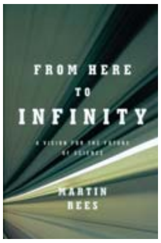
Optimistic about science, pessimistic about policy

From Here to Infinity
A Vision for the Future of Science

Martin Rees
W. W. Norton, New York, 2012. $23.95
(144 pp.). ISBN 978-0-393-06307-3

Reviewed by Joel Primack

Besides making fundamental contributions to essentially every area of astrophysics, Martin Rees has been a leader in science and technology policy. From 2005 to 2010, he served as president of the UK's Royal Society. He has given many lectures and written many books for a general audience about science and the modern world. *From Here to Infinity: A Vision for the Future of Science*, which is based on his four BBC-sponsored Reith Lectures from 2010, is the best available brief summary of Rees's views on science and its implications.



Rees is passionate about increasing the general understanding of science. In the chapter "The Scientific Citizen," he says,

> It's a *cultural* deprivation not to appreciate the panorama offered by modern cosmology and Darwinian evolution—the chain of emergent complexity leading from some still-mysterious beginning to atoms, stars, and planets—and how, on our planet, life emerged and evolved into a biosphere containing creatures with brains able to ponder the wonder of it all. This common understanding should transcend all national differences—and all faiths too. (page 19)

Rees notes that there is now, for the first time, a "huge gulf between the artifacts of our everyday life and what even a single expert, let alone the average child, can comprehend" (page 120). Many common gadgets are magic black boxes. If you take apart a mobile phone, for example, you will find in its miniaturized mechanisms few clues about how it works. Moreover, with increasing urbanization, most people have less contact with the natural world. To compensate, science education must be more effective. Ubiquitous computers and the Web can help.

The difficulty of understanding even something as basic as an atom should induce skepticism of anyone claiming to have answered the most profound aspects of our existence. "So," Rees says, "I have no religious beliefs; however, I respect the customs and rituals of the Anglican Church in which I was raised" (page 127). Because he has denied that science and religion should be regarded as enemies, Rees says he's been described on Richard Dawkins's website as a "compliant Quisling."

Rees also wants people to understand the limitations of science and technology. It is sometimes much easier to comprehend distant things than nearby ones; scientists have long been able to predict solar eclipses, but it's hard to forecast, even a day before, whether an eclipse will be visible through clear skies. The US program of Moon landings was a success because celestial mechanics and rocketry were already understood, but the "war on cancer" has been much less successful because so much relevant science is still being discovered. People also need to understand risk. "We fret unduly about carcinogens in food and low-level radiation," Rees says. "But we are in denial about low-probability, high-consequence events that should concern us more. The recent financial crash was one such event; but others that haven't yet happened—lethal pandemics are one example—should loom higher on the agenda" (page 23).

In 2003 Rees published an entire book on the unique dangers of the 21st century. His working title was *Our Final Century?* (His British publisher, Heinemann, removed the question mark; the title change by the US publisher, Basic Books, to *Our Final Hour* shows, Rees says, the impatience of the US public.) He conjectured that, taking all risks into account, there is only a 50% chance to get through the present century without a disastrous setback. Rees says he's been surprised by how many colleagues think a catastrophe is even more likely. He calls himself a "*techno-optimist*," since most people's lives have been so greatly enhanced by science and technology, and he sees so many opportunities now for the transformational power of optimally applied science in impoverished regions.

That sentiment is succinctly summed up on page 73 in the chapter titled "Surviving the Century":

> There seems to be no scientific impediment to achieving a sustainable world beyond 2050, in which the developing countries have narrowed the gap with the developed, and all benefit from further advances that could have as great and benign an impact as information technology has had in the last decade. But the intractable politics and sociology—the gap between potentialities and what actually happens—engender pessimism.

Although I didn't find a unified "vision for the future of science" in *From Here to Infinity*, there are vision fragments scattered throughout this collection written by a wise, well-informed scientific leader. No doubt Rees would agree with Albert Einstein, who said, "Politics is more difficult than physics."

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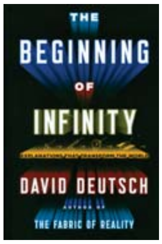
The Beginning of Infinity
Explanations That Transform the World

David Deutsch
Viking Press, New York, 2011. $30.00
(487 pp.). ISBN 978-0-670-02275-5

David Deutsch's idea of a universal quantum computer and his demonstration that quantum interference can give it more power than a classical one are major and lasting contributions to science. With *The Beginning of Infinity: Explanations That Transform the World*, Deutsch applies his broader views on the nature of science and of rational thought to a wide range of questions.



What is good science, and what kind of society fosters it? Will we create artificial intelligence, how will we know if we have, and should the prospect worry us? How should we evaluate political institutions? Is sustainability a goal we should strive for? How long will human civilization exist? Are there limits on what we can come to know? These are just a sampling.

The book's theme is the universality and unlimited problem-solving ability of the explanation-seeking faculty of reason. According to Karl Popper, whose epistemology underlies Deutsch's approach, knowledge consists of explanations: conjectures about how the world is that entail the phenomena to be explained. Good explanations are fragile in that it is difficult to perturb them and yet retain their explanatory power. Moreover, they facilitate understanding and prediction of varied phenomena and survive systematic attempts to falsify them by checking their implications against reality. Though compatible with and influenced in its essence by universal physical law, the reasoning required to arrive at good explanations is neither parochially human nor reducible to physical terms. For Deutsch, the process of explanation through reason, if we embrace it, promises an infinite future in which even in areas like philosophy, art, politics, and ethics, problem after problem is solved and further problems continue to be generated.

Deutsch's conclusions are often sweeping. He argues that all regularities in nature have explanations, and therefore problems are solvable; if we do not solve them, it is because we failed to acquire the requisite knowledge. Yet he also argues that new problems will always arise. Therefore, he concludes, "sustainability," theoretically speaking, is a chimerical notion, aimed at stasis that will lead to death.

Dozens of such provocative arguments will hold the reader's interest. His skepticism about the Turing test for artificial intelligence is nicely argued, and the rest of his discussion of machine intelligence and creativity is engaging. So are his comments on anthropic reasoning in cosmology and elsewhere. The proposal that a good piece of music or art, like a scientific explanation, is "hard to vary" is interesting, but I'm not fully convinced. In any case, the general point that similar criteria may be used to evaluate scientific hypotheses and works of art is a valuable one. Deutsch's standard discussion of mathematical infinities segues into a lovely illustration of how physical law affects computational and perhaps reasoning power. And his argument that social science must acknowledge reason as active in human affairs is well taken, though Deutsch may jump too quickly to conclusions from it.

Deutsch's view that objective correctness is possible in areas outside science is appealing. And his suggestion that Popperian explanation underwrites that possibility is intriguing, but may overemphasize the importance of explanations as opposed to other exercises of reason. A broader, more balanced perspective may be found in the writings of Roger Scruton, Thomas Nagel, and others. Less appealing is Deutsch and Popper's denial of the validity of inductive reasoning; if this involves a denial that evidence can increase the probability of general statements such as scientific laws, it is deeply problematic. To appreciate the nature and proper role of induction, one should also read such Bayesian accounts as Richard Jeffrey's *Subjective Probability: The Real Thing* (Cambridge University Press, 2004) and John Earman's *Bayes or Bust? A Critical Examination of Bayesian Confirmation Theory* (MIT Press, 1992).

Deutsch and Popper also oppose instrumentalism and physical reductionism but strongly embrace fallibilism. An instrumentalist believes that particular statements or entities are not literally true or real, but primarily useful for deriving predictions about other matters. A reductionist believes that they have explanations couched in the terms of some other subject area, often physics. Fallibilism is the view that our best theories and explanations are or may well be false. Indeed many of the best have already proved not to be strictly true. How then does science progress? Our theories approximate truth, and science replaces falsified theories with ones closer to the truth. As Deutsch puts it, we "advance from misconception to ever better misconception." How that works is far from settled. This seems to make premature Deutsch's apparent dismissal of any role for instrumentalist ideas, and his neglect of pragmatist ones, according to which meaning and truth have largely to do with how statements are used and whether they are useful.

For some of Deutsch's concerns, prematurity is irrelevant. But fallibilism undermines some of his claims—for example, that the quantum multiverse theory is a simple consequence of saying the Schrödinger equation is true and that instrumentalism about the quantum wavefunction has the same defects as a more thoroughgoing instrumentalism about scientific theories. The apparently incompatible accounts of the world given by general relativity and quantum theory and the existence of multiple formulations of quantum theory probably sharpen these points. On these matters, and some others, Deutsch neither gives an adequate overview of current thinking nor does justice to alternatives. The treatment of quantum theory in chapter 12, "A Physicist's History of Bad Philosophy," illustrates this, and the treatment of 20th-century philosophy in the same chapter is close to caricature. With respect to philosophy of science, W. H. Newton-Smith's *The Rationality of Science* (Routledge, 1981) and James Ladyman's *Understanding Philosophy of Science* (Routledge, 2002) could provide a corrective that also puts Popperian thought in context.

The Beginning of Infinity is written clearly and is intended for a general audience. But it is also well worth reading by physicists interested in how our discipline fits into the spectrum of human activity or in questions about the future of humanity. The book is so wide-ranging and dense that evaluating its arguments—many of which seem persuasive—is difficult to do in one reading. But I strongly recommend this sprawling, sometimes frustrating, often engrossing book to readers willing to make the critical and creative effort to understand and evaluate its ambitious and often quite philosophical arguments.

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Neural Control Engineering
The Emerging Intersection Between Control Theory and Neuroscience

Steven J. Schiff
MIT Press, Cambridge, MA, 2012.
$55.00 (361 pp.).
ISBN 978-0-262-01537-0

Steven Schiff's *Neural Control Engineering: The Emerging Intersection Between Control Theory and Neuroscience* is largely concerned with predicting and controlling the dynamics of the brain. The problem involves collecting observations of brain activity and filtering out noise and measurement errors.

Issues related to brain dynamics are addressed in perhaps the most interesting part of the book—its final five chapters. Chapter 9 covers Apostolos Georgopoulos's discovery in the 1980s that the direction of a monkey's limb movement is uniquely predicted by the activity of a relatively small population of neurons in the motor cortex. Each of the neurons is tuned to respond optimally for a preferred direction of limb movement, and the vector sum of the neural population activity drives the intended movement. A corresponding effect occurs in the primate visual cortex: The vector sum of the activity of a relatively small population of visual-cortex neurons accurately represents the local orientation of the edge of an object in the visual field. Such findings were seminal for the development of brain–machine interfaces—for example, implanted arrays of microelectrodes. The resulting deluge of data generated by the arrays required much assimilation via so-called Kalman filters.

Chapter 10 provides an interesting introduction to Parkinson's disease and the models developed at the turn of this century by David Terman and colleagues. Their approaches, using simplified Hodgkin–Huxley models, are a first attempt to model Parkinson's disease and provide insight into the efficacy of deep brain stimulation. Chapters 11 and 12 give a brief look at the use of electric fields to stimulate the brain and at recent attempts to understand and control epileptic seizures. The final chapter, 13, is more speculative but raises the possibility that brains themselves implement Kalman filters.

Processing noisy data has its origins in Gauss's 200-year-old least-squares method to minimize the effects of measurement errors. However, the current methods are offshoots of theories developed in the 1930s and 1940s by Norbert Wiener and Andrey Kolmogorov. Those theories minimized the effects of noise and measurement errors from data. Wiener's theory considered continuously changing data that were represented with Gaussian statistics in stationary random processes; Kolmogorov studied very similar processes, but considered data sampled at discrete times.

The problem with both theories was that they dealt only with linear, stationary, and Gaussian processes. It took another 20 years before Rudolf Kálmán in 1960 introduced his filter theory to deal with noisy dynamical systems; it took another 40 years or so before Kalman filter techniques were used to estimate the parameters of equations describing neural activity.

Neural Control Engineering is the first comprehensive account of the most recent developments. Schiff is perhaps uniquely qualified to write it: He is a practicing neurosurgeon, a computational neuroscientist, and a pioneer in the application of control techniques to problems such as chaos. The book's early chapters provide a brisk introduction to least-squares minimization and its connection with Bayes's rule, and thence to processes that incorporate measurements into models of neural activity. In particular, Schiff presents the Kalman filter approach for discrete data, and the Kalman–Bucy filter for continuous data. The first specific neural examples the book considers are the