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GLOBE

VENTURING INTO THE UNKNOWN

How fundamental research creates options for the future

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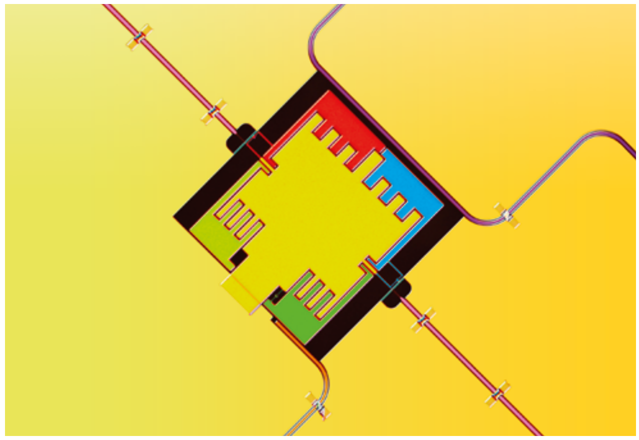

This small quantum circuit was used for simulating a model related to photosynthesis in plants.

For a long time, people regarded quantum computers as an unattainable dream. We now know that it is possible to build such computers. But making them truly useful still requires a fair amount of fundamental research – and a lot of money.

TEXT Felix Würsten

A vision becomes reality

In the 1920s, Werner Heisenberg, Erwin Schrödinger, Wolfgang Pauli and other great physicists worked out the fundamentals of quantum mechanics. They probably never imagined that their exotic-sounding theories would lead people to invest tremendous sums in the manufacture of futuristic calculating machines 90 years later. In fact, recent years have witnessed something of a race to see who can produce the first quantum computer capable of solving tasks that are simply too time-consuming for classical computers. Global technology companies such as Google, Microsoft, IBM and Intel are spending large sums of money on laying the groundwork for the production of quantum computers. The Chinese are likewise investing billions in this promising technology.

Even though people have long extolled quantum computers as genuine miracle machines, the breathtaking pace of recent developments still seems astonishing. After all, there was serious debate among experts just before the turn of the millennium as to whether it would ever be possible to leverage the enigmatic phenomena of quantum mechanics to solve everyday problems.

Now we know that building such computers is feasible, at least in principle. Today’s quantum computers can handle a few dozen quantum bits (or qubits), the basic elements that quantum computers will use to execute tasks, explains Andreas >

Images: Google; ETH Library, Image Archive; ETH Zurich; Gerry Amstutz; Alessandro Della Bella; Quantum Device Lab, A. Potočnik

Wallraff, Professor for Solid State Physics at ETH Zurich. “That raises the question of how much longer we will have to wait until we can use these novel supercomputers for specific applications,” he says. Matthias Troyer, one of Wallraff’s colleagues and Professor for Theoretical Physics, estimates it will be necessary to entangle approximately one million qubits. “That’s a big leap,” he admits. “But we already have very detailed plans for constructing a quantum computer. There are no more fundamental scientific obstacles.”

Different paths

Quantum researchers follow different approaches in their work. Some researchers are keen to use ions as quantum-mechanical objects for computing, while others are pinning their hopes on special semiconductor materials or superconducting circuits. It remains to be seen which technology will emerge as the winner. “Superconducting circuits offer a lot of promise right now,” says Wallraff, who is exploring this technology along with the rest of his team.

There are essentially two key technical challenges. First, it is complicated to manipulate quantum objects accurately, and the electronics required for operating large computers have yet to be developed. Second, today’s components must be drastically reduced in size so that we can integrate them into a manageable computer. One of the problems of superconducting circuits, for instance, is that the techniques typically used in the microchip industry to integrate circuits first need to be adapted for quantum applications to ensure the quality of the qubits. “Chip manufacturers have to come up with truly innovative solutions to accomplish this feat,” says Wallraff.

Applications wanted

Renato Renner, Professor for Theoretical Physics, agrees that recent advances in the development of hardware are impressive, but he now finds himself focusing on a different question: What exactly do we want quantum computers to do? Until recently, scientists knew of only one case where quantum computers were clearly superior to classical computers: the factorisation of large numbers. But this application has no commercial value. Although factorisation can be used to crack modern encryption protocols – an appealing prospect for governments and intelligence agencies – it is not particularly lucrative. Wallraff also takes a critical stance on this issue: “If researchers fail to identify commercially viable applications in the foreseeable future, then large companies may not make the necessary long-term investments. And institutions of higher education do not have sufficient funds of their own to build a large-scale quantum computer that could outperform conventional supercomputers.”

As it turns out, Troyer played a key role in persuading leading computer companies to invest large sums in quantum computing – despite the risks. About three years ago, he demonstrated that a quantum computer can successfully run certain chemical simulations more efficiently than a classical computer. “A quantum computer could allow us to predict far more precisely how molecules will behave,” says Troyer. “That would be very beneficial in the development of new chemicals and materials.” Wallraff concurs that this example makes for a persuasive argument: “As things stand now, drug development costs billions. If quantum computers can offer a competitive advantage, then companies will have a keen interest in developing them even if it requires some major investments.”

Matthias Troyer
is Professor at the Institute for Theoretical Physics. He focuses on key issues in the field of quantum information theory, such as the simulation of materials and quantum devices, quantum software and the applications of tomorrow’s quantum computers.

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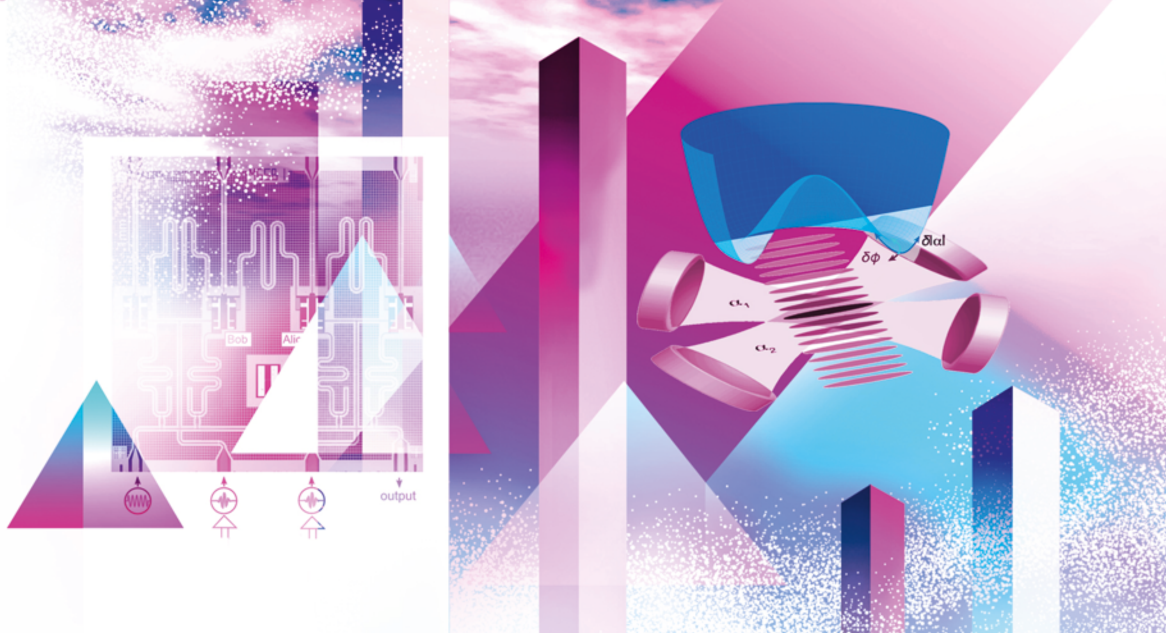
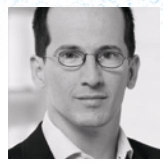
“We have very detailed plans for constructing a quantum computer.”

Images: Giulia Marthaler



“If researchers fail to identify commercially viable applications, the necessary investments may fail to materialize.”



Andreas Wallraff
is Professor at the Laboratory for Solid State Physics. His primary research focus is on quantum information processing and quantum optics with superconducting circuits.

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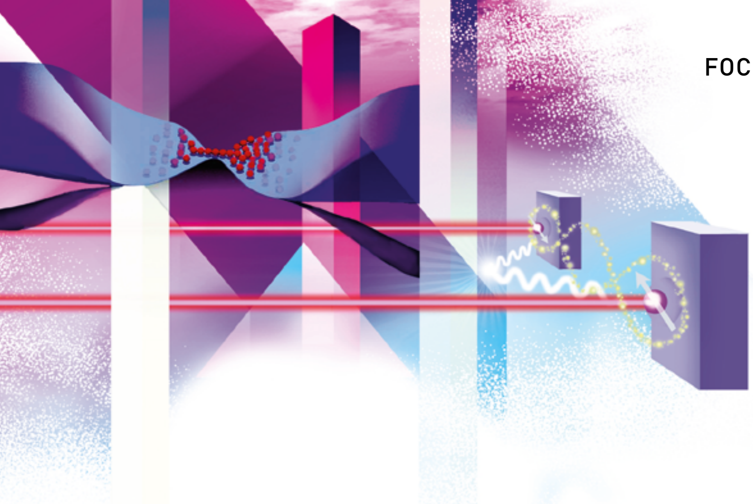
Renner is not concerned by the scarcity of examples of real-world applications. “Quantum computers are still hypothetical devices. Nobody should expect scores of computer scientists to work on a machine that is merely a theory.” But that will change once people start talking about quantum software – and not just quantum hardware, as is the case now. “Quantum computers have a much broader range of software commands at their disposal than do classical computers. That’s why we need computer scientists who really can exploit these advantages,” says Renner.

Troyer is one of the few specialists who already know how to programme quantum computers. “We need computer scientists who have a good understanding of quantum mechanics and feel comfortable working in that field. Building a quantum computer makes sense only if people know how to leverage quantum effects to solve problems,” says Troyer.

Europe versus the competition

The prospect of a paradigm shift in information technology triggered by quantum computing has led some people to ask if Europe can keep pace with Asia and the United States. “Europe has made key contributions to quantum research. All the same, European countries have struggled to use research findings to create economic value,” says Troyer. “That’s partly due to the long-term mindset of American businesses. They are already contemplating what will happen in the computer industry once limits to miniaturisation make the further development of microchips impossible.”

But all is not lost. The European Union recently launched a large-scale flagship programme slated to pro- >



“Perhaps our very understanding of the physical world will change – as it did during the pioneering days of quantum mechanics.”

Renato Renner
is Professor for Theoretical Physics. His research interests include quantum information science, quantum thermodynamics and the foundations of quantum physics.

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vide one billion euros in funding over the next ten years. A key objective is for more European research findings in quantum mechanics to be translated into commercially viable products. It remains to be seen whether this is enough money to keep up with competitors worldwide. China, for example, will invest 10 billion dollars over the next few years in a new national lab for quantum sciences. And the fact that Intel pours billions into designing a new chip puts into perspective the amount that the EU intends to spend on quantum research. Wallraff considers it noteworthy that it is the relatively small countries in Europe that tend to be at the forefront. Austria, Denmark, the Netherlands and Switzerland publish more quantum research per capita than other European countries. “ETH Zurich, and Switzerland in general, have established a good starting point,” says Wallraff. “But that makes it even more important for these countries to figure out now where they want to be in future.”

As technology companies commit more resources to quantum computing, media coverage also increases, largely due to the effusive praise these companies at times heap on any progress they make. The general public may be focusing on real-world applications, but specialists at ETH Zurich and elsewhere who conduct fundamental research still have lots of work to do some 100 years after the early days of quantum mechanics. “A quantum computer is essentially a big quantum-mechanical experiment,” says Renner. As a researcher in fundamental science, Renner hopes for input that could broaden the scope of quantum mechanics. Much like physicists who utilise large particle accelerators to search for clues on how they could advance the standard model, Renner hopes that the construction of quantum computers might reveal potential inconsistencies in quantum mechanics. Physicists are particularly interested in the grey area between the atomic realm, where the rules of quantum mechanics apply, and the macroscopic world, which follows the laws of classical physics. If researchers can someday study larger quantum systems, they will probably better comprehend what exactly occurs in this transitional grey area. “Perhaps our very understanding of the physical world will fundamentally change once more – as it did during the pioneering days of quantum mechanics,” says Renner hopefully. “It would be wonderful if building a quantum computer could help bring that about.” ○