A theorist of errors

Growing up on Einstein Street in Haifa, Israel, Dorit Aharonov was perhaps destined to study physics. But she pursued other interests before finally settling on quantum computation. Haim Watzman reports.

To enter Dorit Aharonov's office is to experience a sudden transition between order and disorder. The corridors of the computer-science building at the Hebrew University of Jerusalem are stark, white and neat. Aharonov's office is a jumble of red-and-orange patterned cushions, article reprints and wicker furniture. It's an appropriate setting for a theorist who has proved that when disorder reaches a certain level, the physics of the quantum realm switches into the classical domain of the world we see every day.

Aharonov devotes herself to the theory behind quantum computers. As-yet unbuilt, these machines would harness the power of quantum mechanics to perform tasks that defeat conventional computers — such as factoring large numbers. Aharonov, now 34, has already made important contributions to this goal by showing that a quantum computer could perform reliably and accurately despite a 'noisy' environment.

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> — Dorit Aharonov

Physics runs strong in Aharonov's family. Her uncle, Yakir Aharonov, is a physicist at Tel Aviv University, and her father is a mathematician who taught her the beauty of numbers when she was little. She later chose physics and mathematics for her undergraduate studies, but the quantum world did not initially capture her imagination. She wanted instead to use physics to study the brain.

A chance encounter

"I wanted to solve the problem of consciousness," she recalls. But she began to think that the problem was still beyond the reach of today's science. "Then, one day, at a wedding, a friend asked me for advice about what direction to take in the study of the brain. I advised him to check out what people in computer science were doing," she says.

Realizing she should take her own advice, Aharonov went to the Hebrew University's computer-science building to find someone to talk to. She was directed to Michael Ben-Or and, as she knocked on his door, she says that she had a strong feeling something important was going to happen. It did. Ben-Or told her about quantum computation. "It fascinated me. It was mathematics, physics and philosophy all in one package," she says.

Back then, in 1994, the problem facing theorists such as Ben-Or was how to prevent a quantum computer from crashing. All computers make errors when they operate, but quantum computers are more susceptible to failure. This is because the quantum states on which calculations depend are very delicate: complex phenomena, such as the spin states of atomic nuclei, can store quantum information but this data can easily be lost if the particles interact with their surroundings. A computer can never be perfectly isolated from its environment, so there will always be 'noise' in the system and, inevitably, errors will arise. Moreover, correcting such errors is almost as difficult as doing the calculation in the first place. So will it ever be possible to do a reliable quantum calculation?

"That was the problem I posed to Dorit," says Ben-Or, who became Aharonov's dissertation supervisor and later her collaborator. Working with Ben-Or, Aharonov proved that at a constant but low level of system noise, a quantum computer can still produce accurate results[1].

"I consider her to be one of the most outstanding young people in this field," says Peter Zoller, a theoretical physicist at the University of Innsbruck, Austria. Zoller wants to build a quantum computer, and he says that Aharonov has been instrumental in laying the theoretical foundations on which a real machine could be constructed. As well as her work on error tolerance, he cites an important proof[2] Aharonov developed with Oded Regev and others while working at the University of California, Berkeley. The proof showed that two existing models for quantum computing are actually equivalent and, as a result, made writing quantum algorithms easier.

While at Berkeley, Aharonov extended her work on computers to address a fundamental puzzle presented by quantum mechanics — why its laws are evident in the world of elementary particles, but not in everyday life. At what point does the world switch from looking quantum to looking classical? Is it simply a matter of scale?

Aharonov showed that for many noisy quantum systems, there is a level of noise above which a transition to classical behaviour is inevitable. Such transitions are much sharper than expected from other theories that predict a gradual shift away from quantum behaviour[3].

Ben-Or says that what sets Aharonov apart is her boldness. As a graduate student she was not shy about contacting leading figures in the field to discuss their work, he recalls. Zeph Landau, a mathematician at the City College of New York who collaborated with Aharonov on the model equivalence paper, says that she is focused but not single-minded, finding time to discuss other pursuits.

Aharonov says that balancing life and work is essential to her research. Like many theorists, she says that she has her best ideas when not thinking about work at all. Her daily yoga session is particularly rewarding, she says: "It disperses the fog. My intuition becomes sharper. When there is less struggle, ideas become clear."

Eastern ideas about the interconnectedness of everything also influence her work. For instance, Aharonov is not fixated on the actual construction of a quantum computer. "The most interesting thing that might come out of an attempt to build one is the discovery that we can't do it," she says. By failing, she adds, we might discover some entirely new physics. ■

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1. Aharonov, D. & Ben-Or, M. Preprint at http://xxx.lanl.gov/quant-ph/9611025 (1996).
2. Aharonov, D. *et al.* Preprint at http://xxx.lanl.gov/quant-ph/0405098, (2004).
3. Aharonov, D. *Phys. Rev. A* **62,** 062311 (2000).

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Relaxed: Dorit Aharonov finds her yoga inspires her theories.