SCIENCE FILE / AN EXPLORATION OF ISSUES AND TRENDS AFFECTING SCIENCE, MEDICINE AND THE ENVIRONMENT; SCIENTISTS TAKE SUBATOMIC ROUTE TO SUPERCOMPUTERS; INNOVATION: BY APPLYING PRINCIPLES OF QUANTUM MECHANICS, RESEARCHERS HOPE TO BUILD MACHINES THAT CAN CARRY OUT ENORMOUS NUMBERS OF CALCULATIONS AT THE SAME TIME.

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Body

Physicists like simple things: billiard balls that collide in precise, predictable trajectories. Gently rolling sine waves that undulate with comforting uniformity through light and sound and trembling Earth. Equations that pare a problem down to its bare roots, exposing the simple, naked truth underneath. E=mc 2 . F=ma.

They like simple schemes for classifying everything in the universe, and simple recipes for cooking it up. So it's no wonder that physicists tend to freak out when the cosmos gets unfathomably complicated. Take the 1950s, for example, when new "fundamental" particles were proliferating like rabbits, produced by the power of newly developed "atom smashers."

Physicist Enrico Fermi sniffed: "If I could remember the names of all these particles, I would have been a botanist."

The discovery of quantum mechanics--that unruly inner world of the atom--turned out to be even harder to accept. In the quantum world, particles don't stay put like billiard balls, but bounce unpredictably around, obeying only the laws of probability. They can be two places at once, and penetrate impossible barriers.

Einstein said that if quantum mechanics turned out to be the true nature of reality, he would have rather been a cobbler or even worked in a gambling casino than be a physicist.

Physicist Erwin Schroedinger reportedly said: "If one has to stick to this damned quantum jumping, then I regret having ever been involved in this thing."

Now, some physicists at Caltech have taken that very "damned quantum jumping" and turned it into a possible solution for some basic problems in computing, they said in a recent briefing.

In effect, they've taken a liability and made it an asset. They turned the jittery uncertainty of the quantum world into a promising new approach to handling huge, previously unmanageable, problems.

The fact is, some things are just too complicated to compute--no matter how powerful your computer. A classic example of such a so-called hard problem is the "traveling salesman" question. If a salesman has to visit stores in, say, 30 cities, how does he arrange his trip in order to travel the fewest possible miles?

If you try to calculate all the possible routes in such problems, the task becomes impossible. "It's easy enough in theory to count up all the paths the salesman could take ," says Caltech physicist Stephen Koonin. "But even if you could count a billion paths per second, you'd still need a million times the age of the universe to do it."

If the salesman decides to add another city to his list at the last minute, the number of possible solutions to his routing problem grows faster than exponentially.

Figuring out the most efficient way to connect cities (or anything else) is critical in countless real world situations. How does the telephone company best link phones, for example? How does a company distribute its goods?

Other hard problems abound in mathematics. Many have far-reaching real world implications for everything from encryption of state secrets to solving problems in fundamental physics.

Recently, scientists have realized that the complexity of the quantum world may be just the thing to match wits with hard problems. They're using the very same uncertainty that made Einstein throw his hands up in despair to build massively parallel subatomic computers.

A so-called ***quantum computer*** would work by dividing up hard problems into a virtually infinite number of bit-sized pieces that could be solved simultaneously. The approach works because any subatomic particle always exists in many states at once. If a particle is spinning along one axis, for example, it's also spinning at all other possible axes at the same time. Only when it's measured does it "decide" how it's really spinning.

As a rough analogy, think of a spinning coin. Is it heads or tails? Well, it's both until you stop the spinning. Then it becomes one or the other.

In the same way, a particle's energy coexists in many different states at once. So do other properties of quantum particles. Instead of being here or there, these subatomic multiple personalities are partly here, partly there, partly this, partly that, partly heads, partly tails.

Quantum computers would take advantage of this complexity to allow a computer to carry out enormous numbers of calculations at the same time. Instead of encoding numbers in bits, these computers would use quantum bits--or q-bits--which contain all the possible quantum states.

In effect, calculating on a ***quantum computer*** would be like calculating on both sides of a spinning coin at the same time--except that quantum states are far richer and more varied than simply heads or tails.

"What gives ***quantum computing*** power is the ability to do many things at once," Koonin said. "You put in atoms that are superimpositions of all possible states at once. So, in a sense, you do all possible calculations at once."

Where normal computers are stuck in the digital world of ones and zeros, ***quantum computers*** could--theoretically at least--have nearly infinite power.

Of course, none of this is close to applications, and there are countless theoretical and practical problems. For the time being, the scientists at Caltech (and other institutions) are approaching the challenge from many different angles--from exploring mathematical codes to devising error-correcting mechanisms to building actual primitive quantum circuits.

"Nobody knows how this is going to shake out," said Caltech physicist Jeff Kimble, who's actually building crude quantum circuits. "But it's a safe bet--if humanity survives long enough--that we will have ***quantum computers***."

Quantum mechanics has always seemed too spooky to be practical. And yet it led to the entire microelectronics revolution--from transistors to semiconductors. So who knows? Maybe the physicists will put quantum weirdness to everyday use again.

If they do, it won't be the first time that complexity has made a harder problem simpler. Einstein himself showed how the universe is much easier to understand in four dimensions rather than three, and some physicists today believe that it's simpler still in 11 or even 12 dimensions of space and time.

So it's encouraging that scientists are coming to terms with complexity. After all, the yearning for orderly arrangements often led physicists astray. Johannes Kepler struggled for decades to shoehorn the elliptical orbits of planets into perfect circles that would stack neatly inside geometric shapes--like Cinderella's stepsister trying to squeeze her big fat foot into the slim glass slipper. He wasn't successful either, but he did discover the laws of planetary motion in the process.

These days, physicists are studying many complex phenomena that were considered beyond their reach only a decade ago--from clouds to chaos to the human mind. If physicists still don't love complexity, at least they've learned to appreciate its sometimes surprising potential.

Complexity Made Simple

Physicists at Caltech hope to turn the uncertainty of quantum theory into a new approach to handling huge, previously unmanageable problems.

Quantum Mechanics

A particle's energy coexists in many different states at once and can be quantified only as it exists when measured. Think of a spinning coin. Is it heads or tails? It's both until it stops spinning.

The Traveling Salesman Problem

Programmed to recognize all possible outcomes at once, ***quantum computers*** could carry out enormous numbers of calculations at the same time.

In fact, they would be able to solve challenging tasks like this one:

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If a salesman has to visit stores in 30 cities, how does he decide which roads to take to cover the shortest distance?

The Quandary: Finding an answer seems simple enough. But even with the fastest computers such calculations become increasingly difficult with each new variable, eventually becoming unsolvable within a reasonable time span.

Graphic

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