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Roads to Reality

Penrose and Wolfram Compared

Contenders

Sir Roger Penrose, retired professor of mathematics at the University of Oxford and collaborator with Stephen Hawking on black hole theory, has written 'a complete guide to the laws of the universe' called *The Road to Reality*.[1] His publisher calls it the most important and ambitious work of science for a generation. Penrose caused a furore in the world of consciousness studies with his 1989 book *The Emperor's New Mind*, which conjectured a new mechanism for consciousness and kept a faithful band of researchers busy for a decade with models based on microtubules and the like. Sadly, the idea fizzled out. The title of the 2002 Tucson 'Toward a Science of Consciousness' conference poetry slam winner was: *Microtubules — my ass!*

Stephen Wolfram, by contrast, is a maverick loner. Educated at Eton, Oxford, and Caltech, recipient of a MacArthur 'genius' award, multimillionaire creator of *Mathematica* — 'now the world's leading software system for technical computing and symbolic programming' (to cite his own dust jacket blurb), he is both author and publisher of the massive volume *A New Kind of Science*.[2] He regards it as the most important and ambitious work of science for three centuries. Yes, Wolfram wishes to be known as the next Newton. He sees human mental processes as embodied computations and hence as equivalent to many irreducible processes in nature, such as weather or the particle dance in rocks.

Whose book should you read?

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[1] **Roger Penrose,** *The Road to Reality: A Complete Guide to the Laws of the Universe* (London: Jonathan Cape, 2004), xxviii + 1094 pages, ISBN 0-224-04447-8.

[2] **Stephen Wolfram,** *A New Kind of Science* (Champaign, IL: Wolfram Media, 2002), xvi, 1264 pages, ISBN 1-57955-008-8.

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Omnium

For Penrose, the road to reality cuts boldly through the twin cities of mathematics and physics. The white line on his road is what he calls the 'magic' of complex numbers. The current orthodoxy in both relativistic and quantum physics is to presuppose a real spacetime continuum. Combinatorial constructions from such elementary items as particles or fields in this continuum form dizzyingly large worlds or sets of worlds. Penrose advocates a metaphysics comprising a complex continuum that is no less dizzying but slightly more mathemagical. To denote the resulting totality, he prefers the pleasantly neutral term *omnium* to such loaded terms as 'multiverse' (2004, p. 784).

Classically, the omnium has four real dimensions. Classical reality is Einstein's cosmos, in which we occupy an expanding bubble of observable spacetime that we call our celestial sphere. Penrose offers an authoritative and informative guide to this reality, including a nice view of the celestial sphere in Minkowski spacetime as a *Riemann sphere*, which can be represented as a curved surface in Euclidean 3-space but is more exactly the manifold with a single complex dimension obtained when the complex plane is 'compactified' by adding a single point representing infinity and projecting it onto a sphere, such that the axes become great circles through the poles zero and infinity and the unit circle becomes the equator. But there is a big problem here. Einstein's beautiful theory of gravity, as the curvature of spacetime, needs a complete overhaul to accommodate quantum theory.

In quantum theory, one of the most paradoxical issues is the *entanglement* of multiple particles in superposed states, which Schrödinger illustrated with his cat and which Einstein considered a *reductio ad absurdum* of quantum mechanics. Penrose calls quantum entanglement *quanglement* (2004, p. 407). For example, a pair of photons emitted by the mutual annihilation of an electron and a positron is quangled because the photons have correlated spins. Whatever spin you measure on one, you know the other has precisely the opposite spin. The problem with quanglement is that almost every particle in the universe may be quangled with innumerable others. Quanglement may even create the classical surface of our phenomenal reality. Although physical reality may contain infinities of possible worlds, the fact remains that all we see is a unique classical world. That may be because we quangle with anything we touch and thus force it to join our world (Aczel, 2001).

Penrose argues forcefully against the claims of superstring theorists to have solved quantum gravity. He is sympathetic to the loop quantum gravity approach, but finally he favours his own *twistor theory* to tackle the problem. A key idea is that light rays carry quanglement:

> Twistor theory … does not directly lead to any notion of a 'discrete spacetime'. Instead, its departure from real-number continuity … calls upon the *magic of complex numbers* as a primary guiding principle for physics (p. 962).

> [A] guiding principle behind twistor theory is quantum non-locality. … [Q]uantum information … can 'travel' one way or the other along a quanglement line … to

> obtain a relativistic scheme, in which idealized light rays [are] the carriers of quanglement. … [W]e may think of a twistor as representing a light ray in ordinary (Minkowski) spacetime. … One can regard such a light ray as providing the primitive 'causal link' between a pair of events (i.e. of spacetime points) (pp. 964–5).

> Ordinary spacetime points are represented as Riemann spheres in [a subspace of projective twistor space]. Points of [that subspace] are represented as light rays in spacetime. Either way the correspondence is non-local. Yet, we can pass from one picture to the other by precise geometrical rules (p. 978).

In his view, quantisation blurs spacetime events but leaves light rays sharp. Remarkably, the spacetime analogues of the Schrödinger equation 'seem to evaporate away in the twistor formalism, being converted, in effect, to "pure holomorphicity"' (p. 986). But the development of these ideas to quantum field theory in curved spacetime is for the future. And Penrose admits that twistor theory is not so much a physical theory as a mathematical reformulation without any new physics.

Let us define *miph* as mathematics, informatics, and physics, and define the *quagmire* as the acronymic conjunction of the following issues:

- The unsolved problem of quantum gravity
- The fathomless ocean of obscurities in M-theory, which is intended to unify several competing variants of superstring theory (Penrose, 2004, pp. 914–915; Greene, 1999, 2004)
- The puzzling concept of quantum information (Nielsen & Chuang, 2000)
- The baffling issue of quantum state vector reduction

Penrose is a master of miph, but the quagmire defeats him.

Automata

For Wolfram, the road to reality cuts through the rapidly growing conurbation of computational sciences. In *A New Kind of Science*, he notes that for the last three centuries theoretical physicists have been using differential equations to model nature. Their models are based on the classical continuum. His proposed new kind of science involves developing discrete models based on computer simulations. The aim of such science is simply to model the variety of natural phenomena in machines. If discrete models suffice for all practical purposes, interest in continuum models will fade.

Pursuing his new miph, Wolfram explored a large number of simple cellular automata simply by running them and looking at the patterns they generated. Intriguingly, he found that automata based on very simple rules sometimes emulate computations of arbitrary complexity. Although all processes can be seen as computations, even if only trivial ones, he concluded that many natural or artificial processes can be seen as *universal* computations.

> The basic point is that if a system is universal, then it must effectively be capable of emulating any other system, and as a result it must be able to produce behavior that

> is as complex as the behavior of any other system. … [U]niversality … occurs in a wide range of important systems that we see in nature (2002, pp. 643–4).

Recall that integer arithmetic is universal because you can do arbitrarily complex computations in it. If you can count, add and multiply, fast enough, you can do anything a supercomputer can do. Wolfram's new principle:

> There are various ways to state the Principle of Computational Equivalence, but probably the most general is just to say that almost all processes that are not obviously simple can be viewed as computations of equivalent sophistication (pp. 716–17).

A sophisticated computation is irreducible, or algorithmically incompressible, and its result is random in the Chaitin–Kolmogorov sense (Chaitin, 1990, p. 15). Wolfram's final words:

> Looking at the progress of science over the course of history one might assume that it would only be a matter of time before everything would somehow be predicted by science. But the Principle of Computational Equivalence — and the phenomenon of computational irreducibility — now shows that this will never happen. … [T]he Principle … implies that all the wonders of our universe can in effect be captured by simple rules, yet it shows that there can be no way to know all the consequences of these rules, except in effect just to watch and see how they unfold (p. 846).

As I see it, the principle says less. It merely suggests that much of the apparent randomness in our universe may be explicable by means of underlying rules. These rules may be universal, and hence equivalent to each other in principle, but it's a long way from apparent randomness to life and mind.

Consciousness

Penrose has given up trying to link his theoretical views to consciousness because the biology of cortical states so obviously has very little to do with the Emperor's cosmic mind. He has just a few pages on consciousness toward the end of his new book:

> I have deliberately refrained from addressing, at any great length, the question of conscious mentality in this book, despite the fact that this issue must ultimately be an important one in our quest for an understanding [of] physical reality. (I have discussed such matters at detail elsewhere, and I have no wish to get embroiled here in many of the contentious issues that arise.) (p. 1030; see Penrose, 1989; 1994; 1997).

It is easy to sympathise. We can regard the biological concept of consciousness as orthogonal to the impersonal concepts deployed in mathematics and physics. We can see the realm of conscious thought either as embracing miphic activity in its entirety or as irrelevant to the objects of miph, which remain unchanged whether or not we are conscious of them.

For this reason, I suggest we regard states of consciousness as reflecting or complementing our miphic worlds or worldviews *as a whole*. But for Penrose the issue is not so clear:

> There is [an] important role played by consciousness in many interpretations of the **R** [reduction] part of quantum mechanics … As far as I can make out, the only interpretations that do *not* necessarily depend upon some notion of 'conscious observer' are … most of those … that require some fundamental change in the rules of quantum mechanics, according to which **U** [unitary evolution] and **R** are both taken to be approximations of some kind of objectively real physical evolution. … I am an adherent of this last view, where it is with gravitational phenomena that an objective **R** (i.e. **OR**) takes over from **U**. … I envisage that the phenomenon of consciousness — which I take to be a *real* physical process, arising 'out there' in the physical world — fundamentally makes use of the actual **OR** process (p. 1032).

How cortical processes can relate to **OR** is obscure, but **OR** is a quagmire issue that nobody expects to solve in the near future.

Wolfram has nothing much to add to conventional wisdom on consciousness:

> I am quite certain that in the end there will turn out to be nothing particularly special about the basic processes that are involved in human thinking. And indeed, my strong suspicion is that despite the apparent sophistication of human thinking most of the important processes that underlie it are actually very simple (2002, p. 631).

For him, we are embodied computers, equivalent in principle to decaying rocks or stars or any other embodied universal automaton, just part of the cosmic computation.

Verdict

The symbiosis of mathematics and physics is nowhere more brilliantly depicted than in Penrose's new book. The dialectic of mathematical logic and physical intuition is like the interhemispheric traffic in a brain of cosmic dimensions, perhaps in the brain of the Penrosian Emperor whose very thoughts crystallise reality in a process of quantum-gravitational **OR**. There is much food for psychological thought in the astonishing series of victories won by mathematicians and physicists in recent centuries, and Penrose has prepared a banquet for those with appetite.

But the book has its flaws. Published in evident haste, it sports numerous typos and minor errors, and the level of both technical and rhetorical finish is very uneven. Material that Penrose has pondered for years is presented with brilliant clarity and precision, but some other stuff, such as the chapter on superstrings, is unsatisfactory and ragged. More damagingly, most readers without degrees in mathematics or physics will find the book impossible.

Wolfram's book is quite different. It is accessible at several levels. The main text is smooth and easy reading, but comprises less than half the total word count. The 349 pages of fine-printed and often very technical notes are a treasure trove for specialists. But the figures and their legends are the real focus of the work. Beautifully printed and presented using brilliantly minimalist notational schemes, many of them reward deep contemplation. The computational effort required to generate them all was obviously colossal, and their cumulative effect is to boggle the mind. The book clearly deserves cult status.

But its science is disappointing. Most of the views expressed in the main text on major scientific questions are vague and subjective, and most of the technical results have only minor significance. Wolfram largely ignores two major topics:

- Memory size and organization are central both to human mental life and to the realism of the Turing machine idealisation of computation.
- Processing speeds range over very many orders of magnitude. Slow processes may not compute much before they are brought to a halt.

And his much-heralded Principle of Computational Equivalence is close to ideas that are already familiar to most computer scientists.

Neither book delivers as much as its publishing hype promises. Penrose gives an inconclusive recap of current thinking and Wolfram gives an inconclusive survey of new vistas. Let Penrose educate you or Wolfram enthral you — the choice is yours.

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