New dimensions in quantum physics

Theoretical physicist Vladimir M. Stojanović took a circuitous route to his research on quantum computers. He is now presenting findings that could provide decisive impetus to this field of research.

By Christian J. Meier

The development of a completely new kind of computer will require input from outstanding scientists. Vladimir M. Stojanović is one of them. The physicist has recently published several theoretical papers that could accelerate the development of quantum computers and their applications. Stojanović believes that in just a few years such computers could solve some complex tasks faster than even the most powerful supercomputers in the world.

Stojanović demonstrated his talents at an early age. As a pupil in his native country of Serbia, he not only excelled in sports but also won competitions in mathematics and physics. He then received his physics degree with the best grades. Stojanović has taken a circuitous path in his research but has been able to develop fresh ideas precisely for this reason. His current field of research is theoretical physics, which bounces ideas back and forth with experimental physics to develop new technologies.

“I believe that this is important for the future of quantum computers.”

In 2003 Stojanović was doing research on the transport of electrical charges in organic semiconductors at TU Eindhoven in the Netherlands. The aim was to develop “plastic electronics” for e.g. particularly inexpensive solar cells. “But then I became interested in another field”, says Stojanović. He moved to Carnegie Mellon University in the US, which is particularly strong in computer science research. As a result, Stojanović was now doing research in a field of physics that is decisively important for the data processing of the future: quantum physics. His research focussed on so-called “superfluids”. These fluids exist at extremely low temperatures and display bizarre properties thanks to quantum physics. For example, superfluids in a rotating vessel do not rotate with the vessel. But this still did not have much to do with quantum computers.

After completing his doctorate at Carnegie Mellon, Stojanovi moved to the University of Basel where he carried out research into important building blocks of quantum computers –- “qubits”. For this new type of computer, they are what bits are for standard computers. While a bit can only store one of the two numbers 0 or 1 at any one time, a qubit can store both values simultaneously. A qubit can be made using a neutral atom that has two energy levels. This is a concept that Stojanović learned at his next stop – the renowned Harvard University in Boston, USA. An atom can exist in a superposition of two energy levels, meaning that it can exist in two states simultaneously.

Several qubits can be in many different states simultaneously and are thus able to store a vast amount of information. Instead of only being able to gradually process information sequentially, which means that complex tasks can take a very long time to be completed, a quantum computer would be able to process huge amounts of data in parallel without any delays.

In the Theoretical Quantum Physics Group at TU Darmstadt, Stojanović is focussing on one of the biggest hurdles on the path to developing a quantum computer. Before qubits can work together in a computer, they have to be linked with one another in a special way. Physicists call this “entanglement”. You can think of several entangled atoms as a sort of collective like a superatom. The problem is that the time needed to entangle qubits increases sharply as the number of qubits grows. This is a paradox because the aim is to use as many qubits as possible to actually save computing time.

Stojanović had an idea for how a special type of multi-qubit entanglement – the so-called W-type entanglement – could be used to link qubits together much more quickly. The approach is very simple. Systems made of many particles have several states with different energy levels. The state with the lowest energy is called the “ground state”. The system will naturally move towards this state itself. Stojanović asked himself Stojanovi had an idea whether it

Information

Theoretical Quantum Physics Group
Dr. Vladimir M. Stojanović
Phone: ++49 (0) 6151/16–20325
Email: vladimir.stojanovic@physik.tu-darmstadt.de
www.iap.tu-darmstadt.de/tqp/grp_stojanovic/index2.html

would be possible to design a system so that its ground state is the desired entangled W state. Even if the system contained a lot of particles, it would reach its ground state very quickly. The problem would thus be resolved. This type of entanglement would also be stable like a swing that remains at its lowest point unless it is pushed.

"The next ingredient came from my work in Eindhoven", says Stojanović. Although his work in Eindhoven did not focus on qubits, it involved systems in which an itinerant particle interacts with multiple point-like oscillators. The ground state of the system had similar properties to the entangled qubit state that the physicist had imagined. For example, a relatively large amount of energy is needed to bring it into another state. "Once you have reached this ground state, it is very stable because no other states with similar energies are available", says Stojanović to describe one of the advantages.

The physicist then transferred this principle to two different physical systems that are already routinely used in quantum-computing research. In one of them, the qubits are made of special electronic materials – so-called superconductors – that conduct electricity without any losses at very low temperatures, while in the other one, the qubits are formed from neutral atoms. "I was very fortunate because this idea came from my experience in other fields of research", says Stojanović. "The fact that I had always been willing to try new things was thus beneficial." His perseverance was ultimately rewarded. The journal Physical Review Letters, which is highly renowned among physicists, published his work. It was a huge distinction because this journal rarely publishes papers by single authors.

Although the findings of Stojanović are still theoretical, he has also considered how to implement them in an experimental setting. "All of the steps can be carried out with established experimental methods", says the physicist, whose work was supported by the Collaborative Research Center CROSSING at TU Darmstadt. In systems proposed by Stojanovi , the time needed to entangle the qubits is thus no longer dependent on the number of qubits, which represents a decisive step towards the development of large, powerful quantum computers. "Another advantage is that the achieved W state is extremely robust", says Stojanović. It is even retained if individual qubits are lost, which can sometimes occur in practice.

"I believe this to be important for the future of quantum computing", says Stojanović confidently. He is currently looking for experimental physicists who want to test his concept in the laboratory and is confident that this will be possible. Stojanović believes that the most useful application for his design will be for so-called "optimisation problems" in which the aim is to find the best possible solution from countless different solutions. "It will help to resolve difficult traffic problems", says Stojanović. This includes things such as a railway timetable with thousands of connections within a complex network that needs to operate as quickly and energy efficiently as possible, while also providing good connections for millions of passengers. Quantum computers could thus enable passengers to enjoy a much more relaxed journey in the future.

The author is a science writer and holds a doctorate in Physics.

Dr. Vladimir M. Stojanovi is carrying out research into the development of quantum computers. He is supported by the Collaborative Research Center CROSSING.

Photo: Katrin Binner

Publications:

Stojanović, Vladimir M. (2021): Scalable W-type entanglement resource in neutral-atom arrays with Rydberg-dressed resonant dipole-dipole interaction. In: Physical Review A, 103 (2), APS Physics, ISSN 2469-9926, **DOI: 10.1103/PhysRevA.103.022410**

(2020): Bare-Excitation Ground State of a Spinless-Fermion–Boson Model and W-State Engineering in an Array of Superconducting Qubits and Resonators. In: Physical Review Letters, 124 (19), p. 190504. ISSN 0031-9007, **DOI: 10.1103/PhysRevLett.124.190504**

(2020): Entanglement-spectrum characterization of ground-state nonanalyticities in coupled excitation-phonon models. In: Physical Review B, 101 (13), American Physical Society, ISSN 2469-9950, **DOI: 10.1103/PhysRevB.101.134301**

Haase, Thorsten; Alber, Gernot; Stojanović, Vladimir M. (2021): Conversion from W to Greenberger-Horne-Zeilinger states in the Rydbergblockade regime of neutral-atom systems. In: Physical Review A, 103 (3), APS Physics, ISSN 2469-9926, **DOI: 10.1103/PhysRevA.103.032427**