FAST COMPUTER IN A COFFEE CUP?

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Body

We can build computers powerful enough to simulate a nuclear explosion, but even our most whiz-bang machines still can't calculate fast enough to predict tomorrow's weather.

Here's the problem: Today's computers still do their calculating sequentially, counting on their digital fingers and chewing on one bit of information before moving at light speed to the next one. Even "massively parallel" supercomputers, machines built with myriad processors to strip apart a problem and mull it over in chunks, can't hack through science's most cosmic problems fast enough to be useful. Why bother asking the fastest supercomputer a question if it's still going to take centuries to spit out a response?

But a ***quantum computer*** - an entirely different animal altogether, one that does its figuring in the subatomic world - now, that would be fast. A ***quantum computer*** could take a question and examine all possible answers, the right ones and the wrong ones, virtually at once. In theory anyway, the right answers would rise to the top like cream on milk, ready for the skimming.

If only researchers could figure out how to build one.

They're working on it. While ***quantum computers*** once were a philosophical conundrum mulled over by theoretical physicists over a round of beers after work, they recently have come under increasingly intense professional attention. One proposal even theorizes that such a computer could do its calculating inside a mug of coffee.

No one laughs anymore at the idea that researchers may one day build this fanciful machine.

The barriers are huge. Ironically, the reasons for the difficulties lie in the same laws of quantum physics that would make such a machine possible in the first place.

The study of quantum physics during the last few decades has taught researchers the arcane rules of the subatomic road. Quantum theorists trying to describe these rules to the uninitiated inevitably use the word counterintuitive, a fancy way of saying it just doesn't make sense.

"Anyone who is not shocked by quantum theory has not understood it," said Niels Bohr, the Danish physicist who helped build the first nuclear bomb.

Most of the "real world" thinks you can be in only one place at one time. We also believe that particles are simply bits of matter.

But in the quantum world, these are the rules: Elementary particles, such as electrons or the photon particles that make up a beam of light, behave like particles and like waves. Theorists believe that electrons hovering around an atom's nucleus follow every possible path at once; the electron can't be said to have followed any one path until it's actually observed. Elementary particles, in a sense, can be in every possible place at the same time. This strange state is called superposition, and it's an important part of how researchers hope to build a ***quantum computer***.

In today's digital computing, each bit of information is either a 1 or a 0. It's either on or off, open or closed. It can't be something in between.

But in the quantum world, a particle can be every possible combination of the two states. It's neither 1 nor 0. It's both. This quantum bit, called a qubit, could, in theory, be linked up with other qubits to create a ***quantum computer***.

Quantum reality creates a serious problem, however. Once you observe the qubit, the moment you measure it, it fundamentally changes. Observation draws the qubit out of the quantum world. It becomes either a 1 or a 0. And your computation is blown.

So ***quantum computers***, if they are to be built, must function without outside interference until the precise moment when the answer is ready, a moment that researchers are learning how to spot.

How then can researchers be certain the qubits are doing their calculating without making mistakes? In conventional computing, this so-called process of error correction can be done by pushing a bit back in the right direction if it gets flipped the wrong way. If you can't interact with a ***quantum computer***, how are you supposed to be certain it's handing out the right answer?

"You take one quantum bit [of information] and spread it over five physical qubits," explains Peter Shor, a mathematician at AT&T Labs Research in New Jersey who is credited with having revived interest in ***quantum computers*** three years ago by proving that such a machine could be made to compute. "You've got one qubit encoded into five qubits. There's enough redundancy that if one is wrong, you can . . . measure how it differs."

Quantum computing skeptic Rolf Landauer, a researcher at IBM in New Jersey, three years ago asserted that no one would ever figure out how to do quantum error correction. He acknowledges that he was impressed when Shor proposed a way to do so. But Landauer warns that Shor's proposal hasn't been tried in large-scale computations, and that even if error correction one day is achieved, ***quantum computing*** continues to face a daunting array of other hurdles.

"My skepticism comes from [the difficulty] in taking each piece of information and putting it through a very, very large number of steps," Landauer said. "There's a great question in my mind whether these clever tricks [that Shor and quantum experimenters have come up with] are adequate to handle a serious amount of computation. My intuitive judgment is that, no, it's just too difficult a thing to do."

Undaunted, researchers are pushing ahead. Several experiments have shown that scientists can manipulate the basic building blocks that could be used to construct a ***quantum computer***. More experiments are planned.

Among the more intriguing proposals is the one that would create a ***quantum computer*** in coffee. Neil Gershenfeld at the Massachusetts Institute of Technology and Isaac Chuang at the University of California-Santa Barbara last month released a paper in the journal Science in which they said they thought they could build a working, limited-use 10-qubit computer in a warm liquid that contains a variety of different organic molecules.

In other words: coffee.

Very limited ***quantum computations*** (such as asking the computer to factor the number 15 - the answer is 5 times 3) could be done inside the tumbling sea of molecules. The mug of coffee would be placed in a strong magnetic field and then hit with radio frequencies in a process called nuclear magnetic resonance spectroscopy. NMR is used by chemists to study the nature of molecules.

In the coffee experiment, the radio pulses would force the nuclei inside the atoms that make the molecules in the mug to "spin" in a specific direction. The spin of an atom tells which way each atom's internal magnet is pointed.

Each molecule then would be made up of perhaps 10 atoms converted by this outside spin control into qubits. The hundred-billion-trillion molecules in the cup each would be a ***quantum computer***, but all the molecules would work simultaneously on the same computation.

The qubits - in this case, the nuclei buried inside the atoms - would be protected from outside interference by their own electrons, spinning protectively around them.

So far, Gershenfeld and Chuang have gotten a vial of liquid containing molecules of alanine to add 1 plus 1 by programming the radio frequency that controls the spin's direction.

Other experimenters have focused on the need to isolate qubits completely from their environment. Using breathtakingly small pieces of equipment called ion traps, they suspend quantum particles called ions - charged atoms or electrons - in a vacuum and then zap them with laser light to turn them into qubits.

At the National Institute of Standards and Technology, a team led by David Wineland and Chris Monroe has been working with ions of beryllium. Inside the trap, Wineland and Monroe line up the ions like a string of charged pearls and then they set it to rocking to and fro.

The motion of the rocking string lets the ions share quantum information up and down the string's length, undisturbed by the outside world. Each ion in the string can be selectively programmed through different types of laser light, Wineland said.

"This isn't something you would want to invest your money in yet," Wineland said. "By anybody's reckoning, this is still a real long shot."

Even if all of the experiments lead to nothing, researchers say, the journey still will have been worthwhile.

"If nothing else, it drives traditional computer scientists to revisit some of their thinking, some of their basic premises," said Nabil Amer, department manager at the IBM Almaden Research Laboratory in San Jose, Calif. "We're still learning about the basic science that's involved. . . . We'll do our darnedest to explore it fully so that, if it doesn't go anywhere, we know that it couldn't have. We don't want to miss anything."

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