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What makes biological organisation teleological?

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Abstract This paper argues that biological organisation can be legitimately conceived of as an intrinsically teleological causal regime. The core of the argument consists in establishing a connection between organisation and teleology through the concept of self-determination: biological organisation determines itself in the sense that the effects of its activity contribute to determine its own conditions of existence. We suggest that not any kind of circular regime realises self-determination, which should be specifically understood as self-constraint: in biological systems, in particular, self-constraint takes the form of closure, i.e. a network of mutually dependent constitutive constraints. We then explore the occurrence of intrinsic teleology in the biological domain and beyond. On the one hand, the organisational account might possibly concede that supra-organismal biological systems (as symbioses or ecosystems) could realise closure, and hence be teleological. On the other hand, the realisation of closure beyond the biological realm appears to be highly unlikely. In turn, the occurrence of simpler forms of self-determination remains a controversial issue, in particular with respect to the case of self-organising dissipative systems.

Keywords Teleology · Organisation · Self-determination · Closure · Circularity

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1 Introduction

This paper explores the conceptual connections between organisation and teleology in the biological domain. Our central claim is straightforward: the organisation of biological systems is inherently teleological, which means that its own activity is, in a fundamental sense, first and foremost oriented toward an end.

The argument developed in the following pages pursues two main objectives, both aimed at supporting this claim. The first objective is to provide a characterisation of teleology that specifically applies to the biological domain, and therefore captures some distinctive feature of the living organisation. Other classes of systems (mainly *artificial* systems, i.e. artefacts) might also pertinently be described as teleological, although not in the same sense that biological systems are. The second objective is to argue that the proposed characterisation of teleology is naturalised, by which we mean that it implies a legitimate and admissible conception of causality from the standpoint of natural science. Biological systems are natural systems, and can be studied as such. However, unlike most other natural systems, biological systems are teleological.

What makes biological organisation teleological? The core of our argument consists in establishing a connection between organisation and teleology through the concept of self-determination. Biological organisation determines itself in the sense that the effects of its activity contribute to establish and maintain its own conditions of existence: in slogan form, biological systems are what they do. Self-determination implies therefore a circular relation between causes and effects: the organisation produces effects (e.g.: the rhythmic contractions of the heart) which, in turn, contribute to maintain the organisation (e.g. the cardiac contractions enable blood circulation and, thereby, the maintenance of the organisation).

By relying on this circularity, we argue that the conditions of existence on which the organisation exerts a causal influence can be interpreted as the goal (*telos*, or final cause) of biological organisation: because of the dependence between its own existence and the effects of its activity, biological organisation is legitimately and meaningfully teleological. However, teleology is interpreted here in a specific sense, precisely because the final cause of the organisation is identified with its own conditions of existence. While the goal of artefacts does not coincide with their own existence (the goal of a knife is not to maintain itself although, of course, it has something to do with its existence since the knife is *designed* for a certain use), in the case of biological systems their goal and their own existence are one and the same thing: in this sense, the teleology is extrinsic for the case of artefacts, and intrinsic for the case of biological systems (Jonas 1966).

The idea that biological organisation realises self-determination and, therefore, grounds a specific form of teleology has a long history in the philosophical literature. In Sect. 1, we briefly review some of the most relevant accounts in this tradition, and compare them with another tradition—rather mainstream nowadays—which has proposed a different understanding of intrinsic teleology, grounded in the process of evolution by natural selection.

Although we agree with previous similar proposals about the general connection between self-determination and teleology, the analysis offered here makes a further step, by claiming that *self-determination grounds teleology because it takes the specific form of self-constraint*. Not any form of causal circularity—this is the background idea—is teleological: circularity as such is necessary but not sufficient for intrinsic teleology. Biological organisation, hence, is teleological because it realises self-determination, i.e. self-constraint.

In Sect. 2, we elaborate an account of biological organisation understood in terms of self-constraint. As we will argue, biological organisation can be adequately understood as a causal regime in which a set of structures, acting as constraints on the underlying, far from thermodynamic equilibrium, flow of energy and matter, realise a mutual dependence among them, which we label 'closure'. Because of closure, the constitutive constraints maintain each other, such that the whole organisation can be said to collectively self-constrain, and therefore to self-determine: accordingly, we contend that closure provides a naturalised grounding for teleology. Moreover, by relying on previous studies (Mossio et al. 2009; Saborido et al. 2011), we suggest that the naturalisation of teleology opens the way to the naturalisation of two related biological dimensions, i.e. normativity and functionality: in particular, constraints subject to closure correspond to biological functions.

The theses advocated above require a justification and a clarification, both developed in Sect. 3. First, philosophical arguments should be provided to explain why self-constraint is the only circular causal regime which can be said to realise self-determination, and therefore to be teleological. On this issue, we contend that if circular causation does not occur as self-constraint, it amounts instead to a chain of transformations in which the system as a whole plays no role in specifying its own dynamics, and these dynamics are sufficiently determined by the external boundary conditions. In contrast self-constraint implies that the circular organisation specifies its own dynamics: that is why only self-constraint involves self-determination, and why biological organisation (by realising closure) is teleological.

Second, one might wonder whether self-constraint, as characterised in Sect. 2, exists beyond the biological domain. The issue is relevant—the question might continue—because if that were the case, then the account should concede that teleology is not restricted to the biological domain. This result seems at odds with both scientific practice and intuition. In reply, we answer that, indeed, if self-constraint were shown to exist beyond the biological domain, the organisational account we advocate should concede that teleology exists beyond biology. Yet, as we discuss, the issue is not settled empirically. On the one hand, any material realisation of self-constraint as closure would presumably be, because of its internal complexity, *ipso facto* biological or, at least, "at the edge" of biology. On the other hand, the question concerning the occurrence of simpler forms of self-constraint (not involving closure) in the natural world is also controversial. The main candidates as examples of minimal self-constraint seem to be physical self-organising dissipative structures, but the various authors who have addressed this issue diverge on the conclusion: for some, dissipative structures do self-constrain; for others, they do not. In this respect, only future investigations could clarify the point, and help to draw more precise boundaries of self-determination, and intrinsic teleology, from an organisational perspective.

2 Naturalising teleology: from selection to organisation

In modern physical sciences, teleology has been discarded as a valid explanatory notion for natural phenomena because of the inversion of causal relations that it involves: the idea that an effect can determine its own cause, indeed, conflicts with the accepted principle of Newtonian science according to which the effect must follow from its cause. As a consequence, since the nineteenth century teleology has been replaced by other principles (geodesics, Le Chatelier's, second law of thermodynamics, attractors...),[1] that account for the tendency of physical systems to reach certain stable "goal states", even under perturbations, without appealing to an inversion of the temporal relation between causes and effects. In a similar way, non-teleological explanations (Sommerhoff 1950) have been proposed for many purpose-like ("quasi-finalistic", in Waddington's words, 1968) *biological* phenomena as, for instance, canalisation and chemotaxis.

Yet, there seems to be a major difference between goal-oriented biological phenomena and physicochemical ones. Indeed, living systems are not only directed toward a certain goal state by external factors; they pursue such states actively or, to quote Kauffman (2000), they are capable of "acting on their own behalf". Biology, therefore, seems to harbour phenomena that are teleological in a more fundamental sense, when compared to the physicochemical domain. This difference is captured for example by Mayr's distinction between *teleomatic* and *teleonomic* processes (1974). The first category includes those processes that are passively goal-oriented, through the action of natural laws (e.g. gravity, etc.), and are characteristic of inanimate matter. In this case the goal state and the means to achieve it are externally determined. The second category, of which living systems are a typical example, includes those processes whose orientation toward a goal is controlled, according to Mayr, by a program or other internal mechanisms. Biology, therefore, faces a challenge: it must provide naturalised explanations, i.e. explanations in accordance with the principles of causation accepted by natural sciences, while at the same time it must adequately capture the distinctive teleological dimension of biological phenomena.

The scientific treatment of teleology in the biological domain has been framed since the nineteenth century by two central contributions: Darwin's theory of evolution by natural selection (Darwin 1859), and Bernard's notion of conservation of the internal *milieu* (Bernard 1865). These two pillars of modern biology, although not in opposition, focused on different aspects of biological phenomenology: evolution vs. physiology, history vs. organisation, adaptation vs. adaptivity respectively. Before discussing the differences, let us point out that, in our view, the accounts of intrinsic teleology relying on either perspective share a common strategy for naturalisation which relates teleology to the contribution to the conditions of existence of a system: they both look for a circular causal regime such that the conditions of existence of a biological entity can be said—in a scientifically acceptable way—to depend on its own effects, even though this causal regime is realised in different ways and by different

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[1] See Bailly & Longo (2011, pp. 182–187). As an example of how these principles are used in physical and biological descriptions see also a textbook in dynamical systems theory, like Rosen (1970).

biological entities in the two accounts (see below). Hence in both cases biological teleology is naturalised by identifying the *telos* with the conditions of existence of the relevant system. The divergence between these two views, we hold, concerns the relevant regime that is supposed to realise an admissible form of causal circularity, i.e. natural selection and organisation, respectively. Let us take a closer look at these two families of accounts.

The evolutionary perspective constitutes the mainstream naturalised approach to biological teleology.[2] The central idea is that the teleological dimension of biological organisms is not to be explained by looking at the present, but at the past, i.e. at their evolutionary history. The notion of adaptation, in particular, grounds teleology in the biological realm, by replacing the role of the Designer with the mechanism of natural selection:

> "Organisms are adapted, hence they are teleological, and (for the Darwinian) this teleology can be explained through, and only through, natural selection" (Ruse 2000, p. 223).

Selection does not only explain change in evolutionary history but it also produces adaptations, since organisms are selected for survival and efficient reproduction in a given environment. In particular, the existence of *current* traits is the consequence of the selection exerted on the effects produced by *previous* occurrences of the trait. In such a way, selection allows us to consider organisms as designed, and their history as teleological, insofar as the existence of a *type* of trait can be explained by some of its specific effects or consequences, that have contributed to the adaptation and survival of the organism to which the trait belongs.

Within this tradition, different positions have been expressed on whether and how evolution grounds teleology.[3] To frame the comparison with the organisation-oriented one, we submit that an evolutionary account of teleology can be schematically described as relying on three core claims. First, it takes the lineage (of organisms and their hereditary traits) as the relevant system with respect to which intrinsic teleology can be grounded. Indeed, the existence of trait types can be said to (evolutionarily) depend on their own effects by taking into account, as mentioned, *intergenerational* occurrences of those traits; therefore, the relevant circular causal regime goes beyond the boundaries of individual organisms (or traits) and requires considering the (relevant) lineage to be described. Second, natural selection is the process through which the evolutionary intrinsic goals of the lineage[4] are reached. In particular, the intrinsic goals—i.e., in the terms expressed above, those effects which contribute to determine

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[2] It is the mainstream approach especially for biologists, but of course not the only one. See Perlman (2004) for a comprehensive review of the contemporary debate on teleology, which analyses the evolutionary approach in a wider context of teleological perspectives. The organisational approach, in our view, can provide a further option, and, we will argue, a naturalistic grounding of teleology that does not incur the limitations of the evolutionary and other approaches, such as the cybernetic one.

[3] For instance Ayala (1970), Millikan (1989), Neander (1991), Kitcher (1993), Ruse (2000).

[4] We are aware of the fact that it is quite unusual to claim that lineages have goals. Yet, we maintain that the appeal to the evolutionary loop between effects and existence to explain teleology implies that the system in which such a loop is realised is the lineage. This claim would deserve a more detailed examination, that we leave for a future work.

the evolutionary conditions of existence of the lineage—are the adaptations fixed by selection. Third, by focusing mainly on the relation between the organism and its environment—unfolding in the temporal scale of biological evolution—it emphasises the interactive dimension of the living organism rather than its physiology. As we will see, organisational accounts diverge from the evolutionary account on each of these claims.[5]

A full-fledged analysis of the strengths and weaknesses of the evolutionary account of teleology goes beyond the objectives of this paper. What matters most with regards to the comparison with the organisational account is that, as some authors have emphasised (Toepfer 2012), the evolutionary account actually presupposes the existence of individual organisms that are able to survive and reproduce in their environment. Therefore, it seems to rely on an account of how individual organisms manage to maintain themselves, which as we will see, *already* involves a teleological dimension. Accordingly, as Christensen and Bickhard (2002) and Mossio et al. (2009) have pointed out, the evolutionary account falls into a form of "epiphenomenalism", insofar as it is unable to capture the teleological dimension expressed by that biological phenomenon which is the capacity of self-determination of an individual organism in its environment. An account of evolutionarily grounded teleology, hence, seems to depend on an account of organisationally grounded teleology insofar as evolutionary adaptation depends on individual adaptive organisation. Organisms seem to draw their teleological dimension on a source that is different and more fundamental than natural selection. The organisational perspective aims at uncovering that source. Let us then turn to it.

Traditionally (Fox Keller 2000; Huneman 2007), the first explicit assertion of the inherent connection between self-determination, teleology and biological organisation can be traced back to Immanuel Kant's *Critique of Judgement* (1790/1987). Unlike any other kind of systems, Kant explains, organisms can be characterised as *natural purposes*, as they are capable of organising themselves, of self-organising. Although, usually, the causes of the existence of a system are external and independent from that very system, in the case of biological organisms the causes are—at least to some extent—internal, in the sense that they depend on the system that they contribute to generate (see also Weber and Varela 2002). In other words living systems are teleologically organised entities whose components produce and maintain each others as well as the whole. It is worth emphasising that the Kantian account of biological self-determination allows for the possibility of making a straightforward conceptual distinction between three categories of systems: physical systems, which do not possess any teleological dimension; artefacts, which are extrinsically teleological (the *telos* is provided from the outside, by a designer or a user and does not coincide with their own existence); and organisms, endowed with an intrinsic *telos*. Although Kant lays the philosophical foundations for an interpretation of biological organisms as purposeful and self-organising systems, he encounters major difficulties in reconciling

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[5] The evolutionary framework is also at the basis of the mainstream approach in the philosophical debate about biological functions, i.e. the so-called selected effect theory (Millikan 1989; Godfrey-Smith 1994). By interpreting Wright's etiological account (Wright 1973) in evolutionary terms, the evolutionary framework defines functions as adaptations.

the intrinsic teleology of biological systems with the conceptual framework developed for natural science in the *Critique of the Pure Reason* (1781/1998),[6] which is based on purposeless natural laws, external efficient causes and mechanical principles.

The scientific investigation of biological self-determination, as mentioned, starts with Bernard (1865, 1878).[7] His main contribution consists in developing an approach capable of dealing with the distinctive aspects of biological organisation without appealing to vitalist principles (Hall 1968; Bechtel 2007). This operation is made possible through the distinction between natural laws, common to all phenomena, and *milieux,* those local boundary conditions that determine the properties of specific phenomena: different *milieux* can harbour qualitatively distinct phenomena without contradicting the general laws. In the case of biological organisms, Bernard distinguishes the external and the internal *milieu* and analyses their relations. The distinctive features of the internal *milieu* of biological systems are fundamentally two (Bernard 1878). The first consists precisely in its self-determination, as all components contribute to the realisation of the conditions in which all other components can exist. The second is represented by its 'constancy'—or stability, in contemporary language—in spite of the continuous variations taking place in the external *milieu*. Both aspects—self-determination and the conservation of the internal *milieu*—express in Bernard's view the teleological dimension of living systems.

In Bernard's view, biological organisms are teleological not only because of their capability of compensating for external variations by means of internal modifications, but also because the conservation of the internal *milieu* serves the main intrinsic goal of maintaining the specific internal conditions for the organism to exist. Conservation and stability are inherently linked to self-determination.

During the 20th century, Bernard's account was particularly fertile, and constituted the reference for the development of theoretical models of teleological processes in biological organisms. An important contribution in this respect is the notion of *homeostasis* formulated by Cannon (1929), which expresses the capability of actively compensating for environmental perturbations through a coordinated physiological action. The explicit and rigorous characterisation of homeostasis, expressed in connection with the notion of *feedback loop*, is due to first-order Cybernetics and, in particular, to the work of Wiener (1948) and Ashby (1956). Initially developed in the context of servomechanisms, the model of homeostasis gave rise to a proliferation of applications, which made Cybernetics the general framework for the investigation of teleological and adaptive behaviours in wide range of domains, including biology.

The cybernetic treatment of teleology is particularly instructive for our purposes. Undoubtedly, its main strength is its generality which, however, turns out to be its decisive weakness when applied to account for biological self-determination (Bedau 1992).

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[6] See for example Zammito (2006) and Sloan (2012).

[7] Claude Bernard's work is neither the only nor the first contribution to a scientific grounding of teleological properties of living systems in the nineteenth century, especially if we take into consideration German Biology (see Lenoir 1981, 1982, for more details). Yet, Bernard's work is crucial for the purposes of this paper inasmuch as it played an important role in the early development of the idea of biological self-determination by influencing the traditions of research of French Molecular Biology, Cybernetics, and that branch of Systems Theory which gave rise to the idea of biological autonomy.

Homeostasis is a mechanism of stabilisation, which formalises Bernard's notion of conservation of the internal *milieu.* As such, it *presupposes* the existence of the organisation that under certain circumstances it contributes to maintain stable. In particular, homeostasis does not capture the most distinctive *generative* dimension of biological organisation, i.e. the fact that the components involved in feedback loops are not only stabilised, but produced and maintained by the very organisation to which they belong. In a word, homeostasis misses precisely self-determination. What specifically matters for the object of this paper is that the cybernetic approach provides an inadequate understanding of biological teleology, because it obscures its specificity with respect to the teleology which is at work for artefacts (Jonas 1953). Technically, the "goal" of a homeostatic mechanism is defined as the interval within which the mechanism maintains the target variables (Rosenblueth et al. 1943). Yet, it does not make any difference from the point of view of the definition whether the interval is extrinsically established by a designer, as in the case of artefacts, or intrinsically identified with the conditions of existence of the system, as in the case of biological systems. Both cases can pertinently be said to be homeostatic. However in failing to account for their difference, Cybernetics misses the crucial dimension of biological teleology.

As suggested by Jonas (1966), the grounding of biological teleology, at first sight so elusive, should be found within the living system, in the constitutive properties of its organisation. This, indeed, is the perspective adopted by a number of later accounts to biological teleology more specifically focused on self-determination. In this perspective, we distinguish between the "genetic" and the "organisational" approaches.

The genetic approach, still very influential, combines the evolutionary account with some insights from Bernard's and Cybernetics' views,[8] and associates self-determination with a specific mechanism within the organism: the genome and its expression. The underlying theoretical framework is that of (mainly French) molecular biology, centred on the notion of *program* (Jacob and Monod 1961; Mayr 1961; Jacob 1970; Monod 1970). In this line of thought, the concept of genetic program, in the context of Darwinian evolution, rehabilitates teleology (Jacob 1970, p. 9) as an admissible scientific dimension. The central idea is that teleological behaviours, which control the form, as well as the adaptivity of biological organisms, are subtended by genetic molecular mechanisms.[9] In turn, these mechanisms, by enabling the reproduction of the organism, determine the conditions of its own persistence. In this perspective, therefore, the goal is not extrinsic, but rather intrinsic to the system, since it is specified by a program that determines its future states. The program, in turn, has been specified by evolution (Jacob 1970, p. 8).

In the genetic interpretation of self-determination, therefore, teleology is naturalised in terms of what Mayr called *teleonomy*, and defined at the intersection between the molecular and cross-generational levels. The fundamental biological goal is the main-

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[8] For the historical relationship between Cybernetics and French molecular biology, see Fox Keller (2002).

[9] We can find here a convergence of genetics, Bernard's theory and cybernetic modelling. The genome evolves in such a way as to provide not only the mechanisms for the construction of structure, but also cybernetic mechanisms for the conservation and stabilisation of the internal milieu of individual living systems (see for example Morange 1994, p. 163). In such a way, the teleological dimensions of adaptation and adaptivity are integrated in a unique framework.

tenance, through reproduction, of biological systems over the generations. As for the evolutionary account, the relevant system that realises self-determination is in fact the cross-generational lineage: in contrast to other accounts, however, the genetic view emphasises the reproduction of the genetic program as the central mechanism that enables biological self-determination. By reproducing their genetic programs, biological systems set the conditions for their own maintenance as lineages. The genetic view of self-determination can therefore be seen in the end as an evolutionary account of teleology, centred on the expression of the genetic program as the main mechanism of the organism that maintains its own evolutionary conditions of existence (Monod 1970, pp. 24–25).

Again, our objective in this paper is not to develop a fine-grained critical analysis of the various naturalised accounts of biological teleology. The description provided aims merely at emphasising their main similarities and differences, so as to locate our own view within the relevant literature. In this respect, one of the main weaknesses of the genetic approach is that the level of the individual organism and its organisation is neglected. The genetic approach considers a specific subsystem (the genome as a program) as the only one responsible for the reproduction of the organism and, therefore, of the self-determination of the lineage. As Maturana and Varela (1973) have emphasised, the choice seems arbitrary, to the extent that it leaves aside all the other processes that make the organism an integrated unity. In addition, it seems to raise both the issues affecting the evolutionary approach (epiphenomenalism) and the systemic-cybernetic one (neglect of the generative metabolic dimension) not to mention the fundamental theoretical and philosophical difficulties carried on by the program metaphor (Rosen 1991; Lewontin 1991, 2000; Longo and Tendero 2008; Bich 2012a).

The organisational accounts, in turn, are more directly and explicitly inspired by Kant's and Bernard's line of thought in addressing the problem of teleology: accordingly, self-determination and teleology are understood, first and foremost, in relation to the organisation of the individual organism.[10]

Some foundational contributions to this view have been provided by the embryology of Paul Weiss and Conrad Waddington, who have developed ideas related to cybernetic stabilisation in the context of specifically biological processes. They characterise processes such as "canalisation" and "molecular self-organisation" in teleological terms as "quasi-finalistic" ones (Waddington 1962, 1968), i.e. oriented toward a final state despite perturbations, thanks to the intrinsic properties of biological organisation. In particular, Weiss (1968) describes distributed dynamics of mutually dependent processes of molecular production, which he conceptualises as a closed network in which each element is correlated with the others; a slight deviation in the state triggers reactions of compensation that involve the whole distributed network. The interdependence he describes, unlike the cybernetic one, is constitutive of the self-determination of the system, as it is directly related to the realisation of the living unity: each component contributes not only to the activity of the others but also to their maintenance. The result is the realisation of a form of collective stability (Weiss 1968, p. 186).

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[10] For an analysis of the contributions of Weiss Piaget, Rosen, and the autopoietic theory to the organisational approach in biology, see Damiano (2012) and Bich and Arnellos (2013).

The first coherent formulation—and today common ground of many subsequent accounts—of the idea of biological self-determination from an organisational perspective has been put forward by Jean Piaget. By relying on Weiss's self-organisation and Waddington's ideas on adaptive mechanisms, Piaget explicitly integrates the notion of self-determining organisation with the dimensions of molecular self-production and thermodynamic grounding (Piaget 1967).

In doing so, Piaget elaborates the crucial theoretical concept of *organisational closure*, which he considers as complementary to that of *thermodynamic openness*, already emphasised by von Bertalanffy (1949). The core idea is to connect the notion of stable flux of exchanges of matter and energy between system and environment, with that of a circular internal order that enables the continuous reconstitution of the components of the system. The concept of closure formulated by Piaget conceives of the dynamics of living systems as a form of self-determination realised through a circular network of processes and components that continuously maintain the living system as a unity. Moreover, Piaget grounds biological adaptivity in the properties of the organisation, and thus provides, following Weiss, a constitutive interpretation of the cybernetic notion of stabilisation. Unlike the evolutionary approach, the organisational one puts more emphasis on the internal dimension of living systems rather than on external influences, by focusing mainly on physiology. In this way, the organisational approach takes into consideration the relation between organism and environment as it unfolds in the present, in terms of internal compensations for environmental perturbations. In particular, Piaget expresses biological self-determination also in terms of the relation to the external environment, to which the system is capable to adaptively interacting so as to maintain its constitutive organisation. By reinterpreting and generalising Waddington's concepts of *assimilation* and *accommodation*, Piaget characterises the interaction between the organism and the environment in terms of (individual) adaptation, defined as the assimilation of external influences which involves an internal self-regulation (accommodation). Accommodation consists in a change in the structure of the circular network of processes of production, which leaves the general relational scheme invariant (Piaget 1967).

According to Piaget, the integration of closure and self-regulation constitutes a naturalisation of the teleological dimension of living systems, by replacing final causes with an intelligible causal regime of self-determination. In his view—and unlike the cybernetic account—homeostatic mechanisms express biological teleology only to the extent that they are inherently linked to the underlying self-determining organisation: the goal states of living systems, according to Piaget, are therefore those determined by organisational closure, the causal regime which continuously produces and maintains the organism.

The connection between organisation, closure and teleology, as we will argue in the following section, is the central tenet on which an adequate naturalised account of teleology should rely. Yet, it is interesting to notice that one of the most famous and influential account of biological organisation, the theory of *autopoiesis*, holds an opposite position about this specific issue. Even thought Maturana and Varela build their model of biological organisation on Piaget's distinction between organisational closure and thermodynamic openness, they explicitly reject any legitimacy and relevance—though not a heuristic one - to teleological and functional explanations

(Varela and Maturana 1972; Maturana and Varela 1973). According to them, autopoietic systems are systems without goals. The main target of their criticism of teleology is twofold: on the one hand, the reductive focus of the genetic approach on a specific subsystem (the genome as a program) as the only one responsible for self-determination; on the other hand, the temporal scale of the evolutionary approach, which has no explanatory significance in analysing individual organisms.

In our view, Maturana & Varela's position is inadequate, because it fails to recognise that it is possible to provide a distinct account of biological teleology by relying on the notion of organisational closure. Discarding teleology *in toto*, indeed, may lead to obscuring the qualitative differences which exist between biological systems and any other kind of natural or artificial systems. Yet, their suspicion with regards to teleology reveals that the very concept of closure suffers from an insufficient characterisation. Although it does point in the right direction, we submit that closure, as described by Piaget, Maturana and Varela is not spelled out clearly enough to capture the distinctive aspects of organisational self-determination. To adequately ground intrinsic teleology, closure must be shown to be a form of self-determination, specifically realised by biological systems.

3 Organisation and self-determination

As this brief historical overview shows, the idea of a conceptual connection between biological organisation and teleology has a prestigious history in philosophy of science and theoretical biology. In very general terms, this tradition has tried to naturalise the teleological dimension by linking it to some form of circular causal regime at work within individual biological organisms. In particular, we agree with authors like Kant, Bernard and Piaget that intrinsic teleology is grounded in a *specific* kind of circular regime, that we have labelled self-determination.

Beyond this general claim, however, what matters is the precise meaning given to self-determination. What does it exactly mean in the biological domain? How do biological systems determine themselves? In this respect, it seems to us that the tradition evoked above has not fully succeeded, so far, in providing a stable and shared account of biological self-determination. Even if we exclude both the evolutionary and genetic interpretation of self-determination, and focus on the organisational one, the issue remains open insofar as the very notion of *organisation* has not (yet) been expressed in fully explicit theoretical terms. In this section, we do not aim at providing a complete framework of organisational principles in biology; yet, by relying on recent theoretical and philosophical work on this matter, we think that it is possible to adequately characterise those specific properties of biological organisation that ground intrinsic teleology.

At first approximation, all authors having focused on the connection between organisation and self-determination emphasise that biological systems realise a distinctive relation between the parts and the whole. Biological organisation consists in a network of mutually dependent components, each of them exerting a causal influence on the condition of existence of the others, so that the whole network is collectively able to self-maintain. As mentioned, Kant refers to this causal regime as "self-organisation".

Yet, the use of this term has progressively shifted during the 20*th* century and has today a precise meaning in Physics, in non-equilibrium thermodynamics: self-organising systems are the so-called "dissipative structures" (Nicolis and Prigogine 1977).[11] In turn, the more recent literature has tended to adopt Piaget's term—closure—as the technical one to indicate the specific causal regime realising biological self-determination. In what follows, we conform to this use.

As it has been recently underlined (Moreno and Mossio in press) the notion of closure conveys the idea that self-determination results from the integrated interactions among a set of entities which would not exist in isolation: each component makes a *specific* and *complementary* contribution to the maintenance of the boundary conditions under which the whole network can exist. Accordingly, by virtue of the interplay between division of labour and mutual dependence that it implies, closure captures a fundamental aspect of the idea of "organisation" as such. In a word, biological systems are organised in the technical sense that they realise closure.

Is this characterisation of closure sufficient to capture the specific regime of self-determination at work in biological systems? At first sight, closure seems to be an adequate tool to grasp the difference with both artefacts and other categories of natural systems: indeed, intuition seems to confirm that it is only in the biological case that the parts exist only insofar as the system does. The parts of a rock do not dissolve if the whole is broken, just as the components of a computer do not disintegrate if the whole machine is disassembled.

In spite of this strong intuitive appeal, yet, we think that this characterisation is insufficient, because the general idea of "mutual dependence" on which closure relies does not exclusively apply to the biological realm: in some cases, physical and chemical systems can also involve the mutual dependence among their constituents and, at first sight, they seem to realise a form of self-determination. Let us mention the example that is frequently evoked in this kind of debate, namely, the Earth's hydrologic cycle. Here, a set of water structures (e.g. clouds, rain, springs, rivers, seas, etc.) generate a cycle of causal relations in which each contributes to the maintenance of the whole, and is in turn maintained by the whole. Clouds generate rain, which (contributes to) generates a spring, which gives rise to a river, which (contributes to) generates a lake, which regenerates clouds, and so on.[12] Does the water cycle realise closure? Is it, therefore, teleological? Actually, some authors (Toepfer 2012) have claimed that non-biological circular systems of this kind should be included in the category of teleological systems. In our view, this position is somehow symmetrical to that hold by Maturana and Varela, and equally unsatisfactory, to the extent that it fails in capturing fundamental differences between physical regimes of this kind and biological organisation. Where does the weakness lie? In a nutshell, our diagnosis is that previous accounts of closure fail to specify the relevant level of description at which biological self-determination occurs.

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[11] In the following section, we will discuss in some details the conceptual relations between biological organisation and physical self-organisation.

[12] As we will discuss in the Sect. 3, it is important not to confuse the water cycle, to which we are referring here (the hydrologic system alone), with supra-organismal systems such as ecosystems, or with even more comprehensive climatic systems which possibly include *biological* organisms as components.

What is the relevant level? Previous accounts of organisational closure have already foreseen the answer, through the pivotal distinction between organisational closure and thermodynamic openness. As Piaget emphasises, an adequate understanding of biological organisation must take into account its thermodynamic openness, i.e. the fact that it is traversed by a continuous flow of energy and matter. At the same time, the activity of biological systems "folds up", and can be pertinently described as a closed network of mutual interactions. Maturana and Varela share this intuition, and explicitly claim that the constitutive closure of biological systems cannot mean that they are "independent", in the sense that they would not need to interact with the external environment; quite on the contrary, their thermodynamic openness makes them inherently interactive, that is, it makes them *agents*. In these formulations, however, the precise relation between closure and openness is not stated in explicit terms: biological organisation is open and yet, *in some other sense*, it is also closed. In the absence of such a precise characterisation, hence, it remains unclear if there is a fundamental difference between biological closure and any other kinds of causal "cycles" occurring in the natural world.

In this respect, a fundamental contribution has been provided by Robert Rosen, who was the first author to have explicitly seen and claimed that a sound understanding of biological organisation should account for the distinction between closure and openness *in terms of a distinction between two causal regimes* at work in biological systems. In his theory of (M,R)-systems (1972), Rosen elaborates a rigorous and explicitly formal account of organisational closure. The starting point is a criticism of what Rosen calls the "Newtonian paradigm" in science, characterised by severe limitations with respect to the admissible causal relations and, therefore, to its explanatory power (Rosen 1985a). The main problem of the Newtonian paradigm, according to Rosen, is that it segregates different causes in different independent structures and eliminates final causes from the picture. The result is a failure to adequately describe both the distinctive properties of complex systems (and, in particular, of living ones), and the richness of their behaviours, as in for example anticipatory behaviours (Rosen 1985b). In other words, circularity and final causes need to be introduced.

In *Life Itself* (1991), Rosen's account of closure is based on a reinterpretation of the Aristotelian categories of causality and, in particular, on the distinction between efficient and material cause.[13] Let us consider a physical process, such as a reaction

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[13] Rosen uses and re-interprets Aristotelian causes as a way of answering the question "why x?" in a description of a natural system, where x is a component or feature of such a system. Rosen does so in terms of physical, chemical and biological descriptions, by interpreting Aristotelian causes in strict relation to mathematical formalism and associating them with physical structures or quantities. In the case of the dynamical description of physical systems, he associates the initial state of a system with the material cause, the parameters with formal cause and the operators with efficient cause (Rosen 1985b). According to Rosen, in the dynamical descriptions of physics there is no space for final causes. When he applies the Aristotelian account in a relational description of biological systems, such as the one he develops for (M,R)-Systems (Rosen 1972, 1991), he identifies: the material cause with matter and energy flowing in the system (the input and the output of a process); the efficient cause with a material structure that affects the process without being directly affected in turn, which he expresses mathematically as a mapping that transforms the input into the output; the formal cause with the global topology of the network, that is, in mathematical terms, the whole graph built on the category formalism. As we discuss below, he characterises final causation with the inverse of efficient causation.

catalysed by an enzyme,[14] which can be described formally as an abstract mapping f (the enzyme) between the sets A (the substrates) and B (the products), so that f: $A =>> B$. If we interpret the mapping in causal terms, and look for the causes of B, Rosen claims (and develops a detailed conceptual and formal justification, that we do not recall here) that A is the material cause of B, in our example the source of matter and energy, while f is the efficient cause, the enzyme that makes the transformation possible.[15] By relying on this formal distinction, Rosen's central thesis is that:

> "a material system is an organism [a living system] if, and only if, it is closed to efficient causation" (Rosen 1991, p. 244).

In turn, a natural system is closed to efficient causation if, and only if, all components having the status of efficient causes are materially produced by and within the system itself.[16]

According to Rosen, the circularity of organisational closure rehabilitates the notion of final cause, and grounds teleology, which cannot be captured in terms of linear causation. His main idea in this respect is that circular causation allows understanding the components of an organism not only in terms of what causes them, but also in terms of their contribution to the realisation and maintenance of the whole, i.e. in terms of both efficient and final causes (Rosen 1991, pp. 48, 252), Within closure, in particular, teleology coincides with the inversion of efficient causation: if x is the efficient cause of y, then y is the final cause of x. The reason is that, because of closure, what x does (y) contributes to the very existence of x. Final causation, therefore, finds its justification in the very organisational principles of the system, without reference to an external designer or user. In such a way intrinsic biological teleology is naturalised in terms of a specific organisation of efficient causes. It is important to underscore that the inversion of efficient causes by no means implies the inversion of the arrow of time. Rosen naturalises teleology by *abstracting* closure from time, and by considering a purely *relational* description of the circular causal regime, and not a dynamical one, based on temporal sequences of states. All subsequent accounts of closure share, we hold, the very same strategy for naturalisation.

An analysis of Rosen's account in all its richness would far exceed the scope and limits of this paper. What matters most for our present purposes is that, by providing a clear-cut theoretical and formal distinction between material and efficient causation, Rosen explicitly distinguishes between two causal regimes which coexist within biological systems: closure to efficient causation, which grounds its unity and dis-

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[14] It could also be a membrane channelling the passage of molecules inside a cell, the heart pumping blood, etc.

[15] Rosen relies on category theory in order to formally describe efficient causes as mappings. Indeed, category theory allows expressing the activity of components as mappings and, at the same time, mappings themselves as the products of other mappings. This adequately captures the hierarchical and manifold character of efficient causes in living systems: they act on processes (enzymes catalyse reactions) and, at the same time, they are produced by other efficient causes (enzymes are produced by other metabolic processes within the cell).

[16] Let us consider the previous example of the catalyst as an instance of efficient cause. A minimal case of closure to efficient causation would be a system which produces all the catalysts necessary for its own activity (Cornish-Bowden 2006). This is what is usually called "catalytic closure" (Kauffman 2000).

tinctiveness, and openness to material causation, which allows material, energy and informational interactions with the environment.

In Rosen's account, self-determination is located at the level of efficient causes: what identifies the system is the set of efficient causes subject to closure, and the maintenance of the organisation is the maintenance of the network of efficient causes. Inspired by the idea of catalysis and its crucial role in metabolism, Rosen takes therefore a clear step forward, with respect to previous accounts, in the characterisation of biological self-determination. For Rosen closure is not conceived of as just any causal cycle of production, in which each component is transformed into another component, by generating a circular chain. Rather, each efficient cause acts on material processes and reactions which produce another efficient cause, without being itself involved in the transformation: the mutual dependence among efficient causes is realised through the action exerted on material causes. In other words, although self-determination concerns efficient causation, it requires an adequate comprehension and description of the intertwined relationships between efficient and material causation. A system closed to efficient causation is such because it is able to act on its own constitutive dynamics, which in turn realise and maintain the efficient organisation.

In our view, Rosen's account has made significant steps towards an adequate characterisation of biological self-determination and, consequently, of intrinsic teleology. In the remainder of this section, we will develop an account which, we think, is consistent with the conceptual framework he set. Indeed, in spite of its qualities, one of the weaknesses of Rosen's account of closure is its abstract character. Closure is defined as involving efficient causes but, without further specification, it might be difficult to identify efficient causes in a system. What actually plays the role of efficient cause in a biological system? How should the relevant level of causation at which self-determination occurs be characterised?

To answer these questions, we submit that the decisive contribution comes from the more recent literature that emphasises, in line with Piaget's initial insights, the "thermodynamic grounding" of biological systems (Bickhard 2000; Christensen and Hooker 2000; Moreno and Ruiz-Mirazo 1999). In particular, Kauffman (2000) has proposed to retrieve the classic idea of "work cycle" (as in an ideal thermal Carnot machine), and to apply it to the context of biochemical, self-maintaining reactions. Based on Atkins' ideas about work, conceived of as a *constrained* release of energy (Atkins 1984), Kauffman argues that a mutual relationship between work and constraints must be established in a system in order to achieve self-maintenance, in the form of a "work- constraint (W-C) cycle".

What are constraints? They can be conceived as local and contingent causes, which reduce the degrees of freedom of the dynamics on which they act (Pattee 1973), while remaining conserved (at the time scale which is relevant to describe their causal action) with respect to those dynamics.[17] In describing physical and chemical systems,

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[17] Their local conservation makes the conceptual difference with respect to material causes. For instance, while the substrates of a chemical reactions are converted into the products, the catalysts accelerate the reactions without being consumed by it. Because of their conservation, cataysts are constraints, while substrates are material causes. See Mossio et al. (2013) for an account of constraints and their role in organisational closure.

constraints are usually introduced as external determinations (boundary conditions, parameters, restrictions on the configuration space, etc....), which means that they contribute to determining the behaviour and dynamics of a system, even though their existence does not depend on the dynamics upon which they act (Umerez 1994; Juarrero 1999). To take a simple example, an inclined plane acts as a constraint on the dynamics of a ball moving on it, whereas the constrained dynamics do not exert a causal role in the production and existence of the plane itself.

When a (W-C) cycle is realised, in turn, the mutual relations between constraints and constrained dynamics change, and become circular: constraints are required to harness the flow of energy (in Carnot's machine, for instance, one needs the walls of the cylinder, the piston, etc…), so that the system can generate work and not merely heat (due to the dispersion of energy). In the case of systems able to determine themselves, these constraints are not independently given (as in the Carnot's machine) but, rather, are produced and maintained by the system itself. Hence, the system needs to use the work generated by the constraints in order to maintain those very constraints, by establishing a mutual relationship between constraints and work.

The work-constraint cycle constitutes a thermodynamically grounded self-determining regime, through which a system is able to self-constrain by exploiting part of the flow of energy and matter to generate work. As such, however, the (W-C) cycle is not supposed to specifically apply to biological systems, insofar as it does not explicitly capture the organisational dimension of biological self-determination. Indeed, closure implies not only the constraining action exerted on the thermodynamic flow, but also a specific *organisation* among the constitutive constraints. And the work-constraint cycle does not elaborate on the nature of this organisation. For this reason, we submit that the crucial conceptual move here consists in interpreting Rosen's efficient cause in terms of constraints: hence, organisational closure should be understood as a *closure of constraints* (Moreno and Mossio in press).

What is lacking in previous accounts of closure is the (explicit) theoretical distinction between constraints and processes, and the related ascription of closure to the organisation of constraints. What is the general picture behind this claim? Biological systems, as many other physical and chemical systems, are dissipative systems, which means that they are traversed by a far from thermodynamic equilibrium flow of energy and matter. In this respect, organisms do not differ qualitatively from other natural dissipative systems. However, what specifically characterises biological systems is the fact that the thermodynamic flow is channelled and harnessed by a *set* of constraints in such a way as to realise mutual dependence between these constraints. Accordingly, the organisation of constraints *can be said to achieve self-determination as self-constraint*, since the conditions of existence of the constitutive constraints are, because of closure, mutually determined within and by the organisation itself.[18]

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[18] Biological self-determination should be carefully distinguished from self-organisation. As mentioned, 'self-organisation' refers nowadays to physical spontaneous phenomena. In contrast, biological systems are (mostly) not spontaneous, in spite of the fact that they generate their own components. Accordingly, to avoid ambiguities, we submit that closure entails a form of self-maintenance of the whole, and not its self-generation or self-organisation.

The appeal to self-constraint allows making more explicit the distinction between two kinds of circular causal regimes: cycles and closure. On the one hand, cycles refer to circular chains of transformations that, under the effects of externally determined constraints, can be described at one level of causation (in particular, that at which processes occur in non-equilibrium thermodynamic conditions). On the other hand, closure indicates a circular causal regime in which a set of constraints described at one level of causation maintains itself by canalising processes and reactions occurring in non-equilibrium thermodynamic conditions at another level of causation: closure is therefore by construction an inter-level causal regime.[19]

The central hypothesis is that closure of constraints constitutes the causal regime that is distinctively at work in biological systems.[20] Unlike both artefacts and physical cycles, biological systems are specific in the fact that their activity maintains (at least some of) the constraints which enable that very activity so that a closed path of causation is realised between the mutually dependent constraints. In particular, closure is the circular causal regime that adequately grounds intrinsic teleology and, consequently, normativity. As it has been recently argued (Barandiaran and Moreno 2008; Mossio et al. 2009) the goal of a closed organisation has an intrinsic relevance for the system, which generates a criterion for determining what norms the system is supposed to follow: the system must behave in a specific way, otherwise it would cease to exist. The intrinsic goal of a system realising closure becomes its norm or, maybe more precisely, its conditions of existence are the intrinsic (and naturalised) norms of its own activity. Lastly, and importantly, by grounding teleology and normativity, closure also grounds functionality: the set of constraints subject to closure are the set of biological functions.

In this respect, it should be underlined that the idea of biological function not only relies on the teleological and normative dimensions, but also on the very idea of organisation. A biological function is a kind of effect that is not only normatively oriented towards a goal, but also conveys the idea of a network of mutually dependent entities, each of them making *different* yet *complementary* contributions to the self-determination of the system. Ascribing functions requires distinguishing between different causal roles in self-determination: this is precisely what happens with a closure of constraints. As a result, the concepts of closure, organisation and functionality are theoretically related to each other: they all refer to the causal regime through which biological self-determination is realised.

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[19] These two levels of causation are of course not the only ones which coexist in biological systems. These usually realise many levels of organisation (unicellular, multicellular…), and possess also regulatory capacities. The point here is that biological organisation as a form of self-constraint requires, necessarily, a distinction between *these two* specific regimes.

[20] Or, at least, in systems being “at the edge” of the biological domain as, possibly, complex chemical networks. In this paper, we do not discuss these categories of systems to the extent that this does not interfere with our main argument.

4 Self-constraint and teleology

With respect to the original accounts, we have argued that more recent theoretical investigations on the principles of biological organisation allow for a more explicit account of the kind of circular causal regime that grounds intrinsic teleology: self-determination as self-constraint, which takes the specific form of closure, i.e. an organisation of mutually dependent constraints. Yet, the argument developed so far leaves two issues open: in this section, we deal with both of them.

The first issue can be expressed through the following question: why is intrinsic teleology exclusively grounded by self-constraint? Even though one concedes that there is a fundamental difference between closure and cycles in terms of their causal structure, it might be argued that cycles, insofar as they do realise a form of circular causal regime, ground intrinsic teleology in the same sense that closure does. Those physical regimes which are adequately described as cycles, in particular, could be said to exist also because of the effects of their own activity: the river exists because it maintains other water structures involved in the water cycle and, thereby, maintains itself. Accordingly—the argument would conclude—the water cycle can be said to be intrinsically teleological (Toepfer 2012).

Of course, advocates of an organisational account of intrinsic teleology cannot easily accept this conclusion, since it would undermine the very project of providing a naturalised grounding which would be *specific* to the biological domain. If any causal cycle can be justifiably interpreted as intrinsically teleological, then biological organisation would not possess any distinctive feature in this respect. Is it the case? In our view, it is not. Although they consist in a circular chain of processes, we argue that physical cycles of this kind do *not* realise self-determination and, therefore, should not be considered as inherently teleological. Let us develop the argument.

Physical cycles, like the hydrological one, are constituted by a set of entities (in the case of the water cycle, the various configurations of water: lake, river, clouds, rain…) connected to each other through a circular chain of transformations. In this sense, it might be said that each entity generates (in the sense that it becomes) the following one in the chain and, indirectly, itself. Unlike a closed organisation, however, the chain of transformations does not generate its own constraints, which are external to the circular dynamics, and independent from them. In the case of the water cycle, for instance, the dynamics of the river are specified in particular by the conformation of the ground and its slope, which are not generated by the water cycle itself.

It should be underscored that the independence of the constraints from the cycle does not mean that the constrained dynamics cannot affect those very constraints. As a matter of fact, the river does dig and modify its bed. Yet, the conceptual point here is that, unlike what happens in the case of closure, the conditions of existence of the water cycle are met independently from the causal action that it possibly exerts on its own boundary conditions (i.e. the external constraints): the water cycle would exist even though the river did not modulate its own bed. Accordingly, we argue that cycles of transformations can be adequately described in terms of far from equilibrium circular dynamics, whose conditions of existence are sufficiently determined by independent boundary conditions.

What is at stake here is a fundamental distinction between a causal regime in which some effects happen to circularly contribute to generate their own (material) causes, and a causal regime which itself plays a role in determining the *conditions* under which the effects contribute to generating their own causes. The idea of intrinsic teleology, we submit, does not merely point to the realisation of a circular relation between causes and effects but, rather, to the situation in which the activity of a system, by producing some effects, contributes to specifying the conditions under which the circular relation as such can occur. It is in this precise sense that the connection between teleology and self-determination is to be understood. By merely obeying (or, at best, modulating) the external constraints, the dynamics of the cycles fail in specifying their causal regime in that they simply realise it. Accordingly, cycles do *not* self-determine. Therefore, they are not teleological regimes.

The conceptual distinction between circular causation and self-determination (i.e. the idea that self-determination is a specific kind of circular regime) clarifies why an adequate account of intrinsic teleology requires considering two levels of causation. Indeed, if there were no principled distinction between processes and constraints, it would be impossible to make the distinction between circular chains of transformation and self-constraint. That is why we have stressed in the previous section the crucial importance of distinguishing, as suggested by authors as Piaget, Maturana, Varela and Rosen, between closure and openness, which allows locating biological self-determination at the relevant level of causation.

The second issue concerns the scope of self-constraint in the natural world. If self-constraint could be shown to exist beyond the biological domain—one could argue—, it would follow that non-biological systems would realise intrinsic teleology.[21] Again, this implication might be at odds with the objective of providing a specifically biological grounding of teleology, and deserves to be addressed explicitly.

Before discussing the occurrence of self-constraint outside of biology, let us say a word about its presence within biology. As we claimed, the biological manifestation of self-constraint takes the form of closure, which is organisation and, more precisely, functional organisation to the extent that, as mentioned, constraints subject to closure correspond to biological functions.

Closure is typically realised by biological organisms, which are a specific subset of particularly complex systems, included in the larger set of organised systems (actually, they meet the requirements to be described as *autonomous* systems; see Moreno et al. 2008;Moreno and Mossio in press). Yet, it seems that biological systems other than organisms may be pertinently described as organised: for instance, both multicellular organisms and their constituting cells realise closure; similarly supra-organismal systems, as symbioses, ecosystems (Nunes-Neto et al. 2014) or even large climate

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[21] We cannot exclude *a-priori* that there might be cases of physicochemical (proto-biological) systems realising closure and, therefore, a basic form of intrinsic teleology. However, it should be underscored that this issue does not concern exclusively the organisational account. According to Bedau (1991), for instance, some kinds of crystals might undergo a process of natural selection, insofar as they are capable, in some adequate circumstances, of reproduction, variation and heredity. Accordingly, they would be teleological from an evolutionary perspective. As such, hence, the fact that the organisational account might possibly ascribe teleology to some physical systems does not constitute a principled difference (or weakness) with respect to the evolutionary one.

regulation systems (to the extent that they include biological systems as constituents) might also possibly be shown to be organisationally closed. If it were the case—and we have no principled objections to this—it would follow that the biological realm includes several classes of organised systems (possibly located at different level of organisation) and, consequently, that each class would be inherently teleological (as well as normative and functional). This implication is important, because it highlights the fact that the organisational account we advocate links intrinsic teleology to closure and organisation, and *not* with the more restrictive concept of organism.

Let us now have a look beyond the biological domain. Does self-constraint occur outside biology? Although we do not have a general answer to the question, we think that some useful clarifications can indeed be provided. As a matter of fact, this question could be interpreted in two different ways, and it might be useful to discuss each of them separately.

On the one hand, one can wonder whether self-constraint *in the form of closure* is realised by non-biological systems, i.e. systems *not* involving the intervention of biological systems as constitutive constraints.[22] In this respect, the crucial remark is that the realisation of closure requires a relatively high degree of complexity, to the extent that only complex chemical functional structures could be able to adequately constrain the thermodynamic flow, so as to generate and maintain a viable self-maintaining network (Moreno and Ruiz-Mirazo 2009; Arnellos and Moreno 2012). To our knowledge, actually, there are no clear examples of non-biological organisationally closed chemical networks, apart from abstract theoretical and computational models as, for instance, the well-known autocatalytic sets (Kauffman 2000). In any case, a material realisation of closure would presumably require such a high degree of chemical complexity that the resulting system would be “at the edge” of the biological domain. Accordingly, the organisational account might definitely conclude that this kind of system would be intrinsically teleological, in the light of its proximity to (or possible inclusion in) the biological domain.

On the other hand, one can ask whether there are simpler, non-organised forms of self-constraint in the natural world. As frequently discussed by the literature, the main candidates are dissipative structures, in which a huge number of microscopic elements spontaneously self-organise, and adopt a global, macroscopic ordered configuration (the “structure”) in the presence of a specific flow of energy and matter in far-from-thermodynamic equilibrium conditions (Nicolis and Prigogine 1977). A number of physical and chemical systems, such as Bénard cells, flames, hurricanes, and oscillatory chemical reactions, can be pertinently described as self-organising dissipative systems.

The question is whether dissipative structures can be described as making a causal contribution to their own maintenance. According to some authors, it is the case: the internal dynamics, enabled by external constraints, produce (and determine) their own attractors which, in turn, constraint the dynamics. In this view, attractors contribute

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[22] Therefore, we deal here with physicochemical regimes which would *not* be “supra-organismal”, as the already mentioned ecosystems or (possibly) larger climate systems.

to maintain the adequate external conditions of the dynamics that produce them. Prigogine himself, for instance, elaborates on original ideas of von Bertalanffy (1949), and ascribes to dissipative structures not only the capacity of reacting conservatively to a certain range of perturbations, but also that of *managing* exchanges with the environment (Prigogine and Stengers 1988). In a similar vein, Bickhard (2000) claims that dissipative structures exhibit self-maintenance, insofar as the actively contribute to maintain the adequate conditions of their own existence.[23] In line with Bickhard's view, Ruiz-Mirazo (2001, pp. 57–58) further develops the understanding of dissipative structures in terms of self-maintenance, by explicitly connecting it to self-constraint.[24] In Ruiz-Mirazo's account, physical self-organisation implies the fact that the dissipative pattern is maintained by a set of constraints, of which at least *one* is produced by the pattern itself.

Yet, the issue has not been settled in the literature. In contrast with the preceding view, several authors (Anderson and Stein 1985; Crutchfield 1994; Minati and Pessa 2006) have argued that dissipative structures do *not* self-constrain and, more generally, do not contribute to their own conditions of existence. In this view, dissipative structures would not be dissimilar from the case of physical cycles discussed above, insofar as their behaviour would be sufficiently determined by the external boundary conditions. According to this interpretation, dissipative structures can be described as situations in which, given a set of external constraints, a set of basic components and suitable initial conditions, collective dynamics emerge and exhibit a specific phenomenology. In turn, these dynamics can be characterised through an attractor that, as such, plays *no* causal role on the very dynamics: an understanding of self-organising phenomena in terms of self-determination would be, in this sense, a projection of the observer (Bich 2012b).

As far as we know, hence, there is no shared answer to the question whether dissipative structures self-constrain and constitute, accordingly, a non-biological case of self-determination. If they do not, it would of course follow that they do not stand as an exception of the claim that self-constraint, self-determination, and thus intrinsic teleology, would be *exclusive* features of the biological domain. What if, in contrast, one advocates—as we did elsewhere—the idea that they do realise a form of self-constraint. In this case, it seems to us that the only coherent conclusion with the organisational account would be to concede that dissipative structures realise intrinsic teleology. Self-organisation would be intrinsically teleological, just as biological organisation is. Yet, this conclusion cannot go without an important remark.

The fact that self-organisation might possibly be described as teleological should not obscure that it would be so by realising a radically different kind of causal regime.

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[23] "A candle flame […] makes several active contributions to its own persistence. It maintains above combustion threshold temperature. It vaporises wax into a continuing supply of fuel. In a standard atmosphere and gravitational field, it induces convection, which pulls in continuing oxygen and removes combustion products. A candle flame, in other words, tends to maintain itself; it exhibits self-maintenance" (Bickhard 2000, http://www.lehigh.edu/~mhb0/autfuncrep.html.

[24] A similar thesis has been proposed by Bishop (2008) in terms of direct self-constraint interpreted as a form of downward causation.

Dissipative structures possess 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-organising systems are systems that are simple enough to appear spontaneously. In particular, they do not realise closure; rather, they would be *minimally* teleological, insofar as they would generate a *single* macroscopic constraint (the structure itself) that, supposedly, maintains itself by acting on its own boundary conditions. Even under this interpretation, thus, the behaviour of dissipative structures would still be mostly and largely determined by external boundary conditions. In this respect, hence, dissipative structures are not organised and, given the conceptual connection we emphasised between organisation and functionality, their parts have no functions.

In a word, dissipative structures and closed organisations would have almost *nothing* in common with respect to their causal regimes, except for the very fact of being both intrinsically teleological.

5 Conclusions

What makes biological organisation teleological? In this paper, we have argued that the answer to this question appeals to self-determination: biological systems are teleological because the effects of their own activity contribute to establish and maintain their own conditions of existence. Again, biological systems are what they do: hence, as explained, they realise intrinsic teleology.

Most of the argument that we developed has been aimed at clarifying the meaning of self-determination and, more precisely, at specifying what kind of causal circularity it involves. In this respect, one of the general upshots of the paper is that, although teleology has indeed something to do with circularities, not any kind of circular causation is relevant to adequately ground intrinsic teleology.

Self-determination grounds intrinsic teleology because, we argued, it must be understood as self-constraint. Biological systems are capable of self-determination because they generate (some of) the constraints that act on their own activity. By generating these constraints, they contribute to determine the conditions at which their organisation can occur; accordingly, unlike other classes of natural (as the controversial case of physical cycles) or artificial systems, biological systems do not merely obey external, and independently generated, constraints. For these reasons, self-determination means self-constraint that, in biological systems, takes the form of closure, i.e. the organisation of a set of mutually dependent constraints.

Characterised in this way, biological organisation can be legitimately said to be teleological without involving any contradiction with the conception of causality accepted by the natural sciences. In particular, closure does not imply an inversion of the temporal relation between causes and effects, since it consists in a purely relational description of the circular causal regime at work. This is why we claim that the organisational account of teleology in terms of closure complies with the exigencies of naturalism.

With this organisational characterisation of teleology in hand, we have briefly explored its occurrence in the biological domain. As a matter of fact, it might be argued that closure is realised not only, and typically, by biological organisms, but also by other systems located at other levels of description, as symbioses or ecosystems. If adequate justification were provided, the organisational account would easily concede that these systems are organised, that is, that they realise a closure of constraints, and are hence teleological in the same way as organisms, inasmuch as their constitutive dynamics are directed towards their own maintenance.

Beyond the biological realm, finding clear cases of intrinsic teleology does not seem an easy task. This seems to support our intention of providing a characterisation that captures some distinctive feature of the living organisation. Self-constraint as closure, on the one hand, requires such a high degree of complexity that any actual realisation might be pertinently included in the biological (or nearly biological) domain. The case of simpler forms of self-constraint seems more controversial: authors having dealt with the issue do not agree on whether the main candidates—self-organising dissipative systems—do self-constrain or not. Future scientific investigations will presumably provide a better understanding of the boundaries of intrinsic teleology, in its more general sense.

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References

Anderson, P. W. (1985). Broken symmetry, emergent properties, dissipative structures, life: Are they related? In F. E. Yakes (Ed.), *Self-organizing systems: The emergence of order* (pp. 445–458). New York: Plenum Press.

Arnellos, A., & Moreno, A. (2012). How functional differentiation originated in prebiotic evolution. *Ludus Vitalis, XX*, *37*, 1–23.

Ashby, R. (1956). *An introduction to cybernetics*. London: Chapman & Hall.

Atkins, P. W. (1984). *The second law*. New York: Scientific American.

Ayala, F. J. (1970). Teleological explanations in evolutionary biology. *Philosophy of Science*, *30*(1), 1–15.

Bailly, F., & Longo, G. (2011). *Mathematics and the natural sciences. The physical singularity of life*. London: Imperial College Press.

Barandiaran, X., & Moreno, A. (2008). Adaptivity: From metabolism to behavior. *Adaptive Behavior*, *16*, 325–344.

Bechtel, W. (2007). Biological mechanisms: Organized to maintain autonomy. In F. Boogerd, F. Bruggerman, J. H. Hofmeyr, & H. V. Westerhoff (Eds.), *Systems biology: Philosophical foundations* (pp. 269–302). Amsterdam: Elsevier.

Bedau, M. (1991). Can biological teleology be naturalized? *The Journal of Philosophy*, *88*(11), 647–655.

Bedau, M. (1992). Goal-directed systems and the good. *The Monist*, *75*(1), 34–51.

Bernard, C. (1865). *Introduction à l'étude de la médecine expérimentale*. Paris: Baillière.

Bernard, C. (1878). *Leçons sur les phénomènes de la vie communs aux animaux et aux végétaux*. Paris: Baillière.

Bich, L. (2012a). *L'ordine invisibile. Organizzazione, autonomia e complessità del vivente*. Soveria Mannelli: Robbettino Università.

Bich, L. (2012b). Complex emergence and the living organization. An epistemological framework for biology. *Synthese*, *185*(2), 215–232.

Bich, L., & Arnellos, A. (2013). Autopoiesis, autonomy and organizational biology: Critical remarks on "Life After Ashby". *Cybernetics and Human Knowing*, *19*(4), 75–103.

Bickhard, M. H. (2000). Autonomy, function, and representation. *Communication and Cognition—Artificial Intelligence*, *17*(3–4), 111–131.

Bishop, R. (2008). Downward causation in fluid convection. *Synthese*, *160*(2), 229–248.

Cannon, W. B. (1929). Organization for physiological homeostasis. *Physiological Reviews*, *9*(3), 399–431.

Christensen, W., & Bickhard, M. (2002). The process dynamics of normative function. *The Monist*, *85*(1), 3–28.

Christensen, W. D., & Hooker, C. A. (2000). Autonomy and the emergence of intelligence: Organised interactive construction. *Communication and Cognition—Artificial Intelligence*, *17*(3–4), 133–157.

Cornish-Bowden, A. (2006). Putting the systems back into systems biology. *Perspectives in Biology and Medicine*, *49*, 475–489.

Crutchfield, J. P. (1994). The calculi of emergence: Computations. *Dynamics, and Induction, Physica D*, *75*, 11–54.

Damiano, L. (2012). Co-emergences in life and science: A double proposal for biological emergentism. *Synthese*, *185*(2), 273–294.

Darwin, C. (1859). *On the origin of species*. London: John Murray.

Fox Keller, E. (2000). *The century of the gene*. Cambridge MA: Harvard University Press.

Fox Keller, E. (2002). *Making sense of life*. Cambridge MA: Harvard University Press.

Godfrey-Smith, P. (1994). A modern history theory of functions. *Nous*, *28*, 344–362.

Hall, T. S. (1968). *Ideas of life and matter* (Vol. 2). Chicago: Chicago University Press.

Huneman, P. (Ed.). (2007). *Understanding purpose?: Kant and the philosophy of biology*. Rochester, NY: University of Rochester Press.

Jacob, F. (1970). La logique du vivant. Une historie de l'hérédité. Paris: Gallimard (Eng. Trans. by B. E. Spillmann, The Logic of Life, New York: Pantheon Books, 1973).

Jacob, F., & Monod, J. (1961). Genetic regulatory mechanisms in the synthesis of proteins. *Journal of Molecular Biology*, *3*, 318–356.

Jonas, H. (1953). A critique of cybernetics. *Social Research*, *20*, 172–192.

Jonas, H. (1966). *The Phenomenon of Life. Towards a Philosophical Biology*. New York: Harper and Row.

Juarrero, A. (1999). *Dynamics in Action. Intentional Behaviour as a Complex System*. Cambridge MA: MIT Press.

Kant, I. (1781/1998). *Critique of pure reason*. Cambridge: Cambridge University Press.

Kant, I. (1790/1987). *Critique of Judgment*. Indianapolis: Hackett Publishing.

Kauffman, S. (2000). *Investigations*. New York: Oxford University Press.

Kitcher, P. (1993). Function and Design. *Midwest Studies in Philosophy*, *18*(1), 379–397.

Lenoir, T. (1981). Teleology without regrets. The transformation of physiology in Germany 1790–1847. *Studies in the History and Philosophy of Science*, *12*, 293–354.

Lenoir, T. (1982). *The strategy of life. Teleology and mechanics in nineteenth century german biology*. Chicago: The University of Chicago Press.

Lewontin, R. C. (1991). *Biology as Ideology. The Doctrine of DNA*. Concord: House of Anansi Press.

Lewontin, R. C. (2000). *The triple helix. Gene, organism, environment*. Cambridge MA: Harvard University Press.

Longo, G., & Tendero, P. E. (2008). L'alphabet, la machine et l'ADN: l'incomplétude causale dela théorie de la programmacion en biologie moléculaire. In P. A. Miquel (Ed.), *Biologie du XXIe Siècle:Évolution des Concepts Fondateurs* (pp. 185–218). Paris: DeBoeck.

Maturana, H. & Varela, F. J. (1973), *De Máquinas y Seres Vivos: Una teoría sobre la organización biológica*, Santiago: Editorial Universitaria. In H. Maturana, & F. J. Varela (Eds.), 1980, *Autopoiesis and Cognition. The Realization of the Living*. Dordrecht: North Holland.

Mayr, E. (1961). Cause and effect in biology. *Science*, *134*, 1501–1506.

Mayr, E. (1974). Teleological and teleonomic, a new analysis. *Boston Studies in the Philosophy of Science*, *14*, 91–117.

Millikan, R. G. (1989). In defense of proper functions. *Philosophy of Science*, *56*, 288–302.

Minati, G., & Pessa, E. (2006). *Collective beings*. New York: Springer.

Monod, J. (1970). *Les hasard et la necessité*. Paris: Seuil.

Morange, M. (1994). Histoire de la biologie moléculaire. Paris: Editions La Découverte (Eng. Trans. by M. Cobb, A History of Molecular Biology, Cambridge MA. Harvard University Press, 1998).

Moreno, A., & Ruiz-Mirazo, K. (1999). Metabolism and the problem of its universalization. *BioSystems*, *49*(1), 45–61.

Moreno, A., & Ruiz-Mirazo, K. (2009). The problem of the emergence of functional diversity in prebiotic evolution. *Biology and Philosophy*, *24*(5), 585–605.

Moreno, A., & Mossio, M. (in press). *Biological autonomy: A philosophical and theoretical enquiry*. Dordrecht: Springer.

Moreno, A., Etxeberria, A., & Umerez, J. (2008). The autonomy of biological individuals and artificial models. *Biosystems*, *91*(2), 309–319.

Mossio, M., Bich, L., & Moreno, A. (2013). Emergence, closure and inter-level causation in biological systems. *Erkenntnis*, *78*(2), 153–178.

Mossio, M., Saborido, C., & Moreno, A. (2009). An organizational account of biological functions. *British Journal of Philosophy of Science*, *60*(4), 813–841.

Neander, K. (1991). Functions as selected effects: The conceptual analyst's defence. *Philosophy of Science*, *58*, 168–184.

Nicolis, G., & Prigogine, I. (1977). *Self-organization in nonequilibrium systems: From dissipative structures to order through fluctuations*. New York: Wiley.

Nunes-Neto, N., Moreno, A., & El Hani, C. N. (2014). Function in ecology: An organizational approach. *Biology and Philosophy*, *29*(1), 123–141.

Pattee, H. H. (1973). The physical basis and origin of hierarchical control. In H. H. Pattee (Ed.), *Hierarchy theory* (pp. 71–108). New York: Braziller.

Perlman, M. (2004). The modern philosophical resurrection of teleology. *The Monist*, *87*(1), 3–51.

Piaget, J. (1967). *Biologie et connaissance*. Paris: Gallimard.

Prigogine, I., & Stengers, I. (1988). *Entre le temps et l'éternité*. Paris: Libraire Arthème Fayard.

Rosen, R. (1970). *Dynamical system theory in biology. Stability theory and its applications*. New York: Wiley-Interscience.

Rosen, R. (1972). Some relational cell models: The metabolism-repair systems. In R. Rosen (Ed.), *Foundations of mathematical biology* (Vol. II, pp. 217–253). New York: Academic Press.

Rosen, R. (1985a). Organisms as causal systems which are not mechanisms: An essay into the nature of complexity. In R. Rosen (Ed.), *Theoretical biology and complexity. Three essays on the natural philosophy of complex systems*. Orlando: Academic Press.

Rosen, R. (1985b). *Anticipatory systems*. Oxford: Pergamon Press.

Rosen, R. (1991). *ife itself. A comprehensive inquiry into the nature, origin, and fabrication of life*. New York: Columbia University Press.

Rosenblueth, A., Wiener, N., & Bigelow, J. (1943). Behaviour, purpose and teleology. *Philosophy of Science*, *10*(1), 18–24.

Ruiz-Mirazo, K. (2001). Physical conditions for the appearance of autonomous systems with open-ended evolutionary capacities. PhD Dissertation, University of the Basque Country.

Ruse, M. (2000). Teleology: Yesterday, today, and tomorrow? *Studies in History and Philosophy of Biological and Biomedical Sciences*, *31*(1), 213–232.

Saborido, C., Mossio, M., & Moreno, A. (2011). Biological organization and cross-generation functions. *The British Journal for the Philosophy of Science*, *62*, 583–606.

Sloan, P. (2012). How was teleology eliminated in early molecular biology? *Studies in History and Philosophy of Biological and Biomedical Sciences*, *43*(1), 140–151.

Sommerhoff, G. (1950). *Analytical biology*. London: Oxford University Press.

Toepfer, G. (2012). Teleology and its constitutive role for biology as the science of organized systems in nature. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *43*(1), 113–119.

Umerez, J. (1994). Jerarquias Autónomas - Un estudio sobre el origen y la naturaleza de loas procesos de control y de formacion de niveles en eistemas naturales complejos. Ph.D. Dissertation, University of the Basque Country.

Varela, F., & Maturana, H. (1972). Mechanism and biological explanation. *Philosophy of Science*, *39*(3), 378–382.

von Bertalanffy L. (1949). Das Biologische Weltbild: Die Stellung des Lebens in Natur und Wissenshaft. Bern: Francke (eng. ed., 1952, Problems of Life: An Evaluation of Modern Biological Thought. London: Watts & Co).

Weber, A., & Varela, F. J. (2002). Life after Kant: Natural purposes and the autopoietic foundations of biological individuality. *Phenomenology and the Cognitive Sciences*, *1*(2), 97–125.

Waddington, C. H. (1962). *The nature of life*. New York: Atheneum.

Waddington, C. H. (1968). The basic ideas of biology. In C. H. Waddington (Ed.), *Towards a theoretical biology* (Vol. 1, pp. 1–41)., Prolegomena New York: Atheneum.

Weiss, P. (1968). *Dynamics of development. Experiments and inferences*. New York: Academic Press.

Wiener, N. (1948). *Cybernetics: Or control and communication in the animal and in the machine*. Cambridge MA: MIT Press.

Wright, L. (1973). Functions. *Philosophical Review*, *82*, 139–168.

Zammito, J. (2006). Teleology then and now: the question of Kant's relevance for contemporary controversies over function in biology. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *37*(4), 748–770.