IS OUR UNIVERSE DETERMINISTIC? SOME PHILOSOPHICAL AND THEOLOGICAL REFLECTIONS ON AN ELUSIVE TOPIC

by Taede A. Smedes

Abstract. The question of whether or not our universe is deterministic remains of interest to both scientists and theologians. In this essay I argue that this question can be solved only by metaphysical decision and that no scientific evidence for either determinism or indeterminism will ever be conclusive. No finite being, no matter how powerful its cognitive abilities, will ever be able to establish the deterministic nature of the universe. The only being that would be capable of doing so would be one that is at once transcendent and immanent. Such a being is compatible with the God of the Christian tradition, which yields that a deterministic worldview is compatible with (yet does not necessarily lead to) a deterministic worldview. A more important point is that because science is never able to establish the determinism of our universe, it can never definitely rule out divine action except on metaphysical grounds.

Keywords: chaos theory; determinism; divine action; John Dupré; immanence; indeterminism; logical possibility; metaphysics; physical possibility; Wesley Salmon; transcendence.

Modern cosmology has found that our cosmos is fitted for life. Our universe is "fine-tuned" to the emergence of complex life forms such as the human being (Drees 1990, chap. 3; Kanitscheider 1997; Barrow and Tipler 1986; Leslie 1989; Smolin 1997). Cosmologist Stephen Hawking writes,

> . . . it seems clear that there are relatively few ranges for values for the numbers that would allow the development of any form of intelligent life. Most sets of values

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> would give rise to universes that, although they might be very beautiful, would contain no one to wonder at that beauty. One can take this either as evidence of a divine purpose in Creation and the choice of the laws of science or as support for the strong anthropic principle. (Hawking 1988, 132)

Hawking, as is well known, dismisses both possibilities and defends the position that our universe is fully self-contained and that the explanations of the "fine-tuning" are hidden somewhere within it.

Similarly, biologist Stuart Kauffman recalls the calculation of Fred Hoyle and N. C. Wickramasinghe that the chances for life to emerge in our universe were 1 in $10^{40,000}$:

> The total number of hydrogen atoms in the universe is something like 10^{60}. So $10^{40,000}$ is unthinkably improbable. If the total number of trials for life to get going is only 10^{51}, and the chances are 1 in $10^{40,000}$, then life just could not have occurred. We the lucky. We the very, very lucky. We the impossible. Hoyle and Wickramasinghe gave up on spontaneous generation, since the likelihood of the event was comparable to the chances that a tornado sweeping through a junkyard might assemble a Boeing 747 from the materials therein. (Kauffman 1995, 44)

Kauffman concludes, "Since you are reading this book, and I am writing it, something must be wrong with the argument. The problem, I believe, is that Hoyle and Wickramasinghe, and many others have failed to appreciate the power of self-organization" (p. 45). Kauffman also opts for an explanation in terms of principles inherent in our universe to cope with the apparent improbability or even impossibility of life's emerging from lifeless matter.

Considering the fine-tuning of the universe, one might say that the initial conditions of our universe were such that intelligent life could emerge; if the initial conditions had been slightly different, we would not be here to know it—a very small difference with enormous consequences, at least from our vantage point. It seems that the principles now being discovered in the sciences of chaotic and self-organizing systems have been crucial for the process of emergence of life (cf. Kauffman 1993; 1995; 2000). Chance and necessity are not opposites, as Jacques Monod once thought, but the intricate interplay between them seems to have been crucial for our existence (Monod 1972; Peacocke 1979; Eigen and Winkler 1982). This means that chaos need not have its customary negative connotations: "Chaos implies the existence of unpredictable or random aspects in dynamic matters, but it is not necessarily bad or undesirable—sometimes [as in the emergence of life] quite the contrary" (Çambel 1993, 15).

Still, the remarkable fact is that we exist. In our search for meaning, humans often wonder whether there is a *reason* why we are here. Are we the inevitable product of an utterly deterministic universe? Is the explanation of our existence to be found somewhere within the folds of nature itself? Are we perhaps a mere outcome of chance? Or might it be that the chance of life's emerging is actually so small that we can reasonably fall back on "supernatural" explanations in which God figures prominently? If one accepts a deterministic universe, it is difficult to conceive how a God who is both immanent and transcendent could influence the history of the universe. Our universe then is a closed area in which all the sufficient grounds for explanations are to be found—we just have to keep on searching; but we can be assured that somehow we are the necessary product of the universe. This is how both Hawking and Kauffman see it, and both believe that we are closing in on the ultimate answers. However, if we assume that our universe is "open" in some way or another, may we not be able to introduce God-talk in accounting for the origins of life? For, if our universe is open, other perspectives on the origins of life become possible, including a religious one. If our universe is in some way open, and if the initial conditions of our universe are crucial for the emergence or self-organization of life, can we find ways to talk intelligibly about God's influencing these initial conditions? And if our universe is inherently chaotic, as many scientists believe, are there possibilities of talking about God's continuous action in our universe?

In this essay I address the questions of determinism and the openness of the universe. It must be admitted that the rationale for the treatment of the subject is a theological point of view: Is it, from a scientific perspective, unreasonable to talk about God's action in the universe? Does science exclude the possibility of God's action? The main question will be, *Do we have valid and conclusive reasons to believe that our universe is deterministic?* The possibility of God's action, with all of its theological pros and cons, will not be dealt with here.

Structure of the Article

The essay is structured as follows. First, we look at the notion of determinism and some descriptions of it. After this conceptual elucidation, we examine the close ties that exist between determinism and scientific method. Some critical points have recently been raised against determinism in science. We evaluate these as well as some criticisms based on chaos theory. One of the main results of this critical assessment will be that we should make a methodological distinction between determinism in principle and indeterminism in practice. The point is that our universe or a subsystem may be deterministic in principle, but, because of our limited cognitive abilities, science is unable to establish this with certainty, and practically it is often useful to deal with it as if it were an indeterministic system.

Next, a thought experiment is conducted to investigate the question of whether a finite being with unlimited cognitive capabilities may be capable of establishing determinism by way of predicting the history of the universe. From this thought experiment it becomes clear why determinism is ultimately a metaphysical notion. However, logically it might be the case that an infinite entity is able to predict the history of the universe. The conclusion is that the classical doctrine of God is logically compatible with metaphysical determinism.

Finally, some general conclusions are drawn. Indeterminism is rejected as an alternative to determinism: like determinism it is a metaphysical claim, but its grounds are as controversial as are the grounds for accepting determinism. Ultimately I argue for a uniformity-of-nature principle, according to which the universe has an order but one that is dynamic, self-organizing, and probabilistic.

WHAT IS DETERMINISM?

The notion of determinism can be marked out in many ways.[1] To name but a few descriptions: (a) Every event has a sufficient cause. (b) Given the past at any time, only one future is possible. (c) Given knowledge of all conditions and laws of our universe at one time, it is possible to predict its subsequent history. (d) Any state of our universe determines a unique future. (e) The totality of being determines uniquely every possible future state of that being.

Each of these descriptions highlights a different feature: causality, predictability, antecedent conditions, laws of nature, the state of the world, time, knowledge. Determinism comes in different forms: metaphysical, scientific (or physical), theological, logical, historical, and ethical. In this essay I restrict myself to metaphysical and scientific determinism. I show how metaphysical determinism underlies the notion of scientific determinism so that it is often difficult to distinguish between them. Statements (a)–(c) entail scientific determinism, while statements (d)–(e) entail metaphysical determinism. The metaphysical determinism of statements (d) and (e)—and (e) is a stronger and more controversial claim of (d)—can also be seen as a generalization of scientific determinism or scientific determinism as a special case of metaphysical determinism. Theological determinism will not be considered here.

A famous definition of metaphysical determinism is Richard Taylor's: ". . . in the case of everything that exists, there are antecedent conditions, known or unknown, which, because they are given, mean that things could not be other than they are" (Taylor 1992, 36). According to Taylor, the notion of determinism is rarely thought about consciously. It is mostly presupposed tacitly; certain philosophers (notably Immanuel Kant, following David Hume) thought of it as an a priori principle. "Thus, when I hear a noise I look up to see where it came from. I never suppose that it was just a noise that came from nowhere and had no cause" (p. 36). For Taylor, determinism is closely tied to the notions of cause and physical necessity, as distinct from logical necessity: "If determinism is true, then anything that happens is, given the conditions under which it occurs, the only thing possible, the thing that is necessitated by those conditions. But it is not the only thing that is logically possible, nor do those conditions logically necessitate it" (p. 42).

Another more technical description of determinism in terms of possible world semantics is John Earman's: Let W be the collection of all physically possible worlds, which means possible worlds that satisfy the laws of nature that hold in our actual world. The world $w \in W$ is then *Laplacian deterministic* if for any $w' \in W$, if w and w' agree at any time, then they will agree for all times. We have to notice that agreements of worlds means agreement on all of the relevant physical properties. A world is *futuristically* or *historically* Laplacian deterministic if for any $w' \in W$, if w and w' agree at any time, then they agree for all later or earlier times (Earman 1986, 13). Earman uses the term *Laplacian* but criticizes the famous example of "Laplace's Demon" to clarify the concept of determinism. The demon is capable of making accurate predictions from the present state of the world of what the future development of the world will be. This links determinism to predictability and, hence, to epistemic abilities: "Depending upon what powers we endow the demon with, we get different senses of determinism" (1986, 7). Earman argues that we should keep the *doctrine* of determinism apart from its *implications*. I agree with Earman on this. However, I also agree with John Dupré, who states that "stressing that determinism is fundamentally a metaphysical doctrine, and hence independent of whether or not we can make particular kinds of predictions successfully, should not obscure the fact that *evidence* for determinism will tend to come precisely from our ability to predict the course of events" (1993, 175).[2] So, even if we need to distinguish determinism from predictability, we still have to maintain that they are intimately linked.

Determinism and Science

Is the doctrine of determinism important in science? And if so, how important is it? I believe that some form of determinism is crucial for doing science. Determinism is basically the belief that there is a fundamental and unchanging order in nature, that this order is all-pervasive, and that we can understand it. Ontology and epistemology join hands in the struggle for knowledge. The order of nature basically is the main ingredient in the history of Western philosophy, science, and—most notably in the Middle Ages, under the influence of the Aristotelian view of the cosmos—in theology.[3] However, modern scientists are convinced that it is not so much rational reflection upon that order that gives us knowledge of it. Rational reflection is left to philosophers. It is through turning to the order itself, confronting it, penetrating it, and manipulating it by way of experiments that science gains knowledge and understanding: "To acquire facts relevant for the identification and specification of the various processes at work in nature it is, in general, necessary to practically intervene to try to isolate the process under investigation and eliminate the effects of others. In short, it is necessary to do experiments" (Chalmers 1999, 28).

However, all human knowledge is subject to error, and so is scientific knowledge. Hence, experimental results are recognized as fallible: they may become outmoded, sometimes they are simply rejected, and, as the history of chaos theory shows, they are often ignored as irrelevant (Chalmers 1999, 31, 37). This fallibility is one property that makes scientific activity critical and empirical. Fallibility seeks refinement, verification, and falsification, whereas empirical reality functions as the ultimate arbiter—at least in a naturalistic understanding of science (see Derksen 1999, 39). This means that experiments can and must be repeated; hence, repeatability is one of the basic demands of science (Derksen 1999, 52).

Underneath the method of experiment lies the belief in the intimate and stable connection between cause and effect: If I do this, that will be the effect, and if I repeat this experiment in exactly the same way tomorrow, the same effect will be the result. The doctrine of causality, and moreover the doctrine of the symmetry between cause and effect ("like causes, like effects"), was formulated by Hume: "Suitably to this experience, therefore, we may define a cause to be *an object, followed by another, and where all the objects, similar to the first, are followed by objects similar to the second*" (Hume [1748] 1999, 146).

As with causality, the stability and reliability of reality is also assumed in the methods of induction. As Hume pointed out in his analysis of causation, however, the method of induction cannot be justified merely by the appeal to experience. As with the connection between cause and effect, so with the connection between one or more observations or experiments and the belief that everywhere under the same conditions the same results will hold until the contrary is proven: this connection "which we *feel* in the mind, this customary transition of the imagination from one object to its usual attendant, is the sentiment or impression, from which we form the idea of power or necessary connexion. Nothing farther is the case. Contemplate the subject on all sides; you will never find any other origin of that idea" (Hume [1748] 1999, 145; cf. Ayer 1973, chaps. 7 and 8). Induction, therefore, is perhaps not ultimately justifiable on empirical grounds but is nonetheless a necessary ingredient of science. Without it no theory could ever be formulated, no law of nature be put into words.

And theories are necessary for translating experimental results into "maps" that help us find our way in the universe.[4] Like a little child in a crowded shopping center screaming for her mother because she is lost in a sea of running people without any fixed point of reference, so would we be lost in the universe without our "maps": the theories we build by way of the patterns we see in the things we find.

We see that experiment, repeatability, causality, induction, laws of nature, maps, models, and theories—ingredients of science as we know it—are based upon the deep-seated belief that nature remains structurally the same from moment to moment, that the experiment I conduct today will yield the same results under similar circumstances tomorrow, that similar causes will have similar effects, and that the future will not differ structurally from the present and the past. Moreover, underlying the epistemology of science is the belief that we can describe the deterministic order of nature wholly in terms of itself—that is, the explanations of natural phenomena and the causes underlying their occurrence are to be found within the realm of nature. Science, therefore, has no need for a supernatural causal factor for its explanations; and determinism, we can conclude, is a necessary ingredient for science.

Criticisms of Determinism

Some philosophers have found this view of determinism in science rather unsatisfactory. Philosopher John Dupré has recently formulated some criticisms of determinism. His objections are twofold. First, he argues that determinism is almost entirely without empirical support. An even stronger claim is that not only *is* there no empirical support but that there *could be* no *conclusive* evidence for determinism, for "determinism claims that there are exceptionless universal laws of nature. Notoriously, the truth of such laws cannot be empirically established" (J. Dupré 1993, 185). Basically, what we have here is the problem of induction: we can never definitely establish that the universal laws of nature are without exceptions. Moreover, in Dupré's thinking there is a kind of "holism"; he holds the view that if any area of the world should turn out to be indeterministic (and quantum indeterminacy might be a good candidate), "the determinism of all other domains is threatened by interaction" (p. 190). "Global determinism can obtain only if it is wholly isolated from causal interaction with objects whose behavior is indeterministic" (p. 187).

One might respond that this is a rather far-fetched argument, for it is a metaphysical belief that there is such a holism in our universe. Sensitive dependence on initial conditions and the exponential amplifications of fluctuations in chaotic and self-organizing systems do constitute good arguments for such a holism. But Dupré's holism, based on chaos theory, is ambiguous; it can be used both to defend and to attack determinism. Dupré uses it to attack determinism, but Wesley Wildman and Robert John Russell use it to highlight the other side of the coin:

> We can say without hesitation that chaos in nature gives no evidence of any metaphysical openness in nature. The fact that a natural dynamical system is open to its environment, which is sometimes described in terms of a whole/part causal relationship, does not entail metaphysical openness, for the entire environment may

be causally determined. . . . Put bluntly, the butterfly effect testifies to the high degree of causal connectedness in certain natural systems, and so is most naturally exploited in support of the thesis of metaphysical determinism. (Wildman and Russell 1995, 82)

Does this mean that chaos theory makes claims for determinism? That is something to be explored in the following sections. For now it suffices to say that the previous arguments for and against the use of chaos theory to establish determinism strengthen Dupré's point. These arguments testify to the fact that it is indeterminate whether or not determinism holds on scientific or empirical grounds alone—and this is exactly the point Dupré wants to make.

Dupré's second objection is that our most successful scientific theories describe a world that is probabilistic rather than deterministic. Quantum mechanics, thermodynamics, and strands of biology all operate with probabilistic rather than deterministic models. This means that "determinism is contradicted by the majority of our most successful scientific theories" (J. Dupré 1993, 189). If this is an empirical argument, it is inconclusive, for it does not say what causes this probability. If quantum indeterminism is true, this is a reason for using probability calculus to argue for indeterminism. However, another approach is to follow Hume, who states: "Though there be no such thing as *Chance* in the world; our ignorance of the real cause of any event has the same influence on the understanding, and begets a like species of belief or opinion" (Hume [1748] 1999, 130). Hume here argues, in the same vein as Laplace would some years later, that chance is merely synonymous with ignorance. If this holds true, Dupré's argument would be empirically inconclusive, for it might still be that our universe is deterministic, but we are (temporally or permanently) unable to take all of the relevant conditions into account, resulting in a probability calculus instead of a valid inference from cause to effect. Furthermore, that we are able to calculate probabilities already means that these phenomena are not completely random. Randomness would constitute an even distribution of chances; probabilities, on the other hand, display certain "preferences" of a system to develop in one way rather than another. This means that in probabilistic systems there is an underlying orderliness, although perhaps not as strong as in deterministic systems. Probabilistic is not equal to indeterministic and opposite to deterministic: chaos theory shows that determinism and indeterminism lie on a continuum.

Dupré anticipated this argument, and he has a counterargument ready. As he sees it, determinism is closely allied to causality. A *cause* he understands to be a sufficient condition for an event to occur. Because sufficient conditions can be determined only at a structural level, one needs to assume that reductionism and materialism are true and apply reductionist principles to determine the sufficient conditions. However, because both reductionism and materialism might be false, as Dupré argues (1993, 85–

167), the sufficient conditions can never be fully specified. In that case determinism fails. This is the crux of his criticisms against determinism: because reductionism and materialism are false, so is determinism (p. 192). However, I believe that Dupré's argument is ultimately unsuccessful. It may well be that reductionism and materialism would be necessary to establish determinism, but our inability to establish determinism does not preclude the universe's being deterministic. It very well may be, only we cannot know for sure. If Dupré's argument is taken not as an empirical but as an epistemological argument (strengthened by results from chaos theory), however, it might be a strong one indeed. Such an argument would posit that we can never attain complete knowledge to predict events with perfect accuracy; all we are able to do is calculate probabilities. I show later on how logical as well as physical arguments strengthen such an epistemological argument.

Another philosopher, Wesley Salmon, also links determinism to causality, but he describes the cause of an event as the set of all relevant conditions. "By a total set of relevant conditions I mean a set of conditions that cannot be supplemented in any way that would change the probability of the given outcome" (Salmon 1998, 43f.). This set of relevant conditions, which yields a probability that some event will occur, counts as the explanation for why the event occurred. "The explanation is . . . a representation of the conditions relevant to the occurrence of the event, and a statement of the degree of probability of the event, given these conditions" (p. 44). The ideal of deductive inferences of causes to events is replaced by a statistical account on the basis of relevant conditions. This approach to causation is different from Dupré's. For the latter the cause of some event is the set of sufficient conditions. Dupré seems to suggest that if all the sufficient conditions were known, one could actually infer with certainty the occurrence of the event. (But because we are never able to establish all of the sufficient conditions, all we have is probabilities.)

Salmon differs in that for him the total set of relevant conditions merely yields a *probability* that the event will occur. This more moderate view has gained some popularity in recent years. Be that as it may, I believe that Salmon's view is flawed. First, the designation *relevant conditions* is extremely vague. What is considered relevant is contingent upon a specific context. Furthermore, something is relative to our understanding at a certain moment: it is relevant "for all we know." What I think is relevant may not seem relevant to someone else. The management of the National Aeronautics and Space Administration in 1986 did not think that the arguments from the engineers for postponing the launch of the space shuttle *Challenger* because of some booster-rocket problems were relevant—a disastrous judgment. *Relevance* is therefore an ill-chosen term. Second, I believe that there is something fundamentally wrong with Salmon's description of explanations in terms of relevant conditions and probabilities.

In Salmon's view, the total set of relevant conditions yields a very high probability for the occurrence of some event. Take, for instance, the set of all relevant conditions for striking a match. In principle, we can calculate the probability that fire will be the result. Suppose that after the match is struck, a flame appears. May we conclude that specifying all of the relevant conditions is the explanation of the fire's having occurred? This would be a non sequitur, for all we can say is that we knew that the relevant conditions yielded a probability of, say, 0.9 that a fire would occur, so it is very *likely* that the fire was caused by the set of relevant conditions, but the fire might *actually* have been caused (though admittedly highly unlikely) by something else. Such an explanation does not give us the crucial information we want—that the set of all relevant conditions *actually caused* the fire to occur. All we can say is that it is *highly probable* that a fire would occur but that the fire actually may have been started by some hitherto unknown cause (perhaps spontaneous combustion). This example may look rather far-fetched, but still the argument is in favor of Dupré's points that we have no conclusive evidence for determinism—only probabilities.

A Special Case for Antideterminism: Chaos[5]

Specifically in theology, chaos theory is often interpreted so as to undermine claims for scientific determinism and, in so doing, to undermine metaphysical determinism in favor of an "open" universe.[6] Scientific and metaphysical determinism are, as we have seen, intimately related. Especially the unpredictability of chaotic systems and the apparent randomness of chaotic behavior are referred to in order to make scientific and metaphysical determinism seem highly implausible options. However, what exactly are the arguments for what I will call *antideterminism* based on chaos theory about? As I see it, four features of chaotic behavior are often involved. Let us first look at the arguments and thereafter investigate their force.

1. Because we can never know the initial conditions exactly but only by approximation, iteration (or feedback) processes will enlarge the errors rapidly until the system becomes unpredictable. This sensitive dependence on initial conditions has become most famous as the "butterfly effect."
2. The evolution of two systems whose initial conditions lie arbitrarily close to each other will diverge very rapidly, and after a limited period of time the behavior of the two systems will show no correlation whatsoever anymore. Errors in calculation also will grow exponentially. This argument is directed against Earman's possible world interpretation of determinism.
3. As some scientists have pointed out, the use of computers becomes a sensitive matter when it comes to chaos (Peitgen, Jürgens, and Saupe

1992, 49ff., 531–35; Stewart 1997, 357–82; Williams 1997, 214–17). Computing the same system (i.e., with *exactly* the same initial conditions) on two computers results in completely different evolutions. The reason for this is that every computer rounds off calculations of irrational numbers (such as the square root of 2) with only limited precision. The rounding-off procedure is necessary for reasons of time and memory capacity.[7] Computers have different kinds of hardware on which the rounding-off precision depends, and, as a result, the same initial conditions result in different evolutions on different computers. This leads to a dramatic conclusion: the question of what the *real* calculation of the chaotic equation is becomes meaningless. All we can say is that there is a plurality of calculations, and they all are approximations. We cannot ever know which is the real one.

4. The behavior of mathematical chaotic systems statistically is indistinguishable from data of a random system; qualitatively, then, one cannot make a difference between deterministic and random systems.

These arguments are valid with reference to the present state of chaos research. Whether they constitute a firm case against metaphysical and scientific determinism, however, is a matter of interpretation. Let us thus evaluate these arguments critically.

Concerning arguments 1 and 2: Sensitive dependence on initial conditions is indeed the foremost reason for the eventual unpredictability of a chaotic system, but one must remember three things concerning chaotic systems. First, there is a "horizon of prediction." It may be that ultimately a system may become unpredictable; yet, for a limited time span, it is possible to make fairly adequate predictions.[8] Prediction is not doomed to failure, only limited. Second, even though chaotic systems become unpredictable, this concerns only their detailed behavior. One can predict with certainty that chaotic systems eventually will land on a strange attractor. However unpredictable the precise location of a system on the attractor may be, one can at least be certain that it *is* somewhere on the attractor (and that it will stay on the attractor). So, even though one may not be able to make accurate claims concerning a system's detailed behavior, one is certainly able to make claims about its general behavior.

Third, even though chaotic systems become unpredictable, at heart the system is utterly deterministic (hence the expression "deterministic chaos"), for the system is ultimately governed by an underlying equation. This means that the evolution of a system is fixed: the iterative steps following each other could not be other than they actually are; the whole future of the system lies already in the initial conditions. It is merely unfortunate for us that our capability of knowing these initial conditions is limited. This means, consequently, that sensitive dependence is not enough to attack Earman's possible world interpretation of determinism. Earman states that two possible worlds with exactly the same initial conditions will evolve in an exactly similar way. This still holds in the case of chaotic phenomena. The only trouble is that in practice we are never able to determine whether two systems have exactly the same initial conditions; all we can say is that we are not able to determine differences in their respective initial conditions. Therefore, if two apparently similar systems diverge, we have to conclude that the initial conditions were not exactly the same. Sensitive dependence on initial conditions and eventual unpredictability may be real phenomena, but they do not constitute enough of an argument for undermining determinism.

Concerning argument 3: It may be that the use of computers has limits. This does not mean that computers are therefore useless in prediction. Without computers we would not be able to calculate chaotic equations at all; it is only with the development of computers that scientists have become able to study chaotic behavior. Furthermore, so-called *shadowing lemmas* state that, within a certain margin of error, computer calculations remain so close to the original trajectory that one can make reliable statements concerning the qualitative behavior of a system. Structurally the computed trajectory is a close enough approximation of the original trajectory: it is its "shadow" (Peitgen, Jürgens, and Saupe 1992, 576–80; Smith 1998, 58ff.; Verhulst 2000, 223).

Concerning argument 4: It may be true that statistically there is no qualitative difference between a random system and a chaotic one. Yet, an analysis of a time series or a reconstruction of the attractor may well point out that the system is chaotic. A *random* process is after analysis "symmetrical"—that is, there is no structure in the distribution of points in a two-dimensional plane onto which these points are mapped; the points are evenly distributed over the entire plane. A *chaotic* process after analysis is "asymmetrical"—that is, it shows a definite structure in the two-dimensional plane. If there appears a structure of which the dimension is smaller than the dimension of the plane, these are genuine reasons for there being a deterministic lawfulness underlying the behavior of the system (Broer and Takens 1992, 56; Stewart 1997, 350; Verhulst 2000, 221f.).

We may thus conclude that arguments for antideterminism can be countered by arguments for determinism: an appeal to chaos for attacking determinism is inconclusive. We must take care, however, not to be too impetuous in drawing conclusions. It may be that the former conclusion yields for *mathematical chaos* (that is, chaos in mathematical models). It is quite another thing to talk about *real-world chaos,* chaos as it occurs in our empirical world. The mathematical models are very "clean" in the sense that they are devoid of noise: they are idealizations. The uncertainty considering the initial conditions is a result of these idealistic models' being calculated by our real-world, and therefore limited, computers. In real-world data there is always some noise; furthermore, establishing the precision of initial conditions, and thus of prediction, is already a major problem in mathematical models. However, in the empirical world there is an even more critical problem concerning how precisely we can know the initial conditions. The problem of determinism in the real world depends on whether infinite knowledge is a practical feasibility. The majority of scientists are convinced that infinite knowledge is needed but is an illusion for finite beings such as we are. On the other hand, scientists also discovered that many real-world phenomena display behavior similar to mathematical models of chaotic systems. One could say that mathematical models are approximations of real-world phenomena or, alternatively, that reality approximates mathematical (idealistic) models (Broer and Takens 1992, 36), but this implies that, although real-world chaotic systems are not predictable, there may in fact be a deterministic orderliness underlying these systems.

A Methodological Distinction

For this reason, I argue for a distinction between determinism in principle and indeterminism in practice. A chaotic system is deterministic in principle in that every state of the system follows necessarily from the former. Iterating a chaotic equation is a highly deterministic process. However, we need to bear in mind that such an equation is a mathematical model, an idealized simulation of a system that resembles but abstracts from real-world systems. When we proceed from the model to the real-world system, things change dramatically. No longer is a computer adequate for determining the actual history of real-world systems. We can neither know the precise initial conditions nor oversee and predict in our everyday world the way in which causal chains intersect. This we call chance.[9] The role that chance plays in our world increases the likelihood that we can never attain complete knowledge of the initial conditions. Every event in our universe relates eventually to the whole of the universe; this is what "sensitive dependence on initial conditions" means. If someone wanted to have precise knowledge of the initial conditions of a real-world event, she would need instantaneous and complete knowledge of every atom in our universe, of its position and velocity, and of every rule that nature plays by—i.e., all of the relevant laws of nature. Human beings, with our finite and limited capacities, would never be able to achieve this. Even if we could, we would not have the capacity to calculate as fast as the universe evolves.

We have arrived, then, at an important point: Although some systems in our universe, and even our universe itself, may be deterministic in principle, we can never know for certain. We may know the rules by which our universe plays (such as natural laws and fundamental constants), but in practice we will never be able to predict the exact outcome or determine every cause of a natural event. Our universe simply is too complex. This means that our universe as a whole and most systems within it must be seen as indeterministic in practice. We must be mindful of the distinction that the claim of determinism in principle is an ontological claim, referring to the structure of the system, whereas indeterminism in practice is an epistemic claim, referring to our limited capacities of predicting and explaining the behavior of the system.

Physical and Logical Possibilities of Predictability

Considering that chaos theory and the epistemological problems of unpredictability result from an incomplete knowledge of the initial conditions of a system, one may well ask whether this unpredictability is due to human limitations or whether a finite being might be able in principle to predict the future of the universe. Might it not be that in the future a highly powerful but still finite supercomputer would be able to predict real-world chaotic systems like, for instance, our weather? Let us consider this intriguing question.

What would be needed for such a calculation is, first, instantaneous knowledge of every object in our universe, from the microrealm of quarks and bosons to the macrorealm of human beings, birds, trees, and galaxies. This means instantaneous knowledge of every position, velocity, direction, and mass of every object the universe consists of. Also needed would be instantaneous knowledge of every rule nature plays by: laws of nature, fundamental constants, and so on. Further, we have to assume that our universe is finite, for finite beings cannot have infinite knowledge.[10] What would be the use of such knowledge? If our universe is perfectly deterministic, having complete knowledge of the whole universe at a certain moment, t_n, would be sufficient to predict the state of the universe at the next instant, t_{n+1}.

Now, the crucial question: Is it possible that a finite entity such as a supercomputer could predict the future? *Possibility* is a tricky word, for it can mean many things in different contexts. Many philosophers distinguish between physical and logical possibilities. Physical possibilities are related to what is possible within the margins of the laws of nature. Logical possibilities are less limited and can be described as possibilities that do not result in a contradiction; logical (im)possibility “typically issues from the very nature of the concepts involved, and is not beholden to the laws of nature. It is logically possible for the laws of nature to be very different from what they actually are” (Sainsbury 2001, 15). Instantaneous complete knowledge of the universe is physically impossible for humans to acquire. Our cognitive abilities are limited, and we do not compute nearly as fast as contemporary desktop computers do. Neuroscientists say that this is due to the wiring of our “hardware,” the human brain. However, there are three other physical problems that are not the result of human limitations but are related to the physical structure of the universe itself. Nature itself limits complete and instantaneous knowledge of the universe, for to know the velocity, position, and direction of every object in every part of the universe (metaphorically speaking, from one edge of the universe to the other) at one instant, we would need to be able to transport information with a speed that far exceeds the speed of light. The principle of locality—that nothing can travel faster than the speed of light—forbids this. Furthermore, the energy needed for such a speedy transport of information would exceed the complete quantity of energy available in the universe. Finally, the indeterminacy that may be present at the quantum level (according to some interpretations) would limit the complete knowledge of the smallest particles. So far, physical limitations prevent human beings from having instantaneous and complete knowledge of the initial conditions of the universe.

But what about logical possibilities? Let us explore these by way of a thought experiment.

A Thought Experiment

Imagine an alternative but perfectly deterministic and finite world in which humans are able to build a computer that spans every part of the universe, from edge to edge, and that is able in an instant to know fully what is going on in that universe. Assume that this world is completely Newtonian—i.e., composed of discrete building blocks, whatever these might be.[11] Assume further that there is no limitation set by the speed of light and no quantum indeterminacy (because these conditions would defeat our thought experiment in advance on grounds previously mentioned). So, information from every part of the universe is immediately available for computation. Would this supercomputer—call it the "Laplace Machine"—be able to predict from the state of the universe at t_n what will happen exactly at t_{n+1}?

To be certain, to say that humans—or whatever finite beings—created this Laplace Machine implies that the machine would be material and therefore finite. It would be finite in the sense that it is subject to (Newtonian) laws that pertain to the matter and energy out of which the machine is built. Moreover, it would be as finite as the universe is.

Let us make the case even stronger. Suppose further that the Laplace Machine is *all-present* at all the different levels of the universe, from the micro to the macro levels of reality, and that it *knows everything* with regard to the inner structure and workings of the universe immediately even though it is a finite machine. Would this yield the ultimate predictability we are looking for?

As far as I can see it, the answer to this is no. I do not see how such a Laplace Machine could even begin to calculate the data of the universe. I said that the machine is finite. However powerful it is in relation to our strongest present-day computers, it still is finite in the sense that it is made out of finite materials: matter and energy. In order to compute all of the data of the universe it would have to take into account all of the finite elements in that universe—that is, all existing matter and energy. However, because the machine is itself finite and part of the universe (that is, built from matter and energy), it has to take itself into consideration, too. In calculating all of the physical data of the universe, the machine, which is a part of the universe, has to take its own material inner workings and physical configurations (let us call it the *brain-state*) at t_n into account.

In order to take this brain-state into account, the machine actually has to go up one level, has to "step out of itself" to look at the brain-state from a higher level, say, L_1. But we said that the machine is wholly part of this universe. Consequently, this metalevel has to be located in this universe as well. For the machine to predict the future, it would have to take into account the brain-state *and* the metalevel brain-state L_1—which means that the machine would have to go up, calculating on a meta-metalevel, L_2. Subsequently it would have to take this level L_2 into consideration on L_3, and so on ad infinitum. The result would be an infinite regress of levels. An analogue is the human stream of consciousness. I cannot look at my stream of consciousness but from some higher level; I can *reflect on* my stream of consciousness only by adopting a metaposition.

Is it possible to avoid this infinite regress by staying on the same level? In that case, the machine's working would constitute a closed system. This would lead to a feedback loop. By taking into account its physical brain-state at t_n, the Machine actually *changes* its brain-state at t_{n+1}. It then has to reflect on that changed brain-state of t_{n+1} at t_{n+2}, by which it alters its brain-state again at t_{n+3}. This results in an infinite feedback loop. To press the point, because the Laplace Machine is inside the system and even part of the universe itself, its efforts to predict the future of the universe interfere with what is actually going on in the universe.

The problem has an analogue in the human brain. Suppose we were able to show the inner workings of our brain on a video screen. Because my looking at the screen would alter my brain-state, I could not inspect my present brain-state without actually changing it. The argument turns into a vicious circle, perhaps not all that different from the outcome of the famous incompleteness theorems of Gödel (see Rucker 1995, 157–88; Nagel and Newman 1959; Lucas n.d.; 1961; 1970, 124–66). We can never "step out" of our brains, as the Laplace Machine can never step out of the finite universe. Whatever action the Laplace Machine undertakes, it ends in either an infinite regress of levels or an infinite feedback loop.[12]

Immanence and Transcendence

It follows from these arguments that on physical as well as logical grounds a finite being like our Laplace Machine can never have enough knowledge of our universe for prediction. For this would entail that the Machine not only have complete knowledge of all the workings of our universe but also that it must take its own brain-states into consideration, and this must result in an infinite feedback loop. Nor would such a being be able to predict chaotic systems, because for this, infinite precision is necessary.

We then might consider the alternatives. Supposing that our universe were deterministic, what entity would be capable of predicting its future? To avoid the already-mentioned problems, it would have to be an infinite being that is both omnipresent and omniscient but not part of the physical universe itself. *Infinite* in this context means "not being constrained by the limitations of the physical and therefore finite universe." The infinite being would have to be somehow present in every element of the system, for it would need instant knowledge of all there was to know in the universe. It also could not be a material part of the universe itself, for that would lead us back to an infinite-regress argument. To be able to predict from the present state of the universe the next state would therefore require a being that is (a) immanent in the universe (omnipresent and all-knowing) and (b) transcending the universe in some way or other. *Transcendence* might for now be defined as "not coinciding with the physical universe."

These properties are compatible with the Being that is worshipped in the Christian tradition, namely, God. Classical doctrine sees God as the creator of the universe. Such creatorship entails that God created the universe but is not subjected to or limited by that creation.[13] God is "above" creation, and this is expressed by the claim that God is transcendent. At the same time, it is said that God is present in or proximate to the creation, and this is expressed in saying that God is immanent. As immanent and transcendent, God is spatially present to all created entities without coinciding with created reality (Van den Brom 1990, 91f.).[14] As such, God might be able to predict the state of the universe at t_{n+1} from the state of the universe at t_n. We have to understand further that the predictions God is able to make differ from human predictions. The workings of the human mind are *discursive,* meaning that it has to "consider things one after the other, making connections by inference and extrapolation, and moving from one element to another in succession" (Ward 1996, 32). On the other hand, God's mind might be *intuitive* in that it is able to "understand all things in one intuitive, nondiscursive, act. God does not need to infer or extrapolate, since God knows everything in its full particularity by immediate apprehension" (Ward 1996, 32; cf. also Van den Brom 1990, 130). In this sense God does not need to make one inference after the other, as humans do, but apprehends immediately at t_n what will happen in the next instance t_{n+1}.

It follows that a God that would be identical to our universe, as in pantheism, would not be able to predict the future of the universe, for such a God would be finite if our universe should turn out to be finite; this would run into the trouble of infinite regress or a feedback loop. A fully transcendent God—that is, a God located "outside" our universe—might be able to predict the future of the universe of the Newtonian possible world, given that limitations of the speed of light or quantum indeterminacy do not exist. Such a fully transcendent God would not be able to predict the future of our actual universe, however, because of the natural limitations just mentioned that are present in our universe. Thus, a fully transcendent all-knowing God making accurate predictions of a deterministic universe would be a logical possibility given the conditions inherent in the possible world of our thought experiment, but not a physical one.[15] A pantheistic all-knowing God is physically as well as logically implausible. It is not a logical impossibility, for we defined *logically possible* as not resulting in a contradiction. An infinite regress is no logical contradiction, although it is to our minds not a satisfactory solution and hence implausible.

We have therefore arrived at the following conclusion: for a truly omnipresent and omniscient deity to be able to predict the history of a deterministic universe would require that deity to be at the same time immanent and transcendent. The classical Christian doctrine of God and metaphysical determinism are therefore compatible from a logical point of view.

The question might arise, however, of whether this compatibility is also theologically tenable. One could come up with plausible theological arguments that God as creator has endowed creation with a certain freedom, independence, and capability of self-support and would thus voluntarily self-limit for the benefit of the creation. The freedom of creation is a necessary presupposition if human beings are to respond freely to God's invitation to be in relationship. The details of such theological arguments will not be dealt with here.

The Claim to Determinism Is a Metaphysical Claim

The crucial assumptions in the preceding argument were that our universe is (1) finite and (2) completely deterministic. However, recent cosmological findings suggest that our universe is infinite both spatially and temporally.[16] (This would lead naturally to a reconsideration of what *transcendence* actually means, but I will not take up that question here.) The second assumption involves a metaphysical issue that finite beings such as we are cannot resolve. If quantum indeterminacy were to remain part of the theories that deal with the smallest elements in the universe, it would constitute an argument for indeterminism at the smallest level. If this indeterminism turned out to be ontological—that is, part of the basic structure of the universe—this would yield an argument for the notion that God's knowledge also may be self-limited, supporting a theological case for the freedom of creation.[17] However, if, say, string theory were able to delete quantum indeterminacy from the theories, the physical question of quantum indeterminacy might be resolved, but that would leave the metaphysical question of determinism unaffected and still open. It might be that the question of determinism or indeterminism will be solved on the microlevel, but for the universe as a whole the question would remain open. Even if there turns out to be ontological indeterminism at the quantum level, this indeterminism might (contra Dupré) be strictly limited to the quantum realm, with no consequences for the rest of the universe.[18]

We thus arrive at the following conclusions: We, as finite beings, are incapable of determining whether or not the universe is completely deterministic, and therefore the epistemological question remains unanswered. Whether the universe is *ontologically* open or not is quite another story, but this too we can never know. The scientific presupposition of determinism can therefore reasonably be dubbed "metaphysical." However, as we have seen, this presupposition is necessary for the practice of science, so we cannot dismiss it too easily. I do not claim that we can do without science. It may be that all human knowledge is subject to error and that scientific knowledge is not excluded from this fallibility. Science, like all human activities, has its limits. However, I believe that science is still our best way of gaining knowledge of the world. Its methods are such that we can check systematically whether, and where, we have erred. That is the reason why criticism is crucial.

Be that as it may, the conclusion that scientific determinism is metaphysical is a statement that should make philosophers and theologians alert and suspicious concerning overly strong scientific claims. As I have tried to show, for science to claim that acts of God are disturbances of the natural order is a non sequitur, for we cannot know whether this claim is true. We do not have, nor can we ever have, complete and instantaneous knowledge of the whole universe. The most we can do is calculate probabilities. Therefore, we can neither logically nor physically exclude the possibility that God has acted somewhere in our universe and will do so again in the future. If the only knowledge we can attain is statistical, we can neither determine nor exclude an exception or an occurring event as an act of God. For all we know, God's action *is* the statistical means: a regularity that neither necessitates nor excludes exceptions to the regularity. In that way God could be said to be reliable and consistent: God is bound by the regularity he created, but within a certain margin (that is, leaving the probabilities intact) God is free to deviate from it (cf. Colwell 2000; Stewart 1997, 350).[19]

INDETERMINISM?

Is it then best to conclude, on the basis of our findings, that indeterminism is actually the metaphysical position to be preferred? This also would constitute a non sequitur, for three reasons.

First, this metaphysical position would leave behind every scientific achievement up to today and render meaningless every a priori scientific claim. If there are no regularities to be discovered, every scientific finding is the result of a chance event and bears no further consideration. This position, however, is not very plausible, and I believe we must conclude that the success of science is not a result of mere chance.

Second, it does not follow that the only alternative to determinism is indeterminism. As I stated earlier concerning chaos and probabilities, determinism and indeterminism are on a continuum; the extremes of this scale are not the only alternatives.

Third, as far as we know, our universe is not indeterministic in the sense that there are events which have no cause (except for the realm of quantum mechanics, but as yet we do not know how this microrealm relates to and influences the macrorealm of everyday life). We do not live in a universe of total disorder, nor could we. If everything changed according to random chance events, we would have to adapt as rapidly as the universe evolves. We would be doomed to extinction. As with determinism, there is no conclusive empirical evidence for indeterminism. The evidence for determinism or indeterminism is at best ambiguous.

CONCLUSIONS: THE UNIFORMITY-OF-NATURE PRINCIPLE

How, then, should we see the order inherent in our universe if not in a deterministic way? I believe that the recent sciences of complexity have revealed to us the self-organizing potential of matter, and this may yield a new perspective on the order of nature that is both scientifically plausible and capable of theological interpretation.

From the Pre-Socratics on through the Middle Ages and up to today, people have been impressed by the orderliness of nature. In theology this order can be related to the God of Israel, the Creator and the God whom Jesus addressed as “Father.” The reliability of this order mirrors the reliability and trustworthiness of God. It would be foolish and, moreover, theological and scientific suicide to abandon this orderliness. However, this does not mean that this order is as static and rigid as it was seen in the seventeenth and eighteenth centuries: our universe is not a machine. It is a realm of law and probabilities, of chance and necessity, of becoming and potentiality, of alternatives in the making. Nature has a uniformity that is not static and deterministic but self-organizing and probabilistic. This uniformity is tacitly assumed by science: it is a regulative metaphysical principle (cf. Nagel 1961, 316–24, 605f.). I call this the uniformity-of-nature principle. According to this principle, nature has laws but leaves room for alternative developments. We live in a self-organizing universe that balances “on the edge of chaos.”[20] Both static, rigid order and complete randomness and disorder would lead to certain death. But a world on the edge of chaos is a place where complexity arises from relatively simple building blocks, where chaos creates an infinity of patterns, and one never knows what will happen next. It is a universe that brings forth life and consciousness: it is a created and creating universe.

Are we, or is life in general, a product of self-organizing processes in the universe, or are we created by God? It is not a matter of either/or but of both/and: to answer requires a shift of perspective. From the perspective of science, life is a product of self-organizing principles of the universe; from the perspective of theology, we are created in the image of God. We are children of the universe, *and* we are children of God. This means that we cannot find God's signature in the empirical world. The statement that this world is created by God is a claim made by faith and is incommensurable with a scientific statement, hypothesis, or theory.

Whether or not our universe is ultimately deterministic we will never know; it is also a question that is irrelevant for our everyday life. As the meteorologist and chaos pioneer Edward Lorenz states, "Let our premise be that we should believe what is true even if it hurts, rather than what is false, even if it makes us happy. We must then wholeheartedly believe in free will. If free will is a reality, we shall have made the correct choice. If it is not, we shall still not have made an incorrect choice, because we shall not have made a choice at all, not having a free will to do so" (Lorenz [1993] 1995, 159f.). All we can do, and we have good reasons for it, is trust in God, who wants a relationship with us. A relationship presupposes freedom of choice and independence, not manipulation, predestination, or some other form of theological determinism. In the end we are free to decide whether we want to relate to or deny God.

NOTES

1. This section relies heavily upon Audi 1995, 197f., 280–82; Cahn 1995; Dray 1967; J. Dupré 1993, especially chaps. 8 and 9; Earman 1986; Honderich 1995, 194–97, 270; Popper 1982; Salmon 1998; Sklar 1995; Suppes 1984; Taylor 1966; 1967a, b; 1992, especially chaps. 5 and 6; and Weatherford 1991.
2. Compare also the statement by Patrick Suppes (1984, 31f.): "The real test of determinism is predictability. Phenomena that we cannot predict must be judged random. Most of us feel, however, that this is probably too stringent a criterion without qualifications of various kinds." The latter remark prevents Suppes from falling into a false-dilemma fallacy.
3. Studies that emphasize this aspect of the order of nature and the rise of modern science include L. Dupré 1993; Funkenstein 1986; Grant 1996; Lovejoy 1936; Wildiers 1973; 1988.
4. I owe the metaphor of theories as maps to Stephen Toulmin (1953, chap. 4).
5. This section is based on Broer and Takens 1992; Davies 1989; Kellert 1993; Peitgen, Jürgens, and Saupe 1992; Smith 1998; Stewart 1997; Verhulst 2000; Williams 1997.
6. This strategy seems especially popular with theologians. See, e.g., Clayton 1997; Ganoczy 1995. That chaotic behavior is actually indeterministic is a view made popular by John Polkinghorne (e.g., 1998).
7. For details concerning rounding-off procedures written in understandable terminology, see Petzold 1999, chap. 23.
8. The weather, for example, is a chaotic system, but it is nonetheless possible (at least most of the time) to make fairly accurate predictions for three to five days in advance. The "horizon of prediction" for our weather lies ultimately between one and two weeks.

9. Arthur Peacocke makes a distinction between two meanings of *chance*: (1) a recognition of our ignorance of the multiple parameters involved in some situations, and (2) the intersection of two otherwise unrelated causal chains (1997, 90). He concludes, "when, in ordinary parlance, some event is said to be 'due to chance' this phrase is really not giving an explanation of the event in question or saying what its cause is, but is simply acting as a stop card. It is saying in effect 'the event in question has many multiple causes, or seems to have been the result of the intersection of unrelated causal chains, so that we cannot attribute any *particular* cause to it'" (p. 91).

10. This is a logical problem as well as a physical one. As many mathematicians have pointed out, the logic of infinity is different from the logic of finiteness (see, e.g., Rucker 1995). In (contemporary) mathematics, the notion of infinity may be well respected, but an important philosophical question that remains unresolved is: If humans as finite beings cannot have infinite knowledge, can they have knowledge of the infinite?

11. "Theorem I" (from Suppes 1984, 18) is in this case applicable: "Let two systems of mechanical particles be such that the particles have the same masses, the forces acting on the particles are the same, and for some time *t* the positions and velocities of identical particles in both systems must also be identical. In other words, the trajectories of the particles throughout time are wholly determined by their positions and velocities at some one instance and by the forces acting on them." As Suppes notes, this theorem depends on the absence of collisions. Collisions would be chaotic and hence unpredictable, as chaos theory has recently discovered, as in the case of billiards. A Newtonian world without collisions is completely deterministic and highly predictable and, unfortunately for some, a fiction.

12. Compare this argument with that of William Poundstone (1991, 239–63, especially pp. 257ff.). Another example of systems' exhibiting infinite regress is in economics. When economists try to predict the market, they actually influence that market by their predictions. Accurate predictions are impossible in such a situation, for such predictions need to include the consequences of such predictions, and the consequences of those consequences, and so on. These arguments also are relevant in the context of a "theory of everything" that is seriously considered by some scientists. As systematic theologian Luco van den Brom has made clear, a theory of everything that explained everything in the universe would also have to explain itself. This, however, runs into the difficulties implied by Gödel's theorem (see Van den Brom 1995, 61f.).

13. It is conceivable, however, that God voluntarily self-limits divine power and knowledge to make room for creation to exist and make free decisions.

14. Van den Brom conceives of God's extensiveness in space in terms of (an infinite number of) higher dimensions of reality (1990, 98–101; 1993).

15. Note the phrase *given the conditions*. One could, I admit, argue the possibility that God is the creator of our universe and therefore the creator of the laws and limits that hold in our universe. But that would not make God himself subject to or limited by those laws; as creator God would be "above" these laws and limitations. So the limitations of quantum indeterminacy and the speed of light would not hold for this fully transcendent God. If this held, such a view of God would be logically *and* physically possible.

16. See *Scientific American* 2001 for some more popular articles about recent cosmological findings and their possible implications. See also Livio 2000.

17. The idea that ontological indeterminism indeed (self-)limits God's power and knowledge is very popular in contemporary religion and science. It is used by Peacocke ([1990] 1993; 2001), Polkinghorne (2000, 105–29), Ian Barbour (2002, 108, 101–17), and John Haught (2000, 109–11). See also Polkinghorne 2001 for a collection of articles on kenosis by various authors.

18. This is suggested by Nancy Cartwright's idea of the universe as a "dappled world." Cartwright calls her position "metaphysical nomological pluralism" and describes it as "the doctrine that nature is governed in different domains by different systems of laws not necessarily related to each other in any systematic or uniform way; by a patchwork of laws" (Cartwright 1999, 31). The idea is that nature is "carved up" into different autonomous domains, each of which is governed by its own set of laws that are applicable only to those specific domains, not universally to other domains. As Nicholas Saunders notes, similar ideas are entertained by Peacocke, especially regarding Peacocke's notion of a hierarchy of levels (cf. Saunders 2002, 211ff.). However, the consequence of a dappled-world view is that the indeterminism inherent in the quantum realm (according to many interpretations) may be valid *only* at the quantum realm and may not be extendible to the rest of the universe.

19. Ian Stewart states that a random system ought not to exhibit any patterns at all, not even on average. The probability of something's occurring therefore indicates the presence of some underlying "mechanism." In Stewart's terms, the presence of probabilities indicates that the system is "deterministic." Stewart does not define this notion of determinism further, but his understanding of the term clearly differs from the statements we have given; it is not rigid but rather leaves room for the possibility of different outcomes.

20. The phrase "edge of chaos" was coined by complexity scientist Norman Packard (cf. Lewin 1992, 44–83).

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