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Matching concepts and phenomena: A review of *Biological Autonomy*

Alvaro Moreno and Matteo Mossio, *Biological autonomy: A philosophical and theoretical enquiry*. Dordrecht: Springer (2015), xxxiv + 221 pp., \$129.00 hbk, ISBN 978-94-017-9836-5

Fred Keijzer

Abstract

This paper discusses Moreno and Mossio's book *Biological autonomy: A philosophical and theoretical enquiry*. The book provides an up to date overview of the authors' work within the organizational approach to mind and life, which is linked to the work of Maturana and Varela but which is here developed in new ways and with a strong focus on the autonomy of living systems. After an overview of the book, the paper focuses on the choice of the guiding concepts for this enterprise – autonomy, agency, organism and cognition – and discusses whether these notions are still up to the task of formulating the key issues to be targeted by the organizational approach.

Moreno and Mossio wrote a wonderful, state of the art synthesis of ongoing work within the organizational approach to understanding life and cognition.¹ Their book brings together a wide variety of topics and discussions within this tradition that opposes reductive mechanistic and strongly gene-centered interpretations of living organizations. The label they choose for this purpose is '*biological autonomy*' reflecting the capacity of living organizations to maintain themselves over time as autonomous entities that resist a broad variety of external and internal perturbations that disrupt and destroy nonliving physical organizations. Biological autonomy is here not only applied to describe what characterizes life, but also extended to deal with notions like agency and cognition, which are placed within the context of living organizations. In this review, I will first provide an overview of the book and subsequently develop some critical remarks concerning the use and influence of certain central concepts.

An introduction and seven chapters

In their introduction, Moreno and Mossio situate their organizational approach in a wider holistic philosophical and scientific context, which is represented by authors such as Waddington, Rosen, Piaget, Maturana, Varela, Pattee and Ganti (p. xxvi). Many of these authors stressed the idea that the constitutive organization of biological systems involves a distinctive regime of causation, which itself requires explanation. Central here is the idea that organisms constitute organized wholes that actively manipulate the conditions for their own existence through their interaction with the environment (p.xxvii). Maturana and Varela's well-known theory of autopoiesis is named as such an account, and biological autonomy constitutes an improved description that is claimed to solve some of the central difficulties with the autopoietic one: its internal focus, its lack of attention for material and energetic aspects (ibid.), and the lack of an adaptive gradient when it comes to maintaining autopoiesis (Di Palolo, 2005).

¹ The book is based on a large number of rewritten articles, many with other co-authors. As such, the book incorporates work of the whole research group around Moreno and Mossio over the last twenty years or so.

Chapter one is the key chapter that introduces the two central concepts behind Moreno and Mossio's view on biological autonomy, *constraints* and *closure*, and discusses how these enable the *regulation* of living systems. Closure has been a key notion within the organizational tradition for many years, most notably as the 'operational closure' within the work of Maturana and Varela. Roughly, operational closure refers to the circular organization of biological processes where these processes actively produce a new state that is equivalent to the starting state, but at a later point in time: this circular organization maintains this set of processes over time. Moreno and Mossio criticize this interpretation because it does not distinguish biological processes from non-biological ones that also exhibit such a self-maintaining organization, such as the water cycle on Earth or Bénard cells in a fluid heated from below. To avoid the notion of closure to apply to such "biologically irrelevant systems" (p. 4), Moreno and Mossio interpret closure as "a specific kind of mutual dependence between a set of entities having the status of *constraints* within a system" (p.5), a move that they also witness by people like Bickhard, Christensen, Hooker, and Kauffman. To introduce the notion of constraint, they start out from the hydrodynamic openness of self-maintaining processes, such as Bénard cells, and the way these processes depend on the continuous throughput of energy and matter. Given the presence of such dissipative systems and the order they produce, constraints consist of determinants that influence the processes that make up such systems. Haken's notion of a 'control parameter' is in my view a very clear way to sketch the role of a constraint in self-organizing systems. Bénard cells consist of large-scale patterns in the movements of the molecules making up a fluid, and these patterns depend on the presence of a heat gradient between the bottom and the top of the fluid. The presence of this heat gradient acts as an external control parameter – a constraint – on the dissipative processes generating and maintaining the macroscopic Bénard cells. As a control parameter, it provides a way to manipulate these cells, simply by switching a heating device on or off. More generally, constraints condition the occurrence and form of the processes that occur in self-organizing dissipative systems, such as living ones. However, what is special and characteristic for living systems is that these are able to constrain themselves from within and so capable of self-determination: The processes making up the system are not fully dependent on external constraints but on constraints within the system. The presence of an enzyme that catalyzes a biochemical reaction would be an example. The control parameters – to use Haken's language – have here become internal to the system (Keijzer, 2001). In addition, biological systems are also much more complex than physical cases of self-organization as they rely on large numbers of such internal constraints that mutually constrain processes acting on their own boundary condition and so maintain the system. At this point, Moreno and Mossio combine the notions of constraint and closure by claiming that living systems can be characterized by the closure of their constraints. Living systems exhibit a network of constraints that mutually produce one another by constraining the processes that generate the required constraints in a cyclical way. Thus, while self-organized process loops are a common feature of dissipative systems, life and its self-determination requires and is characterized by the closure of constraints.

Moreno and Mossio stress that the closure of constraints involves a qualitative change from physical cases of self-organization that goes hand in hand with a quantitative increase of the underlying complexity (p.18). Even more strongly, they state that self-organization cannot even be taken as a "starting point" for the emergence of closure and autonomy. This sounds rather extreme as the operational closure of processes is an essential requirement for this closure of constraints. Still, they want to stress that the closure of constraints is the key feature that is

necessary for the potential increase of functional complexity, which is not an option for systems without such closure (p.18).]

The central reason to set the closure of constraints apart is their role in biological (self) regulation, the means by which living systems actively counteract perturbations within and externally imposed on the living system. Moreno and Mossio differentiate between constitutive stability and constitutive closure. The former is maintained by, for example, negative feedback loops that are present within the active network of constraints in a specific instance and stabilize and maintain that network of constraints. Constitutive stability is the basic case and precursor (it seems) of *constitutive closure*, a more complex and active case of regulation. Here additional constraints come into play to counteract disruptions of closure that result from both internal and external changes that act as disturbances (p.33). Moreno and Mossio use the well-known case of the lac operon in *Escherichia coli* as an example. *E. coli* feeds usually on glucose, the presence of which is essential to maintain the constitutive closure of the bacterium. Low levels of glucose would disrupt this closure even when lactose is abundant because the bacterium – in its present form of constitutive closure – cannot metabolize lactose. Under these conditions, the lac operon is activated, which leads to the expression of previously inactive genes that enable lactose metabolism and in this way re-establish constitutive closure in a new form. According to Moreno and Mossio, the lac operon thus acts as a *regulatory constraint* that influences the constitutively closed organization into a different closed organization, an organization that metabolizes lactose. Regulatory constraints are decoupled from constitutive closure – glucose metabolizing goes on just fine without the lac operon. Instead, Moreno and Mossio argue, they are subject to second-order closure, constituting constraints on the set of different organizations among which they govern the transitions (such as switching between metabolizing glucose and lactose). As Moreno and Mossio put it themselves: “this second-order organization consists of the set of available constitutive regimes of a closed organization *given* a specific set of regulatory constraints and a set of deleterious variations to which the regulatory constraints are specifically sensitive.” (p.35).

Second-order closure allows living organizations to rapidly switch between different appropriate collective patterns and regimes of constitutive closure, where the regulative constraints become decoupled from the constitutive ones. This enables more freedom for variations in regulatory constraints showing new dynamics without immediately disrupting the constitutive organization. Such options for exploration open up possibilities for an increase in complexity, a topic that is further developed in later chapters.

This first chapter forms the heart of the book, setting out the essential ideas on which the rest of the book is built and providing the conceptual toolkit for defining and understanding biological autonomy. This main theme is further developed in chapter four – on agency and the interactive dimension of living systems – and chapter seven on cognition, which represents the most complex form of organization. The remaining chapters discuss more specific issues that extend this main structure. I will give a quick overview of these chapters here.

Chapter two discusses biological emergence and the question of inter-level causation. The central question is whether closure can act as a legitimate scientific concept rather than as a mere epistemic shortcut. The major worry here derives from the metaphysical discussion centered on Kim’s exclusion argument, which creates difficulties for higher-level causation. Moreno and Mossio criticize the idea of interlevel causation that is often stressed in the context of self-organization. Instead they argue that when “a set of constraints realizes closure, the resulting organization constitutes a kind of second-level emergent regime of causation,

possessing irreducible properties and causal powers.” (p.61) In this way Moreno and Mossio try to defend closure as a legitimate scientific concept with a genuine causal role.

Chapter three discusses an organizational interpretation of function. The main philosophical positions concerning function can be grouped in dispositional approaches focusing on the here and now (with Robert Cummins acting as godfather), and etiological ones that stress the causal history of functional traits (Larry Wright and Ruth Millikan are the grandparents here). Moreno and Mossio present an organizational account that combines the important features of both by interpreting function as “those causal effects exerted by the constraints subject to closure that contribute to maintaining the organization.” (p.70) The chapter provides interesting discussions on cross-generational functions and of malfunctions, but does not pay attention to artificial cases of function.

Chapter four picks up the main theme of the book again: the articulating of the organizational approach. This is done by turning to agency, which is cast as the not yet discussed interactive dimension of the constitutive domain. Agency is dissociated from its dominant context in human cognition and cast much wider in a way that makes most living entities agents. Minimal agency involves a capacity to actively effect the environment according to various norms or goals, and to do so in a variety of ways. This becomes a form of adaptive agency when the entity exhibits constitutive closure, and when it discriminates specific processes or structures in its environment acting towards them in a way that is functional for the maintenance of constitutive closure. In this way agency provides the still missing final ingredient to fulfil the conditions for a minimal form of biological autonomy. A clear case of such autonomy is provided by unicellular organisms, for example in the way *E. coli* exhibits a form of chemotaxis by moving up a sugar gradient in their environment (p.97). Interestingly, at this point Moreno and Mossio oppose the enactivist claim (e.g. by Varela and Thompson) that such adaptive autonomous agents enact a meaningful world, which they consider as too anthropomorphic (p.101). Moreno and Mossio maintain their distance from cognitive, leave alone experiential interpretations of minimally autonomous systems. They do introduce a route towards genuine forms of cognition however by stressing the importance of motility. To reach that goal, they build on two more background chapters.

Chapter five deal with evolution, the historical dimension of autonomy. This is a very nice chapter that combines the etiological focus of evolutionary biology with the organizational approach that stresses the biological organization present in the here and now. While there used to be some tension between the two, this chapter discusses how the organizational approach can, and even must, incorporate a historical evolutionary dimension. As the authors phrase it at the end of the chapter, “we do not need history to characterize what an individual organism is; we need history to understand where they come from, as a result of an evolutionary process” (p.139).

Chapter six targets multicellularity and the problems (and opportunities) this brings for autonomy. The central question here is when a collection of cells constitutes a genuine multicellular organism rather than other cohesive multicellular organizations (such as slime mold slugs or biofilms). The chapter provides a comparative approach to pinpoint the essential criteria that allow the specification when a multicellular organization exhibits closure at the multicellular level. While this chapter focuses on the internal, constitutive dimension and not agency, it provides the ingredients for starting to think about higher-level autonomy at a multicellular level and provides the starting point for the final chapter that picks up the main theme of the book again.

Chapter seven focuses on cognition and the question how cognitive phenomena can be understood as a specific and highly complex class of interactive – agentive – capacities (p.167). In doing so, they interpret cognition in a way that is more limited than earlier organizational views that took all of life as cognitive – most famously by Maturana and Varela – without restricting it to the view of traditional cognitive science that limits cognition to human-level cognitive tasks. Without restricting the notion of cognition overmuch, as occurs in the latter case, Moreno and Mossio want to keep cognition as “a specific phenomenon” (p. 168), which is not the case if all life is cognitive. They proceed by focusing on the transition to multicellular organizations and the organizational requirements for enabling complex forms of behavioral agency. Here a key role is played by the nervous system which provides a new dynamic level that is to a significant degree dynamically decoupled from the metabolic constitutive organization of the organism. The nervous system enables the integration of the multicellular organization into a single integrated entity that is not directly dependent on – being decoupled from – organizational requirements. From here on Moreno and Mossio sketch a more familiar story where the evolution of the nervous system supports “the further complexification of animal behaviour” (p.177), most notably in vertebrates, and finally the evolutionary emergence of consciousness and cognition as a result of neurodynamic autonomy. Here they make contact with the work of authors like Edelman and Damasio.

Concepts looking for phenomena

Moreno and Mossio wrote a very good, state of the art account of what the organizational approach has to offer, and in this way also provided a neat synthesis of many different threads that are present in this approach. What I particularly liked about the book is the way in which evolution is now incorporated as a central part of the approach. This is an important step in developing this approach in a way that allows it to make closer contact with mainstream empirical and theoretical biology and to show more widely how an organizational approach can be relevant for understanding biological and psychological phenomena. On this count, it would have been nice if the book had been a bit more accessible as it is difficult to read and understand for someone who is not familiar with the main ideas. Nevertheless, the book is a real achievement and it provides a good conceptual complement to Rosslénbroich’s recent *On the origin of autonomy* (Rosslénbroich, 2014), which takes an approach that is much more empirical.

However, there is also a general point that warrants critical attention. The issue is important as it concerns the potential relevance of the organizational approach as a sound starting point for further, future conceptual investigations of biological organization. Most generally put, my worry with the organizational approach is that methodologically it may be best described as a concepts-first approach. It starts with a set of significant concepts that are subsequently to be *naturalized*; these concepts are used as a guideline to look at a domain – living systems in this case – to articulate how the phenomena within this domain realize aspects that are highlighted by the concepts that are taken as a starting point. In this way, long-standing notions like ‘autonomy’, ‘agency’, ‘cognition’ and ‘organism’ are naturalized – or defined – as aspects or forms of living systems. While the naturalization of mental notions has been a long standing and respected philosophical approach within philosophy of mind, there are now good reasons to be rather critical about such a project: For every ‘real’ case of, say, agency there can be a multitude of ‘unreal’ cases of agency that are left out of consideration. In the remainder of this section, I will sketch why I think that the organizational approach as drawn here by Moreno and Mossio

exhibits this concepts-first approach. To manage this enterprise, I will first focus on the four concepts just mentioned. In the subsequent section, I will discuss why this might become increasingly problematic for the future development of work within the organizational tradition.

The concept of *autonomy* is held central in Moreno and Mossio's book, but I can't help asking myself why it should play this central role. Autonomy usually refers to the way countries govern themselves, an idea that is here applied to convey the way in which living systems maintain a certain – but not an all-out – independence from their surroundings. This autonomy makes living systems special and different from all other physical entities. My worry about the choice of autonomy concerns the way in which it places an abstract (and more generally applicable) concept as the central focus of the organizational approach, rather than the material and organizational living systems themselves. The latter are clear physical entities ready to be studied and the whole reason for any talk of biological autonomy. My worry here is that this focus on autonomy draws attention away from the living organizations themselves. In this respect, I still have a soft spot for old-style autopoiesis and its operational closure and structural coupling, even when it must be critically evaluated. At this point, one can object that my worry is unwarranted as the organizational approach to autonomy provides a truly fundamental account about the central constitutive and the interactive dimensions of any living organization. However, my worry here is that by taking a relatively abstract and established concept – autonomy – this concept provides a limiting focus that may not always be the most open-minded and suitable to make sense of the enormous variety of actually existing living systems or what they do. I will return to this issue in the next section.

A similar worry arises when the interactive dimension of living organizations is cast as *agency*. Like cognition, agency is a concept that is most often encountered in the context of human action and using it as a generic label within this fundamental account of biological organization seems rather strong. A good reason for doing so nevertheless is obviously a preexisting interest in agency itself and the search for a way to naturalize it as a feature of living systems. But this is precisely what makes it problematical. Take this sentence: “what kinds of system would fit the definition of minimal agents from the autonomous perspective?” (p.97). While the question is perfectly legitimate and important, it also embodies a particular way of looking at the interactive domain that emphasizes certain forms of interaction – most notably motility based interactions – while delegating other forms to the background. The influence of using agency as the central concept for the interactive dimension is further highlighted by the discussion on cognition.

According to Moreno and Mossio, the presence of minimal autonomy can be seen as the defining feature for the concept of *organism* itself (p.105). As minimal autonomy applies most readily to unicellular creatures, the key question becomes when and why certain multicellular organizations can be designated as organisms in their own right. This is a difficult issue, and the relevant chapter (six) focuses only on the constitutive dimension of various multicellular organizations to simplify matters. If I understand the text correctly, the conclusion is that animals (sea-urchins are the example) exhibit higher-level (multicellular) autonomy and can thus to be considered as multicellular organisms, while other multicellular forms (cyanobacteria and *Volvox* are discussed) do not show this form of autonomy (at least not unequivocally). However, irrespective whether Moreno and Mossio really accept this specific conclusion, my critique is not *where* one might draw this boundary. The question should be: how relevant is it to draw such a boundary in the first place? One may very well question the ongoing relevance of this long-standing notion of organism, given the richness and diversity of the various lifeforms that have

been discovered. From this perspective, the concept organism becomes easily a conceptual straightjacket that is not fitting the diversity of life out there.

Finally, Moreno and Mossio use cognition as the endpoint of their account of biological autonomy. They ask “how, from the autonomous perspective, *cognitive* phenomena can be understood as a specific and highly complex class of interactive capacities” (p.167). As in the case of agency, a preexisting interest in cognition is understandable and sound. However, it easily provides a restrictive outlook on the living systems that are considered. Cognition is linked to complex forms of agency that soon enough lead from unicellular to multicellular lifeforms, subsequently passing those less integrated and behaviorally complex, and zooming in on free-moving animals with nervous systems. The latter is brought forward as a system that is dynamically decoupled from the underlying metabolism, and able to act as a very fast, multicellular organization that “generates a domain that is highly dimensional, nonlinear, recurrent, and recursive” (p.176), or, in other words, a domain that seems capable of leading to phenomena like mind and consciousness. Of course, this sounds good, and it brings the organizational approach to understanding cognition into the familiar terrain of neuroscience with its discussion of Edelman and Damasio. However, no one in neuroscience has so far come up with an acceptable account how nervous systems enable all these mental goodies. At this point, I do not see why an organizational approach with its very different conceptual focus and expertise needs to rush to make contact with mainstream, human-oriented cognitive neuroscience instead of looking more carefully at a wider range of cognition-like cases.

So far, my intention was to make it plausible that Moreno and Mossio’s account is strongly guided by a limited number of key-concepts. In itself, this is not a critique, however in the next section I will try to show how many long-standing and newly discovered aspects of living systems should make one concerned about the guiding role of these concepts.

Phenomena in need of concepts

In her book *Philosophy of Microbiology*, Maureen O’Malley discussed a variety of philosophical issues derived from microbiology and one of the main messages I picked up from her book is best described by Bachman—Turner Overdrive: “you just ain’t seen nothin’ yet.” The living world is more rich, diverse and strange than anyone had imagined until recently (and undoubtedly will remain so for a long time). The common sense classification in animals, plants and ‘the rest’, like fungi and bacteria is totally insufficient to account for the many different and often weird lifeforms and the ways in which they live. In contrast to common sense, those familiar animals and plants are not prototypical examples of life: both are outrageously large constructions made up from – and by – huge chimerical (eukaryotic) cells that generate extensive extracellular structures where they live together with huge populations of various other microbes. As O’Malley stresses, “the biological world in general is microbial” (2014, p.3), macrobes like us, other animals and plants are exceptions.

Anyone reading this page will be familiar with this modern view on animal and plant life. However, our thinking about life and many of the concepts that we use to describe it often lag in accommodating the many new findings, insights and possibilities. Given this background, it is relevant to look at the organizational approach and its central concepts from this perspective. In this section, I will return to the concepts highlighted above, and contrast them to various examples of living organizations.

How representative is autonomy as a characterization of what is central to life? This question is too difficult to answer here, but it is possible to look for possible exceptions, lifeforms or parts of lifeforms that are – possibly – not autonomous. The clearest case, it seems, of an autonomous organism is a single free-living cell, exhibiting both second-order constitutive closure and some form of minimal agency. Moreno and Mossio themselves withhold the label of agency, and thus autonomy, from certain endosymbiotic bacteria (p.99), as well as viruses (p.97), but also many multicellular lifeforms when they do not fulfil various conditions (e.g. p.152). In this case, most animals are probably autonomous, but it remains a matter of discussion whether or which plants and fungi fulfil these criteria. While this is perfectly acceptable if one is interested foremost in naturalizing autonomy, it may also be taken as an indication that autonomy as conceived of by Moreno and Mossio is not truly the key of life. When the aim is to provide an organizational approach that can deal with the wider array of life involving phenomena, other key concepts might be preferred.

Agency is used by Moreno and Mossio to articulate the essential interactive dimension of autonomy and as such limits the application of ‘truly’ autonomous systems as just mentioned. One may question the choice of agency as the way to designate this fundamental condition for autonomy, as it may not self-evidently apply to non-standard cases of multicellular agency as exhibited by plants and fungi. This is an urgent issue as recently a lot of research on plant intelligence has revived a tradition that goes back to Charles and Francis Darwin (Baluška, Mancuso, Volkmann, & Barlow, 2009 ; Mancuso & Viola, 2015). Plants are shown to have many senses and are capable of intricate behavior in root decision-making (Baluška et al., 2009), olfactory signaling to attract predators for the insects that attack the plants (e.g. Mancuso & Viola, 2015; Trewavas, 2005). So far, the study of fungi intelligence has received less scientific attention than plant intelligence. However, relevant examples go back to the nineteenth century discovery of carnivorous fungi (Primer, 1964). Various fungi-species catch and eat nematodes. Depending on the species, this is done by using adhesive knobs, adhesive nets, non-constricting and constricting rings that trap nematodes like rabbits in a snare, while in other cases active adhesive zoospores function like self-moving sticky mines hunting for nematodes (Barron, 1977). Once the nematode is trapped, or contact made, thread-like hyphae invade the worm and turn the cytoplasm of the worm into fungus. These fungi have many characteristics of agents, for example rings are grown when the fungus detect nematode pheromones (Barron, 1977; Hsueh et al., 2013). Also, and in contrast to carnivorous plants that catch prey much smaller than themselves, these fungi are “giant-killers” (Primer, 1964) that catch prey much larger than themselves.

For both plants and fungi it is unquestionable that they show spectacularly complex ways of interacting with their environment that deserve scientific attention as forms of intelligence. However, while Moreno and Mossio mention plants in their book, they are reluctant in granting them agency, as the interactions are dependent on growth and thus (maybe) part of the constitutive domain rather than the interactive dimension. They refer to Arnellos and Moreno (2015) for a more extensive treatment. However, the interesting point here should not be *whether* plants and fungi qualify as agents, or when. Why should we care? The issue is that the environmental interactions of plants and fungi are (at least sometimes) as complex as they are. If agency does not apply here, these examples still stand and the use of this term agency becomes questionable as a designation of the interactive domain. When agency does not suffice, there is a vacancy for a concept or description that is up to the job.

Closely related to the above is the treatment of the notion of organism. The latter has an intuitively clear and long-standing meaning: “At the end of the eighteenth century, the term became a generic name for individual living entities with inside-outside-interfaces and an inner ‘organization’ of parts” (Cheung, 2010, p.155). However, this seemingly clear notion has with hindsight become awkward to use more generally as there are many lifeforms and collections of lifeforms that do not easily fit the notion of an individual organism. The notion of an individual organism seems tailored to describe individual animals but is less suitable to describe the various forms of other multicellular configurations as exhibited by colonial animals, plants, fungi and ‘the rest’. For microbes, the many ways in which they live together, as well as the many ways in which they live inside, on, or with macrobes also makes the notion of individual organisms ambiguous. According to O’Malley (2014), it might be necessary to redefine organisms, multicellularity and reproduction, which would lead to a very different way of looking at ‘organisms’. Even within the animal kingdom, the units may require further work. Godfrey-Smith (forthcoming) distinguishes between modular and unitary ways to enlarge multicellular units; the first works by budding of more units that stick together forming a colony-like configuration (e.g. Mackie, 1986); the second consists of enlarging the units themselves, which requires extensive developmental programs. Concluding, the discussion on individuality deservedly takes up much attention within philosophy of biology. While the outcome of the debate is unclear, a safe bet would be to argue that the notion of organism just isn’t up to accommodate all these complexities and a more dedicated terminology should be developed to make sense of these many configurations and interdependencies. It seems like a good idea for the organizational approach to turn to this variety rather than articulating a strict reading of ‘organism’ and policing its boundaries.

The last concept pinpointed above is cognition, which connects the organizational approach with mental phenomena, but again in a rather restrictive way: “neurodynamic autonomy is *the organizational ground for the cognitive domain*” (p.189, original emphasis). Cognition is tied to nervous systems as they enable a “*qualitative change* in the relations between the neural domain and the multicellular metabolic organization” (p.189, original emphasis). Thus complex, sufficiently ‘decoupled’ nervous systems are used as a requirement for cognition. This high-level interpretation of cognition may not be the best way to position an organizational approach. First, there is now an increasingly active community that stresses a broad variety of complex organism-environment interactions – often called intelligence or even cognition – in a broad variety of lifeforms without any nervous system. I already discussed work on plants and fungi as cases of non-animal multicellular lifeforms that can be considered intelligent in this way, but the same applies to bacteria (e.g. Lyon, 2015; Westerhof et al., 2014). In addition, there are millions of species of invertebrates with nervous systems for which it will be unclear whether their nervous systems are sufficiently decoupled from metabolic requirements, but which are very well capable of performing behavioral feats that might be called cognitive under a wider reading of ‘cognition’ as is now common within embodied approaches to cognition (e.g. Beer, 2003; Prete, 2004).

Many, maybe most, of these cases have been relatively neglected by research on intelligent phenomena. Using the concept of cognition in a restrictive sense that remains strongly focused on the human example is not helpful in furthering a more gradual and detailed approach to these many alternative ways in which the interactive domain has been filled by various lifeforms. Nor is it helpful in clarifying how these phenomena relate to the human case. Highlighting human-centered cognition as a qualitative change from a metabolism-oriented

domain may be a good way to maintain and strengthen deep-rooted convictions concerning the mind as a separate and autonomous domain. However, I don't see why these long-standing convictions should be prioritized by an organizational approach that could highlight the huge intermediate domain. At this point, it is important to state that Moreno and Mossio also stress that "neural dynamics are ... deeply embodied in the encompassing metabolism" (p.189). It may be more helpful – and it is certainly more interesting – to rethink cognitive and mental concepts from within an organizational approach.

At this point it may be good to go back to Maturana and Varela' (1980) original claim that all life is cognition, or (in an intriguing combination) Godfrey-Smith (2002) who has been arguing for a long time that cognition "shades off" in many small steps to other biological functions. Godfrey-Smith (forthcoming) sees little promise in philosophical "arm-wrestling" where to place any transition to cognition. What we can do is pay attention to the various phenomena in more detail and work towards a gradual account that connects basic forms of life and mental phenomena.

One step in this direction is by paying closer attention to the evolution, forms and functions of nervous systems. Moreno and Mossio discuss the autonomic and sensorimotor nervous system as different forms of decoupling, but much more can and should be said about nervous systems. Jékely, Keijzer and Godfrey-Smith (2015) formulated an option space to organize thinking about the evolution of early nervous systems. They discuss behavior, physiology and development as separate key functions for nervous systems, and two basic ways of operating: input-output and internal coordination. The result is a rich domain of conceptual options to investigate. In particular, the internal coordination interpretation – nervous systems evolved to coordinate bodily organization – is an underdeveloped domain that warrants attention. For example the way in which *contraction-based motility* may have been a key evolutionary change looks promising as a way to develop a gradual account of early nervous system evolution (Keijzer, Van Duijn, & Lyon, 2013; Arnellos & Moreno, 2016), multicellular sensing (Keijzer, 2015), and the animal sensorimotor organization (Keijzer & Arnellos, forthcoming). Paying attention to the conceptual implications of the more detailed operation of nervous systems is a fertile way to develop an organizational approach that matches concepts and phenomena in new and interesting ways.

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