COMPUTING IN A COFFEE CUP? SOME PHYSICISTS THINK ULTRA-FAST QUANTUM COMPUTERS CAN BE BUILT, AND A WARM, ORGANIC LIQUID COULD BE THE MEDIUM.

San Jose Mercury News (California)

MARCH 4, 1997 Tuesday MORNING FINAL EDITION

Section: SCIENCE & TECHNOLOGY; Pg. 1F

Length: 1805 words

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Body

WE CAN build computers powerful enough to simulate a nuclear explosion, but even our most whizbang 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 here and elsewhere may one day build this fanciful machine.

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

The study of quantum physics over 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 "counter-intuitive" - 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, a Danish physicist who helped build the first nuclear bomb.

Most of the "real world" thinks you can only be in 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 - things like electrons or the photon particles that make up a beam of light - behave both as particles and as 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.

Infinite combination

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 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 reviving interest in ***quantum computers*** three years ago by proving 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."

A problem of errors

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, 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 saying they think they can build a working - if 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 five times three) 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 currently is used by chemists to study the nature of molecules.

Exploiting magnetic field

In the coffee experiment, the radio pulses would force the nuclei inside the atoms that make up 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 one plus one by programming the radio frequency that controls the spin's direction. OK, so it's not even up to being a hand calculator yet, but it's a start.

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.

Strength in numbers

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.

"We've taken a baby step with this," he said. "We can do only about 10 operations before it dies. . . . On paper, you can have this thing work as well as you want but there's always some external influence causing the manipulations we do to be imperfect. Those imperfections cascade through and if we don't do a better job than we're doing now it destroys the coherence of the system before you can end a calculation."

Wineland said all ***quantum computing*** systems are "far away from this threshold of purity."

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

But researchers are plugging away at the problems. Here in San Jose, the Quantum Information Department at IBM Almaden Research Center has been working with a different kind of ion trap. Instead of the roughly centimeter-long traps used by Wineland and Monroe, the IBM team plans to use "microtraps" with cavities no bigger than the diameter of two human hairs. Dozens or even hundreds of these microtraps can be made on a wafer-like arrangement vaguely similar to today's transistor-packed silicon chips, said department manager Nabil Amer.

Down to individual atoms

He is planning an experiment using scanning tunneling microscopes - devices capable of letting researchers see and move around individual atoms.

Amer wants to try ***quantum computing*** inside microscopically small magnetic dots, called nano-dots, of iron or another metal.

The tip of a scanning tunneling microscope could be designed to set the spin of atomic nuclei inside the dots in much the same way radio frequencies would do in the proposed coffee experiment.

"The appealing thing about this approach, as well as the (coffee) approach, is that you're talking about bulk, not a single ion or a few ions in a trap," Amer said. "If this ***quantum computing*** is to ever take off, the final approach is probably not going to be ion traps. They are not particularly practical, yet they are an excellent tool for testing the theory underlying ***quantum computing***."

Wait and see

Nonetheless, Amer notes, there's no way of knowing whether the magnetic dot experiment will work.

Even if all the experiments lead to naught, 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," Amer said. "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."

Notes

Cutting Edge

Graphic

Photo, Drawing;

PHOTO:PHOTO COURTESY OF RALPH DEVOE, IBM ALMADEN RESEARCH CENTER

An ion microtrap is used by scientists at IBM Almaden Research Center to hold and study charged particles. The center hole in the photograph is about six-thousandths of an inch across, or about the diameter of two human hairs. The colorful circles are two barium ions inside the center hole.

[970304 ST 1F 2]

DRAWING:Reid Brown, Mercury News Staff Artist

(coffee cup with floating computer parts)[970304 ST 1F 1]

Classification

Language: ENGLISH

Subject: ***QUANTUM COMPUTING*** (91%); PHYSICS (90%); QUANTUM MECHANICS (90%); EXPLOSIONS (78%); NUCLEAR PHYSICS (78%); BOMBS & EXPLOSIVE DEVICES (73%); MILITARY WEAPONS (50%); Computer Future (%)

Industry: ***QUANTUM COMPUTING*** (91%); COMPUTER EQUIPMENT (90%); SUPERCOMPUTERS (76%); MILITARY WEAPONS (50%)

Load-Date: October 21, 2002