love of the former to take an interest in the latter and so become converted to Gould's creed of contingency. If you don't recognize yourself in this description, don't read the book, especially if you are a Gould aficionado. It will only make you sad. □

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Why God plays dice

David Mermin

Beyond Science. By John Polkinghorne. *Cambridge University Press: 1996. Pp. 131. £13.95, $19.95.*

ALL those with even a modicum of intelligence who believe that 'creation science' should be given equal time with evolution in school curricula ought to read this charming little book. John Polkinghorne makes a case that, far from being at odds with the existence of a creator, the fact that evolution is possible at all is powerful evidence of underlying design at another level.

A prominent role in the argument is played by the constellation of ideas associated with the various anthropic principles. Evolution points to God as the Great Tuner of fundamental constants. Polkinghorne finds this far more compelling than the notion that our Universe appears delicately adjusted to make the evolution of life possible, because if it weren't we wouldn't be here to notice it. And he is sceptical of the view that, if the stability of atomic nuclei were grossly altered by tiny changes in certain coupling constants, different avenues would open up to the development of complex carriers of intelligence, which we simply lack the wisdom to imagine.

In addition to the miraculous values of the fundamental constants, there is also evidence of design in the wonderful "opportunity for the interplay of chance and necessity" afforded by quantum theory, which seems ingeniously contrived to be both flexible enough to allow evolutionary variation, yet not so floppy as to threaten the persistence of successful new life forms.

Polkinghorne's grand extension of the argument from design shifts the grounds for scepticism from Darwin back to Hume, about whom he has only a little to say. The problem of evil, he remarks, "can at least be addressed by the insight that this is the necessary cost of a universe allowed to make itself, whose shuffling explorations of possibility will have to have ragged edges". The question of who tuned the Tuner does not come up.

Yet another facet of his case is provided by the mystery of consciousness: why should natural selection have given rise to self-awareness? Would not mindless automata have been at least as successful? The views of many philosophers, here and elsewhere, receive some well-deserved jabs. (On exploring the nature of consciousness by way of thought experiments with extraordinary duplicating machines: "Well, philosophy is wonderful, but peculiar premises may lead to peculiar conclusions.") So do computer models of the mind, for computers are useless without a program. In Polkinghorne's view of consciousness, God appears to be the Prime Programmer Unprogrammed.

Only apparently unrelated to these religious concerns is a critical examination, early in the book, of the account of science as a social construction. This contribution to the 'science wars', unusually temperate for a scientist, lucidly states the claims and articulates the naiveties of the so-called 'strong programme' in the sociology of scientific knowledge. Polkinghorne can be poetic in his defence of objective reality: "Far from the physical world proving to be like clay in our theoretical hands, it displays a diamond-like hardness, resistant to our expectations and imposing upon our minds its idiosyncratic and unanticipated structure." Scientists who admire this elegant dismantling of the view that their discipline lacks objective content may be startled to find later in the book the same thoughtful approach applied to the view that moral and aesthetic principles are social constructions. I suspect the defence of the objectivity of scientific knowledge may have been cunningly contrived to set us up for his attack on cultural relativism.

I have two major criticisms. Polkinghorne takes our ability to treat nature at the quantum level as evidence that our capabilities go well beyond anything evolution could have given rise to, for nothing in the struggle for survival could have required us to be creatures capable of such an understanding. I would have put it just the opposite way. It is because nothing required us to apprehend atomic structure during our evolutionary development that we are incapable of understanding what it is that quantum physics describes. Quantum mechanics is weird to us because we can make inferences about the atomic world only indirectly through the correlations we can arrange for it (called measurements) with those parts of the world (called classical) that evolution has outfitted us directly to apprehend. Polkinghorne dismisses too lightly the mysterious character of quantum mechanics. Although I think I know what he has in mind when he says "[y]ou could never build a wave out of finite collections of particles, but a wave-like state is one with an indefinite number of particles making it up", I would not agree that this explains "how the trick is done" in electron diffraction.

And an eloquent discussion of how it may all end — decay into low-grade radiation, fiery Big Crunch or the persistence of ever-adapting forms of life to the very end — comes down from these lofty heights with a resounding thud for the non-Christian reader with a final slightly uncomfortable ("candour requires me to add") declaration of faith in the resurrection of Jesus Christ. Provincial Christian mythology is a blemish on so grand a theological vision.

I nevertheless enjoyed the book immensely. Although I believe this late-twentieth-century version of the argument by design carries many of the flaws of its venerable predecessors, Polkinghorne's literate sense of wonder at the magical richness of things shines out on almost every page, whether or not one agrees that it implies a creator. □

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From the top down

Philip W. Anderson

How Nature Works: The Science of Self-Organized Criticality. By Per Bak. *Copernicus/Springer: 1996. Pp. 205. $27, £20.50.*

THE rarefied air of the Santa Fe Institute in New Mexico seems to encourage the universalist persuasion: to each scientist, his great idea really seems to be the "theory of everything" that has escaped previous notice, and supersedes all of those promulgated by previous Santa Fe sages (and others). Per Bak now tries to persuade us that he has uniquely found out "how nature works".

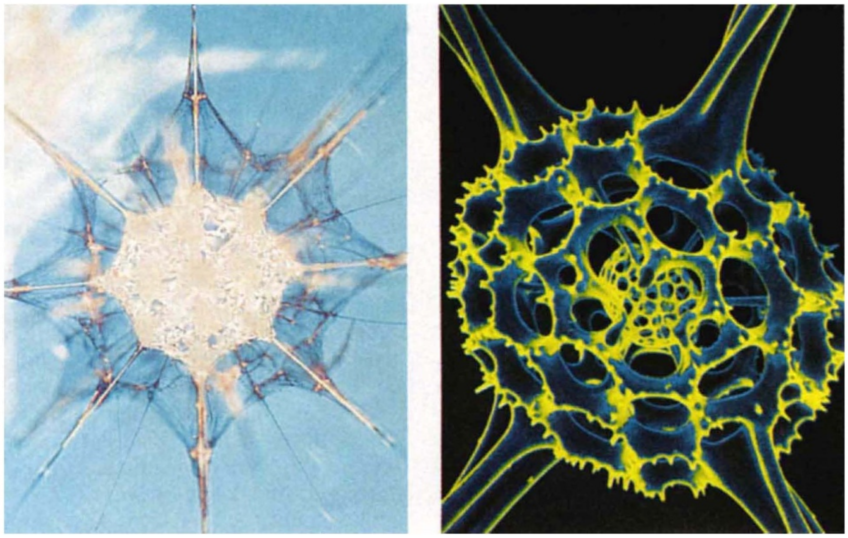
His particular version of the theory of everything is 'self-organized criticality', a theory and a generic scenario of which I have long been a public advocate. It leads, in my mind correctly, to sobering and counterintuitive conclusions about a wide variety of natural and social processes such as climate, tectonics and the macroeconomy. I therefore consider this book a 'must read', despite its exaggerated claims and obvious weaknesses, but because of its importance I could wish that it had been written with more care.

First, let me give a rough idea of Bak's thinking. He takes off from the observation, ably publicized by Benoit Mandelbrot, of the widespread occurrence in nature of 'scale-free' power-law distributions, to which Mandelbrot gave the fortunate name of 'fractals'. The power law appears also in time series — that is, in fluctuations (where it is often called '$1/f$ noise') — and its main practical consequence is that very large fluctuations cannot, in general, be ignored in favour of the cumulative effect of small ones. Mandelbrot was content to pile example on example, but Bak has taken the considerable and important step of trying to produce a mechanistic explanation of these observations.

Bak makes an analogy between the scale-free, power-law regime near a thermal phase transition or 'critical point' and the 'critical' behaviour of a large dissipative, nonlinear dynamical system driven by some slow, large-scale driving force such as solar energy or the slow motion of tectonic plates. In the former case, he argues, the critical point must be achieved by careful tuning of the external parameters such as temperature and pressure, whereas in the latter the system tunes itself to be very close to what he calls 'criticality' by dint of just barely achieving the state in which there is large-scale motion. In both cases there seems to be no natural scale for the sizes of fluctuations, so we see 'critical fluctuations'; but in the latter these arise automatically without tuning, so are 'self-organized'. In the critical state, large fluctuations appear, which he calls 'avalanches'.

With a sequence of simple computer models — the most convincing of which is a gradually growing sand pile — he demonstrates convincingly the possibility of such behaviour and describes in fascinating detail the process by which he and his isolated little group arrived at them. The first four-and-a-half chapters, where these ideas and their first, most successful applications to geology and to earthquakes appear, are a solid contribution to our thinking about complex systems, although, as Bak admits, arguments for universal behaviour seem not quite to fit all real, practical cases.

The other half of the book is far more speculative, and I, at least, cannot accept all of it at face value as readily as the original 'sand-pile' picture. Here we go on to more genuinely complex systems: first computers, then coevolving ecologies ("coevolving dancing landscapes") and the history of evolution, to the brain, to economics, and what have you. Bak's indubitable talent for finding simple models with marvellously complex behaviour comes to the fore, and indeed he can model 'extinction avalanches' in a model of an ecology; but the question here becomes whether the model really captures the essence of the phenomenon or is constructed simply to do what it does. An evolving ecology, or a brain, has more to it than the right statistical distribution of extinctions or of firings. Contrary to Stephen Jay Gould's prejudice, evolution does have a direction (we need not call it 'progress'), and it is not a static replacement of one species by another. So Bak's 'life' is not life as we know it.



Why are eggs egg-shaped and fish fish-shaped? Why do planets look like balls rather than squares or pyramids? Mathematicians Stefan Hildebrandt and Anthony Tromba look at the centuries-old search for fundamental laws governing nature's design schemes. Their book, *The Parsimonious Universe: Shape and Form in the Natural World*, draws on examples from astronomy to microscopy, including these radiolarians — living (left) and skeletal. Springer, $32, £19.50.

Homeostasis, indeed, is a principal ingredient of the workings of all truly complex systems, and Bak's ideas are important in telling us how homeostasis works. But they are not all there is to a brain, an ecology or an economy. Nonetheless, there is much meat in these chapters. The basic message, that large fluctuations (avalanches, storms, depressions, earthquakes) are vital to the dynamics of large systems, is an important and widely ignored fact.

Bak writes with such ease and lucidity, and his ideas are so intriguing, that one reads along only hoping that all is to be believed and accepted at face value. Yet again and again, in those parts of the book that can be personally verified, one regularly finds dropped clangers. Perhaps the intellectual history of chaos is not too important (ascribed almost entirely to Mitch Feigenbaum, a judgement with which only Feigenbaum would concur) and even less so is the history of Brookhaven Laboratory's condensed-matter-physics group. Why does Bak spend a page and a half extolling Brookhaven for its many Nobel laureates in high-energy physics, and then practically without a break set out bad-mouthing the entire enterprise of particle physics? Such thoughtless writing and venting of personal prejudices alert one to possibly more serious omissions.

Another minor error in a field I know well has to do with pulsar glitches. In this connection Bak quotes two authors from Ilya Prigogine's institute who seem to have revived (20 years later and without attribution) the Pines–Shaham starquake theory, which its authors long since abandoned in favour of our mutual work on vortex jumps in the superfluid core. To be ignorant of a decade's work by two of his Santa Fe colleagues is indicative of Bak's scholarship.

Perhaps more serious is his failure to discuss the entire field of hydrodynamics which has served as the classic model for dissipative dynamics. His arguments for self-organized criticality sound much like a generalization of the 50-year-old arguments for scaling (power) laws in fully developed turbulence. It is disingenuous for the book to contain no attempt to relate the two subjects, even while remarking on the fractal outcome of hydrodynamics in the form of weather. In particular, turbulence shows one way in which the arguments can fail, namely qualitative inhomogeneity of the system.

Another missing discussion is of alternative mechanisms for the various Fick's laws and for power laws in economics.

Nevertheless, this book is essential reading for those interested in complex systems in general. Its idiosyncratic personal style may intrigue as many as it turns off, but, like the similarly flawed classic book of Mandelbrot, it will reward a sufficiently sceptical reader. □

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