[P1] Quantum annealing with antiferromagnetic fluctuations

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The purpose of this study is to find appropriate quantum fluctuations that avoid the difficulty of exponentially increasing running time in quantum annealing (QA) [1, 2]. we have found that antiferromagnetic fluctuations facilitate the process of QA for the ferromagnetic *p*-spin model.

Quantum algorithms are expected to solve combinatorial optimization problems that classical algorithms cannot solve efficiently. The same is true for QA. Since QA often outperforms simulated annealing [3], which is a heuristic classical algorithm coming from physics, this is a promising path to follow.

Nevertheless, there exist problems that QA cannot solve efficiently. An example is to find the ground state of the ferromagnetic p-spin model. Jörg et al. have shown that QA with the conventional transverse field costs exponentially long time to solve the problem for $p > 2$ [4]. They have also shown that this system undergoes a quantum first-order phase transition during a quantum annealing process. This is a characteristic feature of hard problems.

To resolve the above difficulty, we introduce antiferromagnetic fluctuations into quantum annealing in addition to the transverse-field term [5]. The analysis of the phase diagram and the energy gap between the ground state and first excited state are used to estimate the efficiency of this method. As a result, the phase diagram shows that there exist quantum paths to reach the optimal solution that avoid a first-order phase transition for intermediate values of *p*. Furthermore, we have found that the minimum energy gap decays polynomially with the system size at a secondorder transition point along the quantum path that avoids first-order transitions.

These results suggest that QA would be able to solve this problem with intermediate values of *p* efficiently.

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