lagrangian*, which determines the dynamic equation associated with homeostasis, while peculiarities of the biochemical and physiological mechanisms determine phenomenological parameters of the Lagrangian. We show in Section 2 that plausible assumptions about *S-Lagrangian* properties lead to good agreement between theoretical descriptions and observed homeostatic features.

1. Biological background

1.1. Homeostasis levels

Living beings actively oppose their degradation in continuously changing environments by means of homeostasis [3] that supports the intrinsic bodily constants within acceptable limits. Maintenance of individual life requires evaluating and regulating its inner state. Homeostatic regularities can be traced to the level of particular cellular parameters, cells, in general, physiological systems of an organism, and an organism as a whole. In this study, we primarily focus on homeostasis of neurons and the nervous system. A cell, as a body, manifests complete homeostasis. This occurs not only to maintain biological constants, but also to regulate physiological functions and motivational behavior. The behaving animal is sensitive to single neuronal spikes and even to their temporal patterning [4]. Moreover, a neuronal spike can serve as a tool of reaction for the whole animal [1]. Individual neurons act in concert to govern behavior [5].

At first glance, homeostatic mechanisms are not complicated. In theoretical research, the problem is often evaluated by the introduction of positive- and negative-feedback loops between the sensor and the metabolic flaw (e.g., [6,7]). Attempts to model homeostatic regulation consider only simple homeostasis, with regulation of each variable described by the introduction of specific individual controllers. However, when homeostatic protection begins to work against a permanent environmental factor or severe injure, these mechanisms become ineffective and living systems utilize indirect paths to assign optimal parameters, depending on the situation.

Homeostatic function depends on sensors, which register deviations from the norm. Fig. 1 illustrates the role of homeostasis in the generation of goals and actions. Sensors of cellular state track the difference between the normal and current state (determining the regulatory goal) and send discrepancies to the homeostatic unit. Appearance of a metabolic flaw triggers the homeostatic device to compensate for the shortage. However, homeostatic resources may not be sufficient to restore disturbed functions. In these cases, living systems may try to change the environment, requiring the environment to be included in the interaction.[1]

The status of the internal environment is not sustainable for all life. Conditions remains stable only at intervals of time as compared to environmental variability. At these intervals, homeostasis counteracts weak disorders in the system and recovers initial conditions (*direct regulation*). Over time, adapting to strong external influences enables life to modify its parameters (*indirect regulation*). If the value of a deviated parameter is not restored, the organism may be able to maintain it by restructuring the optimum of other parameters. For example, stabilization of neuronal activity can be achieved by configuring both synapse efficiency and excitability [8]. Homeostasis readjusts to save some supreme quality criterion that distinguishes the living from the nonliving. The living entity keeps track of a special criterion the degree of remoteness from its destruction. This criterion determines the intensity of homeostatic protection. However, damage may reach such an extent that homeostasis is unable to overcome the irreversible destruction of the living system.

The nature of the general sensor for damage–recovery viability is unclear, though there are options that are significant to the survival of cells and the whole organism. These include energy (ATP level), excitability, intracellular pH levels, and concentration of certain proteins (caspases, cytokines, or antioxidants). These cannot be disregarded by the highest sensors, which could lead to death. For example, a supreme neuronal sensor might be excitability [1]. The action potential represents an electrostatic disturbance of homeostasis that is the necessary first step in the processes of "sentience", which includes detection by an excitable cell of physicochemical danger [9].

1.2. Protection generates action

The artificial incongruity of homeostasis leads to injury, causes increased activity, and leads to the aggravation of damage. Usually, the reaction of nerve tissue is proportional to the incoming excitation. On the other hand, superfluous excitation and

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[1] We do not consider this complicated form of homeostasis in this study, however, our approach is extendable to this case, as well.