Taking the quantum leap

Why now?

IBM Institute for Business Value

A quantum tipping point

Given the opportunity, most businesses probably would leap at the chance to go back in time to capitalize early on yesterday's game-changing technologies, such as the internet. The chance to get ahead of the competition is here again today with quantum computing. The technology is maturing every day and it's now at an early commercialization tipping point. Quantum has the potential to reinvent the worlds of business, science, education and government in fundamentally new ways.

Understated or overhyped?

At its essence, the word "quantum" evokes wonder. Because the word is attention-grabbing, companies use it to brand products as diverse as internet browsers, batteries, fishing reels and healthcare services. But what should truly grab attention is the fact that prototype quantum computers are now commercially available.

What makes quantum computing extraordinary is that it's based on quantum mechanics, which is the deepest explanation of reality available. Quantum mechanics underpins our natural world. Similarly, quantum computing becomes a fundamental building block of computing solutions. Quantum computing exploits the properties of subatomic particles to process information. Richard Feynman, a noted theoretical physicist, identified the potential for quantum computers as far back as 1981.[1] Today, researchers are progressing quantum computing from academic theory to the threshold of commercialization.

This report focuses on quantum computing, which is one of four areas where quantum-related research is exhibiting significant advancement. The other three are quantum communications, quantum cryptography and quantum sensing. While commercially-available, fault-tolerant quantum computers flexible enough to solve any problem may be more than a decade away, businesses may benefit from some aspects of quantum computing as early as in the next five years.

The importance of quantum computing is both understated and widely overhyped at the same time. Perhaps it's appropriate for a major computer science breakthrough that allows information to exist in multiple states and places at the same time. Quantum computing applications use this feature to gain efficiencies.

Although it won't replace conventional computers, quantum innovation represents a new computing paradigm. Quantum can work in unison with current computing infrastructure to solve complex problems that were previously thought impractical or impossible. For example, factoring a large number into primes is the basis of modern cryptography. On a conventional computer, this calculation would take trillions of years. On a future quantum computer, in not too many years, it could take only minutes.

Putting the "quantum" in quantum computing

Quantum computing is a new computing paradigm with powerful implications for business, science, education and government. Two properties of subatomic particles known as superposition and entanglement put the "quantum" in quantum computing.

Qubits (pronounced CUE-bits) are the building blocks of quantum computers. They can exist in a state known as quantum superposition. Superposition makes qubits exponentially powerful. A 2-qubit system can exist in a superposition of four states, a 3-qubit system can exist in a superposition of eight states, a 4-qubit system can be in a superposition of 16 states, and so on. As qubits are added, quantum computing capability can grow exponentially.

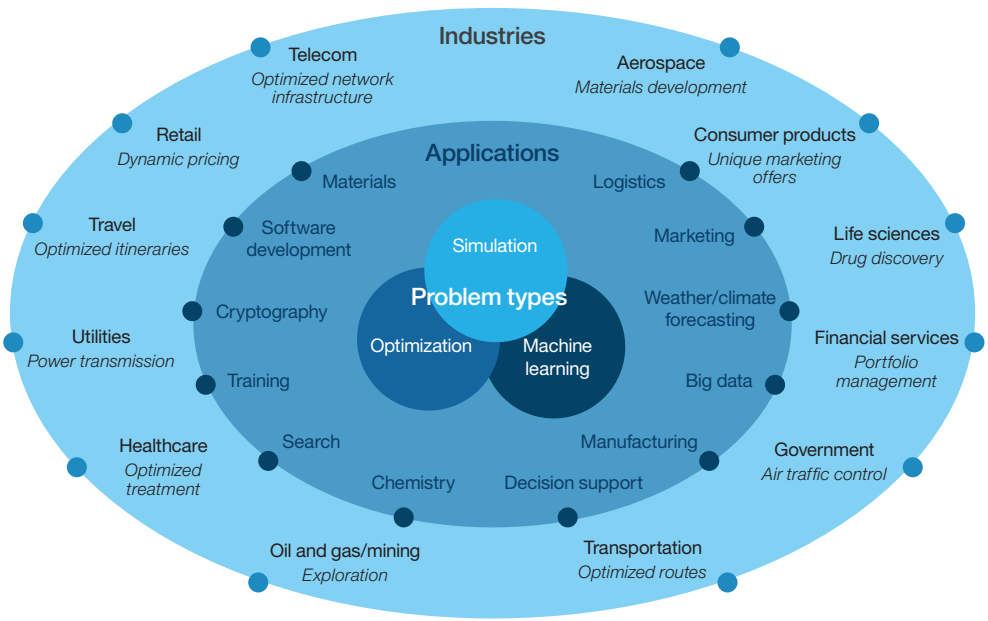
An effect that Albert Einstein called "spooky action at a distance," we now understand as a manifestation of quantum entanglement. Entanglement allows computational exploration of an exponentially large set of opportunities, vastly accelerating the speed at which quantum algorithms run.

The ability to manage superposition and entanglement is what makes quantum computers uniquely effective in solving extremely complex exponential problems.

Applying quantum at work

Given the potential of quantum computing, now is the time to explore the implications for business. Quantum computing is expected to revolutionize the optimization of complicated business systems. It may open the way for breathtaking efficiency in business processes that span everything from basic logistics to complex decision-making (see Figure 1). Quantum computing may be able to solve some of today's known problems faster and provide new tools for solving future problems.

Figure 1
Quantum's potential impact on problem-solving for applications and industries



Consider a logistics problem that involves 50 items, such as a travel itinerary with 50 cities or a shift work schedule for 50 people. Arranging the choices in the optimal order involves working with 30,414,093,201,713,378,043,612,608,166,064,768,844,377,641,568,960,512,000,000,000,000 possible combinations (see sidebar). Historically, humans made these types of decisions based on intuition or prior experience. Calculating the most cost effective (optimal) sequence would take years on a powerful supercomputer, and even then, the answer would only be an approximation.

But finding the best solution on a quantum computer could potentially be completed in minutes. Think of the ramifications for a business that learns its historical approach isn't optimal. Discovering the best answer could save this company vast amounts of money. A new approach could provide customers with profoundly more personalized and precise services and recommendations, and potentially help the company become an industry leader.

Now consider an optimization problem in financial services. For each client, portfolio managers could use quantum computing to optimize a unique mix of exponentially better-tailored investment options in significantly less time. The time saved would give advisors greater capacity and flexibility so they could provide financial planning that is specific to each individual client's investing criteria and risk profile.

But quantum computing can do far more than just solve business optimization problems. Quantum computing also can be used to accurately model the natural world. For example, in molecular chemistry, understanding molecules and being able to simulate their behavior is fundamental to drug discovery. Yet, the best supercomputers in the world can only simulate a system of about 43 electrons, which is terribly inadequate for accurately designing the pharmaceuticals, vaccines and antibiotics that will be required.[2] Quantum computers seem uniquely suited for solving this type of problem.

50! (50 factorial) choices

Calculating 50! choices requires checking 30,414,093,201,713,378,043,612,608,166,064,768,844,377,641,568,960,512,000,000,000,000 possible combinations, one at a time.[3] Using qubits renders the calculation much easier. A quantum computer can represent these choices in a quantum superposition of only 215 effective qubits (log 2(50!) = 214.3). This calculation demonstrates the exponential efficiency anticipated with quantum computing.

Science fiction, quantum fact

Quantum computing's capabilities go well beyond optimization and modeling. Quantum developers are already applying their skills to look at thorny business problems in areas such as data security, fraud detection and machine learning. They undoubtedly will invent dynamic new uses for quantum computing.

Despite claims to the contrary, no one has yet used quantum computing to solve a business problem that could not currently be solved with a classical computer. Only a few, relatively small quantum computers have been built. However, there is a path forward to a transformational quantum future. Homeland Security Research Corp. (HSRC) reports the market for quantum computing will be more than USD 10 billion by 2024.[4] It is only a matter of time. Whether it takes months or years, quantum computing looks to surpass classical computing for specific business problems, such as developing new materials or optimizing airline routes. It's time to get ready.

Companies won't even need to own their own quantum computer to take advantage of its problem-solving capabilities. By 2024, HSRC estimates that quantum-computing-as-a-service will comprise nearly half of the quantum computing market.[5] There are already quantum computers accessible to the public on the cloud for experimentation and education. They are primed to expand.

Ready, set, quantum

Now is the right time for business leaders to prepare for quantum. The conditions are in place to experiment and expand this fundamental new technology. Here are a few initial steps business leaders can take:

- Start engaging now, especially if your organization is involved in chemistry, optimization or machine learning. Quantum computing has made enough progress to warrant some of your time.
- Assign a quantum champion. This person can attend conferences and workshops and assess competing approaches to quantum computing. Champions can look at various ecosystems that are beginning to form around these approaches.
- Evaluate which specific areas of your business may benefit from (or be disrupted by) quantum computing, and which quantum computing approach may work best for you.
- Acquire the right skills. Quantum computing is completely different from conventional computing, right down to replacing the "bit," the base unit of information. People who are open to new problem-solving approaches should be at the top of your list. Consider someone who works on advanced analytics.
- Experiment with a real quantum computer now. Free quantum processors are available over the cloud. Explore the tutorials and simulators and program your own algorithms.[6] Begin considering which problems you want to solve in the quantum era.

As essential as conventional computing is, it has limits. Quantum computing represents a radical new paradigm that may help solve problems we cannot currently solve. Organizations that seek to be in the forefront of this transformational shift will seize competitive leadership. Will you take the leap?

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Experts on this topic

Dr. Robert Sutor

Vice President
AI, Blockchain and Quantum Solutions
IBM Research
linkedin.com/in/bobsutor/
sutor@us.ibm.com

Terry Hickey

Vice President and Partner
Watson, AI and Quantum Computing
IBM Services
linkedin.com/in/hickeyterrence/
hickey@ca.ibm.com

Lori Feller

Partner, Cognitive Innovation & IBM Q
Consulting Global Leader
IBM Services
linkedin.com/in/lvfeller/
lori.feller@us.ibm.com

Route 100
Somers, NY 10589
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Notes and sources

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