Filozofia Nauki, ISSN 1230-6894
Rok XXIV, 2016, Nr 4(96), s. 5-25

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AUTONOMY AND CONTROL
DYNAMICS OF DEGREES OF FREEDOM IN LIVING SYSTEMS

Abstract

According to the organizational view, the autonomy of a living system should be approached from the perspective of processes that contribute to generating and constantly maintaining the internal organization of the living system, as well as to preserving the structural relation between the organism and its environment. However, a living system is both a biological organism and a certain type of complex system. Starting from this perspective, I will define the autonomy of a living system as the totality of the states it can access as response to the challenges of the environment, meaning the totality of the system's degrees of freedom. However, understanding the autonomy of a living system also depends on the account of the controlling mechanisms, which contribute to generating and managing its degrees of freedom. In the case of basic living organisms, one can talk of an adaptive control involving the regulation of the internal processes in order to create a coherent pattern of action that would adjust the internal and external behavior of the organism to the environmental conditions. Regulation of the internal processes and the exchange of matter and energy with the environment determine the emergence of an incipient form of self, which is a consequence of existing correlations among the basic adaptive functions of any biological system. The nervous system provides the organism with an advanced form of control, which implies a flexible and multidimensional state space, whose level of complexity is higher than the one configured by the metabolic reactions. In this case, a sensorimotor self emerges, which is the result of integration of the body and environment into a systemic whole. Moreover, in advanced organisms, such as humans, a new metacognitive level emerges, i.e. consciousness. Consciousness not only enhances the state space of an organism but also creates complex patterns of behavior with new and unpredictable trajectories, which entails multiple and complex degrees of freedom. Consciousness is at the origin of the emergence of a conscious self, which is capable of conscious selection of the constraints that would modulate its behavioral patterns.

Keywords: autonomy, control, degrees of freedom, dynamical system, organizational view, self

According to the current accounts of biological autonomy (De Jaegher, Di Paolo 2007, Di Paolo, Iizuka 2008, Barandiaran, Di Paolo, Rohde 2009,

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Ruiz-Mirazo, Moreno 2012, Moreno, Mossio 2015), an autonomous living system is a self-sustaining system whose identity and unity are the consequences of the dynamics of internal processes, considering the necessity of the organism to adapt to the fluctuations and constraints of environment. The autonomy of a biological system is related both to the internal organization of the system, which is the consequence of the dynamics of metabolic constitutive processes, and to the relations between the organism and its environment (Moreno, Mossio 2015: xxviii). From the point of view of internal organization, a living system is characterized by *organizational closure*, which means that the unity of the system is given by a set of recursive processes that produce and regenerate the components that contribute to the constitution of the processes themselves. This means that the system has the capacity to self-produce — *autopoiesis* (Maturana, Varela 1980) — and self-maintain. Moreover, the identity and unity of the system are consequences of the *homeostatic* character of the system, which implies maintaining its internal unity by preserving the relations between its parts, despite the external fluctuations and changes.

One important result of the autopoietic process is the emergence of a demarcation line between the organism and the external world, which delimits the internal space of the organism and preserves its internal processes. This *boundary*, which is endogenously constituted, facilitates energetic exchanges with the environment, whereby the organism gets the resources necessary to its functioning, as well as information about external changes. Hence, despite the closed character of the internal organization of the organism, any living system is an *open system*, which has energetic and informational exchanges with the environment in which it lives. This means that, on the one hand, the living system is characterized by *structural coupling* with the external world, meaning that the organism and the environment mutually influence each other, as they are in an interdependent relationship (Maturana, Varela 1980, Di Paolo 2005). On the other hand, from the perspective of energy exchanges with the environment, the organism is *far from equilibrium*, which means that it gets its energy from the external world, consuming it in order to maintain its internal organization.[1]

Thus, we can say that an autonomous living system is a metabolic organizational closed system which constitutes its identity and internal unity by

[1] Due to the flows of energetic exchanges with the environment, there is a risk of increasing the entropy of the system and of endangering the stability of the system. However, the internal constraints of the organism modulate the flow of energy, using it in order to regenerate the internal components of the organism and to maintain its internal organization (Ruiz-Mirazo, Moreno 2004: 241).

producing and constantly maintaining its internal processes and components, considering the fluctuations from environment. Furthermore, an autonomous living system is an open system, which has an ongoing exchange of information and energy with the environment to which it is constitutively coupled.

According to this theory, which approaches the constitution of a living system from the point of view of maintaining the unity of its organization (Bich 2012: 217, Moreno, Mossio 2015: vii), autonomy is understood in operational terms. Thus, the organizational view considers autonomy in the context of processes that contribute to generating and constantly maintaining the internal organization of a living system, as well as to preserving the structural relation between the organism and the environment. However, understanding an autonomous living system solely from the autopoietic perspective, i.e. in terms of self-constitutive biological processes, cannot be a universal criterion for understanding autonomy of any living system, irrespective of its degree of complexity. Such an approach disregards the fact that a living system is both a biological organism and a certain type of complex system. This means that its autonomy should also involve capabilities to respond and act, possessed by a dynamical system as a whole.

Consequently, the autonomy of a living system — even in its minimal form — cannot be reduced to the mere processes that give identity and unity to the system. From the point of view of dynamical systems theory, the constituent processes of the organisms have functions with various degrees of freedom, which facilitate its adaptation to the environment. In other words, the adaptive skills of the organism open a new space of action at the level of the whole, absent at the level of its independent parts, with greater possibilities for responding to external perturbations. Therefore, a holistic understanding of the autonomy of a living system implies an explanation from the perspective of the state space configured by the dynamics of its components and their degrees of freedom.[2] Thus, according to this approach, the autonomy of a living system is given by the totality of the states it can access as response to the challenges of the environment, meaning the totality of the system's degrees of freedom.

[2] In terms of the organizational approach, there is a double dynamics of components: an internal dynamics, of the internal organization of the organism, and an external one, of the relation between the organism as a whole and the world (Moreno, Mossio 2015). In terms of dynamical systems theory, this means that a living system is characterized by a double dynamics between the first circularity, a consequence of the organization of the parts by an order pattern, and the second circularity, which is the result of a regulatory loop between organism and environment (Tschacher, Haken 2007).

Hence, to complement the organizational approach, I will first define autonomy of a living system in terms of the degrees of freedom it has as a dynamical system undergoing various exogenous and endogenous constraints. Another aspect important for the autonomy of an organism is represented by its control mechanisms, which regulate the dynamics of internal relations among components and external ones between the organism and its environment. This issue will be addressed in the last two parts of the article, which discuss how living systems can control their degrees of freedom, taking into account the complexity of their organization, as biological organisms and dynamical systems with various degrees of freedom. Moreover, starting from the account of control mechanisms of living systems, I will also explain how they contribute to the emergence of subjectivity and a sense of self, experienced differently by living organisms depending on their level of organizational complexity.

1. ENABLING CONSTRAINTS AND EMERGENCE OF DEGREES OF FREEDOM

According to the organizational view, the self-maintenance of a living system, which is a fundamental requirement of biological autonomy, is a consequence of organizational closure (Mossio, Moreno 2010, Moreno, Mossio 2015). This is understood in terms of internal constraints of the organism, which form a causal web, creating a mutual dependence between its internal processes and components. Constraints are understood as playing a double role: on the one hand, they are approached as local causes, namely consequences of the biological functions of the system's components, which reduce the degrees of freedom of its elements, determining them to adopt a certain behavior. In this case, constraints are considered as limitative conditions, which, by introducing new variables, reduce the system's possibilities of action.

However, if constraints only had a limitative role, the system would have fewer alternatives than its parts (Juarrero 1999: 133). In other words, the sum of the degrees of freedom of the whole would be smaller than the sum of the degrees of freedom of its parts. Nevertheless, the degrees of freedom of the whole are not a simple addition of degrees of freedom of the parts, since the system as a whole has complex degrees of freedom which, independently, its parts do not have.

Therefore, on the other hand, the generative role of constraints is also acknowledged (Bich, Mossio 2011: 386, Moreno, Mossio 2015: 14), as they determine the emergence of new processes or behaviors within the system. According to the organizational view, the coexistence of the two roles played by constraints is not a problem, as it is merely a matter of different interpretation, determined by the time scale at which these outcomes are approached. Namely, across longer time scales, constraints can be considered to be limiting, while across shorter time scales these constraints can be enabling. Enabling constraints are those that cause, within the system, processes that determine the emergence of other constraints, which thus become dependent on the former ones (dependent constraints). As a result, a chain of constraints is generated, which, on the one hand, is in a mutual dependence, and, on the other hand, enables the emergence of the processes that are at the origin of dependent constraints, forming the closure of the organization.

From a dynamical system point of view, an explanation of the enabling role of constraints is given by Juarrero's theory, which defines constraints as "any event, mechanism, or condition that alters a system's probability space" (Juarrero 2015: 514). In this way, constraints are approached not only as restrictive conditions but also as their enabling powers — to extend the state space of the system — are recognized as well. Furthermore, Juarrero (1999, 2000) makes a distinction between context-free constraints and context-sensitive constraints. The former are imposed on the system from the outside, being limitative, as they determine the decrease of the degrees of freedom of the system, constraining it to remain in a certain state. The others are the result of the cohesion of the system's components, which determines the emergence of new properties, by enlarging the number of states the system can access.

The way context-dependent constraints act should be understood in light of Juarrero's distinction (1999, 2010) between constraints operating bottom-up (first-order contextual constrains) and those operating top-down (second-order contextual constraints). The former result from the coupling of the parts of the system, determining a higher-order degree of organization of the system, and so they enlarge the state space of the system by finding some new, alternative response. The latter are the result of causal powers exercised by the new whole on its parts, which enables a new dynamics of the components, compliant with the new order of the system. To put it differently, context-dependent constraints determine the emergence of some new degrees of freedom, greater than that of the system's components. This is possible due to the dynamics of circularity between enhancement of degrees of freedom, as a consequence of enlarging the state space of the system and decreasing the degrees of freedom of the components, by including them in more complex structures with larger possibilities to respond than those of the parts.[3]

Starting from the organizational view and Juarrero's theory, we can say that, from the perspective of the emerging whole, the enabling character of constraints has a double description: on the one hand, it comes from the new regime of organizational closure of the organism, which determines new correlations among its parts and, thus, emergence of some new properties of the system (Moreno, Mossio 2015: 61). In other words, constraints enable the emergence of new dimensions of the state space of living system and, in this way, of new degrees of freedom. From this perspective, constraints can be considered endogenous and exogenous parameters of the system which influence its variables, determining them to describe new trajectories in the state space of the system.

On the other hand, due to the enabling character of constraints, a new configuration of the state space of the system results. This state is a consequence of all the parameters acting on the system at a given moment, which limit its degrees of freedom. In this way, those degrees of freedom that characterize the system at a certain moment will be selected. In other words, the state of the system is a consequence of a higher-order configuration of the parts into a systemic whole — considering the responses it can give to the fluctuations of environment — which represents the system's degrees of freedom at a certain moment.

From this double dynamics of the enabling character of constraints — between enlarging the state space of the system, and selecting the appropriate degrees of freedom — the autonomy of the organism emerges, understood as a dynamical system with multiple and various degrees of freedom.

2. DEGREES OF FREEDOM IN LIVING SYSTEMS

The emergence of closure implies the realization of a hierarchy of constraints, whose complexity is given by the internal organization of the organism. From the perspective of the internal organizational dynamics, organisms are multi-layered structures, whose coordination determines the state space of the system to enlarge, thus creating a multidimensional state space. This process enables the emergence of some new behavioral patterns, with a large basin of attraction and trajectories that are more and more unpredictable.

[3] In other words, enabling constraints determine the system, by decreasing its degrees of freedom, to follow new trajectories, inaccessible when they are absent (Hooker 2013: 761).

These patterns are those that include the degrees of freedom of the components in more complex structures, which give the degrees of freedom of the system at a given time. Thus, the components, together with their degrees of freedom, are configured in a functional whole, which can give a more adequate response to external challenges. From this perspective, the degrees of freedom of a living system represent the totality of states that can be accessed by the system as a result of the system's capacity to organize the internal variables of the organism in various behavioral patterns.

The number and complexity of behavioral patterns (attractors) instantiated by the living system is an indicator of its degree of autonomy. Systems with simple organization have a low number of behavioral patterns. Due to their constituent structures being unable to coordinate a large number of variables, they instantiate low dimensionality patterns, which have simple degrees of freedom. Living systems with advanced biological structures, which can coordinate a large number of variables, create complex patterns with higher-order degrees of freedom, whose number, depending on their complexity, is undetermined. Thus, autonomy of a living system, understood in terms of degrees of freedom, is determined by the number and complexity of the patterns that can emerge in the state space of the system.

From the biological point of view, the degrees of freedom of the organism are the consequence of its abilities (such as the nervous system, consciousness), which unite and coordinate the degrees of freedom of the components, endowing the organism with behavioral flexibility.[4] Thus, the internal organization of a living system involves a hierarchy of the degrees of freedom of the organism, as new degrees of freedom emerge, due to the biological complexity of the organism. This means that the microphysical degrees of freedom corresponding to the chemical processes and physical components of the system are transformed into metabolic degrees of freedom, sensorimotor degrees of freedom or higher-order cognitive degrees of freedom.[5] Each of these

[4] A nervous system enables better coordination of the degrees of freedom of the body, increasing the overall degrees of freedom of the organism by identifying new possibilities to act in the environment. Consciousness provides the possibility to control the degrees of freedom of the organism, by consciously monitoring them, and their enhancement, by including them in larger plans.

[5] According to Pattee (1976: 158-159), the degrees of freedom of a system are classified depending on the constraints affecting the system. For such a classification not to be too elaborate, bearing in mind the multitude of variables characterizing complex systems, the biological complexity of the organism can be used as a criterion. Thus, we will speak of metabolic degrees of freedom (characteristic of simple organisms, with single-cell organization), sensorimotor degrees of freedom (in the case of organisms endowed with a nervous system), and higher-order cognitive degrees of freedom (in the case of organisms en-

types of degrees of freedom has its own complexity, accessing new ways of response to the challenges of the environment.

However, considering the development in time of an organism, one can say that the degrees of freedom of the organism are potentialities, depending on the level of its biological development. This means that the degrees of freedom of an organism are its constitutive parts ever since birth. They are not acquired, being a consequence of the biological structures of organism developing as the organism grows. As such, the degrees of freedom of the organism expand with the development of the organism throughout its lifespan.

The result is that, on my interpretation from the dynamical system point of view, a living system can be seen as a self-organized system which produces and maintains its own degrees of freedom in order to preserve its autonomy. The degrees of freedom of an organism are not fixed like those of a physical system (Pattee 1973: 44), whose degrees of freedom are given by the way it was designed. A living system has potential degrees of freedom, which may or may not be achieved, depending on the external circumstances, by the functioning of its internal mechanisms and by finding the internal and external resources to reach its maximum degree of autonomy. This means that the degree of autonomy of an organism at a certain time is variable, and depends on the internal and external constraints to which it is exposed and on how it controls such constraints.

Consequently, the autonomy of a living system is given by the totality of degrees of freedom a system has and controls. On the one hand, their number and complexity is given by the dynamics of the levels of biological organization of the system. On the other hand, the autonomy of the system is also given by the way it manages to control its degrees of freedom, taking into account the control mechanisms of its internal processes and its relations to the external world. Therefore, autonomy of a living system involves understanding its control structures, which govern its actions and from which the subjectivity of the organism results.

3. BASIC MECHANISMS OF CONTROL AND DEGREES OF FREEDOM

From the perspective of the internal organization of a living system, characterized by organizational closure, control is a consequence of internal con-

dowed with consciousness). Even if such a classification merely outlines the biological field, its goal is to distinguish among various degrees of autonomy with which biological organisms are endowed.

straints of the organism. In terms of the theory of constraints, control implies that, owing to the system's self-organization, one of the constraints should select from the possible trajectories the path the system is to follow at a certain moment in time (Pattee 1973: 42). In this way, the overall degrees of freedom of the system are reduced by selecting those degrees of freedom that are to define the state of the system at that moment. This role is played by various internal factors of the organism, such as the DNA, in the case of basic biological organisms, or mental representation, in the case of organisms with cognitive skills, which "steer" the organism in a certain direction (Keijzer 2003: 245). This means that the organism is guided by its intrinsic factors, which, depending on how they influence the system and on the emerging behavioral patterns, provide the autonomy and self-determination of the system.

An important contribution to this process is made by the complexity of biological structures of the organism which enable new degrees of freedom to be accessed. These structures are organized in a hierarchy endowed with increasingly advanced control mechanisms, which provide new ways to constrain their components and thus to access more complex degrees of freedom (Pattee 1976: 153-154). One can speak of *weak* control, such as homeostasis, regulation, or modulation, which entail managing the degrees of freedom of the organism, or *strong* control, which implies conscious control of actions and an increase of the degrees of freedom of the living system.

From the point of view of dynamical systems, constraints are control parameters of the system (Van Orden, Kloos, Wallot 2011: 632) which restrain the degrees of freedom of the system's components, determining the emergence of a highly-organized new structure. This new structure, emergent at a macroscopic level, plays the role of an order parameter or a collective variable which determines its parts to behave in a certain way. By means of control parameters, an order parameter selects the relevant degrees of freedom modulating the dynamics of the system at a given time.[6] According to this description, when control parameters reach critical states, they can determine the system's behavior to change. If this happens, the system undergoes a phase transition, which means the reorganization of the system and the takeover of its control by other constraints. This determines the behavioral patterns — attractors — to change from within the system (Kelso 1997: 54),

[6] From this perspective, Keijzer (2003: 246) assumes that biological systems have the ability to manipulate their control parameters and thus to form order parameters which would conduct their actions. On this approach, genes are the control parameters of the organism which influence the way the living systems develops and, implicitly, its degrees of development.

and the organism to act according to some other degrees of freedom, appropriate to its new organization.

In the case of basic autopoietic systems, the basic control form is homeostasis, which implies that processes and internal variables of the system are maintained in order to preserve the organization and autonomy of the system. This process is achieved, on the one hand, by constantly maintaining the relations among the internal variables of the organism and, on the other hand, by constantly maintaining the exchanges with the external world. Homeostasis is a form of weak control, which consists of maintaining the endogenous and exogenous patterns of the organism in order to maintain the internal and external equilibrium of the organism. To put it differently, homeostasis is not a form of strong control, which would imply enhancing the degrees of freedom of the system. However, it is a basic form of control, to the extent that it manages the existing degrees of freedom of the system so as not to endanger its stability and existence.

The complexity of the degrees of freedom of the organism depends on the organism's control mechanisms, which are the consequence of its organizational complexity. Thus, in the case of basic organisms, such as single-cell ones, control is carried out in two ways: on the one hand, as control of the organism's interaction with the external world, which is called boundary control, and, on the other hand, as control of internal changes. Boundary control is carried out by the membrane, as an organ that delimits the organism from the environment, facilitating the communication between them. The membrane is a structure that is sensitive to environmental changes, providing the organism with information about external modifications. However, it is also sensitive to internal needs, enabling chemical and energetic exchanges with the environment in order to maintain the integrity of the system. Thus, by transmitting information to the internal environment of the cell, the membrane constrains the single-cell organism to be in a certain state (Mossio, Saborido, Moreno 2009: 827, Ruiz-Mirazo, Moreno 2004) and to select from its potential degrees of freedom those that will be achieved.

At the same time, the membrane constitutes the topological domain of the cell, its own space of action, securing its physical unity. By circumscribing the internal space of the cell, the membrane constitutes its phase space (Bich 2015), within which the organism configures its possibilities for action and, hence, its degrees of freedom. Consequently, the membrane does not enhance the degrees of freedom of the organism by means of an advanced coupling with the environment. This would imply the discovery of some new possibilities of action of the organism in the environment, or even its transformation according to the intentions of the organism. The membrane merely provides a form of basic coupling, which is carried out in order for the organism to adapt and survive. This means that such organisms have simple degrees of freedom, given only by the internal responses to the challenges and changes from the environment.

Besides the control exercised by the membrane, as an organ that sets the boundaries between the internal environment of an organism and the external one, one can also speak of internal control, as a consequence of the organism's metabolism. Internal control does not imply the existence of an organ or centralized structures which would conduct the entire activity of the organism. Internal control is a consequence of the various mutually interdependent organic processes, which together carry out adaptation to the changes in the environment and maintenance of the internal organization of the organism.[7]

In either of its forms, control is carried out in order to adapt the organism to the environmental changes. Therefore, we can generally say that basic living organisms have an adaptive control (Mossio, Moreno 2010: 285), which implies the internal control of the metabolic paths, in order to provide appropriate responses to external disturbances. In other words, adaptive control is a form of control that involves the regulation of internal processes so as to create a coherent pattern of action that would adjust the internal and external behavior of the organism to the environmental conditions.

From the organizational perspective (Moreno, Mossio 2015: 34), regulation is the consequence of second-order constraints, which are the result of the organizational closure of the organism and the cohesion of its parts. The role of regulatory constraints is to stabilize the organism, considering the internal disturbances, and to maintain its unity and identity.[8] Furthermore, regulation is considered to be the consequence of some subsystems which are the result of the organism's organization and act recursively on the constitutive regime to provide an appropriate response to the challenges of the environment (Bich, Mossio, Ruiz-Mirazo, Moreno 2016). On this interpretation, regulation is a consequence of the circular organization existing in the or-

[7] In other words, in terms of biological systems, we do not speak of a hierarchical way to exercise control, which would entail a centralized structure that would conduct the other sub-assemblies of the system. Similarly, we cannot speak of a hierarchy of sub-modules, each one with a specific function (Bich, Arnellos 2012: 100). Living systems are characterized by a variety of types of control (thermodynamic, chemical, etc.), and none of them plays the main executive role, but each of them spontaneously adapts the organism to the environment.

[8] Regulatory constraints are considered higher-order constraints which act among the different levels of the organism (Bich 2015). To put it differently, their causal powers act on the subsystems of the organism, determining the organism's internal configuration at a given time and its predisposition to a certain response.

ganism, which is the result of the network of interdependent constraints in the organism (Bich, Mossio, Ruiz-Mirazo, Moreno 2016).

To put it differently, regulation is the consequence of the circular causality in the organism, meaning the result of the constitutive dynamic relations between parts and the whole.[9] In this double dynamics, the components are those which determine the emergence of an order pattern, which in turn determines a new configuration of the components. From a different angle, control parameters push the system to a certain state, determining the order parameter to impose a certain organization on the system. The regulative control is, therefore, exercised by the dynamics between the order parameter and control parameters, which provide the system with a certain kind of stability at a given time.

One effect of regulation is the re-organization of the internal state space of the system by the emergence of a higher-order pattern which enables new degrees of freedom of the system. In other words, subsystems that contribute to regulating the organism imply a dynamic decoupling from the constitutive regime, which has as its consequence the emergence of some new variables that would not be dependent on the constitutive regime, and thus the emergence of new degrees of freedom (Bich, Mossio, Ruiz-Mirazo, Moreno 2016). Consequently, regulation, as a basic form of control of organisms, involves the emergence of some new levels of complexity within the living systems, which has as an effect the emergence of new degrees of freedom, beyond the basic level of the physical and chemical processes. However, given the structural complexity of such organisms, the degrees of freedom resulting from the regulation of metabolic processes have a low degree of complexity.

Regulation of the internal processes and the exchanges of matter and energy with the environment determine the emergence of an incipient form of self. On the one hand, this form of self is the result of the recursive patterns which maintain the existence of any living system, namely of the emergent coherence of the operational closure (Varela 1997: 73, Thomson 2007: 260). Together, these behavioral patterns, maintained due to the homeostatic character of the organism, achieve its operational identity, which is the most basic form of identity. In other words, this self is a consequence of the internal self-referential organization of the system, which gives the system an identity in time (Varela 1997: 76).

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[9] The relation of circularity as a fundamental trait underlying the functioning of the living systems can be exemplified by the relation between the genetic mechanism, which controls the metabolic system, which in turn contributes to the maintenance and replication of the genetic material of the organism (Moreno, Ruiz-Mirazo, Barandiaran 2011: 324).

On the other hand, self is the result of the unity of the organism, which is the capacity of the organism to preserve its internal processes despite the external perturbation (Varela 1997: 76). Unity gives the organism the possibility to respond as a whole to external challenges. This can be explained by the process of resistance to variance (Rudrauf, Damasio 2006: 438), which is the inertia of any living organism (not only of those with advanced cognitive skills) confronted with changes, manifested in the tendency to maintain its internal equilibrium and processes. This process of resistance to variance entails the coordination of the control structures of the organism, which would provide a response of the organism as a whole to the ongoing perturbations of the environment.

As a result, a form of self, in its most minimal form, emerges from the regulatory mechanisms and processes of the organism. This metabolic self (Deacon 2011) or biological self (Thomson 2007: 260) is not a centralized structure involving higher-order cognitive skills, but is a consequence of existing correlations among the basic adaptive functions of any biological system. Moreover, this basic form of self, the result of the regulatory processes of the organism, is a consequence of the integration of the degrees of freedom of the organism's components in a unitary whole with new degrees of freedom, which together represent the degree of autonomy of the system.

To conclude, organisms with simple organization, such as single-cell organisms, have basic behavioral patterns that cannot have complex degrees of freedom. This is due to the fact that, on the one hand, such organisms are not endowed with a boundary that may afford an advanced coupling of the organism with the world and thus would institute a fully symmetrical relation between the organism and the world. On the other hand, this is because the internal control mechanisms only regulate the degrees of freedom of the internal components and processes, merely providing a basic enhancing of the overall degrees of freedom of the system. Without a higher-order biological control structure (such as a nervous system), which would join the degrees of freedom of the components in complex structures, there is no possibility for higher-order degrees of freedom to emerge. As a result, simple organisms have a minimal autonomy, characterized by behavioral patterns with simple degrees of freedom and limited options to respond to environmental perturbation.

4. CONTROLLING MECHANISMS AND DEGREES OF FREEDOM IN COMPLEX MULTICELLULAR ORGANISMS

The emergence of degrees of freedom with a higher-order complexity is the consequence of the biological complexity of a living system, which involves the emergence of some new organizational levels that introduce new constraints into the system. Thus, in multicellular organisms, besides external physical constraints and internal ones which are the consequence of metabolic processes, higher-order sensorimotor or cognitive constraints also emerge as a result of the development of new levels in the evolution of organisms. Configuration of these new levels determines the emergence of increasingly varying and unpredictable behavioral patterns that are not conditioned by the basic constraints of the organism. The advanced control mechanisms of organisms, such as the nervous system or consciousness, contribute to the emergence of these behavioral patterns, with new and increasingly complex degrees of freedom, which enables higher-order cohesion of the variables of the system.

Hence, the consequence of the enhancement of biological complexity is the increase of the degrees of freedom, together with the enhanced complexity of the control mechanisms that manage these degrees of freedom. Thus, living organisms exhibit more and more developed forms of control, such as behavioral control, cognitive control, etc., which enable the decoupling of the organism from the basic level of metabolic reactions. Furthermore, the control mechanisms of multicellular organisms determine the emergence of some types of self, such as the sensorimotor self or conscious self, which, depending on the degree of complexity of the organism, manifest as increasingly centralized and integrative structures of actions.

Consequently, each level of complexity of biological organisms has different dynamics, given by the control mechanisms of the organism. Together, these levels, each with its own dynamics, make up the degree of organization of the system, which determines the emergence of new ways to act and respond to the challenges of the environment. From the perspective of evolution, a higher-order level of control than that of organisms with simple organization, e.g. single-cells, is that of a living system with a nervous system. A nervous system is considered to be a new informational level, different from the metabolic one, which enables both a higher circulation of information among the components of the system and a better exchange of information between the organism and the world (Barandiaran, Moreno 2008: 337, Moreno, Mossio 2015: 175). In other words, the system enables the enhancement of the degrees of freedom of the organism in two ways: on the one hand, by means of a higher-order coupling of the organism with the world, whereby the organisms are no longer in a causal coupling relation with the environment, but the living systems and the world are correlated systemically. This means that the relation of the biological organisms to the world is no longer given just by direct responses to challenges of the environment or by the adjustment of the internal processes to the external variations. This relation, however, implies the coordination of organism behavior according to the affordances that are perceived directly in the environment, without the need for some higher-order cognitive skills.[10] Thus, between an organism and its environment, one can no longer speak of a simple cyclic loop whereby the organism regulates its behavior depending on the information received from the external world. However, this loop becomes more complex as the organism perceives new possibilities of action in the environment, and so new parameters are detected by the system. In this way, the living system has more options of response, which means more degrees of freedom and an increased degree of autonomy.

On the other hand, approached from the perspective of its internal dynamics, a nervous system generates a new biological level that, although supported by the metabolic one, is decoupled from it by the dynamics of the connections between neurons, which create recursive patterns governed by their own laws (Moreno, Etxeberria 2005: 171). The nervous system creates connections between sensory organs and action skills of the organism, forming sensorimotor patterns, which determine the increase of the ability to coordinate the parts of the system and its response abilities. Instead of metabolic reactions, the regulation of the system is achieved by the sensorimotor pattern network, which provides a higher organization to the organism.

A nervous system is a dynamical system with its own autonomy, which can generate and coordinate a variety of states of the system (Moreno, Mossio 2015: 175). As a dynamical system, the nervous system configures a multidimensional state space of the system, with multiple degrees of freedom (Barandiaran, Moreno 2008: 340), different from the state space configured by the metabolic reactions, which contains a limited number of states. The dynamics of the nervous system determines an increase of the degrees of freedom of the living system by bifurcation of the patterns which provide the possibility to configure more ways of actions. The patterns of actions thus formed in the multidimensional state space of the nervous system have more

[10] Affordances are properties of the coupling between organism and the world (Marcilly et al. 2006), which result from the dynamics of the relation between organism and the environment.

complex degrees of freedom than those of metabolic reactions, by including more variables of the organism–environment coupling. However, they are limited to the internal and external pressures of the organism, as they only represent responses to the variations of the environment or to the internal need. In other words, they are only patterns of action with a predictable and determined trajectory.

The emergence of a network of sensorimotor patterns, which coordinate the relation of the organism with the world, has as a consequence a modification of the biological self of the living system. Instead of the diffuse metabolic self that is at the origin of an incipient subjectivity, an extended self emerges, which acquires awareness of the external world and of its own body when it exerts its skills. This sensorimotor self (Thompson 2007: 49), which is the consequence of the new patterns of action of the system with multiple degrees of freedom, is a result of the integration, due to the nervous system, of the body and its environment into a systemic whole.

To conclude, the nervous system has the ability not only to maintain the degrees of freedom of the system but also to coordinate and enhance them, depending on the circumstances of the environment. The nervous system as a dynamical system implies a flexible and multidimensional state space, whose level of complexity is higher than the one configured by the metabolic reactions. The consequence of correlating the variables of the system by the nervous system, by means of sensorimotor loops, is the emergence of patterns of actions with multiple variables. However, these are dependent on the biological needs of the organism, due to the connection with the metabolic level, or to the variations of the environment, due to the systemic coupling with the world.

In the process of evolution, nervous systems enabled the emergence of organisms with cognitive resources (Moreno, Umerez, Ibańez 1997: 113), in various degrees — which represents another level of biological complexity, endowed with a higher-order degree of autonomy. The cognitive level implies the generation of an informational level, providing maximum flexibility for the behavior of the organism by enhancing the complexity of the regulation of the metabolic-motor functions, the possibility to anticipate the behavior of other organisms and events in the real world, building internal models of reality based on which the organism conducts its actions (Moreno, Merelo, Etxeberria 1992: 70, Moreno, Etxeberria 2005: 171). Furthermore, higher-order cognitive skills can organize parts of the organism in high-order configurations, in order to fulfill complex tasks, assigning them specific functions that they would never have had outside the system.

This is possible due to the complexity of the brain, which is a system with its own dynamics, as a consequence of the patterns resulting from the cooperation of its parts (Kelso 1997: 2). As a dynamical system, the brain has the property of controlling and influencing the dynamics of all the other subsystems within the organism. Moreover, in advanced organisms, such as humans, the neuronal ensembles of the brain create a new metacognitive level, i.e. consciousness. Consciousness contributes to enhancing the control of the system by generating a new semantic-informational level (Juarrero 1999: 85), which goes beyond the sensorimotor, unconscious, and automatic control exerted on the organism, at a sub-personal level, by the nervous system. This new level enables the configuration of the actions of the organism into long-term plans that aim at reaching goals that the organism has consciously set.[11] At the same time, decision-making is done in an inferential manner, by consciously selecting the reasons behind decisions.

Furthermore, from a dynamical system point of view, consciousness plays the role of the internal control parameter that can influence, by means of the patterns it generates, any of the variables of the system. At the same time, consciousness can set new models of order in the organism by generating some complex behavioral patterns that not only increase the number of the degrees of freedom of the system, but also create the possibility for some multidimensional degrees of freedom to emerge.[12] Thus, consciousness creates a state space of the system with multiple and complex degrees of freedom, which contributes not only to the adaption of the organism to the changes from the environment, but also to the enhancement of the autonomy of the system, by identifying new possibilities to act in the environment in which it lives. Consciousness carries out the decoupling from the basic metabolic level of the organism and from the pressures of environment, providing the organism with the maximum level of autonomy that any known biological being can reach.

Consciousness is at the origin of the emergence of the cognitive or conscious self. The conscious self is an extended self, which, in addition to the awareness of bodily feelings, also has awareness of self as a person. This means that the self is no longer a mere set of diffuse feelings or a bundle of

[11] It is called strategic agency, which implies the coordination of the actions of the organism, both in the short and the long term, with a view to reaching its goals (Christensen 2007: 262, 283).

[12] Nonetheless, consciousness is not the only control parameter of a cognitive system. Instincts, desires, feelings, etc. equally represent parameters that influence the behavior of the system in its evolution. The behavior of a living system is the consequence of more parameters that act on one another at a given time, of which only some can be controlled.

sensorimotor response patterns to the challenges of the environment. The conscious self includes ideas, plans, and goals, which the organism consciously sets, representing constraints influencing the behavior of the organism over time. Monitoring the behavior of the organism based on its ideas, goals, and ideals is called self-regulation (Berger 2011: 4). Self-regulation involves the possibility to conduct behavior according to one's own constraints, which are consciously elaborated and selected.[13] This means, in terms of dynamical system theory, that, by the norms they consciously assume, self-regulatory organisms have the possibility to manipulate the trajectory of the behavioral patterns in their internal state space. In this way, new behavioral patterns emerge with multiple alternatives to respond to the environmental perturbations and new degrees of freedom.

Consequently, evolution enables the emergence of higher-order forms of control in organisms with more and more complex degrees of freedom. This means that the evolution of the control mechanisms determines the emergence of new and advanced forms of self, as a consequence of the increasing autonomy of the organisms.

CONCLUSION

To conclude, approaching biological organisms as dynamical living systems provides a different perspective on the nature of their autonomy. The autonomy of such systems is no longer approached merely as a consequence of the degree of internal organization of the organism; rather, it is approached from the perspective of the degrees of freedom which the living system has as a result of the behavioral patterns generated by its biological complexity.

Moreover, the autonomy of a living system also depends on its control mechanisms, which contribute to generating and managing its degrees of freedom. The mechanisms of control of basic living organisms provide only adaptation to the environmental conditions, creating behavioral patterns with basic degrees of freedom and low dimensionality. Therefore, the self of such organisms, which is the result of their regulatory mechanism, is a diffuse self — entailing minimal form of identity and unity.

The nervous system enhances the degrees of freedom of organisms in two ways: on the one hand, it provides a structural coupling with the environment, which allows the organism to act in accordance with external perceived

[13] However, these are not necessary consciously applied, to the extent in which plans or goals conduct the behavior of the organism in the long run.

affordances. This means that the regulatory cyclic loop between organism and the environment becomes more complex as the organism discovers new possibilities to act in the environment. On the other hand, the nervous system creates sensorimotor patterns, by linking sensory organs with the action skills of the organism, which increases the organism's options to respond. Due to the sensorimotor patterns, a new type of self emerges, which is a consequence of the multidimensional state space created by the nervous system.

The highest level of control of living systems is represented by consciousness, which not only enhances the state space of an organism but creates complex patterns of behavior with new and unpredictable trajectories. Due to these patterns of behavior, with a higher-order dimensionality, multiple and complex degrees of freedom emerge in living systems. The self of such organisms is an extended self, which has the possibility to consciously select the constraints which would modulate its behavioral patterns.

As a result, the autonomy of a living system has to be approached in terms of the degrees of freedom of the system, which are the result of the level of complexity of the living system and its control mechanisms. Understanding the control mechanisms of a living system involves understanding the mechanism of generating and managing its degrees of freedom and, at the same time, understanding the complexity of the behavioral patterns generated by the system.

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