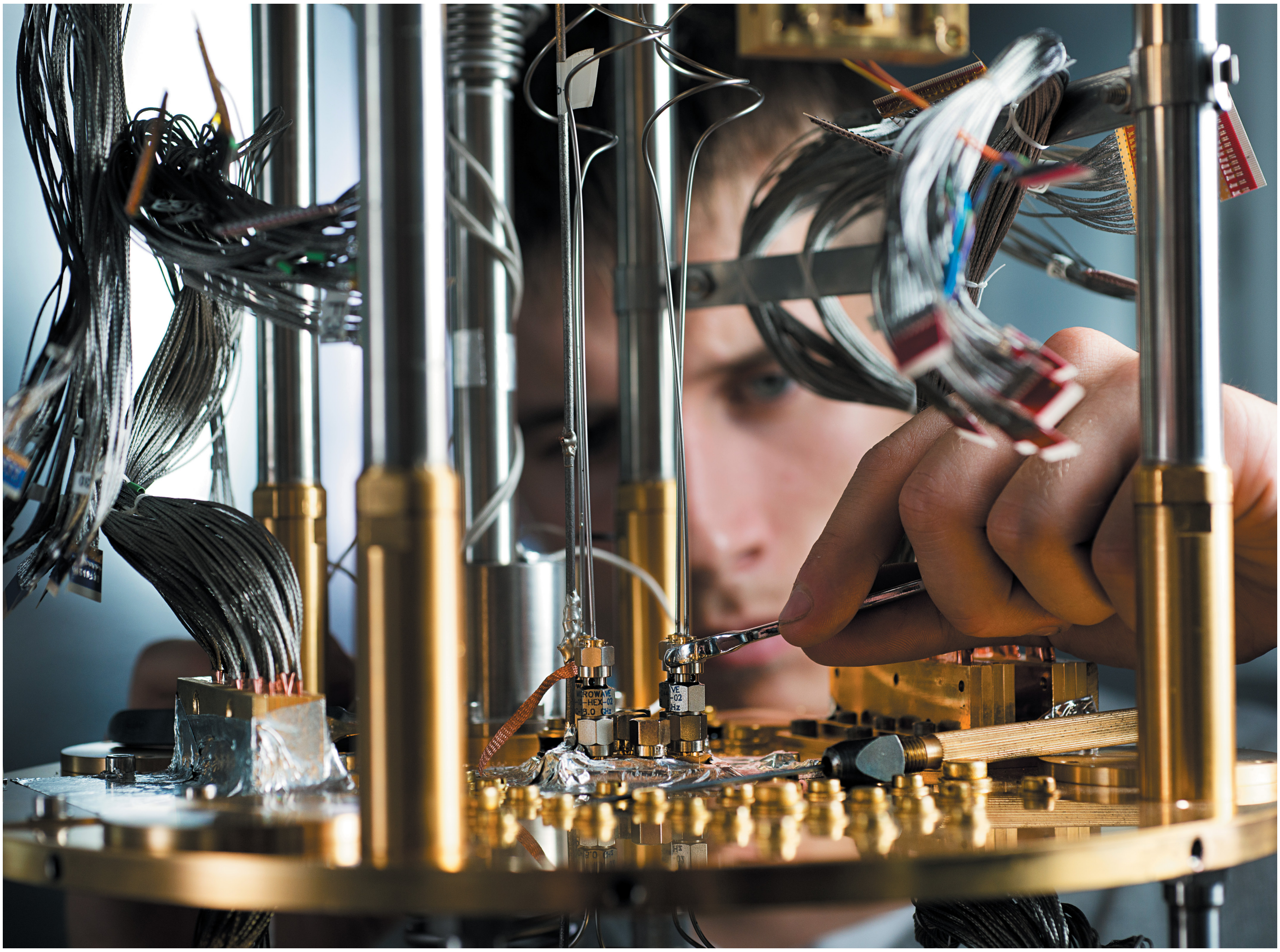
COMMENT




A researcher works on a device for cooling the quantum enhanced processor developed by D-Wave Systems in Burnaby, Canada.

# Keep quantum computing global and open

The race to cash in is draining universities of talent, fracturing the field and closing off avenues of enquiry, warn **Jacob D. Biamonte**, **Pavel Dorozhkin** and **Igor Zacharov**.

In just a few years, the field of quantum computing has moved swiftly from an academic backwater to a subject of vast public and private interest. The ultimate goal of a 'universal' quantum computer — capable of performing any calculation while correcting for noise, faults and disruptions — remains decades away. But billions of dollars are being ploughed into commercializing the first fruits[1].

The US technology company IBM and Canadian firm D-Wave Systems are already selling access to quantum-enhanced calculators. Google, Microsoft and Intel plan to do so in three to five years. These early devices should perform certain tasks faster than a conventional computer. They are, however, less versatile and less powerful than a universal quantum computer, and are still subject to errors and noise. Areas such as machine learning and optimization could benefit — if technical challenges can be overcome[2,3].

But the race to cash in is fracturing the field. Companies are rushing to build large teams of researchers, draining universities of talent[4,5]. Hundreds of start-ups are patenting the products of publicly funded research, closing off avenues of enquiry.

Public funding for quantum computing is also booming. But it is uneven and skewed towards hardware. North American institutions dominate, and drive the field in directions that suit them. They focus on superconductor technologies, for example. Researchers lacking huge labs and infrastructure find it hard to compete. Geopolitical walls are also rising as national security and commercial interests heat up.

All of this is happening at a crucial time. Moore's law — which states that the number of transistors in integrated microchip circuits doubles about every two years — is stalling. And machine learning is opening its doors to entirely new industries. We cannot wait decades for 'quantum advantage': the point at which a quantum processor solves a problem impossible for any existing classical computer to solve. This contrasts with other fields, such as biotechnology, in which the revolutionary technique of CRISPR gene editing emerged 20 years after the field seemed to have peaked in the 1990s.

We appeal to academic and industrial scientists to develop quantum applications in an open scientific spirit. Basic research must not be done in isolation or steered by political agendas. These huge investments and the devices stemming from them should serve all of humankind, like science itself.

## GLOBAL QUANTUM STATE

Most of the concepts underpinning quantum computers have come from publicly funded research. Now that quantum computing is potentially valuable, many governments are ramping up support.

A handful of nations — the United States, the United Kingdom, Japan, Sweden, Singapore, Canada and China — are leading the way. Each committed between US$100 million and $300 million per year to quantum computing research in 2017; the United Kingdom's total public and private investment since 2014 now exceeds $1 billion. In 2018, the United States and the European Union both launched billion-dollar behemoths: the five-year US National Quantum Initiative and the ten-year EU Quantum Technologies Flagship programme. China aims to open the world's largest quantum-research laboratory in 2020 at a cost of $10 billion.

Other countries are following suit. India and South Korea each intend to invest tens of millions of US dollars per year. And Russia includes quantum technology in its top-ten list of national technological initiatives. A number of leading centres are being formed there to coordinate private and government research and development. Large projects should receive up to $300 million in the first phase.

But many of the results flowing from all this investment are being hived off. Corporate interests and a cooling of the international political climate are making it harder for scientists to collaborate and share knowledge[6,7]. Closing off areas leads to pointless replication and time wasted pursuing dead ends.

For example, quantum computing's implications for national security were highlighted in a 2019 report by the US National Academy of Sciences[8], sponsored by the Office of the Director of National Intelligence. Scientists funded by the US Department of Energy now face a ban on collaborating with researchers from some 30 countries, including China and Russia[6].

Such shadows are affecting our research at Moscow's Skolkovo Institute of Science and Technology — an English-speaking advanced research university that was established in 2011 in partnership with the Massachusetts Institute of Technology in Cambridge. We chose to work at Skoltech because of its international, world-class and collaborative atmosphere. Take our origins: J.D.B. is American, P.D. is Russian and I.Z. is a Dutch citizen of Russian descent. Although our close collaborators continue to interact with us, old research agreements between Russia and the EU are fizzling out, with no discussion of renewal. Partnerships between participants in the EU quantum flagship and scientists in the United States, Russia or China now require special negotiations.

## RESEARCH GAPS

Quantum technology risks becoming another 'Moonshot' race in which the winner takes all. North America has built up an insurmountable lead in quantum hardware. Companies such as Google in California and D-Wave in Canada still grant access to their machines without borders in mind — but only through the cloud. No one expects to touch the processors.

European politicians fear they have missed the technology boat. The region has only one large computer-hardware manufacturer (France-based Atos/Bull) with a quantum-technology programme. The EU quantum flagship promotes the development of hardware similar to that being created in the United States, and is investigating some approaches not being widely explored by US efforts. But the EU Commission failed to allocate much funding to quantum applications or algorithm research in the first round — a major omission, in our view. Those behind the flagship effort have indicated that they will invest more in quantum software in subsequent funding rounds.

> ***"Quantum technology risks becoming another 'Moonshot' race in which the winner takes all."***

Many researchers hope that companies will fill the applications gap. But businesses have little interest in addressing the basic theory of quantum information processing, and they often operate in isolation. This means that the proliferation of start-ups and commercialization of quantum software at this early stage could hinder the development of theoretical methods and quantum software tools.

Outdated conventions and assumptions are also holding back the field. The range of applications for quantum-enhanced technology is limited and has not been mapped out. Even known uses, such as the benefits for machine learning, are poorly understood. The devices might not deliver anticipated improvements. Textbook algorithms (such as Shor's quantum factoring algorithm or Grover's search algorithm) seem not to work on non-ideal machines without error correction. Can programmers write better codes that can work on realistic devices subject to noise?

## WHAT NEXT?

Academic researchers must map out the space of quantum-computing concepts and applications more fully. This is a fruitful moment for solving difficult problems that industry and start-ups will not be able to address. How far can these devices be pushed in the presence of noise? Will some developments stall, causing investment to dry up?

Governments should direct more funding to quantum software. Experimentalists are happy to pitch for large sums of money to build a quantum processor that might lead to a Nobel prize. Quantum programmers should similarly state their grand challenges confidently. Sponsors, too, need to understand that this is a long game that requires diverse approaches. Even when the hardware scales up, we might still be unsure what to do with it.

Industry, particularly start-up firms, should work more closely with universities. Companies could fund small theory projects and invest in developing the fundamentals of the field.

And international collaborations should be protected. Governments should work harder to keep science agreements intact despite political disagreements. Scientists and funders must respect the fact that research is truly global, international and open. Researchers relocate all over the globe. There are many random factors behind the jobs we end up with. It is not in anyone's interests to cut off relationships just because one person crosses a border.

Mid-sized quantum processors will appear soon (although they will still be noisy). Will the quantum software be ready? Or will companies kick themselves for failing to invest in the algorithms and ideas that will drive the devices? ■

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