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Ground state search of interacting boson–fermion systems using variational Monte Carlo

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This work is motivated by the limitations of conventional Euclidean Monte Carlo methods, particularly the sign problem, which hinder the exploration of physically rich regimes such as nonzero chemical potential, topological terms, and real time dynamics. To address this challenge, we present a Hamiltonian-based variational approach for numerical simulations of quantum mechanical systems. We benchmark our method on two physical models of interest— $2+1D$ compact lattice QED with Wilson fermion discretization, and the minimal BMN matrix model.

We employ a variational Monte Carlo algorithm, where we construct a parameterized ansatz state and approximate the ground state by minimizing the energy w.r.t. the variational parameters. The ansatz is decomposed into two parts—a gauge/bosonic part and a fermionic part, each constructed using gauge invariant combinations of the underlying degrees of freedom. For the gauge/bosonic part of the ansatz, we work in a continuous basis of the physical Hilbert space to avoid basis truncations (such as cutoffs in electric flux or bosonic occupation numbers, which are introduced to make the infinite-dimensional degrees of freedom numerically tractable). The expectation values are computed in this continuous basis by numerical integration using Monte Carlo. To avoid the fermionic sign problem we approximate the fermionic part of the ansatz as a fermionic gaussian state for each gauge/bosonic field configuration. As a result, the expectation value w.r.t. to fermionic state is computed analytically, removing the need for sampling from fermionic distributions.

We show preliminary results for the ground state preparation in the sign problem afflicted regimes of the $2+1D$ compact lattice QED and the BMN matrix model, demonstrating the viability of this Hamiltonian variational approach and offers a path towards studying regimes inaccessible to Euclidean Monte Carlo.

Parallel Session (for talks only)

Algorithms and artificial intelligence

Author: NAREDI, Pranay (DESY, The Cyprus Institute)

Co-authors: Dr BREHM, Enrico M. (DESY); Dr KÜHN, Stefan (DESY)

Presenter: NAREDI, Pranay (DESY, The Cyprus Institute)

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