Accelerating Probabilistic Quantum Simulation with Intel Loihi 2

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Neuromorphic computing systems exploit brain-inspired principles such as co-location, massive parallelism and stochasticity. The latter makes them promising accelerators for quantum-inspired computing. A prime example are quantum many-body simulation methods that map the quantum solution to an effective classical Ising model, which is then solved with Markov chain Monte Carlo (MCMC) methods. On digital hardware, the scalability of such method is limited by the sequential nature of MCMC. Recently, progress has been made on dedicated sampling schemes for Ising problems on Intel Loihi 2 [1] and SpiNNaker [2]. Yet, for physically relevant problems involving constraints, these approaches suffer from a poor sampling efficiency. Therefore, developing algorithms that enable efficient sampling of constrained Ising models on neuromorphic hardware is critical for large-scale probabilistic quantum simulation.

Here we investigate efficient sampling of antiferromagnetic models relevant for simulation of quantum magnetism with neural quantum states (NQS). NQS is method for classical simulation of 2D quantum systems [3] and maps efficiently onto Ising machines [4, 5]. Building on sampling schemes for Loihi 2 [1], we propose two algorithms for sampling Ising problems with magnetization constraints: one optimized for execution on GPUs and a second designed for distributed spiking architectures such as Loihi 2 and SpiNNaker. We demonstrate training of 2D antiferromagnetic spin models using a hybrid approach in which a GPU or (emulated) Loihi 2 acts as a coprocessor for massively parallel sampling. The constraint-respecting algorithm retains competitive accuracy down to INT8 precision, showing strong potential for large quantum simulations of antiferromagnetic models and future deployment on large scale dedicated hardware featuring billions of Ising nodes [6].

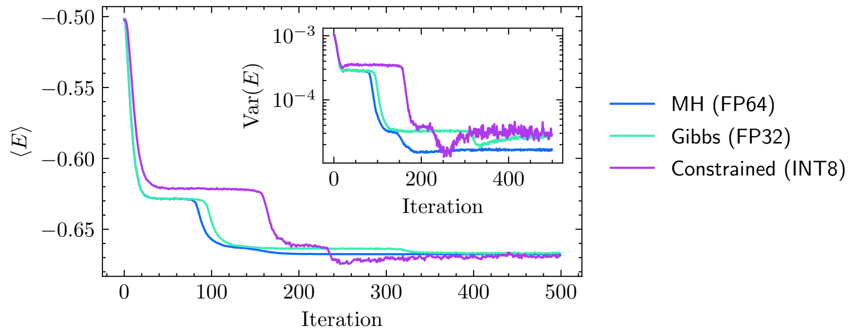

Figure 1: Training of ground state of antiferromagnetic quantum Heisenberg model obtained with Metropolis-Hastings (MH), Gibbs and Constrained sampling.

[1] A. Pierro et al., arXiv:2408.03076, 2024.

[2] Z. Chen et al., Nat Communications, 16(3086), 2025.

[3] G. Carleo et al., Science, 355(6325), 602--606, 2017.

[4] S. Chowdhury et al., arXiv:2512.24558, 2025.

[5] R. Berns et al., Physical Review Applied, 25(2), 024085, 2026.

[6] D. Kudithipudi et al., Nature, 637(8047), 801--812, 2025.