Implementing Hamiltonian Simulation and Variational Quantum Eigensolver on Bosonic Modular Devices

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• Quantum computers use quantum bits (qubits) as basic unit of quantum information and require dilution refrigerators.

• Photonic quantum computing, however, utilizes optical devices such as beam-splitters that are compatible with room temperature and follows the continuous-variable model with qumodes as basic unit.

• Strawberry Fields allows photonic quantum computing to realize the Gaussian Boson Sampling algorithm to solve certain NP-hard problems, including chemistry applications.
Universal gate set:

- **Displacement**: with that transforms a vacuum state to the respective coherent state:

- **Phase space squeezing**:

- **Rotation gate**:

- **Beamsplitter gate**:

- **Kerr gate (non-Gaussian)**:

Wigner representations of output states starting from vacuum after applying:

- Displacement gate
- Kerr gate
- Rotation gate
- Squeezing gate
Given a Hamiltonian, we can simulate quantum dynamics using Strawberry Fields. Take the Bose-Hubbard Hamiltonian for two qumodes:

\[ H = t \sigma \cdot \sigma + \Delta \sigma_z \sigma_z \]

with \( t \) being the transfer integral/hopping term of the boson between the two nodes, and \( \Delta \) the on-site interaction potential. We can now apply the Lie product formula to decompose the time-evolution into CV gates:
• Hybrid algorithm to find the ground state of a given physical system:
  • A guess circuit (ansatz) is executed by the quantum processor to calculate the expectation value of an observable.
  • Classical optimizer is used to improve the guess.
  • Based on the variational method of quantum mechanics:
  • In Strawberry Fields, the TensorFlow backend is supported for better optimization algorithms, machine learning tools, and GPU utilization.
Given an arbitrary Hamiltonian for a physical system, we map into an $N$-mode bosonic second quantization form (Jordan-Wigner transformation, bosonization, Jordan-Schwinger transformation,…):

- Decompose $\mathcal{H}$ where each can be written as a gate supported by Strawberry Fields. This is always viable, since the universal gate set is supported.

- Perform Trotterization (Lie-Suzuki product formula):

- Build corresponding circuit and execute. Note that not all backends support non-Gaussian gates such as the Kerr gate or Cubic phase gate.