D:WAVE
The Quantum Computing Company™

Every so often there is a chance to make a difference, to undertake a project — in the style of the Apollo moon landings — which against all odds makes a "technology of the future"

Quantum Computing for the Real World Today

Despite the incredible power of today's supercomputers, many complex computing problems cannot be addressed by conventional systems. The huge growth of data and our need to better understand everything from the universe to our own DNA leads us to seek new tools that can help provide answers.

While we are only at the beginning of this journey, quantum computing has the potential to help solve some of the most complex computing problems organizations face. We expect that quantum computing will lead to breakthroughs in science, engineering, modeling and simulation, healthcare, financial analysis, optimization, logistics, and national defense applications.

D-Wave's latest-generation system is the D-Wave 2000Q™ quantum computer. With 2000 qubits, it is the most advanced quantum computer in the world. It is based on a novel type of superconducting processor that uses quantum mechanics for computation, enabling it to evaluate an enormous number of possible solutions simultaneously.

The D-Wave 2000Q quantum computer is best suited to tackling complex problems that exist across many domains, such as:

- Optimization
- Machine learning
- Sampling / Monte Carlo
- Pattern recognition and anomaly detection
- Cyber security
- Image analysis
- Financial analysis
- Software / hardware verification and validation
- Bioinformatics / cancer research

D-Wave Systems

D-Wave is the leader in the development and delivery of quantum computing systems and software, and the world's only commercial supplier of quantum computers. Our mission is to unlock the power of quantum computing for the world. We believe that quantum computing will enable solutions to the most challenging national defense, scientific, technical, and commercial problems.

D-Wave systems are being used by world-class organizations and institutions including Lockheed Martin, Google, NASA, USRA, the University of Southern California, and Los Alamos National Laboratory.

D-Wave has been granted over 140 U.S. patents and has published over scientific 90 papers, including many in leading science journals.

D-Wave's headquarters are outside Vancouver, British Columbia, and D-Wave U.S. offices are in Palo Alto, California and Hanover, Maryland.

Quantum Computing

To speed computation, quantum computers tap directly into an unimaginably vast fabric of reality—the strange and counterintuitive world of quantum mechanics. Rather than store information using bits represented by 0s or 1s as conventional computers do, quantum computers use quantum bits, or ***qubits***, to encode information as 0s, 1s, or both simultaneously. This ***superposition*** of states, along with the quantum effects of ***entanglement*** and ***quantum tunneling***, enable quantum computers to consider and manipulate many combinations of bits simultaneously.

Qubits can exist in a state of 1 and 0 simultaneously

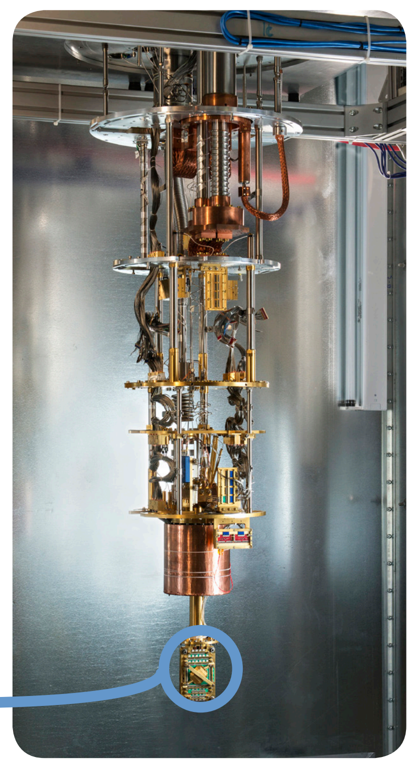
D-Wave systems implement a ***quantum annealing*** algorithm, which solves problems by searching for the global minimum of a function. User problems are mapped to a search for the "lowest point in a vast landscape," which corresponds to the best possible outcome.

The D-Wave 2000Q System

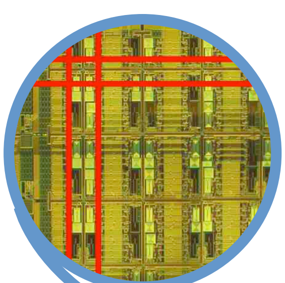
For quantum effects to take place, the quantum processing unit (QPU) must operate in an extreme environment—cooled to nearly absolute zero, shielded from magnetic fields, and isolated from vibration and external signal interference. The QPU is magnetically shielded to 50,000 times less than the Earth's field, and is operated in a high vacuum that is 10 billion times lower than standard atmospheric pressure. The closed-cycle dilution refrigerator within the system cools the QPU to near absolute zero (0.015 kelvin), 180 times colder than interstellar space.

The QPU contains a lattice of tiny superconducting devices (qubits) made from the metal niobium, which exhibits quantum behavior at very low temperatures. Qubits are the basic elements that the system uses to solve problems. Additional circuitry on the QPU programs it and reads out results.

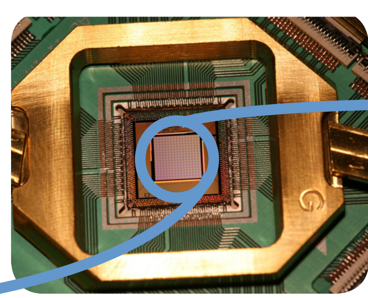
Inside the D-Wave enclosure



Qubits in red



Quantum processing unit



Optimization and Machine Learning

The D-Wave system is used for computationally-intensive tasks such as discrete optimization problems, machine learning, and sampling. Classical computers and algorithms often struggle to perform such computations efficiently and accurately.

These types of problems exist in many different domains—scheduling, mission planning, image analysis, anomaly detection, financial analysis, risk management, and many others. They are some of the most difficult computing problems, with potentially enormous benefits if optimal solutions can be readily computed.

D-Wave systems are intended to complement classical computers. There are many examples of problems where a quantum computer can complement a high-performance computing (HPC) system. While the quantum computer is well suited to discrete optimization, the HPC system is better suited for large-scale numerical simulations.

Programming the Quantum Computer

The D-Wave 2000Q system has a web API with client libraries available for C/C++, Python, and MATLAB. This allows users to access the computer easily as a cloud resource over a network.

To program the system, a user maps a problem into a search for the "lowest point in a vast landscape," corresponding to the best possible outcome. The QPU considers all the possibilities simultaneously to determine the lowest energy required to form those relationships. The solutions are values that correspond to the optimal configurations of qubits found, or the lowest points in the energy landscape. These values are returned to the user program over the network.

Because a quantum computer is probabilistic rather than deterministic, the computer returns many very good answers in a short amount of time—thousands of samples in one second. This provides not only the best solution found but also other very good alternatives from which to choose.

In nature, physical systems tend to evolve toward their lowest energy state: objects slide down hills, hot things cool down, and so on. This behavior also applies to quantum systems. To imagine this, think of a traveler looking for the best solution by finding the lowest valley in the energy landscape that represents the problem. Classical algorithms seek the lowest valley by placing the traveler at some point in the landscape and allowing that traveler to move based on local variations. While it is generally most efficient to move downhill and avoid climbing hills that are too high, such classical algorithms are prone to leading the traveler into nearby valleys that may not be the global minimum. Numerous trials are typically required, with many travelers beginning their journeys from different points.

In contrast, quantum annealing begins with the traveler simultaneously occupying many coordinates thanks to the quantum phenomenon of superposition. The probability of being at any given coordinate smoothly evolves as annealing progresses, with the probability increasing around the coordinates of deep valleys. Quantum tunneling allows the traveller to pass through hills—rather than be forced to climb them—reducing the chance of becoming trapped in valleys that are not the global minimum. Quantum entanglement further improves the outcome by allowing the traveler to discover correlations between the coordinates that lead to deep valleys.

"It's a game changer for the corporation, it's a game changer for our customers, and ultimately it's a game changer for humanity."

Greg Tallant, Research Engineering Manager, Lockheed Martin

D-Wave in Action

D-Wave is working with leaders in business, government, and academia on a wide range of applications that could lead to breakthroughs for many critical problems.

D-Wave's first customer was Lockheed Martin, one of the world's largest aerospace, information systems, and defense contractors. Designing aircraft is a complex exercise, but almost half the cost of building them is the verification and validation that the flight control systems, sensors, computers, communications, and other electronics work together flawlessly. Lockheed Martin is using their D-Wave system to find new ways to create and test these

In 2013 Google, NASA and USRA created the Quantum Artificial Intelligence Lab and installed a D-Wave quantum computer at NASA Ames Research Center. Scientists are using it to explore the potential for quantum computing and its applicability to a broad range of complex problems such as web search, speech recognition, planning and scheduling, air-traffic management, robotic missions to other planets, and support operations in mission control centers. In 2015 Google presented results from their benchmark testing of hard optimization problems running on their D-Wave system demonstrating that *"for problem instances involving nearly 1000 binary variables, quantum annealing significantly outperforms its classical counterpart, simulated annealing. It is more than 10^8 times faster than simulated annealing running on a single core."*

In 2016, Los Alamos National Laboratory acquired a D-Wave system to explore the capabilities and applications of quantum annealing technology. In just a short period of time, their scientists have made progress in a diverse set of applications.

To learn more about D-Wave and the world's first commercial quantum computer, visit us at www.dwavesys.com. Join us on this incredible journey to the future!

"We actually think quantum machine learning may provide the most creative problem-solving process under the known laws of physics."

Hartmut Neven, Director of Engineering, Google

D-Wave The Quantum Computing Company™