The Quantum Way of Doing Computations

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Since the mid-nineties of the 20th century, it became apparent that one of the centuries' most important technological inventions, computers in general and many of their applications could possibly be further enhanced by using operations based on quantum physics. This is timely since the classical roadmap for the development of computational devices, commonly known as Moore's law, will cease to be applicable within the next decade. This is due to the ever-smaller sizes of the electronic components that will enter the realm of quantum physics. Computations, whether they happen in our heads or with any computational device, always rely on real physical devices and processes. Data input, data representation in a memory, data manipulation using algorithms and finally, data output require physical realizations with devices and practical procedures. Building a quantum computer then requires the implementation of quantum bits (qubits) as storage sites for quantum information, quantum registers and quantum gates for data handling and processing as well as the development of quantum algorithms.

In this talk, the basic functional principle of a quantum computer will be reviewed. It will be shown how strings of trapped ions can be used to build a quantum information processor and how basic computations can be performed using quantum techniques. In particular, the quantum way of doing computations will be illustrated with analog and digital quantum simulations, which range from the simulation of quantum many-body spin systems over open quantum systems to the quantum simulation of a lattice gauge theory.