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► **To cite this version:**

Cécilia Bognon-Küss. Metabolism in Crisis? A New Interplay Between Physiology and Ecology. Vitalism and Its Legacy in Twentieth Century Life Sciences and Philosophy, 29, Springer International Publishing, pp.193-216, 2023, History, Philosophy and Theory of the Life Sciences, 10.1007/978-3-031-12604-8_11 . hal-03942142

HAL Id: hal-03942142

<https://hal.science/hal-03942142>

Submitted on 16 Jan 2023

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Metabolism in Crisis? A New Interplay Between Physiology and Ecology



Cécilia Bognon-Küss

Abstract This chapter investigates the hybrid relationships between metabolism, broadly and a-historically understood as the set of processes through which alien matter is made homogeneous to that of the organism, and forms of vitalism from the eighteenth century on. While metabolic processes have long been modeled in a reductionist fashion as a straightforward function of repair and expansion of a given structure (either chemically, or mechanistically), a challenging vitalist view has characterized metabolism as a creative, organizing, vital faculty. I suggest that this tension was overcome in Claude Bernard's works on "indirect nutrition", in which nutrition, rightly conceived as a general vital phenomenon common to plants and animals, was both characterized as an instance of the general physico-chemical determinism of all phenomena and as the sign and condition of the "freedom and independence" of the organism with respect to the environment. I propose that Bernard's theory of indirect nutrition was central in the elaboration of his general physiology and has, at the same time, underpinned a self-centered view of biological identity in which the organism creates itself continuously at the detriment of its external *milieu*. I further argue that this conception of biological individuality as metabolically constructed has since, and paradoxically, supported a view in which the organism appears as an autonomous and self-creating entity. I then contrast this classical view of the metabolic autonomy of the organism with the challenges raised by microbiome studies and suggest that these emerging fields contribute to sketch an ecological conception of the organism and its metabolism through the reconceptualization of its relationship with the environment. The recent focus on a "microbiota – host metabolism" axis contributes to shift the focus away from the classical concept of organism, somehow externalizing vitalism out of the autonomous individual in favor of an ecological, collaborative, and interactionist view of the living.

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C. Donohue, C. T. Wolfe (eds.), *Vitalism and Its Legacy in Twentieth Century Life Sciences and Philosophy*, History, Philosophy and Theory of the Life Sciences 29, https://doi.org/10.1007/978-3-031-12604-8_11

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1 Introduction: The Metabolic Roots of Living Beings

A century-long medical-philosophical tradition has associated nutrition, the operation by which organized bodies grow, preserve, and maintain themselves, with life.¹ In contrast to inorganic bodies, whose preservation seems to be merely the persistence of a previous material state, living organisms preserve themselves by undergoing continuous change: it is by the renewal of their substance in a double movement of composition and decomposition that they succeed in maintaining themselves. Organized beings therefore seem to escape the alternative of identity and otherness since, *via* the process of nutrition, it is certainly foreign constituents that penetrate them and renew their matter, but according to specific modalities by which they appropriate an exteriority to constitute it as their own identity. Thus, for a living body, feeding itself does not only mean compensating for the losses suffered by ingesting foreign matter, or circulating flows of matter and energy in its interior, but also and above all transforming this matter into its own. Now, beyond this equation between life and nutrition, how can we picture the relationships between a metabolic-centered approach to life and vitalism – if the latter isn’t to be understood as a mere heuristic initiating inquiries into the nature of the living and its distinctiveness but also in the complexity of its historical manifestations and the diversity of its philosophical commitments?² In other words, if nutrition-metabolism is pictured as an essential organizing force, as the manifestation of life itself or at least as its main distinctive feature, what kind of vitalist claim does this tradition endorse? Conversely, what philosophical effects can we expect from this confrontation between metabolism and forms of vitalism with respect to contemporary developments in biology?

While metabolic processes have long been modeled in a mechanistic fashion as a straightforward function of repair and expansion of a given structure (either chemically, or physically³), a challenging vitalist view, developed in the eighteenth century, that could be labelled “structural-functional”,⁴ has characterized nutrition as a creative and organizing vital faculty.⁵ Nutrition, far from assembling preformed elements in a preexisting structure, could come to designate processes of alterations and syntheses that were both chemical and vital. If life partly consists in the continuous destruction of one’s own material constituents, then it has to be, simultaneously, a continual regeneration of one’s own bodily matter. Nutrition could then refer to a continuous production of the living being by itself (production of

¹ See Aristotle, *De Anima*, II, 4415b–25.

² For precise characterizations of varieties of vitalism both synchronically and diachronically, see Cimino and Duchesneau (1997), Wolfe (2010a), (2017a), (2019), (2021), Normandin and Wolfe (2013).

³ For an analysis of mechanistic conceptions of nutrition, see Bognon-Küss [Forthcoming](#).

⁴ See Duchesneau (2012) [1982], Wolfe (2017b). This “structural–functional” conception involves a theoretical effort to understand the circular causality (vs. linear) between the parts and the whole and the emergentist nature of the organism’s organization.

⁵ See de Bordeu (1752), Kant (2000), C.F. Wolff (1789), Bognon-Küss (2019).

specialized parts – flesh, muscle, tendon, etc. – and production of new qualities – irritability and/or sensitivity) by virtue of a certain relationship to its environment (the continuous exchanges of materials and reciprocal transformations). What gradually emerged in the eighteenth century, is the possibility of thinking of life as an unstable rather than a static equilibrium, in which decomposition is less a price to pay for life than a condition for its realization. In this respect, the instrumental and technical framework in which the organism had been thought of up to the eighteenth century had to be broken down and replaced by a model in which functional integration, solidarity and self-production of the parts refer to a continuous vital dynamic. In other words, the living is defined as a specific productivity: it organizes itself by organizing foreign matter. When it assimilates, an organism produces its own substance, a new composition of its own which is not reducible to the sum of the components that enter into it. This shift in the way nutrition was understood, as a dynamic and creative process of organization, supported the elaboration of a conception of organisms as self-organized and autonomous entities, capable of producing their organization and maintaining their form beyond their continuous material renewal, due to their exchanges with their environment.

My hypothesis is that this tension between mechanistic and vitalist views was overcome in Claude Bernard's works on "indirect nutrition", in which nutrition, rightly conceived as a general vital phenomenon common to plants and animals, was both characterized as an instance of the general physico-chemical determinism of all phenomena and as the very manifestation of "life in its state of nudity", *i.e.* as the unification of organic destruction and creation. I suggest that Bernard's theory of indirect nutrition was central in the elaboration of his general physiology and has, at the same time, underpinned a self-centered view of biological identity in which the organism creates itself continuously at the detriment of its external *milieu*, to the extent that nutrition becomes, in the case of Bernard, the sign and condition of the "freedom and independence" of the organism with respect to its environment (Sect. 2). Nutrition obviously refers to the trivial fact that all living beings depend on other cells and on an environment for their survival, that living beings are therefore relational – to the point that this circulation of the outside into the body could indicate a possible dissolution of the organism into the world ("Man is what he eats" – "Der Mensch ist was er isst" as in Feuerbach's famous pun⁶). However, this intuition has been replaced by a focus on the autonomy and independence of organisms – a vision that "metabolism" as a concept for thinking about the dynamic maintenance of organisms has initially reinforced: nutrition and then metabolism rather indicated the way by which organisms dialectically construct their own boundaries and their own internal *milieu*.

But what happens to this "metabolic self" when it is confronted with recent findings in microbiology, metagenomics, or evolutionary ecology? The progressive recognition of the diversity, ubiquity, and functional capacity of microorganisms⁷ and

⁶ See "The Mystery of Sacrifice, or Man is what He Eats" in Feuerbach (1990) 26–52.

⁷ Wu et al. (2009).

the correlative exponential development of studies on the participation of microbes in the vital functions of complex multicellular organisms⁸ have had deep impacts on our understanding of the biology of plants and animals. They have profoundly challenged our traditional views of the physiology of nutrition, the performance of metabolic functions, and biological individuality itself, as they shifted the focus to the myriad of bacteria that enable organisms to perform these functions essential to their maintenance and survival. Therefore, what microbiome studies⁹ force us to think about is a progressive decentering of a biology focused on autonomous organisms towards a biology of relations,¹⁰ integrating not only microorganisms as independent entities, but also “their theatre of activity”, *i.e.* the host and the environment (biotic and abiotic) understood as ecological components of these relations.¹¹ The last section aims at examining how these research programs have led to profoundly challenge the classical view of the “metabolic self” – this closed, autonomous, individual organism, capable of constituting its identity alone and at the expense of its food – and how they contribute to sketch an ecological conception of the living and its metabolism (Sect. 3).

2 Metabolism, “Freedom and Independence” or the Self-Production of the Organism

Metabolism is classically understood as the continuous transformation of matter and energy captured from the environment in order to, for any living entity, realize and maintain itself as a system. Ruiz-Mirazo and Moreno (2013) for example describe metabolism as a “persistent far from equilibrium dynamics of self-construction and self-repair” and argue that metabolism is constitutive of biological autonomy in a “dialectical way”, to the extent that the autonomy, distinctiveness, and identity of the organism are precisely achieved through its metabolic openness: organisms reconstruct sets of components of their own (proteins, DNA, RNA, membranes...) that are not present in their environment, through processes of interaction, transformation, and synthesis. Through metabolism, living systems fabricate themselves continuously and “this is precisely what it means to be autonomous.” This equation between autonomy, identity and self-production through metabolic processes is the main philosophical problem I wish to address. I will question the kind of philosophical claim that can be associated with this metabolic-centered

⁸ Jones (2013).

⁹ On the term “microbiome” and its history, see in particular Eisen (2015), Prescott (2017), Berg et al. (2020).

¹⁰ See in particular Gilbert et al. (2012), McFall-Ngai et al. (2013), Sélosse (2012), Tipton et al. (2019).

¹¹ Whipps et al. (1988).

view of life, and to what extent this latter grounds a self-centered conception of biological individuality as being autonomous and self-creating.¹²

2.1 *Direct Assimilation and the Alienation of Organic Life*

The concept of “metabolism” has gradually stabilized as a set of mechanisms linking the vital specificity of organisms to their chemical conditions of existence, and as a scheme through which self-production and the maintenance of biological identity could be apprehended in a naturalistic perspective. What is at stake in the constitution of the concept of metabolism in the second half of the nineteenth century is the establishment of a certain autonomy, independence or freedom of the organism in relation to its environment through the identification of the mechanisms that allow the organism to carry out syntheses. While post-Lavoisieran chemistry thought of animal nutrition as the absorption of preformed immediate chemical principles from digestion, any histochemical element of the animal body having its origin in the food ingested (fat gives fat, muscle substance gives muscle), in a theory of nutrition that can be called “direct assimilation”, metabolism conceives of the organism’s independence from food through the elucidation of its capacity to manufacture complex organic substances (without necessarily finding them preformed in the food). The theory of “direct assimilation” indeed relies on the general hypothesis that physiological processes are caused by a change in the proportion of the elements contained in the substances of the organism, and by a continuous exchange between the interior and the exterior.¹³ From this point on, physiological functions can be conceived as the maintenance of an equilibrium between the proportions of the elements that make up the animal substance: albumin, fibrin, muscle, and gelatin. This leads to the conclusion of the chemical distinction between the two kingdoms of animals and plants: plants synthesize chemical substances (nitrogen) that will after be consumed by animals.

The chemical operations carried out by animals and plants therefore appear as reversed processes: while plants are a laboratory of organic synthesis, animals carry out the analysis of their products, by extracting the nitrogen contained in the plants they consume. Animal nutrition is therefore no more than the absorption of a matter already chemically identical to that of the organism that assimilates it. A conception of nutrition is then established, certainly chemical, but which can be apprehended with two pairs of concepts: on the one hand, static *vs.* dynamic, on the other hand, preformation *vs.* epigenesis.

“Chemical statics” is the name Dumas and Boussingault gave to their approach to organized beings in 1842, centered on the preeminent role of combustion in

¹²For an in-depth analysis of the ontological implications of the concept of organism, see Wolfe (2010b).

¹³See for example Berthollet (1784, 120–125); Cuvier (1810, 99); Holmes (1974).

animal physiology. It is noteworthy that this view of combustion in animals, and thus of the animal-plant complementarity, is not based on direct evidence of the processes, but proceeds from a general understanding of the elementary compositions and chemical properties of the three basic categories of organic substances: carbohydrates, fats, and nitrogenous albuminoid bodies. In these lessons, they argue that if in animals “new organic matters can be born”, these are nonetheless “always simpler matters, closer to the elementary state than those which they received” from the plants. Animals merely undo (assimilate, absorb, analyze) the organic materials formed by the plants,¹⁴ hence this lapidary chemical qualification of the animal: “animals constitute from the chemical point of view real combustion apparatuses”.¹⁵

Consequently, the histochemical elements that make up the animal substance must be a simple aggregate of ingested nutrients, whose immediate principles are selected and separated during digestion. In the end, what does the animal that feeds itself do? It separates these chemical principles according to a chemical reaction that is similar to the one theorized by Lavoisier when he studied combustion *in vitro*. The place of this reaction for these authors is the blood, rather than the tissues – simple receptacles of the principles extracted by digestion. The blood is then conceived as a liquid resulting from the dissolution of the elements that make up the nutrients and which then come to aggregate in the organism. As Claude Bernard summarizes it, in this theory “every histochemical element of the animal body had to have its origin in the food ingested”: the organism is in the end, and in a very literal sense, only what it eats, that is, on the chemical level, an aggregate of “immediate preformed principles of food or digestion.”¹⁶ Ultimately, animal nutrition, chemically conceived, turns out to be “preformationist”: the forms are no longer individual organic forms, but the chemical elements that the animal receives ready-made, and that it cannot produce. One thus understands the theoretical solidarity between the chemical *statics*, the renewed *preformationist* conception of the nutrition and finally, the *complementarity* between chemical passivity of the animals and chemical activity of the plants: “(...) it is in the vegetable kingdom that the great laboratory of organic life resides; it is there that vegetable and animal matter are formed (...), from the plants, these matters pass all formed into the herbivorous animals”.¹⁷

A strong contradiction thus emerges between the philosophical role given to nutrition at the turn of the nineteenth century and this theory of nutrition as direct assimilation. This contradiction has the spectacular effect of alienating organic life from itself, of dissociating its operations on the grounds of a chemical division of nature: the chemical complementarity of analysis and synthesis, of destruction and creation, of decomposition and composition, no longer refers to the phases of a

¹⁴Dumas et Boussingault (1842, 46).

¹⁵*Ibid.*, 4.

¹⁶Bernard (1878, t. II, 382).

¹⁷Dumas et Boussingault (1842, 6).

single process taking place within the living being, but to operations distributed in nature to agents that a wise economy will have cunningly arranged. This massive discrepancy with the physiological elaboration which, at the same time, tries to think the coexistence of composition and decomposition processes in organic life, seemed to be a major obstacle for the elaboration of a general physiology.¹⁸ If post-Lavoisierian chemistry thinks of the animal as the site of a continuous self-combustion, this no longer refers to an inner conflict or to the necessary complementarity of contradictory processes, but to a harmonious distribution of chemical work in nature. The chemical conflict is externalized as organic life dissociates from itself and as animal organization resolves itself in that of the vegetable.

2.2 *Indirect Nutrition as a Means for the “Freedom and Independence” of the Organism*

We can therefore measure the distance that separates such a model from that of metabolism, the prodromes of which can be found in the development of a theory of indirect nutrition in Claude Bernard’s general physiology. What Bernard points out, with the complementarity of chemical destruction and creation in physiology, is the solidarity of what will later be called anabole and catabole, *i.e.* the times of a cyclic processuality that will be named “metabolism” as the articulation of these two moments. The problem solved by this double chemical movement is, in a way, as old as the recognition of the originality of living beings: the unity of order and continuity with constant change.

Nutrition is no longer the simple ingestion and analysis of elements already formed, so that we would find at the end by analysis what we put in at the beginning: it is indirect in the sense that the organism’s own activity interposes itself between ingestion and the final product to create a material specifically appropriate to the conditions and needs in which the organism finds itself. The experiment with the washed liver (Bernard 1855) allowed Bernard to show that an intermediate material (glycogen), secreted and stored in the liver, could produce glucose under certain circumstances. Thus nutrition, insofar as it is indirect, is a sign of this internal environment, the *milieu intérieur* that the organism secretes itself, for itself. It is true that the internal environment is a set of liquids, blood, lymph, etc., in which the cells are immersed and which in a way buffer the variations of the environment so that the cells remain within low ranges of value of their environmental parameters. The relationship of the interior of the organism with the environment is therefore indirect, and this clearly becomes thinkable from the moment when a physiological function so obviously oriented towards the exterior, *i.e.* nutrition, turns out to be in

¹⁸Bichat for example thought of the characteristics of organic life, common to both plants and animals, as the duality of a process continually engaging opposing forces (1800, §1).

reality indirect. More profoundly, this means that the internal constitution of the organism is not so much given by the ingestion of external elements then distributed in the organism, as by the creation, from external simulations such as food, of stocks of tissue or liquid substances from which the organism then draws the elements it needs.

The very notion of glycogen illustrates this idea that the organism is no longer dependent on the vagaries and fluctuations of glucose supply – the organism is not “at the mercy of the slightest whims and narrow necessities of food. The truth is that it is independent of it to a very large extent, and that the living machine still possesses here a kind of chemical elasticity that is its safeguard”.¹⁹ On the contrary, it creates a continuous supply and a stable source of glucose from its own internal processes. Consequently, one must conceive the inner environment not only as a set of liquids but even before that as the effect of a process of continuous constitution of this environment via chemical processes that somehow decouple the organismic inner chemical dynamics, at all levels, from the dynamics of external environment/organism relationship. If the organism includes an interior environment which buffers it with regard to the external variations, it is because it has in it processes likely to create this interior environment on the basis of the external circumstances, and the indirect nutrition is primarily one of these mechanisms.

The corollary of this conception of the internal environment directly affects the teleological conception of nature that was presupposed by the advocates of direct nutrition. To put it in a few words, if there is a teleology of life – in the deterministic framework that Claude Bernard subscribes to – it must be folded inside the organism itself, in terms that are reminiscent of Kantian teleology and its insistence on “internal purpose”. The organism is not in view of anything other than itself, it is, in a way, totally in view of itself, and it is the existence of the internal environment that proves it: “the living organism is made for itself; it has its own intrinsic laws. It works for itself and not for others.”²⁰

In this conception of nutrition decoupled from digestion, food disappears (“In a word, one does not live on one’s actual food, but on that which one has eaten previously, modified and, as it were, created by assimilation”²¹) to the benefit of the vital operations that allow the organism to produce its own substance, its own *milieu*, and finally its independence with regard to the external environment: “(...) the perpetual changes of the cosmic environment do not affect it; it is not chained to them, it is free and independent”.²² Nutrition is therefore an authentic organic creation, “and in this respect, everything is created in the living organism, and nothing comes to it from outside”.²³ The organotrophic or nutritive phenomena are therefore the physico-chemical conditions by which the “nutritive center” (*i.e.*, the nucleus of the

¹⁹Bernard (1878, II, 382).

²⁰Bernard (1878, I, 148).

²¹Bernard (1878, I, 122).

²²Bernard (1878, I, 113).

²³Bernard (1867, 92).

cell) “creates the organism” under appropriate conditions.²⁴ Indirect nutrition thus points towards two constants: a series of conversions in which the identity of the organism is dialectically constructed at the end of chemical elaborations (composition and decomposition, assimilation and de-assimilation); the persistence of this identity through time despite the constant molecular renewal to which the organism is subjected – the organism remains itself by virtue of the constitution of this internal environment through the mechanisms of its internal secretions. In a note of the *Cahiers* edited by Mirko Grmek, Bernard castigated the chemical statics of living beings, the *Stoffwechsel* of the Germans, because for him it was “nothing other than metempsychosis. This is not correct (...) Individualism is the master of physiology. It is found even in digestion, and everywhere”.²⁵ In this somehow enigmatic note, Bernard probably means that the chemical statics, which we have seen serves as the chemical basis for a theory of direct assimilation, *i.e.*, the unimpaired passage of food into another body, is no more than a palingenesis of souls. On the contrary, nutrition, as a creative and organizing force is at the same time the cellular basis of organic individuality and the means through which the autonomy and individuality of the total organism is built.

Independence and freedom thus become the pivots around which a metabolic conception of the organism is developed, and this conception refers to a double dialectic: (1) a dialectical relation to food, since assimilation is conceived as a negation of the otherness it represents; (2) a dialectical relation to the environment, since the constitution of the organism’s interiority and autonomy is achieved by this metabolic openness to the environment. What is at stake in this opposition between theories of direct and indirect nutrition, is the elaboration of a concept and a process supporting the vision of a living body that is autonomous and identical to itself over time. The constitution of this biological problem thus deploys, within the concept of organism, a new dimension of autonomy: it is by virtue of its constant exchanges with its environment that the living body can acquire a certain autonomy and individuality with respect to it.

In “The whole and the part in biological thought” Canguilhem wrote that “it would be wrong to say that Claude Bernard ignored the romantic prestige of the concept of organism, at the very moment when he was developing experimental techniques and clarifying the ideas that allowed him to break, in the field of biology, the logical circle of the whole and the part.”²⁶ Among these ideas, I would like to add, was first and foremost the concept of metabolism: the very concept of metabolism by which organic life was reconciled with itself in the uniformity of its processes, and within which the biological individual could maintain its autonomy from cosmic conditions in spite of and by virtue of the exchanges it has with its environment, and in fact create himself. And although one should be aware of Bernard’s distrust of realistic of substantial forms of vitalism, I have nevertheless

²⁴ *Ibid.*, n°218, 228.

²⁵ Bernard (1965).

²⁶ Canguilhem (1968, 327–328).

sought to show that, through the elaboration of the theory of indirect nutrition, Bernard's general physiology had at the same time sketched out the contours of a concept of organism.

2.3 *The Dialectical Autonomy of the “Metabolic Self”*

This preliminary conceptualization of metabolism provided a framework for thinking about the notion of biological identity, outlining a vision of organisms as self-organizing, autonomous entities by virtue of their relationship to the environment. This elaboration can in fact be understood philosophically within the framework of dialectics, and in particular the Hegelian dialectics, which is known to have taken a close interest in the mechanisms of assimilation in order to think about the self-determination and autonomy of living beings: “The essential point here is the process of nutrition. (...) The process of nutrition is nothing other than this transformation of the inorganic nature into that organic nature which belongs to the subject.”, writes Hegel.²⁷

By feeding itself the animal turns to the outside world and introduces an external substance into itself – this is the moment of externality. Then the organism must overcome, or digest, this externality. Hence, through assimilation the animal returns to itself, and produces its own substance: it transforms the inorganic into its own organic nature. Although food is already chemically organized, it nonetheless represents the inorganic substance for the animal organism that aims at overcoming this alterity. Interestingly, Hegel refers to Spallanzani's experiments on digestion (Spallanzani 1783) to support his theory: the dialectical nature of nutrition is established by physiological experiments that show that nutrition is not a direct and passive process, but a process in which the organism is engaged in a series of chemical transformations which express the realization of its own essence. Through digestion and assimilation, the organism aims at realizing its own identity. In nutrition the organism does not lose its distinctiveness, nor does it dissolve into the world, but it rather imposes its own determination on what it eats.

This philosophical model, by which metabolic identity is thought of as dialectical, has been quite robust. Hans Jonas, for example, has devoted this understanding of metabolism to the constitution of an interiority, autonomy, and self-identity of the organism. In his 1966 book, the *Phenomenon of Life*, Jonas holds that it is in the dialectical relationship that organisms establish with their environment through metabolism that they realize their identity: “The exchange of matter with the environment is not a peripheral activity carried out by a persistent nucleus: it is the mode

²⁷ Hegel (2004), addition to §365.

of total continuity (self-continuation) of the subject of life itself”.²⁸ In this sense, the organism must be understood as the result of its constant metabolizing activity, and this activity – this capacity of building up its parts by the mediation of external matter – is precisely “its being self-centered individuality”. Not only does metabolism emancipate the form of the organism from its immediate identity with matter but it also elaborates a genuine, *i.e.* organic, “mediate and functional kind of identity”.

More recently, philosophers who, following Varela’s work (Varela 1979; Maturana and Varela 1982), favor metabolism in the characterization of life as an auto-poietic system, similarly insist on the dialectical character of the autonomy of organisms: while metabolism refers to processes of continuous transformations of matter and energy taken from the environment, it is precisely in this metabolic openness to the environment that organisms realize their autonomy and identity as they construct from them components that are their own as well as the organizational closure without which the system could not subsist as such (Moreno and Mossio 2015). In the formal perspective of self-organization, living beings are autonomous biological systems whose identity is described as a “circular process of reflexive interconnection, whose main effect is its own production” (Varela 1997). The metabolic relationship to the environment has the effect of this organizational closure, which is understood as circular causality (since there is a feedback loop between the boundaries of the organism, or the cell membrane, and the metabolic circuit). In this model, the coherence and sustenance of the system are therefore the direct effects of the activity of the system as such, and not those of the action of the environment (in the sense that no internal change in the system can be induced by a direct action of the environment). The auto-poietic system is certainly not a unit isolated from its environment by a protective closure, since the condition for the realization of its autonomy lies precisely in the metabolic interactions it is likely to establish with its environment. But precisely, the environment seems to be characterized as a moment in the dialectical realization of an identity: this relationship of metabolic openness to the environment is a question of constructing the delimitation or the closure that ensures the autonomy and individuality of living organisms.

How can this conception of the “metabolic self,” which I have described as self-centered, be reconciled with the reconceptualization of metabolism to which recent discoveries in biology on the role of heterospecific entities²⁹ oblige us?

²⁸ Jonas (1966, 76).

²⁹ Here I refer to cooperative associations of *heterospecific individuals*, namely collectives of biological entities of distinct species (*i.e.* with distinct genealogical, evolutionary histories) that live in close association with one another and are supposed to behave evolutionarily and physiologically as one individual, at one given timescale. For detailed discussions see for example Wilson and Sober (1989), Ereshefsky and Pedroso (2015), Pradeu (2016).

3 Metabolism, Identity, and Microbiome Studies: Challenges from the Ecological View of Life

Biological identity is often held to be circumscribed by three major sets of properties, namely an adaptive immune system discriminating between self and non-self, a genome conditioning unique phenotypic traits, and, among animals that have a central nervous system, brain functions that support personality and cognition.³⁰ One hypothesis I have defended so far is that the concept of metabolism has underpinned, in the historical complexity of its development, a strong conception of biological identity as self-determined and autonomous.³¹

Making sense of the concept of identity means two things: explaining how x is identical in the sense that it is x and not y and can therefore be consequently distinguished from any y ; and explaining how x is capable of being identified as x in different contexts and time intervals - in particular, how x can last as x .³² I will call the first question “distinction” (Id), and the second “persistence” (Ip). In relation to biological identity, the question of “distinction” has often been framed around the general concept of information and has focused in recent decades on narratives that foreground genes and genomes; whereas the question of “persistence” traditionally mobilizes the concept of metabolism, as it encompasses the processes by which individual organisms maintain their identity over time. The question of “persistence”, *i.e.* the maintenance of identity over time, is often framed either in terms of multi-level selection processes (how a collective of cells is protected from selfish mutants, for example³³), or in terms of self-organization, involving studies of metabolism at all levels.³⁴

However, it can be argued that metabolism intimately links these two issues of identity, namely distinction (Id) and persistence (Ip). I underscored that the concept of metabolism emerged in the mid-nineteenth century in opposition to a conception of identity maintenance as direct assimilation. The emergence of this concept of metabolism has thus provided biology with a conception of organisms as autonomous individuals (Id), capable of self-organization and maintenance (Ip) in a wide variety of contexts.

³⁰ See for example Rees et al. (2018), and for a critique Park et al. (2018).

³¹ Note that other metabolic views of physiological individuality have been defended from a a-historical perspective: see Dupré and O'Malley (2009), Gilbert et al. (2012), Godfrey-Smith (2013), Roughgarden et al. (2017).

³² Snowdon (1995), Wiggins (2001).

³³ Michod (1999).

³⁴ Moreno and Mossio (2015).

3.1 Challenges

However, the metabolism around which this conception of identity has been reinforced is now contributing to redraw its boundaries. Indeed, if metabolism underpinned a conceptual figure where the identity of the living being could be grasped and expressed as emerging from the chemical world and the environment, new advances in biology in the field of microbiology and evolutionary biology of symbioses call into question this figure which seemed to equate identity, autonomy and closure.³⁵ For several decades now, we have been measuring the extent to which symbiotic bacteria and organisms are intertwined. Various functions in animals and plants are carried out by symbionts or mutualists of different species: termites use bacteria to digest cellulose,³⁶ healing processes in mammals are due to symbionts, the origin of the placenta in mammals is most probably due to a symbiosis with a virus³⁷, and in vertebrate physiology, lipid metabolism, xenobiotic detoxification, vitamin synthesis and intestinal permeability are all functions performed by bacteria.³⁸ And microbes themselves are now considered as heterogeneous entities: bacteria and archaea contain many viruses (bacteriophages), some of which seem to contribute to their functioning. As far as genetic identity is concerned, this means that the genome of an organism, although essential to its life, is not only the genome of the host. The notion of “metagenome” emerged in the early 1990s³⁹ from the development of computational methods to better understand the genetic composition, activities, and reciprocal interactions of these complex communities, therefore transcending the level of the individual organism. Although the role of the microbiota in physiology and development is widely recognized, there is still no consensus on the impact it should have on our conceptions of biological identity (Id and Ip).⁴⁰

The recognition of the extent of the intertwining of symbiotic bacteria and hosts has thus led to theoretical and semantic innovations: some redefine the microbiota, in a move that contributes at the same time to redefine the very notions of inside and outside of organisms, as a genuine organ of the body, constituted by a collectivity of heterogeneous organisms⁴¹; others argue, under the concept of the holobiont,⁴² that

³⁵ Here I focus on symbiotic associations understood as the cooperative associations of *heterospecific individuals*, see supra, n.33. In this restricted definition, symbiosis is characterized as a subclass of mutualisms, West et al. (2007), and not as a more general type of close and long-termed relation between heterospecific individuals, be it mutualistic, commensalistic or parasitic.

³⁶ Breznak & Brune (1994).

³⁷ Mallet et al. (2004).

³⁸ Nicholson et al. (2012).

³⁹ Handelsman et al. (1998).

⁴⁰ Bordenstein and Theis (2015) vs Moran and Sloan (2015), Douglas and Werren (2016), Rees et al. (2018).

⁴¹ O’Hara and Shanahan (2006).

⁴² Zilber-Rosenberg and Rosenberg (2008).

the “true” biological individual is the host-symbiont unit, which is supposed to be a unit of evolutionary processes and physiological functioning, and not the classical concept of organism. Some philosophers have suggested that biological identity requires conceptual clarification in light of these developments⁴³ or that the concept of individual should be abandoned⁴⁴. I propose that what is at stake in this tension between a metabolic conception of physiological identity and the reconfiguration of the relations between the inside and the outside, unity and plurality, identity and otherness is less the abandonment of the notions of identity or individuality than the way in which this contemporary crisis of metabolism forces us to deploy new strategies for thinking about these concepts. Indeed, it is more a certain strong conception of biological identity as self-determined and autonomous, a conception that has been solidified around the concept of metabolism, that is now in crisis.

Rearranging such a conception in the light of contemporary work does not mean having to give up defining biological identity in this context. If we are willing to admit that nutrition and metabolism allow us to think precisely through these paradoxes (identity in change, autonomy through openness, and these points of passage between the exterior and the interior, the inert and the animate, the other and the same) then they undoubtedly conceal conceptual resources that the history of the stabilization of the concept of metabolism – as a dialectical scheme for thinking about the autonomy of organisms – will have covered up. It is therefore less a question of undertaking a radical critique of the concept of metabolism than of redefining it in the light of these new developments in microbiology, a redefinition that could also be conceived as a reactivation of abandoned or forgotten scientific avenues, and which should in turn contribute to drawing up a renewed conception of biological identity.

3.2 Conceptual Issues: Biology of Organisms and Metaphysics of Identity

These new challenges contribute to questioning the boundaries and the very relevance of the concept of organism and its traditional equation with the idea of biological individuality: first by making the organism the unification of a plurality of heterogeneous entities; second by focusing attention on the networks of interactions between species rather than on discrete and isolated entities. The crisis of the concept of metabolism thus becomes a crisis of the concept of biological identity. The upheavals that I try to think about are therefore both internal mutations in contemporary biology and the impact of these mutations on metaphysical conceptions of biological identity and individuality.

⁴³Hutter et al. (2015).

⁴⁴Gilbert et al. (2012).

In terms of biology, I assume that the shift from an evolutionary biology of competition between organisms to an evolutionary biology of symbiosis⁴⁵ finds its metabolic translation here in the gradual shift from an egocentric conception of appropriation to a vision centered on cooperation and the persistence of otherness. It is clear that this twofold evolutionary and metabolic shift towards plurality and interaction networks in turn disrupts the way in which we compartmentalize the entities that make up the living world. While biology has historically been built around the notion of organism and this traditionally refers to the idea of an autonomous individual with clearly discernible boundaries, it has become clear that the isolated organism is incapable of functioning properly independently. Recent work in plant physiology has shown, for example, that the metabolic, immune, and developmental functions of plants can only be achieved through their membership of a vast network of mycorrhizal fungi.⁴⁶ Although nutrition initially referred to the obvious fact that all living organisms depend on other cells and an environment for their survival, and that living organisms are therefore relational, this intuition was replaced by a focus on the autonomy and independence of organisms – a view that metabolism as a concept for thinking about the dynamic maintenance of organisms initially reinforced. What these different works force us to think about is, on the contrary, this progressive decentering of a biology of organisms towards a biology of networks: in a biological world made up of interactions, can we still identify discrete and autonomous units? Can a multiplicity of bacterial species united around a metabolic function (*e.g.* nitrogen fixation with functional relays between different bacterial species) be characterized as a biological individual? Finally, it is our capacity to identify collective entities as functional and evolutionary individuals that is being questioned here (Bouchard and Huneman 2013).

On the metaphysical level, such a complexification of the picture of life clashes with the concepts with which we traditionally describe the objects that make up the living world. Thus, the concept of individual envelops three dimensions, epistemic and ontological: it is both that which is indivisible, *i.e.* that which remains at the end of processes of logical division (classically in Aristotle), referring correlatively to the properties that make such an individual distinct from any other,⁴⁷ and that which is re-identifiable as the same individual at different moments in time, *i.e.* that which persists or is identical to itself over time.⁴⁸ While biology seems to provide paradigmatic cases of individuality - as Aristotle does in the *Categories* (2a 10–13) in relation to the definition of substance Aristotle 1963 - since “such a man, such a horse” persist in time, can be re-identified as the same man or the same horse at different intervals of time, and are indivisible in the sense that their division would not result in two distinct men or horses, it is at the same time obvious that this intuition is

⁴⁵Doolittle and Baptiste (2007), Sapp (2009), Sélosse (2012), Tripp et al. (2017), Baptiste and Huneman (2018).

⁴⁶Sélosse and al. (2006), Roy and Sélosse (2015).

⁴⁷Lowe (2001).

⁴⁸Strawson (1959).

contradicted by many biological facts, in both aspects of spatial indivisibility and temporal continuity. For example, the discovery of the phenomena of organic reintegration in the eighteenth century, such as the regeneration of freshwater polyps after a longitudinal cut (Trembley), shows that two functional individuals can emerge from the division of an initial individual. Similarly, the idea of temporal continuity clashes with both the constant molecular renewal to which living beings are subject and the existence of holometabolous organisms, *i.e.*, organisms whose development is characterized by a complete metamorphosis of states, such as lepidoptera, beetles, etc. Finally, this common preconception of the indivisibility of biological individuals classically encounters the question of compositionality and levels of hierarchy within living organisms.

This question, which is not new, can be considered as constitutive of the elaboration of the concept of organism, which classically integrates a reflection on the articulation between structures (organs, apparatuses, systems) and functions, with a reflection on hierarchically integrated levels of organization (genes, cells, organs). However, such a question has a new dimension today, since the upheavals I have mentioned - in the field of the evolutionary biology of symbioses, microbiology, or metabolic physiology - no longer only concern the mereological relations between the whole and its parts, unity, and plurality. These works shift the attention of biologists to the nature of dynamic and emergent interactions between a host and hetero-specific entities, without which homeostasis, development or immunity are not possible. To confront these questions is therefore to question the relevance of the metaphysical concept of the individual for contemporary biology, or to elaborate the conditions that would be required for such a concept to be consistent.

These questions about the relevance of a concept of individual for biology are based, as one can see, on a metaphysics of identity, in such a way that it seems difficult to disentangle what, for the living, is identity and what is individuality. Indeed, as has been pointed out, the criteria for attributing individuality are indexed to both distinction (synchronic identity) and persistence (diachronic identity) and therefore imply agreement on a metaphysical concept of biological identity. However, in both respects, the focus on metabolism and the undermining of the biological topics described above pose a challenge to classical metaphysical conceptions of identity. Whether they are metaphysics of substance (what is identical is what remains under change, *i.e.*, substance being understood as an ontologically independent discrete entity, and persistent subject of changes in accidental properties⁴⁹) or of resemblance (x is the same if x resembles itself at two intervals of time), these ontologies are centered on what does not change, change being always derivative, secondary.

The consideration of metabolic processes, on the other hand, obliges us to think about the centrality of change for the living being at all levels, and therefore to elaborate an ontology that allows us to give an adequate account of biological identity, *i.e.*, in a way that is consistent with what science describes. One of the theoretical challenges for today's philosophy is to contribute to the development of a

⁴⁹Robinson (2004).

concept of identity in which change and relationships are central, without being subsumed by an autonomous assimilative center.

Symmetrically, the way in which we classically conceive of biological identity along the two axes of distinction and persistence is strongly undermined here. While the distinction of an individual is supposed to be ensured by the form, it is generally held that persistence is achieved by the continuous renewal of the matter that composes it. This dichotomy between matter and form can be called “hylomorphism”, in a very general sense that goes beyond the content that Aristotle gave to this concept. The way in which this conception was inscribed in twentieth century biology and which refers to the hierarchical distinction between reproduction and metabolism - that is to say, a genome conferring on living beings their distinction, *i.e.*, their form, and a metabolism ensuring the continuous material production of this form - contributed to reinforcing a vision of living beings that is both ‘genomecentric’ and metabolically egocentric. From this point of view, the classical question of the priority of the genetic or the metabolic, of form or matter, of distinction or persistence, in the scenarios of appearance and history of living forms is in a way already inscribed in the structure of the concepts since it presupposes their strict separation. This question ceases to be relevant as soon as the dichotomy between matter and form is blurred by the new ways of defining the concepts of organism and biological identity that this crisis of the concept of metabolism opens up.

3.3 *Ecologizing Biology*

The investigation of these metaphysical questions needs to rely on a paradigm shift in physiology, *i.e.* the ecologization of its focal concepts. In light of the indispensability of the microbiota for the development, functioning and maintenance of organisms, should the microbiota be considered as an organ⁵⁰? If so, should the very notion of organ be redefined to include the contribution of heterospecific and adaptive elements during the life of the organism in its functional dimension? Can the organism itself, as a community of species, then become the object of an ecological type of analysis⁵¹?

Is the concept of holobiont relevant for thinking about this integration between the host and the set of micro-organisms it harbors? and if so, how should it be defined? The holobiont concept, *i.e.*, the set of hosts and microbes designated as an interdependent and co-evolving unit, has been proposed as an alternative to traditional conceptions of the organism as an isolated and autonomous biological individuality.⁵² But such a conception of the living organism is not without questions: does the whole constituted by the host and the micro-organisms constitute a

⁵⁰ Baquero and Nombela (2012).

⁵¹ Costello et al. (2012).

⁵² Zilber-Rosenberg I., Rosenberg E. (2008).

functioning unit for physiology? Whether the holobiont is a unit of selection or not, as evolutionary theorists debate, one must ask what kind of integration between these different organisms would be required for the holobiont to be characterized as a functioning unit. The focus on the metabolic processes carried out by the interaction patterns between host and microbes leads to question the robustness of a conception of identity built on the collaboration between discrete entities. Therefore, some even propose to go beyond the holobiont concept in that it conceptualizes interactions between species from autonomous and separate entities and enshrines boundaries to the detriment of considering networks.⁵³

From this perspective, it is the processes themselves, rather than the individuals who carry them out, that seem robust.⁵⁴ Indeed, although there is great diversity of species and strains in the bacterial taxonomic groups present in the gut microbiota, the essential functions performed by these organisms remain remarkably stable.⁵⁵ Bacteria of different species participate in metabolic cycles, converting nutrients into metabolites that are used by other bacteria to produce other metabolites, which in turn are used by the host. These functional steps can be carried out by a multiplicity of strains present in the gut, so that these cycles can continue regardless of the identity of the organisms carrying them out. This contrast between the stability of metabolic processes and the diversity of the actors that carry them out in some way doubles the complexity of organisms. The compositionality of living organisms cannot be thought of in the mode of a swarm of bees since, in such a model, already appreciated by eighteenth-century vitalists, the discrete entities that make up the whole are identical to each other, just as the multiple bees are genetically equal. Conversely, the holobiont model requires us to think not only of the heterogeneity of the parts, but also of their lack of stability in the execution of metabolic processes. As Falkowski et al. express it: “in essence microbes can be viewed as vessels that ferry metabolic machines through strong environmental perturbations into vast stretches of relatively mundane geological landscapes. The individual taxonomic units evolve and go extinct, yet the core machines survive surprisingly unperturbed.”

To acknowledge the functional inclusion of heterospecific entities in any organism, to conceive their irreducible relevance for its physiological functioning, to integrate ecological concepts of interaction to analyze the very dynamics of the organism and to redefine its health: if these research directions prove robust and consistent, they prompt the substitution of the metaphor of the bee swarm classically used to represent the organism (the parts all serving the whole, the division of labor between food and reproduction instantiated by castes...) with a metaphor of the organism as an ecosystem.⁵⁶ Yet, to what extent is this simply a metaphor? Is there an ontological significance to the assimilation of the organism to an ecosystem of individuals of

⁵³ Simon et al. (2019).

⁵⁴ Doolittle and Zhaxybayeva (2010), Falkowski et al. (2008).

⁵⁵ Doolittle and Booth (2017).

⁵⁶ Van Baalen and Huneman (2014).

different species in mutualistic, predatory and competitive relationships? If the trend in classical community ecology initiated by Clements (1916) and often labeled organicism, has been criticized for its overly metaphorical assimilation of ecosystems or ecological communities to organisms with metabolism, do not contemporary approaches to the organism evoked in this project allow us, on the contrary, to think of organisms as ecosystems, seeing this “like” less as an analogy than as an ontological identity? If there is to be a scientific metaphysics of the organism and its identity, it cannot do without questioning the metaphorical character of the organism/ecosystem analogy that we see unfolding today in physiology, evolutionary biology or even cellular biology (Scadden 2014 speaks of the “cell niche”).

4 Conclusion

If we were to map the stakes of a philosophical reflection on biological identity informed by a genealogical study of the constitution of the concept of metabolism in which this problem crystallized for general physiology and therefore post-Bernardian biology, we would have to distinguish what we would call the traditional self-centered vision of identity, where identity is based on metabolism as a process justifying a constitutive homogeneity of the organism while integrating foreign substances. There are, of course, theoretically varieties of this egocentric vision, depending on whether they focus on thermodynamics, organic chemistry or kinetic chemistry as frameworks for formulating the requirements required by any metabolism, and whether they focus on integration into the body or cell self-maintenance, as key objectives of the metabolic process.

To this self-centered view, we would oppose an alternative, relational view in which identity is the result of the cooperation and conflict of organisms of different species that compose an organism – what the concept of holobiont tries to grasp. Such a vision would integrate the theoretical contribution of the evolutionary biology of symbioses or the metagenomics of cellular activity, but I argue it would struggle to accurately reflect the limits of identity, namely the distinctions between all those microbes, viruses that contribute to the identity of a given living organism. It contradicts the traditional equation between metabolism and biological identity, but at the same time requires a renewed understanding of metabolism.

To what extent does each aspect of the self-centered view prevent the development of processes in which heterogeneous elements – organisms of other species, such as bacteria or fungi – perform or contribute to a vital function? In particular, which aspects of the complex meanings of the concept of metabolism are most problematic in integrating the role played by heterogeneous elements into an inclusive account of biological identity? These are the questions that would probably emerge from taking into account this new frontier of the metabolic concept that is being built today by the renewed knowledge of heterospecific contributions to the biological construction of identity, or by the ecological turn in physiology.

What then becomes of the question of the relations between metabolism and vitalism with which I opened this chapter? In other words, what does this movement of the concept of metabolism, from the elaboration of the self-centered individual to the consideration of networks of interaction, do to vitalism as such? While vitalism traditionally served as a foil for both biology and philosophy, being attached to metaphysical and nondeterministic claims, *i.e.* the hypothesis of nonmaterial forces governing the generation, development and vital functions in living beings, I recalled that vitalism should be understood in the diversity of its historical manifestations and philosophical presuppositions. Minimally, vitalism can be depicted as the commitment to the existence of irreducible vital properties or dispositions, a commitment that seems to have constantly been challenged – and threatened – by the possibility to reduce biological processes to a set of physico-chemical reactions. To Foucault⁵⁷ vitalism plays “an essential role as an indicator in the history of biology”: an indicator of problems to be solved (what constitutes the originality of life without constituting an independent empire in nature?), an indicator of reductions to be avoided (emphasizing the pervasiveness and necessity of concepts of preservation, regulation, adaptation). Interestingly, in the space of these complex relations between the biological and the inorganic, it appeared that the understanding of nutrition as an indirect process of self-organization had, at the same time, contributed to sketch the contours of the concept of organism. With this crisis of metabolism that I have briefly outlined, however, it is not so much the physico-chemical reductions that seem to threaten the integrity of the self-centered individual, than its openness, the dissolution of its boundaries, or its decentering. What is being questioned then in this interplay between vitalism and metabolism is no more the dualism between the organic and the inorganic, but rather the reassuring dualism between the organism and the environment, the very existence of an autonomous and self-creating “milieu intérieur” that delimited the boundaries and independence of the organism from its environment. To this extent, this progressive decentering and complexification of metabolism is at the same time a call to overcome a dialectical conception of the interactions between organisms and their environment and an appeal to externalize vitalism.

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⁵⁷“Introduction” to *The Normal and the Pathological*, Canguilhem (1991, 18).

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