Review of *Biological Autonomy*

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Alvaro Moreno and Matteo Mossio, ***Biological Autonomy.*** Dordrecht: Springer (2015), 221 pp., $129.00.

In *Biological Autonomy*, philosophers Alvaro Moreno and Matteo Mossio present a new theoretical framework for understanding how living organisms differ from other physical systems. Their framework, which they call the "autonomous perspective," addresses biological organisms qua systems. They show how it generates insights into a wide range of questions in philosophy of biology such as, Does causation operate top down? What are functions? Which is more fundamental for the origin of life—metabolism or replication? What distinguishes cognition as a kind of biological process? Moreno and Mossio's systems-oriented approach, with its holistic focus on the organizational features of biological systems (including the entire spectrum from bacteria to large multicellular organisms), is a welcome and refreshing departure from the contemporary plethora of *mechanistic* approaches that emphasize reductive accounts of biological systems as decomposable into hierarchies of parts and operations. The autonomous perspective also provides insights into why mechanistic explanation must be supplemented with other explanatory approaches. In this review, we briefly sketch some of the core ideas of the framework and how the authors apply it to two central problems in philosophy of biology: the nature of functions in biology and how to understand cognition in biological systems in general.

Constraints and Closure. In this section, we explain two core concepts that Moreno and Mossio employ: the concept of a *constraint* in a biological system and the concept of organizational *closure*. Moreno and Mossio's theory is inspired to a large extent by Francisco Varela and Humberto

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Maturana (Varela 1979; Maturana and Varela 1998), who are well known for their own holistic approach to understanding biological systems. According to Varela and Maturana's theory, what is special about biological systems is that they are *autopoietic* (literally "self-producing"). For Varela and Maturana, autopoiesis requires a combination of two features: a topological boundary and biological autonomy. Moreno and Mossio recognize the importance but do not elaborate much further on the first of these. Rather, they focus on autonomy as the key to understanding biological organisms. Moreno and Mossio argue that for an organism to count as biologically autonomous, it must possess at least two distinct capacities, which they refer to as "dimensions" of autonomy:

> *Constitutive*: "producing and maintaining the parts that contribute to the functioning of the system as an integrated, operational, and topologically distinct whole."
>
> *Interactive*: "[promoting] the conditions of its own existence through its interaction with the environment" (xxvi–xxvii).

Moreno and Mossio argue that Varela and Maturana mischaracterize the constitutive dimension and largely neglect the interactive dimension. First, Moreno and Mossio argue that autopoietic theory does not give sufficient weight to what makes self-construction critical, namely, that organisms and the environments in which they live are *dissipative structures*: "macroscopic ordered configuration (a 'structure') in the presence of a specific flow of energy and matter in far-from-thermodynamic equilibrium conditions" (15–16). It is because of the overall flow to equilibrium that, in order to maintain themselves, organisms must perform work on themselves and the environment and, in order to do that, must channel free energy from the environment. Second, as the references to the environment already show, the environment the organism is situated in plays an important role in structuring the processes by which the organism maintains itself.

Moreno and Mossio, however, argue that the problems go deeper—to Varela and Maturana's failure to distinguish processes from constraints. Importantly, for Varela and Maturana, biological autonomy requires *closure*: the system resists certain kinds of perturbations and imposes order on itself by a cycle of internally directed processes that is in some sense closed to the environment. Whereas Varela and Maturana characterize closure in terms of processes, Moreno and Mossio locate it at the level of constraints: the system must be open to external processes to make use of free energy and matter from outside, but the network of mutually dependent constraining entities and structures harnessing this matter and energy is closed insofar as it is internally generated and self-sustaining. For Moreno and Mossio, this closure at the level of constraints is the organizational closure of biological autonomy. Moreno and Mossio stress that a closed system of constraints does not mean a fixed system of constraints. On their account, constraints can be added to or deleted from the closed network as long as each constraint, including any newly added one, is constructed from others and has effects on others. This ability of a system of constraints to alter its component constraints requires a regulative capacity—constraints that causally alter the system of constraints itself so as to achieve some end. Autonomous systems, on Moreno and Mossio's account, are regulated systems.

A closed system of constraints is required for autonomy but not sufficient. In addition, autonomy requires *agency*, which on Moreno and Mossio's account characterizes the interactive dimension through which an autonomous system monitors perturbations from the environment and then "acts on its environment to promote its own maintenance" (90–91). The primary exemplar of an autonomous system is a single-celled organism, such as a bacterium. A bacterium is a dissipative structure, and to maintain itself it must perform work—execute constrained operations that channel matter and energy into itself. To be a self-sustaining, autonomous system, it must be closed in Moreno and Mossio's sense—there must be a set of constraints that channel energy and matter whose members are in part the product of the action of other constraints and have effects on other constraints in the system. The bacterium manifests agency by, among other things, regulating flow across its membrane and moving through the environment. And it is adaptive in that the specific constraints (enzymes synthesized that catalyze specific reactions) can be altered within the system (by, e.g., expressing different genes as needed).

We find this general account of the organization that defines organisms as involving a closed set of constraints highly compelling. But we do find aspects of the way Moreno and Mossio develop their characterization of constraints problematic. Moreno and Mossio characterize constraints as causally affecting processes without being affected by the processes—as "harnessing a thermodynamic flow, without being subject to that flow" (15). In his forward to the book, Cliff Hooker points to how this is problematic. Perhaps anticipating the concern that constraints themselves may undergo changes as they constrain other processes, Moreno and Mossio develop a different account in terms of timescales—at the timescale of the processes themselves, the constraints do not change, although they might at a faster timescale (e.g., enzymes undergo a sequence of changes as they catalyze a single reaction) and at a slower timescale (that on which the enzyme degrades). Although many constraints endure much longer than the processes they constrain, this is not fundamental. There are biological systems in which constraints are made or repaired on the same timescale as the processes they constrain.

We do not consider these concerns fatal but as pointing to the need to explore other ways of making the constraint-process distinction. Just to consider one possibility, instead of appealing to timescales, biophysicist Howard Pattee (1970) argued that the only way to make sense of a constraint being added to a fully deterministic dynamical system is to move to an alternative description (e.g., thermodynamical) that relinquishes some of the dynamical detail. The alternate description treats the same system as one that is dynamically simpler, in which either degrees of freedom have been reduced or dynamical trajectories have been made inaccessible, as a result of the system possessing "constraints" that are separate from the dynamics. We consider these ideas from Pattee to be a promising lead for sustaining the distinction between processes and constraints in a way that avoids Hooker's objections.

Before turning to the application of the autonomous perspective to core issues in philosophy of biology, we note how the account of autonomy in terms of constraints and closure offers a useful perspective on the recent claims of several philosophers of science that mechanistic accounts of explanation are not sufficient to account for biological systems and must be supplemented by, for example, network and dynamical analyses (see papers in Braillard and Malaterre 2015). Whereas the mechanistic approach emphasizes decomposition, these alternative explanatory strategies are directed at understanding the sorts of coordinated activity that arise when one or several hierarchically organized systems of constraints operate on the underlying mechanistic processes. These are what will be required to develop detailed accounts of actual autonomous systems in biology.

Function. One of the core issues in philosophy of biology on which Moreno and Mossio claim their account of autonomous systems provides a distinctive resolution is the analysis of functions in biology. In chapter 3, they present their "organizational view" as an alternative to currently prevalent dispositional views (on which the function of a trait reduces to dispositional properties) and etiological views (on which the function of a trait depends on the developmental or evolutionary history of the organism) of function. On Moreno and Mossio's alternative view, a trait counts as *functional* when it is the causal effect of some subset of the closed, mutually dependent network of constraints that collectively results in the production and self-maintenance of the system as a whole. Since the subset of constraints plays a role (through its causal effects) in sustaining the overall network and is at the same time sustained by it, the trait itself thereby achieves a normative status (i.e., its teleological function) consisting in its constraining role within the entire closed system of constraints.

By not appealing to history in their account of function, Moreno and Mossio avoid standard swamp-man-style objections to etiological views;

whether a system realizes closure of constraints is a matter of how it is currently organized, rather than being a matter of its evolutionary or developmental history. Their view also has several advantages over typical dispositional accounts. First, they are able to distinguish the truly goal-directed behavior of simple biological systems from systems that merely behave "as if" they were goal-directed. According to Moreno and Mossio, truly teleological systems are distinguished by being subject to constraint closure.

Appealing to constraint closure also enables Moreno and Mossio to distinguish function, nonfunction, and malfunction. The distinction between nonfunctionality and functionality is marked by first-order constraint closure. Determining that a trait malfunctions requires the notion of regulation introduced briefly above, which involves second-order constraints that modulate the activity of first-order constraints so that the system can adapt to new environmental perturbations (83–84). A malfunction occurs at the point when the constraint closure of the system is not properly adapted, through regulation, to cope with present circumstances and, therefore, to maintain the organization of the system as a whole.

Bickhard (2007) has also argued that the normativity of functionality is grounded in the capacity for thermodynamic self-maintenance. The main advantage of Moreno and Mossio's view is that it draws on theoretical resources, such as those developed in the writings of Stuart A. Kauffman and Howard Pattee, to spell out the notion of constraint closure that functions are to maintain.

Cognition. Another problem to which Moreno and Mossio apply their view of autonomy is the characterization of cognition. They contend that most existing accounts of cognition are too liberal (e.g., including information processing of all sorts) or too restrictive (e.g., applying only to humans). In chapter 7, Moreno and Mossio draw on their account of constraints to offer a biologically grounded alternative biological framework that does not privilege specific types of processes or anatomy and is neither too restrictive nor vacuous. On their view, there are two factors that set cognitive constraints apart from more basic biological ones: (*a*) plasticity (i.e., the capacity for rapid, responsive modulation) and (*b*) dynamical decoupling from those constraints required for basic autonomy. An organism endowed with these capacities is capable of interacting with its environment in a completely different way than those lacking cognition. Starting with this insight, Moreno and Mossio then ask what kind of organizational or physiological features might facilitate such capacities and find that nervous systems in general seem designed precisely to support these types of processes. Instead of arbitrarily privileging nervous systems, then, they develop principled reasons for considering nervous systems to be particularly important for cognition.

Nervous systems provide for fast and versatile sensorimotor coordination by incorporating diverse types of cells and allowing efficient and modulatable communication between cells. Moreno and Mossio argue that this enables behavior that is qualitatively different from that found in organisms that rely on simpler forms of cellular sensorimotor organization. The evolution of neurons, with their axons and electrochemical neurotransmission and neuromodulatory capabilities, enable precise, targeted, and context-sensitive connectivity between distant sensory organs, muscles, and other systems in large, multicellular organisms.

Higher cognitive activities become possible when there is a subsystem of the organism that is dynamically decoupled from the physiological constraints that are required for basic autonomy. Decoupling is never complete since organisms with nervous systems remain dissipative structures that must be maintained through the organism's activity. But nervous systems do enable activities beyond those required for basic self-maintenance. The special features of neural membranes that allow transduction and successive depolarization, yielding action potentials, provide what cyberneticists Rosenblueth and Weiner have referred to as an "informative or sense-organ" coupling, which they note makes it possible to "convert an external signal with a low energy level into an important reaction" (1950, 323), a key principle in the design of effective control systems. Glial cells in nervous systems further facilitate energetic isolation by forming myelin sheaths that allow faster, more efficient propagation of action potentials across longer distances.

Conclusion. *Biological Autonomy* is a most insightful book that provides a constructive engagement with a range of systems-oriented theorists (including Varela and Maturana, Kauffman, Pattee, and others) whose significance for biology and philosophy of biology is too little appreciated, as well as a cohesive theoretical framework for understanding biological systems. Those interested in biological mechanisms, in particular, would be well advised to attend to Moreno and Mossio's discussion of constraints and constraint closure. Even if one is simply interested in understanding specific mechanisms, recognizing how they are situated within autonomous systems can provide valuable heuristics.

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