Error-free into the quantum computer age

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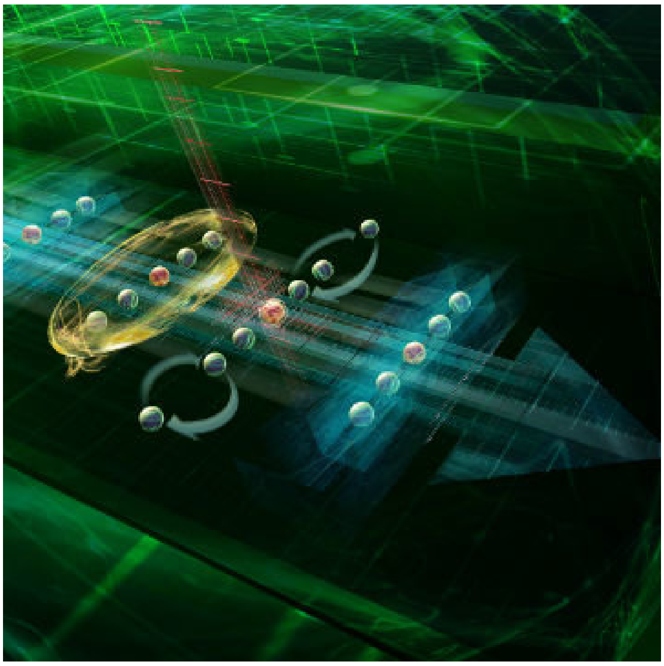

Error-free into the Quantum Computer Age. Credit: H. Ritsch/IQOQI

A study led by physicists at Swansea University in Wales, carried out by an international team of researchers and published in the journal *Physical Review X* shows that ion-trap technologies available today are suitable for building large-scale quantum computers. The scientists introduce trapped-ion quantum error correction protocols that detect and correct processing errors.

In order to reach their full potential, today's quantum computer prototypes have to meet specific criteria: First, they have to be made bigger, which means they need to consist of a considerably higher number of quantum bits. Second, they have to be capable of processing errors. "We still fail in running complex computations because environmental noise and errors cause the system to get out of control," says quantum physicist Rainer Blatt in Innsbruck. "By using quantum error correction, we can respond to this challenge better." Classical computers use similar schemes to detect and correct errors during data storage and transfer: Before data is stored and transferred, redundancy is added to the data usually in the form of additional bits detecting and correcting errors. Scientists have developed comparable schemes for quantum computers, where quantum information is encoded in several entangled physical quantum bits. "Here we exploit quantum mechanical properties for error detection and correction," explains Markus Müller from Swansea University, Wales. "If we can keep the noise below a certain threshold, we will be able to build quantum computers that can perform quantum computations of arbitrary complexity by increasing the number of entangled quantum bits accordingly."

Trapping ions in a maze

Markus Müller and his colleague Alejandro Bermudez Carballo explain that in order to achieve this goal, the capabilities of the technological platforms have to be optimally exploited. "For beneficial error correction we need quantum circuits that are stable and work reliably under realistic conditions even if additional errors occur during the error correction," explains Bermudez. They introduced new variants of fault-tolerant protocols and investigated how these can be implemented with currently available operations on quantum computers. The researchers found that a new generation of segmented ion traps offers ideal conditions for the process: Ions can be shuttled quickly across different segments of the trap array. Precisely timed processes allow parallel operations in different storage and processing regions. By using two different types of ions in a trap, scientists may use one type as carriers of the data qubits while the other one may be used for error measurement, noise suppression and cooling.

A new generation of quantum computers

Building on the experimental experience of research groups in Innsbruck, Mainz, Zurich und

Sydney the researchers defined criteria that will allow the scientists to determine whether the quantum error correction is beneficial. By using this information they can guide the development of future ion-trap quantum computers with the goal to realize a logical quantum bit in the near future that, owed to error correction, exceeds the properties of a pure physical quantum bit.

Simon Benjamin's research group at the University of Oxford showed through complex numerical simulations of the new error correction protocols how the hardware of next generation ion-trap quantum computers has to be built to be able to process information fault-tolerantly. "Our numerical results clearly show that state-of-the-art ion-trap technologies are well suited to serve as platforms for constructing large-scale fault-tolerant quantum computers," explains Benjamin.

Provided by Swansea University
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