THE FABRIC OF REALITY

By David Deutsch
New York: Penguin Books, 1997. 366 pp.

REVIEWED BY ANDY FRIEDMAN*

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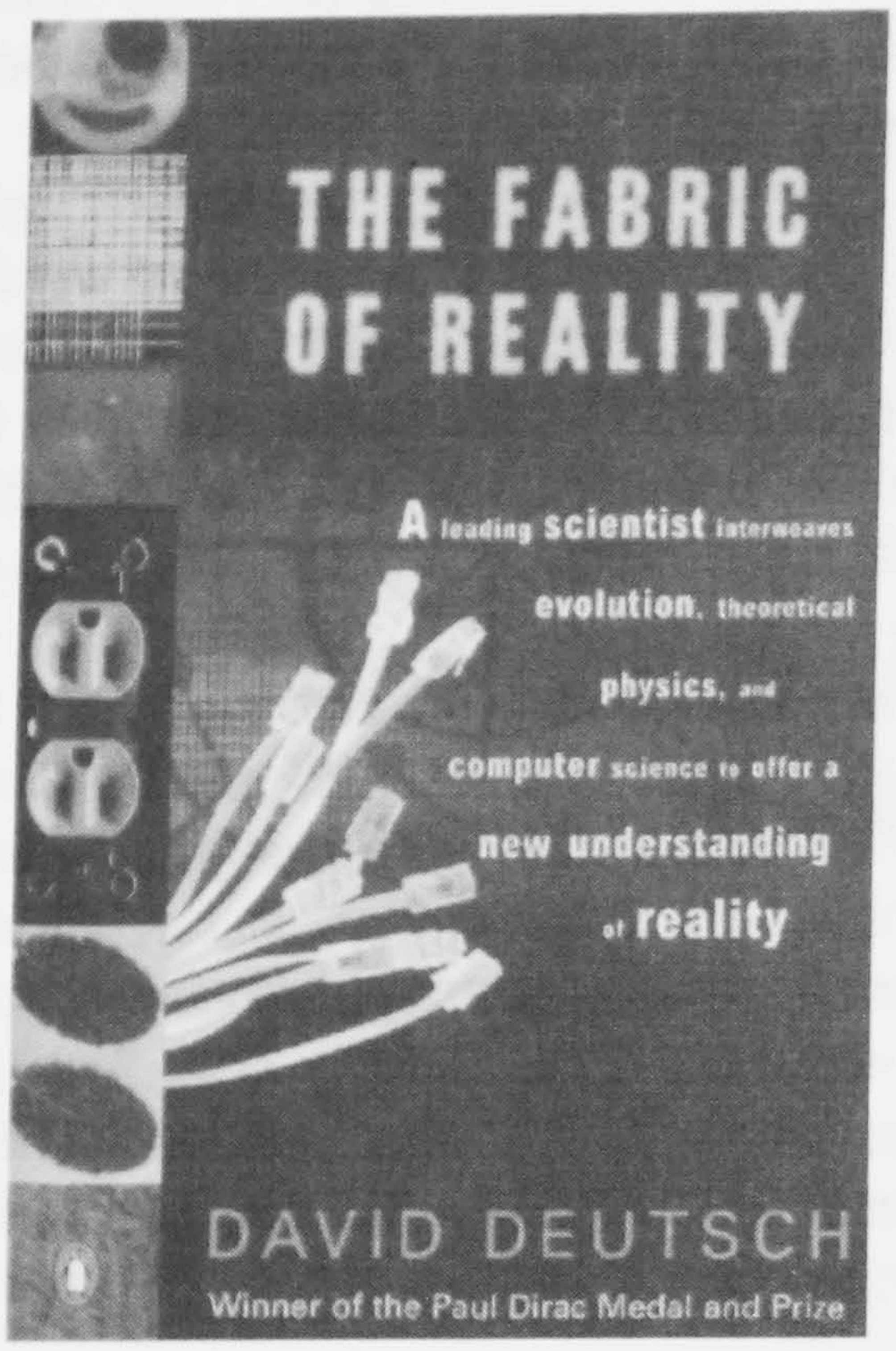
A POSSIBLE HEADLINE OF THE FUTURE? DAVID DEUTSCH THINKS SO.



If you want an unbiased review, you're looking in the wrong place. This book was amazing, and I can't say enough about why you should read it. If you're interested in a book that ties together quantum physics, evolution, computer science, and the theory of knowledge itself, then you've found it in David Deutsch's 1997 eye opener, The Fabric of Reality. (1) Deutsch argues that these "Four Strands" of knowledge, founded in a proper interpretation of quantum theory, when combined, represent a synthesis of our best theories, and one cannot hope to understand the universe without understanding their interconnections.

Deutsch, an Oxford University theoretical physicist, is one of the founders of the burgeoning new field of Quantum Computation (2), a field which may eventually revolutionize not only the power of your laptop, but also our conception of the universe itself. The book discusses in detail the flurry of almost magical tasks that a quantum computer could perform for us, but more importantly, it looks at what the very existence of quantum computers must imply about physical reality. In the end, the only explanation of quantum mechanics consistent with what we know about quantum computation today paints a rather compelling picture. Quantum mechanics is none other than the theory of parallel interfering universes, and this is the major focus of the book.

Before discussing the evidence Deutsch offers for this rather astounding claim of parallel universes, it will be necessary to introduce a little bit about quantum mechanics and Deutsch's argument for what we demand of our best physical theories. Quantum mechanics is widely regarded as our most successful physical theory to date. It has passed innumerable experimental tests, and indeed, we see its predictive power actualized ubiquitously around us today. From the circuitry of your home computer, to the laser in your Discman, a huge majority of modern technological advances, including nearly all digital electronic circuitry, rely on the predictive power of quantum mechanics.

Now if the last sentence had read that much of modern technology depends on our understanding of quantum mechanics, most readers would not have batted an eyelash. But as it stands, such a sentence would not be completely accurate. Deutsch makes it very clear that our understanding of a theory, or its explanatory power, is fundamentally different from a theory's simple predictive power, and arguably much more important. As Deutsch notes, "The overwhelming majority of theories are rejected because they contain bad explanations, not because they fail experimental tests." (3) This is the quandary facing quantum mechanics today. Despite its considerable experimental success, Deutsch argues that the current interpretation of quantum mechanics, the Copenhagen Interpretation, has robbed the theory of much of its explanatory power.

In the Copenhagen Interpretation, the central object is what physicists call the "Wave Function," a function whose square tells you the probability that a particle will be found at a particular place in space and time. Interwoven into the wave function is the information describing all the possible states that the particle could be in, a kind of probability distribution that can be thought of as a sort of bell curve. Now, when physicists describe a system, they speak of the particle existing in a "superposition of states," and only after a measurement is performed can the particle be said to exist in a definite state, to a precision limited by the famous Heisenberg Uncertainty Principle. So we begin with an initial bell curve-like probability distribution, and after the measurement, the distribution gets squished down into a sharp "spike" concentrated at the position of the particle, a process which physicists call the "collapse" of the wave function.

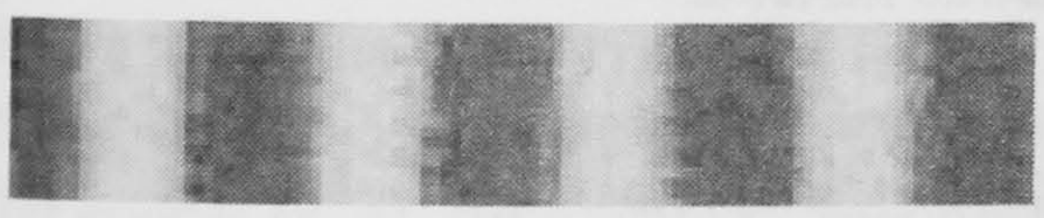
The problem comes when we try to understand what the collapse of the wave function would mean about physical reality. According to this interpretation, a particle cannot really be said to exist until we observe it! Bishop Berkeley, who argued in the early 1700's that reality exists only in the mind, is probably dancing in his grave. What's worse, the collapse of the wave function necessarily contains mysterious, unexplained physics. Upon closer inspection, it amounts to no more than a faster-than-light telekinetic effect that an observer has on a physical system simply by looking at it. If you believe that reality does maintain a coherent existence even when it is not being viewed, then you see the problem here. In the end, wave-function collapse is no more than an ad hoc assumption taken by those who wish to maintain the single-universe worldview.

The most famous example exhibited by the ambiguity of wave-function collapse is the paradox of Schrödinger's cat. Erwin Schrödinger, one of the founders of quantum mechanics, is said to have envisioned a cat inside a box, subject to a rather cruel predicament. Outside observers cannot see inside the box, and inside, there is a contraption set up where a quantum event with a 50-50 probability of occurring, (a radioactive decay, for example) will either trigger the release of poison gas and kill the cat, or do nothing and leave the cat alive. Now the question one might ask is, "Before we look inside the box, what is the state

of the cat?" The Copenhagen Interpretation would answer, without hesitation, "The cat is in a superposition of being half alive and half dead." If you are as annoyed as I am by this kind of answer, fortunately, as Deutsch describes, there is an alternative.

According to the Copenhagen Interpretation, the wave function collapses when you open the box and look inside, and you'll either see the cat dead or alive. But what if the wave function never collapses? In this scenario, the measurement is not limited to a single, "dead or alive" outcome, but in fact, both possibilities are realized. What this means is that the observer can be said to "split," actually observing two different universes, one where the cat perished, and one where it escaped alive. This interpretation, which regards such different possible universes as equally real, was introduced by Hugh Everett in 1957 and is known as the Many Worlds Interpretation of quantum mechanics. Instead of reality consisting of a single universe, we have a vast collection of possible universes, often called the Multiverse.

Aside from these philosophical arguments, the reader might reasonably ask, "Well, what is the evidence for the Multiverse anyway?" Believe it or not, as Deutsch describes in the book's second chapter, our best evidence comes from a version of an experiment often demonstrated in high school physics classes, the famous Young double slit experiment. When you shine a beam of light consisting of photons at a barrier with two slits cut in it, a pattern of bright and dark bands will appear on a screen behind the slits. Now this can easily be explained in terms of the wave nature of light.



The light waves can be thought of like rippling water waves on a pond that interfere with one another to either reinforce each other (bright bands) or cancel one another (dark bands) in different places.

But the most astonishing thing occurs when, instead of sending in a beam of light consisting of gazillions of photons, we only allow one photon at a time to travel towards the screen. Intuitively, one might expect that the pattern on the screen will now simply be randomly distributed around the two slits, since the single photon no longer has all the other photons in the beam to interfere with. But this is not what occurs at all! In fact, when sending in single photons, the interference pattern builds up exactly as before! Now if you're scratching your heads, don't worry, you're in good company.

The Copenhagen Interpretation explains this astonishing result with statements like, "The photon produces the interference pattern by interfering with itself." Deutsch argues that this is patent nonsense. Rather than claiming that single photons are merely behaving as if they were interfering with other photons, why not consider the more realistic possibility that they are simply interfering with other real photons? The ambiguity arises here because, in the double slit, and virtually every other quantum mechanical experiment, quantum mechanical calculations will give you the right predictions about physical reality regardless of which interpretation you accept. But Deutsch's main point is that deciding between the Many Worlds and the Copenhagen Interpretation is not a mere aesthetic choice. While you can predict what the interference pattern will look like with either interpretation, only with the Many Worlds Interpretation can you explain how the interference pattern persists when you send in single photons.

> **"The quantum theory of parallel universes is not the problem, it is the solution. It is not the troublesome, optional interpretation ... It is the explanation – the only one that is tenable – of a remarkable and counter-intuitive reality."** (4)

Even more compelling support for the Many Worlds Interpretation comes not simply from the best explanation for quantum interference phenomena, but what we might eventually be able to do with it, namely building quantum computers with the ability to perform amazingly fast calculations that would be impossible with classical computers. According to the Many Worlds Interpretation, quantum computers could achieve such incredible processing speeds because they exploit the phenomena of quantum interference and allow a calculation to actually be shared amongst parallel universes, a cosmological parallel processor, if you will. It is quite true that practical quantum computers have yet to be built, but the fact that they have been shown to be theoretically possible, (by Deutsch, amongst others) is extremely suggestive in regard to the existence of parallel universes. In his seminal 1985 paper, *"Quantum Theory, the Church-Turing Principle, and the Universal Quantum Computer"* (5), Deutsch showed that it is possible to construct a universal quantum logic gate, forming the foundation for a computer with properties that cannot be explained by any classical theory of computation. With fitting eloquence, Deutsch writes that, "The intuitive explanation of these properties places an intolerable strain on all interpretations other than Everett's," the Many Worlds Interpretation (6). This "intolerable strain" can be seen by examining a particularly practical computational task that only a quantum computer could perform, namely the breaking of today's most powerful encryption codes.

In today's information-driven economy, data security and encryption are paramount, as corporations and individuals are quite intent on keeping their communications confidential. The currently used "RSA" encryption scheme, developed by Ronald Rivest, Adi Shamir, and Leonard Adelman in 1978, uses a method called "Public Key Cryptography," and forces would-be hackers to perform the factorization of a very large number into its two primes in order to break the code. This might seem easy for a number like 15 (with prime factors 5 and 3) for example, but when you're dealing with numbers sometimes in excess of 250 digits, the number of computational steps increases exponentially and the problem becomes intractable for even today's fastest supercomputers. Indeed, in order to factor a number of 400 digits, for example, the computation could easily take longer than the age of the universe! But with a quantum computer, in theory the calculation could be performed in minutes. Now the hackers and corporations of the world would like to know how this could be possible. Deutsch argues that the only explanation consistent with such a calculation necessarily contains parallel universes.

Deutsch then asks us to consider the extreme (but not unreasonable) example of a computational problem so difficult that its solution contains more intermediate steps than there are particles in the observable universe. The relevant number of particles is close to 10^80, according to cosmologists and elementary particle theorists, and if we were to somehow use all of them to construct the fastest possible classical computer we still couldn't compute an algorithm that took, say 10^500 steps. In the context of a quantum computer that actually performs such an enormous calculation, and does it within our lifetimes, Deutsch poses this challenge: since the calculations must have been performed somewhere, *"if the universe we see around us is all there is, where are quantum computations performed?"* (7)

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The question of where quantum computations are performed simply cannot be answered without reference to parallel universes. As with the interference patterns of photons, while you can understand what a quantum computer can do with either interpretation, only with the Many Worlds Interpretation can you explain how the quantum computer is doing it. And this is the bottom line. If parallel universes do exist just like ours, that seems like a pretty important thing to understand about physical reality, and Deutsch believes that when the interference phenomena of quantum theory and the suggestive possibilities of quantum computation are fully understood, the evidence becomes almost irresistible. This reader, for one, remains quite convinced.

So what else might one be able to do with a quantum computer? How about building a virtual reality generator that simulates reality just as well as the real thing? Deutsch argues that the fact that virtual reality is even possible represents something fundamentally important about physical reality. He sums it up with a new version of the Church-Turing principle, named after the mathematicians Alonzo Church and Alan Turing who were instrumental in the creation of the theory of classical computation in the mid 1930's. His Church-Turing Principle states that "every finitely realizable physical system can be perfectly simulated by a universal model computing machine operating by finite means."(8) Deutsch believes that the Church-Turing Principle should be regarded as a full-fledged physical principle, with the same status as the law of conservation of energy and the second law of thermodynamics. But true tests of this principle must await the construction of viable quantum computers, a major technological hurdle to say the least. But one cannot deny that the possibility of a perfect virtual reality generator is as compelling as anything currently discussed in science.

To be fair, it should be noted that the Many Worlds Interpretation of quantum mechanics is currently not the accepted interpretation of the scientific community today. As it stands, the dominant paradigm of the physics community at the turn of the millenium is still entrenched in the single-universe worldview. As a veteran of two quantum mechanics courses here at UC Berkeley, it has been quite clear to me that a fair treatment of the Many Worlds Interpretation is in no way a part of the curriculum. The reason for this, as noted before, comes from the fact that quantum mechanical calculations produce the right answer regardless of which interpretation you accept. One can easily use quantum mechanics as an extraordinarily accurate predictive tool, *whether you understand what is actually happening or not.*

But it is Deutsch's belief, and mine as well, that to use the predictive power of quantum mechanics without understanding how the underlying phenomenon works is simply not good enough, and is nearly tantamount to subscribing to a belief in magic. Rather than magic, Deutsch simply asks us to believe that other universes like ours exist. On the surface, this suggestion does seem incredible, but as David Hume once said, "A wise man, therefore, proportions his belief to the evidence."(8), and at this point in the history of science, the evidence for parallel universes simply cannot be ignored. BSJ

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(2) David Deutsch was awarded the prestigious Paul Dirac Medal and Prize in 1998,
"For pioneering work in quantum computation leading to the concept of a quantum computer and for contributing to the understanding of how such devices might be constructed from quantum logic gates in quantum networks." http://www.qubit.org/people/david/DiracPrize/DiracPrize.html
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Check out David Deutsch's website:
http://www.qubit.org/ people/david/David.html