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Limitations of tensor-network approaches for optimization and sampling: A comparison to quantum and classical Ising machines

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Optimization problems pose challenges across various fields. In recent years, quantum annealers have emerged as a promising platform for tackling such challenges. To provide a new perspective, we develop a heuristic tensor-network-based algorithm to reveal the low-energy spectrum of Ising spin-glass systems with interaction graphs relevant to present-day quantum annealers. Our deterministic approach combines a branch-and-bound search strategy with an approximate calculation of marginals via tensor-network contractions. Its application to quasi-two-dimensional lattices with large unit cells of up to 24 spins, realized in current quantum annealing processors, requires a dedicated approach that utilizes sparse structures in the tensor network representation and GPU hardware acceleration. We benchmark our approach on random problems defined on Pegasus and Zephyr graphs with up to a few thousand spins, comparing it against the D-Wave Advantage quantum annealer and Simulated Bifurcation algorithm, with the latter representing an emerging class of classical Ising solvers. Apart from the quality of the best solutions, we compare the diversity of low-energy states sampled by all the solvers. For the biggest considered i.i.d. problems with over 5000 spins, the state-of-the-art tensor network approaches lead to solutions that are 0.1% to 1% worse than the best solutions obtained by Ising machines while being two orders of magnitude slower. We attribute those results to approximate contraction failures. While all three methods can output diverse low-energy solutions, e.g., differing by at least a quarter of spins with energy error below 1%, our deterministic branch-and-bound approach finds sets of a few such states at most. On the other hand, both Ising machines prove capable of sampling sets of thousands of such solutions.

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