In race toward quantum computing, North Carolina takes center stage

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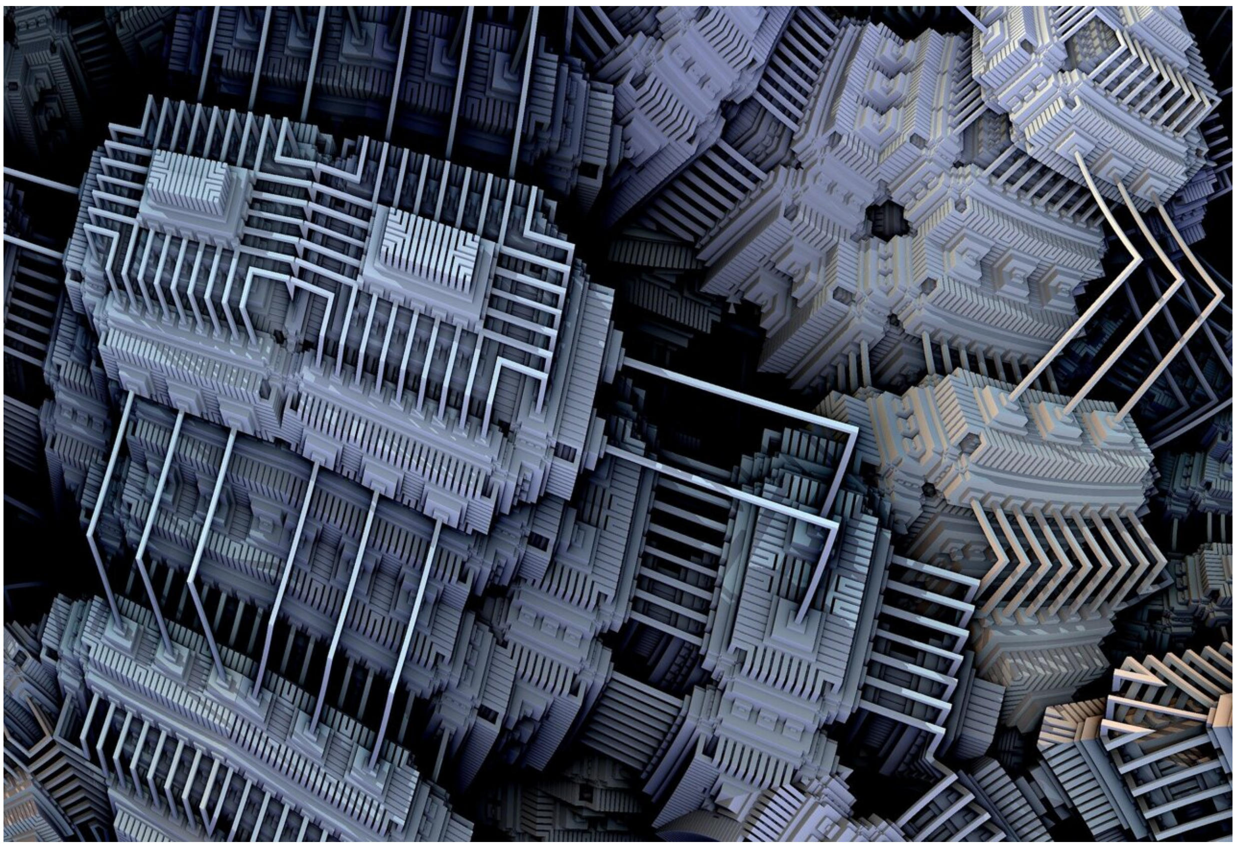

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In the 1950s, computers were bulky, inefficient and limited. They ate up entire rooms but couldn't go beyond rudimentary calculations.

As you know, these machines didn't stay simple; the mid-20th century computer modernized, compacted, and went on to change the world. This is the path many believe quantum computers are now on: elementary today—transformative tomorr... well, we'll see.

The promise of computers based on subatomic physics is tantalizing. In theory, problems that would take classical computers years to solve could be handled by quantum computers in minutes, bursting open advancements in finance, chemistry, artificial intelligence, logistics, cybersecurity and more.

With exponentially enhanced calculating power, scientists may have the tools to discover new medicines. Financial firms could better optimize portfolios. Companies would route supply chains more efficiently, and meteorologists would grow more accurate. Hackers might use quantum's power to bypass passwords but companies and nations could counter by deploying quantum computing to strengthen their cyber defenses.

The possibilities of what quantum could accomplish are vast and hard to pinpoint. Researchers don't know when a real-world quantum breakthrough will occur, but many do say "when," not "if."

"Quantum is progressing faster than many people are anticipating," said Eric Ghysels, a finance and economics professor at University of North Carolina-Chapel Hill. "This thing is coming, and you better be prepared."

Governments, businesses and universities worldwide are spending heavily to prepare for quantum. And in the past few years, the three corners of North Carolina's Research Triangle—Duke University, North Carolina State University, and UNC—have each made distinct contributions to this emerging field, turning the state into a legitimate quantum hot spot.

The power and the noise

In 2018, IBM picked N.C. State's Centennial Campus as the site of its first IBM Quantum Hub in North America.

Two years later, Duke partnered with the Maryland-based company IonQ to open the Duke Quantum Center inside downtown Durham's Chesterfield building. Under their arrangement, IonQ has exclusive rights to the intellectual property the lab produces while Duke has received equity in the public company.

IBM and IonQ—and by extension N.C. State and Duke—are racing toward a common goal: to achieve what's known as "quantum advantage," the still-elusive moment when a quantum computer can perform a real-world task better than a classical computer. (The term "quantum supremacy" refers to a moment when a quantum computer achieves something a classical computer could never accomplish.)

But chasing quantum advantages is where similarities between the two facilities end, said Chris Monroe, cofounder of IonQ and the director of the Duke Quantum Center. "IBM's approach and our approach couldn't be more different," he said.

To understand their differences, it helps to understand some of quantum's underlying science.

Quantum computers reflect the physics of the subatomic world to manage information. While classical computers run on bits represented by digital 1s and 0s, quantum computers use quantum bits, called qubits, to display microscopic states in a much more complex manner.

A pair of quantum mechanical phenomena make these machines exponentially more advanced. The first is called superposition—the capacity of a qubit to be in multiple positions at once until it's measured. The second is entanglement, which is how different qubits are interwoven.

All this can be quite confusing to the layman, and even to other scientists, quantum researchers acknowledge.

"The laws of microscopic physics look very, very different from what you and I experience on a normal day," said Patrick Dreher, the chief scientist at N.C. State's IBM Quantum Hub.

Instead of single answers, quantum computers spit out probability distributions. For example, they wouldn't say 2 + 3 = 5 but would answer with a range of probabilities peaking around 5. This is one of the reasons researchers say quantum computers will augment, but never fully replace, digital Macs or PCs. Quantum machines could handle massive calculations, but quotidian tasks like Microsoft Word, basic mathematics and streaming videos may always be best served by classical computers.

So, what's keeping quantum computers from reaching their potential? There are several hurdles.

As one might expect, the subatomic realm is difficult to control. Atoms naturally bounce around, which can cause contamination that leads to "noisy" results. The microscopic interactions computers must capture occur incredibly quickly, requiring extreme precision, and when errors arise, attempts to correct one qubit can easily interfere with other qubits.

"It's a fragile machine," Dreher said. "And because they are noisy, they have a limited ability to keep doing computations forever."

Despite their limitations, quantum computers have evolved from theory to tangible, functioning machines. Researchers have named this current stage the Noisy Intermediate-Scale Quantum, or NISQ, era. There are several intermediate-scale, noisy computers running today, with Dreher saying no one knows which will be "the home run."

Lasers, atoms and gold chandeliers

Of all the quantum computers in the world, IBM's are likely the most ornate. Nicknamed "chandeliers," they feature gold-plated, five-level apparatuses with an orderly progression of tubes and wires running down to single silicon processor chips. At the bottom rung, each chandelier cools a superconducting chip.

And by cool, IBM means really, really frigid.

Quantum researchers attempt to control subatomic activity by creating extreme environments, and the chandelier does this with temperature. At its lowest level, the temperate is .01 degrees Kelvin, making it one of the coldest places in the universe.

IBM operates more than 20 quantum computers around the world, from upstate New York to Japan, and they offer members of their quantum network—like N.C. State—exclusive access to advanced computers which are kept inside a metal silo and behind a glass cube like a museum art piece. As a member of the IBM Quantum Network, N.C. State scientists can run remote experiments on these computers through the cloud.

Duke students, on the other hand, have access to a quantum computer they can touch. The Duke Quantum Center studies a type of computer called ion-trap, which levitates individual atoms above a gold-plated silicon chip in an airless vacuum. Lasers are then shot at the atom to modify the state of the qubits inside the atom and affect how they interact. Chris Monroe compared the process to plucking a guitar string.

The handful of ion-trap computers at Chesterfield are esthetically less impressive than IBM's chandelier. They stretch out like a crowded city—vacuum chambers, camera lenses, modulators and lasers intricately huddled together. Monroe touts these machines as the most advanced ion-traps in the world and believes once the engineering obstacles are overcome (in short, it's very difficult to precisely strike atoms with lasers), IonQ computers can be widely available.

"We envision a future where quantum computers are in people's pockets," he said.

UNC tackles fintech

While N.C. State and Duke focus on quantum research, UNC is a national leader on quantum technologies in finance.

In May 2020, the school started one of the country's first webinar series on applying quantum to business. To meet the growing demand for quantum, the UNC Kenan-Flagler Business School has adjusted its curriculum to include more about quantum. "The stakes are high," said Eric Ghysels. "A lot of financial institutions realize they better get started now, even if the science is a few years away."

The financial industry is well positioned for early quantum applications. First, it's an analytic-based industry where precise timing and price modeling can mean billions. Many foresee quantum optimizing portfolios and delivering unprecedented account security. Second, with so much money on the line, deep-pocketed companies are making significant investments in the field.

In March, Fidelity entered a partnership with N.C. State's hub, and IBM itself is interested in the research its hub produces for finance purposes. "In terms of fintech, the Triangle is becoming a considerable force," Ghysels said. "Companies want to hire here and settle here."

The Triangle lacks the concentration of quantum companies seen in cities like San Francisco, Boston and New York, but there are signs the commercial side of quantum is burgeoning locally as larger companies like Apple and Google enter the market.

The California quantum computing manufacturer Atom Computing recently based its executive office in Cary, and startups like Dark Star Quantum Lab in Apex seek to find a niche in quantum consulting.

"It makes sense this would be a good place for quantum in terms of applications," said Dark Star CEO Faisal Shah Khan.

Khan noted the Triangle's relative proximity to the financial capital of New York City (same time zone, quick flight away) makes it an even more attractive place for quantum and fintech.

'It will fail in some interesting way'

So when will quantum computers be ready?

"If I knew that, I wouldn't be here as a professor," Patrick Dreher said. "I'd be on Wall Street, or I'd be talking to (venture capitalists). You're asking me in 1949, 'When are we going to build a digital computer that won't have vacuum tubes and need a whole room to make it work?' This is why people win Nobel Prizes."

In 2019, Google announced it had achieved quantum superiority on a contrived mathematical problem, meaning one that doesn't relate to a real-world situation. IBM pushed back on Google's claim, and the quantum superiority debate lingers.

Quantum technology remains in a "pre-competitive stage," said Dennis Kekas, an associate vice chancellor at N.C. State's Centennial Campus. By this, Kekas meant companies generally still share their findings in service of scientific advancement. In academia, UNC, Duke and N.C. State host a weekly Triangle Quantum Computing Seminar Series throughout the school year, inviting experts from around the globe.

At Chesterfield, Duke Ph.D. students are on the front lines of quantum research. Their current lab work focuses on getting ion-trap computers to communicate with each other, sharing information between machines like classical computers can do now. In recent years, they have seen colleagues go on to jobs as quantum business consultants, continue in academia, join IonQ, or get brought into national labs like Los Alamos.

Asked about the future of quantum, the students' perspectives were a reminder that no one knows for sure—not them, not their teachers, not the companies that might hire them—if the quantum dream will ever be realized. They spoke of keeping the long view in mind and noted quantum advantage isn't likely to be right around the corner.

Jameson O'Reilly, a fourth-year Ph.D. student at the lab, said he believes quantum advantage will eventually be achieved, but if it isn't, he said it still will have been worth the effort.

"I think that if it doesn't happen, it will fail in some interesting way," he said. "In a way that gives us more understanding of the universe."