SPOTLIGHT

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Quantum computing has the potential to disrupt many industries by providing powerful computing capabilities beyond classical computers. Quantum annealing, an innovative approach to quantum computing, offers an approach for organizations looking to solve optimization problems and gain a quantum advantage.

Gaining Near-Term Advantage Using Quantum Annealing

July 2023

Written by: Heather West, PhD, Research Manager, Infrastructure Systems, Platforms, and Technologies Group

Introduction

Due to its ability to harness the quantum mechanics of qubits to perform quantum computations, quantum computing has the potential to be the next industry disruptor. This technology is expected to provide organizations with the necessary compute power salient for solving some of the most complex scientific, business, and societal problems, reaching beyond classical compute capabilities. Consequently, many organizations anticipate that quantum computing will lead to both a competitive advantage and a quantum advantage — that is, the ability to solve a problem faster, more accurately, and in a less expensive manner than a classical compute system.

AT A GLANCE

KEY TAKEAWAY

Quantum annealing is a type of quantum technology that can be used to find the best-fit solution for optimization problems. Because quantum annealing exploits the quantum properties of qubits in a manner that allows for easier scaling and reduced error rates, enterprises can leverage this technology in both the short term and the long term to gain a quantum advantage.

Yet quantum computing is not only a young technology but a technology that differs significantly from its classical compute counterpart. The methods and materials needed to fabricate, control, and scale the qubits that provide these systems with their computational power are undefined, forcing quantum hardware vendors to build their quantum machines from the ground up. As a result, the quantum computing hardware developmental landscape is made up of multiple quantum computing approaches from multiple quantum hardware vendors. Each approach is an attempt to develop high-quality qubits or leverage current qubit technology that allows an end user to gain value when solving their complex problems using quantum. The two most prevalent quantum computing approaches currently under development are quantum annealing and circuit (gate-based) quantum computing.

While much of the hype regarding the future advantages of quantum computing centers around the realization of the circuit (gate-based) quantum model, these systems are far from commercialization due to the fragility of qubits, an issue that may take years to resolve. Currently, these highly anticipated gate-based systems are unable to provide large-scale or near-term advantage. Comparatively, quantum annealing offers an approach for enterprises seeking to gain a quantum advantage when solving optimization problems. Yet this technology is often overlooked.

First launched in 2011, the quantum annealer offers a complementary quantum compute solution for organizations looking to use quantum computing to solve complex, real-world optimization problems and gain a near-term advantage today and an anticipated longer-term advantage in the future. Currently, the largest quantum annealing system available is made up of 5,614 qubits and is built to support real world–size applications with up to 1 million variables and 100,000 constraints when operating in a quantum-classical hybrid environment. Organizations have built more than 250 quantum annealing–focused applications across multiple domains such as manufacturing and logistics, financial services, transportation, and life sciences.

The list of organizations using the quantum annealing system is extensive and spans many different industries including financial services, life sciences, and manufacturing and logistics. Quantum annealing not only can be used by companies to solve complex optimization problems today but also will be suitable for solving even more complex optimization problems as the quantum annealing systems continue to scale. So what exactly is quantum annealing, and why is it advantageous to begin experimenting with this quantum technology now?

The Benefits of Using Quantum Annealing to Solve Optimization Problems

Optimization problems are prevalent across all industries and can be the most salient hard problems that businesses need to solve to stay competitive. When solving an optimization problem, organizations are less concerned about finding the absolute right answer, instead focusing on the best-fit answer for a set of given parameters. As a result, optimization problems can be defined as energy minimization problems whereby the lowest-energy state results in the most optimal solution.

Using the quantum properties of superposition and entanglement of qubits, quantum annealing systems accelerate and find the optimal solution for problems with several possible solutions by measuring the energy passing through the qubits (see *IDC's Worldwide Quantum Taxonomy, 2023,* IDC #US49198723, May 2023). Prior to solving an optimization problem, qubits sit at the bottom of an energy wave, like a rock at the bottom of a dried-up well. These qubits are in their superposition state. When a quantum annealing program runs, the energy state (or wave) rises (like water in a well). As the energy wave rises, a hill is created between two valleys, referred to as a double-well potential. The value of the first valley corresponds to the 0 state of a qubit. The value of the second valley corresponds to the 1 state. The qubit will end up in one of the valleys. The coupler, which is used to entangle 2 qubits together, wants the qubits to be the same and does so by lowering the energy of the two states. End users create algorithms to determine what the couplets should look like. Then the quantum annealer works to find the minimum energy of that landscape and hence the most optimal solution to a particular problem.

While some quantum computing hardware vendors suggest that some value, such as accelerated runtimes and improved cost or accuracy, may be derived when using circuit (gate-based) quantum models to solve some types of optimization problems, there are several advantages to choosing quantum annealing over the circuit (gate-based) quantum model for these tasks. First, quantum annealing does not involve the same processing overhead that is needed when using today's noisy intermediate-scale quantum (NISQ) circuit (gate-based) quantum model. Using today's NISQ circuit (gate-based) models to solve complex problems often involves the tuning of parameters on classical computers such as early process error correction and circuit mapping and characterization. In many instances, it can be challenging and time-consuming to choose or tune the correct parameters needed to run a model on the NISQ circuit (gate-based) quantum system. Consequently, when solving an optimization problem using the circuit (gate-based) model, an end user moves from trying to solve a complex optimization problem to trying to solve the hard problem of choosing parameters.

As a result, the costs of using quantum in relation to both processing time and resources increase when trying to solve an optimization problem using the NISQ systems. In addition, the effects of noise on a quantum annealing processor versus today's NISQ circuit (gate-based) quantum model are different. When solving a problem using the NISQ system, only some of the qubits are engaged during the computation process, as defined by the quantum algorithms that are used to program and control select qubits. Yet these select qubits cannot be isolated from the noise of the qubits that are not in use, resulting in the controlled qubits being dominated by the noise of the entire system.

Comparatively, when using quantum annealing, control signals are applied throughout the entire process and system. These control signals become the dominant signals that cause the qubits to evolve when using the quantum annealer. While this may result in the ground state or low-energy state of the qubit at the end of the process, there is still enough information available to make some inferences about the problems being solved. These differences make it possible for quantum annealing to more easily scale the large number of qubits needed to solve even more complex optimization problems.

Current Quantum Annealing Use Cases Resulting in Near-Term Value

The NISQ circuit (gate-based) quantum systems available today are only good for experimentation, specifically for testing small instances and debugging. Organizations are not able to use these systems to gain any value or near-term advantage. Comparatively, quantum annealing is being used by numerous enterprises and organizations from multiple industries to solve real-time optimization problems. For example, companies in the manufacturing industry are leveraging quantum annealing and quantum-hybrid technology to identify the most optimized route for automated guided vehicles on factory floors as a means to transport materials more efficiently. The transportation industry has been using quantum annealing to better optimize the coordination of ride-share and taxi services, accounting for constraints such as vehicle and passenger location and destination and existing routes. Quantum annealing is being used by the logistics industry to increase the efficiency of crane delivery and utilization as well as reduce turn times for trucks. In the financial services sector, enterprise customers are using quantum annealing to determine the optimized solutions related to portfolio/risk management, specifically the risk, return, and transaction costs related to portfolio transactions, while credit card companies are experimenting with quantum annealing to optimize customer loyalty and rewards programs, better protect against fraud and address money laundering, and provide a more personalized customer experience. In the life science industry, organizations are experimenting with quantum annealing to map protein design problems as well as to create antiviral binders to fight diseases.

The list of use cases for quantum annealing is extensive and continues to grow, as the technology advances. The prevalence, size, and complexity of optimization problems will continue to make quantum annealing a relevant quantum technology.

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Considering D-Wave

Established in 1999, D-Wave Quantum Inc. (D-Wave) is the only full-stack quantum hardware, software, and services provider specializing in quantum annealing. The company's quantum computing strategy focuses on delivering near- and long-term customer advantage. D-Wave suggests that while achieving long-term quantum advantage is salient for advancing quantum technology, quantum computing holds little relevancy to end users if the technology is not accessible, available, and able to solve real-world problems with business value.

Quantum Computing Hardware

D-Wave's Quantum Annealing Computing System

D-Wave first recognized commercial success in 2011 when Lockheed Martin Corp. procured the company's 128-qubit quantum annealing machine. Within two years, the company's 512-qubit quantum annealer was procured by a consortium made up of Google, NASA Ames, and the Universities Space Research Association.

Late in 2021, D-Wave first announced the D-Wave Clarity Roadmap, with the core focus being D-Wave's approach to building a large-scale quantum annealing system. The D-Wave approach centers around designing quantum processing unit (QPU) architecture that can deliver a working quantum technology at a large scale. Key to this approach is growth of the D-Wave QPU with regard to the complexity and scale of qubits and connectivity being driven by customer needs. In 2020, D-Wave announced the launch of its current system, the Advantage quantum system, a 5,614-qubit system with 15-way connectivity that is accessible via the Leap quantum cloud platform and is being deployed from three locations, namely USC-Lockheed Martin Quantum Computing Center in Marina del Rey, California; Jülich Supercomputing Centre in Jülich, Germany; and the D-Wave Quantum Center of Excellence in Burnaby, Canada.

Currently, D-Wave is developing the next generation of its quantum annealing system, the Advantage2 quantum system, which is anticipated to be a >7,000-qubit system with 20-way connectivity and increased coherence. To meet these expectations, the quantum computing hardware vendor is updating the topology and fabric of the QPU, which will increase the number of devices that each qubit is coupled to. Specifically, D-Wave is adopting the Zephyr topology with 20-way connectivity for more compact embeddings and shorter chain lengths. The new topology and qubit design are expected to lead to improvements in the energy scale, which will contribute to lower error rates, opening the door for improved performance and coherence.

D-Wave's Quantum Gate Computing System

While D-Wave's flagship technology is the Advantage quantum annealing system, the company recognizes that circuit (gate-based) quantum computing is an important complementary quantum technology, especially for certain use cases such as quantum chemistry. Yet, to solve quantum chemistry problems using a circuit (gate-based) quantum system, error correction will be necessary as the size of the computation will mandate a large number of physical qubits, long coherence times, and high gate depths. Expanding upon the knowledge gained from the design development and fabrication of the annealing quantum processor, D-Wave is developing a superconducting circuit (gate-based) quantum computing system.

Leap Quantum Cloud Service

As part of D-Wave's full-stack approach, the company launched the Leap quantum cloud service (QCS) in 2018. Designed for developers and organizations to easily build and deploy real-world hybrid quantum applications, D-Wave provides real-time access to its >5,000-qubit Advantage quantum annealing systems and hybrid solver services. Leap is accessible to end users in 39 countries globally. Using D-Wave's proprietary algorithms, the hybrid solver services automatically solve problems (made up of up to 1 million variables) in a way that takes advantage of both classical and quantum technologies. Leap includes access to the latest Advantage systems, the Advantage2 experimental prototype, multiple hybrid solvers, the Ocean software development kit, live code, demos, learning resources, and a developer community. These resources accelerate the learning process for new developers interested in quantum programming. For more advanced developers, D-Wave's Problem Inspector returns visual representations of solutions run on the quantum processor. These visual representations can be used to improve quantum programs.

D-Wave Launch

For enterprises looking to gain a quantum advantage using D-Wave's quantum annealing systems and hybrid solver services, D-Wave offers D-Wave Launch. D-Wave Launch is a premium professional service that gives enterprises access to quantum specialists and a network of industry partners. These resources can help guide enterprises seeking to become quantum ready, regardless of where they are in their quantum journey:

- **Phase 1 — Problem Discovery:** D-Wave Launch provides online training, professional services, and access to other tools available through the Leap quantum cloud service, which enterprises can use to help identify use cases and optimization problems that are suitable for running on quantum annealing technology and should deliver a business benefit.
- **Phase 2 — Quantum Proof of Concept:** During this phase, D-Wave works with customers to take the problem identified and map it to the quantum annealing system that is accessible via the D-Wave Leap quantum cloud service. The goal of this phase is to test business-relevant problems in real conditions and create quantum applications. In addition, D-Wave experts and industry partners can provide hands-on training so that enterprises can develop their internal quantum workforce.
- **Phase 3 — Production Pilot:** Through D-Wave Launch, enterprises that are ready to move their quantum applications into test production, in either an on-premises location or a cloud location, receive the support of quantum experts and industry partners to ensure success in getting applications up and running.
- **Phase 4 — In Production:** Once the application is built and deployed, enterprises receive continued support to ensure that these quantum applications run smoothly and continue to deliver business value.

Challenges and Opportunities for D-Wave

Though still a nascent technology, quantum computing is moving toward mainstream adoption, with over 63% of organizations surveyed by IDC indicating that they were currently investing in or planning on investing in quantum computing (see *Emerging Trends in End-User Adoption of Quantum Computing-as-a-Service Solutions,* IDC #US48992122, April 2022). Yet there are still many organizations that are deterred from beginning quantum adoption, with many of these organizations citing that the technology is too early in its development and currently lacks the ability to scale or be relevant or useful to their current organizational needs (see *Market Analysis Perspective: Worldwide Quantum Computing as a Service and Adjacent Quantum Computing Technology, 2022,* IDC #US49589122, August 2022).

While it is true that today's NISQ gate-model systems are useful for mainly experimental purposes, D-Wave's quantum annealing and quantum-hybrid technologies are currently delivering business value via real-world quantum-hybrid applications for enterprise customers across a variety of industries and use cases. Further, because optimization problems are prevalent among all industries, investing in quantum annealing technology is less risky as there is the potential of delivering a near-term ROI.

As the technology continues to develop, organizations currently using quantum annealing technology will have the choice of continuing to solve their current problems as is, adding more parameters to the problems they are currently solving, or using the technology to solve even more complex problems. And even more beneficial, because D-Wave is using the same qubit technology to build its quantum gate model, quantum annealing users will have an easier time transitioning to the anticipated D-Wave gate model to solve other types of complex problems.

Conclusion

With today's circuit (gate-based) quantum computing systems being such a nascent technology, many enterprises find it difficult to justify investing in quantum computing, even though the technology is expected to be an industry disruptor that will allow them to solve some of their most complex problems. Yet not all quantum computing technology should be viewed in this light. Quantum annealing is a quantum computing technology available to enterprises today that can aid in solving complex optimization problems. Optimization problems not only are among the most prevalent types of problems found across all industries but can be some of the most complex, intractable problems that enterprises need to solve to stay competitive. Having the capability to solve these problems could lead to a competitive advantage, which is unachievable using classical compute capabilities. However, quantum annealing should not be looked at as a short-term investment. Quantum annealing technology will continue to advance and scale, allowing for it to be used for solving even more complex optimization problems in the future.

As the only quantum hardware developer in the quantum annealing market, D-Wave is in a unique position of being able to provide enterprises with a quantum computing infrastructure-as-a-service (QCIaaS) offering that is designed to address the needs of enterprises interested in becoming quantum ready using quantum annealing. With access to D-Wave's quantum annealing hardware systems, Ocean software suite of open source Python tools, and Ocean SDK via the company's Leap quantum cloud service, as well as access to a network of industry partners, D-Wave quantum specialists, and training resources, end users are provided with all the tools necessary to be successful in using quantum annealing regardless of where they are in their quantum journey.

About the Analyst

Heather West, PhD, *Research Manager, Infrastructure Systems, Platforms, and Technologies Group*

Heather West, PhD, is a research manager within IDC's Enterprise Infrastructure Practice. In this role, she leads IDC's research on quantum computing. Other areas of Ms. West's research coverage include AI and enterprise infrastructure workloads. Ms. West also manages primary research projects focused on end-user purchasing plans for infrastructure products and adoption of technologies shaping the infrastructure market.

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More About D-Wave

D-Wave specializes in the development and delivery of quantum computing systems, software, and services and is the world's first commercial supplier of quantum computers — and the only company building both annealing quantum computers and gate-model quantum computers. Our mission is to unlock the power of quantum computing today to benefit business and society. We do this by delivering customer value with practical quantum applications for problems as diverse as logistics, artificial intelligence, materials sciences, drug discovery, scheduling, cybersecurity, fault detection, and financial modeling. D-Wave's technology is being used by many organizations globally, including Volkswagen, Mastercard, Deloitte, Davidson Technologies, ArcelorMittal, Siemens Healthineers, Unisys, NEC Corporation, Pattison Food Group Ltd., DENSO, Lockheed Martin, Forschungszentrum Jülich, University of Southern California, and Los Alamos National Laboratory.

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IDC Research, Inc.
140 Kendrick Street
Building B
Needham, MA 02494, USA
T 508.872.8200
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