Studies in History and Philosophy of Science 93 (2022) 47–56

Teleology and the Organism: On Kant's Controversial Legacy for Contemporary Biology

Andrea Gambarotto & Auguste Nahas

Abstract

This paper distinguishes two ways in which Kant's ideas concerning the relation between teleology and biological organization have been taken up in contemporary philosophy of biology and theoretical biology. The first sees his account as the first instance of the modern understanding of teleology as a heuristic tool aimed at producing mechanistic explanations of organismal form and function. The second sees in Kant's concept of intrinsic purposiveness the seed of a radically new way of thinking about biological systems that should be developed by turning teleology into a legitimate concept of natural science. We name the two approaches heuristic and naturalistic, respectively. Our aim is to critically evaluate these approaches and suggest that the naturalistic option, which remains a minority position, deserves to be taken more seriously than it currently is in contemporary biological theory. While evolution by natural selection closes the case on intelligent design, it does not close the case on teleology in general. In fact, the current return of the organism and the recent calls for an agential perspective in evolutionary biology point out that we still have some thinking to do concerning this side of Kant's legacy.

1. Introduction

In recent discussions on the issue of teleology in philosophy of biology, Kant has been singled out as a figure of particular relevance. From a historical perspective, this is unsurprising: his treatment of organized beings comes at a time when the peculiar epistemological status of organisms was a great matter of debate, and the idea of biology as an independent science of organized beings was first being born. A less obvious reason, which we address in this paper, is that contemporary philosophers and theorists have found a peculiar resonance between Kant's treatment of teleology and their continued struggle to make sense of the place of this perennially troublesome concept within the life sciences. In our view, this says as much about Kant as it does about contemporary philosophy of science: we find the third Critique appealing because it speaks to the ways in which we have come to conceptualize the problem of teleology. In this sense, investigating the way Kant's legacy is currently understood provides important insights on the general stances towards teleology currently at play in our philosophical landscape.

We argue that these stances come in two main groups, a categorization which is a function of what each approach deems to be the central aspect of Kant's legacy for the biosciences. The first sees Kant's account as the first instance of the modern understanding of teleology as a heuristic tool aimed at discovering mechanistic explanations of organismal form and function. The second sees in Kant's concept of intrinsic purposiveness the seed of a radically new way of thinking about biological systems which should be brought to fruition by turning teleology into a legitimate concept of natural science. The aim of this paper is to

critically evaluate these two approaches, which we dub as heuristic and naturalistic, respectively. While the core of the paper consists essentially in a review of existing positions, there are two main original aspects that need to be emphasized. First, we propose an important categorization of those positions which, to our knowledge, has never been explicitly formalized.[1] There is much understanding to be gained through such categorization. In fact, we are motivated by the fact that references to Kant as a 'notable precursor' can be found among philosophers and theoreticians with diverging, sometimes even opposed, research agendas. We trace the reason for these diverging accounts back to the unstable ground of the third Critique and argue that we should in fact speak of two different Kantian legacies (Section 2). Secondly, we emphasize the philosophical and theoretical questions lying behind what may be mistaken for a merely exegetical debate. As we see it, disagreements about how we should interpret Kant's legacy hide deeper commitments to how we should understand the apparent purposiveness of organisms. Given recent debates over the role of the organism in biological thinking taking place in major journals of biology and philosophy, this can hardly be reduced to a question of interpretation in Kant scholarship (Sections 3 and 4).

According to the heuristic view (Section 3), Kant's principal contribution to biology emerges from his concern with demarcating the boundaries of science and metaphysics. A central target of his critique is the Wolffian school of metaphysics, according to which teleology is understood as the science concerned with obtaining insights into the wisdom of God via the study of natural products. Despite Kant's belief that such endeavors exceed the proper scope of natural science, he also recognizes the indispensability of approaching biological research with the assumption that the parts of organisms are designed for a purpose. His compromise is to make teleology safe for science by giving it a role as a 'regulative principle' for the search of mechanistic explanations.

In contrast, the naturalist approach (Section 4) argues that Kant's relegation of teleology to a regulative principle as a reaction to dogmatic metaphysics misses the point of Kant's most original, albeit unfulfilled, contribution: the distinction between extrinsic and intrinsic purposiveness. The former identifies the teleology of Christian Wolff and Alexander Gottlieb Baumgarten (and later, William Paley), which equates purposiveness with design, and according to which the appearance of design in nature points to the purposes of a divine rational architect. The latter identifies features like reproduction, growth, and collective self-maintenance as fundamentally distinct from the purposiveness of design. On this reading, Kant's great insight was to argue that the purposiveness of organisms is of a fundamentally different kind from that of machines. Machines are extrinsically teleological (products of design), organisms are intrinsically teleological (self-organizing beings). Yet, because of the limits of his philosophical system, and perhaps the science of his time, Kant was unable to fully capitalize on this distinction by giving intrinsic purposiveness its proper place in nature.

The heuristic approach has a long history within the Darwinist tradition. In fact, from a contemporary perspective, Kant's critique of Wolff does not appear to be entirely dissimilar from the one carried out, half a century later, by Darwin with respect to Paley. This leads to an

[1] Cooper (2018) suggests a categorisation which overlaps somewhat with our own, but in a noticeably different argumentative context. His concern is primarily with the evaluation of different metaphysical positions implied in various accounts of teleology, and the claims which they make about the intelligibility of nature.

interpretation of Kant as Darwinian *avant la lettre*, and to identify in Darwin as 'the Newton of the grass blade' whose coming Kant had foreclosed in 1790. Yet this perspective leaves many of Kant's preoccupations with the notion of intrinsic purposiveness unresolved. In contrast, the naturalistic approach tries to bring those preoccupations to philosophical fruition, and emphasizes the fundamental limitations of Kant's system which prevented him from doing so. Though this may give the appearance that the heuristic interpretation is more faithful to the letter, we deem both approaches to be breaking with Kant in keys ways.

We also argue that the naturalistic option ought to be taken more seriously than it currently is among philosophers and theorists: while evolution by natural selection closes the case on intelligent design, it does not close the case on teleology in general. In fact, current calls for a return of the organism and an agential perspective in evolutionary biology point out that we still have some thinking to do concerning this side of Kant's legacy. We think it is worthwhile to reconsider an understanding of intrinsic purposiveness as a true feature of biological systems and an understanding of organisms as evolutionary agents, while also recognizing that the proper path to concretely developing this understanding into a scientifically acceptable theory remains open-ended.

We develop our argument in three steps. In section 2 we focus on key philosophical issues in the Critique of Teleological Judgment. We do not offer a full-fledged interpretation, nor do we wish to delve into debates regarding the best interpretation of certain key passages; rather, we seek to bring to light the two different Kantian legacies which defenders of the heuristic and naturalistic approaches find therein. While the former elaborates on a more canonical Kant, the latter attends to an apparent undertow that runs through the third Critique. On this basis, in Sections 3 and 4 we consider the fundamental characters and challenges proper to each of the two approaches. In section 5 we draw some general conclusions.

2. Two Kantian legacies: the canon and the undertow

Living beings posed a significant challenge to Kant and his contemporaries. Their intricate order, along with their capacity for reproduction, growth, and self-repair seemed to defy mechanistic explanation and require an appeal to hylozoism or intelligent design. Despite Kant's recognition that living beings indeed defy mechanistic explanation, he could not countenance any other legitimate form of explanation within natural science. That much seems clear. Beyond this, however, the third Critique remains full of unresolved ambiguities which we do not intend to address in this paper. Our focus in this section is to bring out the key aspects which have motivated two diverging ways in which Kant has been put to use in contemporary biological theory. The first of these, which we call the 'canonical' Kant, sees in the Critique of Teleological Judgment a successful attempt at finding a proper place for teleology in natural science by interpreting it heuristically. In contrast, other interpreters find in the third Critique an undertow corresponding to the all too-daring hypothesis that there may be an intrinsic purposiveness to organisms grounded in their self-organization—a promising idea which would never be brought to full fruition within the limitations of Kant's system.

The problem which Kant finds in biological organization is clearly stated at the outset of the Critique of the Teleological Power of Judgment. Kant describes a bird, whose form and function cannot be explained with a reference to mere causal efficiency, because "nature,

considered as a mere mechanism, could have formed itself in a thousand different ways without hitting precisely upon the unity in accordance with such a rule" (Kant, 1790/2000, 5:360). This leads us to assume a teleological principle that makes our judging of such organized products of nature possible. According to Kant, "we adduce a teleological ground when we ascribe causality in regard to an object to a concept of the object as if it were to be found in nature (not in us) [...] and hence we conceive of nature as technical through its own capacity; whereas if we did not ascribe such an agency to it, we would have to represent its causality as a blind mechanism" (ibid, 5: 360, emphasis in the original). This definition is pivotal for contemporary philosophers of biology, because it conveys the idea that, for Kant, teleological explanations necessarily imply a form of technical causality in which the orderly arrangement of parts into an organized whole is caused by the concept in the mind of a rational agent—what Thomas Teufel calls a 'conceptual etiology' (2011). Interpreters point to the First Introduction for further confirmation of this idea, where Kant consistently insists on the notion of a "technique of nature" (Illetterati, 2014). This kind of teleological judging "is rightly drawn into our research into nature, at least problematically, but only in order to bring it under principles of observation and research in analogy with causality according to ends, without presuming thereby to explain it. It thus belongs to the reflecting, not to the determining power of judgment" (Kant, 1790/2000, 5: 360), because otherwise "it would introduce a new causality into natural science" (ibid, 5: 361). This general position is widely articulated throughout both the analytic and the dialectic of teleological judgment.

In the Analytic, Kant argues that if we were to wander on a deserted island and found a regular hexagon drawn in the sand, we could not possibly believe it to be the result of natural forces alone. Its regularity and organization would rather lead us to assume a rational agent as its author, and thus to the conclusion that the island is not deserted after all: "This object must be thoroughly regarded as an end, but not a natural end, i.e., as a product of art." For something to be judged as a natural end, on the other hand, something more is required: it must be at the same time the "cause and effect of itself" (ibid, 5: 370). Kant illustrates this idea with the example of a tree, which generates itself in three different respects: 1) According to the species (reproduction), 2) According to the individual (growth), and 3) According to the parts, "in such a way that the preservation of the one is reciprocally dependent on the preservation of the other" (collective self-maintenance) (ibid, 5: 371). These three features are what mark the difference between organisms and artefacts.

The problem, for Kant, is that the organization of organisms renders them inexplicable by the powers of matter alone (though this seems equally true of artefacts—see Ginsborg, 2004; Breitenbach, 2014b, 2016 for a response; see also McLaughlin, 2014). Kant identifies in nature two kinds of legitimate causality: the efficient causality of mechanism (nexus effectivus), which he defines as the only empirically "real" cause in nature, and the causality according to ends (nexus finalis), where the efficient causality is played by the intention of a rational agent, which Kant defines as "ideal" causality (Kant, 1790/2000, 5: 373). With the above-mentioned features, organisms cannot be explained by any of these two forms of causality: they are too complex to be the result of random events, and yet explaining them through ideal causality would imply invoking a supernatural agent.

Kant thus proposes two criteria for something to be called a natural purpose: 1) It must be a purpose, meaning that "its parts (as far as their existence and form are concerned) [must be] possible only through their relation to the whole" (Kant, 1790/2000, 5: 373). This establishes an analogy between organisms and designed artefacts, where the idea of the whole precedes organization, in the sense that the maker must have a concept of the artefact in mind before he crafts it; and yet 2) for a purpose to be natural, it must also display specific self-organizing features that mark it as being different from artefacts (a clock does not generate another clock, nor does it self-repair after damage): "only then and on that account can such a product, as an organized and self-organizing being, be called a natural end" (ibid, 5: 374, emphasis in the original). An organism, in this sense, is not a "mere machine" because it has "a self-propagating formative power, which cannot be explained through the capacity for movement alone (that is, mechanism)" (ibid, 5: 374). However, this form of self-organization, which some see as defining proper teleological thinking, is "not analogous with any causality that we know" (ibid, 5: 375; see Breitenbach, 2014a, for an analysis of this claim; see also: McLaughlin, 1990, 2014; Nassar, 2016).

These considerations lead to compelling questions concerning the place of teleology as a principle in the edifice of natural science. Kant divides scientific principles into inherent (principia domestica) and extrinsic (principia peregrina): the former belong to the structure of scientific explanation, the latter to heuristics or "auxiliary propositions" (Kant, 1790/2000, 5: 379). Teleology, in this sense, does not belong to the architecture of natural science, but sustains it only from the outside as a guiding principle, albeit a necessary one (Quarfood, 2006). This guarantees that there is "no mix-up between natural science and the occasion that it provides for the teleological judging of its objects and the consideration of God" (Kant, 1790/2000, 5: 380, emphasis in the original).

Such a 'mix-up' is precisely what Kant sees occurring in the work of Christian Wolff, who first coined the term 'teleology' half a century before the third Critique. He used the term to demarcate the part of physics whose function was to make the wisdom of God comprehensible through the study of nature. Hein van den Berg (2013a, 2013b) has convincingly shown how Kant's views on teleology relate to those of Wolff and Baumgarten. For the latter, purposes were always objects of intention and God the intelligent designer. Kant adopted the definition of purpose as intention from his dogmatic predecessors, but, due to the transcendental restrictions of his system, could not appeal to God as a legitimate *explicans*. This made it impossible for him to take teleology as an 'explanatory ground,' such as mechanism, demoting it to a mere 'cognitive ground' (*Erkenntinsgrund*).

The notable point is the equation between 'teleological' and 'technical': Due to the cognitive faculties of our finite intellect, Kant argues, we cannot represent the purposiveness of nature in any other way than through the concept of intention: "it is in fact indispensable for us to subject nature to the concept of an intention if we would even merely conduct research among its organised products by means of continued observation; and this concept is thus already an absolutely necessary maxim for the use of our reason in experience." Or again: "even the thought of them as organised things is impossible without associating the thought of a generation with an intention" (Kant, 1790/2000, 5: 399). This has led several commentators to argue that Kant has "[no] room for a notion of purposiveness that is entirely divorced from

the end-setting intellect" (Breitenbach, 2016, p. 406). Thus, as the famous passage goes, "we can boldly say that it would be absurd for humans even to make such an attempt or to hope that there may yet arise a Newton who could make comprehensible even the generation of a blade of grass according to natural laws that no design (Absicht) has ordered" (ibid, 5: 400).

As the previous analysis shows, Kant is quite explicit in his conviction that we cannot provide mechanical explanations for the peculiar self-organizing features that we see at play in living organisms. This leads us to assume a teleological ground for nature which however must be considered merely as a regulative principle for the faculty of judgment. A key commitment for many (though not all) the members of what we call the 'heuristic' camp is that Darwin provides the solution to Kant's problem: with the concept of natural selection, Darwin contributed precisely the notion Kant lacked in order to provide a mechanistic explanation for design in nature. In this sense, Kant's legacy for a Neo-Darwinian world means that we ascribe all causal power to the mechanisms of natural selection and consider teleology simply as a manner of speaking, which can ultimately be reduced to mechanical (i.e., selectionist) explanations.

Most philosophy of biology today takes this route, with the underlying assumption that the notion of teleology is coextensive with that of design: Wolff coined the notion of teleology as divine intention; Kant problematized its metaphysical implications but realized that without the idea of divine intentions we would never provide a naturalistic explanation of natural purposiveness; Darwin solved the problem by providing a mechanistic explanation for design in nature via the concept of natural selection.

One of the key claims of the naturalistic approach, in contrast, is that Kant's understanding of teleology does not reduce to the simple notion of design, and that this cannot be the whole story. Just as the heuristic approach relates to Darwinism, the naturalistic approach has (often inadvertently) German Idealism as its historical predecessor. The controversial relationship with Kant's third Critique is a central feature of the entire post-Kantian philosophy, a relation that oscillates between praise and criticism: according to both Schelling and Hegel, Kant had a powerful intuition concerning the intrinsic purposiveness of living beings, but due to the rigid boundaries of his transcendental framework, and most importantly his commitment to mechanism as the only true power in nature, those intuitions remained undeveloped. It is impossible to understand the philosophy of nature of German idealism without considering this charge against the orthodoxy of mechanism and the post-Kantian re-evaluation of teleology—not Wolff's teleology, but the intrinsic purposiveness Kant intuited, yet considered scientifically inexplicable. In his Ideas for a Philosophy of Nature, young Schelling insisted that we should turn intrinsic purposiveness into a feature of nature itself: organisms appear purposive because they really are, not because we judge them that way (Schelling, 1797/1989, pp. 30–35; pp. 40–41). In the Science of Logic, Hegel praised the distinction between extrinsic and intrinsic purposiveness as one of "Kant's great services to philosophy" (Hegel, 1816/2010, p. 654).

In this section we have attempted to show how Kant formulated the concept of intrinsic purposiveness and went a great length to distinguish it from the purposiveness of design, but when looking for an adequate conceptualization of such intrinsic purposiveness he lapsed back into an understanding of teleology as design as the only available conceptual model. In the eyes

of some of his successors, this lapse leaves the intuition of intrinsic purposiveness underdeveloped. In this respect, the heuristic approach capitalizes on the canonical Kant, while the naturalist approach aims to capitalize on the unexpressed potential of an undertow that runs through the third Critique: that of intrinsic purposiveness. In the following sections, we address each approach directly.

3. Regulative teleology and mechanistic explanations: the heuristic approach

The heuristic approach argues that Kant's 'regulative' stance on teleology can be fruitfully used by contemporary biologists. This approach seems natural given that both Kant and contemporary biologists have framed the problem of teleology in strikingly similar ways. Take, for example, the often-quoted motto attributed to J.B.S. Haldane, according to which teleology is a "mistress to a biologist: he cannot live without her, but he is unwilling to be seen with her in public" (Mayr, 1988, p. 63). Using Wilfrid Sellars' terminology, we could perhaps read it as portraying a clash between 'manifest image' and 'scientific image' of the organism: on the one hand we cannot help but see living organisms as intrinsically purposive entities, on the other hand our mainstream scientific consensus keeps telling us that this is not (and cannot be) the case, since the only domain in which we can legitimately talk about purposiveness is that of rational human agency. According to the heuristic approach, Kant provides a way to resolve this tension by acknowledging the phenomenal reality of this manifest image, while putting it to use as a guide for mechanistic explanations in biological research.

The heuristic approach has a long history which dates back at least to Nagel (1979) and has been applied to nineteenth-century German biology for the first time by Lenoir (1982). In this pioneering work, Lenoir portrayed Kant as the champion of a naturalized research program that recognized teleology as a fundamental hallmark of living systems, without the philosophical drawbacks of vitalism, which postulates supernatural entities like 'substantial forms' or 'entelechies' as the sources of vital organization. By locating a 'teleo-mechanistic' tradition in which teleology was not entangled with vitalism, Lenoir believed teleology could finally be considered 'without regrets' (Lenoir, 1981; see also; Caneva, 1990), i.e., without metaphysics, by following Kant in considering it a merely regulative principle and use it to provide mechanistic explanations of biological phenomena. More recently, Breitenbach (2014a) and Nassar (2016, p. 58), have argued that Kant's regulative approach to teleology provided "a critical insight regarding the methodology of a science of life," which in turn "laid the theoretical foundations for the emerging science of life, the science of describing the structure, function and processes of living beings, without invoking an unknown, unknowable or occult cause" (ibid, p. 65).

At first sight, this approach seems to suggest a close kinship between Kant's 'as-if' stance toward organic design and the neo-Darwinian approach to naturalizing function-talk in biology through an explanation in terms of natural selection. Ernst Mayr was explicit in claiming that Darwin solved Kant's problem (1974, p. 13; 1988, p. 58). This view is deeply connected to the association of teleology with the gene-centricism of the Modern Evolutionary Synthesis, embodied in Ernst Mayr's notion of 'teleonomy',(first coined by Colin Pittendrigh, 1958, with a different meaning), and implemented around the same time by the first etiological' accounts of biological functions (Ayala, 1970; Wright, 1973), consolidating our current

understanding of teleology as an effect of Darwinian natural selection (Kitcher, 1993; Millikan, 1989; Neander, 1998; Artiga & Martínez, 2016, among others).

In more recent years, authors have tried to update this heuristic reading to support the so-called "extended synthesis" of evolutionary theory that has emerged in the last decade, which includes developmental factors as key elements in our understanding of evolution. In light of this, Kant's understanding of organisms has been interpreted as a philosophical template for integrating the design instances of the modern evolutionary synthesis with the developmental concerns of the extended evolutionary synthesis.

As we shall argue, the most significant challenge to the entire heuristic approach is squaring Kant's notion of a regulative principle with the contemporary idea of teleology as a heuristic. In fact, the idea of a regulative principle implies the assumption of a 'compulsion of reason' to conceive organized beings in a certain way (as purposive entities), which is admittedly unpalatable for a contemporary understanding. This amounts to a bind for the heuristic approach: it must either be admitted that Kant's post-hoc invocation into established debates in philosophy of biology is facile and amounts to little beyond an appeal to authority, or it must contend with the very serious challenge of making sense of a 'compulsion of reason' today.

3.1. The heuristic approach and the modern evolutionary synthesis

The proximity between Haldane's motto and Kant's antinomy of teleological judgment has led several commentators to build bridges between Kant's theory of biology and contemporary evolutionary accounts. For Kant, as for the modern evolutionary biologist, organisms appear to be considered as if they were purposive; a judgment which amounts to no more than a 'heuristic guide' for our eventual discovery of a mechanical explanation for that apparent purposiveness. On this view, which in many ways represents the main position in both Kant scholarship and philosophy of biology, Kant's use of teleology as a regulative principle offers a positive research program for biology, which emerges from Kant's preoccupation with the issue of teleology was an attempt at "boundary maintenance" between proper science on one hand and "metaphysical speculations" regarding vital forces or divine creation on the other (Mensch, 2013, p. 215, fn. 287). In this sense, Kant's treatment of teleology as a 'regulative principle' avoids both the pitfall of Wolffian teleology as divine design and the vitalist's advocacy of intrinsic formative powers.

Breitenbach takes these historical considerations to be readily applicable to contemporary arguments over the role of functions in biology when she submits that "the crucial contribution of the Kantian account is to argue both that teleology plays an important heuristic role in the search for causal explanations of nature and that it is for us an inevitable analogical perspective on living beings" (Breitenbach, 2009a, p. 31). The Kantian perspective "is [thus] not only compatible with the modern life sciences but can advance the debate about teleology in biology precisely because it does not interpret teleology naturalistically" (ibid, emphasis added).

Ginsborg (2014, p. 344) agrees that Kant's approach does not consist in grounding teleology in nature, but rather links "the justification of function ascriptions with the demands of understanding." In fact, "to regard something as a purpose without regarding it as an artefact

is to regard it as governed by normative rules without regarding those rules as concepts in the mind of a designer." In this sense, "thinking of an organism as a purpose, then, does not after all mean thinking of it as a product of design. It entails thinking of the organism as if designed, in that we regard it, like an actual product of design, as subject to normative constraints" (ibid, p. 277).

Translating this idea into contemporary terms, Quarfood (2006, p. 737) argues that, in a Kantian framework, teleology serves a "quasi-explanatory role." This implies that we should always take a "two level interpretation" of Kantian teleology: the object level and the philosophical meta-level. On the former, teleology identifies the object domain of biological research, while, on the latter, it can never be legitimately considered as objectively existent in nature (for a similar proposal, see: Breitenbach, 2008; 2009b). This line of thinking is not dissimilar from Ernst Mayr's (2004), who argues that teleology and function is precisely what marks the irreducibility of biological phenomena to mere physics and chemistry (proximate causes) from the object domain of biology grounded on evolutionary explanations (ultimate causes).

This perspective fits extraordinarily well with the Modern Evolutionary Synthesis, championed by Mayr, which considers functional ascriptions as a shorthand for a mechanistic explanation in terms of random genetic variation and environmental pressures, where the normative constraints on organismal form and function are set by natural selection. Perhaps the first to articulate this position was Ernst Haeckel, who argued that the idea of natural selection was the only thing Kant lacked; had Kant lived half a century later, he would probably have hailed Darwin as the Newton of the grass blade whose very possibility he had categorically denied in the CPJ (Haeckel, 1889, pp. 94–95; see also Cornell, 1986). Such a view seems natural to those who follow Ginsborg (2004) in thinking that for Kant, the problem of teleology is primarily rooted in the inexplicability of the contingent order of organisms with respect to the powers of matter in motion (see, e.g., Kitcher, 2015). In this way, the heuristic approach takes up Kant's use of teleology as a regulative principle and make use of it as a projective understanding of functional and teleological ascription, which is ultimately a strategy for reconciling the apparent teleology of organisms with a scientific image that recognizes mechanism as the only legitimate explanation.

From this perspective, the solution to Kant's antinomy is provided by evolutionary natural selection, which reconciles mechanism and teleology. In fact this argument constitutes one of the most dominant views in contemporary philosophy of biology, which mostly consider the question of teleology to be entirely "worked out" (Ruse, 1996, p. 284; quoted in; Lewens, 2004, p. 4): natural selection rules out intelligent design and provides a naturalized foundation for discussion of design in biology; the molecular revolution completes the job by explaining all ostensibly goal-directed processes as the result of the genetic blueprint implanted by natural selection. In the words of François Jacob, "for a long time, the biologist has found himself in front of teleology as if he were with a woman he cannot do without, but in whose company he does not want to be seen in public. The concept of a program now gives legal status to this hidden affair" (Jacob, 1970, p. 17).

3.2. Updating the heuristic approach for the extended evolutionary synthesis

In more recent years, the idea that we can productively conceive of organisms as artefact-like products of the 'blind' design of natural selection has undergone increasing criticism. For example, Lewens (2004, p. 3) has insisted that "such a picture is almost completely mistaken." In fact, in the course of the last decade, increasing awareness has emerged among biologists and theoreticians that we should rather 'rethink' or 'extend' the Neo-Darwinian synthesis (Laland et al., 2015; Müller, 2017; Pigliucci and Müller, 2010). At the heart of this project is a call for the return of the organism as fundamental explanatory concept in biology (Bateson, 2005; Huneman, 2010; Nicholson, 2014), originally fueled by developments in Evolutionary Developmental Biology and complexity science in the late 20th century (e.g. Goodwin, 1982; Kauffman, 1993), along with an increasing understanding of phenomena such as epigenetics (Jablonka & Lamb, 1995), phenotypic plasticity (West-Eberhard, 2003), and niche construction (Odling-Smee et al., 2003), which amount to a veritable 'revenge of the phenotype' against the geno-centrism of the Modern Evolutionary Synthesis (MES).

Despite the appearance of such a sea change in biological theory, many scholars still feel Kant's heuristic take on teleology can be useful outside of a strictly Neo-Darwinian picture, or that such a picture was in fact "oblivious to Kant's central insights" all along (Moss & Newman, 2015, p. 111; cf. also; Gilbert & Sarkar, 2000). For example, Lewens (2007) has suggested that Kant's heuristic use of teleology helps us make sense of the seemingly end-directed features of organismic development. He argues that a literal understanding of development as teleologically directed to the adult state runs into several problems, especially when it comes to accounting for the meaning of goal failure (pp. 539–544). He suggests that we instead think of this process in heuristically teleological terms, which would play "an essential function in providing [...] a 'guiding thread' for the subsequent articulation of mechanical explanations of development" (ibid, p. 545).

Huneman (2017) suggests an even closer parallel between Kant and contemporary debates in biology, especially those concerning the Extended Evolutionary Synthesis. He argues that Kant's two criteria for a natural purpose can serve as a template for the synthesis between two strands of biological theorizing: adaptationism (design through natural selection) and developmentalism (the self-organizing of organisms through development advocated by Evo-Devo) (see also Moss & Newman, 2015, pp. 94–111). In doing so, Huneman interprets Kant's second criterion for a natural purpose (self-organization) as coextensive with development, and in fact defines it as the 'epigeneticity' criterion, even though epigenetic developmental processes are only one facet of biological self-organization.

As we have seen, Kant illustrates the features of natural purposes discussing the generation of a tree, which takes place on three different levels: 1) Species (reproduction), 2) Individual (growth), and 3) Parts (collective self-maintenance). The second, developmental sense of self-organization is just a subcategory of a larger sense of self-organization, which includes self-maintenance at both the individual and cross generational level. How we characterize this more general sense is a more abstract question which deals with the fundamental nature of organisms as self-regulating adaptive systems. We thus believe that the equation of Kant's self-organization criterion with developmental epigenesis provides us with a restricted understanding of Kant's idea of intrinsic purposiveness, and in doing so avoids

dealing with the unresolved issues at play in Kant's work concerning the 'autonomous' or 'agential' features of biological systems by considering them not as real properties of organisms, but only as projections of our cognition. As such, we deem this move to be in line with recent conceptions of teleology as a useful heuristic.

This suspicion is confirmed in a recent paper on organismal agency by Desmond and Huneman (2020), which distinguishes three ways to understand agency in biological systems: 1) A 'Neo-Fisherian option,' coherent with the framework of the MES, where agency is invoked in purely heuristic terms as a shorthand for selectionist explanations; 2) A 'Neo-Aristotelian option,' identified with Varela (1979), Moreno and Mossio (2015), and Walsh (2012, 2015), which considers agency as a 'constitutive' feature of biological systems as such; and 3) The 'Kantian option' they advocate for, which holds that "(1) the concept of organismic agency is indispensable to scientific explanation and (2) agential explanations are to be conceived non-ontically." This means that our understanding of organisms as "agents with purposes" is, as Kant puts it, a "demand of reason" inherent to our finite understanding, without being interpreted as an objective feature of biological systems (ibid, pp. 35–36).

Kant's claim that reason demands a teleological interpretation of organisms is a far stronger claim than the idea that teleology is a mere heuristic which implies that its use is optional. Whether or not this stronger claim is warranted today is a key question for the heuristic approach which, to our knowledge, has not been addressed. Most seem content to make the weaker claim which, as Lewens (2007) rightly recognizes, amounts to no more than an interpretive gloss on the notion of a 'regulative principle'—one which hardly does justice to Kant's thought (Lewens, 2007, p. 554 fn. 2). If Lewens is right about this, however, one wonders what the appeal to Kant really amounts to, i.e., whether the heuristic approach really is "Kantian" in any interesting sense.

In contrast, Desmond and Huneman (2020) and Breitenbach (2009a) seem to take the strong interpretation of a 'demand of reason' to be part and parcel of their Kantian approach to teleology. In other words, they take it to be true that teleological judgment is a demand rather than a useful, though optional, heuristic tool for advancing biology. Yet this assumption goes undefended and raises some serious questions. Foremost among these is the question of whether such a project requires a wholesale revival of Kant's transcendental conception of Vernunft, or if it is an empirical claim about the nature of human cognition as understood by contemporary cognitive science. In other words, this is the question of interpreting the very idea of a "demand of reason" today, and the onus is on the defenders of this idea to justify it. Even within Kant's own system, the justification for such a claim is opaque at best, and to assert the same thing today would likely be deemed even more problematic by contemporary philosophers and cognitive scientists.

Such worries would certainly be at the forefront of those who take the heuristic approach to be fundamentally misguided. In the following section we unpack this 'naturalist' view, which takes Kant's idea of intrinsic purposiveness to have been a prescient intuition which can only come to its full fruition beyond the limits of his system.

4. Intrinsic purposiveness and agency: the naturalist approach

The project of naturalizing teleology has recently found support from those who argue that a theory of organisms as autonomous, purposive agents is critical for the advancement of biology as a science. This idea can be traced back to the organicist movement of the early 20th century (Nicholson & Gawne, 2015; Esposito, 2016; Peterson, 2016), while a more recent incarnation is found the landmark book by Levins and Lewontin, The Dialectical Biologist (1985) and to the more formal treatment by Lewontin, The Triple Helix (1998). In the famous essay on "the organism as the subject and object of evolution," it is argued that in the classical Neo-Darwinian perspective organisms are conceived as pure objects acted upon by 'internal' and 'external' forces: genes, whose variation is purely random, and environmental pressures which extrinsically act on this random variation. Evolution is only a relation between genes and environment that relegates the organism to the role of mere "medium by which the external forces of the environment confront the internal forces that produce variation" (Lewontin, 1985, p. 88). The work of Richard Dawkins is possibly the most iconic expression of this view. On the other hand, for Lewontin "the organism cannot be regarded as simply the passive object of autonomous internal and external forces; it is also the subject of its own evolution" (ibid, p. 89).

In a similar vein, Walsh (2015) has emphasized that since the establishment of the Modern Synthesis, our understanding of evolution has been exclusively focused on sub-organismal and supra-organismal entities, genes and populations, while the organism has been completely eclipsed from the conceptual landscape of evolutionary thinking. The main reason for this is that the MES still conceives organisms as mere objects, instead of considering them as agents. Walsh (2018, p. 167) insists that agency is a real biological phenomenon and that it should be part of biological ontology, arguing that "organisms call for a special kind of theory," i.e., "an agent theory," in contrast to "most of our familiar scientific theories," which are "object theories." In fact, "the proper study of organisms [...] requires us to take their agency seriously." Accounting for organisms as agents invokes a series of concepts we normally do not associate with natural science: "because there are agents, there are goals, means, norms, hypothetical necessity, and a special mode of explanation—teleology" (ibid, p. 172). Although this seems to "involve us in a non-standard kind of scientific theory" (ibid, p. 175), such an approach is the only possible way to overcome the clash between scientific and manifest image of the organism that has been operative since Kant (see also Walsh, 2006).

We find such a view to be clearly representative of the naturalist approach, which departs from the heuristic approach on two fundamental counts by holding that: (1) While Darwin naturalized Kant's first 'design' criterion for something to be called a natural purpose, the second 'self-organization' criterion poses a particular challenge to the heuristic approach which ignores it (Section 3.1) or sidesteps the problem (Section 3.2); (2) If we are to develop the theoretical potential of the self-organization criterion, we need to address the Kantian undertow of intrinsic purposiveness and take it beyond the limits of transcendental idealism.

Akin to the heuristic approach, the naturalist approach has been defended both in the context of the history of biology and in contemporary philosophy of science. The historical perspective portrays, contra Lenoir, German biology at the turn of the nineteenth century as ensuing from a break, rather than a continuity, with Kant's deflationary understanding of teleology as 'regulative' principle. According to such accounts, both natural scientists

belonging to the so-called ‘Gottingen School’ and natural philosophers connected to German idealism advocated the necessity to overcome Kant's understanding of teleology as a ‘technique of nature,’ based on a heuristic analogy between organized beings and artefacts, and move towards an understanding of teleology in terms of autonomous self-organization (Richards, 2000, 2002; Zammito, 2012, 2017).

The contemporary perspective develops a similar line of argument regarding contemporary debates over function and teleology. It builds primarily on a rich tradition which emerged in the second half of the twentieth century, particularly in the wake of cybernetics and the development of complex systems theory. Notable figures from this period are Jean Piaget (1967), Robert Rosen (1972), Howard Pattee (1973/2012), Maturana and Varela (1980), among others, who pursued the idea that organisms are characterized by a cyclical structure reminiscent of Kant's notion of self-organization; what Piaget first called ‘organizational closure’ (Bich & Damiano, 2008). This distinctive form of organization was postulated to be one of the key factors which explains certain distinctive features of organisms, including the way in which they adaptively constitute themselves as autonomous individuals. Teleology becomes a relevant way to understand the way such systems ‘act on their own behalf’ in order to maintain themselves within a specific set of viability conditions (Deacon, 2012; Mossio & Bich, 2017).

In what follows, we first discuss some early contributions that we see as setting the philosophical foundations for the naturalist approach to Kantian teleology; we then provide a critical evaluation of the work that is currently being done to develop those foundations into a full-fledged theory of biological purposiveness.

4.1. Dissipative systems and autopoiesis

Alicia Juarrero-Roque argues the philosophical difficulties which Kant encountered in his attempt to make sense of natural purposes were primarily caused by the scientific limitations of his time (1985, p. 120). Foremost among these are Newtonian mechanics, which Kant sought to ground on a firm metaphysical basis. Such a ‘Newtonian’ conception of nature was ultimately incompatible with a theory of life, given that it frames causation in terms of extrinsic relations only. In contrast, the ‘formative power’ of organisms seemed to appeal to an intrinsic causal power, inherent to the system itself, by which it becomes ‘cause and effect of itself’ (ibid, pp. 109–112).

Organisms as teleological, self-organizing entities are therefore impossible to account for within a Newtonian picture of nature, yet we are no longer bound by such a restricted picture. Not only do we have a theory of natural selection, but also the sciences of far-from-equilibrium dissipative systems which map closely to Kant's notion of self-organization. In this respect, “what we find anticipated in Kant is a rudimentary systems theory, the recognition of a systemic level of organization with emergent properties that cannot be reduced to an understanding of the components alone” (ibid, p.111). While Kant was correct in saying that organisms cannot be explained by mere mechanism in the Newtonian sense, the situation is starkly different today: by expanding beyond Newton we have also found new possibilities for explaining self-organization, and therefore teleology, naturalistically.

In a similar fashion, Weber and Varela (2002) argue that Kant's projective stance on intrinsic purposiveness amounts to an 'unstable' position which results from the tension inherent in the need to ascribe intrinsic teleology to organisms, but without being able to fully countenance such a move. Yet we are now in a position to overcome such an unstable position and fulfill the promise of Kant's thesis regarding the intrinsic purposiveness of living systems by accounting for it as a real aspect of their being, rather than a mere heuristic in the eye of the beholder.

The key idea here is that Kant's notion of self-organization fits extremely well with the notion of autopoiesis, originally proposed by Maturana and Varela in the 1970's and 80's (see also Thompson, 2007,p. 138). The autopoietic model is a product of the second-order cybernetics inaugurated by Margaret Mead and Heinz Von Foerster in the 1960's, who were fascinated by the possibility of creating machines that could self-control, self-organize, and perhaps even reproduce (see also Keller, 2008, p. 71; Mead, 1968; Riskin, 2016, ch. 9). In the most general terms, autopoiesis defines a simple metabolic network surrounded by a semipermeable membrane, internally organized so as to continuously maintain itself in the face of environmental disturbance (Maturana & Varela, 1980; Thompson, 2007).

Though Maturana and Varela were originally against the notion of teleology, opting to think of it in heuristic terms (1980, pp. 85–88), a major shift occurred later in Varela's life when he discovered the work of Hans Jonas. According to Jonas, organisms are distinctive in that their "being is their own doing" (Jonas, 1968, p. 233); they are continuously threatened by their own dissolution, and must act in order to survive. They do so in virtue of their metabolic activity, which he claimed to be "not only a device for energy-production but as the continuous process of self-constitution of the very substance and form of the organism" (Jonas, 1965, p. 47). This grounds a robust sense of organismic teleology in the sense that "to be is [the organism's] intrinsic goal. Teleology comes in where the continuous identity of being is not assured by mere inertial persistence of a substance, but is continually executed by something done, and by something which has to be done in order to stay on at all" (Jonas, 1968, p. 243, p. 243).

Weber and Varela (2002, p. 114) argue that what is missing from this account is an empirical theory which might explain how such organismal teleology is concretely achieved and suggest that the autopoietic model would fulfill this role. Yet many concerns have subsequently been raised that, at least in its first formulation, autopoiesis was ultimately inadequate to do so (Bourgine & Stewart, 2004; Bitbol & Luisi, 2004; Di Paolo, 2005). These critiques, among others, pointed to serious flaws in the basic assumptions and methods of the theory, and as a result, few stand by it today. Instead, work from several authors currently seeks to develop a more technically precise research program to address these fundamental shortcomings. In what follows we present these developments and draw out the implications which this has for Kant's legacy for biological theory today.

4.2. Intrinsic purposiveness as closure of constraints

Defenders of a naturalistic approach to teleology have sought to build on work from the late 20th century by further specifying the continuities and the discontinuities between intrinsically purposive systems and nonpurposive ones. The challenge for a naturalistic

approach is to simultaneously explain how purposiveness could emerge from nature and therefore be continuous with it, while also explaining the discontinuities which make organisms the unique type of entities that they are.

Crucial to this recent work is the concept of constraint, which authors such as Pattee (1973), Nicolis and Prigogine (1977), and Kauffman (2000) all utilized to understand biological self-organization. Contemporary authors leverage this concept in order to refine our understanding of biological organization as an intrinsically purposive causal regime, while also connecting it to now familiar principles from the science of thermodynamics. The aim of this project is to further the claim that teleology is not, in fact, a completely alien principle, and that it can be a properly scientific concept with a rightful place in biological ontology.

Thermodynamics comes to be relevant for the question of teleology insofar as defenders of a naturalist approach take seriously the Kantian insight that teleology is fundamentally related to the origin of order in biological systems. Though proponents of a heuristic understanding of teleology also take up this idea, naturalists disagree with those who claim that natural selection alone can solve this conundrum. Indeed, as already argued by Kauffman (1993), while natural selection is undoubtedly the main driving force in evolution, it requires as a pre-condition the existence of systems capable of generating the genetic and phenotypic variation which selection can operate on. This does not mean that the theory of evolution by natural selection is wrong, but that it tells only part of the story when it comes to the sources of order in the biological world.

Kauffman's contribution to understanding biological organization is the idea of 'work-constraint cycle.' He employs the notion of constraint to introduce a new conception of organization "that is not covered by our concepts of matter alone, energy alone, entropy alone, or information alone" (2000, p. 4). This notion is fundamentally connected to the notion of work, i.e., the constrained release of energy. To illustrate: though steel balls do not spontaneously fly into the air, they can be forced to do so if they are arranged in a cannon with gunpowder. The ignition of the gunpowder releases energy which expands outward while being constrained by the walls of the cannon, and this channeling of energy allows for work to be done on the cannonball. It therefore takes constraints to do work, but constraints themselves require work in order to exist: cannons do not form spontaneously, and so it takes work (in the form of human labor) to make constraints (in the form of a cannon tube). This leads to a circular relation between these concepts: it takes constraints to do work, but at the same time it takes work to form constraints (ibid, p. 97). Kauffman's contribution to understanding biological organization is the idea of 'work-constraint cycle.' He employs the notion of constraint to introduce a new conception of organization "that is not covered by our concepts of matter alone, energy alone, entropy alone, or information alone" (2000, p. 4). This notion is fundamentally connected to the notion of work, i.e., the constrained release of energy. To illustrate: though steel balls do not spontaneously fly into the air, they can be forced to do so if they are arranged in a cannon with gunpowder. The ignition of the gunpowder releases energy which expands outward while being constrained by the walls of the cannon, and this channeling of energy allows for work to be done on the cannonball. It therefore takes constraints to do work, but constraints themselves require work in order to exist: cannons do not form spontaneously, and so it takes work (in the form of human labor) to make constraints (in the

form of a cannon tube). This leads to a circular relation between these concepts: it takes constraints to do work, but at the same time it takes work to form constraints (ibid, p. 97).

A system which can capture this circularity would be one capable of performing work continuously and autonomously. This counts as the definition of an autonomous agent: a system capable of performing at least one work-constraint cycle (Kauffman, 2000, p. 8). Such a system would be one which is doing work on its own behalf, harvesting matter and energy in its environment in order to perpetuate itself. This reciprocal relationship between constraints and work is key, in Kauffman's view, for understanding biological organization, which in turn warrants understanding living beings as intrinsically purposive agents. The insight here is that for any system as intricately organized as an organism to remain organized for any period of time—let alone for it to propagate itself through growth and reproduction—work and constraints must be coupled so as to form a kind of circular organization. Chemical networks that realize this kind of regime has thus be qualified as 'Kantian wholes' or cases of 'Kantian closure,' given that they are formed of parts which each reciprocally produce each other (Kauffman, 2000; Longo et al., 2012). What a work-constraint cycle concretely amounts to, however, remains underdetermined in Kauffman's account. In light of this, recent work has attempted to elucidate the concrete meaning of a work-constraint cycle.

Building on the work of Rosen and Varela, the so-called theory of 'biological autonomy' (Moreno & Mossio, 2015) is one of a number of theories that attempts to provide an explicit characterization of biological organization as it relates to teleology (see also, e.g., Deacon, 2012). This research program builds on the key notion of organizational closure, with particular emphasis on the relationship between the internal organization of the system and its openness to matter and energy in the environment, which was seen as lacking in the original formulations of closure. As recently argued by Montevil and Mossio (2015, p. 180), "biological systems are at the same time both thermodynamically open and organisationally closed, but no details are given regarding how the two dimensions are interrelated, how closure is actually realised, what constituents are involved, and at what level of description." It thus "remains unclear in what precise sense closure would constitute a causal regime."

In this perspective, biological organization is modeled as a circular causal relationship in which, in a simplified and idealized form, a constraint A channels energy so as to do the work to maintain constraint B, which in turn channels energy to do the work to maintain A. This creates a cyclical form of work in which the whole becomes self-maintaining and self-perpetuating, and becomes an end-directed process insofar as it continuously does work in order to maintain itself. In other words, such a system is teleological because it instantiates a self-determining causal regime whereby "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" (Mossio & Bich, 2017, p. 1104).

While promising, this approach currently faces several open questions. A particularly pressing issue concerns the demarcation between the distinctive organizational principles of organisms and physical cycles such as the water cycle, or dissipative systems such as a candle flame. Both may seem self-maintaining but are clearly qualitatively different from organisms, and both remain challenging borderline cases (Toepfer, 2012; Deacon & Cashman, 2013;

Montevil & Mossio, 2015; Mossio & Bich, 2017; Cusimano & Sterner, 2020; García-Valdecasas, 2021). Moreno and Mossio (2015) suggest that a teleological system is any system that maintains itself, insofar as its activity contributes to the 'goal' of its persistence. But as they themselves argue, such behavior is exhibited in systems far simpler than those which we consider 'living.' Thus, the question: is teleology a distinctive feature of organisms, or is it instantiated by other self-maintaining systems as well?

While a case has been made against the idea that the water cycle is an intrinsically goal-directed process, dissipative systems such as candle flames remain a challenge. A candle flame is often cited as a typical case of self-maintaining behavior: it maintains itself by vaporizing wax and inducing a convection current, which in turn keeps the flame burning. As Bickhard (2017, p. 183) emphasizes, the candle flame is inseparable from this self-maintaining process; it is constituted by it. It therefore seems, counterintuitively, that candle flames are teleological on this account. The key question is then whether persistence is truly a goal of the candle flames activity. Moreno and Mossio have previously argued that any such self-maintaining process (which they also call 'self-determining') is the simplest kind of teleological system (2015, pp. 70–71). Their reasoning is that if the very existence of the flame were shown to be dependent on (and explained by) its activity, then there would be a minimal sense in which its activity aims at its continued existence. Mossio and Bich (2017) express doubts about this claim, suggesting that the issue hangs on the empirical question of whether it is really the system itself which acts to maintain itself, or whether it is maintained solely by extrinsic conditions (p. 1109, see also: Moreno & Barandiaran, 2004, Deacon & Cashman, 2013; Arnellos, 2018; and especially Deacon, 2012, for an in-depth treatment of this issue). The question remains open for the time being.

This issue proves especially difficult when we consider the actual scientific practices of biologists, for whom modelling is an indispensable tool when it comes to understanding complex systems. But as Cusimano and Sterner (2020) argue, there are many equally valid ways of describing the same system depending on the specific questions which scientists wish to answer, and there likely is no complete description which can be appealed to. Depending on the way the system is modeled, it may or may not instantiate closure of constraints, and the relevant features for explaining the system's perdurance may be deemed intrinsic or extrinsic. These considerations call for further investigation in order to truly bring teleological concepts into scientific practice.

Beyond these as-yet unresolved questions, we feel that the core contribution of what we have defined as the naturalist approach has been to conceptualize the organizational principles of organisms in terms of constraints, because it allows us to clearly see that the causal principle at work in their self-maintenance does in a sense introduce a new form of causality into natural science, as Kant feared, but also that this principle has nothing mysterious about it. There need not be a chasm between mechanism and teleology: science can explain how the two are compatible, and as Walsh (2012) argues, there is no reason for teleological explanations to not have the same status as mechanistic explanations. Though the idea is still far from the mainstream, and while the path to concretely developing this approach into a scientific theory remains open-ended, this work might finally break new ground in our understanding of intrinsic purposiveness.

5. Conclusion

In this paper, we argued that Kant's legacy for biology reflects two fundamental attitudes toward teleology today. On the one hand, the canonical Kant is seen to have saved the concept of teleology from dogmatic metaphysics by turning it into a regulative principle, and thereby making it safe for science. One the other hand, a minority of philosophers and theorists finds in the third Critique an undertow that takes intrinsic purposiveness as the inherent feature of self-organizing systems, and as a new causal principle within nature.

The heuristic approach heeds Kant's attempt to maintain teleology as a principle fundamentally extrinsic to proper natural science, whose explanations must ultimately always be mechanistic. The naturalist approach, in contrast, takes seriously the possibility that teleology might constitute a legitimate causal principle in nature. This naturalist move, however, is only made possible by rethinking the dichotomy between mechanism and teleology altogether, and most importantly abandoning the Kantian attitude of putting firm a priori limits on what can and cannot be a legitimate scientific principle. While still far from the mainstream, these developments show us a field thriving with open questions which deserve to be taken seriously by philosophers and theorists engaged with the recent return of the organism as a central concept in our understanding of the biological world.

Funding Sources

This work was supported by the Marie Skłodowska-Curie Actions (795947) and the University of Toronto.

References

Arnellos, A. (2018). From Organizations of Processes to Organisms and Other Biological Individuals. In D. Nicholson & J. Dupré (Eds.), *Everything Flows: Toward a Processual Philosophy of Biology* (pp. 199–222). Oxford: Oxford University Press.

Nicholson, D.J., & Dupré J. (eds), (2018), *Everything Flows: Towards a Processual Philosophy of Biology*. First edition. Oxford: Oxford University Press.

Artiga, M., & Martínez, M. (2016). The Organizational Account of Function is an Etiological Account of Function. *Acta Biotheoretica*, *64*(2), 105–117.

Ayala, F. J. (1970). Teleological Explanations in Evolutionary Biology. *Philosophy of Science*, *37*(1), 1–15.

Bateson, P. 2005. The Return of the Whole Organism, *Journal of Biosciences*, 30: 31-39.

Bich, L., & Damiano, L. (2008). Order in the Nothing: Autopoiesis and the Organizational Characterization of the Living. In *Physics of Emergence and Organization* (pp. 339–369). World Scientific.

Bickhard, M. H. (2017). Information, Representation, Biology. *Biosemiotics*, *10*(2), 179–193.

Bitbol, M., & Luisi, P. L. (2004). Autopoiesis with or without cognition: defining life at its edge. *Journal of the Royal Society, Interface / the Royal Society*, *1*(1), 99–107.

Bourgine, P., & Stewart, J. (2004). Autopoiesis and Cognition. *Artificial Life*, *10*(3), 327–345.

Breitenbach, A. (2008). Two views on nature: A solution to Kant's antinomy of mechanism and teleology. *British Journal for the History of Philosophy: BJHP: The Journal of the British Society for the History of Philosophy*, *16*(2), 351–369.

Breitenbach, A. (2009). Teleology in Biology: A Kantian Perspective. *Kant Yearbook*, 1, 31–

56.
Breitenbach, A. (2014). Biological Purposiveness and Analogical Reflection. In: I. Goy & E. Watkins (eds.), *Kant's Theory of Biology*. Berlin: De Gruyter.
Breitenbach, A. (2016). Normativity and Purposiveness. *The British Journal of Aesthetics*, *56*(4), 405–408.Caneva, K. (1990). Teleology with regrets. *Annals of Science*, *47*, 291–

300.
Cooper, A. (2018). Two directions for teleology: Naturalism and idealism. *Synthese*, 195(7), 3097–3119.
Cornell, J. F. (1986). Newton of the grassblade? Darwin and the problem of organic teleology. *Isis*, *77*(3), 405–421.
Cusimano, S., & Sterner, B. (2020). The Objectivity of Organizational Functions. *Acta Biotheoretica*, *68*(2), 253–269.
Deacon T., *Incomplete Nature: How Mind Emerged from Matter*, New York: Norton.
Deacon, T. W., Cashman, T. (2013). Teleology versus mechanism in biology: Beyond self-organization. In: A. C. Scarfe & B. G. Henning (eds.), *Beyond Mechanism: Putting Life Back into Biology*, Lanham MD: Lexington Books, 290–311.
Desmond, H., & Huneman, P. (2020). The Ontology of Organismic Agency: A Kantian Approach. In A. Altobrando & P. Biasetti (Eds.), *Natural Born Monads: On the Metaphysics of Organisms and Human Individuals*. Berlin: De Gruyter, 33–64.
Di Paolo, E. A. (2005). Autopoiesis, Adaptivity, Teleology, Agency. *Phenomenology and the Cognitive Sciences*, *4*(4), 429–452.
García-Valdecasas, M. (2021). On the naturalisation of teleology: Self-organisation, autopoiesis and teleodynamics. *Adaptive Behavior*.
Gilbert, S. & Sarkar, S. 2000. Embracing Complexity: Organicism for the 21st Century, *Developmental Dynamics*, 219(1): 1-9.
Ginsborg, H. (2004). Two Kinds of Mechanical Inexplicability in Kant and Aristotle. *Journal of the History of Philosophy*, 42(1), 33–65.
Ginsborg, H. (2014). Oughts without intentions: a Kantian approach to biological functions. In: I. Goy & E. Watkins (eds.), *Kant's Theory of Biology*. Berlin: De Gruyter, 259–274.
Goodwin, B. C. (1982). Development and evolution. *Journal of Theoretical Biology*, 97(1), 43–55.
Hegel, G.W.F. (1816/2010). *The Science of Logic*, Cambridge University Press.
Huneman, P. (2010). Assessing the prospects for a return of organisms in evolutionary biology. *History and Philosophy of the Life Sciences*, 32(2-3), 341–371.
Huneman, P. (2017). Kant's Concept of Organism Revisited: A Framework for a Possible Synthesis between Developmentalism and Adaptationism? *The Monist*, 100(3), 373–390.
Illetterati, L. (2014). Teleological Judgment: Between Technique and Nature. In: I. Goy & E. Watkins (eds.), *Kant's Theory of Biology*. Berlin: De Gruyter, 81–98
Jablonka, E., Lamb, M. *Epigenetic Inheritance and Evolution: The Lamarckian Dimenstion*, Oxford: Oxford University Press.
Jacob, F. (1970). *La Logique du Vivant. Une Histoire de l'Hérédité*. Paris: Gallimard.
Jonas, H. (1968). Biological Foundations of Individuality: *International Philosophical Quarterly: IPQ*, *8*(2), 231–251.
Juarrero-Roqué, A. (1985). Self-Organization: Kant's Concept of Teleology and Modern Chemistry. *The Review of Metaphysics*, 39(1), 107–135.
Kant, I. (1790/2000). *Critique of the Power of Judgment*, Cambridge: Cambridge University Press.
Kauffman, S. A. (1993). *The Origins of Order: Self-organization and Selection in Evolution*. New York: Oxford University Press.
Kauffman, S. (2000). *Investigations*. New York: Oxford University Press.
Keller, E.F. (2008). Organisms, machines, and thunderstorms: A history of self-organization, part one. *Historical Studies in the Natural Sciences*, 38(1), 45–75.
Kitcher, P. (1993). Function and design. *Midwest Studies in Philosophy*, 18(1), 379-397.
Kitcher, P. (2015). Review of *"The Normativity of Nature: Essays on Kant's Critique of Judgement,"* by H. Ginsborg. *Notre Dame Philosophical Reviews*.

Laland, K. N., Uller, T., Feldman, M. W., Sterelny, K., Müller, G. B., Moczek, A., Jablonka, E., & Odling-Smee, J. (2015). The extended evolutionary synthesis: its structure, assumptions and predictions. *Proceedings. Biological Sciences / The Royal Society*, 282(1813), 20151019.

Lenoir, T., 1981, Teleology without Regrets. The Transformation of Physiology in Germany: 1790-1847, *Studies in History and Philosophy of Science, Part A*, 12(4): 293-354.

Lenoir T., 1982, *The Strategy of Life: Teleology and Mechanics in Nineteenth-Century German Biology*, Dordrecht: Reidel.

Levins, R., & Lewontin, R. C. (1985). *The Dialectical Biologist*. Cambridge MA: Harvard University Press.

Lewens, T. (2004). *Organisms and Artifacts: Design in Nature and Elsewhere*. Cambridge MA: MIT Press.

Lewens, T. (2007). 'Functions' in M. Matthen and C. Stephens (eds.), *Handbook of Philosophy of Biology*. Amsterdam: Elsevier, 537-559.

Lewontin, R. (1998). *The Triple Helix: Gene, Organism and Environment*. Cambridge MA: Harvard University Press.

Longo, G., Montévil, M., & Kauffman, S. (2012). No entailing laws, but enablement in the evolution of the biosphere. *Proceedings of the 14th annual conference companion on Genetic and evolutionary computation*, 1379–1392.

Maturana, H. R., & Varela, F. J. (1980). *Autopoiesis and cognition: the realization of the living*. Dordrecht: Reidel.

Mayr, E. (1974). Teleological and Teleonomic, a New Analysis. In R. S. Cohen & M. W. Wartofsky (eds.), *Methodological and Historical Essays in the Natural and Social Sciences* (pp. 91–117). Dordrecht: Springer.

Mayr, E. (1988). *Toward a New Philosophy of Biology: Observations of an Evolutionist*. Cambridge MA: Harvard University Press.

Mayr, E. (2004). *What Makes Biology Unique?: Considerations on the Autonomy of a Scientific Discipline*. Cambridge: Cambridge University Press.

McLaughlin, P. (1990). *Kant's Critique of Teleology in Biological Explanation: Antinomy and Teleology*. Lampeter: Mellen Press.

McLaughlin, P. (2014). Mechanical Explanation in the "Critique of the Teleological Power of Judgment." In: I. Goy & E. Watkins (eds.), *Kant's Theory of Biology*. Berlin: De Gruyter, 149–166.

Mead, M. (1968). Cybernetics of Cybernetics. In H. Von Foerster, J.D. White, L.J. Peterson, & J. -K. Russell (Eds.), *Purposive Systems: Proceedings of the First Annual Symposium of the American Society for Cybernetics* (pp. 1–11). New York: Spartan Books.

Mensch, J. (2013). *Kant's Organicism: Epigenesis and the Development of Critical Philosophy*. Chicago: University of Chicago Press.

Millikan, R. G. (1989). In Defense of Proper Functions. *Philosophy of Science*, 56(2), 288–302.

Montévil, M., & Mossio, M. (2015). Biological organisation as closure of constraints. *Journal of Theoretical Biology*, 372, 179–191.

Moreno, A., & Barandiaran, X. (2004). A Naturalized Account of the Inside-Outside Dichotomy. *Philosophica*, 73, 11–26.

Moreno, A., & Mossio, M. (2015). *Biological Autonomy: A Philosophical and Theoretical Enquiry* (Vol. 12). Dordrecht: Springer.

Moss, L., & Newman, S. A. (2015). The Grassblade Beyond Newton: The Pragmatizing of Kant for Evolutionary-Developmental Biology. *Lebenswelt. Aesthetics and Philosophy of Experience.*, 94–111.

Mossio, M., & Bich, L. (2017). What makes biological organisation teleological? *Synthese*,

194(4), 1089–1114.
Müller, G. B. (2017). Why an extended evolutionary synthesis is necessary. *Interface Focus*, *7*(5), 20170015.
Nagel, E. 1979. *Teleology Revisited and Other Essays in the Philosophy of Science*, New York: Columbia University Press.
Nassar, D. (2016). Analogical reflection as a source for the science of life: Kant and the possibility of the biological sciences. *Studies in History and Philosophy of Science*, *58*, 57–66.
Neander, K. (1998). The Division of Phenomenal Labor: A Problem for Representational Theories of Consciousness. *Philosophical Perspectives. A Supplement to Nous*, *12*, 411–434.
Nicholson, D. (2014). The Return of the Organism as a Fundamental Explanatory Concept in Biology. *Philosophy Compass*, 9(5), 347–359.
Nicolis, G. & Prigogine, I. (1977), *Self-organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations*, New York: Wiley.
Nicholson, D. J., & Gawne, R. (2015). Neither logical empiricism nor vitalism, but organicism: what the philosophy of biology was. *History and Philosophy of the Life Sciences*, 37(4), 345–381.
Odling-Smee, F. J., Laland, K. N., & Feldman, M. W. (2003). *Niche construction: The neglected process in evolution*. Princeton: Princeton University Press.
Pattee, H. H. (1973/2012). The Physical Basis and Origin of Hierarchical Control. In H. H. Pattee & J. Rączaszek-Leonardi (Eds.), *Laws, Language and Life: Howard Pattee's classic papers on the physics of symbols with contemporary commentary* (pp. 91–110). Dordrecht: : Springer.
Peterson, E. (2016). *The Life Organic: The Theoretical Biology Club and the Roots of Epigenetics*. Pittsburgh: University of Pittsburgh Press.
Piaget, J. (1967). *Biologie et connaissance*. Paris: Gallimard.
Pigliucci, M., & Müller, G. B. (2010) (eds.), *Evolution: The Extended Synthesis*, Cambridge MA: MIT Press.
Pittendrigh, C. S. (1958). Adaptation, natural selection, and behavior. *Behavior and Evolution*, *390*, 416.
Quarfood, M. (2006). Kant on biological teleology: Towards a two-level interpretation. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *37*(4), 735–747.
Richards, R. (2002). *The Romantic Conception of Life: Science and Philosophy in the Age of Goethe*. Chicago: University of Chicago Press.
Richards, R. J. (2000). Kant and Blumenbach on the Bildungstrieb: a historical misunderstanding. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 31(1), 11–32.
Riskin, J. (2016). *The Restless Clock: A History of the Centuries-Long Argument Over What Makes Living Things Tick*. Chicago: University of Chicago Press.
Rosen, R. (1972). Some relational cell models: the metabolism-repair systems. In *Foundations of mathematical biology* (pp. 217–253). Elsevier.
Ruse, M. (1996). Booknotes. *Biology & Philosophy*, 11, 283–288.
Schelling, F.W.J. (1797/1989), *Ideas for a Philosophy of Nature*, Cambridge: Cambridge University Press.
Teufel, T. (2011). Wholes that cause their parts: organic self-reproduction and the reality of biological teleology. *Studies in History and Philosophy of Biological and Biomedical Sciences*, 42(2), 252–260.
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.
Thompson, E. (2007). *Mind in Life*. Cambridge MA: Harvard University Press.
van den Berg, H. (2013a). *Kant on Proper Science: Biology in the Critical Philosophy and the Opus postumum*. Dordrecht: Springer.
van den Berg, H. (2013b). The Wolffian roots of Kant's teleology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, *44*(4), 724–734.
Varela, F. J. (1979). *Principles of biological autonomy*. Amsterdam: Elsevier.
Walsh, D. (2006). Organisms as natural purposes: The contemporary evolutionary perspective. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 37(4), 771–791.
Walsh, D. (2012). Mechanism and purpose: A case for natural teleology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, *43*(1), 173–181.
Walsh, D. (2015). *Organisms, Agency, and Evolution*. Cambridge: Cambridge University Press.
Walsh, D. (2018). Objectcy and Agency: Towards a Methodological Vitalism. In: D. J. Nicholson & J. A. Dupre (Eds.), *Everything Flows*. Oxford: Oxford University Press.
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.
West-Eberhard, M.J. 2003. *Developmental Plasticity and Evolution*, New York: Oxford University Press.
Wright, L. (1973). Function. *The Philosophical Review*, *82*, 139–168.
Zammito, J. H. (2012). The Lenoir thesis revisited: Blumenbach and Kant. *Studies in History and Philosophy of Biological and Biomedical Sciences*, 43(1), 120–132.
Zammito, J. H. (2017). *The Gestation of German Biology: Philosophy and Physiology from Stahl to Schelling*. Chicago: University of Chicago Press.