Variational quantum simulator of interacting bosons

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Overview

- VQE for interacting bosons
- Determine excited states by penalizing the overlap
- Proof-of-principle experiment on Rigetti’s 8Q device

Variational quantum eigensolver (VQE)

Goal: encode the states in a truncated boson Hilbert space by a finite number of qubits

- Ground state and first-excited state eigenenergies
- Narrowing of energy gap with increasing coupling
- Discrepancy between experimental result and exact solution: hardware noises and sampling errors

VQE for Rabi model on Rigetti’s 8Q device

Trials state’s ansatz

Noisy intermediate Scale Quantum (NISQ) devices

Update

Quantum-classical hybrid algorithm

Efficient measurement

Classical optimization algorithm

Trial state’s energy

Eigenstates and eigenenergies

Input

Quantum phase estimation, time evolution, ...

Applications on boson systems:

- Light-matter interaction
- Electron-phonon coupling
- Quantum field theory

Boson encoding by qubits

Goal: encode the states in a truncated boson Hilbert space by a finite number of qubits

Number basis encoding

| n = N⟩ = |1 1 1⟩q
| n = 3⟩ = |0 1 1⟩q
| n = 2⟩ = |0 0 1⟩q
| n = 1⟩ = |0 0 0⟩q
| n = 0⟩ = |0 0 0⟩q

Position basis encoding

Ref: Phys. Rev. Lett. 121, 110504

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Hardware efficient trial state’s ansatz

1Q-gate layer

Entanglement-gate layers

Optimize toward shallowest circuit: ansatz only consists of gates that are natively supported by the hardware

Cost function and optimization

Eigenstates: |ψf⟩ = argmin |Cj |ψ(θ)⟩

Cost function: Cj = (ψ(θ)Hψ(θ)) + Σk=1 1/2 |ψk⟩|ψ(θ)⟩|^2

SPSA optimization algorithm

→ Stochastic optimization

→ More robust with noisy environment

VQE for Rabi model on Rigetti’s 8Q device

G = 0 0 0 (g)

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Effect due to operation cycle

Noisier first-excited state optimization due to overlap measurement

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