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Important Step towards the Quantum Computer

An Austrian team of quantum physicists lead by Anton Zeilinger have managed to outsmart the quantum world, thereby boosting a quantum computers speed and efficiency. The study marks an important step in the world-wide quest to realize a quantum computer and is featured in the current issue of the weekly science magazine NATURE.

Quantum computers are fascinating and promising applications of the laws of quantum physics. In principle, a quantum computer is capable of solving the exactly same problems as classical computers, however, it has been shown in recent years that a quantum computer can solve a particular class of problems much faster (i.e. in less elementary steps) and even promise to perform tasks utterly intractable on any conceivable classical computer. Famous examples include quantum algorithms to search in unsorted databases or the ability to factor large integers. This quantum "speed-up" stems from the fact that quantum computers are able to simultaneously operate on a large set of input states, a phenomenon called quantum parallelism. Quantum computers owe this to unique quantum features such as superposition, i.e. states can simultaneously exist in a superposition of different states (e.g. "0" and "1"), which is a phenomenon similar to Schrödinger's Cat.

One-Way Quanten Computer

In the actual experiment, the research team (Robert Prevedel, Philip Walther, Felix Tiefenbacher, Pascal Böhi, Rainer Kaltenbaek, Thomas Jennewein and Anton Zeilinger) first of all prepared a so-called cluster-state, which acts as the "resource" for the computation. This cluster state is made up of entangled quantum bits ("qubits" for short), in which each qubit was realized by a photon in the experiment. Such an initial cluster state is so rich in information, that in principle, it contains all the possible outcomes of the calculation one intents to perform. The computation itself proceeds by consecutive measurements on the individual qubits (=photons) of the cluster state, whereby different calculations require different types of measurements. It is important to note at this point that in quantum physics, unlike in everyday life, due to the entanglement – which Einstein termed "spooky action at distance" – measurements influence and alter the state of the remaining photons instantaneously. After those measurements, the states of the remaining qubits are the outcome of the performed computation. Another fundamental feature of quantum physics is that measurement results are intrinsically random. However, the correct outcome of the computation is only guaranteed if the individual measurements yield the desired results. Up until now, the potential users of this quantum computer was limited; they had to wait until "randomly" the right computation had been performed. But with as little as 10 measurements already, this meant that in only one of a thousand attempts the computer would produce the desired outcome! Based on a theoretical proposal of Raussendorf and Briegel (IQOQI Innsbruck), the Austrian research team outsmarted the fundamental principle of measurement randomness with a clever trick.

Feed-Forward renders Quantum Computer deterministic

The problematic randomness of the measurement result can be disarmed if one adapts the choice of subsequent measurements in such a way that the introduced error in the computation is corrected for (so-called error correction). Loosely speaking, one adapts the software of the computer in real-time, so that the quantum randomness does not effect the computation any more. The process of quickly adapting the subsequent measurements is called "active feed-forward", which due to the speed of light, has to be as fast as possible. In the actual experiment, the active feed-forward required high-speed electronic and electro-optical components that change the measurement of the photons and perform the error-correction. With custom-built electro-optical modulators and logic boards this adaptation of the measurement was achieved in just under 150 nanoseconds (1 nanosecond = 1 billionths of a seconds). This also shows that photonic quantum computers are by a factor of 1000 faster than other comparable realizations of quantum computers not based on single photons.

The study was the result of a collaboration of physicists from the Institute for Experimental Physics of the University of Vienna, the Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences in Vienna as well as with a researcher from the Harvard University (USA). This research was supported by the Austrian Science Fund (FWF), the DTO of the U.S. Army Research Offices as well as by the QAP-Project of the European Commission.

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Nature **445**, 7123 (4th January 2007);
Robert Prevedel, Philip Walther, Felix Tiefenbacher, Pascal Böhi, Rainer Kaltenbaek, Thomas Jennewein and Anton Zeilinger: **High-speed linear optics quantum computing using active feed-forward**

Images can be found at: http://www.quantum.at/press/

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