

Autopoiesis, Biological Autonomy and the Process View of Life

Anne Sophie Meincke

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1. Introduction

In recent years, theoretical biologists and philosophers of biology have made increasing efforts to defend organisms as biological players in their own right against overly gene-centred views of life both in developmental and evolutionary biology (in the latter case specifically in the context of the so-called Modern Synthesis). Pursuing a non-reductionist systems biological approach, these scholars emphasise the autonomous character of organisms as self-organising biological systems (e.g., Moreno & Mossio 2015, Walsh 2015, Rosslénbroich 2014), thereby referring back to the older theory of autopoiesis (Varela 1979, Maturana & Varela 1980).¹ Organisms and their characteristic development, it is argued, cannot be understood by looking at their parts only; it is the specific interplay of the parts, their organisation, that needs to be studied as giving rise to a functioning autonomous whole. This is believed to provide new avenues also for the understanding of evolution. Evolution, on this view, turns out to be ‘enacted’ by organisms as “autonomous, purposive systems” (Walsh 2015, 217).

In what follows, I shall investigate some of the basic ontological implications of this approach. What sort of entity, ontologically speaking, is the supposedly autonomous organism? The semantics of the term ‘autonomy’, no less than those of the term ‘autopoiesis’, might invoke the idea of some self-contained, self-sufficient object, not in need for its existence of anything else. This would correspond with a broadly substance ontological view of organisms or reality in general. A substance, according to Aristotle who invented the concept, is a discrete particular that is ontologically independent and the enduring subject of change of accidental properties (Robinson 2014). Thus there is believed to be an intrinsic unchanging core in every substance, defined by a set of essential properties or capacities and serving as the substratum

¹ For a defence of a non-reductionist systems biological stance on organisms that draws on Robert Rosen’s cognate idea of organisms as metabolism-repair systems cf. Cornish-Bowden (2006).

for any change to occur. Change and process, if there are any, depend on substances. More generally, the world is seen as most fundamentally consisting of things, i.e., entities the identities of which can be defined independently of change, and which are neatly separated from one another.²

Substance or thing ontology is the default view in Western metaphysics. Explicitly or implicitly, it guides philosophical investigation in its entire spectrum.³ This includes the philosophy of biology as evident from the predominance of mechanistic theory programmes, reflecting and underpinning corresponding research agendas and methods in the contemporary biological sciences (Bechtel 2006, Bechtel & Abrahamsen 2005, Glennan 2002, Machamer et al. 2000). The behaviour of living systems is explained in terms of the interactions of their parts, i.e., in terms of so-called mechanisms, where the parts constituting those mechanisms are taken to be discrete entities with certain intrinsic capacities.⁴

However, there is an alternative ontology, as emphasised recently by a minority group of philosophers of biology, biology-inspired metaphysicians and biologists: process ontology (Nicholson & Dupré 2018, Meincke 2018a, Simons 2018, Jaeger & Monk 2015, Campbell 2015, Ulanowicz 2013, Baptiste & Dupré 2013, Dupré 2012, Jaeger et al. 2012, Bickhard 2011).⁵ Process ontology takes process and change to be ontologically primary, assuming that things, if there are any, are derived from process. Things, or ‘substances’, it is argued, have to be reconceptualised as stabilised higher-order processes that persist as long as stabilisation can

² The term ‘thing’ as I use it is wider than the technical term ‘substance’ that, within the philosophical discourse, refers to either the specific Aristotelian (essentialist) concept of a discrete particular (belonging to some natural kind) or to some of its later derivatives, e.g., the Cartesian concepts of mental versus material substance (substance dualism). It is worth stressing, though, that ‘thing’, in the definition given above, is a technical term too, alluding to the everyday understanding of the word but not necessarily coinciding with it.

³ For notable exceptions see the overview of the history of process philosophy in Seibt (2016). Seibt, who was the first to promote process philosophy in the context of contemporary analytic metaphysics, has repeatedly diagnosed Western metaphysics with being under the spell of the ‘myth of substance’, cf., e.g., Seibt (1997), 143.

⁴ The relations between the so-called New Mechanism, substance ontology and process ontology are, however, complex. The New Mechanists do not deny the existence and relevance of processes; instead, most of them endorse a dualistic ontology according to which mechanisms are composed of entities and activities (the latter also being called interactions or operations) (Machamer et al. 2000, Bechtel 2006, Illari & Williamson 2013). Yet, what distinguishes these accounts from genuine process ontological accounts is the assumption that entities composing mechanisms can be identified independently of the activities or processes in which they are involved. This is in line with the further substance ontological tenet that for every process there must be a substance on which this process is ontologically dependent.

⁵ A close affinity to process ontology is also apparent in Hans Jonas’ philosophy of the organism (Jonas 1966) as well as in the organicist movement in biology in the mid of last century (most notably, Waddington 1956), both currently being rediscovered by today’s philosophers of biology (Meincke 2018a, Weber & Varela 2002, Gilbert & Sarkar 2000, Nicholson & Gawne 2015).

be maintained (Meincke 2018a, forthcoming). On this view, change is constitutive of identity through time, this identity to be understood as genuinely processual and lacking sharp boundaries. Processes in nature come in nested hierarchies, being entangled with one another through various forms of interaction.

The recent interest in process ontology within the context of the philosophy of biology is triggered by the growing non-reductionist systems biological perspective in the study of life: when being considered as functioning wholes, it appears that organisms are processes, not things. Accordingly, endeavours are being made to promote process ontology as the most suitable ontological framework for biology, pursuing the ambition to thus alter and enhance scientific practices and the acquisition of new biological knowledge (Nicholson & Dupré 2018). The claim is that the systems biological turn in biology has to be accompanied by a process ontological turn with respect to the underlying ontological framework.

In this paper, I shall not directly argue for this claim even though it is not (yet) a popular one and has been met with explicit criticism in the mechanistic camp of philosophers of biology (Austin 2016). Assuming that some version of process ontology is indeed appropriate for biology, I shall instead address the question of whether the process ontological turn envisaged for biology and the philosophy of biology is actually compatible with the appeal to biological autonomy and autopoiesis common among the supporters of the non-reductionist stream of the systems biological turn. If so, this would lend indirect support to the project of combining these two turns.

The task, hence, is to assess the theories of autopoiesis and biological autonomy against the background of the two competing ontologies, thing or substance ontology on the one hand and process ontology on the other. Are the concepts of autopoiesis and biological autonomy neutral in the sense that they could be combined with either ontology? Are they actually rooted in substance ontological ideas, as one might surmise on semantic grounds? Or do they rather, if understood properly, call for a process view of life? I shall argue for the latter, by defending the theories in question against substance ontological misunderstandings while at the same time indicating relevant differences between them and identifying potentially problematic points.

I shall proceed as follows: I shall first explain in what sense the theory of autopoiesis seems clearly committed to a process view of life. I shall then raise some worries as to how deep this commitment actually goes by looking at the idea that autopoietic systems realise so-called organisational closure, and by discussing how the theory of biological autonomy re-conceptualises closure in the attempt to remedy what appear as deficits of the autopoiesis theory. This discussion will clarify why living systems, whether understood according to the former or the latter theory, cannot be substances.

2. Autopoiesis: A Process View

The theory of autopoiesis was developed by the Chilean biologists Humberto Maturana and Francisco Varela in the last century. 'Autopoiesis' translates to self-production and is meant to provide a universal criterion of life purely in terms of the organisation characteristic of living systems: any system exhibiting autopoietic organisation, on this view, qualifies as a living system: "the notion of *autopoiesis* is necessary and sufficient to characterize the organization of living systems" (Maturana & Varela 1980, 82).⁶ The autopoiesis theory thus follows a relationalist (or formalist) paradigm in explaining life: life is taken to be constituted by specific relations between material components so that it is impossible to define and identify these components independently of those relations. Even though, admittedly, the actual material basis of a given autopoietic system has an impact on how autopoiesis is realised,⁷ the organisation is claimed to be fundamentally the same in any material instances of autopoiesis and, i.e., of life.⁸

Maturana and Varela emphasise that this organisation is the same not only across individual living systems but also across time in any given individual living system, namely in a distinctive manner that sets autopoietic organisation apart from other types of organisation:

⁶ All italics in quotes are taken from the original if not stated otherwise.

⁷ "The actual way in which such an [autopoietic] organization may in fact be implemented in the physical space, that is, the physical structure of the machine, varies according to the nature (properties) of the materials which embody it" (Maturana & Varela 1980, 81).

⁸ "It is our assumption that there is an organization that is common to all living systems, whichever the nature of their components" (Maturana & Varela 1980, 76). An even more radical version of this view is Robert Rosen's relational biology that is said to follow the maxim "Throw away the matter and keep the underlying organization" (Rosen 1991, 119). According to Rosen, "[t]he most materially disparate natural systems can still be analogous" if they share the same "bauplan" (ibid.). "Life is the manifestation of a certain kind of (relational) model. A particular material system is *living* if it realizes this model" (Rosen 1991, 254).

An organization may remain constant by being static, by maintaining its components constant, or by maintaining constant certain relations between components otherwise in continuous flow or change. Autopoietic machines are organizations of the latter kind: they maintain constant the relations that define them as autopoietic.

(Maturana & Varela 1980, 81)

The diachronic identity of a living system does not depend on the diachronic identity of its material parts or components but rather on the diachronic identity of the relations between those components. This is important because there is no such thing as a diachronic identity of material components in living systems, at least not in the sense of a given set of entities identifiable and re-identifiable independently of the functional role they play in the system as a whole. Instead, we know that the components of living systems undergo constant material renewal; they are, as Maturana and Varela put it in the quoted passage, “in continuous flow or change”.

Autopoietic organisation thus seems characterised by a discrepancy, or even tension, between the stability of the relations on the one hand and the instability of the relations on the other. However, this is not yet the full truth about autopoietic organisation. It would, for instance, be wrong to think of an autopoietic system as being comparable to a network of pipes accommodating a constant flow of water, or to honeycombs containing fluid honey. What is missing in these latter systems is interdependency between the stable structure and its unstable contents, an interdependency that actually proves inappropriate any analysis of living systems in terms of a container-content model.⁹ Organisms are not containers of changing stuff. Instead, what changing stuff there is, and how it changes over time, is determined by the organisation of the system. At the same time, this organisation is itself maintained through the individual changes performed. The stability of the relations between the components of autopoietic systems is not a given but brought about by the ever-changing and interacting components of these systems; it is the result of processes of on-going stabilisation.

⁹ This is why Maturana and Varela resist categorising autocatalytic processes as instances of autopoiesis: “Autocatalytic processes do not constitute autopoietic systems because among other things, they do not determine their topology. Their topology is determined by a container that is part of the specification of the system, but which is independent of the operation of the autocatalysis” (Maturana & Varela 1980, 94).

The neologism 'autopoiesis' aims to capture both the productive and the self-recursive character of the organisation of living systems. Here is Maturana and Varela's well-known definition:

An autopoietic machine is a machine organized (defined as unity) as a network of processes of production (transformation and destruction) of components that produces the components which:

- (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and
- (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network.

(Maturana & Varela 1980, 78f.)

The network of processes of production of components produces the components which in turn produce the network of processes of production of components. Paradigmatically we find this in the metabolic cycle of the cell as the simplest and most fundamental unit of life, where the exchange of matter and energy with the environment allowed for by membrane boundaries permits the bounded dynamics of a metabolic network which produces the metabolites that constitute the membrane boundaries (Varela 1997, 75).

Living systems are self-producing systems in this sense – and they are nothing over and above self-production: if they stop metabolising, they cease to exist. There is no unchanging core, exempted from the turnover of matter and energy; instead self-maintenance is achieved through an all-encompassing process of destruction and reconstruction:

Since the relations of production of components are given only as processes, if the processes stop, the relations of production vanish; as a result, for the machine to be autopoietic, its defining relations of production must be continuously regenerated by the components which they produce.

(Maturana & Varela 1980, 79)

The stability of the relations between the parts observable through time, hence, is in fact brought about by process and change. Paradoxically speaking, we can say that the parts of autopoietic systems change, and have to change, such that the relations that define them do *not* change but remain stable.

This assigns a role to change which, against the background of traditional Western metaphysics, is rather provocative. For centuries, we have been told by substance ontology that change presupposes identity, namely the identity of a substance; it was held to be inconceivable that it could somehow be the other way around. Living systems teach us that the allegedly inconceivable is not only possible but in fact the rule in biology. Certain changes or processes need to happen in order for living systems to continue existing over time (Meincke 2018a, forthcoming). The fact that living systems do exist over time so that we can reidentify them as numerically the same at different times, should not tempt us to overlook their thoroughly processual character. Autopoiesis as described by Maturana and Varela is clearly a process; and so are autopoietic systems, which are defined solely in terms of their autopoietic organisation. As Varela puts it: “Organisms are fundamentally the process of constitution of an identity”, to which he adds: identity is “not meant as a static structural description (it is a process)” (Varela 1997, 73).

I thus disagree with DiFrisco’s (2014) diagnosis that the “picture of the living system” presented by the theory of autopoietic is “static” (510), by dismissing the “generative” character of the relations between the components of living systems (509; cf. also 510). DiFrisco infers this from the alleged commitment of the autopoiesis theory to the doctrine of ‘hylomorphism’ which he – following the French philosopher Gilbert Simondon, but somewhat deviating from the common understanding – defines as a “pattern of thinking which separates the ‘form’ of the living system from its ‘matter’” (499).¹⁰ DiFrisco sees this hylomorphistic commitment at work in the relationist approach of the autopoiesis theory, which motivates his double claim that (a) that the autopoiesis theory, as a result, conceives of living systems as machines (510) and (b) in doing so neglects these systems’ dynamicity (506, 508).

However, apart from the fact that Maturana and Varela explicitly deploy a *dynamist* understanding of the term ‘machine’ (1980, 76),¹¹ the relationalist approach does not at all rule out the dynamicity of autopoietic systems, namely, as we have seen, precisely not

¹⁰ Common philosophical understanding stresses the *inseparability* of matter and form which are taken to constitute a genuine unity according to hylomorphism, as opposed to dualistic accounts.

¹¹ “We maintain that living systems are machines and by doing this we point at several notions which should be made explicit. First, we imply a non-animistic view which it should be unnecessary to discuss any further. Second, we are emphasizing that a living system is defined by its organization and, hence, that it can be explained as any organization is explained, that is, in terms of relations, not of component properties. Finally, we are pointing out from the start the dynamism apparent in living systems and which the word ‘machine’ connotes.”

because of the assumed thoroughly processual character of autopoiesis. Maturana and Varela make this clear once more when explaining why a crystal, whose organisation “is specified by the spatial relations which define the relative position of its components” (1980, 79) does not qualify as autopoietic:

although we find spatial relations among [an autopoietic machine’s] components whenever we actually or conceptually *freeze* it for an observation, the observed spatial relations do not (and cannot) define it as autopoietic. This is so because the spatial relations between the components of an autopoietic machine are specified by the network of *processes of production of components* which constitute its organization and they are therefore *necessarily in continuous change*. A crystal organization then, lies in a different domain than the autopoietic organization: a domain of relations between components, not of relations between *processes of production of components*; a domain of processes, not of *concatenation of processes*. We normally acknowledge this by saying that crystals are *static*.

(Maturana & Varela 1980, 79f.; italics added).

The (according to DiFrisco) allegedly missing acknowledgement of the ‘generative’ character of the relations between the components of living systems is exactly the key point of acknowledging living systems as autopoietic systems.

In the light of its core claims so far considered, the autopoiesis theory, hence, appears to be clearly committed to a process view of life. Understanding organisms as autopoietic systems means to understand them as self-organising biological processes, i.e., as a specific class of dynamic entities for the identity of which change is essential. Insofar as these self-organising processes can be scientifically investigated, the theory paves the way for a research programme that is naturalistic (‘mechanistic’ in Maturana and Varela’s terminology) in allowing for a scientific study of the origin and constitution of life in purely natural terms, and yet is anti-reductionist by prioritising the examination of the life-constituting processes over the examination of the material parts involved in these processes.¹² The theory of autopoiesis

¹² Maturana and Varela use the term ‘mechanistic’ as an antonym of ‘vitalistic’ (1980, 74), i.e., devoid of the reductionist connotations the term has today: “Our approach will be mechanistic: no forces or principles will be adduced which are not to be found in the physical universe. Yet, our problem is the living organization and therefore our interest will not be in properties of components, but in processes and relations between processes realized through components” (1980, 75).

thus seems to possess the potential to serve as a fruitful resource for underpinning the claim that process ontology is the framework appropriate for (systems) biology.

3. Biological Autonomy: The Improved Closure Thesis

However, there are also difficulties to which we shall turn now. We shall hereby look only at those difficulties relevant to the present task of assessing the autopoiesis theory with respect to its ontological commitments.¹³ Is this theory really a credible proponent of a process view of life? What might make one hesitate to affirm this is a feature that has been discussed controversially in other contexts: the idea that autopoiesis is a form of ‘organisational closure’.

According to Varela, “[o]rganizational closure [...] arises through the circular concatenation of processes to constitute an interdependent network” (Varela 1979, Ch. 7.2.7, 2.; Varela 1981, 16). Again, most paradigmatically and fundamentally organisational (or operational) closure is realised in metabolism, as visualised here:

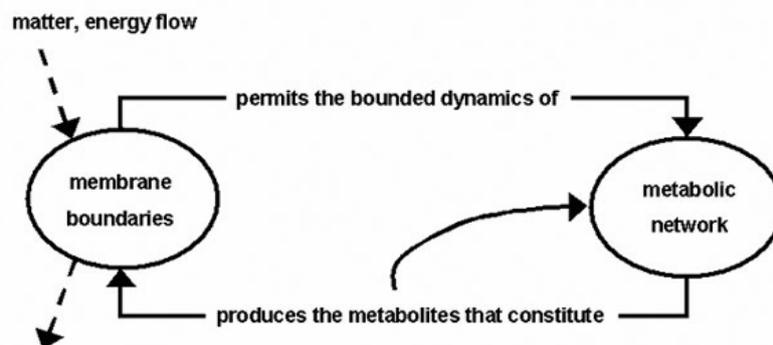


Fig. 1: “Outline of the autopoietic closure of the minimal living organization”

Varela (1997), 75

Autopoiesis, as evident from the diagram, involves some form of circular causality: there is a feedback loop between the membrane boundaries and the metabolic network. And there are many more (negative and positive) feedback loops in living systems. Living systems are a special case of non-linear dynamical systems as being studied by dynamical systems theory.

¹³ Other controversially discussed features of the theory include its dismissal of reproduction and evolution and its equation of life with cognition. For a defence against these criticisms cf. Luisi (2003).

This seems harmless until we consider the fact that we are talking here about feedback loops between relations of component production: living systems are supposed to be self-producing systems insofar as the process of autopoietic identity is “a circular reflexive interlinking process, whose primary effect is its own production” (Varela 1997, 73). Does this mean, as Moreno & Barandiaran (2008, 329) put it, that “the system, as a whole, is cause and effect of itself”? Clearly, a living system is no *causa sui*. An organism might maintain itself; but it has not caused itself to exist:¹⁴ it was rather brought into existence by its parents or parent cells.¹⁵ However, even with respect to self-maintenance one might be wary: an organism is no *perpetuum mobile* either. It does not run by itself. The process of self-maintenance rather depends essentially on interaction with the environment: metabolism is exchange of matter and energy with the environment.

It seems indeed that the environment’s contribution to the self-maintenance of organisms is somewhat underestimated in the theory of autopoiesis. Though the existence and necessity of an autopoietic system’s interaction with the environment is in principle acknowledged, the concept of organisational closure emphasises that any such autopoietic system “attains coherence through its own operation, and not through the intervention of contingencies from the environment” (Varela 1979, 55). Rather than being the environment’s achievement, it is the organism’s own achievement that it continues to exist as a unity in time. According to Maturana and Varela, it is in fact “the most peculiar characteristic of an autopoietic system [...] that it erects itself *by its own means*, and constitutes itself as distinct from the environment *by way of its own dynamics*” (Maturana & Varela 1992, 30; italics added).

In this picture, the environment appears as something hostile against the resistance of which identity through time needs to be defended. Autopoietic systems lose their boundaries if they fail to bring about organisational closure, and, hence, they vanish.¹⁶ Organisational closure,

¹⁴ Moreno recognises this in Moreno & Mossio (2015), 5f. (fn. 7): “Biological systems maintain themselves but do not generate themselves spontaneously (as *wholes*, although of course they do generate some [sic] their functional components).”

¹⁵ Maturana and Varela (1980) famously dismiss reproduction as not being essential to life: “Reproduction requires a unity to be reproduced; this is why reproduction is operationally secondary to the establishment of the unity, and it cannot enter as a defining feature of the organization of living systems” (100) (cf. already footnote 13).

¹⁶ “[T]he the unity’s boundaries, in whichever space the processes exist, is [sic] indissolubly linked to the operation of the system. If the organization of closure is disrupted, the unity disappears” (Varela 1979, 55).

accordingly, is thought to involve an exploitation of all changes for the maintenance of identity,¹⁷ with the result of minimising the effects of environmental changes on the internal dynamics of the autopoietic system. This is captured in the idea of ‘structural determinism’ according to which external events only ‘trigger’, rather than ‘determine’, structural change in an autopoietic system, such as when a washing machine starts washing after somebody pressed the relevant button (Maturana 1987, 73). As a consequence, there is no room for the possibility of any internal changes of the autopoietic system being ‘instructed’ by the environment in the sense that we could trace them back in some direct way to what happened in the environment.¹⁸ Instead, the environment is seen in the first place as a source of ‘perturbations’ which are compensated by the autopoietic system through internal structural changes.¹⁹

Whatever other critical points would need to be raised about the concept of organisational closure,²⁰ the point that matters for the present investigation is that some of the characterisations of autopoiesis linked to that concept may create the impression of the autopoietic system being a self-contained unit isolated from its surroundings via some in-built self-protection mechanism called ‘closure’. Identity, according to this interpretation of the autopoiesis theory, is admittedly processually constituted; but in a way that perpetuates the old story of the individual with well-defined boundaries. The very fact of forming a causal circle seems to deeply divorce the autopoietic process from its environment. It thus does not come as a surprise that the apparent closed-off character of the autopoietic system or ‘self’ is a recurring theme in common readings of the theory, whether critical or sympathetic (e.g.,

¹⁷ “[...] closure and the system’s identity are interlocked, in such a way that it is a necessary consequence for an organizationally closed system to subordinate all changes to the maintenance of its identity” (Varela 1979, 58).

¹⁸ Varela therefore actually rejects speaking of ‘feedback’ as this concept “requires and implies an external source of reference, which is completely absent in organizational closure” (Varela 1979, 56).

¹⁹ “[A]ll apparent informational exchanges with its environment will be, and can only be, treated as perturbations within the processes that define its closure, and thus no “instructions” or “programming” can possibly exist” (Varela 1979, 58). “Autopoietic machines do not have inputs or outputs. They can be perturbed by independent events and undergo internal structural changes which compensate these perturbations” (Maturana & Varela 1980, 81).

²⁰ One of these is the question of whether in order for a system to qualify as autopoietic it really has to produce *all* of its components itself. As we now know, organisms provide accommodation for plenty of other organisms, and even in cells there are components which are not directly produced, such as essential amino acids, maybe also mitochondrial DNA.

Villalobos & Ward 2015, Pradeu 2012, 197ff., Swenson 1992). Is the autopoietic system, hence, just a substance wolf in process sheep's clothing?

The time has come to look at a theory that claims to address the shortcomings of the autopoiesis theory while building upon its strengths: the theory of biological autonomy, developed in the last two decades by Alvaro Moreno and a number of collaborators (e.g., Moreno & Mossio 2015, Arnellos & Moreno 2015, Barandiaran & Moreno 2008). Against the current prevalence of evolution-centred explanations of life, the theory of biological autonomy intends to raise awareness for the fact that “organisms, understood as cohesive and spatially bounded entities”, are the fundamental instances of “the biological domain's organised complexity” (Moreno & Mossio 2015, xxiii). Organisms are characterised as systems realising biological autonomy, namely in the following sense:

[T]he constitutive organisation of biological systems realises a distinct regime of causation, able not only of producing and maintaining the parts that contribute to the functioning of the system as an integrated, operational, and topologically distinct whole but also able to promote the conditions of its own existence through its interaction with the environment.

(Moreno & Mossio 2015, xxvif.)

As indicated by this definition, two dimensions of biological autonomy – “two regimes of causation” (e.g., 11) – need to be distinguished, namely the constitutive dimension of metabolic self-constitution²¹ and the interactive dimension of adaptive interaction with the environment (xxviii). However, this difference must not be understood in the sense that the two dimensions would somehow be independent of one another. Instead, it is claimed to be crucial to acknowledge that the constitutive dimension *requires* the interactive dimension of biological autonomy. This is because as far-from-equilibrium dissipative structures, living systems, while being operationally closed, are energetically open: they are “thermodynamically ‘hungry’, in need of coupling with the environment” (Barandiaran & Moreno 2008, 328). In return it follows that while, in more complex organisms, the interactive dimension of autonomy can be locally decoupled from its metabolic basis (as it is the case with behavioural agency that is sustained by the nervous system (Moreno & Mossio 2015, 175ff.),

²¹ Elsewhere this dimension is also referred to as ‘basic autonomy’ (e.g., Moreno & Etxeberria 2005).

the functions of any adaptive interactions with the environment are to be regarded as deriving from the core function of metabolic self-constitution (90).²²

As a matter of fact, Maturana and Varela do recognise the interactive dimension of living systems by assigning a pivotal role to metabolism in the constitution of autopoiesis. Moreno and colleagues accordingly concede that closure, in the autopoiesis theory, “goes hand in hand with *interactive openness*” and so “by no means meant to signify the ‘independence’ of the system vis-à-vis the external environment” (Moreno & Mossio 2015, 6); but they insist, given the fundamental importance of the interactive dimension, that it should “enter into the definition-constitution of the autonomous system” (Moreno & Mossio 2015, xxvii) rather than being “added, a posteriori, in the form of structural coupling” (Barandiaran & Moreno 2008, 327). Only this, they further argue, will also ensure that the resulting account delivers a criterion that applies uniquely to living systems as opposed to non-living systems.

The criticism that the autopoiesis theory falls short of sufficiently distinguishing between the living and the non-living guides the construction of the proposed alternative account of living systems in terms of autonomy. Moreno and Mossio accept Varela’s ‘Closure Thesis’, according to which “[e]very autonomous system is organizationally closed” (Varela 1979, 58), but they complain that the account, as it stands, “*fails to locate closure at the relevant level of causation*” (Moreno & Mossio 2015, 4). The reason they identify for this is the fact that “closure is understood as closure of processes” (ibid.) rather than as a closure of so-called constraints, the latter being defined as “local and contingent causes, exerted by specific structures or processes, which reduce the degrees of freedom of the system on which they act” (5).²³ While closure of processes is realised also by physical and chemical systems, such as, for instance, the hydrologic cycle, what is distinctive about biological systems, according to Moreno and colleagues, is that these systems bring about closure of the constraints acting upon constitutive processes (ibid.). This “capacity for self-determination, in the form of *self-constraint*” (ibid.) is meant by the definitional statement that a biological system, in addition to its ability to maintain itself, is “able to promote the conditions of its own existence through its interaction with the environment” (xxvif.; cf. above).

²² Arnellos & Moreno (2015) coin the term ‘constitutive-interactive closure principle’ for the reciprocal relationship between the two dimensions of biological autonomy.

²³ For this and the following see also Montévil & Mossio (2015) on which Moreno and Mossio substantially rely.

As evident already from this rough outline, the theory of biological autonomy makes a valuable contribution to clarifying the notion of closure by elaborating on aspects that (to say the least) remained underdeveloped within the framework of the autopoiesis theory. Most importantly in the present context, the environment gets upgraded from a mere source of perturbations to playing an essential role in the self-constitution of organisms. An organism's necessary interaction with its environment is acknowledged as constituting a separate order of causation, which provides the ontological basis also for more sophisticated interactions with the environment than to be found in metabolism, i.e., for higher forms of agency (Moreno & Mossio 2015, ch. 4, Arnellos & Moreno 2015, Barandiaran & Moreno 2008).²⁴ In fact, to act in some robust sense of the word is to actively engage in an exchange with environmental entities, including actively seeking for opportunities for such engagements. It is difficult to accommodate this active and outgoing character of interaction in a picture that, as the one drawn by the autopoiesis theory, emphasises the protective function of organisational closure of minimising influences from the environment.

However, again there is a possible concern with respect to the ontological commitments of the theory of biological autonomy. Although it looks as if thinking of living systems in terms of biological autonomy rather than autopoiesis helped to prevent the impression of them being some sort of encapsulated, purely self-referential and in that sense substance-like entities, we might wonder whether this move comes at the cost of compromising on the process character of life in other respects. This has to do exactly with the thesis central to the theory of biological autonomy that organisational closure has to be understood as a closure of constraints rather than of processes. Where does this leave the key claim of the autopoiesis theory that living systems exist in the mode of producing their own identity through time, i.e., that living systems are processes?

In order to answer this question we need to get a grasp on what 'constraints' are supposed to be. Moreno and Mossio distinguish them from 'processes' as follows:

Processes refer to the whole set of physicochemical changes (including reactions) occurring in biological systems, which involve the alteration, consumption and/or production of relevant entities. Constraints, in turn, refer to

²⁴ For a discussion of this theory of bio-agency with respect to the possibility of artificial agents cf. Meincke (2018b).

entities that, while acting upon these processes, can be said to remain unaffected by them, at least under certain conditions or from a certain point of view.

(Moreno & Mossio 2015, 11)

In order to be able to constrain the processes of metabolic self-constitution, the entities in question cannot, and must not, themselves be involved in those processes; they rather need to “exhibit symmetry with respect to a process (or a set of processes) that they help stabilise” in the sense that their “relevant aspects [...] be conserved under the transformations” (ibid.). Examples discussed are the vascular system’s regulation of the flow of oxygen and an enzyme’s speeding up a chemical reaction (11ff.): these effects would not be possible if the vascular system lost its regulating powers on the way and the enzyme its speeding up powers respectively. Constraints are stabilisers of processes; and in order to do their stabilising work they need to be stable themselves.

It is, however, fair to ask how they become stable in the first place. And here Moreno and Mossio give us an important hint: constraints must display symmetry “at that time scale [...] at which their causal action is exerted” (13). This is important because, as a matter of fact, entities like the vascular system or enzymes do change in relevant respects at other (longer or shorter) time scales (ibid.). Hence, even though constraints theoretically “can be treated, at [the relevant time scale], as if they were *not* thermodynamic objects because, by definition, they are conserved with respect to the thermodynamic flow, on which they exert a causal action” (14), this does not mean that they ontologically are not ‘thermodynamic objects’. They *are* thermodynamic objects just like all other components of living systems. Whatever part of an organism comes to take over the function of a constraint on more basic processes is dependent for its own existence on these processes – not directly, but at least indirectly.

We thus can admit that the specific causation Moreno and Mossio describe by referring to entities called constraints²⁵ does not involve a (direct) thermodynamic “flow between the constraint and the constrained process or reaction” (15), while denying that this, in ontological terms, diminishes the processual character of living systems as conceptualised by the theory of biological autonomy. Living systems are nested hierarchies of processes which are more or

²⁵ Moreno & Mossio (2015, 52ff.) refuse to rely on the notion of ‘formal causation’ while regarding causation through constraints as a weak form of ‘downward causation’.

less stable depending on the time scales at which they are described, and depending on which other processes they are compared with. In other words: what Moreno and Mossio address as constraints are, ontologically speaking, processes too, just slower ones compared to the processes constrained. And these latter processes are themselves stabilised through other constraining processes, with all these processes forming a “network of mutually depending constraints” (57). This, in fact, corresponds well with the core insight of the autopoiesis theory that a living system exists as the process of producing its own identity.²⁶

4. Conclusions

I have argued that both the theory of autopoiesis and the theory of biological autonomy are committed to a process view of life. Both theories analyse living systems as entities that exist by *making themselves exist* in a continuous process of self-production, most fundamentally through metabolism as the exchange of matter and energy with the environment. Within the theoretical frameworks offered, there is, hence, no way to make sense of living systems in static terms; if we abstract away from change and motion, we lose sight of what we intend to investigate: the living system, or organism, as such. Any stability to be observed in living systems is the result of continuous process and change. This emphasis on the genuinely processual mode of existence of living systems entails, as we have seen, a strong anti-reductionist stance: the identity of a living system cannot be reduced to the identity of its parts insofar as the identity of the parts is itself dependent on the production of the identity of the living system as a whole. It is therefore impossible to treat an organism as a thing that is composed of smaller things.

However, I have also discussed some²⁷ other respects in which it might seem that living systems, as viewed by the autopoiesis theory and the theory of biological autonomy, actually

²⁶ I am therefore not entirely convinced of Moreno and Mossio’s criticism that the autopoiesis theory, by lacking “the (explicit) theoretical distinction between processes and constraints” (2015, 6), also fails to provide a sufficiently sharp distinction between living and non-living systems. Maturana and Varela’s emphasis that an autopoietic system “has its own organization (defining network of relations) as the fundamental variable which it maintains constant” (1980, 79), and that the “concatenation of processes” rather than mere processes alone make an organisation autopoietic (79f.; quoted above), points towards a view in line with the idea that living systems, qua autonomous systems, promote the conditions of their own existence. This does not touch on the point that the theory of biological autonomy deserves credit for fleshing out the interactive dimension inherent in this autopoietic process.

²⁷ One aspect left out for reasons of space concerns the ontological status of boundaries. The emphasis on boundaries in both the autopoiesis theory and the theory of biological autonomy might seem reminiscent of the

do resemble things so that one would have to doubt the consistency and depth of these theories' commitment to a process view of life. Does the concept of organisational closure not draw the picture of an entity that, by producing itself, is ontologically independent of its environment, i.e., the picture of a self-contained, isolated individual that has become famous and predominant in Western philosophy under the title of 'substance'? I have argued that this is not the case. Autopoiesis does not refer to circular causality in the sense of a *causa sui*; and, as Moreno and Mossio (2015) repeatedly emphasise, "autonomy is not independence" (17, 88, 97, 197). We can see this more clearly when – as undertaken by the theory of biological autonomy – acknowledging in explicit terms the interactive dimension that is inherent in the process of metabolic self-constitution in virtue of the system's thermodynamic openness. At the same time, we can – as equally suggested – do theoretical justice to the associated distinctive form of causation, that is, to the generation of closure through a mutual dependence of constraints acting upon processes of self-constitution, while bearing in mind that any such constraining causation, ontologically speaking, is a case of (higher-level) processes acting upon (lower-level) processes.

It thus turns out that the concepts of autopoiesis and biological autonomy are not neutral against the alternative between substance ontology and process ontology. There is no coherent way to reconcile the idea of autopoietic or biologically autonomous entities with these entities being substances. Substances, as considered by philosophers for more than two millennia, do not constitute and maintain themselves through interacting with the environment. Their identity is supposed to precede any change they might undergo, this not leaving any space for something like an environment to matter, let alone for this environment to take over a constructive role in a process of constitution of identity. As meritoriously highlighted by the theory of autopoiesis and the theory of biological autonomy, organisms, by contrast, are entities for the identity of which change, including ex-change with the environment, is essential, which is to say that they are processes. Autopoiesis and biological autonomy, if understood properly, call for a process view of life.

idea of a substance as a discrete particular neatly separated from its surroundings. As I intend to show elsewhere, this impression is mistaken. Living boundaries – properly understood – do not isolate the organism from the environment but rather allow for, and enact, the interaction with the environment that is constitutive of the organism's synchronic and diachronic existence. Living boundaries, in both theories, are processual just as living systems are.

The good news for those who aim to promote a process ontological turn in the scientific and philosophical investigation of life, hence, is that they can find in the autopoiesis theory and in the theory of biological autonomy two trustworthy and helpful allies for their endeavours. Similarly, those seeking to resist reductionist mechanistic research agendas in biology and the philosophy of biology with a convincing holistic approach are well-advised to turn to process ontology in general and to the rich body of theory provided under the headings of ‘autopoiesis’ and ‘biological autonomy’ specifically. Insofar as such a holistic approach is the objective of an increasingly important part of systems biology, this underpins the claim that the systems biological turn in the study of biological life should take the form of a systems-biological-cum-process-ontological turn.

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