Quantum annealing: how hard can it be?

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Quantum annealing is a proposed method for finding solutions to computationally-hard optimisation problems. It is analogous to simulated thermal annealing, in which thermal fluctuations drive a system defined by a multidimensional Hamiltonian into its ground state with some high probability. In quantum annealing the thermal fluctuations are accompanied by quantum fluctuations, potentially enabling the system to escape from local minima by tunnelling.

The quantum annealing device manufactured by D-Wave Systems Inc. finds the ground-state spin configuration of an Ising spin glass, currently with up to 1000 spins. Each spin is encoded in the flux state of an r.f. SQUID. By studying the behaviour of a designed Hamiltonian encoded on the D-Wave chip, we have shown that its dynamics cannot be explained by a fully classical model [1]. In spite of this and some impressive demonstrations of both generic problems [2] and specific real-world problems including error-correction decoding [3], the D-Wave machine currently shows no speedup with respect to classical solvers which are optimised for its native “Chimera” architecture. This is due to the fact that problems which map directly onto the D-Wave machine are typically easy for classical solvers [4].

The Chimera architecture features only first- and second-order spin interactions. It is known that problems with interactions of order three and higher are computationally hard for classical solvers. Hardware implementation of third-order interactions between r.f. SQUIDs is, however, non-trivial. Here I will show (a) how to generate hard problems featuring cubic spin interactions; and (b) how such interactions can be efficiently implemented in hardware using r.f. SQUIDs [5]. Such hardware could be incorporated into future quantum annealing devices similar to the type currently being developed by D-Wave Systems.

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