ISSN: 2996-962X

Research Article

Archives of Biology & Life Sciences

About Organisms. A Teaser

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Submitted: 2024, Feb 08; **Accepted:** 2024, Mar 03; **Published:** 2024, Mar 21

Citation: Burgstaller, W. (2024). About Organisms. A Teaser. *Archives Biol Life Sci, 1*(2), 01-07.

Abstract

Organisms are the central research objects in biology. Therefore, we should try to think about the question, what an organism is. The following text is a teaser trying to illuminate this question from the perspective of older authors from the 20th century, but also considering work from the 21th century. Thereby, topics such as the meaning of the term organization, closure to efficient causation and constraints, and the question whether an organism can be regarded more as a thing or more as a process are touched upon.

Keywords: Organization, Closure to Efficient Causation, Closure of Constraints, Organizational Closure, Thing, Process

1. Introduction

This text is intended as a teaser. Systematic presentation, stringent logic of argumentation and completeness are therefore not my goals, rather a meandering through the topic guided by my own associations (one could also say: by an "inner" logic). For this I want to rely more on quotations than on my own words. These quotations are intended to encourage the reader to take a closer look at the respective authors and their work.

Superficially considered, the term "organism" undoubtedly has something nebulously-mystical about it. One has the vague feeling that this term describes something important, but cannot say exactly what this importance consists of. Etymologically, of course, one can state: the organism is the organized. But how is an organism organized? What distinguishes an organism from a crystal, the solar system, or a machine, all of which are also organized? Can we even hope to understand how an organism functions "as a whole"?

Why should we even think about the term „organism“? (i) Because the knowledge that could be expected to be gained would decisively change the approach to the scientific study of organisms and would undoubtedly make it more realistic; (ii) Because it could deepen our understanding of ourselves as human beings and put it on a new footing; and (iii) Because it could give us a new understanding of health and disease. Apart from these hoped-for gains in knowledge, it is simply exciting to explore where such a reflection might lead us.

Other authors (see the following paragraphs) also emphasize that it is important to think about such questions of theoretical biology, as, for instance, what an organism is, questions which are at the border between biology and philosophy. This is true not only for theoretical biologists but also for “pure” experimentalists (which of course do not exist).

An inexhaustible and inspiring source in this respect – both for theoretical concepts and for concrete examples – is the two-volume work "Theoretical Biology" by Ludwig von Bertalanffy (Bertalanffy 1932, 1951). In the first volume, Bertalanffy covers the basics of an organismic theory, physicochemistry, and the structure and development of organisms. The second volume deals with the system organism, metabolism and growth. In his book “Das biologische Weltbild” Bertalanffy (1949) says on the necessity of philosophical reflection for biologists:

"On the other hand, however, the basic biological attitudes [of the researcher; WB] determine the problems that the researcher sees in the first place; they determine his research question, his experimental procedure, the choice of methodology, and finally the type of explanation and theory given for the phenomena studied. In fact, the dependence on prevailing attitudes is only the stronger the less conscious it is." (Bertalanffy 1949, Das biologische Weltbild, p 32; translation WB)

Woodger (1929; p 477) says on the same subject: „… because no investigator works or can work without some theoretical background however hypothetically it is entertained.“ And by quoting Whitehead (Woodger 1929, p 4): „To neglect philosophy when engaged in the re-formation of ideas, is to assume the absolute correctness of the chance philosophical prejudices imbibed from a nurse or schoolmaster or current modes of expression. It is to enact the part of those who thank providence that they have been saved from the perplexities of religious inquiry by the happiness of birth in the true faith.“

More recently, Hofmeyr (2017) emphasized, in order to counteract a one-sided, reductionist understanding of biological research: „It is clear that philosophical considerations can and should make an important contribution to keeping systems biology on the right track. There is a well-developed field of systems philosophy […] and systems biologists would do well to make that required reading for themselves and their students“. This is intended to promote the all-important holistic approach and to underscore the importance of this "philosophical lens" alongside the "reductionistic lens of molecular biology" and the "historical lens of evolutionary biology."

2. Organisms are Organized 1: More Than Chemistry and Physics and Molecular Biology

Fitting in retrospect, my seventh and eighth grade high school biology textbook was entitled "The Organism." As a student, I didn't realize how central the organismic concept is to biology. During my professional work as a microbiologist and fungal physiologist, I kept coming across "organismic" aspects, both with older authors such as Ludwig von Bertalanffy, Joseph Henry Woodger, Kurt Goldstein, the members of the "Theoretical Biology Club" from the 1930s, Jean Piaget, and Conrad Hal Waddington, as well as in more recent literature (see the following sections). Again and again, I have been captivated by attempts to describe the essence of the difficult term “organism”.

The first thing that comes to mind when one reads the term "organism" are large, multicellular living beings like animals and plants. But single-celled living things, such as bacteria, yeasts and fungal mycelia, are also genuine organisms. At this point I would like to cite a definition of the term "organism" given by the physicist and philosopher Mario Bunge and the zoologist and philosopher Martin Mahner in their book "Foundations of Biophilosophy" (Mahner and Bunge 1997). I came across Mahner and Bunge's book late in my professional career, following a hint from my friend and colleague Reinhold Pöder, but was immediately intrigued by the clarity of concepts as well as presentation in this book.

„An elementary biosystem is any biosystem such that none of its components is a biosystem.“ (Mahner and Bunge1997, p 147)
„A composite biosystem is any biosystem composed of (at least two elementary) biosystems“ (Mahner and Bunge1997, p 147).
„An organism is a biosystem (whether elementary or composite) which is not a proper subsystem of a biosystem.“ (Mahner and Bunge1997, p 147).

These are rather "formal" definitions, but they are based on a less formal, more substantial definition of the term "living system" (Mahner and Bunge 1997, p 141 pp). Rendered in my own words, according to Mahner and Bunge, a living system is characterized by the following properties: it consists of proteins, nucleic acids, carbohydrates, and lipids; it has a metabolism, can maintain a certain intracellular milieu (homeostasis), and can maintain and repair itself; it has a flexible and semi-permeable boundary layer; it can use and store "free energy"; all control systems are interconnected or networked by chemical signals.

Implicitly, every biologist assumes that what we call "organization" is THE essential feature of an organism. And in almost all physiological experiments we destroy this very feature by our methods of investigation. But although the results of such experiments may be clear and unambiguous, they tell us little about the behavior of the investigated structures and functions studied in an intact organism. We cannot escape this dilemma. This is precisely the reason why we urgently need the organismic points of view for our research, in addition to the reductionist point of view.

Bertalanffy remarks on this: "... but the biologist must consider the organism as a whole. […] we may, with Woodger (1929, p 263), call this limit of the chemical approach that of organization” (Bertalanffy 1932, p 49, 50).

"A living organism is a system, organized in hierarchical order, of a large number of different parts, in which a large number of processes are so ordered that by their constant mutual relation within wide limits, in the case of constant change of the substances and energies building up the system itself, as well as in the case of disturbances caused by external influences, the system is preserved or produced in the state peculiar to it, or these processes lead to the production of similar systems." (Bertalanffy 1932, p 83).

"Since the basis of life is organization, the characteristic of life processes is their order, the study of the individual substances and processes in the organism, even their most penetrating, physico-chemical analysis cannot mean a complete explanation of the phenomenon of life. This way of working misses the essential characteristic of the living: namely, that the processes in the organism are so ordered that they guarantee the preservation of the whole. [...] A system-law for the organism as a whole is therefore what must be added to the explanations of the individual processes." (Bertalanffy 1932, p 115).

"... for a natural thing without organization and without its maintenance in alternation on the basis of conditions located in the system itself is not a `living organism'." (Bertalanffy 1949, p 124 ff). Woodger (1929, p 287, 290), in his chapter „Theory of Biological Explanation“ starts with the notion that “… the molecules with which the biochemist deals do not exist in nature.“ He then states that it is „… a clear recognition that organization above [italics by Woodger] the chemical level is of great importance in biology“. From this it follows that: „Is it not the first *fact* [organization, W. B.] which strikes us about organisms? Is it not a bare analytical judgement (in the Kantian sense) to say that organisms are organized?“

„If the concept of organization is of such importance as it appears to be it is something of a scandal that biologists have not yet begun to take it seriously but should have to confess that we have no adequate conception of it.“ (Woodger 1929, p 291). This is still true today.

„… since an organism is an organism from the start (if it has a start) whereas the house is not a house until it is finished. Organisms are not `made´ they do not even `develop´ […] Organisms merely persist – for a time.“ (Woodger 1929, p 294).

„By a cell therefore I shall understand *a certain type of biological organization* not a concrete entity.“ (Woodger 1929, p 296). „… so that the properties of a part are different when it is in its place in the organic hierarchy from what they are when it is removed from it.“ (Woodger 1929, p 310).

„… distinguished from an aggregate by the nature of the relations between its parts.“ (Woodger 1929, p 310). „But from what has been said about organization it seems perfectly plain that an entity having the hierarchical type of organization such as we find in the organism requires investigation at all levels, and investigation at one level cannot replace the necessity for investigations of levels higher up in the hierarchy.“ (Woodger 1929, p 316).

Rosen (1991, p 155) stated „… a system is organized if it autonomously tends to an organized state “A material system is an organism if and only if it is closed to efficient causation“. Piaget (1992, p 97): „…the concept of organization has finally been recognized as the central one in biology.“ Athel Cornish-Bowden et al. (2004) stated: „… a proper understanding of the nature life will require metabolism to be treated as a complete system, and not just as a collection of components.“

Hofmeyr, J.-H. S. (2007, p 217): „… an organism is a system of material components that are organized in such a way that the system can autonomously and continuously fabricate itself, i. e. it can live longer than the lifetimes of all its individual components.“ Koutroufinis (2019, p 54, 60): „Organisms are the only physical entities that can form and maintain their own shape by changing their components. [...] The material structure of the organism on the one hand and its material and energy production on the other hand are so intertwined that no continuous separation of causing and caused processes is conceivable".

Nicholson (2018, p 159): „Organisms, on the other hand, exhibit a dynamic organization in the sense that their form […] reflects a stabilized pattern of continuous material exchange with their environment. Organismic organization is dynamic in a further respect, namely in ist capacity to modify itself so as to compensate against external perturbations.“ The core characteristic is, as Hofmeyr (2017) puts it: "... taking seriously their organization into a living whole". In this context, one should not be deceived into thinking that measuring all cell components in real time and under different conditions automatically leads to an understanding of what a cell does and is. Hofmeyr (2017) calls this the "omics delusion." This would only be "... good old reductionistic biology in a new guise" (Hofmeyr 2017).

What is needed, is stated in the title of the article of Nicholson (2014): „The Return of the Organism as a Fundamental Explanatory Concept in Biology.“ And further: „In a way, it is the organism itself that adjucates the ascription of functions to its parts according to how they help it meet its physiological needs and cope with its environmental surroundings.“

3. Organisms are Organized 2: What Does „Organization“Mean?

The following selection of quotes was shaped having unicellular organisms (bacteria, yeasts) or mycelium-forming fungi in mind, not multicellular organisms. Standing on the shoulders of giants, there is only one „little fish in my basket“ (“Here is the basket: I bring it home to you. There are no great fish in it. But perhaps there may be one or two little one which will be to you taste.” van Dyke 1899): to state in a rather rough, shortened and pointed manner, that the organism as a whole is it, which rather heterarchically, than hierarchically, regulates its metabolism and physiological behaviour. This is it what should direct our research and experiments much more. In the following I present a selection of quotes, which should help to shed some light on the term „organization“. These quotes are meant to be appetizers for a more detailed study of the cited articles.

Looking into recent literature, the most important concepts underpinning the statement that organisms are organized are: Organisms exhibit closure to efficient causation, closure of constraints, organizational closure, and control mechanisms are organized heterarchically. These terms are illuminated in more detail in the following paragraphs. One important feature of organization is that organisms are closed to efficient causation, also named as metabolic closure or organizational closure. This term, probably coined by Robert Rosen, is described in more detail in the work of Athel Cornish-Bowden and coworkers, in particular Maria Luz Cardenas.

„The essential but often overlooked point is that enzymes, and all other proteins are themselves products of metabolism, and thus metabolites. […] … which Rosen expressed in the statement that ´an organism is closed to efficient causation´.“ (Letelier, Cárdenas, and Cornish-Bowden 2011). In a very detailed review on theories of life („in search of an ideal theory“) Cornish-Bowden and Cardenas stated (Cornish-Bowden and Cárdenas 2020):

„In metabolism the efficient causes are the catalysts, or enzymes. Closure to efficient causation thus means that all of the enzymes used by an organism need to be synthesized by the organism itself: none are given from outside.“ (Cornish-Bowden and Cardenas 2020) „Closure to efficient causation, or the need for all specific catalysts used by an organism to be produced internally, implies that a true model of an organism cannot exist, though this does not exclude the possibility that some characteristics can be simulated.“ (Cornish-Bowden and Cárdenas 2022).
A summary and extension of Rosen´s theory, as well as a biochemical realisation of this theory, can be found in Wolkenhauer and Hofmeyr (2007), Hofmeyr (2021), and Vega (2023).

„… the processes in the living cell can be divided into three classes of efficient causes that produce each other, so making the cell closed to efficient causation, the hallmark of an organism. They are the *enzyme catalysts* of covalent metabolic chemistry, the *intracellular milieu* that drives the supramolecular processes of chaperone-assisted folding and self-assembly of polypeptides and nucleic acids into functional catalysts and transporters, and the *membrane transporters* that maintain the intracellular milieu, in particular its electrolyte composition.“ (Hofmeyr 2021)

„In this meta-level sense I find the description ‘organisationally invariant systems’ a quite useful alternative to ‘systems that are closed to efficient causation’, but then it must be consistently used only in that sense; ‘organisational invariance’ cannot at the same time serve as the name for one particular mapping in the system. Another suggested realisation of the replication mapping is ‘one gene–one enzyme’ (Louie, 2009). However, a gene is not an efficient cause: as sequence information, it is via transcription to mRNA the formal cause of an enzyme.“ (Hofmeyr 2021).

Mossio and Moreno (2010), Montevil and Mossio (2015), and Mossio et al. (2016) emphasize the role and importance of so called “constraints” as causal regimes of their own and elaborate a specific understanding of the notion of organization expressed in terms of closure of constraints. Mossio et al. (2016): „… biological organization is to be understood as a *closure of constraints*. In other words, claiming that biological systems are organized means, in a theoretical precise sense, that some of its constituents acting as constraints realize a regime of mutual dependence between them, which we label `closure´.“

„… namely that there are irreducible structures of nested correlated interactions, that is, organisations, that are key to understanding why the biochemical details are as they are, genomes included, and that such organisational design is as fundamental to understanding as is the biochemistry.“ (Moreno and Mossio 2015, foreword).

„Broadly speaking, processes refer to all those transformations (typically physical processes, chemical reactions, etc.) that occur in biological systems and involve the alteration, consumption, production and/or constitution of entities. Constraints, in turn, refer to entities that, while acting upon these processes, can be said (in some appropriate sense) to remain unaffected by them. A variety of entities can play the role of constraints in an organism, be it in the form of boundary conditions, parameters, restrictions on the configuration space, etc.... In some cases, constraints are exerted by external physical forces and fields, which are essential for life as we know it: for instance, gravitation canalizes development (Bizzarri et al., 2015). In other cases (which, as mentioned, are of paramount importance in the biological domain), constraints are exerted by specific material structures within the organism. In all situations, constraints contribute to determining the behavior of the system (be it physical, chemical or biological), by reducing the degrees of freedom of the processes and dynamics on which they act.“ (Mossio et al. 2016, p 28).

„… both the vascular system (with respect to oxygen transport) and enzymes (with respect to chemical reactions) act as constraints within the organism.“ (Mossio et al. 2016, p 29). „The central outcome of the theoretical distinction between constraints and processes is a distinction between – to use a philosophical jargon – two regimes of causation. For a given effect B of a process or reaction, one can theoretically distinguish, at the relevant time scale, between two causes (or, as Rosen put it, two answers to the question “why B?”): the inputs or reactants A that are altered and consumed through the process, and the constraints C, which are conserved through that very process. Constraints constitute a distinct kind of causes insofar as they are not reduced to the thermodynamic flow, and to the material inputs or reactants.“ (Mossio et al. 2016, p 29).

„… performing a function means exerting a constraint on a target process or reaction. All kinds of biological structures and traits to which functions are usually ascribed satisfy the definition of constraint given above, albeit at various different temporal and spatial scales. In addition to the vascular system and enzymes, some intuitive examples include membrane pumps and channels (which constrain both the inward and outward flow of materials through the membrane) as well as organs (such as the heart which constrains the transformation of chemical energy into blood movement). The principle of organization grounds functionality within biological systems: constraints do not exert functions when taken in isolation, but only insofar as they are subject to closure.“ (Mossio et al. 2016, p 31).

In Aristotle's concept of causality his causa formalis corresponds to what is now called “constraints”: „ … the formal cause to be a constraint on the efficient cause“ (Hofmeyr 2021). So, besides efficient causes like enzymes, constraints are an addition causal regime.

As I see it, the most concrete work on what biological organization and control in organisms could be, is presented in the work of Leonardo Bich in collaboration with Matteo Mossio, Alvaro Moreno and William Bechtel (Mossio and Moreno 2010; Winning and Bechtel 2018; Bich et al. 2020; Bich and Bechtel 2022 a; Bich and Bechtel 2022 b). In particular Bich et al. (2020) established a model using glycemia regulation to demonstrate in biochemical detail the concept of closure of constraints and organizational closure.

„… that the causal organization of a system consists exactly in its spatiotemporal organization combined with the operative constraints.“ (Winning and Bechtel 2018, p 294).

„The tendency or capacity to resist, re-route, displace etc. various forces is just what it is to be a causal power. Thus, on our view, when constraints enable objects to have novel, emergent behaviors, this is tantamount to the emergence of causal powers. Enzymes provide an exemplar of how constraints generally account for the causal activities of mechanisms. Thus, on our view, when constraints enable objects to have novel, emergent behaviors, this is tantamount to the emergence of causal powers. Enzymes provide an exemplar of how constraints generally account for the causal activities of mechanisms.“ (Winning and Bechtel 2018, p 294).

„While external agents can exercise control over machines, the controllers of biological mechanisms must be other mechanisms within the biological system. Constraints are the theoretical linchpin that ties these capacities together and accounts for biological mechanisms as causally efficacious, far-fromequilibrium dissipative structures that are autonomous in terms of control.“ (Winning and Bechtel 2018, p 307).

„The specificity of living systems is that they are organized, by which we mean that their constitutive constraints collectively produce and maintain each other and, ultimately, the whole system itself. The resulting organization realizes a distinctive regime, called organizational closure or closure of constraints, in which the very existence and activity of a set of constraints depends on their mutual relations and interactions.“ (Bich et al. 2020).

„At the intracellular level, the coordinated activity of organized constraints such as proteins, membranes and nucleic acids, contributes to the realization and maintenance of the organized system that contains them, by channeling the flow of matter and energy necessary to build these components and to run the internal processes of the system […] what we label the first-order regime of closure […] living systems possess a specialized class of organized constraints (which means that they are also maintained by the organism), that we label regulatory, that act as higher-order controllers upon first-order constraints“ (Bich et al. 2020).

„Organization here refers to the way production and transformation processes are connected so that they are able to synthesize the components that realize them using energy and matter from the environment.“ (Bich and Bechtel 2022 a, p 98).

„… it treats the organism as a whole as the starting point and the main focus when addressing what is distinctive about living organisms“ (Bich and Bechtel 2022 a).

„The autonomy tradition thus emphasizes a generative framework in which there is a mutual dependence between components of the organism, such that the very existence of each component depends on its relationship with the others and with the system as a whole.“ (Bich and Bechtel 2022 a, p 99).

„ … emphasized the circular relation between processes of production and components (Organizational closure) even as the system is open to and exchanges matter and energy with the environment“ (Bich and Bechtel 2022 a, p 99).

„Constraints, as understood in the autonomy tradition, are components that figure causally in the generation of processes“ (Bich and Bechtel 2022 a, p 99).

„… the constrained release of energy in organisms accounts for the production and maintenance of the very constraints that make the performance of work possible. In this view, for the set of constraints operative in an organism to realize closure, the existence and activity of each of these constraints acting on processes must depend on the action of other constraints in the system. A system realizing closure of constraints is able to maintain its dynamical organization despite the constant transformations and turnover at the level of components“ (Bich and Bechtel 2022 a, p 99).

„ … a function is identified as the contribution a constraint makes to the realization and maintenance of the organization that produces it“ (Bich and Bechtel 2022 a, p 99).

„Moreover, in a strong sense, constraints depend on the whole organism while the whole organism is dependent on the contributions of each of its constraints.“ (Bich and Bechtel 2022 a, p 99).

„Integrating multiple sources of information does not require centralization.“ (Bich and Bechtel 2022 a, p 104).

„We contrasted hierarchical control, in which a central controller receives information and directs activities throughout the whole system, with heterarchical control in which control is distributed among multiple control mechanisms. We also argued that heterarchical control is likely to have evolved in biological organisms through the incremental incorporation of new control mechanisms that measure additional variables or that integrate the measurements performed by other control mechanisms and act on various mechanisms in light of these measurements“ (Bich and Bechtel 2022 a, p 104).

4. The Causal Effects of Constraints and Organizational Closure Imply That Metabolism Is Also Determined by The Whole

„More generally still, consideration of metabolism as a whole puts the emphasis on certain systemic aspects that are crucial but which can pass unnoticed if attention is always focused on details. […] The fact that a complex network of interactions connect genes to phenotypes emphasizes the idea that only through the understanding of the whole can we understand the function of the parts.“ (Cornish-Bowden et al. 2004).

„… as expected from a systemic and functional point of view, the control of metabolic steady-state fluxes should lie in the demand process.“ (Hofmeyr 2008).

„To conclude, we present a mechanistic, compartmentalised, model of an eukaryal organism in full detail, which can act as a valuable, computable, knowledge base. We show how it can be used to compute protein costs and identify active growth-limiting constraints, and how it can be combined with quantitative flux and proteomics data to provide unprecedented insight into cellular physiology. Finally, we show that also in eukaryal cells, metabolic strategies can be understood on the basis of growth rate optimisation under nutrient and proteome constraints. What remains to be understood is how the cell’s signalling and regulatory networks manage to implement these (optimal) proteome allocation strategies.“ (Elsemman et al. 2022).
“The paradox of the organism refers to the observation that organisms appear to function as coherent purposeful entities, despite the potential for within-organismal components like selfish genetic elements and cancer cells to erode them from within.” (Patten et al. 2023).

5. A Side Note on The Organization of Organisms: Is It More Appropriate to Consider an Organism as A Thing or As A Process? Does an Organism Consist of Things or Of Processes?

The densely interwoven web of relationships in an organism suggests that organisms can also be understood as a web of processes rather than a web of things – that processes interact with each other rather than things (Dupre and Nicholson 2018; Nicholson 2018).

„What morphology establishes as form and structure actually signifies a temporal cross-section through a spatiotemporal stream of events. Structures are, for our human scale, long extended, slow, functions on the other hand short and fast process waves. [...] The consideration of the organism as an expression of a flow of events has very far-reaching consequences. (Bertalanffy 1949, p 129, 130; in German, translation WB).

„This essay, and the book more generally, defends the thesis that the right way to understand the living world at all levels is as a hierarchy of processes rather than things.“ (Dupre and Nicholson 2018, p 11).

„From a metabolic perspective, it is simply a matter of fact that, in an organism, *everything flows*. Of course, this is not to say that everything flows at the same rate.“ (Dupre and Nicholson 2018, p 17, italics by the authors).

„One of the most significant consequences of the processual hierarchy of the living world, then, is that it makes the physicalist dream of absolute reductionism impossible. […] It also means that we cannot pick out any level in the hierarchy as ontologically or causally primary. […] a process ontology has no trouble in recognizing that causal influences can flow in different directions. […] it is no longer incoherent or mysterious to assert that the properties of the parts are partially determined by the properties of the whole – a claim, by the way, that biologists (especially physiologists and embryologists) have been making for centuries on the basis of their empirical investigations.“ (Dupre and Nicholson 2018, p 27).

„Our argument in this essay has been that process ontology is far more concordant with the understanding of the living world provided by contemporary biology than ist substantialist rival. […] Thus the empirical findings of biology are inexorably driving us towards processualism, even if it is less intuitive than substantialism.“ (Dupre and Nicholson 2018, p 39).

„The organism is a whole of interrelated processes, which determine their own essence by their relations to each other in such a way that the whole consisting of them has a regulative closed dynamic, so that it can maintain and develop autonomously in its environment.“ (Koutroufinis 2019, p 645; in German, translation WB).

6. Conclusion: An Organism Is First of All A Unified Whole

That an organism is more than the sum of its parts is actually trivial, in principle known to every biologist, and was also the opinion of Karl Popper: „Therefore, I think that the non-reducibility of biology to non-biological sciences, which has always been asserted, is due to the non-reducibility of biochemistry to chemistry.“ (Popper 1986, first Medawar lecture).

A similar point of view was taken by Ludwig von Bertalanffy, Joseph Henry Woodger, and the Theoretical Biology Club of the 1930s. In the second half of the 20th century, Conrad Hal Waddington (1966) and Jean Piaget (1992) continued this tradition in a particularly impressive way. Then molecular biology came, with all its merits on one hand, but also with its exaggerated claim to be able to explain all on the other hand.

In the 21st century, the importance of the organismic point of view is again coming more clearly to the fore, not least because the molecular view is increasingly reaching the limits of knowledge and explanation. In addition to the authors already cited, I would like to mention two more here: Denis Noble (2017, 2022) and Spyridon Koutroufinis (2019).

“Understanding the organisation of organisms in terms of scales and levels is an essential prelude to developing the theory of Biological Relativity. […] the minimal kit required to be a living system is found at the level of a whole cell.” (Noble 2017, p 64/65).

“… many physiological functions cannot be ascribed to entities lower than the cell.” (Noble 2017, p 171).

„… gene-centrism has been a disaster, since prediction from elements to the whole system only rarely succeeds, whereas identifying whole system functions invariably makes testable predictions at an elemental level.“ (Noble and Noble 2022).

„… an organism always does something as a whole. The material structure of the organism on the one hand and its material and energy production, material and energy transformation and transmission on the other hand are intertwined in such a way that no continuous separation of causing and caused processes is conceivable. Because the result of each inner-organismic process, its output, serves as input, as cause for other processes.“ (Koutroufinis 2019, p 60; in German, translation WB).

I would like to close this essay with a remark of Peter Mitchell taken from „The culture of imagination. An essay on Creativity in the Sciences, in the Arts, and in Life“ (Mitchell 1980): „As Karl Popper has pointed out, innovative discoveries in science are not usually made simply by looking at a certain aspect of nature and recording what is there. They are made by an act of imagination – by a conjecture about nature – in which one says: wouldn´t it be interesting if such and such were so, because that might then explain this complicated phenomenon better than any existing theory? After such a conjecture has been made, one sees nature in a new light, and one may be led to do new experiments to discover whether the conjecture may be true.“

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