International Workshop „Quantum Annealing and its Applications in Science and Industry“ (QuAASI'16)

The international workshop „Quantum Annealing and its Applications in Science and Industry (QuAASI'16)“ took place from 26 to 28 July 2016 in the Rotunda of the Jülich Supercomputing Centre. The goal of the two-day workshop, followed by a D-Wave Exploration Day, was to bring together researchers from different communities to discuss both the challenges in using quantum annealing to approach the solution of real-world problems and the requirements on optimization and design of existing and future quantum annealing hardware.

About 60 researchers from Germany, Switzerland, the Netherlands, the United Kingdom, the United States and Canada participated in the workshop. The history of quantum annealing and the design of D-Wave's quantum processors, the implementation of various optimization problems and machine learning on D-Wave machines, the study of the behavior and performance of D-Wave quantum computers, the various approaches designed to extend the applicability of these devices to larger, more connected optimization problems, and related topics were highlighted in the talks. The D-Wave Exploration Day provided detailed insights into the hardware architecture. Programming techniques and tools available were demonstrated by remotely running examples on one of the D-Wave 2X™ quantum computers with more than 1000 qubits located at the headquarters of D-Wave Systems in Burnaby, Canada.

Discrete optimization and quantum annealing

Optimization challenges are ubiquitous. They affect the sciences and the whole of society directly and indirectly. They comprise, among others, flight and train scheduling, vehicle routing, power trading and scheduling, supply chain network optimization, planning and scheduling of production processes, organ allocation and acceptance optimization, cancer radiation treatment scheduling, and optimizing target interactions for drug design. Optimization also lies at the heart of machine learning, artificial intelligence, computer vision and data mining.

In many of these practical optimization problems the task is to find the best solution among a finite set of feasible solutions. Such problems are formulated as discrete optimization problems. A standard way for solving discrete optimization problems is to first construct an integer or mixed-integer programming model, involving discrete or both continuous and discrete variables, and then use a software package such as CPLEX to solve the constructed model.

The new strategy proposed is to use quantum annealing for solving those optimization problems which can be mapped to a QUBO, a quadratic unconstrained binary optimization problem. Quantum annealing is a new technique, inspired by the classical simulated annealing techniques which are based on temperature fluctuations, for finding the global minimum of a quadratic function of binary variables by exploiting quantum fluctuations. Its main potential targets are combinatorial optimization problems featuring a discrete search space with many local minima. Many challenging optimization problems playing a role in scientific research and in industrial applications naturally occur as or can be mapped by clever modeling strategies to QUBOs.

D-Wave Systems

D-Wave Systems, founded in 1999, is the first company that has commercialized quantum annealers to carry out quantum computations. Their quantum annealers are programmable artificial spin systems manufactured as integrated circuits of superconducting qubits. Qubits or quantum bits are the elementary building blocks of a quantum computer, similar to the bits in a digital computer. The latest D-Wave quantum computers, D-Wave 2X™ systems, operate with more than 1000 qubits and over 3000 couplers connecting the qubits for information exchange. The D-Wave 2X™ niobium quantum processor, a complex superconducting integrated circuit containing more than 128,000 Josephson junctions, is cooled to 15 mK and shielded from external magnetic fields, vibrations and external radiofrequency fields of any form. A D-Wave 2X™ system requires less than 25 kW of power, most of which is consumed by the refrigeration system and the front-end servers. Currently, D-Wave Systems is testing their next generation of quantum computers having more than 2000 qubits. These new systems are scheduled for release in mid 2017.

D-Wave quantum processors are capable of solving QUBOs by mapping binary variables to qubits and correlations between variables to couplings between qubits. During a "quantum computation", the system of interacting qubits evolves according to a quantum adiabatic annealing process. At the end of this process the qubits are read out to get the optimal or near optimal solution of the optimization problem.

Current D-Wave quantum processors have a so-called Chimera graph architecture, thereby connecting a given qubit with at most six other qubits. Solving optimization problems on such an architecture requires the embedding of the problems on the Chimera graph. This obviously limits the range of optimization problems that potentially can be solved on such a machine, but nevertheless, some very hard real-world optimization problems might be among them. Hence, exploring the potential of quantum annealing on this operational prototypic hardware for some real world problems is a challenge that should be taken up.

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