Review

Reviewed Work(s): Explaining Chaos by Peter Smith

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alive and kicking.

One last word. An issue that philosophers of religion have often overlooked is the historical claims that some religions make, especially Christianity and Islam. Many Christians, for instance, hold that the central evidence for their faith is neither cosmological nor teleological, but historical, and that the best available reason we have for theism itself is the evidence that God became human in Jesus. In parallel with this, I believe many Muslims would say that the Q'uran is the clearest sign there is of God's existence. Haldane distinguishes arguments for *theism* from arguments for *Christianity*, but still sees the importance of the issue: see his pp. 202 ff., and compare Smart's remarks on New Testament criticism (pp. 60 ff.). For those of us who think that religious beliefs are either historically based or else not based at all, it is gratifying to see philosophers seriously airing the historical issues for once—even if neither author enters the lion's cage by evaluating the historical evidence not only for Christianity but for Islam too. (A good recent book on New Testament criticism—which tends incidentally to undermine Smart's scepticism about whether such criticism could support Christianity—is another exchange between scholars of differing views: Marcus Borg and Tom Wright, *The Meaning of Jesus* (SPCK, 1998).)

At this stage in history, it's hard for a book about God's existence to come across as a must-read (unless you're paid to do it). By that stringent test, this book is unusually successful. The authors are to be congratulated on producing a remarkable and valuable book.

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Explaining Chaos, by Peter Smith. Cambridge: Cambridge University Press, 1998. Pp. viii + 193. H/b £37.50, P/b £12.95.

Chaos theory spells the end for determinism, the demise of reductionism, and the death of prediction; it is the dawning of a law-less, anti-Cartesian, holistic science, one making room for genuine creativity and free will. Well, no. These declarations, and others like them, are either plainly false or grossly exaggerated, as Peter Smith demonstrates in *Explaining Chaos*. His book is a skilled philosophical commentary on chaos theory, proving that it is of a piece with dynamical systems theory in general: no more, no less. Chaos theory, he admits, introduces few philosophical problems not already present in mathematical modelling of dynamical systems. *Explaining Chaos* does more than debunk overstated claims, however. The modelling of dynamical systems is philosophically very challenging, and its chaotic aspects particularly highlight its interesting features. Chaos theory is the perfect context to discuss questions of scientific explanation, modelling, approximate truth in science, randomness, the limits of prediction, and so on. It is these topics upon which Smith concentrates. The book is therefore a kind of case study in general philosophy of science, one hoping that chaos will help illuminate problems in philosophy of science and vice versa.

The book is very much written for a philosophical audience. It should not be confused with the multitude of popular science books explaining chaos. Here the reader will encounter topics such as approximate truth and Miller's problem, explanation, anomalous monism, and even semantic supervaluationism—hardly the standard fare for the typical book on chaos! That is not to suggest that the book is all philosophy and no science. Perhaps almost half of the book is devoted to explaining the science of chaos. Thus the reader is introduced to many of the paradigmatic chaotic systems, e.g., the Lorentz model, and their properties, e.g., bifurcations, period-doubling. The more taxing sections are set off from the main text and are interspersed throughout. The non-expert reader can therefore chose a better or lesser understanding of (say) fractal dimension when reading about fractals, depending upon whether she chooses to pause the main story and read the fractal dimension box. The science is typically explained very neatly and enthusiastically.

Explaining Chaos is divided into ten chapters organized around a central question. The question is, how can anything as seemingly unrealistic as chaotic models be used to represent systems in the world? This question develops over the first three chapters, and the next seven elaborate on different aspects of the answer. Along the way, we are treated to more exposition of the science of chaos and many side issues in philosophy.

Chapter one introduces the Lorentz model, a model devised to explain convection in the atmosphere, and displays its various features (confinement, sensitive dependence, aperiodicity). Turning to fractals in chapter three, Smith describes their mathematical features, noting the infinite intricacy of mathematical monsters like the Cantor set. He argues, plausibly, that its hard to see how any piece of nature would require a fractal to represent it, when a finite prefractal would always seem to do the job just as well. But now we have a problem: the strange attractors of chaotic systems require this fractal geometry.

The problem is a general one, not particular to chaotic systems, and it is worthy of attention. Chaos theory idealizes nature, to be sure. But at least at first glance, it idealizes nature the wrong way round. Frictionless planes and such examples *leave out* 'irrelevant' detail; chaotic models *add* 'irrelevant' detail. They model real-world systems with infinitely intricate geometries in state space that no real system's temporal evolution could possibly follow. Yet despite all this 'surplus structure' scientists appear to use these models to describe, predict and explain physical behaviour. How is this possible?

After some discussion of this question in chapter three, Smith develops an answer in chapters four, five, and seven, which discuss, respectively, how these models predict, how they can be approximately true, and how they can explain. Chapter six is an interlude on more mathematical issues, discussing, for instance, the claim that 'period three' implies chaos. The remaining three chapters tackle the related questions of the empirical success, if any, of chaos models (chapter eight), the topic of randomness (chapter nine) and the definition of chaos (chapter ten).

There is a lot that will interest philosophers here. Smith argues, contrary to some, that chaos requires no fundamentally new notion of explanation, that chaotic models do not have poor predictive ability, and that there is no one best definition of chaos. He proposes a solution to Miller's problem for close-tracking accounts of approximate truth. The discussion of randomness is informative and stimulating. The book is also filled with small side notes on peripheral issues, for instance, chaos and psychology, reductionism, and many mathematical topics.

The heart of the book is the answer to the problem of explaining how models as odd as chaotic ones can serve science successfully. His answer appeals to two broad strands. One is simplicity. He believes the simplicity of the models might well compensate for their empirical mismatch. The problem is then to characterize the respects in which chaotic models are simple. The other is approximate truth. He argues that a dynamical model is approximately true just in case the geometric structure of trajectories in the model is sufficiently close to the structure of trajectories in the world. They especially have to resemble each other in the key respects that the theory is concerned to describe. For one theory, actual match of trajectories over some local range may be more important than a rough match globally; for another theory the match might not be as important as the existence of the same critical points. No doubt there is a lot right about this general answer (which I haven't done justice to by any means).

But I do have my reservations about it. It is of course true that in mathematics there are often very precise measures of how close two geometric structures are. For example, the codimension states in some sense 'how far' a function is from being a Morse function (a smooth function with only nondegenerate critical points). Smith seems to think that once we've identified the appropriate interests, the math will just take care of itself in determining how close two geometric structures are. But perhaps it's worth emphasizing just how tricky and disturbingly interest-relative this will be. First off, the relevant math to determine the similarity between two structures just might not exist. Not much is known about certain types of functions and geometric structures. Assuming the math exists, consider how difficult matters are even for an extremely simple function, the curve $f(x)=x^3/3$. Suppose it represents the real world values for some parameter of a bridge. It has a single degenerate critical point at the origin. The curve $g(x)=x^3/3+1x$, however, has no critical points, yet the curve $h(x)=x^3/3-1x$ has two nondegenerate critical points. Which one better tracks $f(x)$? Maybe neither do, since perhaps the degenerate critical point was important, in which case we might go with some member of the family $\frac{1}{4}x^4+\frac{1}{2}ax^2+bx$. Assuming degeneracy isn't crucial, we have to decide whether nondegenerate critical points are to be weighted more than perfect matching. But these choices are not all-or-nothing: some other curves with two critical points will be wildly mismatched with the actual curve. Presumably too much mismatch will trump having the right number of critical points, if critical points are what is important. We need an extremely complicated similarity metric, one derived almost entirely by our interests. But should it really be the case that an ontological notion, approximate truth, should hang so much on pragmatic factors? Such contextuality certainly sits awkwardly with a realist conception of verisimilitude.

Smith claims that his answer is better than one whereby we deem a dynamical theory to be approximately true when it differs by small modifications from a true theory. He has two complaints about such theories. First, what counts as a small modification? Fair enough. But doesn't his proposal suffer from a similar question (as above) regarding what counts as close tracking? Second, such theories, he says, founder on 'stubbornly unrevisable' theories. Classical fluid mechanics cannot be made strictly true by fine-tuning, he says, because there is no cancelling out the axiom that fluids are continua. Again, fair enough. But how does his theory handle such cases? Smith says that what is important is saying that the world is roughly as the theory says it is. How is a theory of continua roughly like a world filled with discrete entities? Close tracking. But close tracking between exactly what? More needs to be said to fill in this schema.

In general, I would have liked to see more discussion of reduction than Smith provides. The discussion occupies only two pages, yet this is a topic that philosophers have come to in light of chaos again and again. I think it's also highly relevant to many of the topics Smith discusses. To see this, let's first ask exactly what types of systems in the world are chaotic? This is a neglected question that has always bothered me about the literature on chaos, and despite Smith's efforts in answering it much more could be said. At the outset Smith confines the notion of chaos to dissipative systems (ones not conserving phase space volume) because conservative systems cannot describe models with attractors. This means that Hamiltonian systems cannot exhibit chaos in Smith's sense. As Smith concedes, this is contrary to what much of the physics literature says. Deterministic Hamiltonian systems can display all manner of intuitively 'chaotic' properties, e.g., homo- and heteroclinic points; and the famous Arnold cat map is area-preserving. But let this pass, for I agree with Smith that it's hopeless to discover the 'true' unique definition of chaos (we surely don't have much of a pre-theoretical concept of it). He can define 'chaos' as he likes.

But it's funny that, defined like this, he doesn't then point out that on the standard way of thinking, it follows that all chaos occurs in non-fundamental science. Usually we think that all non-conservative forces are phenomenal, that at the fundamental level everything is conservative. A natural question then arises: how can chaotic models be an approximately true description of the behaviour of fundamental entities that are non-chaotic? We've heard questions like this before: e.g., how can the time asymmetric Boltzmann equation be an approximately true description of the behaviour of a bunch of entities evolving according to fundamentally time symmetric equations? Phrased in terms of inter-level theory relations, we're on familiar ground. It is a mundane observation that a reducing theory need not have literally the same properties as the theory to be reduced. And we know that it is often a difficult job to show how a low-level theory can reproduce, under the right conditions, the appearance of the phenomena that is described by the higher-level theory—but this is the job that needs doing.

Consider the problem of phase transitions in statistical mechanics. This is analogous to the problem mentioned earlier regarding fluids and approximate truth. Phase transitions, such as liquid water turning into ice, can only be understood at the statistical mechanical level by taking the thermodynamic limit (where the number of particles and the volume go to infinity). The limit cannot be viewed as an idealisation or approximation in the ordinary sense since we do not approach phase transitions as we approach the thermodynamic limit; that is, we don't approach the right behaviour as the number of particles and volume get larger. Prima facie, this is a problem for those claiming statistical mechanics does reduce thermodynamics to mechanics. By analogy with philosophy of mind, it is as if a physicalist offered a reduction of the mental to the neurobiological that hanged crucially on the assumption that the brain had infinite volume and infinite number of neurons! Now because the statistical theory contains the same geometric singularity, say in the specific heat, Smith's theory, applied here, would score points because he could say the statistical model is approximately true despite its appeal to the thermodynamic limit. But since everyone agrees that ice cubes contain a finite number of particles and occupy finite volume, we still have some substantial work to do to understand what is really going on, and the honorific 'approximately true' isn't going to help. Similarly, a chaotic model says that a system has features that no real fundamental classical system can actually have. We are then told it approximates the world. Good. But we still want to know how a bunch of particles can give rise to this behaviour.

Looking at the issue this way also helps when it comes to the role of chaos in scientific explanations. Smith criticizes many authors but never fully develops his own account; instead we get the 'applied theorist's implicit position', namely, that the 'robust' features of models are candidates for explanatory significance (129). But what is the philosopher's position? Are these causal-mechanical explanations or structural explanations or what? Again, it seems to me that discussing reduction more would have helped here, too. Seeing (at least Smith's definition of) chaos as a special science tells us that we can expect chaotic explanations to function broadly like special science explanations—however they function.

Let me finally mention two topics that were left out of the book, one perhaps wrongly and one perhaps rightly. Smith doesn't treat the frequent claim that being a K-system is a sufficient condition for chaos and that mixing is a necessary condition for it. Neither concept from the ergodic hierarchy is even mentioned. This is presumably justified by his concentration on dissipative chaos. But the claim seems relevant to the discussion of randomness (chapter nine) and of the definition of chaos (chapter ten). And it's also relevant to the question of where in the world chaos resides, for it's questionable whether there actually are fundamental mixing and/or K-systems in our world. The only examples I know of are wildly unrealistic systems. If they exist only at the macrolevel, as pinball machines and the like, then the above points are relevant.

The other topic missing from the book is quantum mechanics. Indeed, there is not a single entry under Q in the index. I feel that this absence is not detrimental to the book. A discussion of quantum chaos may have taken Smith too far afield, both in terms of accessibility and topic. As it is the book is an attractive self-contained treatment of one theme in philosophy of science. Adding the quantum may well have ruined this virtue and also seriously lengthened a nicely sized book. But of all the topics surrounding chaos that appear to be particular to chaos, the problem of the apparent lack of chaos in the quantum realm and the alleged threat to the correspondence principle stand out. Readers interested in this topic should therefore be warned that they won't find it here.

Explaining Chaos is a fun read. The writing is crisp and clear. The topics are fascinating and numerous, which, together with the style, make the book very engaging. It deflates over-inflated claims about the relevance of chaos theory, ably explains science in an accessible manner, and makes contributions to the general philosophy of science. The book can be read with profit by philosophers interested in chaos and even those who are primarily interested in questions of scientific methodology. The book would also be useful in teaching a course or section on chaos theory, either at the undergraduate or postgraduate level.

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