V. Boiko, BSc Student
O. Pasichnyk, PhD in Education,
Associate Prof., language advisor
Khmelnitsky National University

QUANTUM COMPUTING: CHALLENGES AND PERSPECTIVES OF DEVELOPMENT

Quantum computers are incredibly powerful machines that take a new approach to processing information. Built on the principles of quantum mechanics, they exploit complex and fascinating laws of nature that are always there, but usually remain hidden from view. By harnessing such natural behavior, quantum computing can run new types of algorithms to process information more holistically. They may one day lead to revolutionary breakthroughs in materials and drug discovery, the optimization of complex manmade systems, and artificial intelligence. We expect them to open doors that we once thought would remain locked indefinitely [5].

As of 2018, the development of actual quantum computers is still in its infancy, but experiments have been carried out in which quantum computational operations were executed on a very small number of quantum bits. Both practical and theoretical research continues, and many national governments and military agencies are funding quantum computing research in additional effort to develop quantum computers for civilian, business, trade, environmental and national security purposes, such as cryptanalysis.A small 20-qubit quantum computer exists and is available for experiments via the IBM quantum experience project. D-Wave, a company based in Vancouver, Canada, has been developing their own version of a quantum computer which uses annealing.

Large-scale quantum computers would theoretically be able to solve certain problems much more quickly than any classical computers that use even the best currently known algorithms, like integer factorization using Shor's algorithm (which is a quantum algorithm) and the simulation of quantum many-body systems. There exist quantum algorithms, such as Simon's algorithm, that run faster than any possible probabilistic classical algorithm. A classical computer could in principle (with exponential resources) simulate a quantum algorithm, as quantum computation does not violate the Church–Turing thesis:202. On the other hand, quantum computers may be able to efficiently solve problems which are not practically feasible on classical computers.

Until recently, it seemed like Google was leading the pack when it came to creating a quantum computer that could surpass the abilities of conventional computers. In a Nature article published in March 2017, the search giant set out ambitious plans to commercialize quantum technology in the next five years. Shortly after that, Google said it intended to achieve something it's calling 'quantum supremacy' with a 49-qubit computer by the end of 2017.

Now, quantum supremacy, which roughly refers to the point where a quantum computer can crunch sums that a conventional computer couldn't hope to simulate, isn't exactly a widely accepted term within the quantum community. Those skeptical of Google's quantum project – or at least the way it talks about quantum computing – argue that supremacy is essentially an arbitrary goal set by Google to make it look like it’s making strides in quantum when really it’s just meeting self-imposed targets.

Whether it’s an arbitrary goal or not, Google was placed to the supremacy post by IBM in November 2017, when the company announced it had built a 50-qubit quantum computer. Even that, however, was far from stable, as the system could only hold its quantum microstate for 90 microseconds, a record, but far from the times needed to make quantum computing practically viable. Just because IBM has built a 50-qubit system, however, doesn’t necessarily mean they’ve cracked supremacy and doesn’t mean that they’ve created a quantum computer that is anywhere near ready for practical use.

Where IBM has gone further than Google, however, is making quantum computers commercially available. Since 2016, it has offered researchers the chance to run experiments on a five-qubit quantum computer via the cloud and at the end of 2017 started making its 20-qubit system available online too.

But quantum computing is by no means a two-horse race. Californian startup Rigetti is focusing on the stability of its own systems rather than just the number of qubits and it could be the first to build a quantum computer that people can use. D-Wave has already created what it is calling a 2,000-qubit system although many researchers don’t consider the D-wave systems to be true quantum computers. In February 2018 the company announced that it had found a way of fabricating quantum chips from silicon, which would make it much easier to produce chips using existing manufacturing methods [4].

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.

The D-Wave 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 quantum processing unit 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 period 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.

D-Wave systems are intended to be used to complement classical computers. There are many examples of problems where a quantum computer can complement an HPC (high-performance computing) system. While the quantum computer is well suited to discrete optimization, for example, the HPC system is better at large-scale numerical simulations [2]

Researchers have taken an important step toward the long-sought goal of a quantum computer, which in theory should be capable of vastly faster computations than conventional computers, for certain kinds of problems. The new work shows that collections of ultracold molecules can retain the information stored in them, for hundreds of times longer than researchers have previously achieved in these materials.

These two-atom molecules are made of sodium and potassium and were cooled to temperatures just a few ten-millionths of a degree above absolute zero (measured in hundreds of nanokelvins). The results are described in a report this week in Science, by Martin Zwierlein, an MIT professor of physics and a principal investigator in MIT's Research Laboratory of Electronics at the MIT-Harvard Center for Ultracold Atoms.

Many different approaches are being studied as possible ways of creating qubits, the basic building blocks of long-theorized but not yet fully realized quantum computers. Researchers have tried using superconducting materials, ions held in ion traps, or individual neutral atoms, as well as molecules of varying complexity. The new approach uses a cluster of very simple molecules made of just two atoms.

The molecules have three key characteristics: rotation, vibration, and the spin direction of the nuclei of the two individual atoms. For these experiments, the researchers got the molecules under perfect control in terms of all three characteristics – that is, into the lowest state of vibration, rotation, and nuclear spin alignment.

“We have been able to trap molecules for a long time, and also demonstrate that they can carry quantum information and hold onto it for a long time, – Zwierlein says, and that, one of the key breakthroughs or milestones one has to have before hoping to build a quantum computer, which is a much more complicated endeavor.”

The use of sodium-potassium molecules provides a number of advantages, For one thing, the molecule is chemically stable, so if one of these molecules meets another one they don't break apart [3].

Talking about other researches, now scientists are conducting a series of detailed experiments to try and find out how the quantum computer works.

It's easy to think of computers and brains as similar – both process information, and make decisions, and deal with inputs and outputs. But some scientists think the incredible complexity of the brain can only be explained by quantum mechanics.

In other words, phenomena like quantum entanglement and superposition, all the knotty stuff of quantum physics, are actually regular occurrences inside our brains. Not everyone is so sure, but we might be about to get an answer either way.

Other experiments will look at the potential for decoherence, which happens when the links and dependency between qubits – the idea of quantum entanglement – start to break down. For our brains to be quantum computers, there must be a built-in way that our biological qubits are shielded from decoherence.

Yet another experiment is going to investigate mitochondria, the cell subunits responsible for our metabolism and sending messages around the body. It's possible that these organelles also play a significant role in qubit entanglement.

“Quantum computing processes could eventually help us explain and understand the brain's most mysterious functions, like the way we hold on to long-term memories, or where consciousness, emotion, and awareness actually come from”, – says one of the team, Matthew Fisher from the University of California, Santa Barbara [1].

So, as we can see, scientists are actively working on the creation of a supercomputer of the future and are testing them for efficiency. It is difficult to predict in advance the technical breakthrough and in which branches of science people will make a new technical leap. But, of course, this day will come sooner or later.

REFERENCES

1. Are We All Quantum Computers? Scientists Are Conducting Tests to Find Out [електронний ресурс] https://www.sciencealert.com/are-we-all-quantum-computers-with-quantum-brains

2. How D-Wave Systems Work [електронний ресурс] https://www.dwavesys.com/quantum-computing

3. Ultracold molecules hold promise for quantum computing [електронний ресурс] http://news.mit.edu/2017/ultracold-molecules-hold-promise-quantum-computing-qubit-0727

4. What are quantum computers and how do they work? [електронний ресурс] http://www.wired.co.uk/article/quantum-computing-explained

5. What is quantum computing? [електронний ресурс] https://www.research.ibm.com/ibm-q/learn/what-is-quantum-computing