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Hybrid Quantum-Classical Computing

How to unlock quantum computing's power today

Quantum computing is one of the most disruptive technologies to come along in the last few decades. In fact, it's difficult to overstate its potential transformative power. While mainstream quantum computing systems are still in development, hybrid quantum-classical computing (HQCC) can unlock quantum computing's power today. It's an approach that can help early quantum adopters significantly mitigate the risks and challenges associated with adopting this technology.

Through ongoing research and co-innovation projects, Dell Technologies is contributing to HQCC advancements, focusing on enhancing existing technologies and exploring new frontiers.
Our collective efforts are aimed at sharing our learnings to help early adopters speed time to innovation and discovery, and to stay ahead of the technological curve in this rapidly evolving domain.

Make a quantum leap in computational capabilities

Quantum computing changes everything

We believe quantum computing will significantly accelerate the ability to solve problems not possible on classical computers, enabling awe-inspiring advancements in tackling complex problems. Teams will be able to uncover answers to intricate questions in mere minutes - questions that might require today's most powerful supercomputers hundreds or thousands of years to resolve. In scenarios where classical brute force methods are the only viable option, quantum computing will offer a compelling alternative for achieving success.

The potential impact on humanity is as exciting as it is incalculable. Pharmaceutical companies could use quantum computing to vastly increase the speed and efficiency of drug development and to catalyze a wave of life-changing discoveries. Faster, more accurate weather modeling could protect lives and property, helping to mitigate the effects of global climate change on billions of people. Quantum algorithms could be used in chemical materials development for new fertilizers that promise to eliminate famine and support ever-growing populations. The leap-frog capabilities in quantum algorithmic processing unlock truly revolutionary progress across an unimaginable range of use cases.

18% projected increase in quantum budgets for 2025, signaling confidence in the technology's maturation.*

*QuEra Survey Report: Quantum Readiness, January 2025. https://quera.link/ready

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Quantum computing: a primer

Moore's law—which famously predicted the doubling of computer processing power every two years—is running into very real physical limitations that are slowing the pace of innovation with traditional computing. Optimizing code and creating customized processors and accelerators has helped speed up computing performance. But as these measures bump into physical boundaries, the industry is eagerly seeking new ways to increase compute performance that don't require, as Gordon Moore put it, "cramming more components onto integrated circuits."[1] Many are exploring fundamentally different computing architectures, like quantum computing.

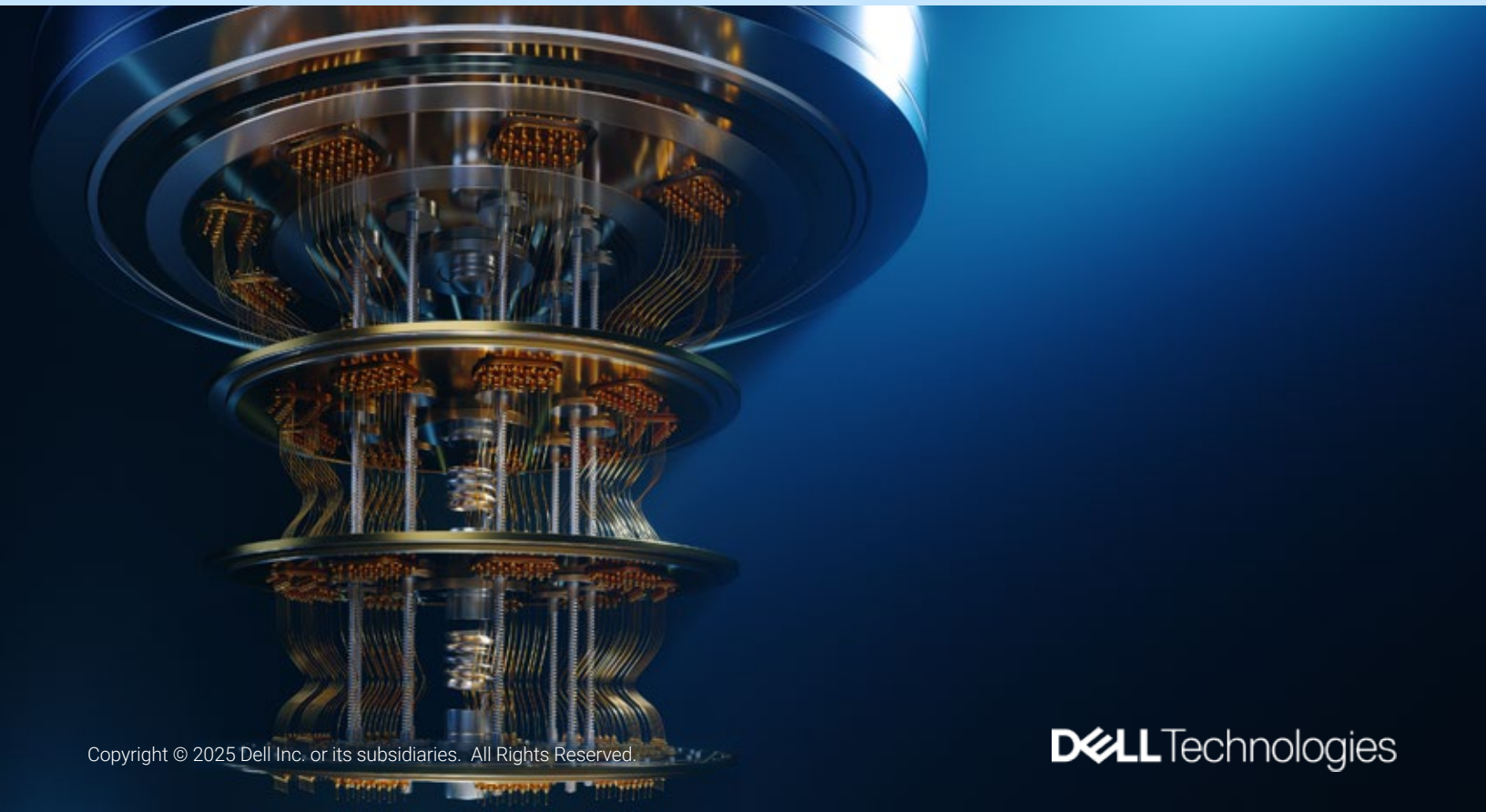
Quantum computing is an approach to developing and programming computing systems that is built on the foundations of quantum physics. As a basis of comparison, a classical computer uses binary digits (bits) that can express a value of either one or zero, meaning two bits can be in only one of four possible states—00, 01, 10 or 11—at any given time. Because the computer can only process one input at a time, it solves a problem the way you might solve a maze, by trying every possible path until you find the way out.

In contrast, quantum computing transcends the realm of traditional binary computing by harnessing quantum phenomena such as superposition, entanglement, and interference. In quantum systems, the fundamental unit of information is the qubit. Unlike classical bits, which are always either 0 or 1, a qubit can exist in a superposition state where its value is not defined until measured. When measured, it will collapse to either 0 or 1 with probabilities determined by its state. Any changes to the quantum state of an entangled qubit instantly affect its paired qubit, harnessing this phenomenon to create an exponential multiplier effect for qubits that significantly enhances processing speed. Due to these properties, a quantum system can process information in fractions of the time it would take classical binary systems, yielding exceptional computational power and the potential to solve complex problems more efficiently.

[1] Electronic Design, Can Advanced Materials Address Moore's Law Slowdown and the Chip Shortage?, June 2022

Yet, quantum computing still has challenges today

Quantum computers are currently in their early stages of development, characterized by limited qubit counts and relatively low fidelity rates. Systems will require significant improvement to achieve practical applications. The main challenges arise from their inherent sensitivity to environmental influences, such as noise and temperature fluctuations, which can cause errors and decoherence in a qubit. Additionally, the control mechanisms required to implement instructions are prone to errors due to the intricate interplay of quantum phenomena, making it challenging to maintain coherence and accuracy. The complexity of quantum algorithms and the need for extensive error correction mechanisms make it challenging to scale up qubit counts and improve overall computational power. Moreover, the quantum computers' limited capabilities in solving complex optimization problems and machine learning tasks, which are critical applications in many fields, highlight the pressing need for HQCC approaches that can leverage the strengths of both paradigms.



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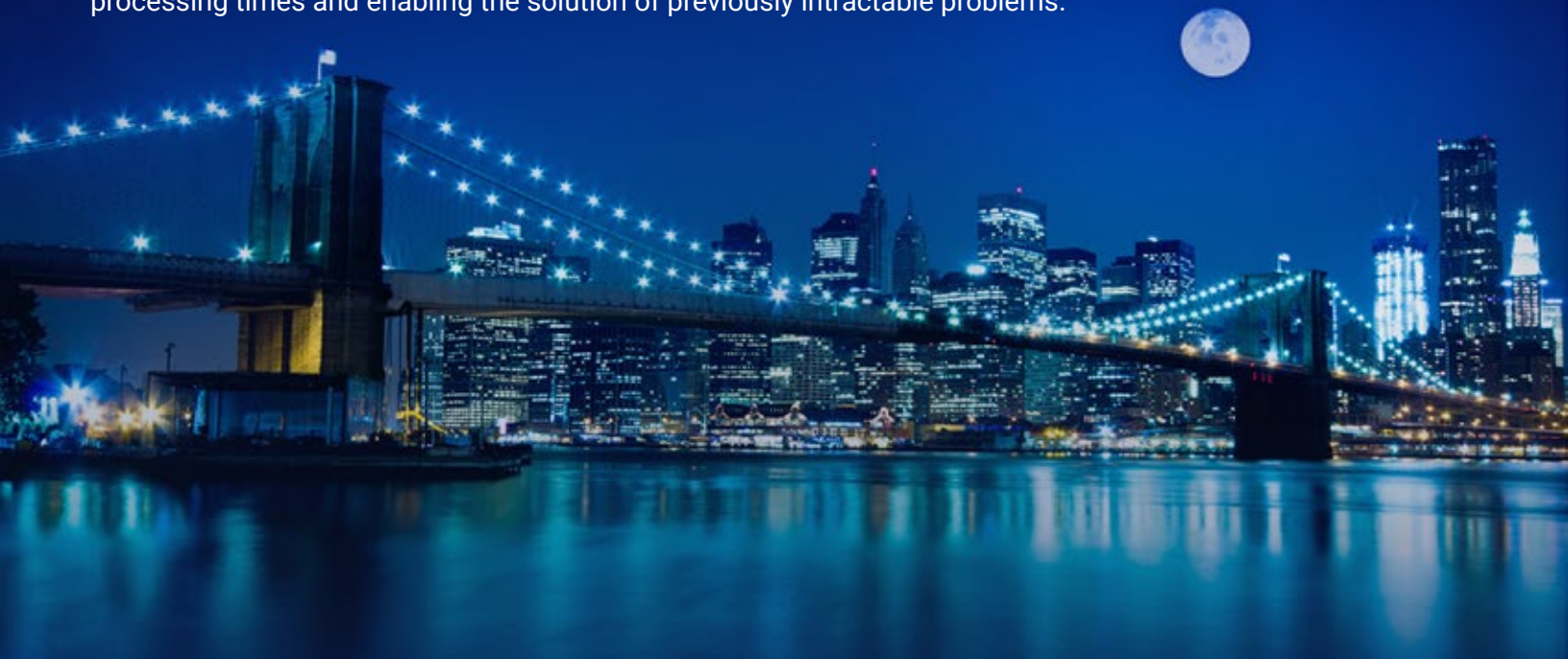
Hybrid bridges the gap

The immediate future lies in HQCC

Given those challenges, the immediate future lies in HQCC, an approach that maximizes current capabilities while paving the way for more advanced quantum systems. HQCC represents a paradigm shift in computational science, combining the unparalleled processing power of quantum computers with the known efficiency of classical high-performance computing (HPC).

HQCC is a computational paradigm that integrates both classical and quantum computing technologies. It aims to leverage the unique strengths of each technology to solve complex problems that cannot be efficiently addressed by either classical or quantum computers alone. There's a common misperception that the quantum computer will replace all classical computers. In practice, quantum systems require classical infrastructure to harness their true power. In an HQCC system, different Quantum Processing Units (QPUs) can be integrated. Another benefit is that virtual QPUs built on classical computing hardware—which emulate physical QPUs and can run quantum algorithms—can be substituted for simulations and experimentation. Additionally, General Purpose Units (GPUs), Neural Processing Units (NPUs), Central Processing Units (CPUs), and other computational resources can be utilized to simulate quantum systems and perform classical data processing tasks. This approach allows for the efficient execution of a wide range of applications by combining the capabilities of both quantum and classical computing technologies.

These hybrid systems can be leveraged to enhance the efficiency of classical algorithms by offloading computationally intensive subroutines to quantum computers, thereby accelerating processing times and enabling the solution of previously intractable problems.



Start your journey to quantum adoption today with HQCC

How can you get started with HQCC? The following three-step approach will help to lower the barriers to entry, minimize the risks associated with adoption, and facilitate the implementation of HQCC systems, bridging the gap between theoretical advancements and practical applications.

Discover

learning & experimentation

Identify

use cases & benefits

Deploy

deployment & ROI

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Discover: Lower the barriers to entry with learning and experimentation

Quantum computing is an emerging field, and hiring quantum talent will continue to be a challenge for the foreseeable future. This can also be a costly undertaking for many organizations. So, the first stage of preparing your organization for quantum computing is to do some foundational research. Look up some introductory guides. Read some articles. If you don't know where to begin, Dell has some great information at dell.com/quantum-computing. Once you're ready to experiment, consider emulation for developing, porting and optimizing code for quantum computing on a classical infrastructure so your organization doesn't have to break the budget to get started with experimentation.

> "This hybrid emulation platform represents an important step forward for the Qiskit Ecosystem and the quantum industry as a whole. The platform allows users to work with Qiskit Runtime on their own classical resources, making it easier for both new users and established quantum developers to build and refine their algorithms. We look forward to working with Dell to expand the horizons of the quantum industry."
>
> — Jay Gambetta, VP of Quantum at IBM[2]

A checklist from Dell to prepare your organization for quantum computing

- [ ] Do some foundational research
- [ ] Look up introductory guides
- [ ] Read some articles
- [ ] Visit dell.com/quantum-computing

[2]Dell Technologies blog, Exploring Hybrid Classical-Quantum Compute, September 2021.

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Solving Unsolvable Problems in Minutes

Classical computer processors can only do one calculation at a time, so the more complex the problem, the longer it takes. That makes answering data-intensive questions subject to physical limitations. A problem that requires more power and time than a classical computer can reasonably accommodate is called an “intractable problem.” Quantum computing can solve these types of problems in just minutes.

Identify: Reduce adoption risks by exploring use cases and benefits

Once you understand the basics of quantum computing, you’ll be ready to start brainstorming ways that your organization can use the technology. Not every computing problem is well-suited to quantum processing. You wouldn’t want to use it to do any kind of calculation that has one exact answer. For example, you shouldn’t use it to calculate your tax bill or process your payroll. On the other hand, it can be very good at solving optimization problems. If you need to choose the best answer from a group of possible right answers, quantum computing may be ideal.

Some organizations are already experimenting with quantum computing for a variety of use cases, noted in the figure on the following page. Even if you aren’t in one of these industries, you probably have similar use cases where it would be helpful. The key is to look for situations that are difficult to model because of a large number of variables. You also want use cases that are intrinsic to your business, where improving operations would have a large impact on your bottom line.

Use cases by industry

Digital services, IT and professional services	Agricultural, chemical and material science	Financial services technology	Healthcare and life sciences	Supply chain, distribution, logistics and transportation	Manufacturing	Security
Consumer recommendations	Chemical product design	Investment risk analysis and investment optimization	Disease analysis	Disruption management	Design optimization and simulation	Secure data communication
Search engine optimization	Product lifecycle	Fraud detection, finance security and transaction settlement	Disease risk reduction	Transport freight forecasting	Structural design and fluid dynamics	Secure data encryption
Video streaming predictions	Oil and gas refining and leak detection	Finance product recommendation and optimization	Advanced diagnostics and imaging analysis	Supply chain and distribution management	Autonomous vehicle navigation	Access control optimization
Digital information and distribution analytics	Reservoir simulation	Portfolio management	Genomics	Warehouse optimization	Fabrication and manufacturing optimization	Cryptography algorithms
Data management optimization	Quantum chemistry and materials discovery	Regulatory management	Clinical trial enhancements	Workforce scheduling optimization	Robotics optimization	Safe tape drive
Network optimization			Medical/drug supply chain	Transportation optimization	Quality control	Blind quantum computing
				Fleet management	Manufacturing supply chain	Anomaly detection

Deploy: Enable frictionless deployment into production and real business benefits

HQCC offers a flexible approach to deploying quantum computing solutions into production. By combining classical processing with the power of quantum computing, Hybrid Quantum-Classical Systems (HQCS) enable developers to create and test quantum algorithms in a familiar classical environment before deploying them on expensive quantum hardware. That means you can achieve frictionless deployment into production, accelerating your entry into the quantum computing era while minimizing the intrinsic risks of embracing a new technology.

This hybrid approach works by providing an emulation environment that allows for rigorous testing and validation of quantum-based solutions, reducing the risk of errors or inefficiencies that can arise from direct deployment onto quantum hardware. With HQCS, you can develop and refine your quantum-based solutions without the added expense and complexity of working directly with quantum hardware. And with improved interoperability between classical and quantum systems, HQCS enable seamless integration with existing infrastructure and workflows. This increased flexibility allows you to adapt quickly to changing market conditions and customer needs. Additionally, HQCS provide enhanced scalability, enabling scaling up or down depending on the problem size, reducing the risk of over- or under-investing in quantum computing resources.

Co-innovate with Dell Technologies

Dell is at the forefront of quantum computing, providing the technology that underpins HQCC and makes tomorrow's innovations possible. Reach out to us if you're interested in tapping into our expertise as quantum computing evolves.

Dell.com/Quantum-Computing | Quantum.Assist@dell.com

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