CHAOS: WHERE SCIENCE AND RELIGION MEET?

A CRITICAL EVALUATION OF THE USE OF CHAOS THEORY IN THEOLOGY

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In: N.H. Gregersen, U. Görman, H. Meisinger (eds.), *Studies in Science & Theology 8. Yearbook of the European Society for the Study of Science and Theology 2001-2002*. Aarhus, Denmark: University of Aarhus, 2002, 277-294.

Abstract: Chaos theory is mentioned in many contemporary theological discussions concerning divine action. However, in these discussions theologians often forget that theology is different from science. Also, chaos theory is a fairly recent phenomenon on the scientific stage, and it may be premature to focus on metaphysical issues arising from our present knowledge of chaotic systems. In this paper I want to expound on these two issues. First there will be a short introduction to some central concepts of chaos theory: sensitive dependence on initial conditions, mixing, dense periodic points, and the presence of a strange attractor. Thereafter, the theological proposal of John Polkinghorne, who sees God's action as information-input in the initial conditions of chaotic real-world systems, will be dealt with as a case study. Finally, a theological and philosophical evaluation of the case study will follow.

Keywords: chaos, determinism, divine action, information, John Polkinghorne, language, methodology, model, philosophy of science, science and theology.

1. INTRODUCTION[1]

In recent years, the word "chaos" has had a profound influence not only in science, but also in theological and philosophical thinking, although it must be admitted that little philosophical reflection on chaos theory and concepts involved in that theory has as yet been done. (However, notable exceptions are Kellert 1993, Leiber 1996, and Smith 1998.) In my opinion some philosophical topics of chaos theory, like the relation between mathematics and reality, modeling, the notions of causality and determinism, and the relation between explanation and prediction, are in need of further investigation. This will be necessary also for the benefit of theology, as many theologians have hailed chaos theory as a new paradigm in science, and are trying to incorporate chaos into a theological framework.

This paper focuses especially on the use of chaos theory in theology. I will present as a case study the theology of John Polkinghorne. I will try to raise two points: first, conflating scientific and theological language will result in a scientific theology which has destructive influence on a theology of divine agency; second, with the present knowledge about chaotic systems, the shift from the mathematical concept of chaos to a (theological) metaphysics based on chaotic dynamics is premature.

The structure of the paper is threefold: first, I will give a brief description of mathematical chaos. Thereafter, I want to explore a theological proposal that sees chaotic dynamics as inherent in our universe and as a possibility for God to act in the world; the proposal will be that of John Polkinghorne. Finally, a theological and philosophical evaluation of this position will follow.

2. MATHEMATICAL CHAOS

The dogmatician Alexandre Ganoczy stated that the term "chaos" probably cannot be unambiguously defined but only phenomenologically described (Ganoczy 1995, 33). This may be true for the contemporary state of affairs concerning chaos research. However, in recent years a number of mathematical definitions of chaos have been proposed, one of which is the much used definition by Robert Devaney, which names three common characteristics of chaos (Devaney 1989, Peitgen et al. 1992, 536):[2]

1. sensitive dependence on initial conditions,
2. mixing, and
3. dense periodic points.

It is important to see what is involved here. A mathematician starts for example with the famous discrete Logistic equation $x_{n+1} = ax_n(1\text{-}x_n)$, $n = 0,1,2,...$, originally used to describe the behavior of a population. Then she takes an initial value x_0 and starts to calculate the next term of the series x_1. The outcome of the calculation will serve as the input for the calculation of the following term. This feedback process is called "iteration." The results of a series of iterations, with different initial values, can be represented geometrically in a so called "phase space plot." Phase space is the abstract space in which every possible state of a system is depicted; every point in phase space equals some specific state of the system. In the geometrical representation of this phase space of the Logistic equation, the dots or points of the possible outcomes form a mapping which is the evolution of the equation in time. The Logistic equation is an example of a chaotic system, exhibiting the following characteristics.

2.1. Sensitive dependence on initial conditions

The first characteristic, sensitive dependence on initial conditions, means that it makes a lot of difference for the outcome of an iteration how the outcome is rounded off, e.g. 5.17488**35** or 5.174884 – even if the difference seems so small. Rounding off takes place in the case of finite data, i.e. estimations. But even if the calculations are fairly precise, rounding off takes place. This rounding off process is then performed by, for instance, a pocket calculator with a display of only ten characters. But a more powerful computer also rounds off, even though a computer is much more precise than a pocket calculator. This only means that it takes longer (i.e. more iterations) before the system becomes unpredictable. Infinite precision of data is impossible to attain and an error margin is therefore always present. The error margin increases exponentially as the iteration process progresses. Orbits of two arbitrarily close initial points are likely to diverge exponentially in time. Consequently, to avoid the problem of sensitive dependence, one needs infinite accuracy to make exact predictions, which is of course impossible. In popular terms the phenomenon of sensitive dependence is known under the heading "Butterfly effect" (Lorenz 1993, 181ff.). Sensitive dependence is one of the main causes of the unpredictability of a chaotic system.

2.2. Mixing

The second characteristic, mixing, is a property of a dynamic system. Roughly, this property means that points from an arbitrarily small subinterval of a unit interval eventually get spread out all over the entire unit interval after a finite number of iterations. Or in other words: you can get everywhere from anywhere else. In more technical terms it can be said that the property of mixing means that some interval *J* on the graph of the equation can be reached from some other interval *I* on the graph of the equation after some iteration. Alternatively formulated: one can find a starting point x_0 in I that will enter interval J after a certain number of iterations. A physical analogy of mixing is the stirring of milk in a cup of coffee: the milk spreads through the whole coffee.

Mixing makes a chaotic system ambiguous: on the one hand the behavior of the system is completely orderly, for it stays within the parameters of the unit interval, and it is deterministic (i.e. governed by an equation); on the other hand, however, the property of mixing leads to what is called ergodicity (i.e. the property that every point approaches every other point of the unit interval in a finite number of iterations), and the method of using statistical histograms shows that statistically one cannot distinguish between deterministic behavior of a chaotic system and completely random behavior.

2.3. Dense periodic points

The third characteristic, the density of periodic points, means that there are infinitely many points with infinitely different periods. A periodic point is a point which cycles through a number of intervals. A point which cycles through three different intervals, has a period three. Because a chaotic equation has (in theory) an infinitely complex structure, two theoretical observations can be made:

a) in the case of a chaotic equation, in every arbitrary interval there is an infinite number of periodic points;

b) there will also be periodic points with infinite periodicity.

However, although theoretically there are infinitely many periodic points, practically we will never be able to find these, for all (finite) computers make rounding-off errors. And these rounding-off errors will be amplified exponentially because of sensitivity on initial conditions, so that we will never achieve the exact periodicity, but only quasi-periodicity. We can save the appearances of periodicity for only a limited number of iterations; after that, sensitivity strikes and the periodicity becomes unstable.

2.4. Strange attractors

Except for these three characteristic another important indication for chaoticity of a system is the presence of a strange attractor. Furthermore, a strange attractor indicates the underlying orderliness of the system. The notion of an attractor in phase space can be made more explicit by way of an analogy. Suppose a baker puts a drop of ink on a piece of dough; after that he stretches the piece of dough, thereby stretching the drop of ink into a line. After the stretch the baker folds the dough back on itself. So now the line of ink is folded back onto itself with a little layer of dough separating the line. If the baker were to stretch and fold the piece of dough an infinite number of times with an incredible accuracy, the line of ink would have an infinite intricacy. Now back to phase space. Through selecting the parameters under which the system evolves, phase space is a finite, bounded region. This means that if an orbit in phase space has the tendency to wander off, phase space can make the orbit fold back onto itself. Some other orbits, however, will wander out of phase space (or, as mathematicians say, go to infinity). Through an infinite number of iterations, and an infinite number of stretch-and-fold actions, the result can be an intricate structure of orbits in a specific region of phase space, called a “strange attractor.” It is an attractor, because it attracts nearby points in phase space; it is strange, because it is infinitely intricate with self-similarity on all scales (i.e. a strange attractor is a fractal).

After this very brief and rather technical introduction to the complex matter of chaotic dynamics one could remark that this is a rather dull exposition of chaos theory. That, I admit, would be a correct observation. However, the dryness of the exposition serves a purpose: it makes perfectly clear that chaos theory is a mathematical theory. The confrontation with these mathematics empties the term "chaos" of more possibly mythical connotations by making clear that chaos in the scientific sense is a purely neutral mathematical term. It does not deny, however, that chaos in the scientific sense is also a very interesting concept and perhaps has consequences for the way we see, and think about, the world. In any case, chaotic systems have some very peculiar features: they are deterministic, though eventually unpredictable; statistically they display randomness, but seen from a more geometrical perspective, the underlying attractor is deterministic and highly ordered (though complex); finally, a chaotic system displays infinity in the finiteness of phase space.

The mathematical exposition also shows that mathematical chaos is conceptual. And here we arrive at a crucial point. After James Gleick published his best-selling book *Chaos* (Gleick [1988] 1997), which documents the fascinating beginnings of chaos research, many scientists started enthusiastically to search for chaos in real-world phenomena. The first results looked promising but recently there has been some doubting whether there is "pure" chaos in the real world. We will pick up this subject again after giving a brief exposition about how the search for real-world chaos had an impact on theological thinking about the world.

3. THEOLOGICAL CHAOS

3.1. Determinism and God's action

For theology, the notion of divine agency is crucial, but not unproblematic. If one says that God is not interacting with this world, what then to make of the biblical stories of God's interaction with the world and with his people? And what then about people's stories about God's action in their lives? In philosophy of religion, the notion of a non-interacting God is called "deism." Deism implies a God that is non-personal, non-relational and non-interactive. Theism, on the other hand, holds that only a personal God can have relations with people, and for having relations God needs to be interactive with the world. It seems as if this argument is circular, but for theologians who are theists, the notion of a personal, relational and interactive God is crucial. However, problems arise when the questions of *how* and *where* God acts are considered. Here, the dialogue with science reaches a crucial phase.

The scientific worldview is necessarily a deterministic worldview, a world governed by laws, causes and effects. That is, science defends "the view that the state of the world at any instance determines a unique future, and that knowledge of all the positions of things and the prevailing natural forces would permit an intelligence to predict the future state of the world with absolute precision." (Berofsky 1995, 197.) If this is true, then where can God act in the world? Roughly two options are available:

1. If the *immanence* of God in the world is emphasized, God acts in the world like a causal factor amongst others. This would imply that God is in the world, or even, a part of the world. This latter "spinozistic" argument is the opposite of the theological argument that God is also transcendent (i.e. "more than" the world), although immanence and transcendence need not contradict each other.
2. If God's *transcendence* is emphasized, God acts from outside the world. God is then seen as "breaking into" the universe from some location outside of it. This would imply that God's action could somehow be localized. Moreover, this would mean that God breaks the laws of nature, which he created in the first place; this would make God arbitrary, and contradicts God's trustworthiness.[3]

Consequently, there seems to be a conflict: either determinism is true (but then God's action is scientifically and theologically problematic), or it is not (but then science is utterly defeated, for it is based on the assumption of determinism). Can chaos theory be of any help? Some theologians, amongst whom John Polkinghorne is the most prominent, think it does.

3.2. Chaos in the theology of John Polkinghorne

John Polkinghorne is at present probably the most important exponent of an approach that uses chaos theory in a theology of divine action. Polkinghorne, once a scientist, now an Anglican priest, tries to stimulate the dialogue between science and theology, while attacking the scientific metaphysical claims of reductionism and determinism. In the following I focus on an article by Polkinghorne (Polkinghorne 1996) in which he summarizes his approach.

Polkinghorne focuses mainly on the problem of unpredictability in chaotic systems. As we have seen, the property of sensitive dependence on initial conditions is the reason why making accurate long-term predictions about the system's behavior is an almost impossible task. Polkinghorne thinks that the question whether this unpredictability is a problem of human ignorance or an ontological property inherent in chaotic systems is a question which is ultimately resolved on the basis of a metaphysical decision: "In the case of chaos theory, I feel we face a … metaphysical choice whose answer cannot be settled by present scientific knowledge alone" (Polkinghorne 1996, 247). Polkinghorne thus chooses to see the unpredictability as having its place in the ontology of chaotic systems. This is a consequence of his critical realist position, which has as a motto: "Epistemology models Ontology" (Polkinghorne 1996, 246). Whether or not this motto is appropriate to describe critical realism in general is a point which will not be considered here.

The epistemological vulnerability of prediction in the case of chaotic systems then is seen as having two reasons. First of all, "[t]he causal net resulting from [a] bottom-up account is not drawn so tightly that it does not leave room for the operation of other forms of causality" (Polkinghorne 1996, 247). It is not entirely clear what Polkinghorne means exactly by "other forms of causality"; it seems as if he regards information input as also a form of causality, as we will see later. Because a chaotic system is highly sensitive on initial conditions (i.e. starting situations which differ only infinitesimally from each other informationally but do not differ energetically), the behavior of a chaotic system will show a startling variety of evolutions. Therefore, information input, which Polkinghorne seems to identify with non-energetic input, can cause radically different behavior in chaotic systems due to sensitivity on initial conditions. What Polkinghorne seems to be suggesting is that an entity with infinite knowledge of the initial conditions could alter the behavior of a system by tampering with these initial conditions by way of information input, which would be undetectable for us because there is no difference in energy levels in the different initial conditions. This argument has received major criticisms, as we will see later.

The second reason for predictive vulnerability of chaotic systems is that this vulnerability is also due to the irreducible influence of the system's environment on the evolution of the system. In Polkinghorne's words: the environment "participates in the specification of future development. Therefore informational causality will have a holistic or 'top-down' character to it" (Polkinghorne 1996, 247). As I understand it, the environment in which the system is embedded, influences the system's behavior also in an informational and non-energetic way.

From these two reasons for predictive vulnerability Polkinghorne infers a metaphysical conjecture: "The physical world is subtle and supple in its constitution. It is open to causal influence by the exchange of energy between its constituent parts (as described by physics) and *also* to the operation of holistic pattern-forming agencies which can be thought of as 'active information'" (Polkinghorne 1996, 247; italics in original). The mathematics of chaos then is only an approximation of reality: “The deterministic equations, from which classical chaos theory has been derived, are to be understood as *downward emergent approximations* to that more supple physical reality. They must arise from treating individual parts as if they were isolable from the environment” (Polkinghorne 1996, 247; italics in original). In this way, Polkinghorne thinks he is able to counter the scientific claim of metaphysical determinism and reductionism by using a critical realist interpretation of chaos theory for defending an open universe in which “holistic pattern-forming agencies” are the explanatory complement of normal causal processes.

But what are these “holistic pattern-forming agencies”? According to Polkinghorne these may take three forms: a) there may be yet unknown holistic natural laws; b) human action might also be an example of holistic action; and c) “It is entirely conceivable that God also interacts with the creation through the input of active information into its open physical processes” (Polkinghorne 1996, 248). Polkinghorne theologically prefers the last option, thereby giving the notion of divine action explanatory force.

The idea that God could interact by way of real-world chaotic processes has, according to Polkinghorne, at least six theological consequences. First of all, we will not be able to discern the locus of God’s action; that is to say, God’s action will always be hidden. “All forms of agency intertwine in the inter-relating complexity and sensitivity of a chaotic world” (Polkinghorne 1996, 249). Secondly, since clearly not all real-world processes are chaotic, it is granted that some parts of the universe are orderly and highly predictable. “Their regularity will be to the believer signs of divine faithfulness” (Polkinghorne 1996, 249). Thirdly, the processes that are unpredictable due to sensitive dependence on initial conditions, and which can also be called “open to the future” can be extrapolated to the universe as a whole; then the picture is that of “an open future in which both human and divine agency play parts in its accomplishment” (Polkinghorne 1996, 249). Divine and creaturely action then are intertwined; creatures can co-operate with the Creator. Fourthly, according to Polkinghorne the vision of God acting through chaotic processes is not a new instance of the God-of-the-gaps idea; for “God is not being invoked to explain that which is currently scientifically unexplained, but which is, in principle, scientifically explicable” (Polkinghorne 1996, 250). Fifthly, if our world is a world of becoming and the future is genuinely open, that is, not to be predicted because of the inherent chaotic dynamics and external influences of the environment of physical chaotic systems, then not only is the future unknowable for us, but “even God does not know the future. That is no imperfection in the divine nature, for the unformed future is not yet there to be known. … The act of creation involves a voluntary limitation, not only of divine power in allowing the other to be, but also of divine knowledge in allowing the future to be open” (Polkinghorne 1996, 250). Sixth and finally, petitionary prayer is possible without doing violence to the scientific integrity of the world. Polkinghorne offers a specific view of the concept of prayer in this respect: “we are offering our room for maneuver with respect to the open future to be taken by God and used to the greatest effect in collaboration with that room for manoeuvre which is reserved to the divine providential interaction” (Polkinghorne 1996, 250).

4. Evaluation

Two important criticisms considering Polkinghorne’s use of chaos theory in theology can be made. The first criticism looks at the scientific and theological perspective and Polkinghorne’s conflating of their different though related languages. The second criticism deals more with Polkinghorne’s overestimation of contemporary results of chaos theory for a theological metaphysics and a real-world description.

4.1. Scientific and theological language

One important criticism as to Polkinghorne's use of chaos theory for a model for divine action is that of Willem Drees, and concerns Polkinghorne's view of information-input. As we have seen, Polkinghorne seems to identify information input with non-energetic input. However, as Drees points out, there is no physical evidence that there can ever be information input without energy input. That means that if God should want to act in physical chaotic systems by way of information input, there would also be energy fluctuations, which could in principle be detected (Drees 1996, 95-100).[4]

Drees' argument seems valid, although it is a scientific argument. But how can a scientific argument refute a theological argument? The problem with Polkinghorne's argument is that he seems to confuse scientific language with theological language in such a way that theology and science could easily become competitors once again. To put the point in more general terms: If you make a theological argument on the basis of scientific terms and data (i.e. scientific language), you make your theological position vulnerable to scientific arguments. Both languages, theological and scientific, are then used as if they were on the same level. And this is why Drees can give a scientific argument against Polkinghorne's theological conjecture. Polkinghorne thus seems to disregard the notion of a plurality of languages, of which more and more scholars (in the footsteps of the later Wittgenstein) become aware nowadays. Language in this view is multidimensional and multifunctional. One of the dimensions of language is that it is able to express a specific *perspective* on something. In that sense, theological language expresses a different perspective on things than scientific language. Saying that some occurrence in my life was an act of God is not explanatory in the same sense that some physical event occurred due to natural causal factors; saying that some event was an act of God is having a specific perspective on some event – or in other words, saying that God is active in the world is a type of "aspect seeing" (Verbin 2000). Scientific language, on the other hand, expresses a rather different perspective on the world. Thus, science and theology (or religion in general) have different perspectives on the same reality. Or, to use an analogy from philosophy of science: science and religion are different paradigmata which are *logically* incommensurable. To put the difference rather crudely: scientific language is used to explain physical events and to describe facts about the way the world is; theological language is used to give meaning to the occurrence of those physical events, it deals more with commitment, beliefs, convictions, and attitudes. To speak about God's action as a parameter in a scientific theory is making a category mistake, for God has no place within a scientific frame of reference. Similarly, in theology it is meaningless to pray: "Our Holy Quark, who art in thy eternal Quantum Realm..." This is not to say that the languages of science and theology have absolutely no relation to each other, for both science and theology are basically directed towards the same world, even though they have different conceptual schemes (they "see" different things). I admit that more needs to be said about this, but I will postpone this to another occasion.

Summarizing: Polkinghorne sees scientific and theological language as if they are on the same level. This makes his "theory" of divine action vulnerable to scientific counter-arguments. Furthermore, Polkinghorne misses the point that scientific and theological language have different functions due to different conceptual schemes.

One further necessary point needs attention. Completely severing scientific from religious language has the imminent danger of making the dialogue between science and religion meaningless (except perhaps in the case of ethical discussions). This danger needs to be avoided. The problem of talking about God's action in a world described by the natural sciences might then be overcome by making use of *models*. In that case, concepts and theories of science might be used as metaphors or (analogical) models in theological discourse. Perhaps chaotic systems can become theological models for God's acting in the world – though this is a line of thinking that is not pursued here further.

4.2. Chaos theory and the physical world

As we have seen in section 2, contemporary research of chaotic systems is still very much a mathematical activity. However, many sciences (of which physics and economics are perhaps the most prominent) use mathematics for describing or explaining the dynamics of physical processes. That means that mathematical models are convenient for elucidating and/or explaining the underlying dynamics of many processes in the real world. Polkinghorne's line of thinking seems similar. One of the premises of his argument for divine activity in the world seems the following: the mathematics of chaotic systems are approximate but descriptive models of real-world processes. However, the relation between the mathematics of chaos and real-world systems is more problematic than Polkinghorne seems to imply.

One of the crucial features of chaotic systems is the notion of *infinity*. Unpredictability of chaotic systems is due to the fact that chaotic system have an infinite range of possibilities for behavior. Strange attractors have an infinite intricacy. Also, fractals (whether the fractal structure of a strange attractor or a computer generated geometric picture) are infinite with regard to the self-similarity on every scale. But, as the philosopher of science Peter Smith asks, can it really be said that real-world phenomena also have a touch of infinity?

For example, to say that the coast of Britain has an infinite intricacy (as Benoit Mandelbrot proposed, stating that the coast of Britain is a fractal), if taken literally, is rather absurd. For the coast may be self-similar on some scales, but not on every scale (compare for instance the view from a satellite with the view from a wanderer on the beach). So, Smith concludes, "[t]he truth about the coastline of western Britain, then, is really rather unexciting. By happenstance, it is roughly like one of those finite, non-fractal, constructions ... – constructions which are produced by an iterated operation which, *if* carried out infinitely often, *would* produce a fractal. No reason here, therefore, to talk of the 'fractal geometry of nature' – or not, at any rate, if that is meant literally" (Smith 1998, 33; italics in original). The italics in this quotation are important. So, real-world structures (like e.g. the cauliflower) cannot be called "fractal" in the literal-mathematical sense, because they miss the infinite intricacy that is characteristic of real fractals – the molecular level eventually gets in the way and self-similarity is gone. Or, in other words: the mathematical model of a fractal does not stand in a one-to-one mapping relation to a real-world fractal-like structure.

Something similar can be said with respect to the mathematical modeling of the chaotic dynamics of a system. Indeed, as noted above, the unpredictability of chaotic systems results from the infinite intricacy of the strange attractor of the system. However, "the very thing that makes a dynamical model a chaotic one (the unlimited intricacy in the behaviour of possible trajectories) can not genuinely correspond to something in the time evolutions of the modelled physical processes – since *they* can not exhibit sufficiently intricate patterns at the coarse-grained microscopic level" (Smith 1998, 41; italics in original).

What follows from this is that the chaotic mathematical models *are more complex than the real world*. When one considers the notion of model, this result is curious. Normally, scientific models are simplifications of real-world phenomena; some details of the real-world phenomenon are left out of the corresponding model, because otherwise the model would be too complicated to be applicable. However, in the case of chaotic models and their relation to the real world, the situation is exactly the opposite. The models of chaotic systems are more complex than the real-world systems of which they may be a model. The connection between mathematics and real-world phenomena in the case of chaos theory becomes diffuse. It cannot simply be said that physical processes possess a chaotic dynamics; there is more to it than that.[5]

Returning to Polkinghorne, what we can say about his use of chaos theory as a description or descriptive model for our world, is that Polkinghorne makes a big metaphysical leap when talking about chaos in connection with the physical universe – and even more when God enters the scene. Polkinghorne seems to *identify* mathematical models with real-world dynamical systems, and this identification is, as I have tried to make clear, not without complicating factors. The only way out for Polkinghorne, as I see it, is to have a Platonic metaphysics where mathematics are the real entities or prototypes of which the real world is just an approximation. But Polkinghorne suggests the opposite when he states that the "deterministic equations, from which classical chaos theory has been derived, are to be understood as *downward emergent approximations* to that more supple physical reality" (Polkinghorne 1996, 247).

As complicated as the relation between chaos-models and real-world dynamical systems may be, it is true that as science progresses it becomes more and more clear that there may be a *structural similarity* between chaos in mathematics and some real-world dynamical behavior. The similarity might be found in the *dynamics*. Perhaps the coastline of Britain is not literally a fractal, but there are some (intuitive) similarities which suggest that the underlying processes might be comparable. It might then very well be said that Britain's coastline is a *finite approximation* of an infinitely intricate fractal geometry. Physically this might be proven by finding so-called Lyapunov exponents in real-world dynamical systems; or it might be a matter of *seeing as...* – an interaction between the real world and the mind of the observer. After all, interpretation is the process where mathematics and the real world come together.

5. Conclusions

Polkinghorne's proposal to use chaos theory in theology to describe God's action in the world is, as we have seen, filled with difficulties. In my point of view, Polkinghorne is not taking seriously the particular character of theology. Theology is not some kind of natural science, neither in methodology nor in intent. Theology needs to take science seriously, but need not embrace the methodological and metaphysical presuppositions without which science would be impossible (i.e. determinism, reductionism, etc.). Theology needs to take science seriously because science deals with the world – from a theological point of view, science studies God's creation... but not God. Not even theology "studies" God. Theology merely reflects on what people say about (their experience of) God. Theology studies the narratives about the world and about God's way with people. And from the perspective of those narratives that people tell, God is an actor which gives meaning to those narratives. A theology of creation therefore needs not a theology of nature, but a *theology of narratives*... and one of those narratives a theology needs to reflect on is the narrative that science tells about the way the world is.

Notes:

[1] This is a revised and expanded version of a paper which I delivered on the ECST VIII Conference in Lyon. I want to thank Henk Broer, Peter Barrett, Niels Henrik Gregersen, Jitse van der Meer, and Knut-Willy Saether for their stimulating and valuable comments on the paper.

[2] It has to be noted that this definition is not the standard definition. Other chaos theoreticians, like Henk Broer in Groningen, see sensitive dependence and the presence of a chaotic attractor as the main characteristics of a chaotic system (cf. Broer 2000). The discussion continues.

[3] The argument that God acts by way of "secondary causality" also does not hold. If God were to act through the causal chains of the natural world, then again there are two options. *Either* God has built his purposes in the causal chains which are at work in the world; this would imply divine determinism, for everything that happens, happens because God has willed it so (and then what about evil?); also, the danger of deism is present again. *Or*, God acts through the natural laws and causal chains, which only pushes the question of the locus for divine action one step back.

Apart from these two options, there is a third option: the dipolarity of transcendence and immanence, or even a "trinitarian" concept of God. This option tries to evade the negative consequences of too much stress on either pole, but is too complicated to be treated here.

[4] An argument against Drees' position could be that he rules out God's action in the world as a *physical* possibility, because God's action would generate energy fluxes that would be, in principle, detectable. Drees conflates the general notion of "possibility" with the more narrow notion of *physical* possibility – which is due to his naturalist metaphysics. However, the range of physical possibilities is much more limited than the range of *logical* possibilities. And it is a logical possibility (i.e. it is not self-contradictory) that God can act in the world by information input without energy input. However, even if the argument of logical possibilities is useful in general against more physicalist and scientistic worldviews, the argument is irrelevant in the case which is currently under discussion, for Polkinghorne himself seems to defend the physical possibility of God action, and therefore makes himself vulnerable to Drees' argument.

[5] Another complicating factor is that "real" chaos even in mathematical systems is particularly hard to find. It is very difficult to distinguish between chaos and extremely long-periodic behavior (although methods for dealing with this problem are becoming more and more sophisticated).

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