

3. Beyond Systems Theoretical Explanations of an Organism's Becoming: A Process Philosophical Approach¹

SPYRIDON A. KOUTROUFINIS

This essay may be read as an application of one of the most central ideas in Whitehead's work: that the main task of metaphysical schemes of thought is to *criticize scientific abstractions* or, more specifically, *to criticize the confusion of something abstract with something concrete* in different sciences.² This will be discussed in the context of a classical topic of natural philosophy, the *equifinality* of an organism's generation. With this term Ludwig von Bertalanffy, founder of formal bio-systemic thought in the early 20th century, referred to the essential tendency of living beings, and open systems in general, to reach a certain terminal state via different possible developmental pathways. According to von Bertalanffy, the central subject of theoretical biology is the problem of *ontogenesis*, i.e., the generation of an adult multicellular organism. This is a question which has not adequately been considered by philosophers in recent decades. Instead, they focused their attention on supposedly more interesting issues, such as the evolution of the species, the generation of life and above all the nature of consciousness. Unfortunately, the choice of focus ignored the fact that the metabolism of even the simplest bacterium is more than just a very complex physicochemical system. It was not for nothing that Aristotle had made the problem of the self-sustainability of a living being and of its embryonic development the main subject of biophilosophy: a position it held until the rise of Darwin's theory of evolution.

¹ I gratefully acknowledge the editorial help and critical remarks of Terrence Deacon, Robert Valenza, and Andrew Packard.

² See Whitehead 1979, 7f.; 1953, 70.

Since the 1930s, most bioscientists have proceeded from the assumption that organisms arise and preserve themselves by means of efficient causation and that only blind forces such as those studied by physics and chemistry, are at work in organisms. In modern biology there seems to be no place for a kind of thinking which I will later describe as *mentalistic teleological thinking*.

This essay is divided into two parts. The aim of the first part is to show that thinking embryogenesis only in terms of efficient causation, which operates on the basis of the theory of nonlinear dynamical systems, poses serious problems. Failing to recognize this would be a clear case of Whitehead's "fallacy of misplaced concreteness", meaning the confusion of the abstract with the concrete. In an attempt to overcome this problem, the second part of the article presents an alternative approach to teleology which I call *mentalistic teleology*.

1. The insufficient understanding of teleology in current bio-systemism

In the first half of the 20th century the attempt was made to banish all teleological thinking from biology. While biologists and philosophers of biology still talk about "teleology", it is not always clear what they mean by this term. Difficulties of definition apart, it is possible to describe teleology as the theory of events which tend to reach certain terminal states, to stay in them or to oscillate around them.³ The definition is metaphysically neutral. It leaves open the question of whether the causes prevailing in organisms are mental or deterministic-material. Therefore, it is applicable both to living and lifeless nature and even to mechanical devices such as robots that are controlled by programs.

Most biologists are similarly content to use teleology as a synonym for equifinality. In contemporary biology the term "teleology" is used in connection with organisms, organs and behaviors to express the idea that these all display an affinity to a particular terminal state *strictly because of their own scientifically measurable efficient causality* (see below). This

³ For similar positions see Mayr 1991, 59; 2000, 416, 405; Toepfer 2005, 36; Hull 1974, 103ff.

separates scientific teleology from the ancient Greek concept of teleology which was based on the metaphysical idea of final causality – Aristotle’s *telos* or *causa finalis* – and the presupposition that an organism is shaped by (*proto*)mental factors acting within it.⁴ Biophilosophy as distinct from philosophy of biology (see introduction of this volume) is free to introduce new perspectives on teleology going beyond modern biosciences.

1.1. On the current scientific concept of organisms as complex dynamic systems

A system is defined as a *dynamic system* if its state at any given moment can be described as a limited set of time-dependent or state variables $x(t) = [x_1(t), x_2(t), \dots, x_n(t)]$ for which a function F can be formulated stating mathematically the connection between states at times t and $t + \delta t$. The properties of this function reflect the *causal* relationships at work within the system. The set of state variables $[x_1(t), x_2(t), \dots, x_n(t)]$ spans an *abstract space*, the system’s so-called “state-space”.

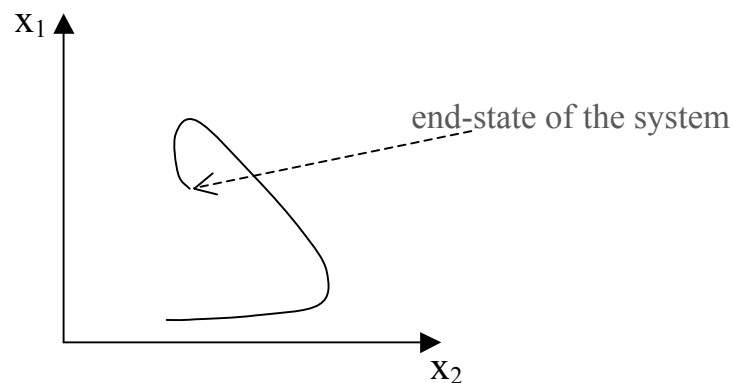


Fig. 1: State-space and trajectory of a dynamic system with two state variables.

It is important to keep in mind that the change or development of a dynamic system is not merely the result of the function F , but depends also on a group of externally fixed parameters. The most abstract formula for a dynamic system must therefore be (Ebeling and Sokolov 2005, 40):

⁴ For more details about the history of the concept of teleology from antiquity to 20th century see Koutroufinis 2013, 2012.

$$x(t + \delta t) = F(x(t), p, \delta t); p = [p_1, p_2, \dots, p_m] \quad (\text{formula 1})$$

The letter p represents a set of *parameters*. All parameters are externally fixed constants. They represent either real constants or quantities assumed as being constant, the latter being the usual case. *Their role is to constrain the development of the state variables $x(t)$.* Usually, every state in a stable dynamical system can be calculated from its preceding state. This is sometimes not possible in unstable systems because some states have more than one possible successor state under actual (natural) conditions (see fig. 5). But even these systems allow, at least in principle, the calculation of all *potential* future states of the system's development given its state at a certain time. The fact that every potential state in a given dynamic system, whether stable or unstable, can be mathematically calculated from its preceding state shows that a dynamic system is governed by *efficient causality*. By “efficient causality” I mean the following:

- Firstly, that the state of a system at any given time is exclusively the function of its state and the state of the internal and external factors at work on it at the immediately preceding point in time.
- Secondly, that the transition from one state to the next is governed entirely by factors – whether intrinsic to the system or from its environment – which can be completely described in modern scientific terms,⁵ especially in terms of today's physics and chemistry (with the exception of quantum theory, which is sometimes understood in terms associated with human consciousness). By definition, these descriptions exclude mental aim-oriented final causes and thus any non-scientific teleology.

It follows that the transition can be *exhaustively* plotted in abstract spaces designed on the basis of classical physics⁶ and chemistry. So, all natural events whose actual (fig. 1) or potential (fig. 5 and 7) development can be

⁵ Such factors are: firstly, the *laws of physics and chemistry*; secondly, *quantities in physics and chemistry*, appearing either as dynamic variables or as constants (i.e., parameters; see section 1.3), such as the concentration of substance X, its reaction speed, pH value, pressure, temperature, free energy, etc.; and, thirdly, *stochastic* factors influencing the outcome of real processes in experimental physics and chemistry, such as thermodynamical and quantum-physical fluctuations.

⁶ The term “classical physics” includes theories of self-organization or complexity based on non-linear dynamic systems' theory.

displayed by trajectories in abstract spaces and whose causality can be exhaustively reduced to scientifically describable factors (see. footnote 5) are merely governed by efficient causes. Dynamic systems can be subdivided into conservative and dissipative dynamic systems. The energy of the latter “dissipates”, that is, it disperses and must be replaced by the environment. *Dissipative systems produce entropy*. As we shall see, it is precisely the fact that they produce entropy that allows dissipative systems (under certain conditions) the kind of spontaneous structuring of their behavior in space-time commonly labeled as “self-organization”.

1.2. The paradox of self-organization: system organization spontaneously increases in the process of destroying the cause of its increased organization

Statistical entropy is a concept applicable only to systems with a huge number of particles and serves as a measure of disorder. Boltzmann and Planck define the statistical entropy of a system as the average value of its uncertainty (Ebeling 1976, 13).⁷ A system is uncertain if there are many possible states in which it might be. Ideally, each of these states corresponds to a point in its state-space which can, with a particular probability, be the actual state of the system. The statistical entropy of a system is the average value of the probabilities of all possible states which the system might occupy. Accordingly, statistical entropy is related to the concept of *possibility*.

The order and the statistical entropy of a system which has n degrees of freedom can be depicted using a high-dimensional state-space (fig. 2).⁸ For

⁷ Concerning the connection of entropy and uncertainty see Ebeling and Sokolov 2005, 85f.

⁸ The number of degrees of freedom that a system has depends on both its constitution and the way in which it is described. In statistical mechanics, $6m$ degrees of freedom are assigned to a system which consists of m elements. This is the case because each element has 6 degrees of freedom. Its complete description requires three spatial positions: its location in the three spatial dimensions x , y and z ; and the three velocities v_x , v_y and v_z with which it moves along these dimensions. Chemical systems consisting of n different molecular species (the concentration of which can vary) are considered

each of the possible states there is a particular point in this abstract space to which it corresponds. Thus a limited area of the state-space represents all the states which the system can possibly occupy at a given time.

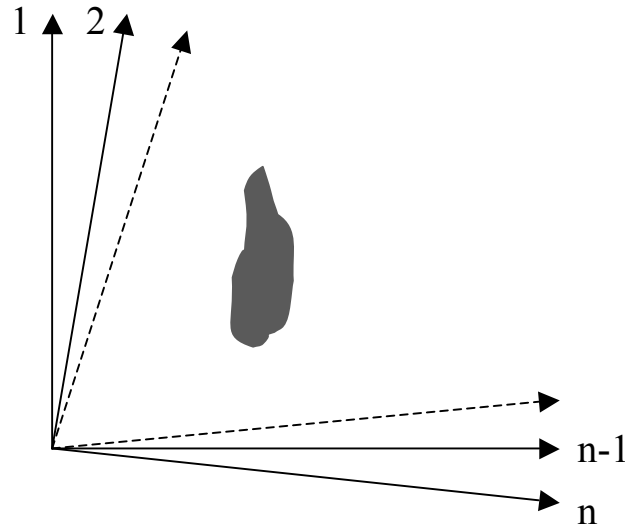


Fig. 2: The high-dimensional state-space-volume of the possible states of a system with n degrees of freedom at a given time.

The conviction that living beings are self-organized complex dynamical systems is central to current theoretical biology. “Self-organization” is a technical term. It means that the increase of a system’s order – that is, the decrease of its entropy – is the result of efficient-causal interactions between its elements and not the outcome of the action of a single real or ideal entity such as an acting person or a program. Self-organization does not mean elimination of entropy or uncertainty but just their diminution (fig. 3).

Systems serving as models of self-organization require *gradients* of energy and/or material. A typical example of such a gradient is the difference of temperature $T_1 - T_2$ in the so-called Bénard convection. This occurs when the lower layer of a fluid is heated and the upper layer is kept at a cooler temperature (T_2). At a certain difference of temperature between the bottom and the top of the fluid, the heat flux reaches a critical value

to be completely described if the concentration of all n molecular species is indicated at each point in time (see fig. 7). Thus they have n degrees of freedom.

and convection arises. Coherent macroscopic movements emerge in the fluid and form a highly structured pattern of hexagonal cells (fig. 4). This phenomenon represents a so-called “phase transition”, i.e. the change of one mode of dynamics to another: in this case the transition from heat conduction to convection. In Bénard convection the phase-transition, i.e., the self-organized pattern formation, does not occur immediately but takes several minutes (depending on the fluid).

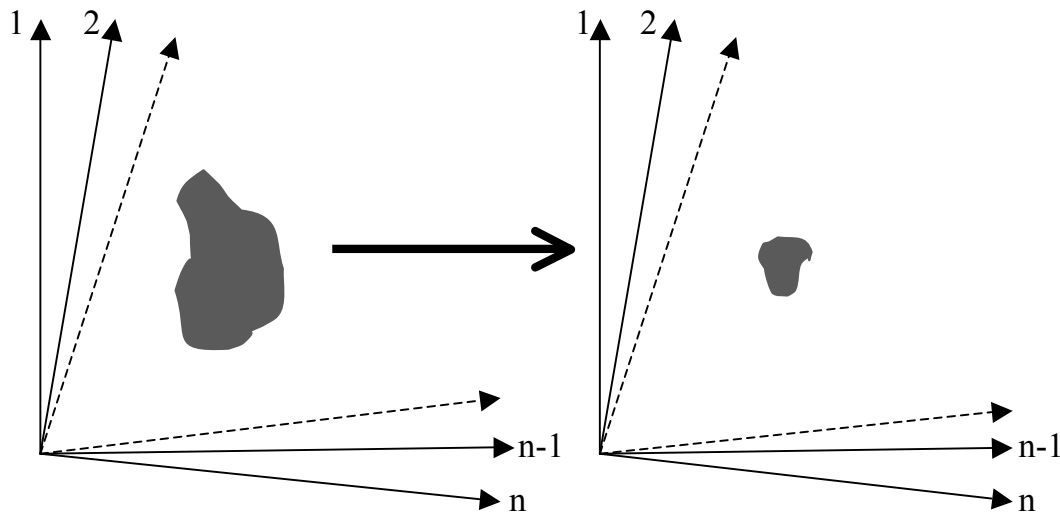


Fig. 3: The diminution of a system’s entropy equals a decrease in the number of possible states.

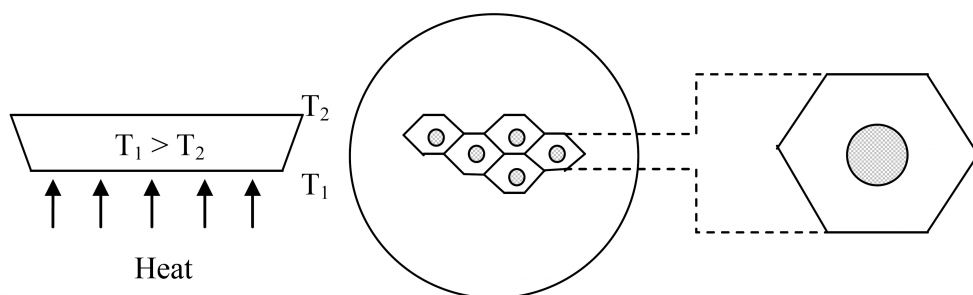


Fig. 4: The Bénard convection. The upward movement of the heated fluid in the center of each cell forms a cylinder. Fluid that has cooled down flows downwards in the hexagonal area around the cylinder.

There is a fundamental finding in thermodynamics with consequences for the applicability of the theory of complex dynamical systems to biology; these consequences are often misunderstood. It states that every form of self-organization of a physico-chemical system amounts to a

decreasing of the gradients which are imposed on the system and which move it away from the thermodynamic equilibrium, that is, from the state of total lack of physical becoming. *Each self-organized system tends to return to equilibrium.* The hexagonal Bénard cells transport heat upwards faster than simple heat conduction thus *increasing the rate of gradient destruction.* Two well-known physicists go to the heart of this finding:

“As systems are removed from equilibrium, they will utilize all avenues available to counter the applied gradients. As the applied gradients increase, so does the system’s ability to oppose further movement from equilibrium. [...] No longer is the emergence of coherent self-organizing structures a surprise, but rather it is an expected response of a system as it attempts to resist and dissipate externally applied gradients which would move the system away from equilibrium” (Schneider and Kay 1995, 165).

According to this position, *all self-organized phenomena that occur in inorganic systems arise only because they oppose the causes of their self-organization.* The decrease of entropy inside a system enables it to increase the rate of degradation of the externally imposed gradients.

This essential property of dissipative dynamic systems means that they increase their *entropy production* in the process of decreasing of their own entropy. This is not paradoxical, since entropy and entropy production are two different quantities.⁹ Open systems may increase their entropy production and at the same time decrease their local entropy if they export entropy faster than they produce it.

It is easy to see why self-organized pattern formation involves both a tendency to oppose displacement away from equilibrium and an increase of entropy production. Firstly, work is required to resist externally imposed factors that tend to displace the system away from equilibrium. Secondly, work can only be performed by a system that in some way constrains the flow of energy through it, i.e. an ordered system. In other words, self-organization involves the *intensification* of a system’s mutually supporting (i.e. correlated) internal processes. Thirdly, according to the second law of thermodynamics all real (and not idealized) physical processes produce

⁹ In physics the symbol for entropy is S and for entropy production P. Entropy production is a rate. It has the dimension “entropy divided by time”.

entropy. Therefore intensification of the correlated dynamics within a self-organized system increases its capacity to do work to oppose displacement from equilibrium *and* increases the rate of entropy production. In Bénard convection, for example, the gradual formation of the hexagonal cells enables the system to produce more entropy than it did before the phase transition from heat conduction to convection took place.

Production of entropy means the dissipation of energy or degradation of the capacity to do work. Energy cannot be created or destroyed in a system (forbidden by the first law of thermodynamics or law of conservation of energy) and the system cannot upgrade already degraded energy (forbidden by the second law of thermodynamics) in order to degrade it again. Thus the system can produce entropy as dictated by the second law only if it degrades the energy which it is supplied with from the outside, that is to say by the externally applied gradients. In other words, in order to oppose external gradients the system does work that uses (degrades) the energy provided by these same gradients.

So from the point of view of thermodynamics the decrease of a system's local entropy, i.e., its self-organization, requires an increase of its entropy production. This does not constitute an extremum principle of physics as is often characterized in the “principle of maximum entropy production.”¹⁰ This is because the increase of entropy production may stop before this quantity reaches its possible maximum.¹¹

To conclude, the emergence of self-organized higher-order macroscopic structure (pattern formation) in inorganic dissipative systems, *only serves the degradation of externally imposed gradients through entropy production*. It is therefore ultimately self-destructive.

1.3. Examples of modeling biomolecular processes in systems biology

Some bioscientists, primarily systems biologists, maintain that organisms *are nothing more* than dynamical systems that can be expressed using the language and terminology of physics and chemistry. They eagerly

¹⁰ See Sagan 2008, Salthe 2010, Swenson 1997.

¹¹ For criticism of the principle of maximum entropy production see Nicolis and Nicolis 2010, Ross et al. 2012.

anticipate the development of mainframe computers capable of providing computer-simulations of whole organisms, which, they assume, will be possible within the next fifty years.¹² In doing so, they attribute ontological and not just heuristic relevance to the theory of dynamical systems, making any such development philosophically interesting.

Both the solving of nonlinear differential equations and concomitant computer simulations are fundamentally important for formal reductions of cellular processes in contemporary systems biology. But both operations require some specific conditions. I will focus on a currently inescapable methodical reality which is of major importance for the philosophical discussion about the relevance of self-organized dynamic systems theory to biology: the sharp distinction between dynamic and static quantities or, in other words, between variables and parameters (see formula 1).

Parameters may represent specific quantities or they may be *abstractions* that summarize the relations between quantities describing cell properties (such as volume, temperature, pressure, pH-value, etc.). In simulations, parameters are assigned by systems biologists. They are either experimentally derived, estimated or simply taken from other published studies. The sharp distinction between variables and parameters is readily apparent in many texts on systems biology. In the following, three typical examples will be briefly introduced.

The first example refers to bistable behavior, which is a special kind of instability. Bistability is a phenomenon often encountered in the theory of dynamic systems. Bistable systems are common in systems biology. Bistability is philosophically interesting as it shows that there are areas of indetermination in the development of some dynamic systems. Gardner et al. published in *Nature* a model for the mutual regulation of the activity of two genes which was developed on the basis of the well known Operon-model of Jakob and Monod. Both genes transcribe a protein – a so-called repressor protein – which blocks the activity of the other gene, so that both genes inhibit each other. The dynamics of this system of two interwoven *negative feedback* relationships can be described by two state variables, U and V, which are associated with the concentrations of both repressor

¹² See Wolpert 1995, Tomita 2001, Normile 1999, Wayt Gibbs 2001.

proteins. The variation of the concentrations of both proteins can be represented by two differential equations (Gardner et al. 2000, 339).

$$\frac{dU}{d\tau} = \frac{\alpha_1}{1+V^\beta} - U$$

$$\frac{dV}{d\tau} = \frac{\alpha_2}{1+U^\gamma} - V$$

These coupled non-linear equations are so-called “dimensionless” equations.¹³ The quantities α_1 , α_2 , β and γ are the *parameters*. Their value is determined by the experimenters. They are, however, kept constant in each single experiment and corresponding computer simulation as well. There are many ways to manipulate the values of the parameters – one possibility is through the variation of the ambient air temperature. As for the suitability of dynamical systems theory to explain the dynamics of an organism, one must first and foremost keep in mind that even the modeling of the self-organization of just two dynamic quantities requires that four static quantities or parameters be externally determined.

Certain combinations of the four parameters lead to a bistable behavior. Such a system has two possible stable terminal states. The corresponding state-space, with some of the potential trajectories, would then appear as follows:

¹³ In dimensionless equations the quantities have to be recast by judicious scaling so that no units need appear. In the two equations provided by Gardner et al. the left sides seem to have the quality of rate and the right sides the quality of concentration. However U and V do not represent concentrations and τ does not represent time. The two sides of the equations can be reconciled because these symbols represent only values *associated* with concentrations or time.

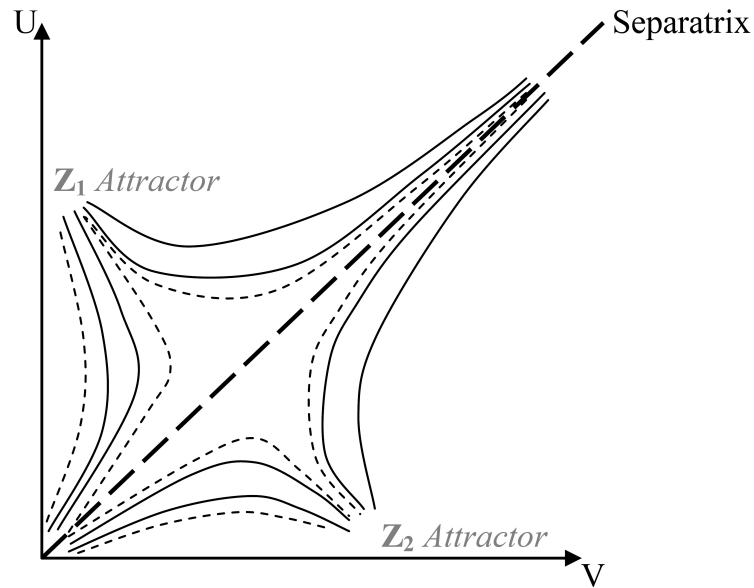


Fig. 5 (Based on Gardner et al. 2000, 340 and Ebeling et al. 1990, 150): For certain adjustments of the parameters a bistable behavior emerges, meaning that two stable alternative terminal states, Z_1 and Z_2 , are possible.

Two alternative stable terminal states, Z_1 and Z_2 , are possible, representing either a high final value of U and a low one of V (Z_1) or the opposite (Z_2). It is as if the state-space were divided into two separate areas by an imaginary line, which is why the latter is called “separatrix”. Theoretically, for all initial states above the separatrix, it is impossible to reach the state Z_2 : the trajectories necessarily transfer them to the state Z_1 . The opposite applies to all states below the separatrix, which cannot reach the state Z_1 . In the immediate vicinity of the separatrix some of the initially closely neighboring trajectories diverge strongly from each other; this is typical of bistable dynamics. If the initial state of the system is located very close to the separatrix, quantum physical effects and thermal fluctuations are able to spontaneously transfer the system’s state to the other area of the state-space. Only under theoretical (i.e., purely mathematical) conditions does the separatrix forbid the shift of the system’s development from one area of the state-space to another. Under actual conditions – meaning conditions under which random fluctuations exist – such transitions may occur in the immediate vicinity of the separatrix.

The second example refers to the modeling of some interdependent biochemical reactions of the cell cycle. Paning et al. published a model of a

simple network of three interconnected reactions from the cell-cycle of a frog's egg (2007, 498). It is worth noting that the computation of the self-organization of this nonlinear system with only three dynamic quantities requires 13 parameters – that is, 13 quantities which take no part in the dynamics of the modeled self-organization. For modeling the cell cycle of yeast the same authors use 36 coupled differential equations – i.e., 36 variables – on which they impose 143(!) parameters (ibid. 499).

Finally, in 2012 a group of biophysicists and bioengineers of the Stanford University and the Craig Venter Institute published a whole-cell computational model of the bacterium *Mycoplasma genitalium* that “includes all of its molecular components and their interactions” (Karr et al. 2012, 389). The model “includes more than 1900 experimentally observed parameters” (ibid. 391). Most of them “were implemented as originally reported” in “over 900 publications” and “several other parameters were carefully reconciled” by the model makers themselves (ibid.).

1.4. Why dynamic systems theory cannot describe organismic dynamics

It is typical of all mathematical accounts of self-organized behavior with which I am familiar – whether in physics, chemistry, or biology – to *essentially depend on a high number of externally set parameters, some of which symbolize gradients*. The sharp division between variables and parameters is not problematic within physics. In real inorganic systems those quantities (which in the models are represented by parameters) cannot be influenced by the system's dynamics itself. In the solar system, for example, neither the mass of the sun nor the gravitation constant – both of which in the models are represented by parameters – are affected by the positions and the movements of the planets. It is obvious, however, that this logic does not apply to organic processes. *In biological systems global factors that influence system dynamics are often internally generated*. For example, although cell volume is an important factor affecting cellular chemistry, the variation of cell volume during the cell cycle is internally regulated. Hence, it is evident that even the most primitive organisms exhibit dynamical characteristic that cannot be modeled by the theory of

self-organization. In strong contrast to formal models, the quantities in real networks within organisms are highly dependent on the network's own inner dynamics. In order to preserve themselves in the face of deteriorating conditions, organisms trigger multiple adaptive changes in the factors affecting their internal dynamics (Falkner and Falkner (in this book); Plaetzer et al. 2005). In modeling them as dynamic systems, these changes ought to be described as *internally* controlled changes of parameters if the model makers claim to have created a realistic model of the organism's internal causality. *A model which realistically mirrors the organism's autonomy must be able to calculate at least a significant number of its parameters.* It must be able to independently calculate and adjust also (but not only) those parameters which describe the organism's exchange of energy and materials with its environment. All organisms are constantly doing this. It is a core defining feature of organism!

Therefore, with regard to the sufficiency of dynamic systems theory for biology, the crucial question is whether the sharp distinction between dynamic and static quantities – variables and parameters – that characterizes current formalisms of self-organization actually misrepresents organismic dynamics.

1.4.1. Theoretical evidence

As outlined above, in mathematical models and computer simulations of dynamical systems, parameters are quantities which constrain the development of the systems' dynamics (see section 1.1). Simulation of a fairly autonomous dynamics that could be a model of real organisms would therefore demand that internal dynamics be able to modify a significant fraction of the constraints (parameters) affecting this dynamics. This would be a self-constraining or self-constrained dynamics.

Thus, the minimum requirement that the modeling of real – i.e., biological – self-organization would have to fulfill is that the model calculates how the organism regulates the energetic-material gradients that it depends upon. In mathematical models of self-organization these gradients are represented by externally set parameters. But within current physics this possibility is *excluded*, primarily because all inorganic

dissipative dynamic systems have an inherent *entropic tendency* (see section 1.2). They are organized by the gradients imposed on them and so their organization cannot regulate those gradients.

There is another principal reason why a dynamical system's model ignores the possibility for parameters to be calculated in the same way as variables: *Differential equations require a sharp distinction between variables and parameters*. Therefore, within contemporary formalism, it will probably never be possible to dynamize parameters. For mathematical reasons, no formal system is able to compute these quantities within the system.

Often this criticism is rejected on the grounds that many processes in real organisms take place under constant conditions as well. This is, of course, the case, but the constant-holding of such conditions is something that cannot be taken for granted; on the contrary, it is an *achievement of the organism itself*: its *overall dynamics* holds certain quantities at least nearly constant. In the formalism of dynamic systems theory this means that “the overall dynamics of the system repeatedly generates nearly the same value for particular variables”.

To put it in a nutshell: For physical and mathematical reasons within theories of dynamic systems or self-organization there is an insurmountable strict distinction between dynamic state variables and externally set parameters – i.e., between constrained and constraining quantities.

It is not only the present author who doubts the possibility of a mathematical formalism which describes a dynamics capable of constraining its own constraints. A prominent founder of systems biology, Stuart Kauffman, writing on the essential limitations of modern scientific formal descriptions of living organisms, says:

“Consider a cylinder with a piston inside and a compressed working gas between the piston and the cylinder head. The gas can expand, doing work on the piston, pushing it down the cylinder. What are the *constraints*? Evidently the cylinder, the piston, and the location of the piston inside the cylinder, with the gas trapped between the two. But where did those constraints come from? Well, it took work to make the cylinder, work to make the piston, and work to put the gas into the cylinder and the piston in afterward. [...] It appears to take work to make constraints and constraints to make work! [...] [T]he released energy that does

work can be used to construct more constraints on the release of energy, which constitutes more work, which in turn constructs more constraints. *Note that these notions are not in the physics or chemistry we have been taught.* One begins to have the sneaking hunch that all this constraint construction on the release of energy – which, as work, can construct more constraints on the release of energy – has something profound to do with an adequate theory of the organization of processes. *We have as yet not even the outlines of such a theory [...]* Nor is the point I am making merely rhetorical. A dividing cell does precisely what I just said. [...] This organization of process is carried out by any dividing cell, yet it is stunning that we have no language – at least, no mathematical language of which I am aware – able to describe the closure of process that propagates as a cell makes two, makes four, makes a colony and, ultimately, a biosphere. [...] [T]he way Newton, Einstein, Bohr, and Boltzmann taught us to do science is limited”. (Kauffman 2002, 132-136; italics by S.K.)

Kauffman complains of nothing less than the inability of standard physics and chemistry to describe a self-constraining process – one whose dynamics regulates many of the constraints it (the dynamics) requires, i.e., many parameters (including energetic gradients). Describing such a high degree of self-referential causality is a task for which current mathematical languages are ill-equipped. Systems governed only by efficient causes – that is, systems without any mental capacities – but able to influence most of their parameters would exhibit *an enormous number of causally indefinite states* in their state-spaces. Such systems would be unstable to a much higher degree even than dynamic systems whose state-spaces have areas where closely adjacent trajectories tend to diverge strongly (see fig. 5). Instability is a phenomenon often encountered in the theory of dynamic systems and in systems biology – even if certain parameters are firmly set. The bistability diagrammed in fig. 5 is a kind of instability which occurs even though the parameters are set to fixed values by the model makers.

Because of the *entropic tendency* inherent in an inorganic (and non-mental) dissipative dynamic system the more the system is able to attain influence over its parameters – especially those representing energetic-material openness, i.e., the existence of gradients – the more it will become disorganized. Such a system would tend to continually increase the system’s *internal* entropy, i.e., to a permanent increase of the number of its possible states (fig. 6). The entropic tendency of a dynamic system which

is governed entirely by non-mental (blind) causes can only be limited if its parameters remain *externally* controlled.

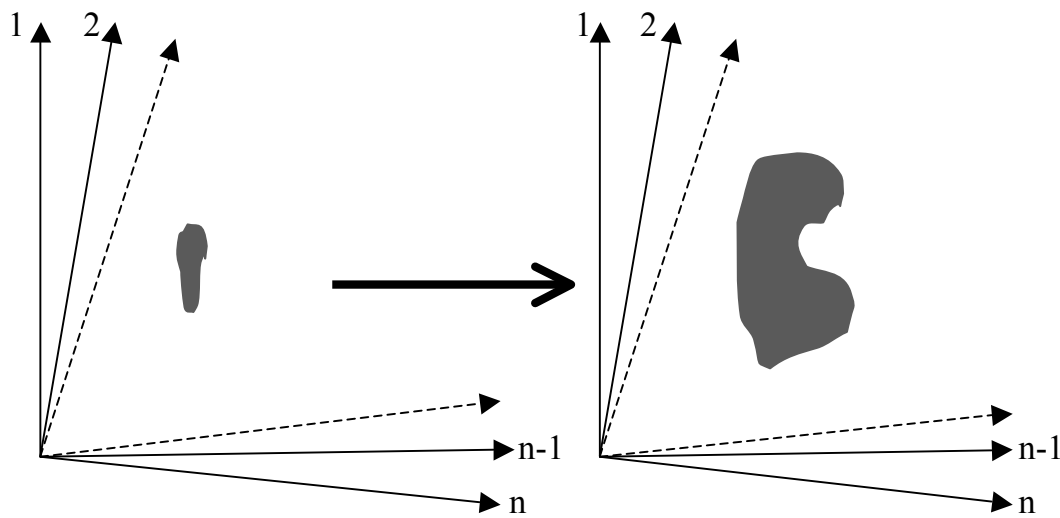


Fig. 6: The increase of entropy within a system depicted as the increase in the number of possible states.

Figure 7 shows another way of describing the increase of entropy – caused by the lost of constraints – as the increase of the number of possible trajectories. If figure 7 represents a model of a real organism’s dynamics, *only a very limited number of these possible trajectories would be biologically viable*; in other words, *very few would represent states of being alive*. This is the case since though biological structures are physicochemical structures they constitute only a vanishingly slight number of the latter. In fig. 7 the long curve represents a thin bundle of biologically viable trajectories, while the dotted lines stand for developmental trajectories which are possible in terms of physics and chemistry, but fatal from a biological point of view. They involve the derailment into areas of increasing entropy or uncertainty.

This leads necessarily to the following aporia: How does an organism succeed in avoiding *derailments* into areas of disorder if it often faces possibilities equally valid from the point of view of physics and *lacks any capacities* allowing a biologically adequate choice between these possibilities?

In the past the answer might have been “the genes” or “genetic information”. But both these notions are much less clear today than they

were some decades ago. Now we understand that genes are massively co-determined by the organism's dynamics.

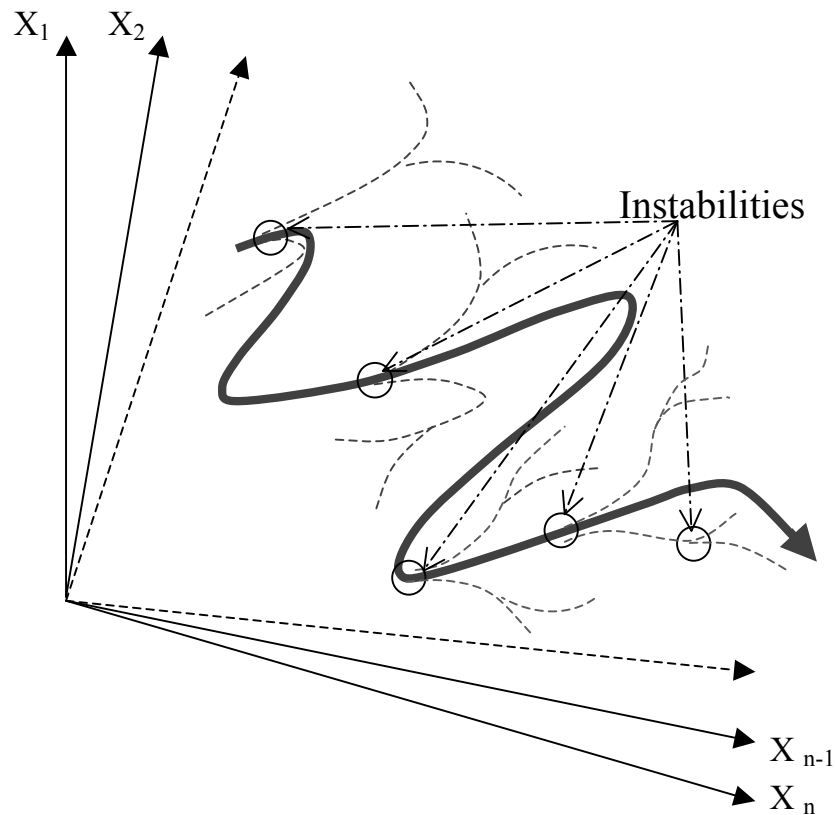


Fig. 7: Permanently occurring instabilities in the development of a hypothetical dissipative dynamic system which influences the value of its parameters entirely by non-mental (blind) forces. If understood as displaying a real organism, the variables X_1 to X_n represent important dynamical quantities (like concentrations of proteins and signal substances etc.), the coherent variation of which is characteristic of an organism. The long curve and the dotted lines do not represent single trajectories but rather bundles of these.

1.4.2. Experimental evidence

There is also experimental evidence demonstrating that the causal order of organisms remains beyond the reach of a standard physical model of self-organization. Biologists have known for a long time that the exchange of energy and material between real organisms and their environment *cannot* be understood in terms of increasing entropy production. This follows

because a high rate of entropy production means a high rate of the degradation or waste of energy. The experimental and theoretical research of Gernot and Renate Falkner clearly shows that the metabolic exchange between cyanobacteria and their environment only exhibits a high rate of entropy production if the physiological adaptation of the bacteria to their environment has been disturbed and is merely being readjusted (Falkner and Falkner, this volume). The act of physiological re-adaptation, as they describe it, effects a *decrease* of entropy production and not its increase. This is the opposite of what is to be expected from a physico-chemical theory of self-organization. Only an organism which is no longer in a state of optimal adaptation seems to function in a way consistent with the physical conception of self-organization. When out of balance with its environment this biological system is in a state of low entropy but produces entropy at a high rate. But as soon as re-adaptation is reached, the organism is situated at a state of low entropy and low entropy production as well. This fact contradicts the predictions of standard dynamical systems models. So, while the act of physiological adaptation begins as if the organism were following the laws of inorganic self-organization, in the latter stages it proceeds in a manner that can only be explained in biological terms. It is plausible that all organisms tend to develop toward a minimization of entropy production. Physiological re-adaptation is a biological act that requires the *internally conditioned* and coordinated variation of many dynamic quantities which, in the models of systems biologists, are described as fixed parameters.

There is also experimental evidence showing that a process of minimization of entropy production takes place during embryonic development. The results of numerous measurements in several studies have led to the conclusion that the entropy production “indeed decreases at separate stages of the ontogenesis (if early stages of development are excluded)” (Martyushev and Seleznev 2006, 40).

1.5. Summary and conclusion of section 1 – the essence of the organism

Every organism must act anti-entropically – i.e., maintain or reduce its low level of entropy – *without* requiring most of the conditions of its self-

organization to be externally set. Both theoretical considerations and experimental evidence make clear that *the theory of self-organization of physics is too weak to account for real biological self-organization* (Koutroufinis 1996). From this point of view the essential feature of an organism is that its dynamics constrains itself whereas the dynamics of inorganic self-organized systems do not. Organismic dynamics does not require that a large number of constraints are externally given as they are in inorganic systems. In other words, organisms are able to generate most of their critical constraints autonomously.

To fail to see the limitations of the theory of dynamic systems – and thereby consider the models of systems biology as appropriate descriptions of an organism's internal causality – is a clear case of Whitehead's "fallacy of misplaced concreteness", since it confuses something abstract (model) with something concrete (organism).

Nevertheless the theory of dynamic systems allows us to make a crucial assumption about organismic dynamics. *A system which has the complexity of an organism and is ruled only by efficient causation would face a huge number of equally valid possibilities in its development.* Of course, only very few of these are biologically viable.

This result invites us to go beyond the ontological limitations of current scientific teleology. Since it is not capable of accounting for anti-entropic behavior in real organisms, we should consider conceptions of teleology which go beyond the confines of physics. We should consider the relevance of causal factors which are not efficient causes in organisms. We need a form of teleological causality which does not violate the efficient causality of physics and chemistry, but coexists with it, for it is obvious that laws of physics and chemistry remain valid in organisms.

2. Mentalistic teleology and process philosophy

Scientific teleology is founded on metaphysical presuppositions entirely different from those of mentalistic teleology. The fact that many dynamical systems of interest to science and technology reach a terminal state in an abstract state-space (see fig. 1 and 5) at a later time can be exhaustively explained by the material structures of the systems that were *physically*

present at an earlier time. The same is the case for the convergence of the operations of a computer towards a terminal state.

The idea of a mental teleological factor, on the other hand, is rooted in two main presuppositions:

- Firstly, that there are causal factors oriented towards something *physically absent*.¹⁴
- Secondly, that the operations of such factors cannot in principle be exhaustively explained by referring to the material structure of something physically present.

Mentalistic-teleological factors do not influence a system's development from the future by "pulling" it to a particular goal, as has often been (wrongly) claimed. They act in the present: they *anticipate*. Anticipation is a mental operation of the anticipating subject occurring in the present – it has nothing to do with time-reversal. *Mental teleology is there if a subject in its present is anticipating for its own future something physically absent in the present*. My understanding of this idea is not at all metaphorical. Anticipation is *experienced* by the anticipating agent; it has an *inner* side, a *quale*, as do all our mental acts. So far science has not succeeded in reducing the qualia of mental acts to physically or spatio-temporally present facts.

However, mentalistic teleology should *not* be taken to ascribe consciousness to cells, unicellular organisms, plants and lower animals. Muraca's clear distinction between intentionality (Zwecksetzung, ZS), which is the conscious setting of an aim, and agency (Zwecktätigkeit, ZT), which does not necessarily imply consciousness, helps to avoid this common misconception (Muraca, this book: section 2.3). Mental activities refer *to* something; for example, the perceptions of heat. But only in very rare cases can they be likened to human intentionality and awareness. In almost all cases mentalistic teleology takes place entirely within the realm of *unconscious* sentience. By "sentience" I mean a very specific form of

¹⁴ I owe the concept of *absence* to Terrence Deacon, professor for biological anthropology at the University of California, Berkeley. He has introduced the term to current discussions about teleology, function and information (2007). However, in contrast to my process philosophical understanding of organismic teleology Deacon rejects the relevance of any kind of protomentalist factors in organisms (2012, 77-79).

making distinctions on the basis of qualia. It is an apprehension of reality rich in qualitative contrasts which stresses some of its aspects while ignoring others. The qualia of very simple living beings like unicellular organisms appear to be undifferentiated experiences of sympathy and antipathy.

In my opinion this conception of teleology is tied to at least two conditions:

- Firstly, in contrast to the convictions held within *classical* physics, the (spatiotemporally present) physical side of the organism attains causal relevance through the mediation of something else. This “something” is correlated to the physical side of the organism, but not determined by it. The non-physical side of the organism can be thought of as the “organismic subject”.
- Secondly, and closely connected to this is, that which is physically present allows the physically absent organismic subject to act in different ways. This means that the physical state of the organism at a specific moment permits the realization of different physical states at the next moment (see fig. 7).

Both these conditions must be met, because talking of “subjectivity” and “anticipation” makes no sense if the future is already fixed in the present.

I consider Whiteheadian process-metaphysics to be conducive to this conception of mentalistic teleology.

2.1. A brief excursus on the metaphysics of Alfred N. Whitehead

The ontological basis of Whitehead’s natural philosophy has been outlined in the introduction to this volume. Here I will summarize his metaphysics by discussing six points important to the topic of ontogenesis:

- 1) “Process” is the central concept of Whiteheadian ontology. Whitehead does not call changes or movements “processes”, but only individual or indivisible events. Another word for what Whitehead calls process is “actual occasion” or “actual entity”.
- 2) All actual occasions have a double nature: a mental-physical or subjective-objective bipolarity. All processes are acts of determination of their own nature or essence. The subjective or inner side of processes

consists in their striving for self-determination. Actual occasions manifest the result of their self-determination in space and time in order to express their subjective or inner side. As space-time-data they may become objects of other actual entities which are still in the act of becoming, i.e., still in the subjective phase of their existence. So, completed actual occasions can be integrated in later (still becoming) processes or subjects.

3) It is essential to the Whiteheadian theory of causality that every physical or spatiotemporal fact, even the simplest quantum event in an atom, can only have an effect after it is taken in by a still non-completed actual entity. Whitehead's term for this inclusion or absorption of an object in the self-determination of a new subject is "physical prehension". This concept is related to the ordinary concept of apprehension, but means the most elementary form of perception and experience in nature and is in very few cases accompanied by consciousness. Not only the fact of this absorption (through prehension) is determined by the absorbing subject itself, but also *how* the absorbed object will be integrated into the absorbing subject. Whitehead emphasizes the creativity of all actual occasions.

4) The many already constituted actual occasions which are prehended by a becoming actual occasion as its objects and absorbed into its own self-creation¹⁵ provide the becoming process with a spectrum of different possibilities for its actualization: The physical constitution of the immediate past of a becoming actual entity (i.e., the material constitution of its prehended objects) determine certain possibilities for the self-creation of the new process. The objects do not offer more than "real potentialities", as Whitehead calls them, without being able to determine which of them will be actualized by the new process.

5) The subjective side of the becoming process creates the essence or, as Whitehead calls it, the "real internal constitution" of the process through an act of decision between the real potentialities: "[...] 'decision' is the additional meaning imported by the word 'actual' into the phrase 'actual entity'. 'Actuality' is the decision amid 'potentiality'. The real internal constitution of an actual entity progressively constitutes a decision [...]" (Whitehead 1979, 43, italics by S.K.). The manifestation of the completed (fully determined) actual occasion as a spatiotemporal datum is its

¹⁵ See introduction of this volume: section 3.2.

objectification – the expression of its act of decision between real potentialities.

6) The process reaches its terminal state only after the decision has eliminated all uncertainty concerning the actualization of real potentials. Only then does the new actual occasion appear as a spatiotemporal datum. Accordingly, the end of a Whiteheadian process is a “jump” in the space-time of physical reality. Its physical manifestation is extremely short-lived; it is more like a flash of lightning. The micro-physical and micro-chronic events of quantum-physics (e.g., electronic and photonic events), the simplest subjects according to Whitehead, disappear after a 10^{-x} -second-lasting presence in space (where x is considerably bigger than 3 and at most equal to 43). The most complex and long-lasting processes are the acts of human consciousness, which can last up to a maximum of a few seconds and manifest themselves as macroscopic patterns of neuronal activation in the brain.

2.2. Decisions for life: living occasions

Whitehead considers the macroscopic enduring things of our day-to-day experience to be *societies* of actual occasions. Although almost all actual occasions have a *micro-chronic* presence in ordinary three-dimensional space, their extremely fast sequence allows societies to appear as *macro-chronic* (i.e., persisting) things. Most societies are very simply organized, so that the actions of their microscopic processes do not support each other mutually. No *macroscopic* coherent activity emerges in these societies. But some societies are organized in such a way that their actual occasions do support each other. They are the most dynamic and causally prevailing parts of the bodies of living beings; Whitehead calls them “living societies”. The mutual support of microscopic processes has the effect that the whole organism acts like a single macroscopic process: it autonomously takes in matter and energy and determines their causal relevance. In sharp contrast to the self-organized systems of physics, living societies impose on themselves material and energetic gradients, for example by searching for and taking on matter and energy in the form of food by themselves.

For Whitehead the body of an organism is just the external, objective side of a society of highly complex mental-physical processes appearing in space-time. In his metaphysics, organisms are considered as societies of processes called “living occasions” (1979, 104).¹⁶ Living occasions do not ontologically differ from other actual entities. Their peculiarity consists only in that they introduce something to the life of an organism that has not been realized ever before in its past. It is characteristic for living occasions to not conform to the past history which they inherit. They introduce something new to the history of a living being which cannot be totally explained as result of its past.

As mentioned above, the organismic subject is the factor which lends causal relevance to the organism’s physical side. It prehends the organism’s most recent state and creates the succeeding state by its own manifestation or objectification. Thus process philosophy does not regard the physically or spatiotemporally manifest part of the organism as a gapless chain of physical states in which each state automatically determines its successor state.

Let us return to the aporia concerning the avoidance of derailments into areas of disorder (fig. 7). Like all actual entities every living occasion has a mental and a physical side. Its mental side recognizes the possibilities of the very near future and makes a choice which is biologically viable. Then its physical side manifests this choice as a material datum in space-time and thus determines the state of the organism. The “regions” of the state-space where living occasions can act are the unstable states in the development of the organism (fig. 7). The concept of living occasions provides the following solution: *A single living occasion can provide an organism which is at the very beginning of the divergence of neighboring trajectories in an unstable area of its state-space with a biologically viable direction.*

By means of its manifestation as a spatiotemporal datum with a certain material constitution, a single living occasion is able to keep an organism whose development passes through indetermined areas of the state-space away from states that are biologically not viable (fig. 8). The physical constitution of the immediate past of a becoming living occasion – i.e. the

¹⁶ See introduction of this volume: section 3.5.

material constitution of that part of the organism which has been prehended by this process – provides the new living occasion with various possibilities for the creation of its own (newly synthesized) material constitution. Thus, the physical state of an organism at a certain point in time and the laws of nature allow a range of possible developments to occur in the immediate future of the organism. The living occasions that take place at this point in time will actualize only one of these real potentialities, which they will do by their own manifestations as the new material facts of the organism. The peculiarity of living occasions consists in their deciding upon developmental paths that are *biologically viable* and not just physically and chemically *possible*. Such important decisions cannot be made by ordinary actual occasions.

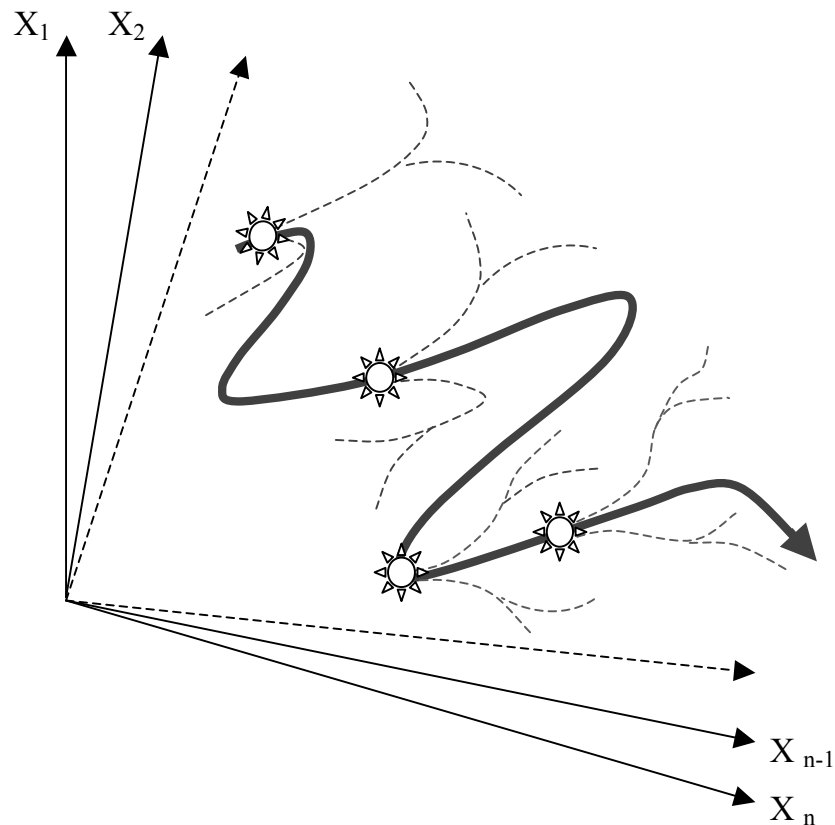


Fig. 8: The “suns” symbolize *living occasions*. Their decisions actualize very few physico-chemical real potentialities which are biologically viable: they prevent the organism from derailing to the lethal developments represented by the dotted lines, thus keeping it on a biologically viable track.

Entropy is uncertainty.¹⁷ Since living occasions reduce uncertainty through the exclusion of almost all of the possible future states of the organism they are essentially anti-entropic agents. They protect embryogenesis from teratogenesis (i.e., monstrosity) and control the regeneration of the mature organism in the event of injury or disease.

Whiteheadian natural philosophy has inspired physicists like Roger Penrose (1995, 1994, 1989) and Henry Stapp (this volume, 2004) and the physician Stuart Hameroff (2007, 2003, 1996). Their writings are of particular interest for the discussion of living occasions in terms of current quantum physics. They, along with other scientists, argue for the existence of actual occasions of *mesoscopic* size which play a decisive role in biological events (see also Gunter, this volume). Thanks to their size these processes would easily be capable of moving the state of an organism onto a certain trajectory which is both possible from the point of view of physics and biologically viable, thereby preventing the derailment of the organism to areas of high entropy. Such quantum events would not be blind quantum fluctuations – as they are actual occasions – but directed *and* mental acts; they would be mental-teleological processes. In this connection, it is noteworthy that a lot of progress has been made recently in the explanation of photosynthesis by applying the idea of quantum events that remain coherent over mesoscopic distances and non-microchronic timescales.¹⁸

Quantum theory allows us to make a very important clarification at this point: The last figure and figure 7 should not be interpreted in terms of classical or statistical mechanics. Because of Heisenberg's uncertainty principle, the development of the organism should not be considered as occupying a certain point in the state-space at a certain point in time as these figures suggest. At a point in time it occupies a very small volume of the state-space, but because of Heisenberg's uncertainty principle this volume cannot be infinitesimally small. The organism's development can be portrayed by a sequence of such volumes. Thus Whitehead's rejection of the scientific abstraction of "simple location" (1953, 61f.) may also be applied to the depiction of the organism's development in state-space,

¹⁷ See section 1.2 and fig. 3 and 6.

¹⁸ See Collini et al. 2010, Engel et al. 2007, Lee et al. 2007.

although it is important to point out that his criticism does not follow from the uncertainty principle but from his own idea of prehension (ibid. 86f.).

Figure 8 often leads to another misunderstanding which should be guarded against: the figure does not imply that each living occasion has a “map” on which all possible developments of the organism’s dynamics, like the streets of a city, are drawn in advance. Only *we* as outside observers are able to draw a “map” containing all possible trajectories, even if only in principle¹⁹ – the biologically viable ones and all the others. Protomental processes like living occasions cannot have such a “map” at their disposal as they are not endowed with consciousness. Thinking of a *decision* as the willful pursuing of a long-term plan fails to recognize that the real meaning of this word in English and other European languages refers to the rejection or elimination of options. Of course, it is possible to reject an entire plan consisting of a tree-like web of succeeding decisions. But this would require a high developed conscious being which has mastered complex logical operations with abstract entities, giving it a large time horizon. The simpler an organism, the more “short-sighted” are its plans. It would be incorrect to say that the living occasions which prehend those parts of an organism just beginning to derail into states of increasing disorder realize this danger by comparing the actual state with the ideal state and measuring the deviation. They do not analyze the material constitution of which they prehend; rather, they *experience* it. Living occasions do not correct the development of the organism like the captain of a ship, who calculates the course anew by using an oceanographic chart and navigational instruments. Rather, they are led by something which may be described as remembering the experience of the state of being healthy. The organism corrects its embryogenesis by means of its inner perspective or self-experience, its *inwardness*, which it possesses even as an embryo. Every multicellular organism has an embryogenetic and an immunological memory. The latter is mainly individual as it results from experiences encountered during ontogeny which only occurs once; the former is supra-individual as embryogenesis is rooted in the species.

¹⁹ I use “in principle” to mean “if we had a perfect science (physics, biochemistry, biophysics etc.), knew all the details about the physical constitution of the organism and had unlimited computer-power”.

It is not possible to say more about this topic here for this would require focusing on the intricate query of the rootedness of embryogenetic memory in the species to which the organism in question belongs. Also, other essential questions cannot be addressed here: What coordinates the contemporaneous, and causally independent, living occasions which prehend different parts of the organism so that their decisions generate a coherent result which looks like the decision of a single subject that could be called the “organismic subject”? Would it make sense for each living being to hypothesize a single overall organismic subject with its own inwardness which would be the source and hence the coordinator of the short-lived living occasions? Could this long-lived organismic subject be conceived as an actual entity?²⁰

2.3. *Processual teleology*

Whitehead regards every becoming of an actual entity as a “teleological self-creation” (1967, 195). He does not, however, reduce teleology to the concept of function in the way that neo-Darwinists and most of the contemporary philosophers of biology who accept the concept of teleology do.²¹ The essence of a living occasion consists in a powerful decision; this decision is powerful because it is, to a significant extent, anti-entropically effective. Such decisions are protomental acts which have at least an elementary capacity for experience. The subjective side or mental pole of the living occasion experiences its own tendency towards one possible development and its rejection of all the others with the phenomenal qualities (qualia) of sympathy and aversion respectively.

Whiteheadian ontology is based on the original and genuine understanding of “telos” which avoids the confines of functionalism. All kinds of end-states in the development, readaptation, behavior,

²⁰ I have dealt with these questions in my book *Organismus als Prozess* (forthcoming).

²¹ On the reduction of teleology to function in neo-Darwinism see Mayr 1991, 75, 61; Brandon 1990, 188; Ariew 2007, 179. The most recent kind of biological neo-teleologism is theoretically founded on dynamic systems theory, that is on theories of self-organization and complexity (Koutroufinis 2013, 314, 318-327), Christensen 1996).

regeneration etc. of organisms can only then be reached if they are striven for as something positively experienced. Aristotle's teleology goes beyond functionalism as well. His world view simply *forbids* considering a natural process controlled by blind, i.e., non-mental forces, as being able to achieve the kind of ordered result attained by an appropriately formed organic structure that serves the purpose of staying alive, like an organism or an organ, rather than degenerating into chaotic malformation (*Physics* II, 198 b33-199 a1). Aristotle would never assume that non-mental processes would be able to produce something as ordered as a single cell.

Another common position of Aristotle and Whitehead is that teleology is a mentalistic notion which does not presuppose the idea of conscious agency. It is crucial to Aristotelian metaphysics that, in nature, mental agents are only rarely conscious of their acting.²² Conscious action is only a seldom occurring special case of mental activity.

Despite important similarities to Aristotelian teleology, Whiteheadian natural philosophy and its understanding of *process* introduces a new kind of teleology which is unique in the history of Western metaphysics. It is no accident that one would search in vain for the concept of "entelechy", a term so central in Aristotle's theory of teleology, in Whitehead's works. Whitehead supports a moderate teleology or final-causality conception. His most basic hypothesis is that all elementary processes or actual entities are acts of experience striving towards the ultimate determination of their own essence. This means that an actual entity *does not strive to achieve a predetermined end-state*, as teleological development is often interpreted, but first and foremost to find out what would be an appropriate end-state for itself: in other words, to define the aim of its own self-creation. Central to this is the idea that the crystallization or gradual development of the aim or telos towards which an actual entity strives belongs to its essence: "Process is the growth and attainment of a final end" (1979, 150). In this sense, one may say that Whitehead replaced the in some respects static substance-philosophical teleology of antiquity and the middle ages with a

²² "It is absurd to suppose that purpose is not present because we do not observe the agent deliberating. Art does not deliberate. If the ship-building art were in the wood, it would produce the same results by nature. If, therefore, purpose is present in art, it is present also in nature" (*Physics* II, 199 b26-30).

processual teleology. His metaphysics offers to biophilosophy a modern basis for a re-conception of genuine Aristotelian insights concerning telos and organism. The combination of processuality and mental-physical bipolarity allows a transformation of the Aristotelian concept of telos – as an insoluble connection of terminal state and purpose – beyond both the old metaphysical concept of substance and the neo-Darwinistic reduction of purpose to function.

Whitehead's processual teleology does not suffer from the serious shortcomings of substance-ontology and different versions of vitalism. In particular, by virtue of the mental-physical bipolarity of actual occasions, it is free from the substance-dualism which haunts many approaches, for example psycho- and neo-vitalism.

Another serious shortcoming of both substance-dualism and psycho-vitalism is that they implicitly violate the law of the conservation of energy by introducing nonphysical forces that act upon matter. In contrast, because of abstaining from additional nonphysical entities Whiteheadian ontology is able to abide by the conservation of energy law: The Whiteheadian cosmos is a vibrating one since the most elementary entities of actuality, the actual occasions, are not persisting substances that are permanently present in space-time, but rather flashes of spatiotemporal existence – vibrations of being. Instead of thinking of the "soul" and the "matter" of the organism as two persisting entities or substances which interact, Whitehead considers living beings as special societies, the members of which permanently originate and perish. The material side of the processes of the living being is actualized over and over again with a very high frequency. The living occasions and all the other actual occasions taking place within organisms manifest themselves in space-time as quanta of energy; thus *they are the energy of the organism*. With their mental side they can make two important decisions: firstly, how they will distribute the overall energy which comprises their physical side in the body of the organism and, secondly, with what material constitution, that is to say with what molecular structure it will be manifested there. Thus they do not "push" the constitution of the organism's body into a certain state (into a certain location in the state-space) by any non-material "forces"; this would violate the law of the conservation of energy. Whiteheadian

processes do not act on the material world “externally”, but rather “internally” through their manifestation *as* matter.

3. Conclusion

Viewing organisms as merely dynamic systems in terms of physics and chemistry cannot explain their real autonomy. Organisms viewed in this limited way would succumb to the serious problem of instability: The organism’s dynamics would permanently enter phases in which the trajectories of its development would diverge strongly; furthermore, most of them would derail the organism’s development into fatal disorganization. But at the same time the problem of diverging trajectories offers a fruitful application for Whiteheadian teleology. It indicates that the future development of the physical side of the organism is causally open to a certain degree so that a particular kind of Whiteheadian processes, namely living occasions, have possibilities of choice. Living occasions can provide an organism which is at the very beginning of the divergence of neighboring possible developments with a biologically viable direction by means of their manifestation as spatiotemporal data with a certain material constitution. The essence of each living occasion is a decision which has an anti-entropic effect, since it strives to prevent the organism from increasing its entropy.

Bio-systemism and Whiteheadian process-philosophy can be merged into a higher synthesis whose core idea can be formulated as follows: Bio-systemic thinking can in principle²³ describe the *possible* developments of an organism, while the organism’s actual development, consisting in the decision between real possibilities, is accessible to Whiteheadian process philosophy.

²³ For the meaning of “in principle” in this context see footnote 19.

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