14 Control Hierarchies: Pattee's Approach to Function and Control as Time-Dependent Constraints

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Overview

This work presents an approach to understand the origin and nature of level formation and control processes in the biological realm and to account for the specific interlevel relations they give rise to, which adopts the form of biological *organization*. It is argued that the idea of constraint-mediated control hierarchy developed after Pattee is an appropriate way to address both complementary demands posed, on the one hand, by the challenge of finding a plausible replacement for the familiar but controversial "universal hierarchical ordering" and, on the other, by the emerging program of reconstructing the concept of level of organization. This proposal is consistent with new revisions both of the neo-mechanist view and of the skeptical and deflationary reactions that initially triggered the concern motivating the approach here defended. The conclusion supports the need to incorporate into the current debates the idea of hierarchical control based on very specific constraints in order to clarify interlevel relations when dealing with living systems.

Hierarchical control is the most universal organizational principle of living matter.
—Pattee (1971a, p. 47)

14.1 Introduction: Some Motivations

As many of the contributions to this volume acknowledge, we have recently seen a surge in interest regarding issues of levels of organization and hierarchy in philosophy of science. This renewed interest is due in great part to the neo-mechanist approach (without forgetting the continuous work in other areas such as, for instance, evolutionary hierarchical theory; see Tëmkin, this volume). However, this same interest has also provoked a skeptical reaction highlighting presumed problems and inadequacies of the very concepts of *level* or *level of organization* and, subsequently, of *hierarchy* itself (i.e., Eronen, 2013, 2015; Eronen & Brooks, 2018; Potochnik & McGill, 2012; Thalos 2013).

The analysis provided in this chapter responds firstly to a longstanding motivation regarding the related problems, on the one hand, about how to understand the origin and nature of control processes and of level formation in the biological realm and, on the other hand, about how to account for the specific interlevel relations they give rise to, in the form of biological *organization* (Umerez, 1994). More recently, this interest has become coupled with concerns regarding the generalized depiction of interlevel relation in terms of plain composition and the resulting deflationary or skeptical reaction (Umerez, 2016).

Simultaneously, this chapter also seeks to respond to a double challenge. On the one hand, I consider how to tackle Potochnik and McGill's (2012, p. 133, n. 5) challenge of finding a plausible replacement for "universal hierarchical ordering" and, on the other, how to contribute to Brooks's (2017, p. 153) program of reconstructing the concept of level of organization by presenting a usage with its explicit aim. I will argue that the idea of *constraint-mediated control hierarchy* developed after Pattee is one way to address both complementary demands. First, this is a good (if not the only) instance of a sound concept of hierarchical relation among levels that is not ambiguous or vague in its characterization and that does not entail any given universal ordering. Second, it has the very specific and explicit aim, triggered by the question regarding the origin of life, to help understand the nature of living phenomenology stemming from the nonliving physical realm. But, at the same time—and due precisely to the restricted and specific character of both the original account and its purpose—it might be of more general application to other cases, and above all, it may constitute the bottom and common ground to characterize the specificity of living organization as such.

I am confident that this proposal is consistent with new revisions both of the neo-mechanist view and of the skeptical and deflationary reactions that are central to my concerns. We have simultaneously seen the incorporation by Bechtel of the idea of control (Winning & Bechtel, 2018) into his previous views, the defense (or at least admission) by Eronen (Brooks & Eronen, 2018) of the scientific and heuristic value of the concepts of levels and hierarchies, and the proposal by other authors (Brooks, 2017; DiFrisco, 2017; Green & Batterman, 2017) of specific uses or meanings of those concepts, for instance, with the help of the notion of scale, but without attempting to abandon or replace them.

In order to achieve these goals, I will proceed in this chapter as follows. I will briefly recap my proposal to reconstruct the meaning of level of organization by means of an articulation of several concepts defining kinds of relations, among which *organization* is both the most inclusive (encompassing all) and the most specific (fulfilling all the conditions), including the relation of control. Next, in order to complement my understanding of the concept of "level of organization" with one analogous to the concept of "hierarchy," I will introduce in some detail the starting points of Pattee's contribution to hierarchy theory, placed in the wider context of his early theoretical development and centered on his elaboration of the concept of constraint. I will then propose an articulation of the concepts of hierarchy, distinguishing among different kinds of interlevel relations that are defined based on the type of constraint present. In the last section, I will reiterate the need to incorporate the idea of hierarchical control into the current debate in order to clarify interlevel relations when dealing with living systems. Finally, I will extract some general consequences and conclusions derived from this approach.

14.2 Levels, Composition, and Organization

I have recently argued, first, that some of those negative or reticent reactions (skeptical and deflationary) are derived from a problematic view that privileges particular conceptions of the ideas of level and hierarchy, which I fail to see as representative, and from a serious oversight of other, more constructive approaches (although these approaches are often admittedly outside standard philosophical literature) (Umerez, 2016, pp. 67–68). Referring to the "widespread suspicion in the philosophical literature regarding the legitimacy of considering inter-level relations," especially from top down, I have maintained that "an oversight of the very relevant scientific approaches and a restricted rendition of the concept of levels of organization are two motives" for such rejection of levels and hierarchy (Umerez, 2016, pp. 65–66).

Next, I have also argued that in some current renditions of the idea of (biological) level, the issue of "organization" is taken for granted. In particular, the basic notion of "composition" employed turns out to be too general and weak to account for "organization" (as in "levels of") (Umerez, 2016, pp. 80–81). In addition to more specific concerns about the concept of composition (such as Eronen's 2013 and, more detailed, 2015 criticism of the notion of "component" and "same-level criterion"), I have addressed, in an opposite direction, a more basic concern implying that the mechanist approach of, for instance, Craver and Bechtel (2007) is not actually a purely compositional one, but involves other traits or characteristics that make it a very special kind of composition (i.e., *organizational*). This reading, on the one hand, might constitute a response to certain criticisms against levels (such as Eronen's) but, on the other hand, it could also compromise the exclusion of interlevel relations from causal consideration (upward and downward) by virtue of being allegedly just constitutive in a plain sense. A similar suspicion and possible way out also affects some aspects of the proposal of organizational closure as "an emergent causal regime" using the notion of "configuration" by Mossio et al. (2013) and Moreno and Mossio (2015, chap. 2).[1]

In both cases, the central concepts involved are always introduced with explicit qualifications: *mechanisms* are *organized* collections of activities and entities, and *configurations* are whole sets of inherent AND *relational* properties of the constituents.[2] The difficult issue is where to ground the organizational or configurational nature of those groups of components such that they are different from "mere aggregations" BUT are accounted for just in terms of composition (this being the premise used to dismiss relations of downward causation—general or reflexive—reinterpreted as merely constitutive).

In Umerez (2016) I made an attempt to clarify the notion of level, that is, *level of organization*, in biology (recapped from Umerez, 1994). In this work I provided a reconstruction of the concept, articulated around five features that indicate kinds of relations between elements giving rise to some specific form of level arrangement. Those features include *composition*, *integration*, *emergence*, *control*, and, encompassing them all, *organization*. The reconstruction is articulated because it is built around a common but abstract criterion—kind of relation—and goes from the more general to the more specific, providing a progressive specification of the concept of level in which each additional form of relation includes the previous one, but not vice versa, in a manner that is reminiscent of Salthe's (1993) representation of a specification hierarchy: {composition {integration {emergence {regulation {organization}}}}}.

I supplemented this with a detailed examination of what is involved in the relation of composition considering four (nonexhaustive) aspects: (1) nestedness, (2) partial ordering, (3) homogeneity and heterogeneity of component parts, and (4) the discreteness or continuity of the arrangement. According to this analysis of composition, I claim that it does not permit, just by itself, distinguishing organized sets of components from mere aggregates (too unspecific a relation) and that, therefore, something else is involved, since neither "organized collections" nor "configurations" can be taken as primitives or as given. This "something else involved" amounts precisely to nontrivial causal relations at different levels: specific and precise interlevel causal relations that bring about *organization*:

> Therefore, when considering organization, we are referring to complex systems implying some form of interrelation among elements that goes well beyond mere composition: such systems manifest integrated global emergent properties, capable of regulating the behavior (dynamics) of their constituents. (Umerez, 2016, p. 75)

This brings us to the next issue with respect to current accounts and debates about levels and hierarchies: that of how to interpret the relation among levels. But first, let us introduce Pattee's approach with some detail, in order to examine how the concepts of constraint and control hierarchy were proposed and used with the purpose of understanding and explaining biological organization and complexity. While he was not, of course, the only one to address the issue in these terms, Howard Pattee is commonly acknowledged to have opened this path and to have provided a well-grounded and comprehensive account of these notions and related concepts. For instance, both groups of authors mentioned in this section refer to the work of Pattee and, in particular, to his elucidation of hierarchical control based on the concept of constraint. In the case of the organizational approach of Moreno and colleagues, the influence of Pattee has always been acknowledged as one of the central cornerstones of the very approach in the collective work of the IAS Research group, particularly in their application of the concept of constraint and other related ideas (like that of dynamical decoupling). In the mechanist camp, explicit recognition by Bechtel of this inspiration is found in virtually all of his recent publications incorporating control.[3]

Other authors are also involved in this recovery, for instance, Hooker or Korn, to mention just two cases that single out Pattee's contribution and, specifically, his analysis and elaboration of the concept of constraint. Dealing with various inadequate hierarchical descriptions, Korn (2002) states that "the one exception to this confusion is the work of Pattee (1969) in which a hierarchy is described as a descending arrangement of constraints" (p. 200), reaffirming this credit in Korn (2005, p. 138). More influential in the philosophical discussion is the assessment by Hooker (2013), who, in a paper that highlights the role played by constraints to understand complexity, said that "it was Pattee who emphasised the importance of constraints, especially of such coordinated constraints, to biological organisation and evolution" (p. 761).

14.3 Pattee and the Wider Context of the Debate

As I anticipated in the introduction, this analysis is concerned with the conceptual role of the ideas of control and constraint, in the specific rendition of them formulated by Howard Pattee, because I think it may help to illuminate two relevant issues. On the one hand, it illustrates the possibility of a hierarchical approach with levels of organization free of some of the problems of definition and practical use that have been attributed to both terms (level of organization, hierarchy). And, on the other, it simultaneously suggests an alternative and precise way to interpret the notion of interlevel relation and the derived issue of causation.

Let us recall that the deflationary distrust and disaffection with the concepts of level of organization and hierarchy are justified with the indictment of their alleged ambiguity, plurality, and potential confusion of meanings. I have previously questioned, as have others (Brooks, 2017), whether this reaction is justified or instead is derived from focusing on particular accounts of those concepts while overlooking others. Besides, this very suspicion is not in itself novel and has its own antecedents. I have previously noted (Umerez, 1994), among many others, for instance, Bunge's stern analysis of both terms "level" and "hierarchy" in the 1960s/1970s, a time that witnessed a great interest on issues related to hierarchy and levels of organization.

But here I would rather recall Marjorie Grene's participation in the 1968 *Symposium on Hierarchical Structures* (Whyte et al., 1969). Grene had at that time already addressed the issue of levels in biology (Grene, 1967), dealing with ontological as well as epistemological problems regarding "levels of reality." In her short contribution, she starts by sharing a very general impression of most of the participants, stating: "To a philosophical observer, the first lesson of this conference was that the use of the word 'hierarchy' is strikingly equivocal. In diverse disciplines, it signifies diverse concepts" (Grene, 1969, p. 56). As the symposium distributed its content into three parts—inorganic, organic, and artifact hierarchies (following an initial one dealing with the concept itself)—Grene continues her analysis by comparing biologists' to astronomers' usage of the term. She notes,

> Biologists on the other hand, when they worry about hierarchical organization in living things, are concerned about (at least) doubly determinate systems: systems such that an arrangement of the elements comprising the systems constraints the behavior of the elements themselves, the controlling order thus constituting an upper level (not necessarily larger, however) in relation to the elements so ordered, which, in turn constitute a lower level of the system. Dr. Pattee's definition characterizes this kind of situation quite clearly. (Grene, 1969, p. 56)

She ends the observation by adding that the interest of people working on artifacts is closer to the biological sense.

There is another key insight by Grene I would like to recall here. When dealing with Bunge's strict analysis and its eliminativist corollary (Bunge, 1969), Grene (1969) points out that "by this excision [of looser meanings of hierarchy] he would, it seems, eliminate *all* the uses actually made of the term by all the scientists concerned. … Such a drastic revision of scientific–and philosophical–vocabularies, however, appears ill-advised" (p. 57). The reasons she gives for not following Bunge's exhortation are, I think, as accurate now as they were then: on the one hand, she thinks that philosophers should not (she says "cannot") try to be prescriptive regarding the use of scientific terms, and on the other, she argues that a clear disclosure and explanation of the different meanings in different contexts (or usages) should solve the problems involved in the term's meaning. She also adds a more substantive reason, which might perhaps be susceptible to stronger contemporary criticism, yet is worth considering: she thinks that the several meanings have something in common: "In every case there is *ranking* of some kind; in most cases, moreover, it is a ranking of *real* entities or of levels of organization" (Grene, 1969, p. 57).

Regarding this last appraisal, I would like to explore the issue, not of what hierarchies in general have in common, but of what the hierarchical arrangement in living systems has at its core in the terms of the epigraph of this chapter: *control as the basis of organization*.

14.4 Pattee's Early Introduction of Control and Constraint

Let us then examine some of the contributions made by Pattee, one of the main theorists in the 1960s/1970s, a time when the issues of hierarchy and levels of organization, if we may say so, reached a peak. Pattee has not defended or advocated anything like a traditional layer-cake view (an object of much of the current criticism) or a merely compositional approach (focus of most of the deflationary views). Pattee, together with other contemporaries (for instance, Robert Rosen), set out a different research program establishing that the central problem in the study of hierarchies and levels of organization was not as much the structure, specifying which levels are in a fixed ordering, but the relation between levels, understanding how they originate and interact (*hierarchical interfaces*).

In fact, Pattee has not endorsed any version of those textbook modern "scala naturae" pictures depicting the series from atoms to biosphere. The few times in which he presents what most closely resembles a "list" of hierarchical levels of control (levels of organization), for instance, in Pattee (1971b), where, under the heading of "biological examples of the problem," he includes the following: genetic code, developmental controls, integrated cognitive systems, and language structures (pp. 257–260). Even here (as in general) he is more concerned with the "hierarchical interface" than with defining the levels themselves. More recently Pattee (2009), when recalling the role of complementarity in his work on hierarchies, comments on the need to specify the domain being analyzed:

> The concept of complementary hierarchical models is essential for modeling complex systems (e.g., Pattee 1973a). Every level of biological organization requires a different operational definition of information and interpretation. It should be clear that a model of the cell's interpretation of molecular information in the gene must be different from a model of the brain's interpretation of the information in this sentence. It is a waste of time arguing over concepts like information, interpretation, and function without specifying the domain of the model. (p. 296)

The same final warning also applies to the very concepts of level or hierarchy.[4] In this sense, Pattee was very clear about his specific aim quite early on. As he has stated more than once, his interest in hierarchies stemmed from the necessity to address conceptual difficulties found in his research on the *origins of life*. As a physicist dealing with the "highly unlikely and somehow arbitrary constraints which harness these laws [of Physics] to perform specific and reliable functions" (Pattee, 1970, p. 117), he focused on studying the origin and nature of hierarchical controls in biological systems (and limited accordingly his use and analysis of the idea of hierarchy). He explicitly introduces this specific aim at the opening of his first published work on hierarchies:

> The origin of life problem is the context in which I began thinking about hierarchies. The origin of life is perhaps the most mysterious hierarchical interface of all, but at the same time I believe it may present one of the most instructive approaches to general hierarchical control problems. This is because the lower level pre-life processes are ordinary physics and presumably subject only to precise laws which do not include extra hierarchical rules or constraints. However, to be recognized as "alive" a collection of matter must exhibit some additional integrative function by exerting a collective control over the individual molecules. This integrative function is what characterizes *hierarchical control*. (Pattee 1969a, p. 161)

Let us then address the question of control in his work, an issue Pattee has dealt with since his first papers. Indeed, Pattee (1961) deals already with genetic controls in quite a standard way. But in his contribution to a volume on *Advances in Enzymology and Related*

Subjects of Biochemistry, he points already to the concept of *control* in order to understand the origin of life:

> Consequently we may expect that the origin of life problem will shift away from the evolution of the building blocks and the elementary operations of joining them together, to the more difficult problem of the *evolution of control* in complex organizations. This problem is more difficult because the idea of "control" is not defined in the same sense as we can define biochemicals.... From this point of view, the question of the origin of life becomes the problem of understanding elementary molecular control processes, and of formulating a theory of the evolution of molecular control. (Pattee, 1965b, pp. 405–406)

At the other end of his publishing trajectory, Pattee eventually introduced the three key concepts in the title of the book that compiles some of his papers—law, life, and language—in terms of control. In particular, the first two appear as opposites, law as absence of control, and life as characteristic of "*individual* organisms with *variable heritable controls*" (Pattee, 2012a, p. 3). In between, we find a corpus of work devoted to understanding life by clarifying the kind and nature of those processes of control[5]—and to elucidating the means, processes, or devices by which this relation of control among levels is exerted and materialized physically in biological systems in the form of *constraints*.

The first use of the concept of constraint, already suggestive of what became his characteristic treatment, is found in the chapter on "Physics, Automata, and the Origin of Life" contributed to the Symposium on Fundamental Biological Models, entitled *Natural Automata and Useful Simulations*, the proceedings of which he edited (together with Edgar A. Edelsack, Louis Fein, & Arthur B. Callahan) in a book with the same title of the symposium (Pattee et al., 1966). This paper is an attempt to study hereditary processes from a physical standpoint and describes the molecular models of replication based on tactic copolymerization that he was developing during those years.[6] He introduces the concept of constraint to help define hereditary models, distinguishing already between holonomic and nonholonomic constraints (see next section), applied to simple mechanical models (from a inclined plane with one mass rolling down, to another with several masses rolling down, and to a more complex one that includes an escapement delaying the movement of the masses) or other automata models as growing helical chains, which he had worked on previously as *molecular sequence computers* (Pattee, 1961).

Next, he introduces the idea of a *classification process* as necessary for understanding hereditary processes (Pattee, 1967). This new concept is defined in terms of the operations of nonholonomic constraints, and he already singles out the enzyme as the main materialization of this kind of constraint in natural (not artificial) domains.

> In terms of molecular reactions this non-holonomic condition implies that the number of energetically possible states is larger than the number of reactions actually available to the system. Now the chemical reactions which are available as distinct from those which are energetically possible can differ only in the activation energy and entropy, so that we are led to associate classification or hereditary propagation with the control of rates of specific types of reactions. Of course in cells the epitome of such specificity and catalytic control of reactions is the enzyme. (Pattee, 1967, p. 416)

Then, as he has recalled several times, Grene introduced him to Polanyi's work (1968), and the ideas he had been developing in previous years regarding the specificity of living systems in terms of the basic difference between law-based and constraint-based behavior or phenomena began to adopt the form of an explicit hierarchical theory:

What I call symbolic constraints on a lawful dynamics Polanyi (1968) calls special boundary conditions that “harness” dynamical laws. My hierarchy theory was an elaboration of Polanyi’s concept of the functionally irreducible hierarchical levels of boundary conditions. (Pattee, 2012a, p. 24)

From this moment on, the next decade would see the elaboration of his ideas about hierarchies and levels of organization in an attempt to rigorously characterize the nature and origin of interlevel relations adopting the form of control (functional hierarchy). He would use all these concepts derived from mechanics in order to accomplish this goal.

14.5 Interlude: Basics from Mechanics

As has been repeatedly noted, Pattee grounds his approach on very basic concepts pertaining to the physical sciences, particularly mechanics. In order to account for the dynamics (behavior) of any physical system (biological systems being a special case of physical systems), he reminds us that, in principle, we simply need to know the initial conditions and the laws of motion. Leaving aside for a moment the issue of measurement implicit in the procurement of those initial conditions (subsequently expressed as records and therefore of a symbolic nature), we should, at least, address the question of an *alternative description*, which is at the core of Pattee’s hierarchical perspective and is derived from the use of the concept of constraint, as is done in physics.

Physical laws and initial conditions: It is well known that, in physics, initial conditions and laws of motion provide an exhaustive description of the possible behavior—future and past—of a mechanical system. In principle, there is no need to add any other condition, as this would be redundant. The choice of the coordinates of the system that specify its configuration or state space defines all the possible degrees of freedom of the system or all the possible trajectories of its elements. These coordinates establish the variables of the motion equations of the system. Laws of physics are usually expressed in the form of differential equations with respect to time based on energy principles or in the form of other equations derivable from these (except, e.g., the mathematical relation between classic and quantum laws). From the principles of conservation or invariance, we derive the laws of movement, which are independent from any particular configuration of initial conditions. Laws of motion, then, tell us that the state of the system will change in time in a certain way. In this sense, laws of nature are, in principle, inexorable and incorporeal.

Constraints: Any other description of the behavior of a physical system that is not a detailed microscopic description requires additional, or auxiliary, conditions. In principle, this situation is solved in classical mechanics by introducing additional equations called constraints. Such constraints are the result of relatively permanent forms or structures that limit the degrees of freedom of the system. The purpose of this addition is to simplify the study, description, or calculation of the behavior of a given system at macroscopic scales (while quantum mechanics can resort to the notion of steady state, classical mechanics need them to explain solid bodies and to explain other kind of constraints such as boundary conditions imposed onto matter in certain experimental settings and the fabrication of machines and artifacts). Constraints, unlike laws, must be the consequence of what we call some form of material structure such as molecules, membranes, or any kind of surface. These structures may be static or time dependent, but in any case, it is important to realize that they are made of matter that obeys fundamental laws of nature, in addition to behaving as constraints. What does this mean? If the laws of movement are complete and inexorable, what else can be said? Why is an equation of constraint not redundant or inconsistent? Here we have to realize that constraints cannot be treated as fundamental properties of matter. Unlike laws, that, as noted, are inexorable and incorporeal, constraints might be accidental or arbitrary and must have some distinctive physical materialization in the form of a structure of sorts. This is why we say that constraints are always *alternative descriptions* of part of the system (the same as measurements, incidentally). That is, constraints cannot be expressed in the same language as the microscopic description of matter. In fact, a constraint selectively ignores microscopic degrees of freedom in order to provide a simplified prediction or explanation of motion. In other words, the concept of constraint must represent a selective loss of detail, and therefore, in the realm of physics, the forces of constraint are inevitably linked to a new hierarchical level of description.

Thus, one of Pattee's main contributions is to distinguish and characterize two kinds of hierarchical relations—structural and functional—based respectively on two kinds of physical constraints: *holonomic* constraints are auxiliary conditions that limit permanently the degrees of freedom of a system and are, therefore, the basis for structural hierarchies, while *nonholonomic* constraints are variable auxiliary conditions that limit in time the number of degrees of freedom of the system, being the basis for the functional hierarchies typical of living systems. The latter are dynamical structures that establish time-dependent relations among degrees of freedom but introduce a different temporal scale (see Umerez, 1994; Umerez & Mossio, 2013, p. 494).

14.6 Pattee's Hierarchical Approach

With these conceptual elements imported from physics, Pattee launched himself into developing a hierarchy theory fitting his interests in theoretical biology. This is in part why I claim that in Pattee's work on hierarchy, we can find the foundation and potential development of a naturalist(ic) approach to biological hierarchical organization (Umerez, 2001, pp. 165–166). Accordingly, following the discussion above, he primarily developed the foundations of such a theory in a compact series of publications at the end of the 1960s and the beginning of the 1970s, culminating in an edited volume on the subject (Pattee, 1973a). It goes without saying that after this, he continued expanding and refining his account.

In his initial contribution to the previously mentioned 1968 *Symposium on Hierarchical Structures* he stated that the main basic characteristics of hierarchical controls are that they are autonomous in the sense that they produce their own rules, which are not externally imposed and are a fully-fledged part of the physical world; furthermore, they have a specific effect on individual elements of the collection (out of which they have arisen) and produce some integrated function of the collection as such (Pattee, 1969a, pp. 162–163). In a later paper, he lists more specifically "Some Properties of Control Hierarchies" (see Pattee, 1972, pp. 11–18).

With this original motivation in mind, Pattee develops an increasingly complex approach grounded on those basic concepts and distinctions taken from the language of physics (law/rule, initial conditions/boundary conditions/constraints, dynamics/record [measurement], rate dependent/rate independent, etc.) and extends it to more general epistemological issues (matter/symbol, observer, *epistemic cut*, etc.) in his attempt to give an account of the specificity of fully natural but nontrivial interlevel relations in biological systems. For this, he takes the cell as the basic instance and the enzymatic reaction as the paradigmatic process.

In a very illuminating conversation with Robert Rosen (and Raymond Somorjai) on theoretical biology, conducted by physicists Paul Buckley and David Peat (who in their Preface justify including a round-table discussion on theoretical biology in a book "otherwise concerned with the problems of physics" because the subject "has all the intellectual challenge and excitement associated with physics in the twenties"), Pattee makes clear the precise scope and aim of his view:

> My concept of hierarchy is very much more *limited*; it has to do with the alternation between descriptions and constructions, the idea being that at one level we have dynamical systems in the very general sense, that is, state descriptions and rate-dependent transformations between states which we then describe (or define, if you like) by the proper choice of observables. At another level we have rate-independent global or asymptotic structure, or, if you like, singularities or instabilities. One can label these things differently.… The two modes of description, which I call dynamic and syntactic, are complementary in the logical sense.… This is what I mean by hierarchy: it's an alternation of levels of description upon systems. Another way to say it is an alternation of continuity and discreteness. One can think of the external system as being continuous, obeying dynamics and having instabilities in the sense of continuous systems where infinitely small causes have large observable effects. Now, the *description*, on the other hand, is always a *course grained view* of this, a discrete view. (Pattee, 1979a, p. 118)

14.7 Articulation of Concepts of Hierarchy

Based on the distinctions introduced by Pattee, we can conduct an articulated analysis of the concept of hierarchy, similar to the one previously applied to the concept of level of organization, by using the kind of interlevel relation and, in particular, the type of constraint as a criterion of clarification of the intended meanings (Umerez, 1994).

Hierarchy, as *generic interlevel relation*, may be defined as *a transitive and asymmetric relation of partial order among the levels (more than one) that constitute a system*. This means that the elements entering the mutual relation are subsystems (intralevel relation) that are related among themselves as levels (interlevel relation), in a successive order within which such levels are lower with respect to the immediate higher level ("lower" and "higher" meaning just a relative position of succession in a partial ordering). Without this (mutually) relative order, there is no hierarchical disposition in any operative, defined, or nontrivial sense of the concept. I emphasize that these are merely the minimal conditions that any hierarchy must meet, since it implies only a generic relation of composition in which lower levels are related to higher ones insofar as the former constitute (make up) the latter. This relation then runs in one direction, that is, is unidirectional from lower to higher, without allowing us to talk properly of interaction (interrelation) in its fullest sense. The idea of hierarchy as a generic relation among levels is usually applied in the formulation of models of complex systems. In this sense, it is used to describe such systems out of subsystems (or elements) that are related among them by virtue of, for instance, the size or the number or elements, the intensity of connecting forces, processes or behaviors, temporal scales, or any other trait that might define the levels. Next, we take into consideration further conditions for adequately obtaining interactive interlevel relations, which are no longer so common and affect a more restricted range of hierarchical systems. The idea of interaction among levels as a more specific relation stems from the necessity to account for the reverse effect on higher levels on lower ones.

14.7.1 Hierarchy as Interaction: Global Constraint

Hierarchy, as *interactive* interlevel relation, is defined as *a relation of constraint in which higher levels limit globally and permanently (some) degrees of freedom of lower levels*. According to its characteristic, we will call this constraint and the kind of hierarchy it produces *structural*. This definition must be understood as complementary to the previous one, since it derives from it and therefore presupposes and specifies it. This means that not all hierarchies should meet this definition, but those that do must simultaneously meet the former one. This definition, on the one hand, *presupposes* the previous one because it is in the former that the sense of the lower/higher relation is determined and, on the other hand, specifies the former because it limits the generic relation to one of constraint. Constraint implies a composition relation among the components that produce it and adds a relation of limit onto those very components. Therefore, this relation, in contrast to the one previously described, is bidirectional. But it must be noted that it continues to be asymmetrical and transitive. It is just that now there will be a double asymmetry: one in the sense of composition and another one in the sense of the limitation. There are, then, two disjoint complementary relations that provide a fuller sense of interlevel relation.

The reference to this double transitivity introduces a further issue regarding the understanding of these kinds of constraints. Recalling the mechanical functioning of constraints, we stated that, in theory, laws and initial conditions are not only necessary but also sufficient elements to obtain a total description of the trajectories of a system. The introduction of constraints as auxiliary conditions is grounded on the possibility of making an alternative description of some of the variables of a given system. It is an alternative description that implies a simplification of the system under observation, because part of its dynamical details is ignored. The next case involves the other kind of constraint that represents the stricter notion of interlevel relation.

14.7.2 Hierarchy as Control: Specific Constraint

Let us now consider the concept of hierarchy derived from an interlevel relation in the form of an individualized constraint on specific elements. This is based on the sense of nonholonomic constraint. This type of specific constraint implies a variable action that imposes temporal limitations on certain degrees of freedom. Consequently, hierarchy taken as control relation can be defined as *a relation of constraint in which higher levels limit individually and in a variable way the degrees of freedom of specific components of lower levels*. According to its character, we will call this constraint and the kind of hierarchy it produces *functional*. Its variable and specific nature means that it operates a reduction of degrees of freedom that is selective and, therefore, should be understood in functional terms. In this regard, it is important to note that constraints, particularly functional ones, impose a reduction in the degrees of freedom of the elements of the system that revert to a simultaneous increase in the total degrees of freedom (of the system itself). Pattee often cites an accurate formulation by Stravinsky in his *Poetics of Music* that grasps the wider sense of this apparently paradoxical principle: “The more constraints one imposes, the more one frees one’s self of the chains that shackle the spirit…and the arbitrariness of the constraint serves only to obtain precision of execution” (quoted in Pattee, 1971b, p. 256; 1973b, p. 74; 1981, p. 127).

In less poetic terms, the source of this increase in degrees of freedom stems from the classificatory action of variable constraints. By acting selectively and temporarily, they introduce new distinctions that, although reducing the original variables of the system, extend the state space with respect to other additional parameters. That constraining action adopts the form of selection and classification in a way that it creates new distinctions where there were none previously. When the degrees of freedom of individual elements are limited, particularly when it is done specifically through control constraints, the variety of differentiated behaviors increases along with, in general, the variety of options of the global system. Therefore, the general significance of constraint, as an alternative description, acquires in this case an even greater relevance, since, in contrast to structural constraints that are integrable in the general coordinates of the system, functional constraints are not and instead entail a redefinition of the system. In sum, in this case, constraints produce not only a reduction in degrees of freedom in the system but also a classification among its elements.

14.8 Hierarchy, Interlevel Relation, and Control

Having revised the conceptual constituents of constraint-mediated control hierarchy, we can come back to the initial issue and discussion opened at the beginning of the chapter. I argue that depriving the hierarchical arrangement or the relations among levels (of organization) of any causal relevance has been another factor promoting deflationary accounts that quite naturally follow from that renunciation. However, as advanced in the first sections, some of the authors who provided an alibi to this reaction have begun to revise or widen their views by explicitly incorporating the issue of control into their approaches. I will concentrate here, again, on Bechtel, as well as on Moreno and coauthors.

Whether dealing with the compositional (Bechtel) or configurational (Moreno et al.) aspects of organization, each asserted that interlevel causation is not necessary because it collapses into constitutive relations. Instead, causation was reserved for intralevel relations within a system or to generic relations between different systems, which then might be at different levels.

As is well known, Craver and Bechtel (2007) clearly asserted that “[on] our view, the interlevel relationship is only constitutive” (p. 562), and interpreted interlevel causes (both bottom-up and top-down) as “mechanistically mediated effects.” Mechanistically mediated effects are “hybrids of causal and constitutive relations,” in which causal relations are exclusively intralevel, and interlevel relations are only constitutive. In response to understandable presuppositions, Bechtel disclosed his former reluctance:

> Mechanisms, after all, behave as they do because of the operations of their parts, and is natural to construe this relation as causal. Certainly, there are relations between levels within a mechanism… . But there are good reasons not to characterize the relation between a mechanism and its parts causally. The notion of causation commonly entails a number of associations that do not comport well with interlevel relations. (Bechtel, 2008, p. 153)

In turn, Mossio et al. (2013) have interpreted part–whole relations as a kind of "relational mereological supervenience," involving in a complex way an intermediate stage of *configurations*. In this view, organizational closure is defined as a network of constraints where emergent causal powers are derived from constraints but without proper interlevel causation, which is taken to be a constitutive relation. They do this because of their constitutive interpretation of relational supervenience and a configurational interpretation of emergence (where, as we have seen before, configurations include both the inherent and relational properties of the constituents in certain contexts).

These consequences regarding the nature of interlevel relations are consistent with their understanding of composition seen above. Nevertheless, when considering issues of control (or regulation), Moreno (et al.) are willing to assume that causal relations may be identified between the controller and the controlled, situated at different levels within the system. This was already present in Moreno and coauthors' previous work (summarized in Moreno & Mossio, 2015, pp. 28–37) and has also recently been incorporated by Bechtel into his extended "account of causality in biological mechanisms" (Winning & Bechtel, 2018, p. 290).

Bich et al. (2016), in turn, offer a detailed analysis of biological regulation and argue that we need to distinguish between *dynamical stability* and *regulation* as two different forms of control mechanisms that help to maintain biological organization in the face of perturbations.[7] The second regulation implies a hierarchical distinction between the controller and the controlled, which are located at different levels and are of a different nature:

> Our thesis is that the robust and adaptive behaviour of living systems requires more complex mechanisms than those ensuring basic network stability; mechanisms that specifically rely on the asymmetry or hierarchical distinction between controlled and controlling subsystems. We propose to use the term "regulation." (Bich et al., 2016, p. 239)

Both kinds of control (in their terms) are exerted through different kinds of constraints, respectively constitutive or regulatory, implementing first-order control in the case of dynamical stability or second-order control in the case of regulation (also their terms). But again, the main point is that the latter requires a distinct module or subsystem that is *dynamically decoupled* from the regulated one, acting at different rates and thus independently (Bich et al., 2016, pp. 239, 253–258).

I cannot discuss here in detail whether this view of strict regulation (control in my terms) is consistent with an in-principle denial of the existence of intrasystem interlevel causation (what Mossio & Moreno dubbed *nested causation*) or to which extent this view of regulation through hierarchical constraints (since it is not intralevel) should be interpreted as a constitutive relation (unless is taken as external to the system). The discussion should, rather, center on whether and in which cases such control (regulatory) mechanisms (i.e., the constraints) are formed out of those very components and activities of the lower-level dynamics that they contribute to control (i.e., regulate). Moreno and Mossio (2015) say that, in the absence "of any compelling argument in favour" of "the possibility that biological organisation might involve nested causation," they defend the constitutive interpretation (pp. 58–61). I wish here instead to recognize the importance of including the notion of control as a fundamental hierarchical kind of relation among different levels of organization.

The same applies to Bechtel's incorporation of hierarchical control into his account. In a recent paper, he identifies as a limitation of the neo-mechanist approach the fact that it has not recognized the importance of control (Winning & Bechtel, 2018, p. 307) and proposes to include it as a third type of relation:

> Mechanist philosophers have construed this relationship in terms of either composition or causation (i.e., causal production). But there is a third type of relationship that often exists between processes in mechanisms—control—which has important implications for understanding the nature of mechanisms and mechanistic explanation that have not yet been fully appreciated. (Winning & Bechtel, 2018, p. 288)

In an accompanying footnote, the authors remark that classifying control as a third type of relationship does not imply a suggestion “that control is non-causal.” Adopting this third kind of relationship calls for a review of interlevel relations as well:

> The notion of top-down causation has been fraught with controversy. Much of this turns on the notion of levels employed. What is it for one entity or causal process to be located at a higher level than another? In the context of biology and neuroscience, an important sense of level arises in the context of control–a controller is at a higher level than the system it controls. (Bechtel, 2017b, p. 203)

In this accompanying footnote, besides crediting Pattee, Bechtel states that hierarchical control is a very important notion regarding top-down causation (Bechtel, 2017b, p. 221). The inclusion of control relations in the mechanist account and its consideration as a form of top-down causation by Bechtel does not necessarily imply by itself a change in his previous position about interlevel causes (within a system). It may, however, at least make room for further conceptual schemes beyond composition and intralevel causality.

Moreover, we see in both the mechanist and the organizational approaches that the relation of control through material constraints plays a key role in identifying and accounting for levels in a very specific and operative way, as controller and controlled. This notion of levels is neither ambiguous and limited to controversial compositional interpretations nor related to layer-cake and universal presuppositions (see, e.g., Brooks, 2017, for the latter). Thus, regardless of the constitutive interpretation of some interlevel relations, the main point here is the relevance of constraints and of control hierarchies in dealing with biological organization. In fact, understanding how constraints and control hierarchies work might help us to better elucidate the nature of interlevel relation with respect to causation, which is the subject of much confusion and controversy.

14.9 Conclusion

In this chapter, I have introduced Pattee’s approach, discussed its relevance for current debates, and used some of his insights to extract consequences regarding the nature and interpretation of hierarchical organization and relations among levels of organization in biological systems. One of these consequences is to place the relation of control, originated as an autonomous nonholonomic constraint, at the very center and basis of the idea of organization, as used in “biological organization” or “levels of organization.” Another is that it may help to assess whether and in which sense we may characterize this relation as causal.

In a sense, this approach is one response (among potentially others) to the demand for a description of specific and precise usages of hierarchy and levels of organization. Moreover, even if it is somehow restrictive in its definition and range of application (biological systems), it aspires to have a certain degree of more general applicability. This potential generality derives from the fact that, as far as we limit ourselves to levels of organization in biological systems, we can postulate that in all cases we have to refer, at least implicitly, to levels in the terms stated in this chapter: as having at its core a relation of control as an organizational principle. One final consequence, then, would be that by incorporating the idea of control through material constraints, we can make sense of the relation between levels in a system in both directions, upward and downward, each being different but complementary. In both cases, we are now able to characterize specific relations of constitution and specific relations of control in ways that are mutually dependent, bidirectional, and asymmetric because when the direction of the specific relation is reversed in our analysis, it is due to a different criterion or principle.

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Notes

1. This and other differences of interpretation are part of the ongoing debate among members of my own research group (IAS-Research), in the development of the specific *organizational approach* to biological systems that we share.

2. See Love (this volume) for a different account of specific stable configuration states as levels of organization. This account relates the recognition of such configurations specifically to transitions and the relationship between cell and tissue levels, exposed and defined through manipulation practices.

3. Bechtel (2017a, p. 256), Bechtel (2017b, p. 221, n.1), Bechtel (2018, p. 575), and Winning and Bechtel (2018, p. 290).

4. I have previously adopted and emphasized this aspect: "The biological scope of our approach explains the restricted use of these terms to the cases of hierarchies in which levels interact not in a trivial or just lawful way, but in a specific way as autonomously originated rules exerting an arbitrary control over the lower level dynamics" (Umerez & Moreno 1995, p. 142).

5. And other more complex epistemic and semiotic aspects that turn out to be intricately connected, but which I will not be able to elaborate here. As I have said elsewhere, there is no proper substitute to reading Pattee's papers (Umerez, 2001, p. 160). For further analysis of some of those aspects, see also Umerez (1995, 1998, 2009).

6. He has developed some of those automata models in other papers, such as Pattee, 1961, 1965a, 1965b, and he describes them again in Pattee (1968a) and in his contributions to the first and second meetings of the symposia *Towards a Theoretical Biology*, organized by Waddington (Pattee, 1968b, 1969b).

7. I will not dispute here the choice of words, making "control" the generic term encompassing both kinds of processes and redefining "regulation" in a stricter sense. It seems that we could easily take the reverse option by using regulation as the general and reserving control for the more specific and demanding, as we more frequently see in the literature.

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