"The universe we observe has precisely the properties we should expect if there is, at bottom, no design, no purpose, no evil and no good, nothing but blind pitiless indifference. . . . DNA neither knows nor cares. DNA just is. And we dance to its music."

This is a bit too remote. It is the dance, of course, that is important to us. It produces events that, if not good or evil, are certainly excellent imitations. There is also a certain remoteness about Dawkins's metaphor of a river. His image of a digital river is, it would seem, coloured by his experience of the well-tamed genteel rivers of the English countryside. There are no rapids to roil the flow, no chasms and sudden changes of direction. Yet it is becoming increasingly apparent that dramatic events can happen to the digital river, and it would have been exciting if he had explored some of them.

He goes too far in rejecting the claims of the proponents of punctuated equilibrium. Even though the idea as originally proposed had no mechanism attached to it, more and more mechanisms are being found that can speed up and slow down evolution. Walter Gehring and his collaborators can make compound eyes appear all over the body of a fruitfly, like a rash. This tells us something about the capability of a fly's genome to do startling things, a capability that is already present and that Gehring can tap into.

The book, although an excellent introduction to many important evolutionary ideas, slightly suffers because of Dawkins's reluctance to discuss some of these fascinating recent breakthroughs. Had he done so, the river that emerged might not have been so limpid but it could have provided a wilder ride. ☐

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Emerging new science

Ian Stewart

Thinking in Complexity: The Complex Dynamics of Matter, Mind, and Mankind. By Klaus Mainzer. *Springer: 1994. Pp. 329. DM58, $58, £23.*

SYNERGETICS, non-equilibrium thermodynamics, catastrophe, symmetry-breaking, chaos, fractals, self-organized criticality, antichaos, complexity. . . . For as long as I can remember, small bands of scientists led by maverick gurus have chopped away at their own little corners of a big problem — the occurrence of complex structures in what ought to be a simple Universe. One of their common themes has been the emergence of 'collective phenomena', the insistence that the whole is not so much greater than the sum of its parts as different from it.

The deeper theme, however, is nonlinearity. Huge areas of traditional science are based on linear thinking, often without explicitly recognizing it. Classical population genetics, for example, is linear: it models a population as a homogeneously mixed pool of genes and studies only the proportions of particular genes. It is a 'mean field' theory that bases its entire conceptual armoury on a convenient fiction. Traditional mathematical economics is also relentlessly linear in viewpoint because of its emphasis on equilibrium behaviour and a one-dimensional additive measure of value. An instructive example of the sheer vapidity of this way of thinking is a recent comparison of the cost of global warming with the cost of preventing it, carried out by the Intergovernmental Panel on Climate Change (IPCC). Among other remarkable assumptions, the study valued the life of a European at ten times that of the life of an Asian, concluding — although not in quite these words — that it makes economic sense to let Bangladesh sink beneath the waves to avoid minor discomfort in England.

There are many places where linear thinking works well, otherwise it would not have survived, but a cruel irony has led to its widespread adoption in many areas where it does not. Scientists reasonably work with what tools they have to build the biggest edifices they can manage. Linear mathematics is easy, whereas nonlinear mathematics was — at least until recently — impossible. So scientists erected overblown monuments to linear thinking, blissfully unaware that nature is largely nonlinear.

The times, they are a-changing. Nonlinear modelling is one of the biggest growth areas in the whole of science. To those of linear upbringing it may seem undisciplined — and it is, but only in the sense of its 'not belonging to any particular discipline'. It is an irreducibly interdisciplinary way of thinking and it slices the cake of science in totally new directions.

Klaus Mainzer argues the case in favour of nonlinear thinking across the scientific board, from quantum mechanics to human society. He is unusually strong on history, taking care to place each argument in its proper historical context. This is an effective technique, driving home the fact that nonlinear methodology has its roots in ancient debates about matter, life and the mind.

Our deepest theory of matter, quantum mechanics, is linear — indeed it is probably the most spectacularly successful linear theory we have ever had — but the process that turns a quantum system into a classical measurement is manifestly not. So something nonlinear is going on, which cannot be captured by Copenhagen-style special pleading about collapsing wave functions.

Life poses irreducible problems for linear thinking. If one crushed all living creatures together with a huge mortar and pestle, the resulting chemical mix would show few of the characteristics of life (although it would mimic a linear 'gene pool' superbly). Life is a nonlinear process of increasing complexity, explicable in terms of dissipative self-organization.

With regard to the mind–brain problem, Mainzer has little time for either Descartes or Penrose. His approach is best summed up by a direct quotation: "The emergence of mental states. . . is explained by the evolution of (macroscopic) order parameters of cerebral assemblies which are caused by nonlinear (microscopic) interactions of neural cells in learning strategies far from thermal equilibrium". This thesis is developed in greater detail in the ensuing discussion of artificial intelligence and the self-organizing and learning abilities of neural nets.

Finally we come to the problem of political, social and economic order in human society. Linear thinking views these things in mean-field terms, for example in concepts such as 'the inflation rate' and 'the unemployment rate'. Note those 'the's'. In a real economy, individuals suffer their own variable inflation rate and their own even more variable unemployment rate. The macro-variables are emergent features of a complex system of millions of interacting agents, each with its own micro-variables. In a classical linear economy, stock markets never crash.

All very well, but what should we actually do? The epilogue has some suggestions. Mainly they are to recognize the interdependence of systems that we usually try to keep separate (such as economics and the environment) and to accept that complex systems develop emergent properties — in short, to stop thinking linearly. Nonlinearity is not a universal answer, but it is often a better way of thinking about the problem. It is certainly better than the linear thinking that led the IPCC to conclude — no doubt without realizing it — that it makes sense to let nine Asians die in order to keep one European alive. ☐

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