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A business leader's guide to quantum computing

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A quantum-powered future is an increasingly likely scenario.

As the technology progresses, we're seeing three key quantum use cases that have the potential to revolutionize industries and supercharge scientific discovery — optimization, machine learning, and simulation. Leaders foresee advantages with the advent of quantum computing, including the ability to tackle novel challenges, boost operational effectiveness, and accelerate the resolution of complex problems.

We'll explore promising applications in each of these areas as quantum computing increasingly gets ready for its close-up.

Quantum is Counter Intuitive

Traditional computers use lightning-fast math to solve problems from spreadsheets to artificial intelligence, whereas quantum computers derive their power from the counter-intuitive physics of atoms. Since they perform calculations differently, quantum computers may be able to solve currently unsolvable problems, while potentially being unable to solve simple problems. They are not "super" supercomputers, but something entirely new.

Learning to program these new devices is also different. Quantum Information Science (QIS) is a nascent field, with developers learning to harness the power of these new machines. Training QIS practitioners is akin to training data scientists; it can take 2 years to become proficient and longer to become an expert.

Meanwhile, will quantum computers be the answer to having too much data and needing more processing power? Not today, but perhaps someday…

Recent Advancements

The field of quantum computing has witnessed remarkable progress in recent years. A pivotal achievement was announced by QuEra, which demonstrated the first programmable logical quantum processor capable of encoding 48 logical qubits[1]. This breakthrough, and others like it, paves the way for quantum computers that can execute complex algorithms to address real-world challenges. This advancement signals a promising trajectory for quantum computing and shows a more defined path toward the development of scalable, fault-tolerant quantum systems.

In December 2023, IBM introduced the 1,121-qubit Condor processor[2], along with the Heron processor, offering new levels in performance and stability. Furthermore, the collaboration between Quantinuum and Microsoft has led to the creation of four logical qubits[3] from 30 physical qubits, achieving an 800-fold enhancement in error rates. Collectively, these milestones not only demonstrate significant technological strides but also edge us closer to realizing a commercial advantage through quantum computing.

Promising Applications

Optimization, Machine Learning, and Simulation

Quantum computing is expected to significantly impact areas such as optimization, machine learning, and physical simulation due to its ability to perform certain complex calculations much faster than traditional computers. For optimization, quantum computing offers the ability to quickly explore and evaluate large spaces of potential solutions, finding optimal or near-optimal solutions more efficiently, which is crucial for logistics, resource management, and scheduling problems. In machine learning, quantum algorithms can potentially train models more quickly and accurately. In the realm of physical simulation, quantum computers can model complex systems and phenomena at a deeper level than classical models, providing insights into fields like materials science, pharmaceuticals, and environmental science, which are beyond the reach of current classical computational methods. These capabilities could lead to breakthroughs that save time, reduce costs, and unlock new opportunities across various industries.[4]

Optimization Algorithms

Optimization problems arise when trying to identify the best solution in a constrained system (e.g., scheduling hourly workers, planning bus routes, or picking the best stocks.) The field of optimization has seen significant advances in the last 15 years,[5] and quantum computing promises to supercharge that progress.

For businesses, better optimization answers can be worth millions of dollars. For some problems, quantum optimization can provide faster, better answers than traditional computers. As such, quantum computers are expected to have major implications for industries that rely on optimization for challenges such as cost minimization, revenue maximization, risk management, logistics routing, supply chain scheduling, resource scheduling, portfolio optimization, and transaction reconciliation. For example, the Port of Los Angeles, one of the busiest container ports in the United States, leveraged quantum annealing technology to optimize its cargo operations[6]. The port reduced the time and cost associated with cargo handling by optimizing the order of container truck loading. The quantum solution enabled the port to lower crane resource usage while increasing the number of crane deliveries by 60%.

In healthcare, quantum computing can enhance efficiency and accuracy in clinical trial design[7]. By optimizing the selection of trial sites and participant cohorts, drug trial outcomes can be shortened, and the likelihood of successful outcomes improved. This is one of several compelling future uses of quantum technologies in healthcare.

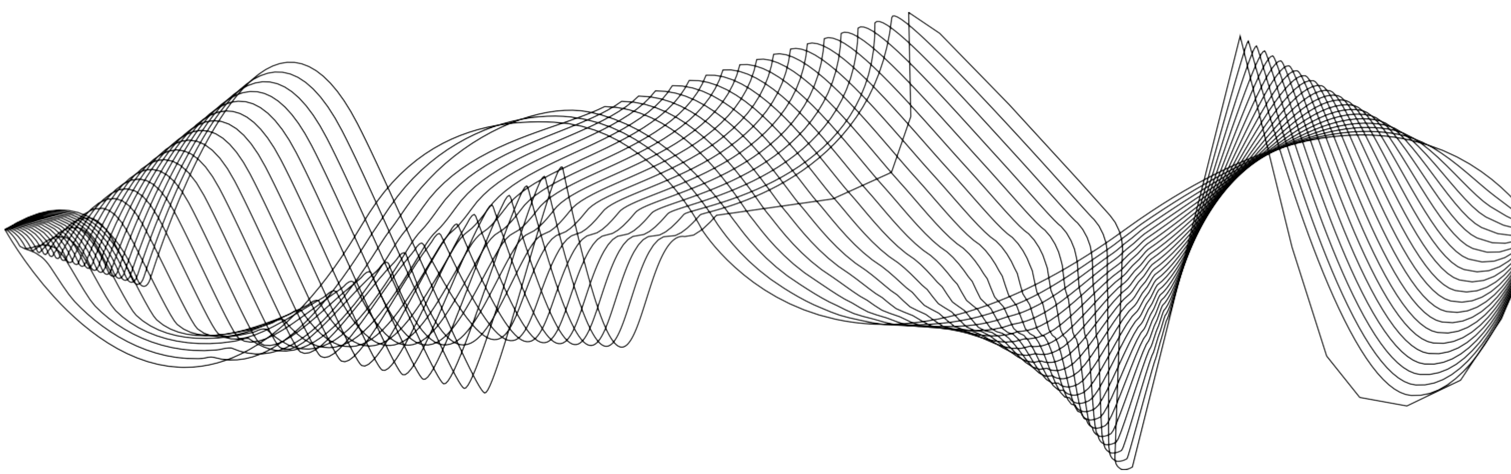
Machine Learning

Quantum Machine Learning (QML) combines the power of quantum computing with machine learning, offering new capabilities. Research indicates that QML appears to be more sensitive to small fluctuations in data, allowing it to train to higher accuracy with less data than comparable classical approaches. As such, QML may transform how organizations identify patterns, make predictions, and gain actionable insights from their data.

In financial services, QML's ability to detect hidden complexities can be used to improve areas like fraud detection. Advanced QML techniques could improve data simulation and prediction. For instance, generative models, especially in the form of Generative Adversarial Networks (GANs) and Quantum Circuit Born Machines (QCBMs), show promise for simulating complex market behaviors and could potentially offer a significant edge in financial analytics. This advantage is crucial for tasks like back-testing financial models against historical data, where traditional models may fail to capture complex market dynamics or suffer from overfitting[8].

In life sciences and healthcare, QML may improve diagnostic models for detecting rare diseases or uncommon occurrences by requiring less input to identify associations. QML may also improve clinical trials by detecting complex patterns and predicting patient outcomes with higher accuracy. Moreover, QML's ability to train models with less data may help in dealing with data use that is restricted by health privacy laws. And QML holds the promise of improving the clarity of medical images, enabling real-time data adjustments for safer trials and facilitating global data sharing to expand collaborative medical research efforts[9].

Roche, a pharmaceutical company, is exploring QML to improve the drug discovery process by analyzing complex biological data to find more precise and faster development processes for new drugs. Cleveland Clinic and IBM recently announced a 10-year partnership to research QML in health care and life sciences to improve patient care, genomics research, and drug discovery[10].



Simulation

Future quantum computers may conduct molecular simulations more efficiently and accurately than classical computers, making them a critical discovery tool for industries that need to predict the properties and performance of materials and simulate or optimize materials and their development processes[11]. As a result, quantum computers could help design engineers develop better pharmaceuticals, plastics, fuel cells, chips, and other products and materials while eliminating painstaking lab work[12].

One such use for quantum molecular simulation is in drug discovery[13]. Pharmaceuticals can take a decade or longer to bring to market because companies should assess billions of possible drug reactions and side effects that vary from person to person. Quantum simulations may allow “in silico” testing which lowers costs and reduces the time to bring life-saving treatments to market. Quantum simulation may also increase new drug success rates and improve safety during human trials, thus, improving clinical trial outcomes. While today’s quantum computers only allow realistic simulations of simple molecules, research is ongoing and rapidly advancing. For example, IBM researchers pushed the boundaries, simulating more complex molecules using current quantum computing hardware assisted by supercomputers[14].

Beyond impact in pharmaceuticals and chemical industries, quantum simulations can provide significant business values in sectors like financial services, automotive, and aerospace industries. For instance, complex financial instruments like options and derivatives can be evaluated more accurately and efficiently using future quantum hardware[15]. Similarly, the design and development of next-generation aircraft and high-performance vehicles can benefit from quantum computing’s ability to solve complex math problems[16].

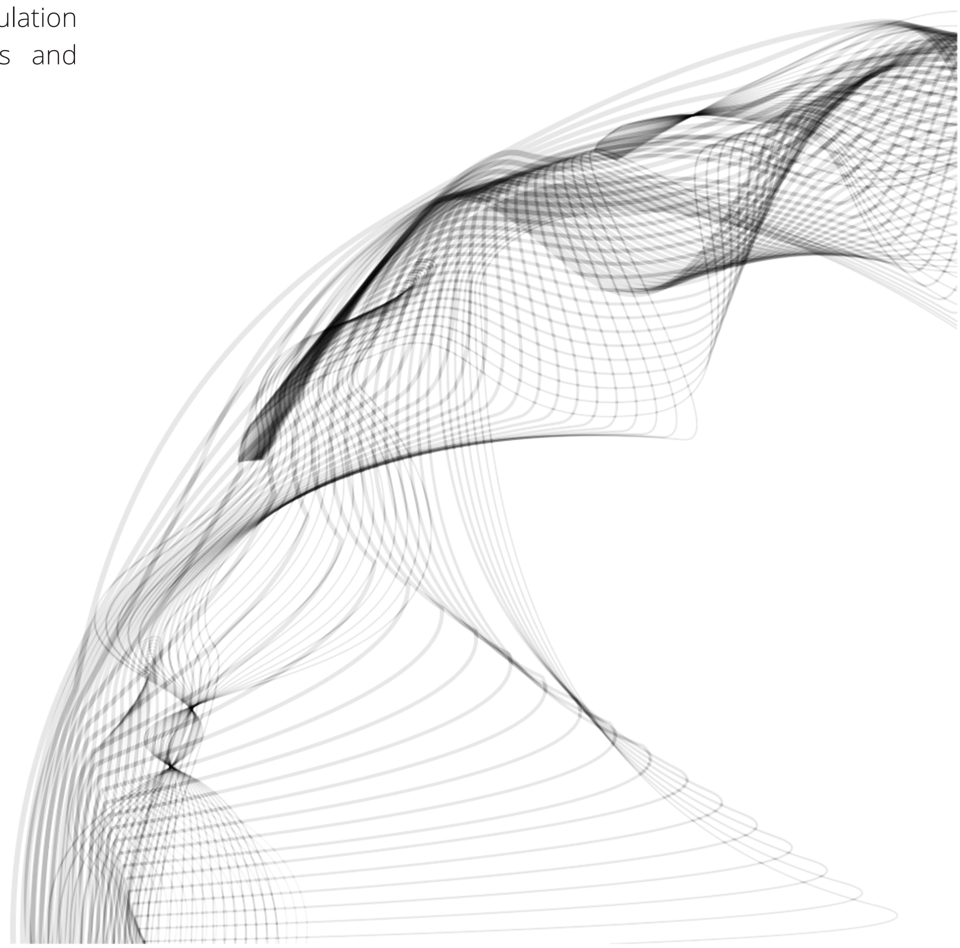


Figure 1: Quantum Computing: Example Applications in Industries

	Optimization Algorithms	Machine Learning	Simulation (Chemistry & Material Science)
	Identification of the best solution or process among multiple feasible options	*Enabling faster processing, training, pattern recognition, and predictive analytics*	*The simulation and modeling of molecular, atomic, and subatomic systems*
Cross-Industry	• Supply chain optimization • Vehicle routing optimization • Scheduling & workforce optimization	• Fraud detection • Anomaly analysis • Advanced predictive models • Recommendation engines	• Materials discovery • Protein structure prediction
Consumer	• Distribution optimization • Pricing optimization • Product portfolio optimization	• Freight forecasting • Disruption management • Targeting engines	• Environmentally friendly material discovery
Natural Resources	• Grid optimization • Distribution optimization • Production optimization	• Drilling location detection • Structural design • Fluid dynamics	• Surfactants and catalyst discovery • Process simulation
Financial Services	• Liquidity optimization • Portfolio optimization • Collateral optimization	• Trading strategies • Anomaly detection • Fraud detection	• Derivative pricing • CAT modeling • Investment, product risk analysis
Government	• City planning • Emergency management • Case assignments optimization	• Fraud detection • Future predictions	• Advanced materials research • Climate change simulations
Health Care and Life Sciences	• Clinical trial optimization • Medical/drug supply chain optimization	• Medical imaging & diagnostics • Genomic analysis • Disease risk predictions	• Molecule interaction simulation • Material & drug discovery
Technology, Media, and Telecommunications	• Network optimization • Infrastructure placement and allocation	• Predictive maintenance • Consumer targeting • Fault analysis in circuits	• Semiconductor materials discovery • Materials process optimization

Approaches to Building Quantum Computers

There are many ways to build a quantum computer. Each approach brings different tradeoffs, considerations, and passionate supporters. The primary approaches being explored today include superconducting qubits, silicon dots, trapped ions, neutral atoms, photonic systems, topological qubits, and quantum annealers, each offering unique methodologies and potential benefits for quantum computing.

Each approach features strengths and distinct challenges. In general, the different solutions tradeoff speed against stability and flexibility against scalability. For instance, building a quantum annealer (a special-purpose computer that focuses on solving optimization problems that uses quantum fluctuations to find the lowest energy state of a system) is more straightforward than building a general-purpose calculating device. Superconducting devices are fast but tend to be less stable whereas neutral atoms and trapped ions tend to be slower but more stable. As improvements occur, the relative tradeoffs evolve. Unlike today's computers, quantum computers tend to interact with their environments, degrading performance and creating errors. Thus, the focus of many quantum computing companies is on improving performance and mitigating errors.

The variety of approaches support vibrant research within the quantum computing ecosystem, presenting numerous opportunities for innovation and breakthroughs. The collective exploration and enhancement of these approaches enriches the landscape, driving technological advancements and paving the way for minimizing or overcoming specific limitations.

Get Prepared

Currently, optimization, machine learning, and simulation are emerging as primary applications for quantum technology, with the most significant impacts expected as quantum capabilities mature. At the same time, business and technology leaders should recognize that future applications could extend beyond current predictions, potentially revolutionizing unforeseen areas.

Decades ago, the early Graphics Processing Unites (GPUs) were designed to enhance the graphics in high end games, today they underlie pioneering AI technologies—a shift few anticipated.
Today, quantum computers are largely being viewed as accelerators for existing computing functions. In the future, new and transformative uses for quantum computers may be discovered, highlighting the unpredictable trajectory of groundbreaking technologies. When it comes to paradigm-shifting new technologies, projections often fail to capture the full range of possible futures.

Talent in quantum computing will be a key constraint as the technology evolves. Given current public roadmaps and timelines, it is important to invest in understanding these technologies today before they become indispensable. Understanding possible use cases for your organization and running proof-of-concepts can help clarify needed skills, organizational constraints, and potential value. Leaders will need to be proactive, given the time lag in building capability and talent – particularly in industries where first mover advantages exist.

Business leaders should remain informed and agile in planning for the future. Quantum Information Scientists may take years to nurture. Given that time horizon, a wait-and-see attitude could miss critical opportunities to test and experiment with the technology while competitors gain ground. We encourage a more strategic approach, heavily seasoned with pragmatism.

- **Understand industry impact.** Learn about quantum's potential repercussions in your industry. What problems could quantum help you solve? Be aware of important technology developments and how others in your field are investing in and experimenting with quantum technologies.

- **Develop and refine your strategy.** Bring together the talent with the skills and knowledge to develop a quantum strategy. You may choose to act today or wait for a trigger—such as a competitive or technology development—that will serve as a prompt for further investment. Decide who will lead the quantum charge when it's time to engage.

- **Test and learn.** Harnessing the power of quantum computing will not be a "one and done" exercise, nor will a week of training suffice. It will require dedicated, sustained investment and effort to realize its value.

Although quantum computing technologies are in their infancy, their potential impact on industries and businesses is too great to ignore. Respect the potential risk of falling behind and be proactive in preparing for the quantum future.

Endnotes

1 Harvard, QuEra, MIT, and the NIST/University of Maryland Usher in New Era of Quantum Computing by Performing Complex, Error-Corrected Quantum Algorithms on 48 Logical Qubits, Dec 6, 2023

2 IBM Debuts Next-Generation Quantum Processor & IBM Quantum System Two, Extends Roadmap to Advance Era of Quantum Utility - Dec 4, 2023

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9 Quantum Machine Learning Revolution in Healthcare: A Systematic Review of Emerging Perspectives and Applications | IEEE Journals & Magazine | IEEE Xplore

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12 A business leader's guide to quantum technology, End note 14, April 15, 2021

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14 Quantum-centric supercomputing: The next wave of computing | IBM Quantum Computing Blog

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