THE IDEA OF CREATION AND THE THEORY OF AUTOPOIETIC PROCESSES

by Niels Henrik Gregersen

Abstract. Systems theory is proposed as a major resource for reconceptualizing a Christian theology of creation. Section I outlines the principles of the theory of autopoietic systems and discusses in particular Manfred Eigen's and Stuart Kauffman's differing views of the emergence of life. Section II shows how biblical texts conceive of God´s "blessing" as a divine installment and reshaping of spatio-temporal fields for creaturely self-productivity. On this double basis, Section III undertakes a constructive attempt to formulate a theology of self-productivity within a Trinitarian framework. The unity of divine self-consistency and capacity for self-relativization is seen as the clue for understanding how God not only sustains the world in general but also influences particular processes by changing the overall probability pattern of evolving systems.

Keywords: autopoietic systems; blessing; creation; divine action; M. Eigen; S. Kauffman; N. Luhmann; A. R. Peacocke; systems theory; Trinity.

God did not make the things, we may say; no, but He made them make themselves.

—Frederick Temple, *The Relations between Religion and Science*

While interpreting the first chapter of Genesis, the Jewish sages behind the *Midrash Rabbah* of Genesis pondered why the first book of the Torah does not begin with an *alef*, the first letter of the Hebrew alphabet, but rather with the second letter, *beth*. The fact that the lines in the shape of this letter (ב) are closed at the sides and only open in the front was taken by the rabbis to enclose the message that "you may speculate from the day

Niels Henrik Gregersen is Associate Professor of Theology at the University of Aarhus, DK-8000 Aarhus C, Denmark. An early German version of this paper was presented at the conference Die Welt als Schöpfung verstehen und verantworten, Evangelische Akademie Loccum, 10–12 December 1995. Main parts of the present essay were delivered at the Templeton Workshop in Oxford, 23–27 July 1996.

[*Zygon*, vol. 33, no. 3 (September 1998).]
 ISSN 0591-2385

that days were created, but you may not speculate on what was before that" (Jaki 1992, 44).

Keep the Letter Beth *in Mind.* This advice seems wise to follow, especially when employing the term *autopoiesis* in relation to a creation theology. The purpose of this essay is thus not the question of ultimate beginnings (or how to begin beginnings) in terms of a *creatio ex nihilo.* The issue is the possibility of a theological interpretation of the creative transformations of nature. More specifically, I want to address how to construct a thought model by which it is possible to understand and describe the relation between God the Creator and natural creative processes from the point of view of a Christian creation theology. Is there an inner contradiction between the notion of God's creation (Gr. *ktisis*) and the scientific concept of the self-development of nature (Gr. *physis*, or self-growth)? If not, what kinds of thought models are available that may overcome this apparent contradiction in terms?

I suggest that the concept of autopoiesis (literally meaning "self-creation" or, better, "self-production") is a candidate. The overall thesis is the following:

(1) God is creative by supporting and stimulating autopoietic processes.

Since this sentence is a hybrid containing both theological and scientific elements, it is in need of some clarification. In creator language, God is qualified as having a priority in relation to the autopoietic processes constituted by divine action. Thus, the theological and scientific elements are placed on different levels: the constitut*ing* and the constitut*ed* levels. This priority of divine action has a universal extension in both Jewish and Christian traditions: Everything that exists ("Heaven and Earth") derives its being from God's letting-it-be.

Now the divine modes of actions are further characterized by the adjectives *supportive* and *stimulating*. These adjectives are here used symbolically when applied to God, since they transcend their ordinary meanings. God is not "supporting" the world in the same way as Atlas supports the globe, namely, apart from the world itself; neither is God "stimulating" the world in the same way as a chemical catalyst stimulates a process, namely, as a discrete substance. Rather, God supports autopoietic processes by constituting their inner dynamics as in the classical notion of continuous creation. However, while the idea of God's supportive action is general in scope, the notion of God's "stimulating" action refers to particular instances where different outcomes are possible, given the situation as a whole, similar to the classical concept of particular divine actions. I do not claim that the causal route of particular divine actions can be empirically traced (here is the difference from Atlas and from a chemical catalyst); neither do I claim that God is acting nonuniformly everywhere.

The position I do hold is that it makes sense, both conceptually and with regard to our common world picture, to assert that God not only continuously supports autopoietic processes but also may stimulate them in particular directions as they unfold themselves. I am thus suggesting a thought experiment that can be rephrased as follows:

(2) (*a*) *If* God is the creator of all-that-is, and
(*b*) *if* autopoietic processes take place in the realm of nature,
(*c*) *then* it is meaningful to say that God is active as Creator in these autopoietic processes by supporting their inner dynamics and possibly by stimulating their dynamics in certain directions.

Within this framework, I hold that there is a compatibility between the concept of creation and the concept of self-productive nature and that no pantheistic collapse is involved in (1) or (2). Moreover, I shall aim to show that the concept of autopoiesis facilitates an array of theological interpretations of the relation between God and nature.

My argument will be organized in three sections: Section I defines the scope of autopoietic theory and discusses two important explanatory models for self-organizing systems inside prebiotic and biotic regimes: Manfred Eigen's and Stuart Kauffman's. Section II relocates the idea of self-production within important strands of Jewish and Christian imagery of divine creation. Section III proposes a sketch for a theological redescription of autopoietic systems as supported by and stimulated by God.

I. The Theory of Autopoietic Processes

1. THE CONCEPT OF AUTOPOIESIS. From the outset, it should be noted that the leading concept in the following discussion, "autopoiesis," is not an empirical one. The natural sciences—the biological and medical in particular—have developed many words for internally structured processes, like *autocatalysis* (the product of a process being the catalyst for that process), *autolysis* (the breakdown of tissues created by the enzymes active inside the tissues themselves), and even *autointoxication*. The term *autopoiesis* has been coined by the theoretical biologists Humberto R. Maturana and Francisco J. Varela as a theoretical concept that must be redefined for empirical purposes.[1]

a. Autopoiesis Is More than Self-Organization. While the concept of self-organization still retains the idea that systems are organized out of preestablished elements, the concept of autopoiesis more radically contends that the elements themselves may be created only within organized superstructures. Self-transformations extend not only to the organization of the system but also, sometimes, to the elements of the system themselves.[2] It is only in a cell, for instance, that we meet the special arrangements of molecules that make up its membrane. The membrane is not only a demarcation line between the inside and the outside of the cell: its elements also participate in the internal life of that cell and cannot exist independently from the cell system as a whole. Or consider the procedures of the immune system. When an organism is under attack, the specialized cells called lymphocytes respond by producing antibodies to the molecules that invade and threaten the organism; but out of the lymphocyte repertoire for producing antibodies, only those antibodies are cloned that match the invader (Edelmann 1992, 73–80).

Inside autopoietic systems, therefore, there is no separation between producer and produced. A cell's being is given only in and with its internal dynamical operations (*esse sequitur operari*), and the system is not a substance definable prior to its operation (immune systems are therefore individual from person to person). It is the internal functioning of the system that determines *whether* or not the cell builds up new elements and *how* the cell picks up (or ignores) specific elements of the external world (Maturana and Varela [1987] 1992, 43–52).

b. The Parts Are More than the Whole. This insight also has consequences for the relation between biological and psychological systems. Psychological systems build on biological systems as their energetic resource, but their mental operations produce a world of their own where mental "elements," such as particular intentions or motivations, begin to operate according to their own internal correlations. Thus, it is only through feeling that I can determine what I am feeling and what it is that I am experiencing. This operational closure of the mental also functions the other way around: the pain of the hypochondriac is a real element of the psychological system, having all sorts of causal consequences, though there is no identifiable biological disorder generating the feeling of pain. Biological and psychological systems are, of course, intertwined insofar as the psychological functions depend on the biological, but once feelings appear they form an internally closed autopoietic system. What belongs ontologically to the same nexus of realities (we do not have consciousness without a biological basis) divides into different operational systems that causally interact with one another. This interaction may be described as a reciprocal interpenetration: there is an influence from the biological system to the psychological one (such as the feeling of well-being or an ache) just as there is an influence from the psychological system to the biological system (such as stress or tranquility).[3]

Taking autopoietic theory seriously implies that it is not for purely epistemological reasons that the sciences make use of different concepts, theories, and methods aligned to different levels. The three systems mentioned already (the biological, psychological, and social systems) belong to the same nexus of realities, but it would not be adequate to claim that they ontologically ("in reality") make up one simple entity. The idea of the natural-world-as-a-whole (or the system of systems) is an abstraction compared with the variety of differently operating systems. According to the theory of autopoietic systems, ontological priority should be attached to the latter rather than to the former, since the reality of "the world as a whole" is itself a result of the interpenetrations between the type- and code-different systems observed. The parts are more than the whole (Luhmann [1984] 1985, 20–28).

Autopoietic theory, therefore, not only supports the idea of a theory autonomy, claiming the nonreducibility to physics of the theories and concepts of the sciences of higher levels but also adopts the idea of process autonomy, namely, that different systems are not causally reducible to one another, since the different systems display new causal properties of their own. Autopoietic theory is nonetheless fully compatible with a constitutive materialism, which claims that there exist no other elementary particles than those known by the physical sciences—or in principle knowable by them. Neurons, for example, are built up of well-known atoms formed into large and flexible molecular structures. Neurons, however, exist only as elements within the brain system as a whole—they are never found free-floating or in rocks. Neurons are thus the co-products of the fundamental capacities of elementary matter (the constitutive level) and of the capacity of more highly developed somatic systems (the structuring level of information-processing systems). The matrix of nature is a complex order occupied by very different kinds of ordered operations with different kinds of causal chains. The code of hormonal signals, for example, differs from the code of feelings that differs from the codes of social communication, and yet we all know the extent to which they interact (Luhmann 1990).

Thus, epistemological plurality has an ontological basis (how much and how far is an open question) in the operational closure of the different systems themselves. At the least, systems have causal spin-offs in type-different systems (e.g., hormones affect psychological states and vice versa), of all grades from negative feedback (balancing each other) to positive feedback (mutual enhancement). Thus, we face a continuous crisscross interpenetration of different kinds of operational systems. As soon as we leave the level of fundamental physics, we are confronted with a world of naturally polycentric systems, uncontrollable (and therefore unpredictable) from the constitutive level of fundamental physics—or from any other singular perspective. Relative to the unilateral or bilateral causal connections, this fact of multilateral and type-different causalities seems to be by far the most dominant feature of the world as we know it (Gregersen 1997, 169–74). The evolutionary process seems to be driven on by type-different autopoietic systems, sometimes competitive, sometimes symbiotic, sometimes in synergetic resonance, then in dissonance with each other.[4]

c. Six General Principles of Autopoietic Systems. On the basis of the foregoing, it is now possible to expound some general principles of autopoietic systems:

(1) Autopoietic systems are *energetically open systems*, dependent on external supplies.

(2) While autopoietic systems are energetically open, they are *operationally closed*. The closure of the system is even a precondition for the way in which the given system handles its openness vis-à-vis its environment. The cell, for instance, is open for energy supply only so long as the energy input does not break down its membrane and internal structures.

(3) The *self-reproduction* of autopoietic systems is *not necessarily tied to specific physical structures*, since the structures may change as the dynamical system operates. The immune system, for instance, does not always protect the frontiers that are under attack but may, rather, reproduce the system by forming new strategies of survival through structural self-transformations. Self-reproduction often happens through self-production.

(4) Also the *elements* of the autopoietic system are *constituted by the system itself* by way of (selective) inclusion or exclusion (Luhmann [1984] 1985, 41–44, 60). The membrane, for instance, lasts only as long as the cell-system lasts.

(5) Interpenetration between differently structured systems always takes place on the basis of the given system itself. In one system, the intrusion of a new chemical element makes no difference; yet in another, the consequences can be enormous. The effect of interpenetration is always *co-determined by the system itself* (Gregersen 1987, 142–45).

(6) The idea of autopoietic systems is *a farewell to ideas of preestablished "seminal forces"* or fixed blueprints (cf. Luhmann [1984] 1985, 172). It is destabilization of given structures that triggers further self-production (or death).

Already from this theoretical outlook it is obvious that the concept of autopoiesis is not designed to discuss either cosmological beginnings (in terms of Big Bang theory and its rivals) or ontological questions related to the theological doctrine of *creatio ex nihilo*. Rather, it is a general theory for systems that are already in the game, one way or the other, and that will have to cope with the demands of self-formation vis-à-vis an unpredictable environment and an even more unpredictable future. *Autopoietic theory refers to the continuous self-making of local* *processes.* But, as I intend to show in section II, this is what the Jewish and Christian images of creation are focusing upon: God's continuous proliferation and structuring of a manifold world with internal differences as well as interrelations. But first, let us take a look at some empirical examples of autopoietic processes as they emerge in the abiotic and biotic realm. My point is that autopoietic theory may cast a new light on the processes leading from abiotic chemistry to biotic forms of life (see section I, parts 2 and 3).

2. AUTOPOIETIC ORDERS IN ABIOTIC SYSTEMS. Already in abiotic regimes a certain amount of disorder seems to be a precondition for creativity (Heinz von Foerster's "order from noise" principle). Most revealing on the abiotic level is the spontaneous pattern formation in some nonequilibrium systems, dissipated by energy—the pattern formations dubbed "dissipative structures" by Ilya Prigogine. While one intuitively would expect that systems exposed to more energy input would kinetically react even more chaotically, the opposite is the case: the molecular motions begin to correlate with one another to produce a supra-molecular form of organization. A well-known case is the Belousov-Zhabotinsky reaction, a mixture of chemical ingredients that make up an oscillating "chemical clock" of shifting blue and red colors with well-formed shapes interrupted by a chaotic regime of violet, with unclear shapes in between. Here we face an example of an autocatalytic process where *X* produces *Y*, *Y* produces *Z*, and *Z* again *X* (cf. Prigogine and Stengers 1984, 146–53).

Other dissipative structures, however, do not have this cyclical character. Some dissipative structures are open not only in the thermodynamical sense of energy input but also in a developmental sense. The futures of these systems depend on the highly critical state of small fluctuations inside the system (or induced from the outside). Since it is the small internal fluctuations (or the externally adduced noise) that trigger the different space-time configurations, these historically open systems are not predictable in any detailed sense. It is possible only to make a statistical distribution map of the bifurcations that these systems might undergo. This means that the law of great numbers, that is, the idea that fluctuations outweigh each other in the long run, does not hold in these nonequilibrium systems. Small differences may be the triggers of self-enhancing cascade processes. Prigogine in fact holds these fluctuations to be instances of ontological flaws in nature. According to this interpretation, the uncertainties of statistical distributions not only are derived from our ignorance of the exact values of the parameters but are rooted in reality itself.[5] Though this ontological interpretetation is controversial, three undisputed characteristics of these now well-known structures should be emphasized here:

(1) They have to do with emergent and repeatable bottom-up orders: *spontaneous order out of disorder*.

(2) Nevertheless, synergetic phenomena tend to happen only in larger chemical systems (Prigogine and Stengers 1984, 115, cf. 155f): *holistic order upon elementary disorder*.

(3) There seems to be a subtle interplay between the general laws of chemistry and the fluctuations inside the system: *creativity through the interplay between general order and local disorders*.

There even appear to be striking similarities between some of the dissipative structures in abiotic chemistry and in living beings. Structurally, we find the same feedback loops between the general system and the elementary level of physical constituents, both in the case of self-enhancement (positive feedback) and in the sense of self-balancing (negative feedback). No less striking are the phenomenological resemblances. The Bénard cells, for example, have almost the same form as the octagons of beeswax. Similarly, the Belousov-Zhabotinsky reaction looks in some of its states very much like the aggregations of slime molds (see illustrations in Coveney and Highfield 1990, 192–93). Certainly, here we are still at the ideographic level of describing morphological similarities. It would, however, be natural scientifically to look for algorithmic relations underlying such patterns. Both Manfred Eigen's (1987) "hypercycle theory" and Stuart Kauffman's (1993) search for the "laws of complexity" can be seen as important steps in this direction.

3. AUTOPOIESIS IN BIOTIC SYSTEMS. Living systems are themselves instances of nonequilibrium systems. Through a spontaneous formation of localized orders they strive against the general stream of the second law of thermodynamics. Life, however, is not fully characterized by its nonequilibrium character. Three additional criteria have been proposed (by Alexandr Oparin) to distinguish living from nonliving systems (cf. Küppers [1986] 1990, 198): (1) metabolism, (2) self-replication, and (3) genetic mutability.

It is interesting that at least (1) and (2) have precursors in nonequilibrium chemistry. Metabolism is certainly a form of energy input and output, and in some autocatalytic reactions in chemistry, we meet something very similar to biological self-replication. Genetic mutability (3), however, has served as a source of the manifold forms that we meet only in the world of biology. A theory of genetic mutability is therefore pivotal to any account of evolution.

a. The Ladder of Complexity: The Hypercycle Theory. Manfred Eigen's and P. Schuster's hypercycle theory was especially designed to model how a species of RNA-virus of a bacteria (*Escherichia coli*) was able to reproduce itself by utilizing the chemical products of the bacteria as a catalyst for the replication of the virus (Eigen 1987, 225–45). This hypercycle makes up a complex autocatalytic process that takes place only in the presence of the whole family or "population" of macro-molecules. While this property of self-replication is found in nature only in host cells with fully developed DNA structures (the *E. coli* bacteria), it also has been possible to re-create the same autocatalytic processes outside living cells under specific in vitro conditions (details in Küppers [1986] 1990, 271–73).

From the hypercycle theory, it becomes evident that cooperation is as important for selection processes as is competition. The hypercycles form symbiotic alliances, where even whole "species"—here the RNA viruses—can replicate themselves autocatalytically only in connection with other species, in this case the *E. coli* bacteria (Eigen and Winckler [1975] 1987, 246–52). Manfred Eigen thus sees the hypercycle model as a typical example of the selective advantage of higher-level complexities.

By introducing a purely formal game-theory model for explaining the general trend of selection processes (Eigen and Winckler [1975] 1987), Eigen and colleagues find that a ladder of complexity is built into the evolutionary process as such. Empirically important for the evolution of genes is the capacity to attain both a certain genetic stability and an openness for "neutral mutations" (Eigen 1987, 255). Such mutations, whose fitness (compared with nonmutants) is neutral in the present environment, may show a selective advantage in later life niches.

In Eigen's interpretation, physical chemistry forms the constitutive level of the genes—their basic atomic units are their *conditio sine qua non* —but he adds that on the developmental level of the genome as a whole, it is the informational pattern that takes the lead: "The chemistry recedes into the background. . . . What counts after the emergence of the first genes is first and foremost the changeable *information*" (Eigen 1987, 254, emphasis in original). Now Eigen finds that his idea of a built-in ladder of complexity implies a "heresy" in relation to the received idea of Darwinian evolution: "In contrast to the classical interpretation, an internal drive towards the optimal peak of value takes place in the process of evolution . . . the quality of an 'anticipating' process of selection seems to occur—a genuine heresy, according to the classical interpretation of Darwinian selection" (Eigen 1987, 256).

I do not think, however, that Eigen's interpretation is in any real conflict with neo-Darwinian theory. Also, neo-Darwinism thinks in terms of populations, with an array of gene distributions, rather than in terms of insulated self-identical individuals (as often stressed by Ernst Mayr). Moreover, the idea of applying game theory to selection without making specific demands on the initial situation in fact goes back to the biology of the 1930s—compare Sewell Wright's "shifting balance theory" (Dennett 1996, 193). When Eigen furthermore defines efficiency as a "value peak"

(*Wertgipfel*), he points to the well-winnowed historical results of biological evolution. Since "value" from the very outset is identified with efficiency, and the more complex organizations (some of them using symbiotic alliances) have turned out to be more efficient, the idea of an evolution with a built-in teleological "foresight" (put in quotation marks also by Eigen) is only a poetic reformulation of a teleonomic process, where the process "owes its goal-directedness to the operation of a program" (Mayr 1982, 48) with functional advantages. In Daniel Dennett's phrase, evolution always uses its own previous results (here the genetic program) as a "crane" for further self-development, never beginning from point zero (Dennett 1996, 73–80).

Thus, the fact that Eigen has focused on cooperation along with competition as one of the pivotal "cranes" by which evolution attains higher peaks of complexity does not challenge an overall neo-Darwinian explanatory pattern. Eigen's picture of evolution, however, is obviously more open to a religious interpretation than is the picture of evolution as a mere story of accidental beginnings and subsequent teeth and claws. True, evolutionary processes always proceed in local ad hoc steps of selection, but these local procedures always take place inside a general framework that rewards higher level structures, including the strategy of symbiotic alliances, that are so important, according to Eigen, for the steps from abiotic to biotic systems. Eigen's insistence on the *fact* of increasing higher level structures on the macro-evolutionary level (understandable within a general game-theory model), combined with his detailed analysis of the *mechanism* of symbiotic processes on the micro-evolutionary level (the hypercycle model), is at least consonant with a theological interpretation of the evolutionary story. Jacques Monod's (1972) explicitly antireligious interpretation of evolution as the quasi-miraculous result of a singular event of pure and unexpected chance is no longer tenable. The emergence of life, given the relative short time scale of our universe, is far from theoretically improbable (Küppers [1986] 1990, ch. 3).

Although no overall workable empirical model for the emergence of life has yet been developed, the empirical fact that life forms appeared around 3.45 billion years ago, only about 1 billion years after the formation of the earth, seems to warrant (though not to prove) that life arose spontaneously from abiotic chemistry. In the search for such a theory, the hypercycle model is an encouraging step. It has the advantage of being modeled upon an empirical test case: the replication of RNA polymers under specific chemical conditions. But in other respects, the hypercycle theory is restricted: (*a*) the theory does not explain the ways through which the RNA and DNA structures themselves have arisen, and (*b*) the theory does not explain the phenotypical features of the richness of individuals, populations, species, and life forms. I shall deal first with the second question by discussing Ballmer's and von Weizsäcker's ultracycle model (part 3*b*), before coming to Stuart Kauffman's new proposal for tackling the first question (part 3*c*).

b. The Role of the Phenotypes: The Ultracycle Theory. What about the evolution of life processes once they have developed? Thomas T. Ballmer and Ernst von Weizsäcker have pointed to a limitation in Eigen's game theory model, namely, that it presupposes a strict extinction of alternatives. If this model is transferred to the level of phenotypes, the model leaves out of the account the importance of isolation and the subsequent production of local ecological niches (Ballmer and von Weizsäcker 1974, 248). Ballmer and von Weizsächer therefore propose the supplementary concept of ultracycles at the phenotypical level of ecosystems. Here we also find positive feedback processes between individuals inside populations and larger ecosystems: "Complexity creates new complexity: selecting more complex individuals in populations dispersed throughout different niches contributes to the complexity of the ecosystem itself. We shall name such a state of a biological evolution, which has positive feedback, an *ultracycle*" (1974, 256; emphasis in original). The relation between the digitalized "messenger RNA" and the more constant DNA structure, carrying greater information, is seen by Ballmer and von Weizsäcker as a parallel to the cooperation between the activities of the individuals and the niches of the ecosystem, the carrier of the larger information at that higher level. The ecological niches work as catalysts for the self-reproduction of individuals, as the DNA does for the RNA.

At least on the level of more highly developed animals, we find beings that pursue interests in their own survival and survive only by utilizing the possibilities arising out of their interplay with their environments. Ballmer and von Weizsäcker, therefore, point to the need for a theory about "the development of individuals that pursue *purposes* and have *intentions*" (1974, 256, emphasis in original). Thus, living systems define themselves by their inclusion and exclusion of elements from their environments.

Let me give two illustrations of the relevance of the ultracycle concept by Ballmer and von Weizsäcker: First, the life of wolves cannot be understood without their prey. But a change in the environment may function as a catalyst for a new behavior on the phenotypical level. Some populations of wolves have, in fact, changed their own nature by cooperating with human beings, developing into dogs. In geographical settings like Alaska and Greenland, the symbiotic lifestyle of humans and dogs has evolved in only a few thousand years, without which neither humans nor dogs would have survived to the extent they have. Likewise, in the last hundred years the still remaining wolves of the northern part of Europe have changed their behavior away from attacking human beings. As soon as learning processes emerge during evolution, the capacity for flexible self-production through intentional strategies actually comes to make a difference to survival rates. No evolutionary biology should therefore omit discussion of such items as the evolution of animal minds and of intentionality (see, for example, Griffin 1994).

The recent evolutionary history of the influenza virus A can be counted as another example, far below the threshold of consciousness. The subtype A_5 of this virus caused in the year 1918 the death of approximately 20 million people within a few months, the so-called "Spanish flu epidemic." Since then, the human immune system has caught up with this type. Later, local epidemics of closely related strains of virus A appeared. Both the virus, through mutation, and human beings, responding through immunization programs, have formed autopoietic systems, changing their own internal structures vis-à-vis their changing environment (Jantsch 1980, 188–91).

Although the proposal by Ballmer and von Weizsäcker has not been developed into a quantitative model, it deserves attention as a tool that might be helpful for analyzing the functions of the phenotypical macro-evolutionary level, analogous to the functions at the micro-evolutionary level of genetics. At the very least, it shows that evolution involves not only an ability to store information from the past in the genome but also a capacity to cope with a changing environment through learning processes.

c. Searching the Laws of Complexity: Stuart Kauffman. The non-quantitative character of the proposal of Ballmer and von Weizsäcker may explain why their ideas (as far as I know) have not been very influential up to now. More recently, however, an algorithmic model for evolutionary "fitness landscapes" has been proposed by the theoretical biologist Stuart Kauffman. In his major work *The Origins of Order: Self-Organization and Selection in Evolution* (1993) and in the more popular account *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity* (1996), Kauffman claims (not very modestly) to lay the foundations for the second half of a full understanding of evolution through placing Darwinian theory in a broader context (1993, vii). According to Kauffman, the neo-Darwinian paradigm has to be supplemented with "the search for the laws of self-organization and complexity." The evolutionary story is driven by selection *and* prebiotic laws of self-organization. Thus, we are both "the children of ultimate law," born out of chemistry, and "the children of the filigrees of historical accident," the remnants of contingent adaptations and selections (Kauffman 1996, 185).

Like Eigen and colleagues, Kauffman also underlines the importance of cyclic couplings. But since he is looking for an overall theory that is capable of explaining (at least in general terms) the route to the RNA-DNA couplings, Kauffman has reservations as to the explanatory potential of the hypercycle theory. First, Eigen's point of departure, the *E. coli* bacterium, has about three thousand genes, while simple free-living cells, the *pleuromena*, have only between two hundred and one thousand genes; that is, Eigen's analysis begins at a relatively high level, while Kauffman wants to explain the ways of macromolecular couplings up to that level. Second, Kauffman doubts the presupposition that bare single strands of RNA have gradually developed themselves into the established double stranded RNA-DNA systems. Third, Eigen and colleagues presuppose that the elements in the hypercycle have exactly the same connection with one another, which is not a very usual feature in nature (Kauffman, 1993, 357–67).

In short, one may say that Eigen's model has the advantage of providing an empirical test case, while its deficiency is its lack of generality. Therefore, Kauffman wants to focus on the spontaneous formations of chemical autocatalytic networks of a more variated form: "The secret of life, the wellspring of reproduction, is not to be found in the beauty of the Watson-Crick pairing, but in the achievement of collective catalytic closure" (Kauffman 1996, 48).

According to Kauffman's model, life might have emerged quite suddenly through the phase transitions that appear as a consequence of chemical reactions where molecules function as catalysts for one another and end up creating more stable systems. Though his model is mostly theoretical (he does not offer an empirical test case as did Eigen), Kauffman can in fact point to the general chemical tendency to form autocatalytic systems, even when starting from very different initial conditions. The route from chemistry to life may thus be pluriform: "Given almost any way in which nature might determine which chemicals catalyze which reactions, a critical molecular diversity is reached at which the number of red catalyzed reactions [those displaying developmental properties, NHG] passes a phase transition, and a vast web of chemicals crystallizes in the system. This vast web is, it turns out, almost always collectively autocatalytic" (Kauffman 1996, 65). Kauffman's point is, then, that given the nearly universal tendency to form macromolecular networks, life systems may not have emerged piecemeal (as in the bare RNA model) but as a whole. In this sense, Kauffman declares himself to be an "unrepentant holist" (1996, 69; cf. 1993, 367).

Now, autocatalytic sets do not know of the hierarchy between the level of genetic information and the level of the phenotype. In a horizontal way, "the system serves as its own genome" (Kauffman 1996, 73). Correspondingly, Kauffman goes on proposing a general mathematical model that applies both to the genotype interactions inside the organism as well as to the phenotype interactions between organisms and their environment. Most interesting is Kauffman's insistence that chaotic processes play a formative role for the evolution of evolution. The relevance of chaos theory (or of nonlinear mathematics) lies at hand, since autocatalytic processes are hypersensitive to the introduction of new entities in the environment; new entities may inaugurate either a catastrophe or a phase transition in the system as a whole, among which some turn out to be stable through the attractors of chaotic systems.

Both concerning the interaction between genes internal to the organism and with respect to the interactions between organism and environment, it is the connectivity, the array of "epistatic couplings," that makes all the difference. Given any gene N and any phenomenological expression, or trait N, in the organism, the gene and the trait appear in several versions, or alleles. The specific fitness function of the gene N now depends on its couplings with the inputs from other genes K (inside the same organism), since the K genes are responsible for switching on and off the very functions of gene N. In this way a genotype NK fitness landscape can be simulated on a computer (Kauffman 1996, 169–76). The genetic functions and properties thus arise only inside the fitness landscape as a whole: life is "not located in the property of any single molecule—in the details—but is a collective property of systems of interacting molecules" (Kauffman 1996, 24).

Similarly, a phenotype trait in an organism N displays its efficiency or nonefficiency only in relation to the phenotypical traits of other organisms, again defined as K. Now we have a phenotype NK fitness landscape. In such epistatic couplings, the traits of the organism have to adapt not only to the traits of the same organism but also to eventual adaptations of other organisms. We thus have in front of us a coupled fitness landscape (quite similar to the idea of the "ultracycle" advanced by Ballmer and von Weizsäcker).[6]

Kauffman now distinguishes between three main evolutionary strategies. One is the co-evolutionary arms race (the "Red Queen" strategy) where all species keep changing their genotype and phenotype as they go along, improving their fitness level comparatively (1996, 216f.). An example of this type could be the race between the HIV infection and the human immune system, in which HIV currently seems to have the upper hand.

Genetic dances, however, are not always lethal for both species, as is the case in AIDS. Another strategy is the evolutionary stable strategy (ESS) where the interplay between genotypes and phenotypes gains an advantage that is kept by refraining from altering the genotype dramatically. This is the normal situation in many so-called food chains in nature.

Kauffman, however, highlights the third possibility of co-evolution, arising in hypersensitive interconnected systems at the edge of chaos. It is not always a selective advantage to be too rigid when cells are to live in a changing body and organisms are to survive in unstable environments. For purely mathematical reasons, the peak value of evolution is attained in a combination between stability and flexibility. In computerized scenarios of artificial life, Kauffman has been able to show that it is the algorithmic values located at the edge of chaos (so to speak, between the Red Queen and the evolutionary stable strategy [ESS]) that provide the most promising avenues for a co-evolution of complexities (1996, 224–43). The system then oscillates between almost frozen relations and chaotic ones, but near the borderline we find those candidates for co-evolutionary couplings that enable an increasing average fitness for most organisms in the NK landscape, while the risk of extinction of species decreases significantly (1993, 255–81).

If Kauffman's proposal succeeds in experimental application in real life situations, outside the safe walls of computerized artificial life, we may have a general theory for co-evolution that covers both the prebiotic chemistry, the biomolecules of genes, and the phenotype interactions between organisms and environment. The same ratio holds in all cases. The role of natural selection would still be a pervasive factor, but selection would take place inside a code of life: the laws of complexity. Darwinian selection has to do with the tuning of the ad hoc parameters until the NK couplings click and conjoin in the structuring regimes at the edge of chaos. "As if by an invisible hand, the system tunes itself to the optimal K values [the optimal amount of epistatic couplings, NHG] for everyone," Kauffman comments (1996, 232).

It seems evident that this view of evolution is close to religious intuitions of the orderliness of the world of nature—not because of Kauffman's occasional (and indeed ambiguous!) reference to the hidden hand (whose hidden hand?) but rather because of the implications of his evolutionary picture. Kauffman's theory suggests that "we are the expected," on account of the algorithmic relations endemic to nature. Thus, these laws for the evolvability of evolution are structuring the proliferation of structures throughout history. Religiously, we are waited upon by God as the Creator of these laws. But Kauffman's evolutionary picture does not leave us with general laws, since his theory also points at the endemic open-endedness of creation. The history of evolution could have followed and perhaps will follow threads of attunement other than those realized in human history.

II. Models of Creation and Self-Production in Genesis

1. DIVINE CREATION AND THE SELF-PRODUCTIVITY OF THE EARTH. Our leading thesis of "God creating by supporting and stimulating self-productive processes" may appear counterintuitive to anyone who is steeped in the idea that creativity belongs to Almighty God, while creatures are utterly dependent on God. What I intend to show in this section is that nonetheless the biblical concepts of creation are far more

diversified. In the Genesis narratives, and even more so in Old Testament ideas of God's blessing, we can recognize a recurrent pattern of God (*a*) unilaterally creating the world in order to make possible (*b*) binary relations between Creator and creature, and (*c*) multilateral relations between the creatures in the horizontal nexus of space and time, conjoining life processes and cultural processes. Thus, the issues behind our lead question, How is God's creation to be understood in relation to "self-making" creatures?, is not quite as exclusively modern as one might expect.

In the Genesis 1 story of creation, we do not find only the idea that God "created" the world by dividing light and darkness, the waters under the vault from the waters above it, earth and water (Gen. 1:1–4).[7] God also invited the created to produce further creations on their own: "Let the earth produce growing things; let there be on the earth plants that bear seed, and trees bearing fruit each with its own kind of seed" (Gen. 1:11, REB).[8]

One might find here the traces of the old mythology of the fertile Mother Earth (cf. Sirach 40:1; Ps. 139:5) (Westermann 1976, 122). The authors behind Genesis 1 used this mythology to point to the processes of natural self-unfoldment, well known from everyday life. The grammatical form of the Hebrew *jussiv* rather than the strict imperative retains the association of an invitation, literally meaning: "let the earth green the green!" Thus, the very grammatical form of Genesis 1:11 seems to emphasize the iterative character of natural growth (Steck 1975, 93f). The Old Testament scholar W. H. Schmidt (1964) renders the meaning of the whole context like this: "The Word of God which first [v. 3.6, cf. 14] was alone in its creative action . . . now gives away its power of creation, that is, the Word is turned into the prescription, directed to the already created world, that it should itself put forth further new realities" (p. 106). In this reading, a sort of self-limitation of the power of God seems to be intended in the Genesis story of the self-producing earth. *The objects of creation thus become the subjects of creation.* There is no hint of a fear that this limitation is imposed upon God from the outside. Rather, it is seen as the intention of God, as the way in which God exercises the superb splendor of divine self-realization as Creator.

Michael Welker (1991, 58–60), in a critical continuation of process theology, has rightly emphasized that the notion of God's creation has been too uniformly described in modern theology in thought figures of divine overpowering and creaturely dependency. In both of the two creation accounts of Genesis 1:1–24a and 2:4b–25, God rather binds Godself to the internal dynamics of creation. In fact, the story of creation tells us about bilateral relations between God the Creator and the creatures that are assigned different powers by God: "The creating God is not only the acting

God, but also the reacting God who responds to that which has been created. . . . Only a distorting abstraction can block out the fundamental characteristic, emphasized throughout, of God's action as action that reacts, that lets itself be determined. Reaction in perception, evaluating, naming, and separating intervention; reacting in giving space for the human being's own activity" (Welker 1991, 61). Thus, God "saw all that he had made" (Gen. 1:31). God "called" the light, the vault, and the earth (Gen. 1:5, 8, 10, REB). Especially in the second creation story (Gen. 2:4b–25), the idea of cooperation between Creator and creature becomes dominant. God cooperates with the powers of the earth by sending the rain and by forming Adam (literally meaning something like "soil-creature") from the dust of the ground (*Adamah,* or soil; Gen. 2:5, 7). And, again, God formed the human beings in order to continue God's work of "giving names" to the co-creatures of the human being (Gen. 2:19).

Soon, in the perspective of Genesis 3–11, the assignment for human beings is to take active part in the transformation of the ongoing story of creation, in breeding (nomadic life styles) as well as in tilling (agricultural life styles). The evolution goes on from the domain of sexual reproduction into the sociocultural domain. In this picture, the inventions of human culture are not seen as deviations from God's "original" creation but rather as a participation in God's creative act of unfolding and fostering new appearances on the scene of history. The bilateral relation between Creator and creature thus opens up a field of multilateral relations between the creatures.

However, because of the fact of sin and disorder—the fundamental incongruence between God and creaturely action—it is clear that one cannot give *carte blanche* to identification or even parallelism of divine and creaturely action. But neither can one understand the Judeo-Christian idea of creation in a two-leveled manner, in which God is utterly productive and creatures are merely instrumental to God. It is in concrete spatio-temporal relationships that God's continuous work accomplishes itself. The work of the six days does not end up in an ultimate stoppage of creativity. The seventh day is the day of both rest and waiting: God saw that the world was good (Gen. 1:31), blessed the day, and made it holy (Gen. 2:3) in view of what was to come. God apparently creates by inaugurating a colon rather than putting a period: the world is given, and yet it is in the process of unfolding.

The importance of the self-productive capacities of nature—given, sustained, and elicited by God—was not neglected in classical Christian tradition. The church father Saint Augustine took Genesis 1:11 and the passages that follow to mean that God in the primordial creation implanted hidden "causal reasons" (*causales rationes*) or "seminal forces of the future" (*quasi semina futurorum*) into the earth; these germs do not, according to Augustine, have the form of material, ostensible substances (like a normal seed) but are seedlike immaterial powers intended by God to unfold themselves in the continuous story of Creation: "They were made by God when in the beginning He made the world and created simultaneously all things to be unfolded in the ages to follow" ([ca. 400] 1982, 190).[9] In one sense, then, the world is seen by Augustine to have been perfected in the six days of creation a long time ago, since these created *causales rationes* reflect the *aeternae rationes* of God; yet in the perspective of physical time, the world is unfolding its inner tendencies throughout the ages at the appropriate time.

In the Eastern traditions, the history of nature was generally given an even stronger prominence. The Holy Spirit, described by the Nicene Creed as the "giver of life," was generally interpreted as the *energeia* (though not the essence, or *ousía*) of God, which gives itself to the benefit of the *oikonomía* of creation. Gregory of Nazianzus, for example, saw the difference between the energies of the Spirit and the energies of material processes as one of sovereignty but not one of place (since the energy of God works inside creation). The difference between the energy of God and material energies, then, is that the material energies are always conditioned by the push of antecedent causes, while the energies of God's life-giving Spirit are always initiated by Godself, unconditioned by external factors (Gregory of Naziansus, *Orations* 31, 6; cf. Bergmann 1995, 164f.).

Thus, it seems that a sheer contraposition of divine power and the powerlessness of creatures does not account for the more differentiated view of the God-world relation in Genesis 1 and in subsequent Christian interpretations. Not only does God create the fruitful divisions inside nature, but also the lights in the vaults of the heavens "separate day from night" (Gen 1:14, REB). Not only do creatures enjoy the works of creation in receptivity, but God also enjoys the world, seeing it as "very good" in each instance (Gen. 1:4, 10, 12, 18, 21, REB) and as a whole (Gen. 1:31). God does not reign over the earth in splendid isolation but does so as the creator of the sun that "governs the day" and the moon that "governs the night" (Gen. 1:16, REB).

Thus, being a creature means enjoying the gifts of life and actively participating in God's creative works. Also the Creator is both active and reactive—though, *nota bene*, in this order. Thus, I do not think that one can escape all notions of a hierarchy between Creator and creature despite the fact, so rightly highlighted by Welker and others, that the Genesis narratives tell a story in which God alternates with the creatures as active agents. In narrative form God's ontological priority is spelled out in the temporal structuring of the story of the six days: on the very first day, God says: "Let there be light" (Gen. 1:3, REB). Only later, on the fourth day, does God create the star-lights in the vault of the heavens and bestow upon them the mandate to participate in God's brightness by separating day and night (Gen. 1:14).[10]

This double creation of light was from the outset reflected in the Hexameron commentaries of Christian traditions. Since Thomas Aquinas (*Summa Theologiae* Ia q 105, 5), the idea of a common action between Creator and created in the domain of creation has been philosophically reflected in the doctrine of a *concursus divinus et humanus* (a cooperative "running-together"), which has played an important role in the idea of divine providence: God is acting as the one fundamental and universal cause, the first of order (not only of sequence), while creatures are working on the secondary and derived level as the many particular and interactive causes in the web of nature.[11] In other words, God's primary action of creation is a context-constitutive action, laying the basis for all subsequent unfoldments. All actions of the creatures, however, are context dependent.

The crucial question, however, is whether divine actions also take on context-dependent traits. Due to the tacit presupposition that divine perfection does not allow for any receptivity, theologies in the Augustinian and Thomistic tradition have generally denied a real exchange in the direction from creation to God. God has from an eternalistic point of view "seen" the temporal unfolding of seminal courses and the sequences of human activities, and also those of human freedom; consequently, there cannot exist any context-sensitive divine action when seen from the perspective of God. How different is the creation story! Insofar as God, according to Genesis 1 and 2, is inviting the creatures into a productivity of their own (based on God's constitutive action) and insofar as God is engaged in the future of that world, there is a real reciprocal interaction between God and creature. Consequently, *God's creativity takes on a context-sensitive and even a context-dependent form* when God is seen as appreciating, evaluating, and subsequently correcting the productivity of the creatures. Creatures are thus passive and active, while God is active and passive; this order is irreversible.[12]

2. THE BLESSING OF GOD AS A STRUCTURING PRINCIPLE. The distinctive togetherness of God and creatures comes even more to the fore in the notion of God's blessing of the living creatures. The same words of blessing are said to animals and human beings: "Be fruitful and increase" (Gen. 1:22, 28 REB). This blessing is interpreted not only as a word but also as a creative power that God gives away to the living creatures so that they can reproduce themselves abundantly, "multiply and fill the earth." The Old Testament scholar Hans-Peter Müller rightly points out that God's blessing is conceived as an immanently working spatio-temporal force (Müller 1991). The blessing of God not only is bestowed upon the individual creatures but is working inside of them: "there is juice in a

cluster of grapes, and folk say, ‘Do not destroy it; there is blessing in it’” (Isa. 65:8, REB).

This archaic notion of blessing thus transcends the early modern notion of a division between human and nonhuman parts of our nature: fertility is common to human and nonhuman beings alike. God’s relationship with the blessed beings pervades their functioning and existence: “You are a brave man, and the Lord is with you” it is said to Gideon, and in a subsequent verse it is said to him: “Go and use this strength of yours” (Judg. 6:12–14, REB). In the blessing, thus, there is no opposition between the transcendence and immanence of God, since the blessing is at once personally assigned by God and working as a quasi-natural force. The blessing is in its givenness, and yet at the same time the blessing is what it turns out to effect in the future process of unfolding and use. Hans-Peter Müller points to the fact that archaic thinking and recent scientific modes of thought might be comparable on this point, insofar as both are focusing upon the “structuring tendencies” (*Strukturierungstendenzen*) in the development of living beings (Müller 1991, 245– 51). We might say that *the blessing of God is a structuring principle at once transcendent in its origination and immanent in its efficiency.*

The blessing of God refers both to God’s support of the inner fruitfulness of the “ordinary” processes of growth, necessary for survival, and to the “extraordinary” stimulation of energies that exceed survival needs and provides a surplus of strength and life-value to individuals and communities. Blessing thus encompasses both an element of fundamental sustenance and an element of superabundance. The fact that the dynamics of the blessing are finite, however, shows its transitory presence in the creatures. At some time or another, the power of the blessing will return to God.

The central importance of the blessing in the Genesis story was again not neglected by later interpreters, although it was surely underestimated. Martin Luther, commenting on Genesis 1:21 and following passages in his *Lectures on Genesis* (1535–1545), was highly sensitive to the central role of God’s blessing for life processes. Blessing has to do only with living beings, Luther noticed, because at this level God initiates “a new method of growth and increase.” Luther also remarked: “What [Moses] calls a blessing (*benedictio*) the philosophers call fertility (*foecunditas*).” For blessing, in Genesis 1, means multiplication (*multiplicatio*), and when the blessing of God sounds, the multiplication is immediately effected (*statim est efficax*). Luther referred to the growth of nature as a “great miracle” (*magnum miraculum*), though we are so accustomed to natural processes that the miracles seem to us commonplace (WA 42, 39–41 = Luther 1987, 52–54).

When explaining the meaning of God's blessing, Luther thus employed a sacramental terminology, as also happens elsewhere in his writings on the sacraments (cf. Gregersen 1995). Both in creation as well as in the sacraments we meet God covered by created nature, never as a bare deity: "God envelops Himself in His works in certain forms, as today He wraps Himself up in Baptism, in absolution etc." (WA 42, 10 = Luther 1987, 11). In the light of this, Claus Westermann ([1974] 1976) could rightly dub the blessing of God the first sacrament in the world of creation.

Again we seem to face a two-phase structure of, first, God's unilateral creation "In the Beginning," then the multiple forms of Divine-creaturely cooperation, "each of their kind." Already the creation stories demand an overcoming of the usual binary thought models of the God-world relationship. We seem to find a fertile soil, on the basis of which we can entertain the constructive task of a theology of creation.

III. A THEOLOGY OF SELF-PRODUCTION

1. OVERCOMING BINARY THOUGHT MODELS IN RECENT CREATION THEOLOGIES. Generally, classical theology was formed on the presupposition that God's omnipotence means that the cosmic story is fixed, at least when seen from the eternal perspective of God, simultaneous with past, present, and future time.[13] Only in the mid-nineteenth century were the first steps made toward a truly relational concept of the omnipotence of God. The power of God was then understood as the omnipotence of love that radically limits itself in order to make room for the freedom and self-development of creation. By this kenotic move, a new kind of correspondence between God's work in creation and in Christ was attained.

During the post-Darwinian struggles, this new idea found an important new application, as exemplified in the introductory quotation by Frederick Temple (1885, 115). It was professed that God's omnipotence was to be understood from God's use of power, namely, to inaugurate a creativity of the natural processes themselves. The distinction between God's "creation" and the "makings" of natural processes became both urgent and fruitful, but the distinction was no longer framed in contrastive terms.

I think it is no exaggeration to say that this concept of self-limitation has attained a nearly consensus status in the theology of today. Both Continental theology (Moltmann 1985, 92–104; Jüngel 1986) and Anglo-Saxon theology (e.g., Macquarrie 1984, 177–82; Ward 1990, 31– 34) assert that God creates by letting be, by letting the world into existence and thereby also leaving room for a self-development of nature (Peacocke 1979, 196–203; Polkinghorne 1988, 51–89). What may appear as divine self-limitation is in the Christian reading a testimony of the self-realization of the God whose power is pervasively informed by divine love (*omnipotentia charitate dei formata*).[14]

The soil is thus well prepared for the idea that God creates and transforms the world through supporting and stimulating self-making systems. Let me refer back to our initial thought experiment and expound it a little further:

- Granted that mathematical laws of complexity and biological mechanisms of selection actually govern the emergent properties of evolution (Kauffman's extended Darwinian paradigm);
- granted that the laws of complexity are intrinsically statistical and only seldom prescriptive (Prigogine);
- granted that variations are extremely important for the creation of novelties during evolution;
- granted that self-productive systems generate a degree of process autonomy and exert type-different causal influences (autopoietic theory);
- and, finally, granted that God is the Creator of this world (Christian faith)—how can theology redescribe these findings?

After assessing the prolific role of chance in evolutionary processes, drawing upon the work of A. R. Peacocke, D. J. Bartholomew, and others (section III, part 2), I proceed by articulating fragments of a theology of nature that seems to me to conform well to autopoietic theory. In three areas in particular, I find a fruitful resonance of autopoietic theory with a theology of creation: The notion of God includes a unity of eternal self-consistency and of spatio-temporal self-relativization (section III, part 3); God's suffering and compassion with creatures and natural processes gains a central place in the understanding of God's interrelation with nature (section III, part 4); a model for how particular divine actions may stimulate autopoietic processes can be developed (section III, part 5). In all three cases, I hope to show that science-related theology may benefit from drawing from the resources of "thick" constructive theologies that remain in contact with religious tradition rather than developing itself only on the basis of a minimalistic and "thin" philosophy of religion. However, while my perspective is theological, I aim to show that the issues that I appropriate theologically all relate to autopoietic theory.

2. SHORT-SIGHTED CHANCE, LONG-SIGHTED LAWS. From the perspective of a theology of creation, I still think that the position developed by the statistician D. J. Bartholomew in continuation of A. R. Peacocke's work holds: "[S]ince chance is such an integral part of creation, it must be part of God's plan. Thus we can agree that everything that

happens is ultimately God's responsibility while denying that every single happening has a meaning in terms of God's intention. His purpose is rather to be seen in the aggregate effects of many such happenings" (Bartholomew 1984, 118). Religiously interpreted, the distributions of chance are not arbitrary but depend on God's initial setting. By letting the world into being as a self-organizing and even sometimes self-productive world (as defined above, section I, part 1), God is continuously upholding the reproductive and self-productive capacities of matter from its simple to its most complex forms.

It would appear that the proposal by Stuart Kauffman has corroborated the scientific presuppositions behind this theological interpretation. In Kauffman's evolutionary picture, we find in fact an interplay between (1) the deep-seated mathematical laws, explaining the general direction of evolution toward higher complexity, and (2) the fact that the turning points of evolution are always determined ad hoc in the local settings that are decisive for the outcome of the selection game: "We, the children of ultimate law. We, the children of the filigrees of historical accident" (Kauffman 1996, 185). The fine-tuned interplay between very general but far-sighted laws of complexity and the short-sighted ad hoc game of selection is open for a religious interpretation.[15]

On the basis of this framework, God can be described as the "Creator of heaven and earth"—of the actual world (symbolically speaking, Earth) and of the realm of possibilities (symbolically speaking, Heaven). As Creator of the self-evolving world, then, God is continuously acting amorally (since randomizations occur with no distinction between good and evil), but God is not acting immorally, that is, with an evil intent. Rather, from the purview of the evolutionary story as a whole, God's apparently amoral creation shows the consistent intent of supporting and stimulating the autonomous character of a pluriform world. God's wisdom is "multicolored" (Eph. 3:10: *polypoikilos*).

Fundamental as this appropriation is, it is hardly sufficient from a theological point of view. Is God to be thought of as having created a general ladder of evolvability and then leaving the world to itself after having carefully made the right distributions of chance in the first place? This view, standing on its own, would certainly imply a kind of "statistical deism" (Russell 1995, 22). Three further layers of theological interpretation shall therefore be proposed.

3. GOD'S INFINITE POWER OF SELF-CONSISTENCY AND SELF-RELATIVIZATION. The first layer of theological interpretation refers to the doctrine of God. In the pluriform world of autopoietic processes, it seems that God could not understand the lives of the creatures from the purview of only an atemporal and decontextualized perspective. Mere "logical

relations" (which constitute eternal divine knowledge according to classical doctrine in the wake of Boethius) would not mean understanding the spatio-temporal perspectives of the higher ordered creatures from within. An "elusive presence" (Samuel Terrien) of the God who penetrates into the depth and width of human existence is, however, what is proclaimed in both the Old and New Testaments (e.g., Ps. 139; 1 Cor. 2). God is "closer to ourselves than we are ourselves," as it was phrased by Luther.

It seems to me that the Christian belief in God's incarnation should occupy a central role in conceptualizing God's intimate knowledge of the particulars of the actual world. According to Christian faith, God understands and interacts with the world by self-limitation to the levels of reality to which God wishes to communicate Godself. To embodied human beings who are born and are going to die, God communicates as one who is born and is going toward personal death, living in skin, flesh, and bone. To humans who are living in hope and anguish, God communicates Godself as one who knows how to hope and how to fear and tremble. To humans who are living socially within the confines and openness of language and signs, God communicates Godself as one whose words and deeds are performed in the public dimension of shared existence. God's communicative word enters into all the dimensions of being in order to understand them from within. This remains a paradox to the two-level thinking of a Platonic tradition. But this is actually what is to be expected from the perspective of autopoietic theory if God can be said to respond to the joys and sufferings of creation.

In the light of autopoietic theory, it is not a surprise that Christian tradition holds that it is only through the deep incarnation of God as Christ, and only through God's continuously inhabiting the world as Spirit, that God can retain the unique divine combination of distance and nearness in God's relation to self-productive organisms. God's wisdom (traditionally attributed to the eternal Logos of God) would not be perfect and penetrating by being merely eternal, without condescending to the different levels of the multifarious world. While the deficiencies of human knowledge rest on the restrictions of our own perspectives, the perfection of divine knowledge implies that God is both personally self-consistent throughout all times and yet capable of an infinite self-relativization. Only so would God retain God's transcendence and yet be able to understand each creature from within its own internal perspectives: a mental event as a localized psychological phenomenon, a social sign as a spatio-temporally structured event, and so on. It seems to me that this intimate character of divine co-knowledge with a multitude of different perspectives is religiously of primary importance. Relative to this, the classical claim of God's detailed knowledge of future contingents has hardly any constitutive importance for religious faith.

In this respect, the process philosopher Charles Hartshorne introduced a most helpful theory of God's eternal-temporal knowledge to replace that of Thomistic eternalism (Hartshorne [1948] 1964, 8–15; 116–34). Although it cannot be developed properly in the present context, I think that a Trinitarian concept of God entails semantic resources for expressing an even more complex concept of the divine attributes than the one offered by the dipolar God of process theology: The Logos of God (the eternal Son) not only immanently *contains* the full pattern (John 1:1) of the will of the Father but also, in the mode of the incarnate Son, *reveals* this pattern to the world. The Logos of God, however, cannot reveal anything to anybody who is not made conformal with the revelation (just as type-different systems cannot communicate). The reception of the "divine persuasion" is thus not a matter of course (as often presupposed by process theology) but demands a genuine communion between Creator and creature on the level of Creation itself.[16] If grace is to be imparted, the work of the full pattern of divinity (the Logos) needs to be supplemented by the works of the Spirit of God, who explores the depth of individuality and imparts the Christ pattern to the faithful, thus making the unwise, wise (cf. 1 Cor. 2:10). Again, we find the interplay between the *full pattern of wisdom* (the eternal Son) and the *localized power of wisdom* (the Spirit revealing the truth to the disciples; John 16:13). The fullness of truth is therefore not a general truth but the truth that is practiced, that is, related to time and circumstance.[17]

In this interpretation, the Trinitarian thought pattern articulates the unity of God's self-consistency and power of self-relativization as well as offers a semantic framework for understanding God's living exchange with the world of particulars.

4. GOD AS COMPASSIONATE PARTAKER OF NATURE. The God who delegates formative powers to the creatures is, moreover, not the absent spectator God. God is present as the Father "above all, through all, and in all" (Eph. 4:4, REB). Already, on this interpretative level of theology, the charge of a disguised evolutionary deism seems misplaced. God's infinite capability of self-relativization has reverberations into the very heart of God. God is the compassionate co-sufferer of the trials and errors, accomplishments and breakdowns of creatures. As the passionately interested God, God also supports and stimulates creatures who, on their side, are co-exploring the joys and risks of God's creation.

My theological emphasis here is that it is not only by the *productive actions* of God but also by the *productive responsiveness* of God that God is the living God, the God for all of us. Thus, it belongs to the core of Christian faith that God in the birth, trials, and death of Jesus has exposed divine nature to the experience of suffering.[18] If the story of Jesus is the self-revelatory story of God, God has not carried the costs of the evolutionary trials and errors in replacement of the sufferings of living beings. Rather, God has in Christ co-carried the suffering of all sentient beings—in the promise of co-carrying the sufferings of any individual before and after the death of Christ. Thus, Christ not only died the death of sinners. He also died the death of natural beings, in particular the death of the losers in the game of mutual social acknowledgment.

In a trinitarian interpretation of the death of Jesus Christ, Jürgen Moltmann has rightly underlined that God suffers not only as the compassionate Father, following the beloved Son (and, in him, following all other beloved creatures) into the anguish of death, but also that God suffers as the Son, himself a victim of suffering and death (Moltmann 1972, 228–33). Again, the doctrine of the Spirit of God becomes essential, for the Spirit of God is the consoler who addresses each individual who suffers; and again we find the same structure of God's own suffering (in the Son and the Father) and the Spirit's power of localized presence in the world of particulars and individuals. In this way, it is understandable why the theme of the passion of God has been religiously more important in Christian tradition than the idea of divine actions that normally attracts the attention in philosophical theology. To this latter topic, however, we now turn.

5. DIVINE ACTION AS A STRUCTURING CAUSE IN AN AUTOPOIETIC WORLD. So far, I have presented a picture that attempts to establish a semantic coherence between a constructive theology of creation and autopoietic theory. This last interpretative layer deals with the question about the place of particular divine actions in a self-productive world.

Of course, all kinds of qualifications should be kept in mind here, since God is not a separate factor to be introduced into a scientific framework. Either God is active all over, or God is not at all involved in the affairs of the world. However, God is not necessarily acting in a uniform way all over. How, then, can we conceive of God's particular actions?

It would appear that many difficulties arise from the expectation that in order to think of particular divine actions, we have to think about God as a *triggering cause*, who is switching in and out in order to hold the course of history on track. In this case, God would be conceived as acting in the world of nature by sometimes subtracting from, sometimes adding to the natural processes. Some have argued that exactly this view is an option in a postmechanistic world picture. It has thus been proposed that such triggering causes could take place either in the realm of quantum processes or in the realm of chaotic processes. Particular divine actions along this line would not be scientifically discernible as long as the overall probability pattern is kept stable.

Another possibility that I am going to explore here is to think of God's nonuniform actions in terms of *structuring causes*. Philosopher Fred Dretske (1995) suggested the distinction between triggering and structuring causes, and he has proposed mental events to be of the structuring kind rather than of the triggering kind. A pressure on the key of my computer display is an example of a triggering cause of the cursor movement. The hardware conditions, such as the electrical connections in the computer and the software programming, are examples of structuring causes. Dretske points to two important differences between these type-different causes: (1) The structuring cause is never sufficient to obtain an effect. One still needs to press the key. Thus, there is no constant relationship between cause and effect in structuring causes as there is in triggering causality. (2) While the triggering causal relationship is one to one (one press on the key means exactly one particular letter on the screen), the structuring cause relationship is a one-to-many relationship: one act of wiring the computer works (we hope) for a long time—constant rewiring is not necessary. Structuring causes thus configure the circumstances under which future triggering causes can work (Dretske 1995, 121–25).

An advantage of this thought model is that God does not do anything that replaces the ordinary operations of nature. The workings of nature would still be the only triggering causes (like the Thomist concept of secondary causes). God is rather the underlying causality that enables the creatures to trigger themselves forth in their given setting. God, however, does not necessarily do this the same way everywhere. The expectation stemming from faith in a caring God is, rather, that God may act differently, according to time and circumstance, condescending Godself to the spatio-temporal pluriformity of systems. Working as a structuring cause, God is seen as *reshaping the possibilities as history goes along, by acting in different ways in different contexts*, in analogy to other mental events.

"How? By which means?" the skeptic will ask. My answer is that no one who knows what he or she is asking can expect an answer to this question. We are here facing the basic "conundrum" (Austin Farrer) of the causal joint between God the Creator and the world of creation that no theory of Creation can ever account for or supersede (cf. Peacocke 1993, 164f). What we can do, however, is to make clear where the notion of God's reconfiguring of possibilities may be applicable and where it is not. In my view, talking about God as structuring or reconfiguring the possibility space of self-productive systems, each of its own kind, is only an option for those systems that actually display a change of the overall probability pattern. This is, however, the case in evolutionary systems, as shown by Karl R. Popper (1990). Popper's propensity theory offers an ontological interpretation of epistemological statistics. Probabilities are, according to Popper, "as real as forces, or fields of forces" (1990, 12).

Sometimes the prediction is 1 (necessary), sometimes 0 (impossible), but in most cases of nature, we have to deal with contingencies, with values between 0 and 1. The propensities, however, are located not in the elementary substances themselves but in the total physical situation of which the elements are part. Furthermore, since the constellations are changing, the propensities themselves are also changing. According to Popper, only some physico-chemical propensities are stable while others (among them, evolutionary situations) are changing and therefore "not measurable, since the situation cannot be repeated. It is unique" (1990, 17). Thus, Popper's propensity theory should hardly be taken as an argument for a fixed divine blueprint, built into the world from the outset, but rather should be taken as an argument for the theological interpretation that the dice are not only loaded once and for all by God but also differently reloaded in the continuation of evolutionary history.[19]

The theory of autopoietic processes generalizes this fundamental idea with respect to more highly developed systems: The rules for procedure are decided by the procedures themselves. The metalevel is thus itself subject to reconfigurations in a horizontal process. Due to positive feedback processes, autopoietic systems are autonomous systems, since the propensities of the system (their "laws") are further engraved through their functioning. Learning to play the violin alters the functioning of the brain and the body and thus enhances the propensity (changes the possibility space) for playing more violin in the future. In this case, the physiological, mental, and social systems interpenetrate one another, since brain activity, the attention to the melodic and rhythmic flow, the reading of notes, and communication with other participants reinforce one another. From a theological perspective, such an *auto*nomous process is at the same time a *theo*nomous process if God is the stimulating power of inspiration who elicits the most fruitful possibility spaces in which the creatures try out their pathways, and who also restricts other possible possibility spaces.

In consequence, the place of divine action is both *inside* the operation of the type-different autopoietic processes themselves, in their gracious prolificacy, and *in between* autopoietic systems in the cross-fertilization of systems that remain different and yet penetrate one another. The doctrine of God's infinite capacity of self-relativization (section III, part 3) here becomes pivotal: Only the self-relativizing God possesses an awareness of all type-different systems from within.

Here we find some important differences between a structuring and a triggering model. According to Keith Ward (1990), God can perform particular actions only by conserving the constraints of the overall pattern: "[God] is limited in the number of changes he can bring about. Crudely, he can bring about more probable changes quite often, and less probable changes very rarely" (p. 121f). In the structuring model of divine action, however, there are no such fixed constraints, since the idea is the opposite one, that God may change the constraints themselves at many different levels in and between autopoietic systems. In the triggering model, God's "in-formating" of the processes would be seen as a definite selection of a definite pathway (thus, the presupposed concept of information seems to involve physically carried bits; such information, of the Shannon type, pushes a system in a certain direction). In the structuring model, God's information is more indirect but no less effective in the long run. God is seen as constantly shaping and remolding the possibility spaces of autopoietic systems. God may thus work simultaneously on different levels of reality by opening (in-formating) or by constraining (or ex-formating) their possibility spectra. Hereby, probability rates are raised for some pathways rather than for others. God may thus stimulate each system on a system-relative basis by influencing the operational constraints of each level. At the same time, God, working simultaneously on all levels, may be weaving the different systems together by making possible fruitful arrays of interactions between the type-different systems. The presupposed concept of information here is not that of a physical push in a specific direction but rather of a continuous though hidden change of the possibility spectrum.[20] This idea seems to me to reflect better the biblical notion of blessing (see section II, part 2), which likewise contains the sense of "superabundance," the surplus of becoming that echoes God's transcendence on the temporal axis.

I am the first to admit that this structuring model of divine action cannot answer the aforementioned "how" question (as indeed no other model of divine action can). It is also obvious that I can offer no more than a suggestive model, since I have to conjecture about God's action in the physical world, which is not only beyond physical detection but also beyond any direct religious experience. I think, however, that the suggested model of divine action has some relative advantages:

a. Theological Advantages. (1) The model articulates a divine influence on the processes of nature that transcends the popular idea that God acts only by creating the world system as a whole (uniformitarianism). (2) Furthermore, the model conforms with the fundamental idea of God's infinite capacity of self-relativization, which is most radically shown in the event of incarnation. (3) Though the model is conjectural on the physical arena, it conforms structurally with the biblical idea of blessing and with biographical experiences of God's steadfast yet patient interactions with human beings by restricting or opening the possibility spaces of their lives.[21]

b. Philosophical Advantages. (1) The model applies a philosophical model of mental events on divine action without any ad hoc interventions of the triggering type. (2) Likewise, the model avoids a spatial conceptualization of God as a faraway ultimate environment of the world-as-a-whole; rather, divine action is conceived of in terms of a localized (system relative) informational influence, though with far-reaching consequences for future situations.

c. Scientific Advantages. (1) The model does full justice to the integrity of creation: God lets the creatures trigger their own future; God neither adds nor subtracts any energy from the creatures. Thus, from a scientific perspective God apparently does nothing! Where God actually does make a difference, according to the religious interpretation, is to stimulate the powers of nature to follow new pathways for their use of energy. The amount of energy is the same; only the use and operation of the energy budget differs. (2) Nonetheless, the idea of divine action as a structuring cause has a family likeness in thought structure to the theory of autopoietic systems. In both cases, a new mode of operation and coordination of energy means a real change of being: *esse sequitur operari*. A structuring cause thus effects real changes in the world, though no physical energy has been added or taken away. (3) The structuring model, as expounded here, is open for scientific falsification if a bottom-up deterministic ontology should prevail.

In the view of divine action taken here, the creative reconfiguration of nature by God takes on a thoroughly temporal or processual character. The questions about "how to do" or "how to proceed" become still more urgent relative to the questions of classical science, "what it is that exists." This turn from a substantialist ontology toward a relational ontology marks a paradigm shift in systems theory as well as in theology.

If the general theory of autopoiesis holds true, there is an innate tendency toward complexification in evolution that opens up an indeterminate array of constellations between systems, sometimes competitive, sometimes symbiotic. The self-consistency of divine influencing, according to Christian belief, is given with the steady intent to support autonomy while stimulating the qualitatively most intense interactions between self-productive systems. God is the God seeking highly patterned resonance and symbiosis: "Peace"—a peace beyond the anemia of lazy self-repetition and beyond the restlessness of hazy change.

NOTES

I wish to thank Arthur Peacocke for his most helpful comments to the first draft of the English text of this paper. Over the years, the discussions with Arthur Peacocke have been invaluable for the formation of my own work.

1. A first collective volume introducing the field was M. Zeleny (1981); the story of the development and refinement of the theory of autopoietic systems since Heinz von Foerster's principle of "order from noise" is analyzed in Krohn, Küppers, and Paslach (1988).

2. By "elements" I am not here referring to the physical elements of matter, such as quarks and atoms, but to the components of particular higher-ordered systems. All such system-relative elements are, of course, constituted by the elements of fundamental physics.

3. It should be noted that Francisco J. Varela wants to restrict the use of *autopoiesis* to the cases in which it is possible to specify unequivocally the elements and the interactions of the systems. On the biological level, he finds operational recursiveness only in cell systems (molecules/chemical products), in immune systems (clones of lymphocytes/co-adaptation between the products of lymphocytes), and in nerve systems (neurons/synaptic couplings) (Varela 1988, 124f). Maturana (1988) has applied the analysis also to human societies, while Niklas Luhmann ([1984] 1985; 1990) has developed the theory to cover both social and mental phenomena. In this sense, the concept of autopoiesis has introduced a new scientific paradigm that crosses the divide between natural and human sciences (Krohn, Küppers, and Paslach 1988, 441, 455).

4. In this respect, autopoietic theory is partly congruent and partly in tension with A. R. Peacocke's use of systems theory. Peacocke speaks in favor of a theory autonomy (or of a conceptual nonreductionism), but at the same time he underscores a strong interconnectedness of natural processes, from elementary physics to human experience, and vice versa. Peacocke apparently fears that the concept of a process autonomy would imply the intrusion of new elementary entities such as spirit, *élan vital*, and so on (cf. Peacocke 1986, 17–19). This is obviously not the case in autopoietic theory: By its acceptance of a constitutive materialism, autopoietic theory denies an autonomy of existence of higher level systems; these always depend ontologically on lower level systems. Autopoietic theory, however, does claim a process autonomy since type-different systems operate on the basis of their own internal codes. Thus, the fact that type-different systems cannot be written together in a uniform causal scheme has an ontological basis in pluriform evolution itself.

More recently, Peacocke has underlined that (*a*) higher level processes are as real as the lower systems (cf. Peacocke 1993, 39–41, 224f.) and (*b*) that higher-level systems even may exert constraints upon their constituent basis in a "top-down" manner. By "top-down" causality, Peacocke means the whole-part constraints that the system-as-whole exerts on the lower levels (e.g., the Bénard system). So far, Peacocke and autopoietic theory are fully congruent. It is clear, however, that Peacocke presupposes that the world (ontologically) forms an interdependent unity of causes and constraints on the level of the world-as-a-whole. Only quantum theory and human agency display ontologically indeterminist features, while the rest of the world is taken by Peacocke to be ontologically determined (1995, 279f.). According to autopoietic theory, by contrast, indeterminism is a pervasive feature of reality, since type-different causalities are constantly intersecting with one another without being subsumable under one category, not even from a God's-eye perspective. Speaking of "levels of reality" is thus a metaphor pointing to the existence of type-different systems (cf. note 20).

5. Prigogine refers not only to the possibility of indeterministic quantum effects in large-scale systems but also to the observation that probabilistic descriptions have shown themselves to be empirically closer than the determinist ones to the fine-grained nature of nonequilibrium processes, especially those displaying the fundamental role of irreversible processes (cf. Prigogine 1990, 104, 110). For a discussion of Prigogine's indeterminist and René Thom's determinist interpretations, see Gregersen (1997, 166–69); for my own stance with respect to chaos theory, see Gregersen (1997, 170–72).

6. It is also clear, however, that computer simulations of the development of life methodologically leave out of sight the evolution of intentionality and learning (so central to the proposal by Ballmer and von Weizsäcker). The interface between the biological and cultural aspects of life has to be addressed in other conceptualities coming from sociobiology, cultural anthropology, history, philosophy, and theology. In fact, the Old Testament symbolism of God's creation and blessing consistently interrelates the biological and the cultural dimension (see section II).

7. The specific word for divine creation, *barah*, thus literally means "dividing," or "cutting in pieces" (Ezek. 23:47).

8. REB denotes the Revised English Bible.

9. *De Genesi ad litteram* 6.18 (tr. Augustine 1982, 190). Compare *De Genesis ad litteram* 6.25; *De Trinitate* 3.8; 3.13. On the (pre)evolutionary theory of Augustine as a whole, see Mitterer (1956, 58–67).

10. This aspect is more clearly stated in Welker's (1995) later contributions when commenting on Genesis 1:4 and 1:14: "The Priestly writing evidently wants there to be a clear differentiation between, on the one hand, the total domain of divine action and, on the other hand, the domain of earth together with the heavens above it" (p. 180).

11. This doctrine was commonplace for both Roman Catholic Thomism, Lutheran Orthodoxy, and to some extent also the Reformed tradition; see the critical survey by Karl Barth ([1960] 1986, 94–107).

12. Also, in his suggestive proposal to see human beings as the created co-creators of God, Philip Hefner admits that humans in their cultural adaptations to reality are creators only "in a derivative sense" (1993, 39). If so, I prefer to follow the existing language rules by reserving the term *Creation* for God's activity, while the activity of creatures includes the productivity of autopoiesis. Humans beings, in particular, are cooperators with God, actively participating in the context-dependent creativity of God, though not in the context-constitutive creativity of God. In this picture, human beings are seen as co-explorers with God, since humans have the role of "consciously and intelligently cooperating in the processes of creative change" (Peacocke 1979, 306).

13. The classical text is Boethius: *De consolatione* V, prosa 3–6. Thus, even while Thomas Aquinas allows for an element of chance between the secondary causes, there is no chance in relation to divine providence (*Summa Theologiae* Ia q 103,7 ad 2).

14. In this reading, there is a continuity in Christian tradition supporting the kenotic move in more recent interpretations of divine Creation. Also, according to Thomas Aquinas, for instance, it would imply a lack of power and greatness in God if the creatures were not given a created power of their own; see, for example, *Summa Theologiae* Ia q 105,5.

15. It should be noticed, however, that the laws of complexity do not allow for an a priori prediction of specific outcomes in the form of a logical deduction. Neither the civilization anno 2000 nor the appearance of the human species or even the phylum of mammals can be predicted. Both Bartholomew (1984, 138) and Peacocke (1986, 50ff.; 1993, 62–69) declare that the emergence of a humanlike consciousness is safeguarded by stochastics alone. Karl Popper's philosophy of propensity (1990, 14–17), however, does not warrant a global evolutionary progress in such detail, nor does Stuart Kauffman's theory provide the basis for very specific outcomes. The laws of complexity have the status of general post-hoc explanations.

16. That the doctrine of the Trinity implies an ontological-relational *communio* between God and humanity is the key thesis of Catherine M. LaCugna's ([1991] 1993) stimulating reinterpretation of the Trinity.

17. Likewise, Christ's promise of the coming of the Spirit when he departs (John 14–17) is structurally conformal with the story in Acts of the disciples who are seen with the Pentecostal lights distributed to each individual of the community (Acts 2 : 3). The recurrent idea is that God's incarnation of the full pattern of wisdom in Christ is followed up by the concretely inhabiting Spirit.

18. Unfortunately, major parts of tradition claimed that suffering pertained only to the human nature of Christ. This crypto-Nestorianism is, in my view, highly problematic.

19. My appropriation of Popper's propensity theory here differs from (but does not exclude) A. R. Peacocke's (1993, 65–69); see note 15. Popper in fact ends up in a position similar to Wolfhart Pannenberg's general view of natural laws as time dependent: since the realm of applicability for any law comes about only in the course of time, the laws originate as a "form of process"; therefore, they have a certain, but principally a limited, stability (Pannenberg 1993, 105–8).

20. Compare Puddefoot's (1996) clarifying distinction between (1) bits information of the Shannon type, (2) meaning information on the level of consciousness, and (3) shaping information that always presupposes the achievements of evolution as information-embodied processes. Also, in my model, God shapes and remolds a system only on the basis of its already attained propensities. The concept of structuring causality, therefore, differs from a concept of miracles.

21. Please note that I do not claim that my proposal of God as a structuring causality exercising a continuous but nonuniform influence on type-different systems is self-sufficient. Rather, I take the model as a supplement to two fundamental strategies: (1) God is the creator of the fixed laws of elementary physics (a nonnegotiable position). (2) If chance is intrinsic to nature, the letting be of a scheduled interplay between law and chance is part of God's creation (the early Peacocke-Bartholomew proposal).

The proposal that God may act by changing the regularity patterns and possibility spaces by working inside of and in between the different levels of reality has nonetheless, I think, some distinctiveness in relation to two more recent proposals: (3) There may be enough room for divine influence on the world within the statistical constraints of probabilistic laws as long as God conserves the overall probability pattern; some find a physical place for particular divine action in quantum processes only (Robert J. Russell et al.), while others take a singularist approach with respect to other statistical processes as well (Polkinghorne, Ward). Finally, (4) God's interaction with the world may be modeled as a kind of boundary condition, exercising a continuous constraint on the world-as-a-whole and thereby indirectly changing the course of particular events. By this model, developed by the later Peacocke (1993, 53–55, 157–60, 373f.; 1995, 282–85), God can obtain particular changes in the world only in a roundabout way through the world-system-as-a-whole. My model is in critical continuation of Peacocke insofar as I reallocate Peacocke's fruitful idea of whole-part causation from the global arena to the interaction between type-different systems on local levels. See note 5 and the fuller argument for a differentiated notion of divine action in Gregersen (1997).

References

Augustine, Aurelius. [ca. 400] 1982. *The Literal Meaning of Genesis.* Vols. 1 and 2. Trans. and annotated by John Hammond Taylor, S.J. Ancient Christian Writers no. 41–42. New York and Ramsey, N.J.: Newman Press.

Ballmer, Thomas T., and Ernst von Weizsäcker. 1974. "Biogenese und Selbstorganisation." In *Offene Systeme I. Beiträge zur Zeitstruktur von Information, Entropie und Evolution*, ed. Ernst von Weizsäcker. Stuttgart: Klett.

Barth, Karl. [1960] 1986. *Church Dogmatics*. Vol. 3, Part 3: *The Doctrine of Creation*, ed. G. W. Bromiley and T. F. Torrance. Edinburgh: T. & T. Clark.

Bartholomew, David J. 1984. *God of Chance*. London: SCM Press.

Bergmann, Sigurd. 1995. *Geist, der Natur befreit. Die trinitarische Kosmologie Gregors von Nazianz im Horizont einer ökologischen Theologie der Befreiung*. Mainz: Matthias-Grünewald-Verlag.

Coveney, Peter, and Roger Highfield. 1990. *The Arrow of Time: The Quest to Solve Science's Greatest Mystery.* London: Flamingo.

Dennett, Daniel C. [1995] 1996. *Darwin's Dangerous Idea: Evolution and the Meaning of Life*. New York: Touchstone.

Dretske, Fred. 1995. "Mental Events as Structuring Causes of Behaviour." In *Mental Causation*, ed. John Heil and Alfred Mele. Oxford: Clarendon.

Edelman, Gerald M. 1992. *Bright Air, Brilliant Fire: On the Matter of the Mind.* New York: Basic Books.

Eigen, Manfred. 1987. *Stufen zum Leben. Die frühe Evolution im Visier der Molekularbiologie*. Munich: Piper.

Eigen, Manfred, and Ruthild Winkler. [1975] 1987. *Das Spiel. Naturgesetze steuern den Zufall.* Munich: Piper.

Gregersen, Niels Henrik. 1987. "Freedom and Evolution: Systems Theoretical and Theological Perspectives." In *Free Will and Determinism*, ed. Viggo Mortensen and Robert C. Sorensen. Aarhus: Aarhus Univ. Press.

_____. 1994. "Theology in a Neo-Darwinian World," *Studia Theologica* 48: 125–49.

_____. 1995. "Natural Events as Crystals of God: Luther's Eucharistic Theology and the Question of Nature's Sacramentality." In *Concern for Creation: Voices on the Theology of Creation*, ed. Viggo Mortensen. Uppsala: Svenska Kyrkans Forskningsråd.

_____. 1997. "Three Types of Indeterminacy: On the Difference between God's Action as Creator and as Providence." In *The Concept of Nature in Science and Theology: Part 1.* Studies in Science and Theology, vol. 3, ed. Niels Henrik Gregersen, Michael W. Parsons, and Christoph Wassermann. Geneva: Labor et Fides.

Griffin, Donald R. 1994. *Animal Minds*. Chicago: Univ. of Chicago Press.

Hartshorne, Charles. [1948] 1964. *The Divine Relativity: A Social Conception of God.* New Haven, Conn.: Yale Univ. Press.

Hefner, Philip. 1993. *The Human Factor: Evolution, Culture, and Religion*. Minneapolis: Fortress Press.

Jaki, Stanley L. 1992. *Genesis 1 Through the Ages*. London: Thomas More Press.

Jantsch, Erich. 1980. *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution*. Oxford: Pergamon.

Jüngel, Eberhard. 1986. "Gottes ursprüngliches Anfangen als schöpferische Selbtsbegrenzung. Ein Beitrag zum Gespräch mit Hans Jonas über den 'Gottesbegriff nach

Auschwitz.'" In *Gottes Zukunft—Zukunft der Welt. Festschrift für Jürgen Moltmann*, ed. Hermann Deuser et al. Munich: Chr. Kaiser.
Kauffman, Stuart. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. New York and Oxford: Oxford Univ. Press.
_____. 1996. *At Home in the Universe: The Search for Laws of Self-Organization and Complexity.* New York and Oxford: Oxford Univ. Press.
Krohn, Wolfgang, Günther Küppers, and Rainer Paslach. [1987] 1988. "Selbstorganization—Zur Genese und Entwicklung einer wissenschaftlichen Revolution." In *Der Diskurs des radikalen Konstruktivismus*, ed. Siegfried J. Schmidt. Frankfurt am Main: Suhrkamp.
Küppers, Bernd-Olaf. [1986] 1990. *Der Ursprung biologischer Evolution. Zur Naturphilosophie der Lebensentstehung*. Munich: Piper.
LaCugna, Catherine Mowry. [1991] 1993. *God for Us: The Trinity and Christian Life*. New York: HarperSanFrancisco.
Luhmann, Niklas. [1984] 1985. *Soziale Systeme: Grundriss einer allgemeinen Theorie*. Frankfurt am Main: Suhrkamp.
_____. [1986] 1988. *Ökologische Kommunikation: Kann die moderne Gesellschaft sich auf ökologische Gefährdungen einstellen?* Opladen: Westdeutscher Verlag.
_____. 1990. "The Autopoiesis of Social Systems." In *Essays on Self-Reference*. New York: Columbia Univ. Press.
Luther, Martin. [ca. 1535] 1987. *Luther's Works*. Vol. 1: *Lectures on Genesis*. Chapters 1–5, Trans. and ed. Jaroslav Pelikan. Saint Louis: Concordia.
Macquarrie, John. 1984. *In Search of Deity: An Essay in Dialectical Theism. The Gifford Lectures 1983–84*. London: SCM Press.
Maturana, Humberto R. [1985] 1988. "Biologie der Sozialität." In *Der Diskurs des radikalen Konstruktivismus*, ed. Siegfried J. Schmidt. Frankfurt am Main: Suhrkamp.
Maturana, Humbeto R., and Franscisco J. Varela. [1987] 1992. *The Tree of Knowledge: The Biological Roots of Human Understanding*. Rev ed. Boston and London: Shambhala.
Mayr, Ernst. 1982. *The Growth of Biological Thought: Diversity, Evolution and Inheritance*. Cambridge: Harvard Univ. Press, Belknap Press.
Mitterer, Alfred. 1956. *Die Entwicklungslehre Augustins*. Vienna-Freiburg: Herder.
Moltmann, Jürgen. 1972. *Der gekreuzigte Gott. Das Kreuz Christi als Grund und Kritik christlicher Theologie*. Munich: Chr. Kaiser.
_____. 1985. *Gott in der Schöpfung. Ökologische Schöpfungslehre*. Munich: Chr. Kaiser.
Monod, Jacques. 1972. *Chance and Necessity.* London: Collins.
Müller, Hans-Peter. 1991. "Segen im Alten Testament." In *Mythos-Kerygma-Wahrheit*. Berlin and New York: de Gruyter.
Pannenberg, Wolfhart. [1970] 1993. "Contingency and Natural Law." In *Toward a Theology of Nature: Essays on Science and Faith*, ed. Ted Peters. Louisville: Westminster/John Knox.
Peacocke, Arthur R. 1979. *Creation and the World of Science. The Bampton Lectures, 1978*. Oxford: Clarendon Press.
_____. 1986. *God and the New Biology.* London-Melbourne: J.M. Dent and Sons.
_____. 1993. *Theology for a Scientific Age. Being and Becoming—Natural, Divine and Human*. London: SCM Press
_____. 1995. "God's Interaction with the World: The Implications of Deterministic 'Chaos' and of Interconnected and Interdependent Complexity." In *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert John Russell, Nancey Murphy, and Arthur R. Peacocke. Vatican City State: Vatican Observatory Publications; Notre Dame, Ind.: Univ. of Notre Dame Press.
Polkinghorne, John. 1988. *Science and Creation: The Search for Understanding*. London: SPCK.
Popper, Karl R. 1990. *A World of Propensities*. Bristol: Thoemmes.
Prigogine, Ilya. 1990. "Loi, histoire . . . et désertion." In *La querelle du déterminisme. Philosophie de la science d'aujourd'hui*, ed. Stefan Amsterdamski et al. Paris: Gallimard.
Prigogine, Ilya, and Isabella Stengers. 1984. *Order out of Chaos: Man's New Dialogue with Nature*. Toronto: Bantam.

Puddefoot, John C. 1996. "Information Theory, Biology, and Christology." In *Religion and Science: History, Method, Dialogue*, ed. Mark W. Richardson and Wesley J. Wildman. New York: Routledge.
Russell, Robert John. 1995. "Theistic Evolution: Does God Really Act in Nature?" *CTNS Bulletin* 15: 19–32.
Schmidt, Werner H. 1964. *Die Schöpfungsgeschichte der Priesterschrift*. Neukirchen: Neukirchener Verlag.
Steck, Odil Hannes. 1975. *Der Schöpfungsbericht der Priesterschrift*. Göttingen: Vandenhoeck and Ruprecht.
Temple, Frederick. 1885. *The Relations between Religion and Science*. London: Macmillan.
Varela, Fransisco J. [1987] 1988. "Autonomie und Autopoiese." In *Der Diskurs des radikalen Konstruktivismus*, ed. Siegfried J. Schmidt. Frankfurt am Main: Suhrkamp.
Ward, Keith. 1990. *Divine Action*. London: Collins.
Welker, Michael. 1991. "What Is Creation? Rereading Genesis 1 and 2." *Theology Today* 48: 56–71.
_____. 1995. "Creation: Big Bang or the Work of Seven Days?" *Theology Today* 52: 173–87.
Westermann, Claus. [1974] 1976. *Genesis*. Neukirchen: Neukirchener Verlag.
Zeleny, Milan, ed. 1981. *Autopoiesis: A Theory of Living Organization*. New York: North Holland.