Autonomy and Degrees of Freedom in Dynamical Living Systems

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Table of Contents

Publications

All of the chapters included in this thesis are reproductions of published and unpublished papers, as specified below:

Chapter 1: Negru T. (2016). Self-organization and autonomy: Emergence of degrees of freedom in dynamical systems. *Filosofia Unisinos*, *17*(2), 121-131

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Introduction

In the past decades the notion of autonomy has been applied to biological systems, meaning the ability of an organism to constantly maintaining its internal organisation despite external disturbances. The main idea of this thesis is that the notion of biological autonomy can be best accounted for by adding to the theories of autonomy of biological systems the perspective of the dynamical systems theory. Therefore, in this introductory chapter I begin by presenting the classical conception of personal autonomy, and then I sketch the differences between this approach and the biological one. Starting from here, I demonstrate how there is a gap between the two conceptions of autonomy that can be overcome by a new approach of autonomy, combining the autopoietic accounts with dynamical system theory. Finally, I present an overview of the thesis, suggesting some of the questions such a new approach should answer.

1. Autonomy as a mental phenomenon

1.1. Terminological clarification

From the etymological point of view, the term autonomy comes from the Greek words "*autós*," self, and "*nomos*," law or rule. In other words, autonomy means "self-law" or "self-rule", namely, we call autonomous an agent capable of self-governance. Thus the concept of autonomy changed its area of applicability from the political field, where it was initially used to define Greek cities that could pass their own laws (Kȕhler, Jelinek, 2012, p. ix), to the field of personal freedom. In this latter meaning, autonomy refers the capacity of a person to act according to their own ideas, rules, and plans, in order to fulfil the goals such person set. Therefore, autonomy of a person can be understood in terms of self-determination, which refers to the fact that a person acts according to their own will, namely, that they have the ability to deliberate and set their own goals, without being influenced by an outsider. From this perspective, autonomy can be associated to the concept of authenticity, in the sense that autonomous agents are the ones who act according to their decisions, which means that the individuals' life is a consequence of what they actually are (Kȕhler, Jelinek, 2012, p. x). To put it differently, the autonomy of a person involves an authentic self, which is constituted throughout the individual's life by the decisions they make that determine the course of their life.

It follows that the term autonomy is a complex concept, which can be approached from several perspectives (see Dryden, 2020). Thus, we talk about moral autonomy, which is the ability of a person to formulate their own moral laws and to follow them. Personal autonomy refers to a person's ability to make decisions about his or her life, according to their own desires, aspirations, and goals. Political autonomy refers to the ability of a group, community, or state to make decisions about the laws they follow. In addition, we can also talk about machines or artificial agents' autonomy, which is the ability of a machine with artificial intelligence to make its own decisions and to behave independently of other agents. From all these definitions it results that the autonomous entities are those that have the capability to govern themselves, according to some norms that they themselves set and accept.

1.2. The evolution of the concept of autonomy in the history of philosophy

The idea of the multidimensional nature of autonomy is also highlighted by the way this concept has been understood over time. Thus, in ancient times, Plato (Ferrari, 2000) and Aristotle (Ameriks, Clarke, 2000) spoke of the rational part of the soul (*logos*, in Plato; *rational soul*, in Aristotle), which represents the true nature of man, and which should guide the other parts of man. Aristotle speaks of *autarkeia*, which means self-sufficiency and refers to one of the conditions to achieve happiness, which involves making decisions by an agent, only on the basis of his own reason, without being dependent on other external conditions. In these approaches, autonomy is a quality of people who have reached a certain level of understanding and who have the ability to lead their lives according to higher principles.

The concept of autonomy is more clearly defined, in the Modern period, by Immanuel Kant. This time we talk about moral autonomy, in the context of what Kant (2002/1785) calls autonomy of the will, which is a condition of the Categorical Imperative. According to Kant's conception, for moral norms to be universal, they should be separated from any subjective grounds. This means that moral decisions should not be influenced by feelings, emotions, habits, but they should rely on reason. In this way, moral actions are only those that are based on duty, i.e., they are unconditional and that are mandatory to be performed in any situation (they ought to be done). If the moral law is not imposed from the outside but comes from reason, it means that it is the expression of the man's will. Thus, man has the ability to set laws for himself and to guide himself in his actions according to these laws, which means that he has an autonomous will. Autonomy, in this approach, is a consequence of the reason with which man is endowed, and it is an essential condition of his morality.

After Kant, the concept of autonomy was used to establish concepts such as individuality or, later on, authenticity (Dryden, 2020). Thus, the Romantics emphasized the importance of developing the uniqueness of the person's self. John Stuart Mill also pointed out the importance of developing human individuality, identifying autonomy with an important element in achieving personal well-being. And, in the phenomenological tradition, autonomy was associated with authenticity, either as an affirmation of the individual self against the inauthenticity of the crowd (M. Heidegger, 1996/1927), or, through a critical approach (E. Levinas, 1979/1961), as a sign of the selfishness of the one who is not interested in what happens to the others (Christman, 2018; Dryden, 2020).

In the contemporary period, the concept of autonomy has been developed in several approaches of analytical philosophy. Thus, the idea of personal autonomy was debated by H. Frankfurt (1988) and G. Dworkin (1988), in terms of hierarchies of desire (Taylor, 2005, p. 4), in order to develop a conception of free will and to investigate whether personal and moral freedom can be defended in the circumstances of the existence of natural determinism. In Frankfurt's terms (1988), the main characteristic of human beings is that they have "second-order desires", and „second-order volitions" unlike animals that have only "first-order desires." This means that while first-order desires merely involve wanting or not to doing any action, "second-order desire" involve that the person wants or not to have a certain desire. Moreover, second-order volitions means that a person wants that first order desire to be their will. Personal autonomy is understood precisely in these terms, as the possibility of a person to accept or reject a desire.

Similarly, Dworkin (1988) considers that autonomy should not be confused with liberty, power, or control, which are merely conditions to achieve personal autonomy. In Dworkin's approach (1988, p. 20), autonomy means the ability of people to reflect critically on their desires and to accept or reject them based on higher-order values. Owing to this meta-reflection capacity, people become responsible for their actions and thus they can lead their lives as they wish.

Consequently, both views argue that human autonomy is a consequence of directing his / her behaviour, not according to their immediate desires, but according to the decisions of a higher-order cognitive level, which has the ability to evaluate and reflect on primary desires. To the extent that this higher-order level is made up of that person's desire and values, then it means that man is guided in life by what is authentic to himself as an individual. In this way, a compatibilist perspective of human freedom is supported whereby the person's autonomy is accepted despite the determinism that dominates the natural world.

Similar concepts have been supported by M. Bratman or A. Mele. Thus, to Bratman (2005) an autonomous agent is a planning agent, i.e., he is able to design long-term plans, which would coordinate his actions and thoughts over a longer period of time. In this way, according to Bratman, self-governance does not necessarily imply evaluative judgments, but our higher-order cognitive level consists of plan-type attitudes that represent the person's agential authority.

From another perspective, A. Mele (2001) discusses the issue of autonomy in the context of another important characteristic of an agent, i.e. self-control ability. Self-control is defined in opposition to *akrasia*, which designates the weakness of will. This means that self-control is the ability of an agent to conduct their life as they judge best (Mele, 2001, p. 5). In this case, an autonomous agent is seen as a person who has control, at least to some degree, over what they decide to do.

Last but not least, the idea of autonomy appears in political theory, in the context of discussions about liberalism. According to the liberal theory, an autonomous citizen is an independent rational agent, capable of self-governing, who makes decisions based on his ideas and decisions, which together form a "true self" (Christman, Anderson, 2005). To the extent that self is an important component of a citizen's autonomy, the discussions focused on whether we should abandon this conception of self, because it does not have precedence over the values and principles of the community in which the citizen lives (Sandel, 1998), or whether we should defend it, having recourse to other theories about the self, such as the narrative conception about the self (Velleman, 2005) or a multidimensional conception of the self (Meyers, 2005). In this way, autonomy becomes from an issue related to the personal dimension into one regarding the way man lives in society.

What can be observed from this summary of the concept of autonomy, in the history of philosophy, is that autonomy is a multidimensional concept that involved the correlation with other themes in philosophy. Thus, there have been discussions about autonomy and authenticity, where autonomy means achieving what a person really is. Moreover, autonomy was correlated with the idea of self, as an important condition of the latter. Autonomy was also approached as a condition of the morality of human beings. And last but not least, autonomy was also discussed in the context of the topic of the relation between man and society.

It follows that autonomy should be understood as an essential characteristic of the human being. However, according to the classical approaches, autonomy is understood as a mental phenomenon. Such an understanding of autonomy does not offer an approach to this phenomenon from a biological perspective. This results from the fact that man is a biological creature, which like any living organism has a certain degree of autonomy, which allows it to survive in the environment in which it lives. This means that in the case of the human being, as in the case of other living systems, we can talk about autonomy in a more naturalistic way. It follows that the mental dimension of autonomy can be complemented by the biological one that can bring a new perspective on this phenomenon, both in the case of human beings and of the other living organisms.

2. What is biological autonomy?

As a fundamental feature of living systems, autonomy refers to the ability of an organism to survive, in environmental conditions, independently, without help from the outside. This means that living organisms have the ability to self-maintain and adapt to the changes in the environment so that they preserve their functional and operational properties. In some approaches, the property of living systems to maintain their functioning, despite external or internal disturbances, has been called robustness and has been considered a prerequisite for autonomy (Rosslenbroich, 2014, p. 24). Robustness should be seen as a condition of autonomy, which implies other components.

This means that according to biological autonomy theorists, a living system involves more than resistance to environmental disturbances. An autonomous living system is an active system, which means that it involves controlling its adaptive processes. This feature is demonstrated by the difference between the autonomy of a living system and dissipative structures, such as the phenomena resulting from the spontaneous self-organization of matter. According to these approaches, while in the case of living systems the control of exchanges with the outside is directed from the inside, dissipative structures imply the external control of boundary conditions (Ruiz-Mirazo, Moreno, 2004, p. 238). It follows that one of the main features of living systems is their ability to maintain themselves from the interior without any external support. Thus, a basic autonomy emerges which implies the control of the internal constitutive processes of the organism as well as of the exchanges with the outside (Ruiz-Mirazo, Moreno, 2004, p. 240). This means that basic autonomy involves, in addition to robustness, the control of internal and external processes of the organism in order to maintain it in the changing environmental conditions.

However, these characteristics were not considered sufficient by other biological autonomy theorists to define the autonomy of living systems. In addition to regularizing the internal processes of the organism, which aim at maintaining the system, the following can also be listed as conditions of an organism's autonomy: a boundary by which the body regulates exchanges with the exterior, establishing rules of behaviour and ways of reacting to environmental stimuli, achieving an interdependence between the parts of the system[1], emergence of a time autonomy, and maintaining phenotypic stability in the conditions of environmental disturbances (Rosslenbroich, 2014, p. 32). In this way, the autonomy of a living system, even in its basic forms, becomes a complex process, which involves a permanent constitution by the dynamics of the internal organization of the organism and the dynamics between the organism and the environment.

The complex character of autonomy is also wittnesed by the fact that, in the current literature, several types of autonomy have been discussed, which would characterize living systems. For example, depending on the emphasis on the living system's external behaviour, or on the internal organization, a distinction was made between behavioural autonomy and constitutive autonomy (Froese, Virgo, Izquierdo, 2007, p. 456). According to this approach, behavioural autonomy refers to the way the organism behaves in its environment, as having a certain degree of independence, and aims at achieving certain goals through a robust and flexible behaviour. While constitutive autonomy refers to the way in which the autopoietic theory explains the achievement of a living system's autonomy through self-production of its internal components (Froese, Virgo, Izquierdo, 2007, p. 457)[2]. In this way, an idea is introduced that will be present throughout the discussions on biological autonomy. Namely, that autonomy can have a twofold approach, i.e., from the external perspective of the organism, as its interaction with the environment, or from the internal

[1] What was called normativity, whereby internal processes and components are evaluated depending on their contribution to making the whole (Ruiz-Mirazo, Moreno, 2012, p. 32).
[2] More about autopoietic theory in the next section of the Introduction.

perspective, as a way of achieving independence by the organism, as a distinct entity in the environment in which it lives.

Another way of approaching the autonomy of a living system, which encompasses the two types of autonomy described above, can be done considering its degree of development, which has been reached in its evolution. Thus, one can talk about an increasing autonomy, which refers to reducing the influence of the environment on the organism (interactive autonomy) and to enhancing the self-referential functions of the organism (constitutive autonomy) (Rosslenbroich, 2014, p. 39). According to this theory, there are several characteristics that contribute to increasing the autonomy of an organism: „1. Changes in spatial separations from the environment; 2. Changes in homeostatic capacities and robustness; 3. Internalization of structures or functions; 4. Increase in body size; and 5. Changes in the flexibility within the environment, including behavioral felxibility" (Rosslenbroich, 2014, p. 39). In this way, the autonomy of a living system is no longer seen as a permanent feature of the living system, but one that can evolve over time, depending on the way the organism transforms as a result of its adaptive needs.

In general, approaches to the autonomy of biological systems have been grouped into two categories: monistic approaches, which speak of the existence of a single type of autonomy that can be gained in different ways, depending on the complexity of the organism (Barandiaran, 2017, p. 412). And pluralistic approaches, which discuss the existence of several types of autonomy, depending on the phenomenological field under discussion: the autonomy of the cell, the autonomy of multicellular organisms, the autonomy of behaviour, the autonomy of inter-subjective interaction, the autonomy of the social or the political (Barandiaran, 2017, p. 412). The existence of several approaches to autonomy opens the possibility to discuss autonomy as a complex phenomenon, with multiple consequences in approaching living systems.

Starting from here, I present some theories about biological autonomy, which were developed by their initiators so as to reach other topics of interest regarding living systems. These theories are autopoiesis theory, with its enactivist developments, and organizational theory. In this way, my intention is to evaluate the current state of research and prospecting ways to expand the theoretical approach to biological autonomy. Starting from here, open questions will be addressed in the following sections. The aim is to complete biological approaches with the perspective of dynamical systems.

3. Autonomy and Autopoiesis Theory

According to the classical autopoietic theory developed by Maturana and Varela, a living system is considered an autopoietic machine, which means that it is „a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network" (Maturana, Varela, 1980, pp. 78-79). In other words, autopoietic machines are those that do not produce something external, but their internal processes produce the components necessary maintaining these very processes.

From this description several characteristics of autopoietic systems can be deduced: first of all, autopoietic systems are homeostatic, i.e., they aim to keep the variables and their internal organization constant (Maturana, Varela, 1980, p. 78). Secondly, due to the self-referential character of their internal processes, autopoietic systems constitute their own identity and unity. Identity is a consequence of global coherence resulting from the self-constitutive processes of the organism (Varela, 1997, p. 73). Whereas unity also results from this self-producing coherence that keeps intact the network of the internal processes (Varela, 1992, p. 5). It follows that the identity and unity of living systems are operational in nature, resulting from the basic processes of the organism. Even in this basic form, they are the basis for the constitution of the organism's individuality, which implies the invariant maintenance of its internal organization through its ongoing constitution (Maturana, Varela, 1980, p. 80).

To the extent that autopoietic systems have as a consequence, through their internal organization, reaching a general order pattern, it results that another characteristic of them is reciprocal causality. That is, the dynamics of their internal components determines the global whole dynamics, which in turn constrains the internal components to behave according to an order pattern. Last but not least, even if autopoietic systems delimit their own space from the outside, they are coupled with the environment in which they live. In this way, living organisms define their field of interaction with the outside, in which they communicate and exchange information.

What results from this characterization of autopoietic systems is that their main feature is that they are organizationally close. This means that all the characteristics of a living system derive from the recursivity of its internal organization, which is based on the production of the components that support this organization. In this way, the living system no longer needs an external component to support its existence. It becomes an autonomous agent that can survive more or less dependent on environmental conditions. It follows that at the basis of autonomy of an autopoietic system lays the organism's organizational closure (Varela, 1979, p. 58). Due to this internal organization, which aims to maintain internal parameters constant by creating a global coherence, which ensures the dependence of internal components according to an order pattern, the organism gains its identity and unity. Thus, it becomes an autonomous agent that is constitutively coupled with the environment and has a flexible behaviour whereby it can adapt to changes in the environment.

According to Varela (1979, p. 57) autopoiesis is an organizational closure case, just as the autonomy of living systems is just a case of autonomy in general. This means that organizational closure, and implicitly, the autonomy of living systems, can be achieved by other means, depending on the degree of development of the organism.

For example, the nervous system offers another type of organizational closure based on sensorimotor loops, which involves “coupling movements with a stream of sensory modulations in circular fashion” (Varela, 1992, p. 9). Thus, in the case of multicellular organisms, another type of identity emerged, different from that of autopoietic systems, which involves a cognitive self that is a consequence of sensorimotor patterns of the organism.

In conclusion, the autopoietic theory approaches biological autonomy as a consequence of the operational closure of the organism’s internal structure. Autonomy is a result of the constitutive processes of the organism from which the identity, unity and self of the organism emerge. Depending on the degree of the development of the organism, organizational closure may take many forms, which means that we can speak about different levels of autonomy of living systems.

4. Autonomy, Enactivism and Organisational Theory

In the enactivist theories subsequent to the autopoietic conception, Maturana and Varela’s theory was supplemented so as to provide an answer to several unresolved issues (such as: adaptivity, precariousness, sense making etc.) related to the autonomy of living systems. Thus, an important prerequisite of an autopoietic system was considered adaptivity, thought of as the ability of the living system to be tolerant to changes and to actively monitor environmental changes and compensate for their tendencies (Di Paolo, 2005, 2010). In this way, the organism gains a certain degree of flexibility, which means that despite its homeostatic nature, which aims to maintain certain parameters, the adjustment of behaviour is made within some limits and not returning to the same state.

In this context, an additional prerequisite of autopoietic system autonomy was identified as precariousness (Di Paolo, 2005; De Jaegher, Di Paolo, 2007). This means that in the absence of a network of processes that constitutes the organizational closure of an organism, the living system's components cease to exist. Thus, autonomous agents are defined as living systems that, owing to their internal organizational closure, constitute an identity, which they maintain under precarious circumstances (Di Paolo, 2005, p. 55). In this way, autonomy is approached as a prerequisite of maintaining the viability of an organism between certain parameters.

In addition to this new prerequisite of autonomy, enactivist theories have also considered another way of approaching the autonomy of cognitive systems. Thus, unlike the classsical computationalist conceptions, which considered that the living system passively receives information from the world, on the basis of which they build representational models of the world, enactivist approaches consider that organisms enact the world in a meaningful way (De Jaegher, Di Paolo, 2007). This process is called sense-making, which means that, when the organism constitutes its identity and self, it determines the emergence of its domain of interactions, i.e., its environment, which thus becomes a meaningful world (Thompson, 2007, p. 158). In this way, the organism does not perceive the world in a neutral way, but starting from its needs and goals.

This characteristic of the living organisms to give meaning to the world in which they live is also at the origin of social relations and the development of society. Participatory sense-making designates the process of interaction and coordination of the actions of two or more autonomous agents (De Jaegher, Di Paolo, 2007, p. 492). An autonomous organization – with its own identity, which does not cancel the autonomy of the agents involved – results from this coupling (De Jaegher, Di Paolo, 2007, p. 493). In this case we speak about another type of autonomy, of social interactions, which is based on the participating agents' autonomy. This new level of autonomy of living systems shows that in the sense-making process of the world, its meanings are not created individually, but through the common contribution of autonomous agents.

Another way of approaching autonomy, starting from the same autopoietic theory, belongs to organizational theory. The starting point of this theory is the approach of autonomy from the point of view of the operational closure of the organisms, as it was achieved in the autopoietic conception. However, the new theory comes to provide an answer to two objections raised against autopoiesis theory, both concerning autonomy of the living systems. Thus, on one hand, in the autopoiesis theory, autonomy was perceived as the internal determination of the operational closure and, on the other, autonomy was approached in abstract and functionalist terms, without taking into account material and energetic aspects (Moreno, Mossio, 2015, p.xxviii). According to the supporters of organizational theory, these two problems are solved by the fact that their theory takes into account both the "situatedness" of a living system and the fact that they are thermodynamically open systems i.e., systems that have energetic and informational exchanges with the exterior (Moreno, Mossio, 2015, p.xxviii). In this way, they distinguish between the constitutive and the interactive dimension of autonomy, which were previously explained.

The novelty of organizational theory lays in the fact that it approaches the organizational closure of living systems in terms of constraints. To put it differently, the network of constitutive processes, which have the property of realizing the internal components of the living system, due to their interdependence, achieves a closure of constraints (Moreno, Mossio, 2015, p.15). These constraints act on the thermodynamic flow to which the organism is subjected, determining the maintenance of its internal organization under conditions of environmental disturbances. Thus, constraints are approached as what limits the system's degrees of freedom and determines them to adopt a certain type of behaviour.

Organizational theory also calls into question the existence of second-order constraints whose role is to regulate the internal organization of the organism, when the network of internal processes is endangered (Moreno, Mossio, 2015, p.34). Thus, due to constraints, the internal organization of the organism self-maintains, considering the external and internal disturbances. In this way, autonomy of the system is understood starting from its self-constraining and self-determining properties, whereby the organism's identity and unity is constituted.

The theory of constraints is extended by organizational theory to other aspects of biological autonomy, such as agency or evolution. In addition, other levels of autonomy are discussed, such as the autonomy of multicellular organisms or organisms with higher-order cognitive skills. But, as organizational theory is discussed in its most important aspects throughout the thesis, this theory is presented in each chapter, depending on the topics discussed.

The idea that can be deduced from the presentation of the biological approaches of the autonomy is that, despite the common features of these theories, each of them comes with a different perspective on this phenomenon. Thus, the autopoietic approach offers a minimalist explanation of autonomy that takes into account the self-constitutive processes of living systems. The enactivist theory refers, in particular, to gaining autonomy, under the conditions of ongoing interaction between organism and environment. Whereas the organisational theory explains autonomy in terms of internal constraints, which contribute to the organisational closure of the organism. Therefore, the biological perspective of autonomy requires a unitary explanation, but one that also provides an understanding of autonomy according to the developmental level of the organisms under consideration. Such an approach to autonomy is formulated in the course of this thesis, starting from dynamical systems theory. The need for such an holistic approach to autonomy also stems from the difference between the mental and biological approaches to autonomy.

5. The gap between personal and biological autonomy

From the presentation of the two main directions in the approach of autonomy, the classical, i.e., the mental one, and the biological one, it can be concluded that there is a gap between how autonomy is conceived from a personal point of view and its naturalistic perspective. This gap stems from several differences that can be noticed from the analysis of the two approaches.

Thus, on the one hand, personal autonomy refers to the individual as a person, namely, as a being endowed with higher-cognitive skills, who has a self and acts, in the environment – social, natural, etc. – in which she/he lives, on the basis of rules that she/he gives they themselves lay out. From this perspective, it is only the humans that are considered autonomous beings, because it is only them who have meta-cognitive abilities, which can reflect on their desires and urges. Personal autonomy is an important component of the agency of human beings, which refers to the ability to make decisions about one's own actions without being influenced by someone else.

Biological autonomy, on the other hand, refers to any organism as a complex system that has a certain internal organisation and establishes adaptive relationships with its environment. Biological autonomy refers to the self-sustaining capacity of any living system to maintain its internal equilibrium in the conditions of environmental disturbances. Thus, biological autonomy does not imply higher-order cognitive skills, but is a constitutive characteristic of any biological system, whether we are talking about unicellular organisms or those with complex organization, i.e., with nervous system, consciousness, etc.

It should, therefore, be considered that we can talk about biological autonomy in gradual terms, its level being determined by the complexity of each biological organism. This means that autonomy should not be approached only from the constitutive perspective of the organism. Rather, it must also be explained in terms of the possibilities the organism has to access new ways of responding to environmental challenges.

From the presentation of the two approaches to autonomy, it appears that this gap could be overcome by finding an underlying theory that explains autonomy both as a mental phenomenon and from a constitutive point of view. Thus, not only a minimalist explanation of autonomy would be offered, but an holistic approach, which would explain in the same terms the autonomy of any biological system, taking into account its degree of development. In this way, autonomy is explained in terms of other structures that characterize a living system, such as self, agency, or control.

Such a connecting theory, as I said, can be found in the dynamical systems theory, which can explain not only the functioning of basic organisms with lower-order cognitive skills, but also of organisms with higher-order cognitive skills. The starting point is the biological approach to autonomy, since it refers to its constitutive dimension. This is complemented by the dynamical systems perspective so as to result in a new holistic theory of autonomy, which explains this characteristic for any type of organism, taking into account the different possibilities of response of these organisms to environmental challenges.

6. Autonomy and Dynamical Systems Theory

The idea that living systems can be approached from the perspective of dynamical systems theory comes both from the initiators of autopoietic theory and from the supporters of the dynamical approach. Thus, Varela (1979, p. 55-56) considers autonomous systems as mechanistic (dynamical) systems, which due to organizational closure instantiate a type of dynamical stability, which can explain in better terms the survival of the organism considering the environmental disturbances. From the other perspective, the scope of the dynamical hypothesis was considered biological agents, more precisely, the possibility to explain cognition in dynamical terms (van Gelder, 1998, p. 619). To the same extent, the enactivist followers of the autopoietic theory as well as the organizational theory sometimes appeal to the dynamical system theory in their explanations.

The starting point of the dynamical systems theory is the idea that living systems are systems that change over time and, therefore, the evolution of such systems should be explained from the perspective of the dynamics of internal changes and not in classical computational terms. According to the classical approach, understanding a system should explain its states, which are arranged in a certain structure, considered to be static and final (van Gelder, 1998, p. 621). Moreover, from a computational point of view (van Gelder, 1998), systems are characterized by an input to which an output corresponds, and cognition is explained by static internal representation of symbol tokens. Unlike this way of understanding systems, the dynamical approach considers that input and output form an ongoing process, and, therefore, cognition should be understood in a non-representational way, by models that describe the change of the system's states (van Gelder, 1998, p. 622). In this way, living systems are understood in terms of the dynamics between the organism and the world, which involves another conceptual apparatus for explaining the behaviour of a biological system.

As dynamical systems, living systems are understood as open systems, which have ongoing information and energy exchanges with the world, being systems far from thermodynamic equilibrium (Thelen, Smith, 1998, p. 271). Due to the flow of exchanges with the environment, dynamical systems have to maintain their internal organization. This means that an important component of the functioning of living systems is the free-energy principle (Friston, 2010). According to this principle, in order for a living system to maintain its internal organization constant, given the ongoing changes in the environment, it should minimize its free-energy. In order to lower its entropy, the system makes predictions about the changes in the environment and acts on these predictions, so as to avoid surprises and keep its states constant.

This is possible because the system is characterized by nonlinearity, which means that by aggregation, the whole exhibits emergent properties that, individually, the parts do not have. Consequently, the system has the ability to self-organize so as to provide answers to environmental challenges, using the resources and capabilities at its disposal. In this way, the system can have more states than the sum of the states of its parts.

The totality of the system states forms its state space, which is represented as being made up of the points corresponding to each state of the system. Each state has an associated direction and a value of change, which represents its vector field. In state space, trajectories are configured, which unite several points corresponding to the states of the system and which have a convergent dynamics, in the sense that they are self-closing trajectories. These patterns formed in the state space of the system from circumscribing a subset of states (limit set), which determines the behaviour of the system at a given time, are called attractors. Each attractor has a basin of attraction, formed by the points to which that attractor converges.

Depending on their complexity, attractors were grouped into three classes: equilibrium point attractors are made up of a single point in state space, which means that the system has a single state (Beer, 1995, p. 179). Periodic attractors are an orbit in the state space, which repeats itself, so that the system oscillates between these states (Horgan, Tienson, 1992, p. 30). Chaotic attractors are those with unpredictable trajectories, which does not mean that they are random, only that they have a complicated dynamics, due to the fact that they encompass a very large number of variables.

Attractors provide stability to the system because they involve setting up a trajectory around a region of the state space. So, if the parameters of the system vary, within tolerable limits, their trajectory changes very little, being convergent to subsequent trajectories and delimiting the same states. However, the system can change its behaviour due to significant change in the parameter values, whose effect is the bifurcation of their trajectory. The system becomes unstable until another pattern of behaviour emerges. Thus, at the level of the state space of the system, there are also limit sets that are unstable, called repellors, whose trajectories are not convergent (Beer, 1995, p. 179). It follows that the state space of a system consists of stability and instability zones (that together form a dynamical landscape), which the system accesses according to the values recorded by their external parameters.

In general, the appearance of an attractor within the system means that at its level an order parameter (or collective variable) emerges, which restricts its degrees of freedom at a given time. From this perspective, we can say that a system has a multitude of degrees of freedom, which cannot be instantiated all at the same time. The degrees of freedom represent the possibilities of action that the system has as a whole, as a result of the cohesion of its parts, in a unitary whole. By the appearance of order parameter, the system accesses only the degrees of freedom that can be achieved at a given time, depending on the external conditions and its internal mechanisms of survival.

This can also be explained in terms of the constraints that emerge in the living system. Thus, according to Juarrero's approach (1999, pp.140-143), in a dynamical system there are two types of constraints: first-order contextual constraints, which result from the aggregation of the parts and operate at the same level of organization; and second-order contextual constraints, which are the result of the emerging properties of the whole and determine the possibility of new degrees of freedom of the system to emerge. In this way, the enabling role of constraints is recognized, which, even if they restrict the degrees of freedom of the system components, open the possibility to access new degrees of freedom of the system as a whole. This approach to constraints, in terms of the dynamical systems theory, is discussed during the present thesis, in addition to the organizational theory.

Considering how living systems are explained, the dynamical approach can also be used to complete the understanding of autonomy of biological systems. In a classical definition, autonomous agent means "any embodied system designed to satisfy internal or external goals by its own actions while in continuous long-term interaction with the environment in which it is situated" (Beer, 1995, p. 173). Although such a definition makes some clarifications as to what the autonomy of a living system might be, it does not provide an explanation of autonomy in terms of dynamical systems. This is done during this thesis, in which the autonomy of a dynamic living system is explained in terms of the behavioural patterns that emerge in the system and the degrees of freedom of a living system.

7. Chapters Overview[3]

What can be deduced from the summary of biological theories on autonomy, as well as from the presentation of the dynamical approach of living systems, is that these two perspectives can be combined to provide a new understanding of the concept of autonomy. This involves answering a few questions, such as: what is meant by degrees of freedom and how do they emerge in an organism? What is the role of the self in controlling and managing the degrees of freedom of a living organism? How does free-energy principle contribute to the appearance of new degrees of freedom of the organism and to gaining the autonomy of the organism? What are the types of agency that characterize a living system and how does each of them contribute to the emergence of degrees of freedom and of the autonomy of the organism? All these questions will be addressed in the chapters of the thesis with the intention to show that the autonomy of a living system can be understood in terms of degrees of freedom of the organism.

This thesis is organized into four chapters, each representing an article published as it was developed. Even if the four parts were developed independently, their purpose is common, i.e., to complete the issue of autonomy approached from a biological perspective (e.g., autopoiesis theory, enactivist theory, organizational approach), with the perspective of dynamical systems theory. In addition to the main topic, related topics were discussed in the thesis, such as agency, self, control, etc. These concepts are essential to understanding the autonomy of a living system, so it is important to provide an account of them from the perspective of dynamical systems theory. Moreover, these concepts were approached from the perspective of the new conception of autonomy, trying to provide other explanations for these important aspects of understanding living systems.

Thus, in the first chapter, called "Self-Organization and Autonomy: Emergence of Degrees of Freedom in Dynamic Systems," I approach autonomy from the perspective of the self-organization process. From this point of view, autonomy means the generation of identity and the minimal unity of a system, as a consequence of the self-production of internal components and processes of an organism, self-regulation of its internal variables, and self-sustaining of its internal resources. However, a living system is also a dynamical system, which means that the emergence of identity and the unity of the system is inseparable from the generation of its degrees of freedom. These degrees of freedom have different levels of complexity, given by the multidimensional patterns instantiating them, offering various alternatives to respond to environmental perturbation. From the point of view of the multidimensionality of degrees of freedom

[3] This part is made up of the abstracts of every article.

of a living system, which depends on the degree of self-organization and complexity of the organism, one can distinguish three types of autonomy: minimal or basic autonomy, sensorimotor autonomy, and strong autonomy. Put in these terms, autonomy depends on the abilities of the organism to access some degrees of freedom of higher complexity, to enhance its degrees of freedom by its coupling with the environment, as a result of its bodily skills, and to consciously control and monitorize its degrees of freedom, as a result of its higher-order cognitive abilities.

In the second chapter, entitled "Autonomy and Control: Dynamics of Degrees of Freedom in Living Systems," the issue of autonomy is explained first from an organizational perspective. According to organisational theory, the autonomy of a living system should be approached from the perspective of processes that contribute to generating and constantly maintaining the internal organisation of the living system, as well as to preserving the structural relation between organism and environment. However, how we have already seen, 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 understanding of controlling mechanisms, which contribute to generating and managing its degrees of freedom. In the case of basic living organisms, one can talk about 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 behaviour 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 an advanced form of control to the organism, 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 the integration of the body and environment into a systemic whole. Moreover, in advanced organisms, such as humans, a new metacognitive level emerges which is consciousness. Consciousness not only enhances the state space of an organism but creates complex patterns of behaviour 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 has the ability to consciously select the constraints that would modulate its behavioural patterns.

The aim of the third chapter, „Self-organization, Autopoiesis, Free-energy Principle and Autonomy", is to extend the discussion on the free-energy principle (FEP), from the predictive coding theory, which is an explanatory theory of the brain, to the problem of autonomy of self-organizing living systems. From the point of view of self-organization of living systems, FEP implies that biological organisms, due to the systemic coupling with the world, are characterized by an ongoing flow of exchanging information and energy with the environment, which has to be controlled in order to maintain the integrity of the organism. In terms of dynamical system theory, this means that living systems have a dynamic state space which can be configured by the way they control the free-energy. In the process of controling their free-energy and modeling of the state space, an important role is played by the anticipatory structures of the organisms, which would reduce the external surprises and adjust the behavior of the organism by anticipating the changes in the environment. In this way, in the dynamic state space of a living system new behavioral patterns emerge enabling new degrees of freedom at the level of the whole. Thus, my aim in this chapter is to explain how FEP, as a principle of self-organization of living system, contributes to the configuring of the state space of an organism and the emergence of new degrees of freedom, both important in the process of gaining and maintaining the autonomy of a living organism.

In the fourth chapter, „Self, Agency and Autonomy in Dynamical Living Systems", my intention is to offer a new explanation of the self both from the biological and dynamical systems theory perspectives. This means that I support the idea that the self is a consequence of biological control mechanisms, either of the internal processes, or resulting from the interaction of an organism with the environment. Thus, we are talking about a self not only depending on the complexity of the organism, but on how it is formed as a result of dynamical living systems, as well as how the self contributes to the emergence of the agency of living systems. From the perspective of the dynamical systems theory, the self will be approached as a bundle of patterns resulting from adapting of a living system to the conditions of the environment. To this purpose, in the first part of the chapter, the self is understood starting from three characteristics of the living systems, which result from the self-organisation of the organic matter: identity, unity and self-maintenance. In the second part, I discuss one of the most important characteristics of the self: agency. The sense of agency is approached as being made of three components: coupling of the organism with the world, the control of the internal and external processes, and prediction. In the third part, I discuss three types of agency of living systems: minimal, sensorimotor and cognitive agency. In conclusion, I discuss the issue of the relation between the self and autonomy, considering the self as a consequence of the degrees of freedom of a living system.

The last part of the paper is dedicated to conclusions, where I discuss both the advantages of understanding autonomy from the joint approach of biology and the dynamical systems theory, and the consequences of the new way of understanding autonomy as a consequence of the degrees of freedom of the organism.

Chapter 1. Self-Organization and Autonomy: Emergence of Degrees of Freedom in Dynamical Systems

Introduction

In terms of autopoietic theory, both in the classical version and in the later developments, autonomy designates a feature of living organisms, i.e., of biological systems with adaptive mechanisms, which have the capacity to self-sustain and survive under the conditions of environmental perturbations. Autonomy is an emergent property of the self-organisation of a living system as a principle that lies at the origin of the emergence of forms of life. Thus, autonomy is approached only from the perspective of constitutive processes of self-organisation, which contribute to creating basic organisms (cell- or unicellular-type organisms). However, the approach of incipient forms of life, regarded as simple dynamical systems, does not solve the issue of understanding the autonomy of organisms with a much more complex organic architecture.

Consequently, in this article this I intend to identify types of autonomy of living systems, taking into account the results of autopoietic theory, with further developments, as well as the living systems approach in terms of the dynamical system theory. Thus, in the first section, „Self-Organization and Autonomy", I will show how the basic processes of autopoiesis, have contributed to creating what we may call operational autonomy. In the second section, „Self-organization and Degrees of Freedom in Dynamical Systems", I will discuss the topic of self-organisation from the perspective of dynamical systems, showing that the self-organisation process is inseparable from the process of producing the system's degrees of freedom. From here, I will define the autonomy of a living dynamical system in terms of the degrees of freedom it may access.

Finally, in the last sections, assuming the definition of autonomy in terms of degrees of freedom, and, considering the degrees of structural complexity of living systems, I will draw a distinction among three types of autonomy: minimal autonomy, which has been approached in different versions of autopoietic theory, sensorimotor autonomy, which belongs to organisms with minimal cognitive resources, and strong autonomy, which can be met in the case of organisms with higher-order cognitive skills.

1. Self-Organization and Autonomy

The starting point of dynamical system theory in approaching living system is the theory of biological organisation, according to which biological organisms are the consequence of the spontaneous self-organisation of living matter, which is not governed by strict laws, nor is the consequence of an internal agent, such as a self (Thelen and Smith, 1998) or some external forces. Self-organization is the result of a propensity to order exhibited by living matter, whereby elementary particles are coupled in an on-going interaction, which determines the occurrence of some complex structures with emergent properties that can self-sustain considering external conditions.[4] From this perspective, a self-organizing system is not only a mere assemblage of previously separate components, but entails their dynamic interaction in order to configure a new higher-order steady structure, with properties that cannot be reduced to individual properties of parts, and which would resist environmental perturbations. Thus, the propensity of living organisms to self-organization determines the emergence of forms of life with different organic complexity, able to exhibit higher patterns of behaviour as a response to environmental challenges that are decoupled from the basic mechanisms of their biological life. Consequently, one can say that living systems are self-organizing systems, which have the ability to self-maintain and adapt spontaneously to environmental circumstances, exhibiting various degrees of organic complexity and autonomy.

The emergence of autonomy of a living system should be understood starting from the constituent processes that are at the origin of its self-organization, such as the process of autopoiesis. In Maturana and Varela's terms (1980), living systems as autopoietic machines are characterized by their constantly maintaining an internal organization, which entails the continuity of the organism's internal processes without any other external goal. The process of autopoiesis consists of a network of recursive processes that regenerate and preserve internal components of the organism and thus, sustain the network of process that produces them. This means that what characterizes autopoietic systems is operational unity or operational closure, whereby the organism gains identity and unity. According to later enactivist approaches, the identity of an autonomous system is constituted by the recursiveness of the set of interdependent processes, which are self-sustaining and self-generating (Di Paolo and Iizuka, 2008, p. 411), becoming an invariant that persists through time and resists changes caused by environmental perturbations on the organism.[5] Thus, the process of autopoiesis constitutes a unitary whole that self-creates the condition of its existence.

By constituting its identity and unity a living system gains an operational autonomy given by the dynamics of its internal operations. This autonomy should be

[4] In Thelen and Smith's terms, "[s]elf-organization is not magic; it occurs because of the inherent nonlinearities in nearly all of our physical and biological universe" (Thelen and Smith, 1994, p. 58). In other words, self-organization is the consequence of the nonlinear relationship existing among the components of a system, which makes the interaction among the parts determine the emergence of some properties at the level of the whole that differ in quality. Unlike the classical, linear causality, which generates some "aggregative" systems, whose characteristics result from the simple addition of the properties of the components (Thompson, 2007, p. 419), nonlinear causality allows the coupling and mixture of some processes or heterogeneous elements, which would lead to effects that differ structurally from their determining causes. Thus, nonlinearity means more than the simple reorganization of the elements as it allows for reaching levels of higher complexity that cannot be obtained by simply adding parts.

[5] Autonomy entails the existence of an operational identity of the organism irrespective of its level of activity. "Autonomy as operational closure is intended to describe self-generated identities at many possible levels" (Di Paolo and Iizuka, 2008, p. 411).

understood from the fact that an autopoietic system is always embedded within a certain context, trying to sustain and preserve its identity and unity under the conditions of environmental fluctuations and perturbations. This means that an autopoietic system is an open and homeostatic system, which operates under precarious conditions.[6] As an open system, an autopoietic system is characterized by an exchange of energy with the environment. Thus, it is a dissipative structure that, through its interaction with the environment, gets the energy required for its preservation; but it also consumes energy in order to sustain its internal organization, which is subjected to an on-going flow of energy exchange with the environment.[7] Depending on the quantity of energy received from exterior, the system may have moments of instability, reaching certain thresholds and overcoming them through the emergence of new levels of organization.

From the point of view of the energy exchange with the environment, the system is considered to be far from a thermodynamic equilibrium, meaning that it never reaches equilibrium with the environment except by losing its identity, which occurs only by ceasing its activity. As an organism characterized by non-equilibrium, the living system has only a tendency toward equilibrium, undergoing states with a transient stability, which it reaches through on-going regulation of its internal processes.

An important role in this process is played by homeostasis, which, as a feature of living systems, entails the regularization of their internal variables with a view to constantly preserving both the relationships among them and the response patterns determined by the relationship of the organism with the environment. Thus, homeostasis represents the propensity of the organism to maintain some recursive patterns, which are to preserve the autonomy of the system.

Moreover, according to later approaches to autopoietic theory, the autonomy of a living system would imply a boundary that is a result of the on-going interaction among the components, whereby the organism demarcates itself from the exterior and controls the energy flows coming from the environment (Ruiz-Mirazo and Moreno, 2004, p. 238). Boundaries facilitate the structural coupling between the system and the environment whereby the external structure of the system comes to be "as much as part of the complex system as the internal structure" (Juarrero, 2010a, p. 2). In this way, the boundary internalizes the feedback, by sending to the organism signals about external perturbations, which determines the adjustment of its internal reactions in compliance with the environmental modifications. It follows that this boundary, which is a result of self-organization, being generated endogenously, is a structure whose sensibility is

[6] Di Paolo and Iizuka state that "[b]y *precarious* we mean the fact that in the absence of the organization of the system as a network of processes, under otherwise equal physical conditions, isolated component processes would tend to run down or extinguish" (Di Paolo and Iizuka, 2008, p. 411).

[7] However, in some dissipative structures, boundary conditions are either imposed from the outside (as Bénard cells) (Juarrero, 2009, p. 91), or insufficiently controlled (Collier, 2004, p. 153). This means that these dissipative structures are characterised by an exogenous autonomy, which requires an external control of boundary conditions, and not by an endogenous autonomy, which is the exclusive result of their internal processes.

adapted to external changes, making the organism an open system with different possibilities for interacting with the environment.

Starting from this, one can conclude that an autonomous autopoietic system is an open system, embedded within a certain context, which is in a dynamical non-equilibrium with it, whose internal mechanism aims at generating its own components and internal relations with a view to preserving them and, at the same time, generating its own identity and unity by creating a boundary that demarcates the organism from the external environment. Such a system is characterized by an operational autonomy, which represents a weak form of self-governance, to the extent that even if it is produced by the system and makes self-preservation its goal (Collier, 2002, p. 1), it does not involve a conscious regulation of the organic processes or achieving an external goal.[8] Operational autonomy is a consequence of the self-organization of living system, and, therefore, should be understood through its constituent processes. From this perspective, operational autonomy consists in generating identity and the minimal unity of a system, as a consequence of the self-production of the internal components and processes of the organism, self-regulation of its internal variables, and self-sustaining of its internal resources.

2. Self-organization and Degrees of Freedom in Dynamical Systems

The idea behind the theory of self-organization in the dynamical system approach is that the interaction of elementary particles has as a consequence a cohesion between parts owing to the generation of an orderly pattern of behaviour, which takes over control of the system at a certain moment, constraining the degrees of freedom of the components to join them in a functional whole, giving up some of their possibilities to act. The emergent organization of the system is a result of its multi-causal character (Thelen and Smith, 1998, p. 281), according to which the mutual influence of the parts, endowed with causal powers, determines the expansion of the internal processes, cancelling the pre-existing order through the emergence of a higher-order structure, which endows the organism with the ability to respond to environmental perturbations—which the components, separately, did not have. Structurally speaking, self-organization is the consequence of the circular causality relationship of the system (Lewis, 2002, p. 41), which means that the cohesion of the basic elements generates a higher-order pattern, which in turn determines the cohesion of its parts. Circular causality shows that self-organization is an on-going process, where the higher and bottom levels of the system generate and influence one another, determining the stability of the system as a whole as a result of the internal dynamics of the components.

[8] One can speak of a more advanced form of self-governance in the case of an adaptive autopoietic system, which actively monitors its own states and acts towards improving the circumstances of the autopoietic process (Di Paolo *et al.*, 2010, p. 50). A system with properties such as self-monitoring, control of internal regulation, and control of external exchanges (Di Paolo, 2005, p. 430) has the possibility of a better adaptation to the environment by means of complex behaviour, which aims at achieving its own goals and not just a direct adjustment to the exterior perturbation.

This circular dynamics is at the origin of the constitution of organism identity and maintenance of equilibrium, under the influence of energy perturbations coming from the environment.

This means that as dynamical systems, self-organizing systems are not invariable but evolve in time, alternating moments of instability with stability. In terms of the dynamical system theory, one can say that the factors influencing the system, called parameters, operate on its variables, which are in an interdependent relation, determining their simultaneous modification and the change of the system state (Van Gelder, 1998, p. 617). The variables of the system have an on-going dynamic and, due to their coupling with various external parameters, their evolution can be explained by a set of mathematical equations.[9] It results in the system being characterized by several states, which correspond to the alternatives to modify its variables, which, together, form the state space of the system. State space is a representation, in a system of coordinates, of all the acting and responding possibilities that the system could have in its history.

Due to the influence of parameters on the internal variables, the system exhibits moments of instability, depending on the external fluctuations that threaten its internal organization. In phase transition, which is the transition from one steady state to another, the system is oriented towards the discovery of some new self-organizing patterns (Kelso and Engstrøm, 2006, p. 116) by means of a control parameter, which is a transitive pattern that opens the possibility of the system to self-organize in new possible configurations. Control parameter merely facilitates the transition from the old organization to the new one, ensuring the adaptation of the system to the new conditions, without imposing any order pattern. The configuration of the system in a steady state is the result of the emergence of a self-organizing pattern as an order parameter or collective variable, which takes over control and coordinates the variables of the system at a certain moment, determining the reduction of the degrees of freedom of its components (Kelso and Engstrøm, 2006, p. 115-116) to only few alternatives to act. Thus, order parameters define the degrees of freedom of the whole system, which are gained by condensing the degrees of freedom of its components, as a result of the adaptation to the perturbations caused by the external parameters.

An order parameter determines the system to settle into one or a few patterns of behaviour (Thelen and Smith, 1994, p. 58), which means that, from a topological approach, it configures a certain pattern in the system's state space, made up of points in this space corresponding to the states of the system that could be occupied at a given moment. This means that the system comes to be guided by an attractor, which corresponds to the trajectory a pattern of behaviour describes in the state space, which determines the position of the system as a response to the external perturbations. The

[9] Equations represent rules of evolution (Van Gelder and Port, 1995, p. 6) of the variables. Consequently, a dynamical system operates according to certain deterministic sequences where each state of the system is a consequence of a previous state.

system state space contains a number of finite attractors—the less they are, the more organized and steady the system is considered (Newton, 2000, p. 94)—of which only some are active at a certain moment, meaning that they influence the behaviour of the system. Depending on the external perturbations and on how strong these patterns are, as a result of giving appropriate responses to the challenges of the system, the system oscillates between these attractors, which are "the total number of alternative long-term behaviours of the system" (Kauffman, 1993, p. 177), representing the degrees of freedom of the system.

Some attractors have a regular configuration, describing a determined orderly pattern with a uniform trajectory. Such examples are point attractors, which determine the stability of the system by its convergence toward a steady point in its state space. Periodic attractors belong to the same category, having a cyclic trajectory and taking the shape of a periodic loop (Juarrero, 1999, p. 154), which always reverts to its initial state by occupying repeatedly the same positions.

Other attractors, such as chaotic (or strange) attractors, have an irregular trajectory, but not non-coherent, which does not pass through the same points in the state space but occupies convergent positions against the previously covered trajectories.[10] The trajectory of strange attractors is not random, but it has a higher degree of complexity as it corresponds to a higher order. Unlike point or periodic attractors, which are zero- or uni-dimensional (Kauffman, 1993, p. 178), strange attractors are multidimensional, as they are able to have many coordinates represented by the variables of the system.[11]

Thus, beyond the overall degrees of freedom resulting from the configuration of the operational space of the system, represented by state space, attractors, depending on their dimensionality, instantiate these degrees of freedom, which depend on the number of variables that are affected by the particular situation in which the system is embedded. Point and periodic attractors instantiate simple degrees of freedom, which include a limited number of alternatives for responding to environmental perturbations. Strange attractors characterizing higher-complex systems have higher-order degrees of freedom, which offer multiple alternatives to respond and adapt.

To conclude, the self-organization of a dynamical system involves reaching the stability of the system by means of an emergence from the interaction of the components of some self-sustaining operational patterns that can maintain the identity of the system in spite of external perturbations. These operational patterns define the

[10] Attractors have a basin of attraction, which includes the sum of the possible states to be occupied that are determined by that order pattern. In the case of strange attractors, due to their unpredictable character it is difficult to know, even in probabilistic terms, what position in the basin of attraction is to be occupied by the system.

[11] Strange attractors can also occupy intermediate positions between two dimensions. This means that their multidimensionality is fractal in the sense that it can be expressed by fractions and not as an integer (Kauffman, 1993, p. 179; Ward, 2002, p. 213).

degrees of freedom of the system from whose association the autonomy of the system results.

From the point of view of the part–whole relationship, the circularity that is at the origin of the system's self-organization determines the degrees of freedom of the system. The cohesion of the parts and their coordination with a view to adopting a unitary behaviour is due to the constraints within the system, which, by means of a double dynamics, i.e., endogenous and exogenous, determines the generation of a systemic whole, whose causal powers are exercised on the parts. From the point of view of dynamical system theory, the role of constraints within a system is explained by Juarrero's theory (1999, 2010b), which draws a distinction between constraints that limit the response options of the system, namely context-free constraints, and constraints that enable one to find new ways to act, namely context-sensitive constraints. Constraints imposed on the system from the exterior, which belong to the first category, determine the system to change from a state of equiprobability and independence, where anything can happen, to a determined state that reduces the degrees of freedom of the system to one alternative from the previous ones, whereas it cancels the others. If there are no new options for response, context-free constraints are limitative as they cannot be at the origin of the emergence of complexity, which offers a higher-order self-organization to the system.

Different to constraints that only push the system toward a certain state that is to be abandoned as soon as the external pressure disappears, Juarrero (1999, 2010b) stresses the importance of context-sensitive constraints, which are the result of relations set up between the parts of the system as a consequence of adding them. In this case, the consequence of cohesion is the interdependence of elementary particles, whose behaviour undergoes qualitative modifications within the newly created ensemble. Thus, context-sensitive constraints determine the emergence of new properties and generation of some higher-complex levels, which "enlarge the variety of states the system as a whole can access" (Juarrero, 1999, p. 138).

This is possible because context-sensitive constraints operate both bottom-up, by generating the conditions for the emergence of a higher organization, and top-down, by generating the boundary conditions that operate on the lower level. First, one can speak of first-order contextual constraints, which operate toward synchronising and correlating the particles that are at the same level of complexity. By coupling the components, first-order contextual constraints determine the emergence of a new operational space of the system, with more degrees of freedom than its components, which opens new response alternatives to the whole. Second, one can speak of second-order contextual constraints that are the result of the influence exercised by the new emergent level on its components so that they can behave in certain way. Thus, second-order contextual constraints represent the closing loop of the circularity relation among the levels of the system, whereby the higher-order pattern controls top-down the bottom level generating it.[12] In other words, the second-order contextual constraints restrain the degrees of freedom of the parts by diminishing the state space of the components (Juarrero, 2010b, p. 262) and increasing the probability of occurrence of certain events (Juarrero, 1999, p. 146), by configuring the bottom level according to the new higher organization of the system. Thus, new and higher-order degrees of freedom emerge in the system.

The result is that, according to Juarrero (1999), self-organization, due to first-order contextual constraints that operate locally at the level of the elementary particles, determining their cohesion, generates a new structure endowed with higher-order causal powers. The new structure operates globally on the ensemble of particles, conveying on them a different dynamics and having as a consequence the generation of a unitary and systemic whole. In other words, self-organization involves the dynamics of circularity between first-order contextual constraints that generate new degrees of freedom, enlarging the system state space (Juarrero, 1999, p. 145), and second-order contextual constraints that reduce the degrees of freedom of the components by reuniting and configuring them in more complex structures, which offer the system greater alternatives for responding do its parts.[13]

Put in these terms, one can say that first-order constraints generate first-order degrees of freedom, which entail the sum of all states that could be occupied by the new emergent whole. Whereas second-order constraints determine second-order degrees of freedom, which are a consequence of the complexity of the patterns that are configured in the multidimensional state space of the system. Thus, second-order contextual constraints correspond to the order parameters that, as organizing patterns, compress or enslave (Thelen, 1995, p. 57) the degrees of freedom of the components with a view to the emergence of certain behavioural patterns, with basins of attraction deeper than the components of the system have separately. The depth of these basins of attraction, which give dimensionality to attractors, is given by the number of system coordinates, which represent the variables that contribute to the generation of this pattern. Thus, the degrees of freedom of the system are not determined by the positions that could be occupied in the new operational space of the system, resulting from the addition of the degrees of freedom of the components, but rather by the

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[12] The part-whole relationship is described in terms of top-down causation (Juarrero, 2009, p. 89) or downward causation (Thompson, 2007, p. 426) whereby one can understand the causal efficacy of the higher level, which operates by structuring the lower level, in the sense of modelling and limiting the state space of the components according to the requirements of the higher emergent organization.

[13] This means that self-organization operates according to the principle "the whole is more than the sum of its parts" (Baumeister and Vonasch, 2011), which means that the degrees of freedom of the system as a whole are not only a mere addition of degrees of freedom of its components, as the former are of an higher level. The system, owing to the emergent properties, has degrees of freedom that provide a higher degree of autonomy than that of its parts. From this perspective, self-organization as a consequence faces not just the limitation of the degrees of freedom of the system components, but also the increasing complexity of the degrees of freedom of the system and in this way its autonomy.

dimensionality and complexity of the patterns that bring together the states included in this operational space.[14]

As a result, self-organization involves the generation of a new hierarchy of levels where transition to a higher level of organization creates the possibility of accessing some increasingly complex degrees of freedom by adding new coordinates in the state space, which are represented by the system variables. This means that self-organization involves generating and re-generating constraints that modulate the flow of energy and contribute to the recursive maintenance of the organism (Ruiz-Mirazo and Moreno, 2004, p. 241). In the process of generating constraints whereby the organism self-creates the rules for its organization, the living system self-regulates the degrees of freedom of its components. By regulating and modulating the degrees of freedom of its parts, the system creates its degrees of freedom as a whole. In this way, one can define the degrees of freedom of the system as representing the number of possible positions or states the system can occupy, considering its independent variables, without breaking the exogenous or endogenous constraints it undergoes.

To conclude, it results from the convergent approaches of the dynamical system theory in topological terms and from the part–whole relationship perspective, whereby through self-organization the degrees of freedom of the system are produced, which together give its degree of autonomy. This means that the processes underlying self-organization and autonomy should be understood from the perspective of the production of degrees of freedom of the system. Thus, in terms of dynamical systems theory the autonomy of a living system means the self-production (autopoiesis) of its degrees of freedom, the self-regulation of the degrees of freedom of its components, and the self-sustaining of internal processes in order to maintain and to enlarge the degree of freedom of the system. Consequently, the emergence of identity and unity of the system is inseparable from generating its degrees of freedom, whose level of complexity, given by the multidimensional patterns instancing them, offer varied alternatives for responding to environmental perturbations.

3. Types of Autonomy in Self-Organizing Systems

Approaching the autonomy of living organisms in general, it can be inferred that this is a gradual matter given by the self-organization level of the organism and by the complexity of the degrees of freedom the organism has gained.[15] From the point of view of the process of autopoiesis, which means the generation of the system's organization,

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[14] The possibility of accessing the states contained in this operational space is also the consequence of the complex abilities of the system that can determine the emergence of some strange attractors with higher-order degrees of freedom.

[15] Self-organization involves creating new hierarchic levels where each level has a certain degree of complexity. These levels, which are interconnected, provide increasingly developed degrees of autonomy so that the lower levels (e.g., material) are less autonomous, whereas the higher levels, which are supported by the lower ones (e.g., cognitive level), could have a greater level of autonomy (Collier, 2004, p. 166-167).

the degree of autonomy of a living system is a consequence of the way it regulates and modulates its internal processes in order to adapt to environmental conditions. For highly organized organisms, the question of degrees of autonomy is raised in terms of the ability to control their degrees of freedom due to their mechanisms for adaptation to environment. As a result the degree of autonomy of a living system is given by the degree of complexity of the organism's mechanisms, whose role is to maintain its identity and equilibrium with the environment.

Starting from these premises, it is difficult to quantify the degrees of autonomy characterizing the living systems, their diversity being a consequence of the heterogeneity of living kingdoms, where each organism exhibits its own kind of autonomy. However, referring to the multidimensionality of the degrees of freedom of a living system, which depends on the degree of self-organization and complexity of the organism, one can distinguish three types of autonomy: minimal or basic autonomy, sensorimotor autonomy, and strong autonomy.

Minimal Autonomy

Constitutive autonomy of the system (Froese *et al.*, 2007; Froese and Ziemke, 2009), or minimal autonomy (Barandiaran and Moreno, 2008), is the result of the metabolic activity of the organism that generates a minimal identity constituted by the biological processes that sustain the existence of the living system. This minimal identity does not involve complex biological structures that would offer self-awareness to the organism, rather it is a consequence of the (internal) recursive patterns forming at the level of the organism as a result of the constitutive processes.[16] Constitutive autonomy involves generating an identity as a consequence of the operational closure of the organism, whereby it experiences an on-going self-constituting process in order to prevent its disintegration (Froese and Di Paolo, 2011, p. 6).

Preserving the minimal identity of the organism also involves a physical boundary, which separates the organism from the environment, thus becoming a prerequisite for the emergence of its constitutive or basic autonomy (Ruiz-Mirazo and Moreno, 2004, p. 241-247). The basic type of biological boundary is the membrane, whose purpose is, on one hand, to protect the internal processes of the system against environmental perturbations, and, on the other hand, to control the energy flows necessary to its functioning. Membrane demarcates the space necessary to the system so that its basic processes, which regulate its internal responses and through which it communicates with the external world—i.e., catalysis and energy currencies—, are able to function, as the membrane is a boundary with selective permeability and with channels of interaction with the environment, as the result of local and global constraints (Ruiz-Mirazo and Moreno, 2004, p. 245; Moreno and Etxeberria, 2005, p.

[16] From this perspective, Thompson (2007, p. 260) also speaks of a kind of biologic self, "because the dynamics of the system is characterized by an invariant topological pattern that is recursively produced by the system and that defines an outside to which the system is actively and normatively related".

163). This means, on one hand, that membrane is the consequence of internal constraints resulting from the cohesion of the elementary particles and from reactions that connect these particles, and, on the other, that it has causal powers exercising top-down constraints on the basic level by aggregating the elementary particles into a functional whole that contributes to carrying out the same tasks (i.e., the survival of the system within its environment). Thus, membrane is the consequence of endogenous and exogenous constraints that are at the origin of the system's self-organization, playing an important role in its adaptation. Owing to its sensitivity to changes in the system environment, it provides a basic form of coupling and interaction between organism and the environment in which it is embedded, so that the living system can preserve its identity and unity.

Consequently, constitutive or minimal autonomy is the level of autonomy that characterizes living systems with minimal forms of life, which offer responses to the environmental perturbations only by changing their internal organization. Such organisms respond to external changes only at a metabolic level, determining the activation of some adapting processes with a view to preserving the biological integrity of the system (Moreno *et al.*, 1997, p. 115). This means that systems with minimal autonomy have the ability to give automatic responses to the external perturbations, which are the consequence of the mechanisms that would ensure the survival of the organism. In this case, one can speak of a metabolic agency (Moreno and Etxeberria, 2005, p. 163) as a form of agency characterizing a biological organism, which, even if not endowed with self-reflective abilities, has basic intentionality, given by the orientation of the living system toward its environment in order to find the resources required to work properly and preserve its basic functions.[17]

Consequently, minimal autonomy—as a basic form of autonomy of living systems—is not a gradual property of an organism (Froese *et al.*, 2007, p. 459) but comes from the internal biological processes of a living system with a basic structure that generates minimal forms of identity and unity. Minimal autonomy is a property of the biological domain, i.e., of living forms that do not possess cognitive abilities, not even incipient ones. In terms of the dynamical system theory, minimal autonomy is constituted by simple recursive patterns, existing at the level of the system, which generate an order parameter with lower complexity instantiating simple degrees of freedom.

[17] Such an agent, understood in the minimal sense, would be defined as "an autonomous organization that adaptatively regulates its coupling with its environment and contributes to sustaining itself as a consequence" (Barandiaran *et al.*, 2009, p. 367). In other words, a minimal or biological agent is not only the passive receiver of changes in the world but also has the possibility of regulating the flow of information coming from the world, which means that it uses the information received from the environment for its own adaptation (Di Paolo, 2005, p. 443). Therefore, it is also called an adaptive agent, its aims being to adapt to the environment, which entails maintaining some recursive interactions with the environment (Froese and Di Paolo, 2011, p. 10).

Sensorimotor Autonomy

Unlike organisms with simple organization, which have a basic coupling with the world based on the regulation of the organism's internal responses, organisms with a nervous system achieve adaptation through the world's being enacted in a dynamic feedback loop, by connecting sensory processes to motor ones, which opens the organism to the possibility of a nonlinear interaction with the world. From the biological point of view, there is a great difference between organisms characterized by minimal autonomy and those with a nervous system. This means that the degree of complexity of the latter determines the emergence of a level different from the metabolic one, with different dynamics (Moreno and Etxeberria, 2005, p. 167) that offers the system the possibility of accessing other degrees of freedom. This new level, which is dependent on the metabolic one, exercises constraints on the latter, determining new behaviours to appear through the emergence of some new degrees of freedom that would expand the system's alternatives to respond.

In other words, the nervous system, by coupling the sense organs with effectors, integrates the agent into a mobile unity (Thompson, 2007, p. 244), beyond the biological one, which generates some new patterns of action. The organism's coupling with the world is no longer achieved by means of a physical boundary, which, as an interface, facilitates exchanging of energy with the surrounding world. But owing to the nervous system, the organism is integrated into the world through some sensorimotor loops that reunite the internal processes, the body, and the world in a dynamical pattern. Thus, perception is detached from the metabolic responses of the organism, being connected with its movement ability,[18] the two mutually conditioning one another: perception is influenced by the position and movements of the body, and the movements of the body are determined by the need for orientation within the environment, which results from the organism's needs to adapt and survive.

In other words, the organism's perceptual space is structured according to the opportunities to act that are identified in the environment. This means that organisms do not perceive the world in a neutral way, but objects around us are perceived according to their utility in accomplishing our actions. The consequence of the organism's sensorimotor coupling with the environment is the perception of the world according to the affordances (Gibson, 1977) which help the organism to achieve its goals. In terms of the dynamical system theory, affordances facilitate the attractors of the dynamical cycle perception–action by integrating the organism-environment system in a dynamic pattern of action. Affordances do not involve higher-order cognitive abilities, but they are a non-inferential and non-representational way of perceiving the world from the perspective of the sensorimotor abilities of the organism. These abilities

[18] One can also speak about incipient forms of motility in the case of simple organisms, which lack a nervous system; but in this case, motility is merely a result of metabolic processes, i.e. "an extension of the set of mechanisms that are required for self-maintenance" (Moreno and Etxeberria, 2005, p. 167).

demarcate the space of action of the organism within the environment, called its niche, which consists of all the affordances perceived (Silberstein and Chemero, 2011, p. 7).[19]

Consequently, sensorimotor abilities determine the emergence of a different type of agency, which does not merely involve the regulation of the internal processes but also a new way of relating the organism to the world, whereby the former does not based only on internal adaptive reactions alone, but also by gaining information that would improve its abilities to act. Owing to the sensorimotor loop, organisms exercise a feedback control (or closed-loop control) on their variables, where "the inputs provided to the system depend on its current outputs, which are often affected by the current circumstances" (Eliasmith, 2009, p. 137), which means that the world of the organism is continuously constituted anew, by revealing new ways of acting in the world. Thus, the relation of a sensorimotor agent with the world is characterized by what Merleau-Ponty (2005) calls an intentional arc, which corresponds to the set of bodily skills, whereby an organism responds to changes in the world, directly, without the need for cognitive representations. In other words, the world is perceived at the pre-reflective level in terms of the motor abilities of the organism, which involves only direct responses and spontaneous adjustment to changes in the world, without the need for cognitive reflective abilities.

Even if sensorimotor coupling does not involve higher-order cognitive abilities, and sometimes not even a nervous system (Van Duijn *et al.*, 2006), one can speak in this case of a basic or minimal cognition. This is a basic embodied cognition, which entails that information from the environment is processed by the sensorimotor structures and transformed into motor impulses that lead to the performance and success of an action. This means that, through the sensorimotor coupling with the world, the organism receives information necessary for its adaptation since it has access to a new epistemic level, beyond the one generated by the metabolic processes (Etxeberria *et al.*, 1994). Moreover, motility, together with the emergence of the nervous system, leads to a higher organization of the organism and to the generation of some cognitive phenomena, such as emotions and awareness (Moreno and Etxeberria, 2005, p. 170).

Consequently, sensorimotor autonomy entails that organisms are endowed with basic cognitive resources. They are capable of behaviour, which means that they not only simply offer a response as a result of constitutive coupling with the environment, they actually control their interactions with the environment and can pursue the achievement of some goals external to themselves (Di Paolo, 2005). Such an organism, with a multicellular architecture, whose adaptation relies on motility and whose body is controlled by a nervous system, is characterized by behavioural agency (Barandiaran and Moreno, 2008, p. 336). This type of agency entails a type of autonomy, which even

[19] From this perspective, sensorimotor abilities depend on the autonomy of the organism, which involves "the maintenance appropriate relations among the nervous system, the body and the environment, i.e., the maintenance of affordances and the cognitive-phenomenological niche" (Silberstein and Chemero, 2011, p. 10).

if it involves detachment from the metabolic level, entails the coupling of the organism with the world with simple patterns such as cycle attractors, which have degrees of freedom with lower dimensionality. As a result, although sensorimotor autonomy enhances the degrees of freedom of the organism by detecting new possibilities to act within the environment, it remains dependent on the responses to external perturbations without instantiating any higher-order behavioural pattern.

Strong Autonomy

In case of the beings with higher-order cognitive skills, one can speak of strong autonomy, which characterizes an agent that has the ability to control its alternatives to respond and to be consciously aware of its degrees of freedom. This means that beings with higher-order cognitive skills have the possibility to choose their own goals, independently of environmental conditions or immediate organic needs, can imagine plans with regard to future actions, and can conduct counterfactual reasoning, imagining situations where things could have happened differently (Wilson, 2002, p. 626). This is possible as such organisms have the advantage of operating with offline cognition, owing to the existence of a higher-order level, besides the biological and sensorimotor ones, which has the ability to process information and create responses to environmental perturbations, detached from the energetic current flow to which the organism is exposed. In other words, organisms with higher-order cognitive abilities are capable of ideomotor action, which does not represent a mere response to external events (i.e., stimulus-based actions), but involves behaving according to some internal aims and thoughts (Waszak *et al.*, 2010, p. 185).

Higher-order cognitive skills are the consequence of the complexity of the brain, which has the possibility to create patterns of action in a nonlinear way (Kelso, 1997, p. 257). The brain of such an advanced organism is itself a dynamical system, which it self-organizes through the large-scale integration of neurons situated in various areas of the brain, in patterns that determine responses by causing a certain behaviour in the organism. This property of the brain whereby autonomous parts can interact and influence one another, creating a pattern of action without losing its independence or part thereof, is called metastability (Kelso and Tognoli, 2009, p. 107). In the metastable regime, the brain creates a dynamic state space whose coordinates are given by the nonlinear interaction of its regions with various functions, which determines the emergence of patterns with higher-order degrees of freedom.

In the same way as a dynamical system, the brain alternates between states of instability and stability, by the emergence of some attractors, which, owing to the nervous system, participates in the sensorimotor cycle of coupling to the world, determining the emergence of some multidimensional behavioural patterns. Such a brain is capable of strange attractors, with an unpredictable trajectory, which determine stochastic chaotic behaviour (Freeman, 1999, p. 153), with many and complex degrees of freedom. Moreover, the internal relation of circularity, which characterizes dynamical systems, acquires a semantic content (Juarrero, 1999), owing to the emergence, by means of the aggregation of neurons, of a new metacognitive level that is consciousness. This appears to be a globally coherent activity operating as an order parameter (Freeman, 1999), which exercises top-down control, voluntarily and not automatically on the bottom level (Frith, 2009, p. 203). Thus, consciousness facilitates awareness and coupling of the cognitive contents of our thoughts, which are the emergent properties of the patterns of action created at the level of neuronal ensembles.

Consciousness, as a biological phenomenon representing the highest level of cognitive complexity, is at the origin of another type of intentionality, different from the one based on bodily skills, which involves patterns of action with conscious content resulting from the coupling of the organism with the world. These patterns of action, generated by the higher cognitive level to determine the neuronal level to trigger a certain behavioural response, are intentions. Intentions are not the direct causes of our actions but they play the role of context-sensitive constraints, being higher-dimensional, neurologically embodied attractors, which underlie several types of neurons, including the motor ones (Juarrero, 2010b, p. 267); they play the role of structural causes, which guide our actions, programming our behaviour to act in a certain way within certain circumstances (Slors, 2013, p. 107). One can say that such intentions define the vector field of the system, associating to each point in the system's state space a direction of movement, which will be followed in case such a pattern of action is activated.

Consequently, higher-order cognitive agents have the ability not only to monitor and regulate the responses of the organism that appear as bodily or cognitive patterns, but also to control behaviour through the possibility of including intentions within medium and long-term action plans, which are beyond the immediate priorities of the organism. This is possible through regulating the living system's own activity by voluntarily assuming certain norms, with no relation to the basic processes of the organism, but acquired from other forms of life (Barandiaran *et al.*, 2009, p. 372). This means that, in the case of higher-order cognitive agents, not only is interaction with the environment important, so is interaction with similar beings, where new possibilities to extend the autonomy of the living system emerge. Beings with higher-order cognitive skills are capable of participatory sense-making (De Jaegher and Di Paolo, 2007), whereby they coordinate their actions, producing, together with other similar living systems, new significances and values that are not the consequence of the organism's adaptability, but lay at the basis of the social and cultural world. In this new world of meanings, the agents, by choosing the values and norms to follow, have the possibility of reaching a new level of autonomy that cannot be achieved by any other biological organism.

Consequently, strong autonomy represents the highest level of autonomy that a biological being can reach, which involves not only a new identity, but also a personal autonomy.[20] This is possible owing to the complexity of cognitive structures with which such organisms are endowed, which provide them with the ability of a higher-order control of their own actions and degrees of freedom as a result of the emergence of consciousness. Strong autonomy involves the conscious control of the multidimensional degrees of the freedom of the organism, which provides the organism with an unlimited and varied array of open-ended responses to environmental challenges.

4. Conclusion

To conclude, one of the consequences of the capacity of living matter to pursue self-organization is the emergence of autonomy of the living system. Consequently, any living system has some autonomy, given by the level of its evolution as a biological organism and the complexity of its internal organization, which is given by the way it is coupled with the external world and controls its responses to environment perturbation. Taking into account that any living system is also a dynamical system, the result is that autonomy depends on the degree of freedom of the whole system, whereby the organism enhances its possibilities for adaptation to environment perturbations.

Therefore, the autonomy of an organism is a gradual problem that involves, in its minimal forms, the emergence and preservation of the organism's identity and unity. This is minimal autonomy that is the result of constituting processes of self-organisation, which involves simple degrees of freedom. In organisms with a nervous system and minimal cognitive resources, autonomy is defined in terms of second-order degrees of freedom, but with lower dimensionality. It is generated by sensorimotor skills, which open new possibilities for the organism to act in an environment, but remain dependent on the external conditioning. However, situation is different in the case of organisms with higher-order cognitive skills, which involve the conscious control of actions, which means the possibility to access some multidimensional degrees of freedom. Put in these terms autonomy depends on the ability of the organism to access some degrees of freedom of higher complexity, to enhance its degree of freedom through its coupling with the environment, as a result of its bodily skills, and to consciously control and monitorize its degree of freedom, as a result of its higher-order cognitive skills.

[20] Generally speaking, a person is a being endowed with higher-order cognitive skills who behaves according to her own set of values and norms. From this perspective, one can say that "autonomy is a second-order capacity to reflect critically upon one's first-order preferences and desires, and the ability either to identify with these or to change them in light of higher-order preferences and values" (Dworkin, 1988, p. 108).

Chapter 2. Autonomy and Control: Dynamics of Degrees of Freedom in Living Systems

Introduction

According to the current enactivist approach of biological autonomy (De Jaegher, H., Di Paolo, E., 2007; Di Paolo, E.A., H. Iizuka, 2008; Barandiaran, X. E., Di Paolo, E., & Rohde, M., 2009; Ruiz-Mirazo, K., Moreno, A., 2012; Moreno A., Mossio M., 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. 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 organism and its environment (Moreno A., Mossio M., 2015, p. 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 self-constitute by producing and regenerating the components that contribute to the accomplishment of the constitutive processes themselves. This means that the system has the capacity to self-produce (*autopoiesis*) and self-maintain. Moreover, the system's identity and unity are consequences of the *homeostatic* character of the system, which implies maintaining internal unity by preserving the relations between its parts, despite the external fluctuations and changes.

An important result of the autopoietic process is the emergence of a demarcation line between the organism and external world, which contributes to delimit the internal space of the organism and to preserve its internal processes. This *boundary*, which is endogenously constituted, facilitates energetic exchanges with environment, whereby the organism gets the resources necessary to its functioning as well as information about the external changes. Hence, despite the closeness character of internal organization of the organism, any living system is an *open system*, which has energetic and informational exchanges with the environment where it lives. This means that, on one hand, living system is characterized by a *structural coupling* with the external world, meaning that organism and environment mutually influence each other as they are in an interdependence relationship (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 the energy from external world, consuming it in order to maintain its internal organization.[21]

Starting from here, we can say that an autonomous living system is a metabolic organizational closed system, which constitutes its identity and internal unity by producing and constantly maintaining its internal processes and components, considering the fluctuations from environment. Moreover, an autonomous living system is an open system, which is subject to a flow of energetic and informational exchanges 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 unity of organization of its internal levels (Bich, 2012, p. 217; Moreno A., Mossio M., 2015, p.vii), autonomy is understood in operational terms. The organizational view thus approaches autonomy from the perspective of processes that contribute to generating and constantly maintaining the internal organization of living system as well as to preserving the structural relation between organism and environment. But understanding an autonomous living system, solely from an autopoietic perspective, i.e. from the point of view 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 does not take into account 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 be understood from the perspective of possibilities to respond and act which the dynamical system, as a whole, can have.

It results, in my view, that autonomy of a living system – not 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 the 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 abilities to adapt of the organism open a new space of action, at the level of the whole, with higher possibilities to respond to the external perturbations that its independent parts do not have. Therefore, a holistic understanding of autonomy of a living system implies an explanation from the perspective of the state space configured by the dynamics of its components[22] and their degrees of freedom. In my approach, autonomy of a living

[21] Due to the flows of energetic exchanges with the environment there is a risk to increase entropy of the system, which endangers the level of self-organization of the system. Consequently, adaptative systems function according to the free-energy principle (Friston, 2010), according to which an important condition to maintain the internal organization of the organism is to minimize its free energy, by anticipating external changes.

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

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.

Hence, to complement the organizational approach, in the first part of this paper I will define autonomy of a living system, in the terms of degrees of freedom it has as a dynamical system subjected to various exogenous and endogenous constraints. Another important aspect for autonomy of an organism is represented by its control mechanisms, which regulate the dynamics of internal relations among components and external ones between organism and environment. This issue will be addressed in the last two parts of the article, where I will 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 how the self-control mechanisms of living systems function, 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 biological development.

1. Autonomy and degrees of freedom

1.1. Enabling constraints and emergence of degrees of freedom

According to the organizational view, at the origin of self-maintenance of a living system, which is a fundamental requirement of biological autonomy, lies the 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 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 certain behavior. In this case, constraints are considered as limitative conditions, which, by introducing new variables, reduce the systems' possibilities of action. In other words, constraints eliminate certain degrees of freedom of the parts, by introducing them into equations of motion, which will describe the trajectory of the system at a certain moment (Pattee, 1976, p. 159).

But, if constraints would have only a limitative role, the system would have fewer alternatives than its parts (Juarrero, 1999, p. 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. Notwithstanding, the degrees of freedom of the whole are not a simple addition of degrees of freedom of the parts as the system 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, p. 386; Moreno, Mossio, 2015, p. 14), as they determine the emergence of some 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 merely is a matter of different interpretation, given by the time scale when their outcomes were approached. Hence, where across longer time scales, constraints can be considered to be limiting, 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). Thus a chain of constraints is generated, which, on one hand, are in a mutual dependence, and, on the other hand, enable the emergence of 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 relational properties of the parts (Juarrero, 1999, p. 133). Starting from here, Juarrero makes the distinction between context-free constraints and context-sensitive constraints (Juarrero, 1999, 2010). 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 some new properties, by enlarging the number of states the system can access. The way context-dependent constraints act should be understood, starting from Juarrero's distinction (1999, 2010) between constraints operating bottom-up (first-order contextual constrains) and those operating top-down (second-order contextual constraints). The first result from the coupling of the parts of the system, determining a higher-order degree of organization of the system, and thus enlarges its state space by finding some new alternative to respond. The others are the result of causal powers exercised by the new whole on its parts, which enables a new dynamics to the components of the whole, 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 its 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.[23]

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 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, p. 61), and some new degrees of freedom. In other words, constraints enable new dimensions of state space of living system, which, in the case of biological systems is unprestatable,

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

forming an "adjacent possible", from the point of view of evolution (Longo, G., Montévil, M., & Kauffman, S., 2012). In this new state space, made of the totality of states of the system's variables, the organism defines its degrees of freedom as a whole.[24]

On the other hand, due to the enabling character of constraints, the system occupies a certain state in its state space, which is a consequence of all the parameters acting on the system at a given moment. In other words, the new order of the system enslaves and limits the degrees of freedom of the components, achieving thus a selection of the degrees of freedom which will characterize the system at a certain moment. The state of the system involves a higher-order configuration of the parts into a systemic whole, considering the responses it can give to the fluctuations of environment, which represents an instancing of the system's degrees of freedom at a certain moment. From this double dynamics of the enabling character of constraints results autonomy of the organism, understood as a complex system with multiple and various degrees of freedom.

1.2. Degrees of freedom in living systems

Emergence of closure implies the realization of a hierarchy of constraints whose complexity is given by the organizational level of the organism. From the perspective of the internal organizational dynamics, organisms are multi-layer structures, whose coordination determines the state space of the system to enlarge, creating thus a multidimensional state space. This process enables the emergence of some behavioral patterns with a large basin of attraction and with trajectories more and more unpredictable. 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, and due to the constituent structures that cannot 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, instantiate complex patterns with higher-order degrees of freedom, whose number, depending on their complexity, is undetermined. Thus, autonomy of a living system

[24] From this perspective, constraints can be considered endogenous and exogenous parameters of the system, which act on their variables, determining them to describe a certain trajectory in the systems' state space.

understood in terms of degrees of freedom, is determined by the number and complexity of the patterns that can emerge in state space of the system.

From the biological point of view, the degrees of freedom are the consequence of the abilities of the organism (such as the nervous system, cognitive skills), which, depending on their complexity, provide the organisms with different possibilities to adapt and respond to environment.[25] The biological structures of the organism constitute its degrees of freedom by uniting and coordinating the degrees of freedom of the components. The biological structures represent the potentialities of the degrees of freedom of the organism, endowing the organism with behavioral flexibility. The degrees of freedom of an organism are constitutive parts of it ever since birth, they are not acquired, but they are only enhanced throughout the lifespan of the organism.

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.[26] Each of these types of degrees of freedom have their own complexity and give the possibility of decoupling from the lower levels, by accessing new ways of response to the challenges of the environment.

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 as those of a physical system (Pattee, 1973, p. 44), whose degrees of freedom are given by the way it was designed. A living system has potential degrees of freedom, which can be achieved, depending to external circumstances, by the way internal mechanisms function and by finding the internal and external resources to reach its maximum degree of autonomy. [27]

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[25] Nervous system enables a better coordination of the degrees of freedom of the body, together with their increase by identifying new possibilities of acting in the environment. Consciousness provides both the possibility to control the degrees of freedom of the organism, by consciously monitoring them, and of their enhancement, by including them into larger plans.

[26] According to Pattee (1976, pp. 158-159), the degrees of freedom of a system are classified depending on the constraint 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 about metabolic degrees of freedom (characteristic to simple organisms, with single-cell organization), sensorimotor degrees of freedom (in case of organisms endowed with nervous system), and higher-order cognitive degrees of freedom (in case of organisms endowed with consciousness). Even if such classification merely outlines the biological field, its goal is to distinguish among various degrees of autonomy with which the biological organisms are endowed.

[27] According to the optimality principle (Tschacher, Haken, 2007, p. 7), organisms tend to adapt as adequately as possible to the environment, by selecting the most efficient behavioral patterns. This means that they aim, by their actions, is to achieve their maximum autonomy. 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, autonomy of a living system is given by the totality of degrees of freedom a system has and control. On one hand, their number and complexity is given by the dynamics of the levels of biological organization of the system. On the other hand, 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 and the degree of centralizing its actions wherefrom the subjectivity of the organism results.

2. 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 the internal constraints 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, p. 42). Thus, reduction of the degrees of freedom is achieved and selection of those degrees of freedom that are to define the state of the system. 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 having cognitive skills, which "steer" the organism toward a certain direction (Keijzer, 2003, p. 245). This means that the organism is steered by its intrinsic factors, which, depending on the influence on the system and the instantiated behavioral patterns, give the autonomy and self-determination of the system.

An important contribution to this process has the degree of biological development of the organism, which by means of its structures, enables 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, pp. 153-154). Control can be a weak one, as homeostasis, regulation or modulation, which entails managing the degrees of freedom of the organism. Or, one can speak about a 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 the dynamical systems, constraints are control parameters of the system (Van Orden, Kloos, Wallot, 2011, p. 632), which restrain the degrees of freedom of the systems' components, determining the emergence of a highly-organized new structure. This new structure, emerged at a macroscopic level, plays the role of an order parameter, or collective variable, which determines that its parts to behave in a certain way. By means of control parameters, order parameter selects the relevant degrees of freedom and modulates the autonomy of the system at a given time.[28] 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, p. 54), 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. On one hand, this process is achieved 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 means the control of the degrees of freedom of the system, which are the result of some simple behavioral patterns, in order to preserve autonomy of organism.[29]

The level of complexity of the degrees of freedom of the organisms depends on the organism's control mechanisms, which are the consequence of its internal development degree. Thus, in the case of basic organisms, such as single-cell ones, control is carried out in two ways: on 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 the internal changes. Boundary control is carried out by the membrane as an organ that marks the limits between organism and environment, hence the communication between them. Membrane is a structure that is sensitive both to the environmental changes, providing information to organism with respect to external modifications, and 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 internal environment of the cell, membrane constrains the single-cell organism to be in a certain state (Mossio, Sabordo, Moreno, 2009, p. 11) 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, membrane constitutes its phase space (Bich, 2015), within which the organism configures its possibility of action, 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

[28] From this perspective, Keijzer (2003, p. 246) considers that the specificity of biological systems is given by the possibility to manipulate their control parameters and thus to form order parameters which would conduct their actions In this approach, genes are the control parameters of the organism, which influence the way the living systems develop and, implicitly, the degrees of development.

[29] Homeostasis is not a form of strong control that would imply enhancing the degrees of freedom of the system. But it is a basic form of control, to the extent that it relies on managing the existing degrees of freedom so as not to endanger the system's stability and existence.

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. 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 organism and the external one, one can also speak of an internal control, consequences 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 the adaptation to the changes in the environment and maintenance of the internal organization of the organism.[30]

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, p. 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 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.

From the organizational view perspective (Moreno, Mossio, 2015, p. 34), regulation is the consequence of second-order constraints, which are the result of organizational closure of the organism and of 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.[31] Furthermore, regulation is considered to be the consequence of some subsystems, which are the result of the organism's organization, that act recursively on the constitutive regime to provide as appropriate a response as possible to the challenges of environment (Bich, Mossio, Ruiz-Mirazo, Moreno, 2015, p. 15). In this interpretation, regulation is regarded as a consequence of a circular organization existing in the organism, which is the result of the network of

[30] 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, p. 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 adapt the organism to the environment.

[31] 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.

interdependent constraints in the organism (Bich, Mossio, Ruiz-Mirazo,Moreno, 2015, p. 9).

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.[32] In this double dynamics, the components are those which determine the emergence of an order pattern, which in turn determines the new configuration of the components. The regulative control is thus exercised by the dynamics between the order parameter and control parameters, which provide a certain kind of stability to the system at a given time.

An effect of regulation is re-organizing of the internal state space of the system by the emergence of an order pattern at a higher level, which introduces new degrees of freedom within the system. In other words, subsystems that contribute to regulating the organism imply a dynamic decoupling from the constitutive regime, specifically to act thereon, which has an effect the emergence of some variables that would not be dependent on the constitutive regime and thus, the emergence of new degrees of freedom (Bich, Mossio, Ruiz-Mirazo, Moreno, 2015, p. 17). Consequently, regulation, as a basic form of control of the organisms, involves the emergence of some new levels of complexity within the living systems, which has as effect the emergence of new degrees of freedom, beyond the basic level of the physical and chemical processes. However, considering 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, determines the emergence of an incipient form of self. This form of self is, on one hand, the result of the recursive patterns emerged at the level of the living system, which it maintains (Thomson, 2007, p. 260). Together, these behavioral patterns, maintained owing to the homeostatic character of the organism, achieve its operational identity that is the most basic form of identity. On the other hand, self is the result of the organism's sensitivity, which responds as a whole to the external challenges. This can be explained by the process of resistance to variance (Rudrauf, Damasio, 2006, p. 438), which implies the organism as a whole and can be also met in simple organisms. As a rule, we can say that resistance to variance is the inertia of any living organism (not only of those with cognitive skills) confronted with changes, manifested in the tendency to maintain its internal equilibrium and its unity. According to such an approach, this process entails the existence of monitoring and control structures which would provide a response of the organism as a whole to the ongoing perturbations of the environment.

[32] 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, p. 324).

It results that from the regulatory mechanisms and processes of the organism emerges a form of self, in its most minimal form. This metabolic self (Deacon, 2011) or biological self (Thomson, 2007, p. 260) is not a centralized structure involving higher-order cognitive skills, but it 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 the 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 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. And, on the other hand, because the internal control mechanisms regulate only the degrees of freedom of the internal components and processes, without enhancing the overall degrees of freedom of the system. Without a higher-order biological control structure (similar to nervous system), which would join the degrees of freedom of the components in complex structures, there is no possibility for some higher-order degrees of freedom to emerge. It results from here that simple organisms have a minimal autonomy, characterized by behavioral patterns with simple degrees of freedom, which merely provide automatic responses to the environmental perturbations.

3. 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 development of the biological complexity of a living system, which involves the development 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, 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 various and unpredictable behavioral patterns that are not conditioned by the basic constraints of the organism. To emergence of these behavioral patterns, with new and increasingly complex degrees of freedom, the advanced control mechanisms of the organisms contribute, such as the nervous system or consciousness, which enables higher-order cohesion of the variables of the system.

Hence, the consequence of enhancement of biological complexity is the increase of their 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 kinetic control, behavioral control, cognitive control, etc., which enable the decoupling of the organism from the basic level of the metabolic reactions. Furthermore, the control mechanisms of multicellular organisms determine the emergence of some types of self, such as the sensorimotor self or cognitive self, which, depending on the degree of complexity of the organism, manifest themselves 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 dynamics, make 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 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, p. 337; Moreno, Mossio, 2015, p. 175). In other words, the system enables the enhancement of the degrees of freedom of the organism in two ways: on 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 with the world is no longer given by only 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 behaviors, according to affordances (Gibson, 1977) that are perceived directly in the environment, without the need for some higher-order cognitive skills.[33] Thus, between organism and environment, one can no longer speak about a simple cyclic loop, whereby the organism regulates its behavior depending on the information received from external world. But this loop becomes more complex as the organism perceives new possibilities of action in the environment that would provide the living system with the possibility to choose from among more options of response. This ability increases degrees of freedom of the system and thus, its 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 relations among the neurons, which create recursive patterns governed by their own laws (Moreno, Etxeberria, 2005, p. 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

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

the organism. A nervous system is a dynamical system, with its own autonomy, that can generate and coordinate a variety of states of the system (Moreno, Mossio, 2015, p. 175). As dynamical system, nervous system configures a multidimensional state space of the system with multiple degrees of freedom (Barandiaran, Moreno, 2008, p. 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 the degrees of freedom of the living system to diversify by bifurcation of the patterns providing the possibility to configure more ways of actions. The patterns of actions thus formed in the multidimensional state space of the nervous system, even if they have more complex degrees of freedom than those of metabolic reactions, by including more variables of the organism-environment coupling, are limited to the internal and external pressures of the organism. They represent only responses to the variations of the environment or to internal needs, being only patterns of action with a predictable and determined trajectory.

The emergence of a network of sensorimotor patterns, which is to coordinate the relation of the organism with the world, has as a consequence the modification of the biological self of living system. Instead of the diffuse metabolic self that is at the origin of an incipient subjectivity, an extended self emerges, which acquires the awareness of the external world and of its own body, together with exercising its skills. This sensorimotor self (Thompson, 2007, p. 49), is the consequence of the new patterns of action of the system, with multiple degrees of freedom, the result of the integration, due to the nervous system, body, and environment in 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 them with a view to their enhancement, depending on the circumstances of the environment. The nervous system as 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, but which are connected to 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.

Moreover, within the process of evolution, nervous system enables the emergence of organisms with cognitive resources (Moreno, Umerez, Ibañez, 1997, p. 113), in various degrees, which represents another level of biologic complexity, endowed with a higher-order degree of autonomy. The cognitive level implies the generation of an informational level providing maximum flexibility to 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 the events in the real world, building internal models of reality based on which the organism conducts its actions (Moreno, Merelo, Etxeberria, 1992, p. 70; Moreno, Etxeberria, 2005, p. 171). Furthermore, the higher-order cognitive skills, such as consciousness, can organize the parts of the organism in high-order configurations in order to fulfilling complex tasks, assigning specific functions to them that they would never have had outside the system. Thus, consciousness contributes to enhancing the control of the system by generating a new semantic-informational level (Juarrero, 1999, p. 85), 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 in long-term plans that aim at reaching goals that the organism has consciously set[34], as well as decision making, in an inferential manner, by being aware of the reasons behind them.

This is possible due to the brain, which is a system with its own dynamics, a consequence of the patterns resulted from the cooperation of its parts (Kelso, 1997, p. 2). As a dynamical system, brain has the property to control and influence the dynamics of all the other subsystems within the organism. An important role in the process of controlling the behavior of the organism is played by consciousness, namely 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.[35] In other words, consciousness can generate not only cycle attractors, as simple loop patterns, but also strange attractors, with unpredictable trajectories and higher-order degrees of freedom. Thus, consciousness creates a state space of the system with multiple and complex degrees of freedom, which they manage not only in order to adapt the organism to the changes in the environment, but also an extension of the autonomy of the organism, by identifying some possibilities of action in the natural and social environment within which it lives. Consciousness carries out the decoupling from the basic metabolic level of the organism and from the pressures of environment, providing to the organism the maximum of autonomy which a biological being can reach.

The emergence of a higher-order of consciousness is at the origin the emergence of a higher-order of self, cognitive or conscious self. Conscious self is an extended self, which, besides the awareness of bodily feelings, also has awareness of self as a person. This means that self is no longer a mere set of diffuse feelings or a bundle of sensorimotor response patterns to the challenges of the environment, but it also includes ideas, plans, goals, which that organism consciously sets. Monitoring the behavior of the organism based on its ideas, goals, and ideals is called self-regulation

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

[35] Notwithstanding, 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 onto itself at a given time, of which only some can be controlled.

(Berger, 2011, p. 4) and involves the existence of a conscious self which controls the actions of the system. In other words, self-regulation means the possibility to conduct the behavior according to one's own constraints that are consciously elaborate and selected, even if they are not consciously applied. This means, in terms of dynamical system theory, that, by the norms they assume, self-regulatory organisms have the possibility to manipulate the trajectory of the behavioral patterns in their internal state space.

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

4. Conclusion

To conclude, approaching biological organisms as dynamical living systems provides a different perspective on their autonomy. Autonomy of such systems is no longer approached just as a consequence of the degree of internal organization of the organism, but from the perspective of the degrees of freedom which the living system has as a result of the behavioral patterns generates by the level of biological development. Similarly, autonomy of a system also depends on the control mechanisms with which it is endowed and which contributes to generating and managing its degrees of freedom. It results, that autonomy of a living system has to be approached in terms of degrees of freedom of the system, which are the result of the level of complexity of the system and control mechanisms it is endowed with.

Chapter 3. Self-organization, Autopoiesis, Free-energy Principle and Autonomy

Introduction

In the current literature, the free-energy principle (FEP) is approached in the context of predictive coding theory, which provides an explanatory framework about how the brain works, understood as „an inference machine that actively predicts and explains its information” (Friston, 2010, p. 129). This means that the brain does not passively receive information about the world, but it develops a model of the surrounding world, which it permanently adjusts based on the information received from the environment. According to this theory, in order to minimize surprises, the brain makes predictions on what happen in reality. An important role in this process is played by the perception-action dynamics, which actively contributes to predicting the changes in the reality: thus, perception optimizes predictions by inferring the hidden causes of the external changes whereas by action the error of the predictions is minimized.

Minimizing surprises involves limiting free-energy, which is a characteristic not only of the brain but of all self-organizing systems (Friston, 2009; 2010). Free-energy is an important component of all biological systems, because, from the thermodynamic point of view, it is the working energy of the organism. But, free-energy can be understood from the information theory perspective, as a function of both sensory and internal states of organism. In this context, minimization of free-energy involves increasing the probabilistic information relating to the system outputs and their cause. In other words, free-energy is considered as the upper bound of surprise (Friston, 2009; 2010).

Starting from here, one can say that FEP is an important component of the functioning process of any self-organizing system, which, in order to maintain the internal equilibrium, it needs to control the entropy resulting from the flow of information and energy exchanges with the world. FEP is considered a consequence of the propensity of any self-organizing adaptive system to resist disorder and to maintain its identity and unity considering the external perturbations. The integrity of living systems is maintained by limiting the free-energy of the system, which can be achieved by changing the sensory input, by acting on the environment, or by changing the internal states of the system that correspond to the sensory input (Friston, 2010, p. 129). Limiting the free-energy of a living system is a prerequisite of the survival of an organism, involving the development of some mechanisms that would anticipate the changes in the environment and reduce the surprises from the external milieu.

In this context, the goal of my paper is to debate the relevance of the free-energy principle to the problem of biological autonomy, extending the discussion from the Bayesian approach of the brain to the process of self-organization of living systems. Considering this task, the paper is divided in four parts: the first part is an overview of the principles entailed by self-organisation in the case of living systems. In this way, a comprehensive approach of what a self-organizing living system means is achieved, taking into consideration different aspects of self-organization. In the second part of the article, the process of autopoiesis, considered in some enactivist theory as the origin of life, is approached from the point of view of the self-organisation principles, considering autopoiesis as a minimal case of self-organisation. Further, in the third part, the discussion about autopoiesis and self-organization is completed by discussing how FEP is involved both in the emergence of autopoietic systems and, in general, in the self-organization of any living system. Starting from here, in the last part, I discuss the role of FEP in gaining autonomy of a living system, considering two aspects. On one hand, I approach the way FEP contributes both to the internal self-organization of a living system, which in the autopoietic tradition is known as organizational closure, and to the emergence of its degrees of freedom, considering that any organism is also a dynamical system. On the other hand, the autonomy of a living system will be approached taking into account that any system has a boundary, which, in the case of a living dynamical system is a Markov blanket that provides a peculiar type of coupling of the organism with the world. Thus, my aim is that the issue of autonomy of a living system, which has been approached in various developments of the autopoietic theory, to be completed by its approach from the perspective of FEP and dynamical system theory. In this way, a new account of autonomy of living systems is proposed, which takes into consideration not only the recent findings of autopoietic tradition, such as organizational theory, but also the research from dynamical system approach of living systems.

1. Self-organisation in living systems

At the origin of life lies self-organization of living matter which entails the aggregation of molecules in a coherent structure which would resist to the perturbation of the environment. According to the current research self-organization is a ubiquitous process, which can be found all over in nature both in inanimate forms, and in the realm of living system. For instance, self-organizing structures can be dissipative, such as hurricanes or dust devils, that emerge in certain circumstances and last as long as certain conditions are met (Juarrero, 2010b, p. 257). But self-organizing systems can also can also be flexible structures with the ability to evolve and self-maintain (Barandiaran, Moreno, 2008, p. 327). In this case, the maintenance of the system is achieved by adapting the internal behavior to the changes in the environment and influencing the external conditions. These are the living systems, which, as self-organizing systems, involve a set of principles that are interdependent and operate spontaneously36. Together, these principles contribute to the emergence of an autonomous living system.

1.1 Principle of systematicity

The result of self-organization is the emergence of a system, meaning the configuration of some relatively stable structural assemblies, with a unitary behavior. Such a system is characterized by multistability (Camazine, 2003, p. 34) or metastability (Nicolis, Prigogine, 1977, p. 462), which entails the existence of several steady states the system can have, depending on the external conditions and parameters influencing the system. Thus, self-organizing living systems are not rigid structures but they involve a certain flexibility that allows for their fluctuation between certain states (Juarrero, 1999, p. 111).

Consequently, a self-organizing system is a combination of stability and instability. This means that it is a structure which, on one hand, obeys the deterministic laws of classical physics, exhibiting predictable behaviors, and, on the other hand, it is considered statistically unstable, enabling the emergence of new behaviors (Pattee, 1988, p. 328).

Moreover, a self-organizing system involves the fact that certain elements are configured in a structure in which each part has a certain function it would exercise in order to maintain the whole.[37] This means that the elements of the system are selected, in order to be part of the new whole according to the powers they are assigned. Hence, exercising the powers of the parts depends on the functioning of the whole as well as on how they contribute to the integrity of the system. Just as, for instance, certain organs or functions of the living systems are enhanced, whereas other are diminished, according to the contribution to the survival of the organism.

Last but not least, systemicity involves the emergence of some forms of unity and identity of the system. The functioning of a whole involves the unity of processes and its actions. Unity is a consequence of the coherence of the system functions that converge towards the achievement of the same purpose, which is its survival. Identity is a consequence of the fact that processes and actions belong to the same whole. Both the unity and identity of the organism are operational, as they are the result of the internal processes of the system, which contribute to maintain its integrity.

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[36] In other words, the difference between dissipative and biological systems is that in the former case, self-organization is maintained by the energy flow from outside, whereas in the latter, self-organization comes from inside the organism as a consequence of its internal organization. (Ruiz-Mirazo, Moreno, 2004, p. 238)

[37] The part-whole relation can also be approached from the perspective of their properties. Thus, the system can be seen as the total amount of the properties of its parts: "A system is a group of entities with some collective property (...) Maintaining the system is thus maintaining the collective property." (Newton, 2000, p. 92) To put is differently, between the properties of the components and those of the system there is a relation of dependence. This means that "in a system, (...), the properties of the components depend on the systemic context within which the components are located." (Juarrero, 1999, p. 109)

1.2 Principle of spontaneity

Living matter has the property to self-assembly in organized structures which would resist to the entropy of the surrounding world. An important characteristic of the self-organization of the living matter is the spontaneity of the elements coupling, which is carried out without the contribution of an external force or an internal generating principle. In other words: „Self-organizing systems, (....), have need for neither homunculus-like agents located inside a complex system nor any kind of cosmic instruction from the outside ordering the parts around, telling them what to do and when to do it." (Kelso, Engstrøm, 2006, p. 93) This means that self-organizing systems do not need the existence of a self (Kelso, 1997, p. 8), a program (Thelen, Smith, 1998, p. 281) or an external cause that would conduct the coupling of elements. In the self-organizing process, the coupling of elements is carried out spontaneously, without a control center conducting this process. And the laws under which coupling elements is carried out result from the very process of arranging the elements.

Moreover, in the case of living systems, spontaneity is a characteristic of the responses of the organism to the environmental challenges. Behavioral patterns emerge spontaneously without the mediation of a centralizing cognitive structure such as consciousness, which would generate a conscious mediated response to the environmental changes. In other words, living organisms have the ability to spontaneously self-organize under the pressure of environmental constraints, which determine the configuration of the state space of the organism and emergence of a behavioral response.

1.3 Principle of non-linearity

Self-organization enables the emergence, at the level of the whole, of some properties that the independent parts do not have. This means that the whole is not a mere addition of its parts. The aggregation of the elements determines the emergence of some new functions and powers, in the system, which do not represent the mere addition of the characteristics and powers of elements.[38] Aggregation of the elements in a coherent configuration enables the emergence of a higher-order organization of the whole, which exhibit a state space with a high-order dynamics than of the component states. This means that the whole has degrees of freedom greater than those of its components. That is to say, it has alternatives of action and response to environmental challenges, more complex than the sum of alternatives of response of its parts considered independently.

[38] In other words: „...dynamical processes provide empirical evidence that wholes can be more than just epiphenomenal aggregates reducible to the sum of their component parts. The newly organized arrangement shows emergent macroscopic characteristics that cannot be derived from the laws and theories pertaining to the microphysical level." (Juarrero, 2010, p. 257)

The emergence of the new properties is a consequence of the non-linearity which is a characteristic of the biological world.[39] Non-linearity implies the unpredictability of the changes within the system, which means the emergence of new effects that cannot be deduced from the characteristics of the parts. This is possible because, in the self-organizing process, qualitative shifts emerge at the level of the whole that enable the enlargement of its state space and access to some new states by the system as a whole.

To put it differently, in the phase shifts of the self-organizing process „similar causes can have different effects and different causes similar effects; small changes of causes can have large effects, whereas large changes can also result in only small effects." (Fuchs, 2007, p. 853) These shifts that determine new levels of self-organization to emerge are the consequence of the control parameters which exceed some critical values under the action of the aggregate variables of the system. This determines the shift of the organizing patterns of the system and, implicitly, of the dynamics of its basic components meaning the emergence of new patterns of action.

1.4 Principle of circular causality

Self-organization consists not only in the aggregation of some components but it also involves modeling the dynamics of these components by the new emerging whole. Thus, the parts and the whole are in a mutually conditioning relation, which entails that the parts constitute the whole and in turn are constrained to adopt certain behavior by the whole. This circular causation relation determines the emergence of the micro-dynamics of components from the macro-dynamics of system, which in turn will determine the micro-level dynamics. In Kelso and Engstrøm's description (2006, p. 114-115), the circular causality relation involves the coordination of three levels: the "lower level" of the components interaction that results from macro-level (upward causation), the "upper level" that plays a boundary condition role, which constrains the dynamics of the coordinating elements (downward causation), and the "middle level" made of the coordinating patterns between the macro- and the micro level. Thus, circular causality is approached from the point of view of the dynamics between the upward and downward causation.

Approached from the perspective of the patterns created by the system, the circular causality relation entails modeling the dynamics of basic level by the patterns of action it creates at the higher level. In other words, from the coordination of the basic components a pattern of action results that integrates all parts of the system in a whole which share a common dynamics. Thus, the coordination of the components of the system by its macro-patterns enslaves the behavior of the parts achieving the behavior of the whole. From this perspective, the circular causality is based on the slaving principle (Haken, 1983), according to which the formation of the slowest microscopic patterns resulting from the fastest dynamics at the microscopic level involves decreasing

[39] According to Thelen and Smith (1994, p. 58): „Self-organization is not magic; it occurs because of the inherent nonlinearities in nearly our physical and biological universe."

the degrees of freedom of the system components and reducing the states of the system to only a few.

The reciprocal causation relation among the levels of a complex system can also be understood in terms of the dynamics between the control and order parameters. This means that control parameters, which influence the system behavior, determine the emergence of an order parameter, which in turn, by means of the macroscopic order it entails, determines the reduction of control parameters (Bruineberg, Rietveld, 2014, p. 5).

1.5 Principle of adaptivity

Self-organization entails the emergence of a living system that is fit to the condition of the environment within which it lives. Thus, in the self-organization process are involved both the internal parameters of the system, upon which the internal coherence of the system processes depend, and the external ones, a consequence of the environmental conditions. The external parameters determine the selection of those functions and powers that enable the whole to adapt to the changes and fluctuation to the environment. Depending on how it adjusts to the environment, the system is also characterized by certain robustness, which is "the system capacity to maintain its organization in the face of internal and external perturbations." (Barandiaran, Moreno, 2008, p. 331) From this perspective, self-organization implies the emergence and selection of those patterns that would provide the robustness of the organism under the circumstances of environmental changes.

An important role in the process of adaptivity is the way the system is linked to its milieu. As living systems have emerged and developed for generations within a certain milieu, they are coupled initially and structurally with this milieu. Structural coupling involves that the organism, by means of the its organs, perceives directly the changes in the environment and is prepared to provide optimal response to such changes. Thus, a living system is not an isolated structure within the environment it lives, but "the external structure or boundary conditions of complex systems are as much as part of the complex system as the internal structure." (Juarrero, 2010a) This is what enables the living system to interact with the milieu, not only passively, by receiving information from the outside, but actively as well, by transforming the milieu where it lives. In other words, structural coupling involves symmetry between the system and the world, meaning their mutual influence (Di Paolo, 2010, p. 50). By this mutual influence, the organism acquires the information necessary to preserve a state of dynamic equilibrium with the world. Consequently, adaptability involves regulation of an organism according to an interactive cycle between the living system and the world (Barandiaran, Moreno, 2008, p. 335).

Structural coupling is facilitated by the emergence, in the process of self-organization, of a boundary between the living system and the world. This boundary (Ruiz-Mirazo, Moreno, 2004, p 244-245) is a demarcation between the system and the world, and it also enables exchanging information between the organism and the world. Boundary delimitates the internal space of the organism, its inner vital field whereby the system gains the autonomy of its internal processes. Moreover, boundary is endowed with receptors sensitive to the changes in the environment and with structures that enable exchanges with the external milieu, which would facilitate the adaptation of the organism.

1.6. Principle of optimality

Self-organization involves not only the emergence of simple responses of living systems to the environmental challenges. It also involves selecting those responses that are the most appropriate to the challenges in the milieu. In other words, the patterns of action emerging as a result of self-organization are the most efficient to answer to the changes in the environment (Bruineberg, Rietveld, 2014, p. 5, note). This means that, on one hand, the behavioral patterns are generated according to the energetic possibilities of the system. That implies that the organism has the resources required to configure and complete the pattern of action. On the other hand, the patterns generated in the state space of the system should respond to as many parameters as possible of those which influence the system. This means that state space of a system should also be made of optimal states to be occupied by the system in order to provide optimal responses. Thus, the survival of the organism means generating the optimal patterns, according to the energetic abilities of the organism which would enable the coverage of as many variants to respond to the environment.

1.7. Principle of thermodynamic non-equilibrium

The propensity of self-organizing systems is to maintain a state of stability, being from a thermodynamically point of view in a state of non-equilibrium due to the energy and information flows they are subjected to. Stability does not require the system to be in absolute rest as this would mean the end of the system activity.[40] Stability is merely a transitory state, until the perturbation of the system variables and configuration of another stable state. This means that, „In self-organisation, the system *selects* or is *attracted* to one preferred configuration out of many possible states...” (Thelen, Smith, 1994, p. 57) It results that, in case of living systems that evolve in time, self-organization involves reaching a dynamic steady state, considering the environmental conditions and the degree of development of the organism at that time.

To put it differently, from the perspective of energetic and information exchanges, a living system is an open system which is in an ongoing flow of exchanges with the environment. This is due to the structural coupling that determines the ongoing interaction and permanent exchanges with the environment. As the system receives continuously energy from the exterior, it can maintain its current state, but, at the same time, its internal organization is in danger. This happens because, if a too

[40] In Kauffman’s terms (2000) this means that „There is no agency at equilibrium.” (p. 66)

large quantity of energy enters the system, the system entropy increases until the extinction of the system. Therefore, the problem a living system faces is how to maintain low entropy within the system and to control the energy and information flow to which it is subjected (Ruiz-Mirazo, Moreno, 2000, pp. 212-213).

The control of the flow exchanges with the exterior involves that the organism reaches a homeostasis state, whereby it gains dynamic equilibrium with the environment (Newton, 2000, p.93). In terms of dynamical systems, homeostasis means controlling the internal variables of the living system and maintaining them within some boundaries so that the system has a constant behavior oriented towards its preservation.

To conclude, self-organization of living system implies spontaneous emergence of a systemic whole with operational unity and identity which are given by the coherent functioning of its internal processes. The properties of this systemic whole are more complex than those of its parts and cannot be reduced to the properties of the components. The newly emerged whole is characterized by a state of dynamic stability. This is the consequence of the internal dynamics of the system, which is given by the reciprocal causation relation between the parts and the whole, and of the external dynamics, i.e. the state of thermodynamic non-equilibrium between the organism and the environment. Last but not least, a self-organizing living system is a system adapted to the environment, enabling multiple and complex behavioral patterns that are the most appropriate to responding to the external changes. Considering all this, one can say that self-organized living systems are characterized by a dynamic, non-linear and multidimensional state space which is configured, taking into account the adaptive skills of the organism and the external parameters.

2. Self-organisation and autopoiesis

Taking into account that self-organization is an essential process in the emergence and maintenance of life, an important issue for understanding how living organisms function is the relation with the process of autopoiesis, considered to have a significant role in the emergence of life. According to Maturana (1987), the two concepts have nothing in common, that is he would "never use the notion of self-organization [...]. Operationally it is impossible. That is, if the organization of a thing changes, the thing changes." This means that self-organization involves more than a re-organization within the system, but it involves a complete change of the system. In the terms of Collier (2004, p. 168), who analyzes the relation between the two concepts, autopoietic systems are able of self-governing and re-arranging their parts but cannot produce a new organization. In addition, Collier (2004, p. 151) shows that, according to Maturana and Varela (1980), the process of autopoiesis implies the existence of an organized self, whereas self-organization can be achieved in the absence of such a self. Notwithstanding, a closer analysis of Maturana and Varela's theory (1980), from the perspective of self-organization principles, shows the complementarity of the concepts of autopoiesis and self-organization.

According to the classical autopoietic theory developed by Maturana and Varela (1980, pp. 79-80), a living system is an autopoietic machine, which has the capacity to maintain its internal variables constant. This means that living organisms are homeostatic systems that maintain their internal organization invariable. Thus, what differentiates autopoietic systems from other systems is the capacity to self-produce, which means the capacity to maintain their organization by themselves. This is possible because the internal organization of such system is a network of processes that generates and maintains the internal components, which contribute to the functioning of such processes. Hence, the internal processes of the system form an interconnected network that also generates the boundary of the system, which gives unity to the system.

Starting from here, autopoiesis is regarded as a "specific instance" (Varela, 1992, p. 6) of self-organization, that is to say, a type of self-organization characterizing minimal living systems. As a self-organizing process, autopoiesis constitutes the identity of the system: thus, the identity of an autopoietic system is the result of invariant patterns emerging within the system due to its internal organization. These invariant patterns provide stability and continuity to the system, despite the energy flows that continually affect the living system.[41]

Moreover, as a self-organizing constitutive process, autopoiesis is characterized by the dynamics between the local component and global whole, meaning by reciprocal causation between "the local rules of interactions (...) and the global properties of the entity" (Varela, 1992, p. 6).[42] Reciprocal causation is a circular causality where the components interaction determines the production of the whole, which, in turn, determines the maintenance of the components.

Furthermore, another basic characteristic of an autopoietic system is that as biological system it should have a certain relation with the environment. This relation is defined as a reciprocal coupling (Varela, 1992, p. 7), whereby the system, on one hand, separates from the environment in order not to become one with it, and, on the other hand, maintains energy and information exchanges with its external milieu.

Last but not least, one can add that an autopoietic system is not the result of some external force that would create it, nor is it an internal homunculus, it does not lay at the basis of its organization. Even if any living system involves a self – which in its minimal form looks like a coherent pattern emerging from the interaction of local

[41] In terms of the dynamical systems theory, this means that attractors of a system are autopoietic or self-creating, the attractors being the consequence of the system propensity to minimize its entropy (Friston, Ao, 2011, p. 7).

[42] Starting from here, which is from the perspective of the proces of autopoiesis, self-organization can mean „(a) local-to-global determination, such that the emergent process has its global identity constituted and constrained as result of local interactions, and (b) global-to-local determination, whereby the global identity and its ongoing contextual interaction constrain the local interaction." (Froese, Ziemke, 2009, p. 497) In other words, the process of autopoiesis can be described, in dynamical systems terms, as the result of the dynamics between downward and upward causation.

components – this is the result of its internal organization (Varela, 1992, p. 11). The internal organization of a living system emerges spontaneously taking into account only the coherence of the processes of the system and the circumstances in the environment.

Notwithstanding, in the later approaches of autopoietic theory, an important characteristic of a living system, which distinguishes it from other self-organizing systems, is self-determination (Moreno, Mossio, 2015; Mossio, Bich, 2014). According to this approach, biological organisms have the capacity to establish their own condition of existence, due to the circularity which constitutes its internal organization. This means that "the organization produces effect (e.g., the rhythmic contractions of the heart) which, in turn, contribute to maintain the organization (e.g., the cardiac contractions enable blood circulation and, thereby, the maintenance of the organization)." (Mossio, Bich, 2014, p. 2)

Self-determination is a consequence of the closure of the organism which has the capacity to self-constrain. In other words, the network of recursive and interactive processes that constitute the autopoiesis process is at the origin of what Varela (1979, p. 58) called organizational closure. Organizational closure implies that the system has the capacity to self-produce the constraints upon which its condition of existence depends (Bich, 2016, p. 207). Approached from the perspective of the constraints generated by the internal organization of any biological system, organizational closure is understood as biological closure. (Moreno, Mossio, 2015, p. 5) Biological closure involves the fact that a biological system operates by means of the constraints it generates upon the thermodynamic flow it undergoes as open system that operates in far from equilibrium conditions (Moreno, Mossio, 2015, p. 6). Due to biological closure, biological organisms have the capacity to self-constrain, namely to act upon their boundary conditions, which involves self-maintenance and self-determination.

To conclude, according to organizational view, self-determination is a characteristic of biological systems, which is not present in case of other self-organizing systems such as dissipative systems. This happens because: „Dissipative structures posses a low internal complexity, which is precisely what enables them to *spontaneously* self-organise when adequate boundary conditions are met. In contrast to biological organisms, self-organizing systems are systems that are simple enough to appear spontaneously." (Mossio, Bich, 2014, p. 19) The conclusion resulting from this is that the dissipative structures are guided by a single macroscopic constraint, being highly dependent on external conditions. Whereas biological organisms, as systems with a higher-order complexity, have the capacity to self-determine and self-maintain, due to the large number of constraints generated, which are in a close interdependence (that is they form a closure of constraints) (Moreno, Mossio, 2015, p. 16).

From the point of view of dynamical systems, dissipative structures are considered structures dependent on external conditions (Juarrero, 2015, p. 4). But, one may add, these are systems characterized by a limited state space, with finite and lower dimensionality. Due to this state space, they can configure only a limited number of simple patterns, as a response to the pressure of the environment. Unlike these systems, biological organisms, due to their complexity have a state space with a higher-order dimensionality, configured by the multitude of their variables. Such a state space enables the emergence of behavioral patterns with complex, and sometimes, unpredictable trajectories.

However, in both cases, the emergence of new properties of the systems, namely its nonlinearity, is due to the constraints acting onto the system. From this perspective, Juarrero (1999, 2010b) distinguishes between the context-free constraints, which are imposed from outside the system and does not generate novelty and complexity, and context-sensitive constraints, which operate as enabling constraints, determining the emergence of new properties. Context-sensitive constraints act based on the circularity relation between the part and the whole, acting bottom-up (as first-order contextual constraints), by correlating the parts of the system and enlarging its state space, and top-down (as second-order contextual constraints), by its new dynamics which the whole share with its parts. Hence, self-organization of complex systems is understood as the result of the dynamics between the context free and first-order contextual constraints, which by adding and correlating the parts determines the emergence of the new properties of the system, which provide a new dynamics to the system components (Juarrero, 1999, p. 142).[43]

Consequently, enabling constraints determine qualitative changes in the whole system, enlarging the system's state space (Juarrero, 1999, p. 143). Moreover, enabling constraints can determine the modification of the system state space, so that new trajectories can emerge and it can access new states (Hooker, 2013, p. 761). In this context, self-determination, as a characteristic of the higher-order complexity self-organizing systems, is a consequence of enabling constraints. Self-determination refers to the possibility of a living system, due to enabling constraints on the system parameters, to generate new behavioral patterns and to configure a dynamic state space with new degrees of freedom. Organizational closure of a living system is the result of enabling constraints which determine qualitative changes within the system.

To sum up, autopoiesis is a case of basic self-organization in the biological world, which involves all principles of self-organization. Notwithstanding, self-organization in the case of biological organisms involves mechanisms other than those in other self-organizing systems (i.e., dissipative systems). Biological organisms are self-organizing systems that are able of self-determination due to enabling constraints. Thus, organizational closure of the living system, due to the enabling constraints of the system, exhibits a multidimensional state space, which allows the emergence of some complex behavioral patterns. Consequently, if self-organizing dissipative systems have an invariable state space, self-organizing living systems have a dynamic state space, which can be extended depending on the adaptive needs of the system.

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[43] In other words, self-organization involves, due to the constraints it is subjected to, the emergence of at least one bifurcation within the system, which would enable a more or less complex behavior (Hooker, 2013, p.764)

3. The free-energy principle, self-organization and autopoiesis

One of the consequence of the self-organization of living matter in not only the emergence of a system with a coherent structure, but also with the capacity to resist to the ongoing disturbances of the environment. Starting from this, one can say that FEP is an important component of the self-organizing process of a living system, which, as an open system, should control the energy and information exchanges with the exterior in order to not increase the system entropy. This means that without FEP living systems would not be able to exist because "the entropy of their sensory states would not be bound and would increase indefinitely" (Friston, 2013a, p.2), which would result in the extinction of organisms.

Minimizing free-energy has an important role in the organism adaptivity to the environment as well (Bruineberg, Kiverstein, Rietveld, 2016, p.2; Kirchhoff, 2016, p.4). In order to survive, any living organism aims at integrating in the environment where it lives. From the dynamical system point of view this means that from the interaction between the organism and world results a whole as an organism-environment system (Menary, 2007, p. 42). Thus, adaptivity involves the capacity of living organisms to create a system with the world. This means that in structural coupling of the organism with the world, which implies their mutual conditioning (Di Paolo, 2005), an organism-world assembly results with a common dynamics. Thus, the organism does not act as an isolated entity which receives passively information about the environment, but it becomes a part of the world coordinating its actions with the changes in the environment.

An important role in this process of adaptation is played by the internal structures of the living system, which detect and anticipate the changes in the world. Adaptivity involves attunement of the internal processes and actions of the organism with the changes in its econiche. This means that the organism does not develop a representational model of the world based on which it acts. But the organism is itself a model of the world where it lives, having a direct relation with it (Friston, 2013b, p. 213). This involves, on one hand, that it is endowed with skills that complement its econiche, and on the other hand, that between the internal dynamics of the organism and the external one of the environment there is a state of equilibrium or optimal grip (Bruineberg, Kiverstein, Rietveld, 2016; Bruineberg, Rietveld, 2014). Thus, embodied skills of organisms, a consequence of their internal organization, achieve the integration of the organism in the environment and the creation of a system with a shared dynamics with external milieu.

The systemic coupling involving that every self-organizing living system to embody an optimal model of its niche (Friston, 2011), makes the organism to exhibit the best patterns of response to the external challenges (according to the principle of optimality). Moreover, it results from the systemic coupling of the organism with the world that the skills of the organism are directed not only towards maintaining internal organization, but also towards anticipating the changes in the environment. Thus, the organism minimizes the external surprises that may affect the system, maintaining its activity within the boundaries of a low number of states that could ensure the survival of the system (Bruineberg, Kiverstein, Rietveld, 2016.p. 2; Friston, 2011). It results that the self-organizing living systems have the ability to change the configuration of their state space, controlling the states which the organism can access by limiting its free-energy. This means that while functioning, the living systems aim at minimizing the surprises of entering in a certain state (Kirchhoff, 2016, p.4), reducing the degree of freedom of the system and its state space, by regulation of its free-energy.

It results from here that regulation, as a process that contributes to the organism adaptivity (Di Paolo, 2005, p. 430), being a form of adaptive control (Mossio, Moreno, 2010, p. 285), is one of the characteristics of a self-organized living system. According to the organizational theory (Moreno, Mossio, 2015, p. 33), the mechanism underlying the regulation of living systems is explained by second-order constraints, which are different from constitutive constraints, which ensures maintenance of the organism under stable conditions. Second-order constraints emerge when the organization of the system is endangered, having the role to re-establish the internal closure of the organism. In this case, regulation involves modulation of the constitutive regime until the recovery of the closure of the organism. In this approach, regulation takes the form of a circular organization of organism: constitutive constraints are those that are at the basis of second-order constraints, and regulatory constraints by establishing a second-order closure contributes to maintaining the constitutive constraints. Thus, regulation involves decoupling from the constitutive level and increasing the complexity of organism, by means of the emergence of some new levels within the system, with new degrees of freedom.

The circular causality supported by the organism constraints is also at the basis of the mechanism of limiting its free-energy. Thus, at the level of constitutive regime, constraints that are at the basis of organizational closure harness the flow of energy of organism in order to maintain its organization, and, at the same time supports this flow (Bich, Mossio, Ruiz-Mirazo, Moreno, 2015, p. 8). If the constitutive constraints cannot harness the free-energy of an open system, the result is the increase of its entropy. In this case the regulatory constraints, which operate on the constitutive regime, emerge re-establishing the equilibrium within the living system.

Starting from these assumptions, one can say that FEP can be also understood as an important component of the functioning mechanism of the autopoietic living systems. According to Kirchhoff (2016, p. 3), the difference between autopoietic theory and FEP, is that the former refers to self-production and the latter refers to self-preservation. This means that from the autopoietic perspective, self-maintaining of a system is merely an internal issue, which consists in the self-production of its internal components, with no connection with its exterior. Whereas, from the point of view of FEP, self-maintaining of a living system should consider the environment within which it lives. In other words, from the perspective of autopoietic theory, self-organization of a system relates only to its internal organization, which involves maintaining internal processes and components. Furthermore, from the perspective of FEP, self-organization of a living system involves attunement of the system and world, in order to maintain the integrity of the organism, by developing a model of the world by the living system and anticipating the changes in the external milieu.

However, autopoietic theory and FEP are understood as being convergent to the extent that both have as a result maintaining a state of homeostasis of the organism (Kirchhoff, 2016, p.8). According to this point of view, the process of autopoiesis involves minimizing its free-energy by minimally self-produce the components of the organism so that it maintains the model of the world. Thus, organism, both by its internal processes and its actions tends to maintain structurally and functionally integrity of itself (Friston, 2013a, p. 5).

Nonetheless, even if maintaining the internal equilibrium, despite the changes in the environment, represents a defining feature of the self-organizing biological systems (Friston, 2010, p. 127), whereby they distinguish themselves from other self-organizing systems, introducing FEP involves that between organism and the world there is a state of dynamic equilibrium. To put it differently, homeostasis is the tendency of the organism to maintain the internal variables constant. But the steady state of an organism is not constant. It undergoes ongoing changes that imply maintaining equilibrium when moving from one state to another, depending on the quantity of free-energy from the system. Homeostasis is a state of equilibrium characteristic to simple systems that cannot access very many states and whose behavioral patterns aim at returning to the initial state. However, living organisms have a dynamic equilibrium that implies reaching of several states of stability along with the change of external and internal parameters as a result of the energetic changes with the exterior.

Thus, instead of homeostasis, one can speak of allostasis, which means "achieving stability through change of state" (Schulkin, 2003, p.21). This means that living systems are characterized by dynamic stability, which implies that the system is in equilibrium among several states and configures more trajectories to reach its states in the state space. From this perspective, the role of regulatory mechanisms is not to maintain constancy of their internal milieu, but to adjust continuously their milieu in order to survive (Sterling, 2012, p. 5).

An important role in this dynamic of regulatory process is played by the anticipation of the changes in the environment. Thus, living organisms have developed special organs (such as the brain) that would monitor the internal and external parameters of the system so as to anticipate the changes and minimize error by adjusting their behavior according to the external changes (Sterling, 2012, p. 7). In this process, the brain as an anticipatory organ plays the role of coordinating the internal organs and their functions in order to respond as best as possible to its predictions.

Thus, living organisms achieve a predictive adaptation (Sterling, 2012, p. 8), which involves regulating the organism by anticipating the changes in the environment.[44]

Explained from a dynamical point of view, regulation consists not only in mechanisms of constantly maintaining internal variables, but it also involves an external component. That means, minimizing free-energy of the organism, as a principle of its functioning, by anticipating the changes in the environment. Prediction of external changes has as an internal correlative the prediction by the brain of the future needs of the organism. In this way, the brain creates behavioral patterns that would adjust internal state space of the organism depending on the changes detected in the environment. Controlling free-energy involves modeling the state space of organism, its contraction or extension, so as not to occupy those states that would endanger its function and, at the same time, to find the best responses to environmental challenges.

In conclusion, by introducing FEP as one of the principles of self-organization of a living system, it results that biological organisms, due to the system coupling with the world, are in a state of dynamic equilibrium with its milieu. This state of dynamic equilibrium involves adjusting the behavior of the organism by anticipating the changes in the environment that will affect the states of the organism. In terms of dynamical system theory, this means that state space of a living system is characterized not only by several stable states, which it occupies alternatively, depending on the external conditions. But state space of a living system is a dynamic space which can be extended or restrained depending on the organisms predictions and how it controls its free-energy. The consequence of attunement of the internal dynamics of the organism with the external one of the environment is the emergence of a dynamic state space that is configured depending on the anticipations of the organism, by adding or restraining certain states. Moreover, in this dynamic state space, depending on the abilities of the organism, several trajectories can configured in order to reach a certain state.

4. Free-energy principle and autonomy

One of the consequences of self-organization of living matter is to develop an autonomous biological system. Autonomy is the feature of the living systems to function independently of external conditioning, by creating its own conditions of existence to survive. In terms of organizational theory, autonomy of a living system can be approached from a double perspective: from the point of view of the internal functioning of the organism (this is the constitutive dimension by which identity of the

[44] Notwithstanding, anticipation is not a characteristic of the organisms endowed with advanced cognitive skills, such as human beings. Research in biology have shown that we can also speak of predictive behaviors in the case of bacteria (Lyon, 2015) or more developed animals that do not possess reason, such as rats or monkeys (Pezzulo, 2008). As Keijzer (2001) said, taking into account that anticipative behavior required a new macroscopic order that would control the organism, it results that all behavior is anticipative behavior. Thus, predictive adaptation is a characteristic of living organisms whereby the aim is to obtain a dynamic equilibrium with the world.

organism is made up) and from the perspective of the relation the organism has with the exterior (this is the interactive dimension which refers to the system interaction with the exterior) (Moreno, Mossio, 2015, p. xxviii). Thus, autonomy of a living system is a twofold issue, which needs to be examined both from the perspective of the internal dynamics of the organism and from the perspective of the external one.

According to organizational theory, constitutive autonomy is the consequence of the organizational closure, which results from generating within a living system of a new causation regime that produces and maintains the internal components of the living system (Moreno, Mossio, 2015, p. xxvi-xxviii). Thus, between the components of a living system there is an interdependence relation whereby the constitutive elements of the system mutually condition by the emergence of a network of constraints that provides the internal functioning of the organism. Understood from this perspective, autonomy means self-determination (Moreno, Mossio, 2015, p. 5) or self-maintenance (Moreno, Mossio, 2015, p. 9) of the organism, which entails the capacity of a living system to replace its internal components, due to its internal organization, understood as a network of constraints that provides the regeneration of the system.

From the perspective of the internal dynamics of the system, the ability of an organism to self-maintain can be understood from the perspective of the circularity relation between the lower and higher-order level of its organization. This means that the level of the basic metabolic processes generates and supports the higher-order level of processing information, which, in turn, models the behavior of the lower level. The circularity relation between the levels of the systems also determines its dynamic organization, which involves ongoing self-organization of the components of the system according to an order pattern. From the perspective of FEP, the circularity relation contributes to reducing the system entropy, by introducing a macroscopic order to the system according to a self-organizing pattern, under the pressure of environmental conditions. Thus, the free-energy of the system is controlled by the emergence of a pattern of action that would respond to the immediate needs of the organism.

Hence, the main feature of the internal organization of a living system is not merely recursive production of its components, but also creating a more extended state space than its components. Autonomy of living systems does not consist only in preserving its internal organization, but it also refers to the states it can access as a result of the responses to environmental challenges that the organism provides as a whole. Thus, understanding autonomy of a living system should take into account that the state space of a living system is a dynamical one. This means, as we have already seen, that the state space of a living system can be extended or restrained due to the anticipatory structures of the organism that can mobilize its resources in order to configure some new patterns of action. Thus, living systems have the ability to access new states and control new trajectories that encompass such states thus gaining new degrees of freedom.

In other words, by limiting free-energy a new order is introduce in the system. This means that degrees of freedom of the components are restrained, according to the new order, whereas, at the level of the whole, degrees of freedom of the system as a whole emerge. FEP contributes thus to the emergence of the degrees of freedom of the system as a whole, by creating a multidimensional state space and patterns of action whereby the system entropy is reduced.

As mentioned before, in agreement with organizational theory, autonomy of a living system is not merely an issue of internal organization, but it also depends on how the organism couples with the world. Depending on the coupling with the external world, the organism receives information from it and has the possibility to respond to the environmental challenges. An important role in the coupling of organism with the world is played by the boundary of organism. This physical border which is the result of internal processes of organism traces the boundaries between the internal space of the organism and the surrounding world, and also facilitates the communication between them (Moreno, Mossio, 2015, p. xxvii). The circularity relation between the internal processes of a living system, which constitute its physical boundary, contributes both to the preservation of internal processes and to the constitution of the system identity (Moreno, Mossio, 2015, p. xxvii).

From the point of view of FEP, the physical boundary of the organism has a double role: an endogenous one of controlling the internal energies of organism. And from this perspective, one can say that FEP contributes to constituting the identity of organism by controlling its internal energy and redirecting it towards the patterns of action that would provide maximum efficiency of the system actions. However, from an exogenous point of view, the boundary of the organism plays the role to control the external flow of free-energy, filtering the quantity of energy that enters the organism. Thus, FEP contributes to the unity of the living system, protecting its internal integrity.

Depending on the complexity of the organism, this physical boundary can enable the coupling of the organism with the world on several levels. An example of such boundary is the cell membrane which is a permissible selective structure (Ruiz-Mirazo, Moreno, 2004, p.245) that contributes not only to setting the boundaries between the organism and the world, but also to the adaptation of the organism by detecting the changes in the environment. Similarly, the nervous system not only enable the energetic and information interaction of the living system with the world, but also a direct coupling with it, which increases the possibilities of the organism to respond to environmental challenges.

In terms of dynamical systems, the boundary separating a self-organized complex system from its milieu is called Markov blanket. A Markov blanket is defined as a set of states delimiting the internal states of a living organism from its external ones (Friston, 2013a, p.2). According to this description, the states that form Markov blanket are linked with the internal ones of the system, forming thus a network made of parents, children and children's parents. The internal states are a probabilistic representation of the external ones being thus able to anticipate external changes (Friston, 2013a, p.7) and to put the system within a certain state, which would ensure its survival. Consequently, the role of Markov blanket is to stabilize the internal states of the system and to reduce the free-energy resulting from the dynamics between the internal and external states (Friston, 2013a, p.4). As boundary of the system, Markov blanket represent a dynamic demarcation between the organism and the world which enables the systematic coupling with the environment and gaining a dynamic stability by anticipating the states of the system that are to be accessed.

At the level of organism, there can be several Markov blankets (Friston, 2013a, p.10): cell surface, neuronal systems, etc. This means that, depending on their complexity, organisms can exhibit multiple levels of limiting free-energy. Thus, membrane can be approached as a boundary which separates intracellular states from the extracellular ones, hidden from the internal states (Friston, 2013a, p.2). Communication between the two is carried out by means of sensory states (corresponding to the states of receptors and ion channels), which receives the changes within the external states, conveying internal states to them, and active states (corresponding to various transporter and cell adhesion processes), whereby internal states act upon the external states (Friston, Po, 2011, p.2; Friston, 2013a, p.2). This circular relation allows for the regulation of the integral states of single cell organism in agreement with the external changes, by configuring some behavioral patterns, made up of sensory states and active states parameters. Moreover, active states are those that bound entropy of the system, providing thus the integrity of the Markov blanket (Friston, 2013a, p.5). This means that state space of a living system is made up of the active states of the system, meaning of the states which the system can access as a response to the environmental challenges.

To conclude, autonomy of a living system entails taking into account both the internal dynamics of the organism the result of circular causation of the internal parts, and the external one, between the organism and its milieu. Minimizing the system free-energy contributes actively to gaining the autonomy of living systems by configuring and preserving the state space of the system within certain boundaries. State space of living systems is a multidimensional one enhanced by the anticipatory structures of the organism, which enable the access to new states based on predictions of environmental changes. This multidimensional state space determines the emergence of some behavioral patterns with new degrees of freedom. Thus, FEP, as principle underlying the autonomy of living systems, determines modeling the state space of organism, depending on the responses that such organism can provide and the emergence of new degrees of freedom as a result of the complexity of emerging behavioral patterns.

5. Conclusion

To conclude, FEP has an important role not only in the functioning of self-organized living systems but also in gaining of the autonomy of living systems. Minimizing free-energy is a process that contributes both to the constitution of the internal organization of the system but also to the systemic coupling of the system with the world. From the perspective of the system constitutive dimension, enabling constraints characterizing the internal organization of the system determines the emergence of a multidimensional state space, with degrees of freedom higher than those of its components. From the perspective of the interactive dimension, FEP contributes to limiting the energy entering the system by anticipating the changes in its external milieu. The coordination of internal states with external states is performed by behavioral patterns, which also performs attunement of the internal regulating dynamics of free-energy with the external one. Thus, the autonomy of a living system depends on its multidimensional state space and the degrees of freedom of its behavioral patterns emerging from this state space.

Chapter 4. Self, Agency and Autonomy in Dynamical Living Systems

Introduction

In the history of philosophy, the idea of the self has been one of the most challenging issues, which in recent years has been approached from the perspective of current findings in neuroscience, behavioural science or psychiatry. Thus, new topics for debates have been put forward which allowed for the discussion about the neurological correlate of the self, or its interactive, behavioural dimension, or even the pathology of the self. Moreover, the proliferation of the approaches of the self resulted in theorising and discussing several types of the self. This was noticed by Strawson (1999, p.100), who lists several of these recently theorised forms of self: *„the cognitive self, the conceptual self, the contextualized self, the core self, the dialogic self, the ecological self, the embodied self, the emergent self, the empirical self, the existential self, the extended self, the fictional self, the full-grown self, the interpersonal self, the material self, the narrative self, the philosophical self, the physical self, the private self, the representational self, the rock bottom essential self, the semiotic self, the social self, the transparent self, and the verbal self"* Thus, in current literature, the self is understood as a multidimensional phenomenon, which should be discussed not only from a philosophical perspective, but by joint contribution of several approaches that belong to various fields of study.

The discovery of this multidimensional character of the self has determined the change of the classical metaphysical conception of the self, as it was theorised by Descartes (1996/1641). According to the Cartesian conception, the self is an entity of spiritual nature, purely rational, the guarantor of the epistemic certainty and the cognitive core of man's mental life.[45] Against this conception, current researches have highlighted the importance of corporality for constituting the self (Gallagher, 2005; Zahavi, 2005), showing that the self is a discontinuous phenomenon (Strawson, 1999), of phenomenal nature (Zahavi, 2003, 2005), which can be understood as having a fictional character, as the centre of narrative life of a person (Dennett, 1992)[46] or having

[45] Even if modern philosophers agreed with the mental nature of the self, they contested the idea that it has a substantial reality. Locke (1979/1690), for example, considers the self as a consequence of consciousness, which always accompanies thinking. To Kant (1965/1781), the self is approached as a condition of possibility of the unity of experience, meaning as a thought that accompanies any act of knowing.

[46] However, these views are not compatible. According to Zahavi (2007), the self is not the fictional center of narrative gravity, but we can speak about various dimensions or levels of selfhood that can be approached differently from the narrative perspective. Thus, from the phenomenological perspective,

an interpersonal character (Neisser, 1998; Rochat, 1995) and which can have several forms, depending on the degree of biological complexity of the organism (Damasio, 2010). By these approaches, the conception of the self, as an exclusive characteristic of the human being, was contested, the self becoming a feature of any living being. Moreover, explaining the self has become a necessity from the perspective of the biological mechanisms, which is at the origin of its emergence and function.

Approaching the self, as a part of any biological creature, opens the possibility of understanding it also from the perspective of the dynamical system theory. This new perspective results from the fact that living organisms are considered dynamical systems, which have a dynamic relation with the environment they live in. This means that understanding living systems should also include explaining how their state space[47] emerges as well as the patterns of action based on which they act in the world.

Thus, starting from the recent approaches of the self, in this paper, my intention is to offer a new explanation of the self both from the biological and dynamical systems theory perspectives. This new approach of the self uses several already existing theories, which would be useful to recapitulate in order to understand my way of approaching the self. Firstly, the idea of the self I propose is closer to David Hume's conception (2009/1739), which contests the existence of the self as an indivisible entity that would guide our entire mental life. To Hume, the self should be approached as a bundle of impressions and ideas that are interlinking by resemblance or causality relations. Similarly, but from a different perspective, Varela (1992) speaks of a *selfless self* namely "a coherent global pattern that emerges through simple local components, appearing to have a central location where none is to be found, and yet essential as a level of interaction for the behaviour of the whole unity." (p.11) The idea that we should not understand the self as a substantial reality, but that it is a bundle of patterns resulting from the interaction of the adapting mechanisms with which a living being is endowed, is also be supported in this article, but from the perspective of the dynamical system theory.

The idea of approaching the self in terms of a theory of patterns has recently been discussed by Gallagher (2013). According to him, the self should be seen as a pattern resulting from the dynamic interaction of certain features, such as: minimal embodied aspects, minimal experiential aspects, affective aspects, intersubjective aspects, psychological/cognitive aspects, narrative aspects, extended aspects, situated aspects (Gallagher, 2013, pp. 3-4). Unlike Gallagher's theory, the idea supported by me is that, from the standpoint of the dynamical system theory, the self is the result of various patterns of the organism, which aim at maintaining its internal organisation, as a result of different perturbations emerging in the internal or external environment. In this approach, the self is not a certain type of pattern, but it is the convergent point of

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what we call (minimal or core) self is the first personal giveness of the experiential phenomena, namely what gives the subjective character of experience (Zahavi, 2007, p. 184).

[47] According to the dynamical system theory, state space represents the totality of the states that a system can occupy during its evolution.

all such patterns that together contribute to the adaptation of the organism. As a convergent point, the self is not a substantial entity, but a consequence of the internal coherence of any biological system, which results from the need to coordinate the various adaptative patterns of the organism.

Another idea that has generated recent debates in the current literature is that the self is a consequence of the interaction of some mechanisms at various levels in the organism (Thagard, 2014). According to this conception, the self is a multilevel system that results from the integration in a whole of the mechanisms operating at social, individual, neural, and molecular level (Thagard, 2014, p. 145). A similar idea is supported in this article; however, from my perspective, the self is the result of the interaction of various biological control mechanisms of the human being. This means that any living being, depending on the degree of complexity, has developed in evolution, control mechanisms which adjust the internal states of the organism according to external changes. Examples of such control mechanisms are the cell membrane which enables, among other things the chemiosmotic control, namely, it controls the chemical exchanges between the organism and the environment, or the nervous system, which is responsible for the sensorimotor control of the living system, thus integrating the organism in the environment by means of perception-action loop, or consciousness, which provides higher-order cognitive control to the living systems. The sense of the self emerges from the integration of all such control mechanisms in a coherent pattern of action, which provides identity and unity to the living organism.[48]

Consequently, the theory of the self I present in this article combines the biological perspective with the dynamical systems theory. From the biological perspective, I try to explain the emergence of the self starting from its organic origins. This means that I support the idea that the self is a consequence of biological control mechanisms, either of the internal processes, or resulting from the interaction of an organism with the environment. From the perspective of the dynamical systems theory, the self will be approached as a bundle of patterns resulting from adapting of a living system to the conditions of the environment. These patterns are the result of the convergence of internal dynamics of the organism with the external one, whose consequence is the adjustment of the organism behaviour to the changes in the external environment. Considering that two perspectives are interconnected, my intention is to offer a comprehensive approach of the self as a multidimensional phenomenon.

To this purpose, in the first part of the paper, I approach the issue of the self from the perspective of self-organisation, as a process supporting the emergence and maintenance of the living world. The self will be understood starting from three characteristics of the living systems, which result from the self-organisation of the organic matter: identity, unity and self-maintenance. In the second part, I discuss one of the most important characteristics of the self: agency. This means that the organisms

[48] This means that, without a self, organisms could not coordinate and join in a coherent whole the adaptative patterns of the control mechanisms of the biological systems.

endowed with the self are not passive parts of the world but they are systems that have the ability to act on it and to transform it according to their own goals. It results from the capacity to be an agent that living systems, by means of their biological mechanisms, create a dynamical system with the world while conditioning reciprocally. Therefore, the sense of agency is approached as being made of three components: coupling of the organism with the world, the control of the internal and external processes, and prediction. Starting from here, in the third part, I discuss three types of agency which characterize living systems: minimal, sensorimotor and cognitive agency. These three types of agency are approached both from the perspective of biological mechanisms wherefrom their functionality originates and the dynamical systems theory. In conclusion, I discuss the issue of the relation between the self and autonomy, considering the self as a consequence of the degrees of freedom of a living system.

1. Constitution of the self in living systems

Self-organisation is the capacity of living matter to configure, in time, biological systems, able to self-sustain and self-replicate, under the circumstances of the environmental pressures. This means that self-organisation is the process of creating certain systems with various degrees of autonomy, depending on their biological complexity. The creation of some autonomous biological systems is not possible without the emergence of the self that is to guide the organism in its process of adapting to the environment. Consequently, self-organization generates autonomous organisms endowed with a self, which is a consequence of the adaptative patterns of the system. In this way, the self contributes to the autonomy of the living system by coordinating the adaptative patterns in increasingly complex action patterns.

Recent researches of the relation between self-organisation and the self, debating whether the self is merely the result of self-organisation of living matter or it is an important part of this process. An answer to this issue is given by Maturana and Varela (1980), who, from the perspective of autopoiesis process[49], consider that there should be a self who guides the self-production of the components of the living system. The self would be in this interpretation a part of the process of self-maintaining the organism. To this, Collier adds (2004) that self-organisation implies the existence of some proto-selves which should lead to the organisation and emergence of individual selves (p. 164). This means that the self, as the result of the internal conditions of the organism, is a component of the self-organisation process.

From the self-organisation point of view, the self cannot be a prior component of this process because this would mean that the self is a self-contained entity that would add to the self-organisation process. In addition, self-organization is not guided by an

[49] According to Maturana, Varela (1980, p. 78), living organisms are autopoietic machines, which means that they are characterized by the fact that the network of internal processes contributes to maintaining and regenerating the internal components and processes without having an external aim.

external entity, but it is a control-free process. This means that self-organization follows laws, which result from the process of adaptation to the environmental conditions; hence, there is no need to control it from external forces.

To conclude, the self is a consequence of self-organisation but it contributes to maintaining the self-organisation process and the viability of the organism. In other words, the self results from the aggregation of the components in a unitary whole, which is to resist to the environmental disturbances. Moreover, it contributes to the process of adaptation acting as an organizing principle that helps to configure a system adapted to the environment. This is possible because one of the functions of the self is to self-produce the internal processes that help to the very constitution and preservation of the biological organism to which it belongs. Thus, one can say that the self guides the self-production of the components of the living system, maintaining the system identity and unity. In this way, self-organisation produces a system characterised by identity, unity, and self-maintenance, features which are also minimal requirements for the emergence of the self of the system. It results from here that it is important to show how these three basic features of a self-organised system contribute to the emergence of the self of a living system.

a) Identity

Identity is a characteristic of a living system resulting from maintaining of its internal organization constant (Maturana, Varela, 1980) as well as its internal parameters despite the perturbations of the environment. In this interpretation, one does not talk of a self-identity or a personal identity. About this type of identity, we can discuss only in the case of organisms with higher-order cognitive skills. In the minimal sense, the identity can be understood in terms of the autopoietic theory, as being a result of the operational closure[50] of a living system, whereby processes, which support the functioning of the organism, also creates the conditions for their emergence and development (Di Paolo and Iizuka, 2008, p. 411). It is the case of autocatalytic cycles that can sustain and regenerate by themselves from these processes emerging their identity (Di Paolo and Iizuka, 2008, p. 411). Constitution of identity means emergence of a global coherence of internal interlinking processes whose goal is their own production (Varela, 1997, p.73). Identity, in this sense, is an operational identity, as a consequence of the production by the system of some recursive adapting patterns (Negru, 2016a).

Thus, identity is approached from the perspective of the homeostatic character of an organism, which tends to maintain, via the patterns of action that they create, the

[50] Operational closure (Maturana, Varela, 1980) is a consequence of the recursivity of the internal processes of the biological organism, which determines an unitary system. Operational closure does not mean that the system is closed, that it does not communicate with the exterior. On the contrary, it has numerous interactions with the environment but its responses to the external disturbances are given in a unitary manner, as a whole.

internal equilibrium, despite the perturbations of the environment. An important role in this process is played by what the organisational view calls second-order constraints, whose role is to regulate the organism (Moreno, Mossio, 2015). According to this theory, second-order constraints intervene when the stability of the system is endangered, introducing an order pattern that would restore the order in the organism. In other words, second-order constraints act top-down on the organisational closure, maintaining it and thus, enabling the adaptation of the organism to the perturbations of the environment. Identity results from the dynamics between first-order constrains, which are consequences of the cohesion among parts and which contributes to the maintenance of the stability of organisational closure, and second-order constraints, which stabilises the organism whenever internal order is endangered. But, even in this approach, we still talk about an operational identity which results from the functional constraints of the system which determines recursive action patterns at its level.

Approaching the homeostatic character of organisms from the organisational view can be completed with the perspective of dynamical systems. From this point of view, the goal of any living system is to lower internal entropy, by minimization of their free-energy and maintenance of the organism in a limited number of states (Friston, 2010). This means that the living systems, as dynamical systems, tend to maintain constant their internal states by creating some order patterns. These patterns tend towards the organism's behaviour (i.e., attractors) are not randomly created, but they are configured according to the organism's adapting needs. In other words, attractors are patterns which reunite several of the system variables, thus providing a response of the entire organism to the variations of environment. A living system is characterised by several such patterns of action, which have as their goal the survival of the organism despite the perturbations of the environment.

In Juarrero's terms (1999) this means that, "as a dynamic system, (...), an autopoietic system's identity is given by the coordinated organization of the processes that make it up, not the primary material of its components" (p. 125). From this perspective, identity means that all such patterns of action converge towards the same result: constantly maintaining the organism and its internal organisation. Thus, at the level of the system, a bundle of patterns, which are configured in a shared state space, emerge. This bundle of patterns that coordinates itself spontaneously, with a diffuse centre, determines the emergence of an incipient self.

To conclude, identity in its minimal form is the result of recursivity and coordination of the system's basic processes. This operational identity implies an incipient self, which results from the tendency of the living system to maintain constant its internal parameters.

b) Unity

The unity of a living system is its capacity to form, based on its self-referential processes[51] an internal space whereby the organism sets its own limits from the surrounding world. In the autopoietic tradition, this means that unity is the result of what of what also makes the identity of a living organism, namely operational closure (Varela, 1997).[52] Unity and identity are thus a consequence of the coherence of the network of processes that make the system: "the autopoietic mechanism will maintain itself as a distinct unity as long as its basic concatenation of processes is kept intact in face of perturbations" (Varela, 1997, p. 76). From this perspective, the recursive character of the internal processes is at the origin of the emergence of a system that is distinct from the surrounding world, which reacts as a whole to the changes outside it.

From the point of view of the constitutive processes, unity is also a result of the internal constraints of the organism. According to the organisational view (Moreno, Mossio, 2015), owing to organisational closure, biological organisms have the capacity to self-constrain, namely, to modulate the ongoing thermodynamic flow they are exposed to. Thus, internal constraints create a mutual dependence between the components of system determining its action as a whole considering external perturbations.

Unity is also a consequence of the homeostatic tendency of the system to maintain its internal parameters constant. Any living system is characterised by resistance to variance (Rudrauf, Damasio, 2006, p. 438), which refers to the capacity of any organism to maintain its internal equilibrium to deal with the ongoing perturbations. This process involves a response of the organism as a whole, which involves the preservation of its operational unity and identity.

Another way whereby operational closure contributes to constituting the unity of the system is by building a boundary of the system. The boundary of the system is seen as a result of the internal components of the organism, whose role is to maintain the coherence of its internal processes as well as to provide communication channels between the interior and the exterior of the organism (Ruiz-Mirazo, Moreno, 2004, p. 244). Thus, boundary represents the physical delimitation of the organism, which provides the maintenance of its internal processes, but also the interaction with the environment, creating an open system, which could receive and respond to the changes in the environment. Thus, the boundary is not a barrier that contains the organism, but it as a control structure that models the internal space of the organism in a unitary whole, taking into account the changes of the world where it lives.

[51] Self-referential processes are those processes that contribute, according to the autopoietic approach, only to producing and maintaining the network of constitutive processes, without aiming at creating something external.

[52] In this approach, unity means that the organism is a distinct entity in the environment where it lives, responding as a whole to the challenges from the environment. And, identity represents the characteristic of the organism to maintain its internal organization constant and to occupy the same states in its state space.

From the perspective of the dynamical systems, the role of the boundary is to constitute a state space of the systems. Facilitating the energetic and chemical exchanges with the exterior constitutes the states of the organism that may be occupied in the relation with the environment. In this state space, the organism's patterns of action, whose complexity is given by its biological developmental level, will be constituted. The unity of the system also results from the coherence of these processes in the system's state space, which together contribute to the survival of the organism as a whole in the environment it lives. The unity of the organism can be considered as an operational unity, which results from the dynamics of its patterns of action, whose goal is to maintain the internal stability, considering the responses that the organism, as a whole, has to provide to the changes in the environment.

c) Self-maintenance

Self-maintenance is the capacity of an organism to maintain its identity and unity despite the perturbations of the environment, without any exterior support. This capacity, constitutive to any living system was called robustness (Barandiaran, Moreno, 2008) or, it can also be met in the current literature as self-determination (Mossio, Bich, 2014) or in the organisational view, it is called self-maintenance (Mossio, Moreno, 2010; Moreno, Mossio, 2015). A common characteristic of self-maintenance, in these approaches, is the fact that the system has the capacity to act on its boundary conditions (Barandiaran, Moreno, 2008, p. 332) or on the existing conditions (Mossio, Bich, 2014, p. 2). In other words, self-maintenance involves self-referentiality of the internal processes of the organism, which is at the origin of its identity and unity. The living system acts on the internal components and on the energetic flows to which it is exposed from the exterior by constraint, which means that it has self-constraining capacity (Mossio, Bich, 2014; Moreno, Mossio, 2015). This results from the necessity of the organism to regulate the flows and the internal processes with a view to maintaining the continuity of the existence of the organism despite the perturbations of the environment. Self-constraint involves the existence, at the organism level, of a circular causality between the parts and the whole, whereby the parts constitutes the whole, which, in turn, by the new emerging properties, determines the parts to behave in a certain way. Or, in other terms, "the organisation produces effects (...) which, in turn, contribute to maintain the organisation." (Mossio, Bich, 2014, p. 2) It results from here that the organisation of a living system is the consequence of the dynamics of the parts' cohesion and the internal processes, which create a whole that acts by constraints even on the parts that create it. In the terms of the organisation view, this means that at the level of the system, a new causal regime emerges, which determines a closure of constraints that regulate the entire functionality of the organism (Mossio, Bich, 2014, Moreno, Mossio, 2015).

In conclusion, self-maintenance is a consequence of operational closure, which involves the realisation of a relation of dependence between the parts of the organism, by the constraints that such organism, as a whole, exerted on its components. From the point of view of the dynamical systems, this means that at the level of the system, its constitutive processes determine a circular relation between parts and whole, whereby the system regulates its internal processes and the exchanges with the external environment. In Juarrero's terms (1999), this means that the organisation of the system is the result of the dynamics between the bottom-up constraints, the result of the aggregation of the system's components and the top-down constraints, which determine the possibility of new states to emerge, in the state space of the system as a whole.[53] Thus, the system as a whole has the possibility to access some new responses to the challenges in the environment, which the system's independent parts do not have. In this context, self-maintenance represents the characteristic of a living system to self-maintain despite the challenges in the environment, by constituting a state space, where responses emerge, which its parts may not be able to provide. In this way, a sense of self is created as a result of the emergence of some new response possibilities of the organism as a whole.

Identity, unity, and self-maintenance are the three characteristics constitutive of living system, which is also at the origin of the emergence of an incipient self of the organism. Thus, on one side, the self is the result of the internal processes recursivity, whereby the living system creates its own components and acts on its boundary conditions. Moreover, the self is a consequence of the organism's unitary character, which responds as a whole to the environmental changes. In the process of constituting the self, the self-constraint capacity of the living organisms - whereby it regulates the energetic flows it has with the exterior - also contributes. In this context, an important role is played by what the autopoietic tradition called organizational closure. Owing to the self-generating character of the basic processes, the organism gains identity, unity, and self-maintenance. These are also the basic characteristics that determine the emergence of a self and, at the same time, they determine the living system autonomy. Last but not least, to the emergence of the self a main contribution has circular causality characterising any living system, given by the bottom-up and top-down processes dynamics, wherefrom the organism's need to survive as a whole results.

It results from here that the incipient self in not a self in the classical meaning, but it is a bundle of patterns that result from the homeostatic character of the organism, whereby the system gains stability and equilibrium. This organic self is a cellular self (Deacon, 2011) or biological self (Thomson, 2007, p. 260), which is based on the processes whereby the organism aims at surviving under the pressures of the environment. The basic self is a feature of any living system that needs to adapt to the conditions of the environment where it lives, by regulating and controlling its internal variables.

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[53] An example of such dynamics is the case of Benard cells (Juarrero, 1999, p. 141). After self-organizing by heating below, in hexagonal, rolling cells, water molecules become dependent on one another. Thus the behavior of each molecule is guided by the behavior of the emerging whole.

2. Self and agency

One of the important characteristics of living beings is that they are not passive parts of the world we live in, but they have a propensity to action. This means that any organism is an agent that responds to the changes in the environment and act on the environment to modify it according to own goals. Primitive forms of agency can be also met in the case of unicellular organisms that involve only basic motility of living system (Deacon, 2011). Moreover, highly-organised organisms exhibit advanced forms of agency, which do not consist in the mere moving away from potential threats or toward food sources. In advanced forms, agency involves the discovery of new action possibilities in the external world and even the development of long-term plans so that the organism may achieve their goals.

In the current literature of biological autonomy there have been several attempts to explain the characteristics of agency, in any form whatsoever. Thus, an approach of agency considers that is characterised by: individuality, interactional asymmetry, and normativity (Barandiaran, Di Paolo, Rohde, 2009). According to this approach, individuality refers to the fact that organism represents a system different from the environment; interactional asymmetry consists of the fact that the organism is coupled with the world, being conditioned by it, whereas normativity refers to the fact that agents, in achieving their goal, behave according to some norms.

Another way to approach minimal agency belongs to organisational view, which approaches agency from the perspective of four features: the ongoing interaction with the environment, exertion of constrains irrespective of the amount of energy invested by the agent, organism's behaviour according to certain norm or goal, exertion of constraints on its boundary conditions (Moreno, Mossio, 2015. pp. 92-93). In addition, biological systems are considered adaptive agents, which, because they are homeostatic systems, have the capacity to regulate their behaviour in order to be able to face the perturbations in the environment (Moreno, Mossio, 2015 p. 99). Such an approach is conducted from the perspective of the organisation of a living system, which means that autonomous agents are understood as having the capacity to regulate the boundary conditions, as a consequence of their internal dynamics.

Notwithstanding, an approach of the agency of biological organism should also take into account the dynamics which the organism has with the internal and external environment of the living system. To the extent that the organism forms a dynamical system with the environment, by conditioning reciprocally, agency should be regarded as the result of the dynamics between organism and environment, whereby the adaptivity of the organism to the environment is enabled. From this perspective, we consider that agency is the result of three basic characteristics of a living system: coupling the organism with the world, the control of the internal processes dynamics and the interaction with the environment, and the organism's predictive capacity.

a) Coupling with the world.

Even if they define their own living space in the environment, living systems are not completely separated from the environment they live in. On the contrary, getting information on the changes in the environment and the energy exchange with the environment are important processes for the survival of the living system. This implies the fact that the living system and the world are coupled in a constitutive manner, namely, that the two exist in a recurrent interaction characterised by reciprocal perturbations (Maturana, Varela, 1992, p. 75). From the autopoietic perspective, repetitive interactions between the living system and the environment determine their mutual conditioning.

In terms of organisational view, this relation of mutual determination between the organism and the world is not symmetrical, to the extent that the organism is the one that guides this interaction, according to the norms it imposes and taking its goals into account (Moreno, Mossio, 2015, p. 91). In other words, living organisms have intentional skills, whereby they are originally oriented to detect external signals and to find the best ways to survive in the world. In this case, a self is needed whereby the dynamics of the organism' internal needs are coupled with the dynamics of the external environment. Thus, the adaptative patterns of the system are coordinated with a view to realizing the connection, between the interior and the exterior.

This means that any living system, by means of its actions, which represent a response to external perturbations, is a causal source, namely, a self which maintains an ongoing connection with the world (Moreno, Mossio, 2015, p. 91; Ruiz-Mirazo, Moreno, 2012, p. 35). This self is not merely a situated self reflecting the needs of the organism at a given moment but it is an interactive self also reflecting the connections between the organism and the world.

In this way, the living system is defined as an agent whose autonomy consists both in an internal constitutive dimension, implying the preservation of organisational closure, and in an external interactive dimension, implying the maintenance of its internal organisation considering the perturbations in the environment (Bich, Moreno, 2016, p.13; Moreno, Mossio, 2015; Ruiz-Mirazo, Moreno, 2012, p. 35). In this case we talk about autonomy as a result of the possibilities of the organism to act in the world, whose goals are to maintain its identity given the constitutive coupling with the environment.

It results from here that the interactive processes of the organism act as constraints, which determine the organism's self-maintenance, given the changes in the external environment (Barandiaran, Moreno, 2008, p. 332; Moreno, Mossio, 2015). In other words, coupling with the world, also has the emergence of some new types of constraints in the organism besides the constitutive ones, the result of the internal organisation of the organism. The constraints resulting from the interactive processes model the inner space of the organism, according to the environmental conditions, which results in the emergence of some new responses of the organism as a whole to external changes.

These responses, which imply the regulation of structural coupling, represent the adaptive processes, which give rise to adaptive agency (Barandiaran, Moreno, 2008; Froese, Di Paolo, 2011). From this perspective, agents are considered as being able not only of compensatory responses but also of complex behaviour (Barandiaran, Moreno, 2008, p. 332). In other words, constitutive coupling with the world affords organisms, depending on their biological complexity, not only to respond to changes, but also to detect possibilities to act in the world. In other terms, autonomous cognitive systems act as agents, maintaining and regulating the ongoing sensorimotor loops, whereby they maintain the connection with the world (Di Paolo, Iizuka, 2008, p. 411). It results from here that the connection between the organism and the world can be approached at several levels that depend on the capacities of the organism to adjust to and act in the environment.

From the point of view of the dynamical systems, structural coupling of the organism with the world means that the living system forms a dynamical system with the world. In the terms of this theory, living organisms are considered to be autonomous agents, having as an aim through their actions to satisfy some internal or external goals, being under continuous long-term interaction with the environment (Beer, 1995, p. 173). From this perspective, living organisms and their environment are regarded as two separate dynamical systems that have convergent dynamics, meaning that the trajectories of the two systems influence reciprocally, determining the emergence of new behaviours in the case of agents, which otherwise would not have existed (Beer, 1995, p. 182-183). Thus, the idea of the organism's constitutive coupling with the world appears, in the terms of the dynamical system theory, as the issue of the dynamical convergence of the two systems involved.

This is possible owing to the relation of circularity existing between the living system and the world, whereby certain parameters of one of the systems can turn into state variable of the other (Beer, 1995, p. 181). The relation of circularity[54] refers to the fact that organisms acting on the world receive a response from the exterior, which becomes a variable for the new action. In this way, living systems adjust their internal dynamics, consequence of self-organisation of the components, with their external dynamics, resulted from the perturbations in the environment. Moreover, the consequence of this relation of circularity is that at the level of the system a state space emerges, made up of endogenous and exogenous variables of the system, where patterns of action with many degrees of freedom are configured.

This state space contains those possibilities of response which enable the organism's adaptation to the environment, determining the configuration of certain trajectories of the organism (Beer, 1995, p. 184). In this state space, the organism's behaviour as a whole is determined, selecting those patterns of action that facilitate the organism's adaptation to the environment. For this, there is no need for a control

[54] Feedback, in Beer's terms (1995, p. 182).

centre which should guide the emergence of such patterns. Thus, we can say that agency results from spontaneous self-organizing coordination of processes that spans organism and environment (Kelso, Engstrom, 2008, p. 105). Even if from this perspective one can speak of a self in the classical meaning, it emerges as a result of the convergence of these patterns of action whose goal is the organism's survival.

To conclude, constitutive coupling of the organism with the world implies that organism, by its adaptive mechanisms, acts on the world ensuring thus its survival. This means that the self is connected in a constitutive manner with the world as it is oriented towards detecting the possibilities of action in the environment. From this perspective, one can say that living systems possess an interactive self, the result of the multi-level relations which the organism has with the world, which is not also a centred self, being merely the diffuse point of convergence of the organism patterns of action.

b) Control of internal processes and exchanges with the exterior.

Even if agency of living systems does not imply a control centre for all the actions of the organisms, however there should be a way to coordinate them. Coordination as an important characteristic of the self implies the order and coherence of the systems' adaptive patterns so as the organism as a whole resist to the disturbances from the environment.

In terms of organisational view, this is explained by the constraints generated by internal organisation of the organism. Organisational closure, which is at the basis of the identity and unity of any living organism, is understood as mutual dependence between constraints (Moreno, Mossio, 2015, p.20). In other words, the network of recursive processes which are at the origin of the emergence of biological organisms and their autonomy creates a network of constitutive constraints that mutually condition. It results from here, as we have seen, that living organisms have the capacity of self-constraint, which means that they generate the constraints, which represent the requirements for the maintenance their internal organisation (Mossio, Bich, 2014, p. 26).

It can be said that at the origin of agency there is the capacity of living organisms to act on their own internal organisation, by the means of constraints, so that they adapt to the conditions in the environment. Starting from the closure of internal constraints, it also results the interactive dimension of the agency, by extending the causal powers of constraints on the boundary conditions of the whole system (Moreno, Mossio, 2015, p. XXXI). Thus, based on the capacity to act on itself, the capacity of the agent, which becomes thus an autonomous living system, to act on the environment, is created.

From the point of view of dynamical system theory, the constraints existing at the level of any living system are regarded as relations between the variables of the system, which reduce the system's degree of freedom, by limiting its trajectory (Hooker, 2013, p. 757). Thus, the constraints select the degrees of freedom of the system that can be realised at a certain moment, taking into account the system's parameters.

Notwithstanding, the enabling role of the constraints is recognised; owing to the complexity of the organism, such role, which determines a new coordination of constraints, "provides access to dynamical trajectories inaccessible to the unconstrained system" (Hooker, 2013, p. 761). In other words, constraints enable other behaviours when they are joined with other constraints, thus forming a dynamical connection. In this way, in the system's state space a pattern of action emerges with new degrees of freedom that determine a new evolution of the system.

In terms of organisational view, this ability of manipulating the system's trajectory, owing to the constraints emerged in the system, is considered a form of adaptive control (Mossio, Moreno, 2010, p. 285). Similarly, also from the perspective of dynamical system theory, the ability of a constraint to alter the path of degrees of freedom of a variable of the system is considered a form of control as well (Pattee, 1973, p. 42). These convergent opinions in organisation theory and dynamical system theory, come to highlight the idea that agency does not imply a centred self that should control the system. But the control of living systems is carried out spontaneously as a result of the constraints of adaptive dynamics of the system.

An important role in the adaptive process of the system is played by the regulation of the organism's internal processes. As we have seen, regulation implies a set of constraints, independent from the constitutive ones, which should operate on operational closure when this is endangered (Moreno, Mossio, 2015, p. 33). From this perspective, regulation is considered a second-order control, which harnesses the flows of matter and energy of the system in order to maintain its organisation (Bich, Mossio, Ruiz-Mirazo, Moreno, 2015, p. 8). In this approach, regulation involves a circular organisation between constraints that contribute to maintain the organism's internal organisation, which, in its turn contributes to maintaining these constraints (Bich, Mossio, Ruiz-Mirazo, Moreno, 2015, p. 9).

This means that the dynamics between the regulatory and constitutive constraints creates at the level of system an order pattern, which modulates the entire trajectory of the system. Regulation implies that the dynamics between the order patterns, formed at the level of the entire organism, and control parameters that operates locally by controlling the various variables of the organism (Negru, 2016b). In this way, the organism has a flexible behaviour, whereby it offers not only a response to the perturbations in the environment, but new possibilities to act in the world.

The regulation of the system parameters with a view to creating a coherent pattern of action, which should determine a response of the organism as a whole to the changes in the environment, lies at the origin of the emergence of a self. The self, in this approach, is regarded as the invariant topological pattern which characterises the dynamics of any living system (Thomson, 2007, p. 260). It results that the self is the consequence of the dynamics of constitutive and regulating constraints of the system, whereby patterns of action are created, which control the organism's behaviour at a given moment. These patterns of action, resulting from the control of constitutive processes of the living system, have as consequence the convergence of internal processes dynamics with the external processes dynamics in such a way that organism may achieve its own goals. In this way, the self is formed, as a dynamic self, who does not imply a central core, but it is formed by that bundle of patterns, whose goal is to maintain the organism's identity and unity despite the perturbations in the environment.

The degree of complexity of this self is given by the level of complexity of the patterns of action formed at the level of the organism. According to their complexity, the organism's control mechanisms, which create a hierarchy, generate increasingly chaotic patterns, which include more and more variables in the state space of the system. The more chaotic the attractors, the more complex the dynamic of the self becomes, increasing the system's autonomy degree.

To conclude, agency implies the control of the processes of organism in order to maintain constant the internal variables and enable the organism to act in the world. The dynamical self results from the organism's control mechanisms, which are regulated in order to coordinate the internal and external dynamics of the organism. Thus the autonomy of a living system, is not given merely by maintain constant its internal organization, but also from the dynamics of the organism's control mechanisms, which represent the basis for acting in the world.

c) Prediction and anticipatory behaviour.

One of the most important characteristics of any living system is the ability to anticipate the changes in the environment. Based on this ability, living organisms can survive by avoiding surprising situations, which require unexpected responses. At the same time, based on the predictive ability, living organisms can develop patterns of action, which would achieve on long-term their goals. Thus, the ability to predict the modifications of the external variables and prepare some responses, which would maintain the organism's long-term viability, is an important component of a living system understood as an agent.

According to a classical theory, an anticipatory system is: „a system containing a predictive model of itself and/or of its environment, which allows it to change state at an instant in accord with the model's predictions pertaining to a later instant" (Rosen, 2012, p. 313). According to this theory, a significant requirement of anticipatory systems is that they contain an anticipatory model of positions they may occupy of their states and variables in the environment. This does not mean that anticipatory systems are representational systems that act inferentially to adjust the organism's behaviour to the variations in the environment. Such a system would imply an internal representation of the internal and external states of the organism so that to any modification of an external state, the organism may respond by a modification of an internal variable. This model cannot be viable as the majority of organisms do not have representational abilities.

Generally speaking, anticipatory systems act directly, by means, at the level of state space, of a vector field, which is activated whenever the organism detects a change internally or in the environment. This means that living organisms have the ability to constitute some behavioural patterns only based on expectancies regarding internal or external changes. And these patterns emerged whenever the system's variables are about to shift their values.

Detecting changes in the world does not require awareness of regularities in the environment but only adjusting the behaviour according to the external parameters values, by activating some pre-established patterns of action. This means that when external parameters reach certain values, the organism can anticipate the shift of the external state, and then, of its own state, merely based on the data from sensory organs. Similarly, internal changes can be anticipated based on the internal control mechanisms of the living system. In both cases, it act based on patterns of action built based on prior experiences or by internally simulating a situation.

To put it differently, it is not necessary that the organism has a high degree of complexity to anticipate internal and external changes. It's just that the organism's anticipations are likely to include as many variables as possible but this depends on the organism's degree of complexity. This very degree also determines whether the organism's anticipations are made on a short or long term.

Starting from here, in the case of organisms with brain we can also speak of a higher form of regulation called allostasis (Sterling, 2012; Schulkin, 2011). According to the supporters of this theory, one of the most important functions of the brain is to monitor as large a number of internal and external parameters of the organism as possible in order to anticipate its internal and survival needs (Sterling, 2012, p. 7). This means that, in case of the organisms with brain, an anticipatory regulation, which relies not only on responses to environmental changes (as is in homeostasis), but it implies the anticipation of such changes and giving an appropriate response (Schulkin, 2011). From this perspective, anticipating internal and external changes becomes an important requirement of the organisms' adaptation and survival in the environment, which does not imply only maintaining constant its internal variables but also the convergence of the internal dynamics of the organism with the external one of the milieu.

This means that anticipation, as a process participating to the regulation of internal milieu, is part of what the organizational view calls adaptive agency (Moreno, Mossio, 2015). In these terms, one can say that second-order constraints which regulate internal constitution of an organism, and which is at the origin of its interactive dimension, have the ability to anticipate the states of the organism so that it some behavioural patterns emerge in agreement with the new parameters. Thus, at the level of the organism, an extended state space emerges, which is not made only of its current states but also of the states potentially to be occupied by the system as a whole. In this way, the dynamical self, which is the result of the organism's control mechanisms, becomes an extended self, which also includes behavioural patterns resulted from the future states of the organism. Hence, we can say that all living systems have an extended self whose level of complexity is given by the anticipatory abilities of the organism.

To conclude, what one can infer from the presentation of the agency components is that constitutive coupling enables the agent's ability to form patterns of action depending on the changes in the milieu, the control of internal and external processes guides the actions towards a goal, and anticipation implies the formation of patterns of action, taking into account the future states of the organism.

From the characteristics of agency, it results that in the case of living systems one can speak of an interactive self, the result of the agents' relations with the world, a dynamical self, owing to the bundle of behavioural patterns, which are the consequence of the system's control mechanisms, and an extended self, which can anticipate the future states to be occupied by the organism. Starting from these characteristics of the self, several types of agency can be distinguished, depending on the living system's degree of complexity, namely, of its mechanisms to adapt and survive.

3. Types of agency in dynamical living systems

As autonomous dynamical systems, organisms have a self owing to the dynamics of their internal organization, and they are agents able to initiate actions and to act on the milieu so that they survive considering the external changes. This means that agency is an important component of any living organism, which plays an essential role in adapting to the milieu (Moreno, Mossio, 2015; Barandiaran, Di Paolo, Rohde, 2009). Agency represents thus an important component of any living organism, which as part of the world, wants to be an autonomous living system.

However, not all organisms have the same degree of complexity, which means that we cannot speak of the same type of agency in the case of all living systems. Taking into account the diversity of the biological world, it is rather difficult to classify the existing types of agency. Therefore, we classified the agency of living systems into three categories, depending on the general structure of the organisms discussed: minimal agency, corresponding to organism with simple organization, sensorimotor agency, of which we speak in the case of organism with a nervous system, and cognitive agency, which characterises the organisms with higher-order cognitive skills.

These forms of agency are discussed according to the three coordinates of any living agent: the way organism is coupled constitutively to the milieu, the control of internal and external processes, and last but not least, how the changes on the internal and external milieu are anticipated. These aspects are discussed both from the biological perspective and the dynamical systems perspective, so that a comprehensive explanation of the agency can be reached.

a) Minimal agency.

One can speak about minimal agency in the case of simple organisms, which do not imply advanced adaptive structures that would allow them complex responses to the challenges of the milieu. In this case, agency implies regulation of the organism's organizational closure, thus achieving, from a biological point of view, a minimal form of metabolism (Moreno, Mossio, 2015, p. 94). This means that regulation of minimal agents is only a form of homeostasis, which involves maintaining constant the internal variables of the organism. This is achieved by the control of the organism's internal processes, despite the perturbations in the milieu so that the identity and unity of the organism may be maintained. In other words, minimal agency results from the recursivity of the internal processes of a living system, which contributes to the maintenance of its internal organization.

From an interactive point of view, minimal agency, which is a metabolic agency, implies pursuing some functional actions, such as chemical and energetic exchanges with the exterior, with a view to self-maintaining (Moreno, Etxeberrria, 2005, p. 166). This is possible owing to the physical boundary that separates the organism from the world (i.e., membrane), whereby living organisms create their internal space, enabling the organism's basic form of coupling with the world. This coupling implies only the detection of the changes in the milieu owing to the organism's receptors. To these changes, minimal agents will only respond with basic adaptive reactions (such as gender, adjusting internal processes or releasing chemical substances). In other words, minimal agency characterise organisms with several adaptive functions which it integrates in a unitary whole owing to their internal organization.

Even if they do not imply cognitive skills, organisms with minimal agency can anticipate internal changes, according to the changes detected in the milieu.[55] Prediction refers, in this case, to the anticipation of internal processes of the organism, based on the information received from external receptors. Thus, the living system can prepare the activation of some internal processes, based on the prediction of the sequence of some events of thermic or chemical changes in the milieu.

From the point of view of dynamical systems, organisms with minimal agency have a limited state space, where only simple behavioural patterns can emerge. These action patterns imply few variables and can instantiate low degrees of freedom. Therefore, such organisms have a constitutive or minimal autonomy, which implies only adaptive responses to the changes in the milieu that would ensure the survival of the organism and finding the necessary resources to maintain its basic functions (Negru, 2016b). To put it differently, minimal autonomy consists of adapting the organism's internal dynamics to the dynamic of the milieu so that the organism becomes part of the milieu.

In conclusion, minimal agency is a characteristic of organisms with minimal self, which results from the integration in a whole of the basic adaptive functions of any biological system (...). Owing to the basic structures, such an organism has a coupling with the world whereby it can only perceive the external changes and model its internal space in agreement with them. Control, in this case, refers to maintaining constant the

[55] For example, the bacterium that can anticipate internal tendencies (Mossio, Moreno, 2010, p.285).

internal variables by creating an order parameter with simple degrees of freedom, which are the result of the organism's internal organization (Negru, 2016a). Such simple patterns are also created as a result of the anticipation of the changes in the milieu, implying the modelling of the processes and the organism's internal space. Consequently, minimal agency is a characteristic of organisms with a minimal self and minimal autonomy, which means that their patterns of action aim mainly to maintain their own internal organization and not their action in the world.

b) Sensorimotor agency.

In the case of organisms with nervous system, one can speak of a new way of organization of internal components of living systems, but also of a new way to relate to the milieu. The nervous system is considered as a new subsystem of the organism, which, although, in order to function, it depends on the organism's metabolic processes, it represents a new level, detached from the metabolic one (Moreno, Etxeberria, 2005). This means that the nervous system processes the energy resulting for the organism's metabolic processes in order to constitute a dynamic level that would be free from the constraints of the biochemical level (Barandiaran, Moreno, 2008, p.336). The nervous system provides the organism with new possibilities to respond to the challenges of the milieu, which no longer consist in organic reactions to the changes in the milieu, but they imply acting efficiently on the world with a view to achieving the goals of the living system.

It results from here that the nervous system provides the possibility that the organism perceives the world in terms of the action abilities of the organism. Coupling with cu world is achieved thus by connecting sensory information with the motor abilities of the living system, wherefrom sensorimotor loops result. In this way, coupling with cu world is no longer achieved by simple responses to the changes in the world, but it implies interactive patterns, whereby the organism gains by its actions information about the milieu, which it transforms in goals for its actions. Thus, coupling with the world determines the emergence of several perception-action patterns, which connect the organism to the environment.

One of the consequences of this new way of coupling with the world is represented by the fact that the organism's actions are oriented towards the external world and guided by external norms. This means that sensorimotor loops are guided by external goals (Di Paolo, 2005, p.439), generating patterns of action which no longer pursue the regulation of their constitutive level. Moreover, another consequence of the sensorimotor coupling with the world is the fact that the organism perceives the world according to its action possibilities, namely, according to affordances (Gibson, 1977), which guides its behaviour. In this way, the world is perceived not only through the stimuli influencing the organisms' sensory organs, but, qualitatively (Moreno, Etxeberria, 2005), by means of the importance objects have for the achievement of a living system' goals. It results from here that sensorimotor agency implies understanding the world, not in a representational manner, but in a pre-reflective way, depending on the organism's motor abilities (Thompson, 2007, p. 247).

Starting from here, we can say that the nervous system endows the organism with a type of higher control, which no longer implies merely to maintain constant the internal variables of the organism by controlling the metabolic processes and the exchanges with the exterior. Control takes the form of dynamical regulation, whereby various subsystems of the organism – musculoskeletal dynamics, neuroendocrine system etc. (Moreno, Mossio, 2015, p. 176) – are coordinated by an order pattern, guided by the flow of information coming from the exterior. To the extent that the interaction with the milieu is an epistemic one, meaning that it implies gaining some information by the organism, information that would trigger its actions (Etxeberria, Merelo, Moreno, 1994, p. 53), the control provided by the nervous system become an epistemic one. This means that we no longer speak of biochemical responses to the variation of the milieu, but of the embedding of internal and external variables of the organism in a pattern of action that would increase the chances of the organism to achieve its goals.

An important role in this process is also played by the anticipation of the results of the organism's actions. Sensorimotor loops allow the organism to build internally virtual interactions with the environment, which assisted by emotions, allow emergence of complex anticipatory behaviour (Moreno, Etxeberria, 2005, p. 168). In this way a living system with nervous system can anticipate not only the internal changes of the system, as a result of external changes, but also the consequences of its actions. Thus, it can select the most appropriate patterns of action to the fulfilment of its actions.

To conclude, the nervous system can be regarded as a dynamical, highly dimensional, and non-linear system, which determines the emergence in the organism of some complex patterns of action that coordinate a wide variety of states of the organism (Moreno, Mossio, 2015, p. 175-176). Owing to the nervous system, the organism's state space is no longer restricted to the states potentially to be occupied, as a result of the organism's metabolic reactions, but it forms a dynamical landscape, with multiple attraction pools that correspond to the action possibilities detected in the milieu. Thus, at the level of organism, multiple attractors with a higher complexity and multiple degrees of freedom emerge, which allow the organism various ways to achieve a goal. In this way, the nervous system enables the organism different ways to act in the world, which would provide an extended autonomy, with a multidimensional state space and many degrees of freedom.

c) Cognitive agency.

It is a type of agency that we encounter in the case of organisms with higher-order cognitive skills. Namely, we refer here to multicellular organisms, with a complex cognitive life, characterised by higher forms of awareness and even self-consciousness. Consciousness represents a new level of the organism that provides a top-down possibility of self-organization according to some other dynamics, different from the one of the nervous system. This is owing to the fact that the emergence of consciousness, as a result of the coordination between the brain and its different parts, implies the creation of functionally meaningful information (Kelso, Engstrom, 2008, p.106). According to this approach, the informational level is considered to be at the origin of conscious agency, which, thus, can influence the behaviour of an organism. This means that the neural network dynamics determines the emergence of a semantic level that controls, in informational terms, the output of the system (Juarrero, 2009, p. 90).

It results from here that by constitutive coupling with the world, organisms with consciousness enact the world in a meaningful way. In this way, to the objects in the exterior, new meanings are added that no longer have connections with the motor abilities of the organism. Thus, the world is perceived as having more meanings and as being divided into different fields of action. This situation determines the activation of some varied patterns of action, which are conducted according to different norms, depending on the meanings we assign to the objects. Moreover, the informational level that becomes communicable by means of language, it offers the possibility to interact directly with other persons and to create some joint actions. In addition, the others' narratives can be the basis of recreating some situations we have not experienced (Wilson, 2002, p. 626) and of some offline responses to such challenges. In this way, the informational field opened by consciousness creates a multi-dimensional state space, with multiple possible responses and actions.

The emergence of the informational level allows for a different control of the organism, which implies more than the sensorimotor loop with the exterior. Consciousness organises the life of the living systems, incorporating automated responses in long-term action patterns that take into account the possible changes occurred in the natural or social milieu. This means that organisms with consciousness can develop complex plans that would take into account many variables in the development of an action. The behaviour of such organisms is thus guided not only by short-term intentions, whereby immediate needs are met, but also by long-term plans that aim at achieving future goals. In other words, cognitive agency implies "the ability to control goal/task-related, deliberate thought" (Metzinger, 2013), whereby the organism's behaviour is guided on a short and long term.

From the point of view of the dynamical systems theory, the control exerted by consciousness is a consequence of the fact that it is a control parameter (Negru, 2016b) or order parameter (Freeman, 1999, p.157) that is able to influence all the variables of the system. This means that metacognive level of consciousness is able to coordinate the dynamics of the other level of the system so that, at its level, multi-dimensional patterns of action may emerge. To put it in other words, consciousness determines the emergence of strange attractors, which are not chaotic, but highly-complex (Juarrero, 1999, p. 158), but which provides the organism many action possibilities as they have many degrees of freedom.

Last but not least, organisms with higher-order cognitive skills rely on their predictive actions and the anticipation of changes in the milieu. In this process, a significant role is assigned to the brain, namely the role to anticipate both the organism's local needs, so that resources are distributed adequately between the process of the organism, and to the needs resulted from the organism's coupling with the world (Sterling, 2004; Sterling, 2012). In this way, the brain builds patterns of action with several degrees of freedom that would respond to the changes potentially to occur in the milieu.

Prediction represents a major component of the organism's adaptive process. This can be also explained starting from the free-energy principle (Friston, 2010). According to Friston's approach, owing to coupling with the world, organisms are subjected to some permanent energetic and informational exchanges, which they need to regulated so that to maintain its equilibrium with the exterior. This means that they should minimize their free-energy, by predicting, by the brain – which functions as an inference machine that builds a model of the world – sensory inputs (Friston, 2010, p. 129). In this way, the brain has an ongoing predictive activity, which contributes to the emergence of an extended state space, which includes not only the present states of the organism but also its states potentially to be occupied depending on the variables in the milieu.

To conclude, organisms with higher-order cognitive skills have a cognitive or conscious self, which implies the regulation of the organism's behaviour according to some ideas, plans and goals, which the organism consciously sets and determines the awareness of the self as a person (Negru, 2016b). In this way, the organism achieves a strong or a personal autonomy (Negru, 2016a), which means that it has an extended state space where behavioural patterns with unpredictable trajectories and multidimensional degrees of freedom emerge.

To sum up, agency in any of its forms involves the autonomy of the organism. The possibility to act in the world provides the organisms with the possibility to configure behavioral patterns with increasingly advanced degrees of freedom, depending on the organism's degree of complexity. In this way, the organism gains an extended autonomy, which not only responds to environmental challenges but also creates adaptative patterns depending on the anticipated external changes.

4. Conclusion

From the description of how the self emerges, one can infer that that it is not a substantial component of the organism. But the self is a consequence of the dynamics of behavioural patterns, which result from the organism's control mechanisms that contribute to the organism's adaptation to the milieu. From this perspective, the role of the self is to coordinate these patterns in order to reach the best adaptation of the organism to environmental conditions.

As a result of the adaptive ability of a living system, the self is at the origin of the agency of organism, namely, its ability to act in the world. Therefore, it can be described in terms of three characteristics which differ from the classical conception of the self. Thus, it is an interactive self, which results from the organism's coupling the world, it is a dynamical self, meaning that it is the consequence of the bundle of adaptive patterns of action, and it is an extended self, which is generated by the ability to predict, necessary to any organism in order to survive. Starting from here, one can also describe three types of agency, which characterise living systems and are at the origin of three types of autonomies: minimal agency, which is characteristic to organisms with minimal autonomy, namely they achieve only the basic adaptive functions, sensorimotor agency, which relies on the existence of the nervous system, which, owing to the coupling of dynamics with the world, provides an extended autonomy, with various degrees of freedom, and cognitive agency, specific to organisms with higher-order cognitive skills, which have the highest degree of autonomy of living systems, having the ability to form patterns of action with unpredictable trajectories and multidimensional degrees of freedom.

It results that the self, as a consequence of the patterns of action of a living system, is in close connection with the system's autonomy. In other words, depending on the complexity of the organism's patterns of action, whereby the organism has the possibility to provide varied responses to the challenges in the milieu, at the system's level more and more complex degrees of freedom emerge. In this way, the organism gains a certain degree of autonomy, which consists of the totality of the system's degrees of freedom. Thus, the autonomy of a living system is a consequence of the degrees of freedom of the system's adaptive patterns of action, which are at the origin of the emergence of the self. The autonomy of a living system and the self are thus related phenomena, which result from the degrees of freedom of the patterns of action that emerges in the living system.

Conclusion

The main issue addressed in this thesis is the autonomy of living systems. For this, I brought into discussion the most important theories from a biological perspective, which were supplemented with the perspective of the dynamical systems theory. The idea supported after discussing these theories is that, insofar as we admit that a living system is a dynamical system, its autonomy has to be approached in terms of the degrees of freedom the system, as a whole, has. This approach has had consequences for other issues related to the problem of autonomy, which are detail below.

Self-organisation and Living systems

Approached from the perspective of dynamical systems, living systems have as a main feature the capacity to self-organizing. This is a property of living matter, i.e., to create organic ensembles, without any external help, which can self-maintain in the conditions of environmental disturbances. The process of self-organization has been described as having several characteristics:

- systemicity: self-organization has as consequence the emergence of a system with its own identity and unity, which also involves the emergence of this system's multidimensional state space;
- spontaneity: self-organization does not involve any external cause or control centre, but it is a consequence of the internal coherence of the organisms, aiming to resist to environmental variations;
- non-linearity: self-organizing systems exhibit properties of the whole, which, independently, the parts do not have;
- circular causality: self-organization involves the emergence of an order parameter, the result of the dynamics between the lower level, which is the constitutive level, and higher level, which imposes different dynamics on the basic level;
- adaptivity: self-organization creates systems that are structurally coupled with the environment in which they live, and, therefore, can easily adapt to external changes;
- optimality: self-organizing systems select the behavioural patterns optimal for the organism's survival;
- non-equilibrium: self-organizing systems are open systems, which have an ongoing exchange of information and energy with the environment, and, therefore, they are in a dynamical equilibrium.

Self-organisation and Free-energy Principle

Last but not least, another principle important for the functioning of self-organizing living systems is the free-energy principle. According to FEP theorists, any living system involves limiting the free-energy, which results from exchanges with the environment, through its anticipatory mechanisms that minimize the external environmental surprises. The minimization of the system entropy is achieved by the emergence of a self-organizing order pattern, which has as consequence the configuration of the organism's behavioural trajectory. In this way, new degrees of freedom emerge at the level of the system as a whole that give the organism's autonomy. FEP thus contributes to the autonomy of living systems by configuring both the state space of the organism and the patterns of action in response to environmental challenges.

It follows from this presentation that, in the case of living systems, self-organization functions in two ways: firstly, in a constitutive way, by creating systematic ensembles that can resist environmental disturbances. Secondly, in a dynamic way, by configuring its parts so as to provide the most appropriate and varied responses to environmental challenges. In both cases, the consequence of the living matter capacity to self-organize is a system that has all the necessary mechanisms to maintain under the conditions of environmental disturbances, i.e., it is an autonomous system.

From a biological perspective, a special case of self-organization, which has all the prerequisites of self-organized living systems described above, is the autopoiesis process. From the point of view of the autopoietic theory, as described by Maturana and Varela (1980), the autonomy of a system results from the self-referentiality of the basic processes of the organism, through which the identity and unity of the living system are constituted. According to the following enactivist developments, in addition to the self-production of internal components, to the autonomy of a living system also contributes the self-regulation of internal variables and the self-sustaining of its internal resources. However, from the perspective of dynamical systems theory, the self-production of internal components implies the emergence of a system where the dynamics between the cohesion of the basic level and the top-down constraints exerted by the whole on the parts, creates a state space in which patterns of action are configured, with degrees of freedom, depending on the functional abilities of the system. Thus, from this perspective, the autonomy of a dynamical living system implies self-production, self-regulation, and self-sustaining of its degrees of freedom.

The idea that the autonomy of a living system is a consequence of maintaining its internal organization was taken over by organizational theory (Moreno, Mossio, 2015). According to this approach, organizational closure should be understood as the closure of constraints, i.e., the internal organization of a living system, which consists of the set of interdependent and self-constitutive processes, forms a bundle of constraints. As we have already explained, some of these constraints have the role of modelling the thermodynamic flow of the organism in order to maintain its internal parameters, whereas others, i.e., regularizing constraints, emerge only when there is a danger that the network of constitutive processes may disintegrate.

Constraints and Autonomy

However, a problem of organizational theory, which has been pointed out throughout the thesis, is that the enabling role of constraints is not sufficiently acknowledged by this theory. From the organizational theory point of view, constraints are seen only as limiting the degrees of freedom of a system so that a certain trajectory is configured in its state space. Their role to enable is limited only to the emergence of some processes that generate other constraints, which become dependent on the former, thus achieving closure of internal network.

From the perspective of dynamical systems theory, constraints not only limit the possibilities of the organism to respond, but also enable the emergence of new properties at the level of the whole system. In other words, on one hand, by aggregating the components, their degrees of freedom are restricted only to the positions potentially to be occupied depending on the configured whole. On the other hand, the newly emerged system exhibits new patterns of action, with higher degrees of freedom, which, independently, the components of the organism could not access. To put it differently, the100nablingg role of constraints results from the dynamics between, on one hand, the emergence of the state space of the system, by restricting the states that its components can access. And, on the other hand, the extension of this state space, as a result of the emergence of the new degrees of freedom of the system as a whole, which involves the increase of the number of states of the system potentially to be occupied. This relation of circular causality constitutive of the dynamical living systems determines the emergence of a multidimensional state space, with complex degrees of freedom, which the system as a whole can access. It follows that due to the enabling nature of the constraints, living systems gain new degrees of freedom, which means gaining a degree of autonomy from environmental conditions.

Control and Degrees of freedom

The presence of constraints, as a constituent part of an organism's internal organization, can also serve to explain another important component of the autonomy of a living system, i.e., control. From this perspective, control involves directing the behaviour of the organism by certain constraints. These are the result of the internal or external parameters of the system, functioning as control parameters of the living system.

Due to its internal control mechanisms, the organism has the possibility to regulate its internal dynamics and to accommodate it with the external dynamics of the world. In this way, the organism can regulate its degrees of freedom by means of the selection made by the order pattern emerged as a result of its adaptive self-organization.

Depending on the complexity of the control mechanisms, the organisms can exercise a weak control, such as homeostasis, or a strong control as in the case of organisms with higher cognitive abilities. In the case of homeostasis, control involves only managing the system's degrees of freedom so that the organism does not become extinct. At the same time, an important form of control of the basic organisms is regulation that results from the circular causality between the constitutive level and the order parameter, which imposes a new order on the lower level. In this manner, the system exhibits simple degrees of freedom, the result of the metabolic processes of the organism.

In the case of organisms with a nervous system, control is achieved by the emergence of sensorimotor patterns formed by the organism's perceiving abilities and the possibilities of action detected in the environment. Thus, the organism has the possibility to enhance the degrees of freedom of the system, depending on the opportunities detected in the environment. In this way, the nervous system determines the emergence of a new biological level, Ih configures a multidimensional state space of the system, with multiple and complex degrees of freedom.

Last but not least, organisms with consciousness have the possibility to control their behaviour, according to long-term plans and based on inferential decisions, by consciously assumed reasons. Consciousness is a control parameter of the system that influences the other variables of the system, creating complex and unpredictable patterns of order. In this way, consciousness enables the emergence of some multidimensional degrees of freedom of the system, which gives the organism a maximum degree of autonomy.

Consequently, constraints enable the organism to exert control over its ability to respond to environmental challenges. By exerting these constraints, the organism creates behavioural patterns, which, depending on their complexity, instantiate degrees of freedom with variable complexity.

Control and Self

The control mechanisms of an organism are not only at the origin of the degrees of freedom of the system, but they are at the basis of the emergence of a type of self. Self is a result of the process of self-organization of living matter, which determines the emergence of some organisms characterized by identity, unity, and self-maintenance. From these three constitutive characteristics of a living system it results a self in a minimal sense, which is not a centralized structure, but a bundle of patterns, which together contribute to maintaining the stability of the system, under the circumstances of environmental disturbances. An important role in the process of constituting self is played by regularization, as a basic form of control, which is a consequence of the circular organization of the organism. To the extent that, as we have seen, the constitutive circularity of the living system is at the origin of the emergence of its degrees of freedom, it follows that basic self can be approached as a result of the integration of the degrees of freedom of the organism into a whole.

In addition to this incipient self, in the case of organisms with a more developed degree of organization, we can also speak of a sensorimotor self or a conscious self. Sensorimotor self is characteristic of organisms with nervous system as it is a consequence of the patterns of action of system, which have complex degrees of freedom, due to the coupling of the body and the environment into a systemic whole. We can talk about conscious self in the case of organisms with consciousness, as being formed by the consciously set ideas, plans, and goals of the living system, which determine the emergence of patterns of action with multiple degrees of freedom. From the perspective of dynamical systems, it follows that self should be regarded as the point of convergence of patterns of action resulting from the integration of the control mechanisms of the organism (e.g., membrane, nervous system, and consciousness), which offer the possibility of adapting the organism to environmental conditions.

If self is a characteristic of all organisms, it means that living systems are not passive parts of the world, but they are agents that act to achieve their goals. From the perspective of the dynamics between the self and its environment, agency is approached from the perspective of three features of any living system: constitutive coupling with the world, which results in the interactive nature of the self, control of internal processes, and external exchanges, which make the self a dynamical one, as a consequence of the patterns of action of organism, and prediction, which demonstrates the extended character of self, which also includes the potential patterns of action resulting from the future states of the system.

Agency and Self

In this way, we distinguished among three types of agency that could characterize living systems: minimal agency, characteristic of organisms with simple organization, endowed with a minimal self. In this case, coupling with the world determines only basic adaptation reactions of the organism, control involves only the constant maintenance of internal parameters, and prediction refers to the anticipation of the organism's internal states. Sensorimotor agency is a consequence of the nervous system with which advanced organisms are endowed, which due to sensorimotor patterns, determine the emergence of sensorimotor self. Coupling with the world afford organisms to detect the possibilities of action in the environment, the control is an epistemic one that involves the integration of information from perceptual organs with the organism's abilities of action, and prediction refers to the possibility of anticipating the consequences of the organism' actions in order to select optimal patterns of action. We can speak about cognitive agency, the most evolved type of agency, in the case of organisms endowed with consciousness, which have a conscious self. Coupling with the world involves the emergence of an informational level as a consequence of the meanings that the living system assigns to objects and situations in the environment; the control is achieved, due to consciousness, by the emergence of long-term patterns of action with unpredictable trajectories that encompass automatic responses, whereas prediction is based on anticipating changes in the environment and creating anticipatory patterns with multiple possibilities of response. In this way, living systems gain increasingly complex degrees of freedom, depending on their level of development, which determine the emergence of a certain type of self and agency.

Types of Autonomy and Degrees of freedom

The three types of self and agency correspond to three types of autonomy. Minimal autonomy is the type of autonomy resulting from the constitutive processes of a basic organism, which also constitutes its identity and operational unity. Minimal autonomy is a consequence of recursive patterns that maintain the organization of the organism under the conditions of environmental disturbances, and which causes the emergence of an order pattern with a low degree of complexity and few degrees of freedom. Sensorimotor autonomy, which is characteristic of organisms endowed with a nervous system, is the result of the sensorimotor patterns that offer the possibility of decoupling from the basic metabolic level. Thus, the organism has the possibility to enhance its degrees of freedom by detecting new possibilities of action in the environment. However, it remains dependent on the constraints of its environment, which means that its degrees of freedom have few dimensions. The last level of autonomy, i.e., strong autonomy, characterizes the organisms endowed with consciousness, which have the possibility to consciously select the constraints on the basis of which they act. In dynamical terms, consciousness creates order parameters that influence all system variables, determining the self-organization of the components of organism based on non-linear interaction patterns. Thus, it is at the origin of the emergence of behavioural patterns with complex and multidimensional degrees of freedom.

Autonomy and Degrees of freedom

In conclusion, the autonomy of living systems is given by the degrees of freedom with which the organism as a whole is endowed, due to its level of organic and dynamic development. This means that the degree of organization of the organism determines the emergence of a state space, in which behavioural patterns with degrees of freedom with different levels of complexity are configured. The degrees of freedom represent the totality of states that the system can access, as a result of the organism's ability to self-organize internal parameters in different action patterns. Understood in these terms, autonomy is no longer an issue related to the internal organization of an organism, but one that takes into account the dynamics between the living system and the environment.

Nederlandse samenvatting

Het hoofdidee van dit proefschrift is dat de biologische notie van autonomie van een levend systeem het best begrepen kan worden wanneer theorieën over dit type autonomie aangevuld worden met het perspectief van de dynamische systeem theorie. Hoofdstuk 1 benadert autonomie vanuit het perspectief van zelf-organiserende processen. Vanuit dat perspectief betekent autonomie het mogelijk maken van een minimale eenheid van een systeem door het produceren van interne componenten en processen, zelfregulatie van interne variabelen en het zorgdragen voor bestaansmiddelen. Een levend systeem is echter ook een dynamisch systeem, hetgeen betekent dat haar eenheid onvermijdelijk vraagt om gradaties van vrijheid. Hogere vormen van autonomie vragen om gradaties van vrijheid in de belichaamde interactie van een systeem met haar omgeving en het bewust monitoren daarvan. Deze vormen vragen dus om hogere cognitieve vermogens.

In het tweede hoofdstuk wordt autonomie benaderd vanuit een organisatorisch perspectief. Er is sprake van autonomie van een systeem wanneer processen bijdragen aan het genereren en in stand houden van de interne organisatie van een levend systeem en de structurele relatie van dat systeem met haar omgeving. Vanuit dit perspectief definieer ik de autonomie van een levend systeem als de totaliteit van alle systeem-toestanden die reacties zijn op uitdagingen van de omgeving. Autonomie is dus de totaliteit van de gradaties van vrijheid van een systeem.

Doel van het derde hoofdstuk is om het *free energy principle* (FEP), afkomstig uit de *predictive coding* theorie van de hersenen, toe te passen op het probleem van de autonomie van zelf-organiserende levende systemen. Ik leg uit hoe FEP, als een principe dat zelf-organiserend systemen beschrijft, bijdraagt aan het configureren van de *state space* van een organisme en aan het ontstaan van nieuwe gradaties van vrijheid. Beide zijn belangrijk voor het verkrijgen en behouden van autonomie van een levend organisme.

In het vierde hoofdstuk ontwikkel ik een nieuwe verklaring voor het ‚zelf' vanuit zowel het biologische perspectief als het dynamische systeem perspectief. Ik verdedig het idee dat het ‚zelf' het gevolg is van biologische controle mechanismen die zowel kunnen worden kunnen bestaan uit interne processen als uit interacties van een systeem met haar omgeving. Vanuit het perspectief van de dynamische systeem theorie wordt het ‚zelf' benaderd als een bundel van patronen die het resultaat zijn van de aanpassing van een systeem aan haar leefomgeving. Ten slotte bespreek ik de relatie tussen het ‚zelf' en autonomie, waarbij ik het ‚zelf' zie als gevolg van de gradaties van vrijheid van een levend systeem.

Summary in English

The main idea of this thesis is that the notion of biological autonomy can be best accounted for by adding to the theories of autonomy of biological systems the perspective of the dynamical systems theory. Therefore in the first chapter, I approach autonomy from the perspective of the self-organization process. From this point of view, autonomy means the generation of identity and the minimal unity of a system, as a consequence of the self-production of internal components and processes of an organism, self-regulation of its internal variables, and self-sustaining of its internal resources. However, a living system is also a dynamical system, which means that the emergence of identity and the unity of the system is inseparable from the generation of its degrees of freedom. Put in these terms, autonomy depends on the abilities of the organism to access some degrees of freedom of higher complexity, to enhance its degrees of freedom by its coupling with the environment, as a result of its bodily skills, and to consciously control and monitorize its degrees of freedom, as a result of its higher-order cognitive abilities.

In the second chapter, the issue of autonomy is explained from an organizational perspective. According to organisational theory, the autonomy of a living system should be approached from the perspective of processes that contribute to generating and constantly maintaining the internal organisation of the living system, as well as to preserving the structural relation between organism and environment. Starting from this perspective, I 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.

The aim of the third chapter, is o extend the discussion on the free-energy principle (FEP), from the predictive coding theory, which is an explanatory theory of the brain, to the problem of autonomy of self-organizing living systems. Thus, I explain how FEP, as a principle of self-organization of living system, contributes to the configuring of the state space of an organism and the emergence of new degrees of freedom, both important in the process of gaining and maintaining the autonomy of a living organism.

In the fourth chapter, my intention is to offer a new explanation of the self both from the biological and dynamical systems theory perspectives. This means that I support the idea that the self is a consequence of biological control mechanisms, either of the internal processes, or resulting from the interaction of an organism with the environment. From the perspective of the dynamical systems theory, the self is approached as a bundle of patterns resulting from adapting of a living system to the conditions of the environment. In conclusion, I discuss the relation between the self and autonomy, considering the self as a consequence of the degrees of freedom of a living system.

CV

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