Quantum computing machine under scrutiny

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Pictured is D-Wave's current 512-qubit version. Credit: Courtesy of D-Wave Systems Inc.

A new and innovative computing machine is currently attracting a great deal of attention in specialist circles. A team under the leadership of Matthias Troyer, a professor at ETH Zurich, has now confirmed that the machine uses quantum effects. However, it is not any faster than a traditional computer.

D-Wave – a special computing machine with this name has been getting computer scientists and physicists talking for a number of years now. The Canadian technology company of the same name is advertising the machine as a quantum computer. However, whether or not the machine does in fact use quantum effects is the subject of controversial debate amongst experts in the field. If it does, then this would make D-Wave the world's first commercially available quantum computer.

The company sold its system to illustrious customers, piquing the interest of the scientific community and of bloggers and journalists even further. For example, the very first machine was sold to the US arms manufacturer Lockheed Martin in 2011, which provided it to the University of Southern California in Los Angeles for tests. Last year, Google purchased the second machine. D-Wave can solve certain mathematical problems referred to as optimization problems by searching for and finding the state of lowest energy in a system. That is why the technology is of interest to this company.

Analogue device, not a quantum computer

But the question of whether or not D-Wave does in fact use quantum effects is not the only disputed aspect of the machine. Scientists and bloggers have also expressed doubt as to whether the machine can be accurately described as a computer at all. There are also different opinions regarding whether or not it can compute faster than a traditional computer. To find answers to these questions, Matthias Troyer, a professor at the Institute for Theoretical Physics at ETH Zurich, worked together with colleagues at the University of Southern California in Los Angeles and tested the system located there.

In their study, which has now been published in the journal *Nature Physics*, the Swiss-American team of researchers comes to a conclusion that is not clear cut. On the one hand, the scientists confirm that D-Wave does in fact use quantum effects. However, in other areas the researchers are more critical: "D-Wave is an analogue device, a prototype that can be used to solve optimization problems. It would be more accurate to describe it as a programmable quantum simulation experiment", says

Professor Troyer, an internationally recognized expert in the field. "D-Wave is certainly not a universal quantum computer."

Quantum effects, but only momentarily

The researchers came to their conclusions by writing thousands of computing problems of differing complexity and solving each of these one thousand times on three systems: once on D-Wave and twice on a simulation programme for optimization problems that ran on a traditional computer. The simulation programme ran in two modes, where one took quantum effects into consideration and one did not. For each task, the scientists made a note of how often which system delivered the right solution. It turned out that D-Wave behaves in the same manner as the simulation that accounted for quantum effects but differently from the simulation that did not.

The scientists were amazed by this result, because the quantum effects of D-Wave are extremely short-lived, lasting only a few billionths of a second. Physicists describe this as coherence time. Because it generally takes around 500 times longer to solve an optimization problem, most experts assumed that the quantum effects with D-Wave simply could not play any role. And yet they do, as the results of the researchers have shown. "It appears that the quantum effects do not necessarily have to be coherent all of the time in order to have a significance", explains Troyer.

Not faster than a traditional computer

When one considers that research into quantum computers is carried out primarily because of the promise of hugely accelerated computing speeds, then another conclusion arrived at by the researchers is particularly significant, namely that D-Wave is not faster than a traditional computer.

The speed of D-Wave is the subject of intense debate amongst experts in the field, particularly since a publication by a computer scientist at Amherst College caused uproar in May of last year. According to the publication, depending on the computing problem, D-Wave is several thousands of times faster than a traditional computer. The researcher examined a version of D-Wave that almost corresponds to the current version, in existence for one year, with a computing capacity of 512 quantum bits (qubits). By contrast, the study carried out by the researchers from ETH Zurich is based on a predecessor version with 108 qubits.

"Not only have we demonstrated that a traditional computer is faster than the 108-bit version of D-Wave", Troyer responds. "We also used a traditional computer to solve the same problems that can be solved by the new 512-qubit version or hypothetically even higher-performing machines." When these findings are compared with those of the researcher from Amherst College, it becomes clear that D-Wave is consistently slower than a traditional computer for the tests performed. According to Troyer, the problem with the Amherst study is that it compared fast algorithms for D-Wave with slower algorithms for traditional computers. "We developed optimized algorithms for traditional computers. This allows us to match even the current 512-qubit version of D-Wave", explains Troyer. "Nobody knows at present whether a future quantum system like D-Wave with more qubits will offer any advantages over traditional systems. This is an important question, and we are currently using experiments on the 512-qubit machine to find the answer."

Quantum annealing with D-Wave

An imperfect crystal structure made of metals or glass can be improved by heating the material until it glows and then cooling it in a controlled environment. In the hot material, the atoms have a certain freedom of movement and can realign in a more refined crystal lattice. This craft technique is thousands of years old and called annealing. A comparable method has also been in use for the past 30 years in computer science as an optimization process and is called annealing as well.

A typical question that can be answered using this method is the search for the lowest point of a landscape. To understand this better, it is possible to imagine a thought experiment where a sphere located in a landscape is subjected to jolts depending on temperature. At high temperatures, the sphere can hop around the entire landscape. The lower the temperature, the harder it is for the sphere to cross mountains. If an experiment is repeated several times, starting with high temperatures and slowly cooling, at the end of the experiments the sphere will frequently be found at the lowest point of the landscape.

When the D-Wave system solves an optimization problem, it uses a similar procedure. In addition, quantum physics and thus tunnel effects also have a role to play: the sphere (remaining with the above example) is also in a position to tunnel underneath the mountains in the landscape. With D-Wave, however, it is not spheres that are moving. Instead, individual superconducting circuits act as quantum simulations or artificial atoms. For this purpose, the system must be cooled to temperatures of almost absolute zero. The circuits simulate the spin of atoms. There is the spin "up" and the spin "down" as well as (because quantum physics plays a role) superposition of the spins, the state of "both up and down". In the D-Wave circuits, the spins are simulated by the direction in which the electrical current is flowing. Physicists call the optimization procedure used by D-Wave "quantum annealing".

More information: Boixo S, Rønnow TF, Isakov SV, Wang Z, Wecker D, Lidar DA, Martinis JM, Troyer M: Evidence for quantum annealing with more than one hundred qubits. *Nature Physics*, 2014, 10: 218-224, DOI: 10.1038/nphys2900

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