

The Emergence of Biological Value

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1. INTRODUCTION

All the things we think of as paradigmatic cases of design – novels, paintings, symphonies, clothes, houses, automobiles, computers – are the work of human hands guided by human minds. Thus, design might be defined as matter arranged by a mind for a purpose that it values. But this raises the question, what are minds? Presumably, the activity of brains. The problem with this answer, however, is that brains themselves give every appearance of being designed. Most contemporary thinkers view brains as neurons arranged for the purpose of thinking in much the same way that, say, mouse-traps are springs and levers arranged for the purpose of killing mice. But if that is so, then who arranged the neurons? Who or what values thinking, and whose purpose does it serve?

It is generally supposed that there are only two ways to answer these questions. One way has come to be known as *Intelligent Design*. On this view, our brains were designed by other minds existing elsewhere – say, in another galaxy or on another plane of being. But if these other minds are also instantiated in matter, then we have the same problem all over again. If not, then we have an even more difficult problem than the one we started with. To invoke immaterial minds to explain the design of material ones is surely a case of *obscurum per obscurius*.

The other way is what I shall call the *Mechanistic Consensus*. In summary, the Mechanistic Consensus holds that (1) the known laws of physics and chemistry, together with special disciplines such as molecular biology, fully explain how living things work, and (2) the theory of natural selection explains how these laws have come to cooperate with one another to produce the appearance of design in organisms. According to the Mechanistic Consensus, design is not objectively real but merely an optical illusion, like the rising and setting of the sun. On this view, living matter is nothing special. It is just chemistry shaped by natural selection.

In this paper, I will argue that the Mechanistic Consensus is wrong. It is wrong because, conventional wisdom to the contrary, (1) present day physics and chemistry do *not* provide the conceptual resources for a complete understanding of how living things work, and (2) natural selection does *not* provide an adequate means of naturalizing the normative teleology in living things. However, in spite of this failure of the Mechanistic Consensus, I will argue that we are still not forced to the Intelligent Design position, because there exists a third way of explaining the appearance of design in living things.

One of the hallmarks of a machine is that the relationship between its function and its material constitution is arbitrary. Intelligent Design and the Mechanistic Consensus agree that organisms are machines in this sense, consisting of matter that is inert insofar as its function is concerned. Both schools of thought view biological functions as something imposed on inert matter from the outside, by the hand of God or by natural selection, as the case may be. But what if the analogy between organisms and machines were fundamentally flawed? Suppose that the teleological and normative character of living things really derived from an essential connection between biological function and the spontaneous activity of living matter. In that case, such a connection might give rise to systems that prefer or value some of their own possible states over other, energetically equivalent ones, and that strive to attain these preferred states under the constraint of external conditions in accordance with means-ends logic. Then, instead of being an illusion, as the Mechanistic Consensus claims, the purpose and value seemingly inherent in the functional actions of living things might be objectively real. If all of this were so – and I will argue that it is – then living matter would be special, after all. Although we have little idea as yet in what this specialness consists, in the last section of this chapter I will briefly consider the implications of some promising lines of contemporary research in nonlinear dynamics and condensed matter physics for understanding the emergence of biological value.

2. THE MECHANIST'S DILEMMA

Living things give every appearance of purposiveness. It is entirely natural to describe biological processes as functions that operate according to means-ends logic. Functional ends or goals constitute norms with respect to which the means chosen may be judged good or bad, right or wrong, successful or unsuccessful. Furthermore, organisms must be capable of choosing means appropriate to their ends – that is, of being right – at least some of the time. For example, in order to live, a cell must move in the right direction when it encounters a nutrient gradient. The very existence of life presupposes the possibility of correct functioning. On the other hand, organisms are also necessarily capable of error. What appears to be a nutrient gradient may in

fact turn out to be a lure or a poison. Functions are inherently capable of malfunctioning. Right or wrong, organisms behave according to functional logic. *This* is done so that *that* may happen. *A* is preferred; *B* is necessary for *A*; therefore, *B* is chosen. All function conforms to this pattern. Which is to say that, in pursuing their ends, organisms are not propelled by causes; rather, they act for reasons.

Behavior answering to these ordinary-language descriptions clearly exists. It is easily confirmed through elementary empirical observation. True, the teleological and normative language used in the previous paragraph to describe functional behavior might be dismissed as pretheoretical and without scientific value. But this claim presupposes the existence of an alternative theoretical language into which these descriptions can be translated without loss. This language must itself be rigorously purged of all traces of teleology and normativity. Does such a language in fact exist?

Open any cell biology textbook to any page, and what will you find? Talk of regulation, control, signals, receptors, messengers, codes, transcription, translation, editing, proofreading, and many other, similar terms. It is true that this technical vocabulary is an indispensable aid in describing many previously undreamed-of empirical phenomena. Molecular biology has greatly extended the scope and precision of our knowledge, and the terminology it has developed is an integral part of that accomplishment. But the fact remains that these concepts are no less normative than those of everyday speech. Adherents of the Mechanistic Consensus are untroubled by this defect, because they insist that it is only a matter of convenience. A metaphor like "second messenger," they say, is employed only to avoid intolerably verbose descriptions of the mechanistic interactions that underlie the appearances. Such a *façon de parler* is a promissory note redeemable in the hard currency of physics and chemistry. But as with any IOU, the notes issued by molecular biology are only as good as the guarantors backing them up. If the other sciences cannot pay them either, then the promises are worthless. For this reason, it behooves us to take a closer look at the conceptual solvency of the Mechanistic Consensus.

First, we are told that living things are made of ordinary matter and nothing but ordinary matter. And it is true that biological molecules are composed mostly of a handful of elements (CHNOPS), along with traces of some others, all long familiar to chemists. Certainly, there are no unknown elements in living things that are not present in the periodic table. Second, we are assured that the interactions between these elements *in vivo* are basically the same as those *in vitro* described by present day physics and chemistry. This is a more doubtful claim, to which I shall return later, but for now, let us grant this, too. Even so, there remains a fundamental difficulty.

The difficulty is that, while all the individual reactions in the cell may be described in ordinary physical terms as tending toward an energy minimum,

the same cannot be said of the way in which the reactions are organized. When a signal molecule (say, a hormone) interacts with its receptor (a protein), what happens may be more or less understood in terms of biochemistry. But biochemistry has no conceptual resources with which to explain the meaning and the purpose of this reaction – the very things that constitute the reaction *as* a signal, and not just a meaningless jostling of matter. What makes the living cell profoundly different from ordinary inorganic matter is the way in which each reaction is coordinated with all the others for the good of the whole. There is no doubt that this coordination itself transcends the explanatory resources of biochemistry, because it operates according to functional logic, not just according to physical law (Pattee 1982; Rosen 1991; Jonker et al. 2002).

From a purely physical point of view – at least so far as our present state of knowledge is concerned – there is no reason why a reaction that is good for the organism, rather than one that is bad for it, should occur. The very categories of good and bad have no place in physics or chemistry as currently understood, and yet they are at the very heart of life. Every reaction in the cell is more than just a reaction, it is a functional action. Such an action constitutes a choice among states that are energetically equivalent so far as the ordinary laws of physics are concerned. Such preferred states are achieved, not by minimizing energy, but by doing work – that is, by directing internally stored energy here or there according to needs that are normative for the cell. Just as the laws of physics permit me to direct my automobile left or right at an intersection, so too they permit a cell to travel up or down a chemical gradient. There is no use seeking the explanation for such decisions in the physical forces impinging on me or on the cell. It is not physics (at least, not any presently understood physics) that explains purposive action; rather, it is the situational logic of functional action that governs the decisions of cells as integrated wholes (Albrecht-Buehler, 1990; Alt, 1994; Lauffenburger and Horwitz, 1996).

During the past fifty years or so, we have developed a highly sophisticated theoretical framework to explain how such coordinated, goal-directed action works – namely, the theory of feedback and cybernetic control. This theoretical understanding has made possible the construction of complex, self-regulating mechanical systems that operate according to a functional logic similar to that in living things and that fulfill a wide variety of human purposes. There is no doubt that this body of theory provides a great deal of insight into the internal operation of biological systems as well. But there remains a glaring problem. In the case of the machine, we decide what counts as its goal states, and *we* arrange its parts accordingly. Who or what does these things in the cell?

It is often assumed that invoking the concept of information will somehow solve this problem. It is true that all living things utilize information in some sense (Loewenstein 1999). However, this observation merely labels the

problem; it contributes little or nothing to its solution. The reason is that, by definition, information is essentially semantic. Without meaning, there is no information; there are just spatial or temporal patterns. For a pattern to constitute information, we must posit a cognitive agent for which the pattern is meaningful. What, then, is semantic information? One plausible answer is: *a correlation between events and functional actions without tight thermodynamic coupling.*

The proviso is important, because correlations that are the direct result of the laws of physics do not constitute information. Information is only possible where choice exists. For choice to exist, the causes of the correlated events must be orthogonal to each other (Nagel 1998). Causes are said to be orthogonal if they are independent of each other insofar as the laws of physics are concerned – that is, if the existence of one does not necessitate the existence of the other. This is indeed the case throughout the living cell (Monod 1972; Pattee 2001; Polanyi 1969). In short, if the correlation between events in the cell were the direct result of the minimization of energy due to tight thermodynamic coupling, then it would make no sense to speak of their occurring on the basis of information. Since that is not the case, it does make sense to speak in this way. Without tight thermodynamic coupling, an event may act as a trigger of a functional action. In that case, the meaning of such an event may be interpreted as a sign of the presence of conditions favorable to the action. In effect, information is an event that tells a biological function: act now, and you will succeed (Barham 1996). Note, however, that the question of how such a correlation between events and goal-directed actions is possible is essentially the same problem that we have been discussing all along – that of explaining the design or normative teleology inherent in life. Shannonian information theory is of no help at all in solving this problem. It simply assumes intelligent agents at either end of the communication channel; it makes no pretense of explaining how physical patterns can acquire meaning in the first place. For this reason, in its present theoretical articulation, the concept of information is an integral part of the problem. It contributes little or nothing to its solution.

If the functional logic of the cell is irreducible to physical law as we currently understand it, then there would appear to be only two ways to explain it naturalistically. Either the teleological design of living things is, at bottom, a matter of chance; or else there is some unknown qualitative difference inherent in the material constitution of organisms that gives them an intrinsic functional integrity. The first option is appealing to the mechanistic biologist, but it is very hard for the physicist to swallow because of the fantastic improbability of living things from a statistical-mechanical point of view, as has often been pointed out (Eden 1967; Elsasser 1998; Lecomte du Noüy 1948; Schoffeniels 1976; Yockey 1992). The second option has attracted a number of physicists who have thought seriously about life (Denbigh 1975;

Elsasser 1998; Schrödinger 1992), but it is unpalatable to most biologists because to them it smacks of prescientific "vitalism."

This, then, is the Mechanist's Dilemma. Is life a statistical miracle? Or is the Mechanistic Consensus defective in some fundamental way? I will examine the first horn of this dilemma in the next section and the other one in section 4.

3. **NORMATIVITY AND NATURAL SELECTION**

According to the Mechanistic Consensus, the things that happen in organisms do not really happen for a purpose; it only looks that way. In reality, things just happen. Period. What happens in the organism is no different from what happens in the test tube. Enzymes cleave or bond their substrates according to the well-known laws of physics and chemistry. A catalyst is a catalyst. How, then, do mechanists explain the appearance of purposiveness in living things?

They say that some of the things that happen by chance in an organism have the consequence that they enhance the organism's fitness. This means that the probability of the organism's surviving to reproduce within a given set of environmental conditions is increased by the physical or chemical event in question. When this happens, the propensity for that event to occur will be transmitted to the next generation. Then, this event will tend to recur and to have the same consequence in the offspring, so long as the same environmental conditions exist, and likewise in the offspring's offspring. In this way, the representation of the original event in the overall population will gradually increase. At the limit, an event that first occurred in a single organism will spread to all members of a species. In that case, it will appear as though these organisms had been designed for their environment with respect to the event in question. But in reality, all that has happened is that the process of natural selection has locked into place an event that originally occurred by chance insofar as its fit with the environment is concerned.

It is widely assumed that this explanatory scheme gets rid of all the troublesome teleology in biology, but this is a mistake. Natural selection provides only the appearance of reduction, not the reality, as may be seen from a number of considerations. To begin with, we may note that the notions of survival and reproduction undergird the entire Darwinian schema and are not themselves explained by it. But these concepts already remove us from the terra firma of physical interactions and land us right back in the teleological soup. It is sometimes claimed that the stability of a chemical compound constitutes "survival" or that crystal growth is a primitive form of "reproduction," but these metaphors merely obscure the point at issue. Chemical compounds and crystals just seek their energy minimum given a set of constraints, whereas the intelligent responsiveness of an organism to

its environment and the complex coordination of events involved in cell division transcend energy minimization. The latter, distinctively biological phenomena already contain the normative feature of striving to achieve particular preferred states by directing energy in some ways rather than in other, energetically equivalent ways. But this is the very thing we are trying to explain. Survival and reproduction demarcate the boundary between the living and the nonliving, and so are far from the unproblematic mechanistic concepts that a successful reduction would require.

Another problem is the way in which selection theory employs the notion of chance. In order for Darwinian reduction to go through, we must assume that an organism's parts are essentially independent variables, each of which is free to change at random with respect to the other parts and with respect to the whole organism's needs. But if organisms really were made of inert, functionally uncorrelated parts, then evolution would be impossible owing to combinatorial explosion. There has simply not been enough time since the Big Bang for even a single protein molecule to be created in this way with any reasonable probability, much less an entire cell – much less the whole inconceivably complex, functionally integrated organic world we see around us. If organisms were literally machines, they would indeed be miraculous – on this point, the Intelligent Design critique of Darwinism is perfectly sound. If organisms were really made of inert parts bearing no intrinsic relation to function, then we would indeed have to assume that they were designed by a humanlike intelligence, because that is the only conceivable way for functionally integrated wholes made of such parts to come into existence.

However, this does not mean that we are forced to accept the Intelligent Design conclusion. Instead, we may reject the premise. This means treating the “design inference” (Dembski 1998) as a *reductio ad absurdum* of the proposition that organisms are machines. By dropping this assumption, we may view organisms as active and fully integrated systems in which a change in one part leads to appropriate changes cascading throughout the system in accordance with functional logic. In this case, the possibility of evolutionary transformation begins to make sense from a physical point of view, *but now Darwinism has forfeited all of its reductive power*. We have simply assumed the functional organization of the cell, which is the very thing that we claimed to be able to explain by means of the theory of natural selection.

Darwinists often complain that such criticisms are based on a misunderstanding. It is not chance, they say, that bears the explanatory weight in their theory, it is the selection principle. Natural selection is said to act as a ratchet, locking into place the functional gains that are made, so that each new trait can be viewed as a small incremental step with an acceptable probability. But what Darwinists forget is that the way a ratchet increases probabilities and imposes directionality is *through its own structure*. In this context, the structure of the ratchet is simply the functional organization of life. Darwinists

are entitled to claim that the explanatory burden of their theory lies upon the selection ratchet, thus avoiding the combinatorial explosion problem, only provided that they also acknowledge that the structure of this ratchet consists precisely in the intrinsic functional correlations among the parts of the organism. But if they do this, then they must also admit that they have merely assumed the very functional organization that they claimed to be able to explain, thus sneaking teleology in by the back door.

Finally, it is often claimed (e.g., Depew and Weber 1998) that the normativity of biological functions can be fully naturalized in terms of Wright's (1998) analysis, in which a function is a part of a system that exists because of the role that it plays within the system. In the case of biological functions, normative functions are traits that have been selected. That is, if a given trait does *f*, and *f* happens to cause the trait to be favored in the selection process, then *f* becomes the "proper function" (Millikan 1998) of that trait. But this analysis reduces the problem of naturalizing normativity to a matter of agreeing on a terminological convention; it has nothing to do with scientific explanation in the usual sense.

Of course, science often looks to history to explain how the present state of a system came into being, but the present causal powers of a system must nevertheless be explicable in terms of the system's present state. After all, "history" is just a convenient shorthand way of referring to the whole sequence of dynamical states of a given system, the past transformations of which have led to the system's present state. But this sequence in itself does not explain the present properties and causal powers of the system; rather, these are explained by the present physical state of the system, which is the only thing that is actual. Living systems are physical systems, and there is no reason to believe them to be exempt from this fundamental metaphysical principle. Therefore, we must conclude that it is something in the present state of a biological function, not its selection history per se, that accounts for its normativity. We must not confuse the present effects of history with history itself.

In summary, the massive coherence and coordination of the parts of biological systems, all intricately correlated to support those systems in existence as organized wholes, must arise either by chance or by some ordering principle conforming to functional logic. Elementary considerations of statistical mechanics and probability theory suffice to exclude the chance hypothesis.¹ Therefore, there must exist an ordering principle. This principle is logically prior to selection, since novel biological forms must already exist before they can be selected. Indeed, all viable novel forms are always already entrained into a fully integrated functional system before selection occurs. Therefore, variations in living form are the cause of differential reproduction, not the effect. This means that the theory of natural selection tacitly presupposes the functional integrity and adaptability of organisms. Which is another way of saying that Darwinism begs the question of teleology.

4. MATERIAL EMERGENCE AND THE GROUND OF NORMATIVITY IN NATURE

So far, I have argued that neither the known laws of physics and chemistry nor the theory of natural selection succeeds in explaining the teleological and normative characteristics of living things. Since it will be difficult to overcome the Mechanistic Consensus on the strength of these negative arguments alone, I now turn to a positive account of biological value, based on some promising, albeit speculative, lines of contemporary scientific research.

First, we must view our problem against the backdrop of a general picture of cosmic evolution (Denbigh 1975; Layzer 1990). The key concept here is spontaneous symmetry breaking, which is the framework within which the origin of all novelty and all complex structures and processes in the universe must ultimately be understood (Icke 1995). In order to explain this phenomenon, physicists have developed a variety of mathematical tools (above all, the renormalization group) for extracting certain universal properties shared by systems across length scales by abstracting away from physically irrelevant details (Cao 1997; Batterman, 2002). Such techniques work extremely well and seem to reveal a layered world of hierarchical levels, each with its own intrinsic stability and characteristic physical properties (Georgi 1989). The idea is that over the course of its history, the universe has repeatedly produced qualitatively new forms of matter with distinctive causal powers. Anderson (1994) famously encapsulated this insight in the slogan “more is different” (see also Schweber, 1997; Cao, 1998). Thirring (1995) has even gone so far as to speak of the evolution of the laws of nature themselves.

It is true that the asymptotic methods used to model these empirical phenomena have often been interpreted as a gimmick employed to circumvent our own cognitive limitations. But this epistemic interpretation of physical theory is based on little more than reductionist faith (Laughlin and Pines 2000; Laughlin et al. 2001). It is inconsistent with the principle that the best explanation for the success of a theory is that it has a purchase on reality. On the other hand, if we take the success of modern field theoretic methods in physics at face value, then we begin to see the possibility of a new conception of emergence, one that is directly linked to the properties of matter itself in its various guises. Let us call this notion *material emergence*, in order to distinguish it from the more usual idea that emergence is a purely formal property of organization per se.

What reason do we have to believe that biological value is emergent in the material sense? Batterman (2002, 135) notes that “[i]n the physics literature one often finds claims to the effect that [emergent] phenomena constitute ‘new physics’ requiring novel theoretical work – new asymptotic theories – for their understanding.” In other words, wherever novel kinds

of material systems are to be found, we can expect to find qualitatively distinctive causal powers, and hence to need “new physics” to describe those powers. For example, condensed matter in general required the development of many new physical concepts and remains imperfectly understood to this day. Why should this same principle not apply to life in particular? Given these considerations, it is unsurprising that physicists are beginning to articulate the need to tackle the expected “new physics” intrinsic to the living state of matter head-on (Laughlin et al. 2000).

Of course, this understanding of the general principle of material emergence still leaves us with one very pressing question: how can we make scientific sense out of biological value as a physical phenomenon? There are two lines of research that seem to me to bear directly on this question. The first of these is nonlinear dynamics (Auyang 1998; Walleczek 2000). Nonlinear dynamical systems are interesting in this context because their behavior possesses a number of properties that seem to be of potential significance for biology. One of these is robustness, meaning that the system will spontaneously damp perturbations to its dynamical regime, within limits. Such robust dynamical equilibria may be modeled mathematically as “attractors.” Another important property of nonlinear dynamical systems is metastability, which means that, within the abstract landscape of possible dynamical regimes accessible to the system, other attractors exist in the vicinity of the original one. If a metastable system is pushed past the boundaries of its original attractor, it will not necessarily cease its dynamical activity altogether. Instead, it may be pulled onto a new attractor. Such a shift to a somewhat different dynamical regime constitutes a bifurcation event. This phenomenon is of the highest interest for understanding the directed or selective switching between different dynamical regimes in metabolism (Jackson 1993; Petty and Kindzelskii 2001) and other forms of robust short-term (ontogenetic) adaptive behavior in cells (Barkai and Leibler 1997; Alon et al. 1999; Jeong et al. 2000; Yi et al. 2000). Ravasz and colleagues (2002, 1555) point out that “[t]he organization of metabolic networks is likely to combine a capacity for rapid flux reorganization with a dynamic integration with all other cellular function.” Nonlinear dynamics gives us a way of conceptualizing and modeling this cascading functional reorganization of relationships among the components of living systems. By showing how new functional states may be found through the operation of physical principles, it may also serve some day as the basis for a genuine understanding of long-term (phylogenetic) adaptive shifts in molecular structures and dynamical regimes – that is, evolution (Kauffman 1993; Flyvbjerg et al. 1995; Gordon 1999; New and Pohorille 2000; Segré, Ben-Eli, and Lancet 2000; Jain and Krishna 2001; Zhou, Carlson, and Doyle 2002).

Another interesting property intrinsic to nonlinear dynamical systems is the lack of proportionality between causes and effects in their interactions with the wider world around them. This disproportionate response

to events impinging upon them from their surroundings is a hallmark of all living things. If organisms are conceived of, not as machines made up of rigidly connected parts, but as a dense network of loosely coupled, non-linear oscillators, each sensitive to a range of specific low-energy inputs from its surround, then we begin to see how information in the semantic sense just discussed is possible. On this “homeodynamic” view of the organism (Yates 1994), information is anything that acts as a trigger for the action of such an oscillator (Barham 1996). The role of such a trigger in the functional action of an organism is to coordinate the timing of actions in such a way that they become correlated with favorable environmental conditions, where “favorable” means tending to support the continued homeodynamic stability of the oscillator. On this view, then, the meaning of information consists in the prediction of the success of functional action, where “success” likewise means the continued homeodynamic stability of the oscillator. This dynamical interpretation of semantic information provides us with a new physical picture of the cognitive component of adaptive functional action.

Most, if not all, of the authors of the studies just cited would probably contend that they are working squarely within the Mechanistic Consensus. So why do I interpret their work as contributing to the overthrow of that worldview? Because nonlinear dynamics cannot be the whole story. After all, inorganic dynamical systems such as hurricanes and candle flames are not alive. They do not utilize information in the dynamical sense just described, nor do they draw on internal energy stores to do work against local thermodynamic gradients in order to preserve themselves in existence – all of which are hallmarks of living things. Rather, they are thermodynamically tightly coupled to their surrounds and are merely minimizing energy under a given set of constraints. Furthermore, dynamical networks with many of the properties just discussed can be constructed out of inorganic materials, as in neural networks. And yet a neural network is just fulfilling our functions, not its own. It has no internal tendency to prefer one energetically equivalent configuration over another. It is we who choose which configuration counts as a correct solution to a given problem. Once the boundary conditions have been set by us, everything else is just minimizing energy.

With nonlinear dynamics, we have still not reached the heart of the matter, where the leap from passive energy minimization to the active directing of energy in accordance with preferred goal states occurs. Still lacking is an understanding of how it is possible for dynamical networks to strive to preserve themselves – that is, to value their own continued existence. Philosophical mechanism posits a contingent link between function and matter. Therefore, in order to transcend mechanism, we must penetrate the mystery of the essential link between biological value and the living state. To do this, we must look beyond nonlinear dynamics, which is necessary but not sufficient for this task.

One of the most interesting lines of contemporary research that holds some promise of providing the missing piece of the puzzle is the investigation of the cell as a *sui generis* condensed phase of matter – the living state. There are several different approaches here that will eventually need to be integrated. One is work on the global properties of the protein–phosphate–ordered water gel that constitutes the main phase of the cytoplasm in all living cells (Ho et al. 1996; Watterson 1997; Pollack 2001). Another is work stressing the direct link between the physical structure of the cell components and the coordination of cellular functioning (Hochachka 1999; Kirschner, Gerhart, and Mitchison 2000; Surrey et al. 2001; Whitesides and Grzybowski 2002). A third is work on the intrinsic dynamical properties of proteins arising from their energy degeneracy and manifold competing self-interactions (“frustration”) (Frauenfelder, Wolynes, and Austin 1999). Finally, there is the highly suggestive, if speculative, work on adapting the formalism of quantum field theory for use in describing the directed transfer of energy along macromolecular chains via coherent resonances within a hypothetical electric dipole field (Li 1992; Wu 1994; Fröhlich and Hyland 1995; Ho 1997, 1998; Vitiello 2001). All of these approaches share the assumption that there is more to the coordination of functional action *in vivo* than can be explained by mechanistic interactions observed to date *in vitro* or even *in silico* (Srere 1994, 2000). It is becoming clear that new, nondestructive experimental techniques for probing the real-time dynamics of macromolecular interactions are needed if we are ever to achieve a genuine theoretical biology (Laughlin et al. 2000).

How can such research programs help us to understand the ground of normativity in nature? By showing how life is “an expression of the self-constraining nature of matter” (Moreno Bergareche and Ruiz-Mirazo 1999, 60). Ultimately, this means showing how living systems function as integrated wholes, using information in the dynamical sense and doing work in order to maintain themselves in existence. It means showing how a mere physical system acquires the capacity for striving and preferring, how it becomes a self-existing *pour soi* (Jonas 1982). And it means showing how all of this occurs through a process of material emergence.

It is impossible to say exactly how this happens in advance of the scientific breakthrough that will provide the eventual explanation. Whether any of the specific lines of research alluded to here are on the correct path is perhaps doubtful. But it is important to see that there are already ideas on the table that seem to be moving us in the right direction. Today, the emergence of objective biological value is no longer scientifically unthinkable.²

5. CONCLUSION

In the end, the idea that life is special is just plain common sense. After all, it is a matter of everyday observation that animate systems are fundamentally

different from inanimate ones. A broken bone heals; a broken stone doesn't. If this homely truth has been lost sight of, it is undoubtedly because the mysteriousness of teleology and normativity have made them ripe for exploitation by irrationalist opponents of science. I think it is mainly for this reason that those sympathetic to science have seized upon every advance in biology since Friedrich Wöhler synthesized urea in 1828 to proclaim that "organic macromolecules do not differ in principle from other molecules" (Mayr 1982, 54). But this essentially defensive maneuver holds water only against the backdrop of reductionism. Against the backdrop of material emergence, it makes no sense at all. Why should organic macromolecules not be very different in principle from small molecules, when liquids are very different from gases, and solid matter is very different from both? If more really is different, then why should those behemoths, proteins, not have special causal powers that small molecules do not possess? The time has come for naturalists to rethink their metaphysical commitments in light of the Mechanist's Dilemma. After all, why should biologists and philosophers feel that they must be *plus mécanistes que les physiciens*?

As a scientific methodology, the machine metaphor has been extraordinarily fruitful. No doubt it will remain so for a long time to come, although there are many signs that we are beginning to bump up against the limits of its usefulness. But however that may be, as a metaphysics, mechanism has always been incoherent. The idea that a machine could occur naturally at all, much less that it might have its own intrinsic purposes and values, is simply an article of faith for which there is no rational support. Nevertheless, I want to emphasize that the attack mounted here against the Mechanistic Consensus should not be construed as an attack on science itself. We must carefully distinguish between the operationally verifiable results of science and philosophical extrapolations from those results. As Unger (2002, 10) has recently reminded us, the reductionist outlook is "a particular *philosophical approach* to science, rather than something science itself actually delivers."

Whether any of the alternative approaches too briefly surveyed here will prove to be of lasting value, only time will tell. But one thing is certain: it is not necessary to choose between the Mechanistic Consensus and Intelligent Design. The emergence of objective biological value as an intrinsic property of living matter is a coherent alternative that warrants further investigation.

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“left-Aristotelian” alike – and to absolve them all of responsibility. Philosophy makes strange bedfellows.

Notes

1. Chance may still play a more modest role, of course. The role that chance plays in evolution is analogous to that of trial-and-error search in individual organisms. All learning, whether ontogenetic or phylogenetic, involves groping for new ways of functioning. Life is intelligent, not clairvoyant. But the crucial point is that even trial-and-error search is still essentially teleological and normative in character. Searches are aimed at particular preferred states, and trials are evaluated accordingly.
2. For further references, as well as discussion of the philosophical significance of this literature, see Barham (2000, 2002).

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