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" an achievement of today.

The D-Wave Quantum Computer

Despite the incredible power of today's supercomputers, there are many complex computing problems that can't be addressed by conventional systems. The huge growth of data ("Big 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 technical, commercial and national defense problems that organizations face. We expect that quantum computing will lead to breakthroughs in science, engineering, modeling and simulation, financial analysis, optimization, logistics and national defense applications.

D-Wave's flagship product, the 512-qubit D-Wave Two™ quantum computer, is the most advanced quantum computer in the world. It is based on a novel type of superconducting processor that uses quantum mechanics to massively accelerate computation. It is best suited to tackling complex optimization problems that exist across many domains such as:

- Systems optimization
- Machine learning
- Pattern recognition and anomaly detection
- Financial analysis
- Software / hardware verification and validation
- Bioinformatics / cancer research

D-Wave Systems

Founded in 1999, D-Wave Systems is the first commercial quantum computing company. Our mission is to integrate new discoveries in physics, engineering, manufacturing and computer science into breakthrough approaches to computation to help solve some of the world's most complex challenges.

D-Wave systems are being used by world-class organizations and institutions including Lockheed Martin, Google, NASA and USC.

D-Wave has been granted over 100 US patents and has published over 60 peer-reviewed papers in leading scientific journals.

With headquarters near Vancouver, Canada, D-Wave U.S. is located in Palo Alto, California.

Quantum Computing

A quantum computer taps directly into the fundamental fabric of reality – the strange and counter-intuitive world of quantum mechanics – to speed computation. Rather than store information as 0s or 1s as conventional computers do, a quantum computer uses qubits – which can be 1 or 0 or both at the same time. This “quantum superposition” enables quantum computers to consider and manipulate all combinations of bits simultaneously, making quantum computation powerful and fast.


Qubits can exist in a state of 1 and 0 simultaneously

D-Wave systems use quantum annealing to solve problems. Quantum annealing “tunes” qubits from their superposition state to a classical state to return a set of answers scored to show the best solution.

The D-Wave Two System

In order for the quantum effects to take place, a quantum processor must operate in an extreme environment - temperatures close to absolute zero, shielded from magnetism, and isolated from vibration and external signals of any form. The environmental enclosure shields the processor to 50,000× less than the Earth’s magnetic field.

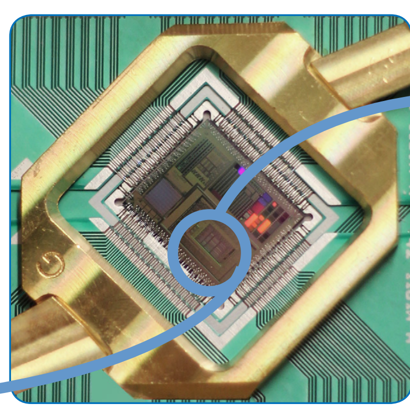
Inside the box the closed cycle dilution refrigerator lowers the temperature at each level until it reaches almost absolute zero (0.02 Kelvin), 150x colder than interstellar space.

The quantum processor contains a lattice of tiny superconducting circuits (qubits) made from the metal niobium, which exhibits quantum behaviors at low temperatures. Qubits are the basic elements that the system uses to solve optimization problems.

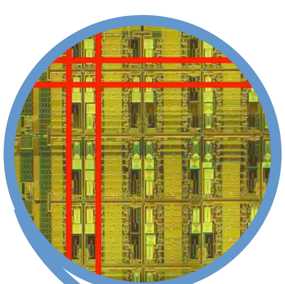
The quantum processor is surrounded by electronics used to program the processor and read out the results.

Dilution refrigerator

Quantum processor



Qubits in red



Discrete Optimization Problems

The types of problems the quantum computer is designed to solve are called discrete combinatorial optimization problems. The most cited example of this kind of problem is the "traveling salesman problem". The objective is to find the shortest possible route between a given list of cities, with the constraint that all cities must be visited exactly once and the salesman must end up at the original city. When the number of cities is small, the problem is easy. As you start adding more cities the problem becomes exponentially harder. With 10 cities, there are more than 180,000 possible routes. With 12 cities there are almost 20 million!

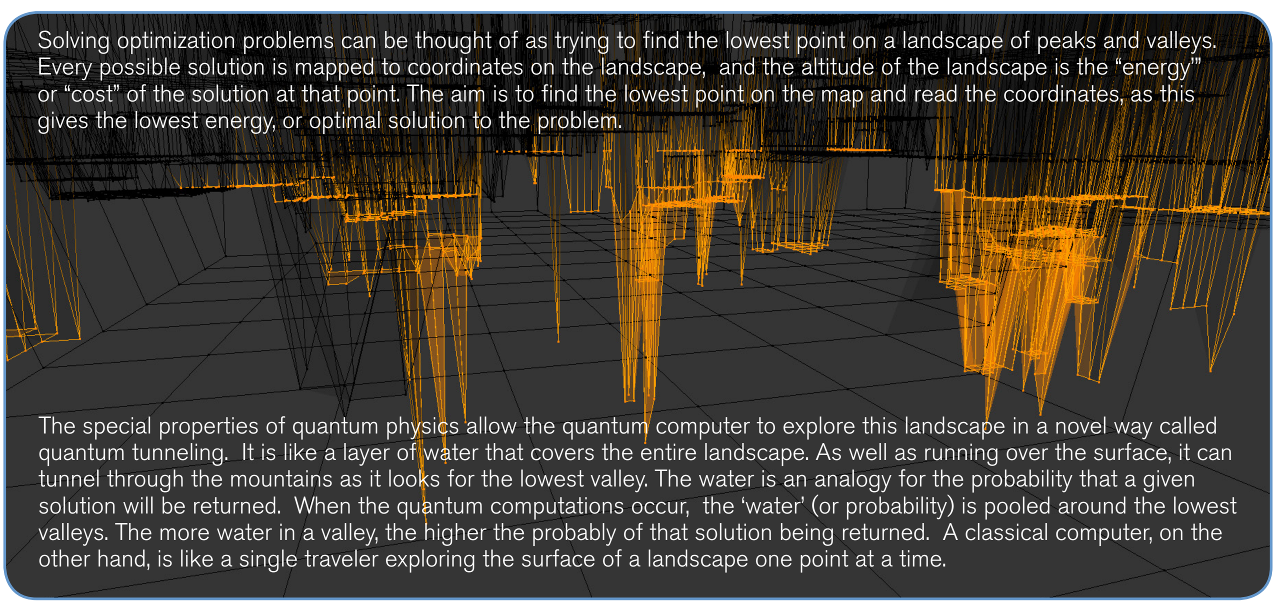
How important are these types of problems? Consider the US trucking industry, which consumes about 60 billions gallons of fuel per year. At an average cost of $3.90 for a gallon of diesel, the cost per year is $234 billion. If the distances traveled could be reduced by as little as 1%, cost savings of $2.3 billion could be achieved - not to mention the environmental benefits. As fuel usage also depends on speed and other factors, adding other considerations to the problem (which exponentially add difficulty to the problem) could result in even more savings.

These types of optimization problems exist in many different domains - systems design, mission planning, airline scheduling, financial analysis, web search, cancer radiotherapy and many more. They are some of the most complex problems in the world, with potentially enormous benefits to businesses, people and science if optimal solutions can be readily computed.

Programming the Computer

A user interfaces with the quantum computer by connecting to it over a network, as you would with a traditional computer. The user's problems are sent to a server interface, which turns the optimization program into machine code to be programmed onto the chip. To program the system a user maps a problem into a search for the "lowest point in a vast landscape" which corresponds to the best possible outcome.

The processor considers all the possibilities simultaneously to determine the lowest energy required to form those relationships. The computer returns many very good answers in a short amount of time - 10,000 answers in one second. This gives the user not only the optimal solution or a single answer, but also other alternatives to choose from.



Solving optimization problems can be thought of as trying to find the lowest point on a landscape of peaks and valleys. Every possible solution is mapped to coordinates on the landscape, and the altitude of the landscape is the "energy" or "cost" of the solution at that point. The aim is to find the lowest point on the map and read the coordinates, as this gives the lowest energy, or optimal solution to the problem.

The special properties of quantum physics allow the quantum computer to explore this landscape in a novel way called quantum tunneling. It is like a layer of water that covers the entire landscape. As well as running over the surface, it can tunnel through the mountains as it looks for the lowest valley. The water is an analogy for the probability that a given solution will be returned. When the quantum computations occur, the 'water' (or probability) is pooled around the lowest valleys. The more water in a valley, the higher the probably of that solution being returned. A classical computer, on the other hand, is like a single traveler exploring the surface of a landscape one point at a time.

> “This is a revolution not unlike the early days of computing. It is a transformation in the ways computers are thought about.”
>
> Ray Johnson, Chief Technical Officer, Lockheed Martin

D-Wave in Action

D-Wave is working with leaders in business, government and academia on a wide range of very computationally-intensive applications that could lead to breakthroughs in diverse fields such as systems design and validation, healthcare, mission planning, financial analysis, global logistics and defense and intelligence.

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 acquired a D-Wave system to find new ways to create and test these complex radar, space and aircraft systems.

> “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, Flight Control & VMS Integration – FW, Advanced Development Programs, Lockheed

In 2013 Google, NASA and USRA created the Quantum Artificial Intelligence Lab and installed a D-Wave Two™ quantum computer at the NASA Ames Research Center. Google is focused on improving algorithms for machine learning and artificial intelligence which, according to Google Director of Engineering Hartmut Neven, “can help researchers construct more efficient and more accurate models for everything from speech recognition, to web search, to protein folding.” NASA will investigate whether the system can optimize the search for exoplanets - planets outside of our own solar system.

> “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

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!