schemes, honed to protect both biodiversity and other ecosystem services, are being implemented, aligning economic forces with conservation.

So far these marriages of human enterprise and conservation are small, localized efforts, often subsidized by external resources. Urgently needed are a scaling up of these experiments and a critical analysis of what works and what does not. With *Win-Win Ecology*, Rosenzweig provides the inspiration. What we now need is the hard work of implementing his vision, without surrendering too much in the process.

PHYSICS

Breaking Barriers to Quantum Computing

Andrew J. Landahl

Sometimes great barriers provide great opportunities. While we clamor for faster and faster computers, engineers are working harder than ever to miniaturize components to meet our demand. Before too long—some pundits predict by 2030—they will come face-to-face with the so-called "quantum limit." In this realm, electrons behave less like baseballs and more like weird waves of many possible baseballs. Even worse, any attempt to extract information from such quantum objects would necessarily disturb them via the famous uncertainty principle. Instead of this being seen as the fatal blow to miniaturization, a new and more productive viewpoint has emerged: why not coax the weird quantum waves themselves to compute? To the surprise of many, not only can this be done, but for some problems doing so is a radical improvement. As George Johnson writes in *A Shortcut Through Time*, "Quantum computing would be to ordinary computing what nuclear energy is to fire."

A Shortcut Through Time
The Path to the Quantum Computer
by George Johnson
Knopf, New York, 2003. 221 pp. $24, C$36. ISBN 0-375-41193-3.

To better appreciate this comparison, imagine storing a bit, a 0 or a 1, in a system at the quantum limit. Quantum physics tells us that such a system can also store any superposition of both bit values; in essence it can store both a 0 and a 1 at the same time, a state Johnson denotes by ⦶. (That is, a 0 and 1 written in the same space, not the Greek letter phi.) Compute a function on such a quantum bit (or qubit), and the function is computed on both possibilities at the same time. Stranger still, compute a function on three qubits in the state ⦶ ⦶ ⦶, and the function is computed on all eight possible bit combinations at once. A little calculation shows a few hundred qubits would allow one to compute a function on more possibilities than there are atoms in the visible universe.

Image not available for online use.

Form, not substance. Johnson describes his anticlimactic experience with the Geniac to emphasize that "a computer is…just a box with a bunch of switches."

This exponential explosion seems less exciting once one learns that reading out the answer returns only one, randomly chosen function value of the many possible. The magic begins when the questions posed are more clever. Suppose, for example, one asks not what the function on a single input is, but what its periodicity over all inputs is. A quantum computer can solve such a problem extremely rapidly—and in less time than it would require to evaluate the function separately on each input. It is as though a quantum computer makes an end-run around all classical computations needed to find the answer—what Johnson calls "a shortcut through time."

Like computer engineers, Johnson also faces a great barrier. Challenged by a magazine editor to write "a short book explaining how [a quantum computer] would work," Johnson has no special expertise in either quantum physics or computer science. Yet some of the most conceptually abstract ideas from these fields are critical to understanding quantum computers. As with quantum computing, the presence of this barrier makes the final product better. Relying on his skills as a science writer for the *New York Times*, Johnson uses clocks, tops, and waves to explain a Tinkertoy version of quantum computing that quickly gets the reader involved and hungry to learn more.

The science in the book is fairly accurate, and the few minor lacunae are small enough to ignore when one considers the benefit: Johnson's powerful illustrative analogies and nearly kinesthetic accounts of how quantum computers function. Readers are privileged to hear "silently clattering switches" and witness "a number refracted through some kind of mathematical prism." Readers will also feel comforted by Johnson's personal and amiable tone. For example, when discussing computational universality, he relates his childhood experience with the Geniac Electric Brain, a toy he disappointingly learned was made of switches and bulbs instead of the colorful transistors and capacitors he had hoped for. One aspect of newspaper writing that is blessedly absent from the book is an over-reliance on sensationalism: Johnson devotes a fair amount of space to the stiff challenges faced by those struggling to build large-scale quantum computers; the largest to date is only seven qubits large.

In such a short popular book, it is impossible to cover every topic. Indeed, since Johnson began his book, quantum computing has blossomed into quantum information science. That field is now exploring the limits and speedups for many information-related tasks including communication, cryptography, metrology, compression, error-correction, and even, rather exotically, teleportation. Nevertheless, Johnson surveys quantum computing's demesne admirably, while delving every now and again into an aspect he finds particularly intriguing. My only criticism of this approach is that the rapid changes of subject are a bit jarring and haphazard. I had a hard time following this random walk, and when I reached the end of the book, I did not have a clear vision of where the field is going. Still, those who are unfazed by the zig-zag trip will find some true gems, including a particularly lucid description of Peter Shor's famous algorithm for number factoring on a quantum computer.

Despite some quibbles about its organization, I recommend *A Shortcut Through Time* to nonspecialists seeking to learn more about quantum computers. Don't miss Johnson's journey as he tears down technical barriers and brings the quantum fire from the mountain.

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The author is at the Center for Theoretical Physics, Room 6-405, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA. E-mail: alandahl@mit.edu