HPC/AI-Assisted Quantum Computing

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HPC-assisted Quantum Computing

- Verification of quantum supremacy and advantage in a collaboration with Quantinuum and JPMorgan Chase
- HPC-assisted quantum simulations (Operator Backpropagation Method)
- Development of scalable and parallel AI quantum compilers with Fred Chong's group:
    - Decomposition of circuits into lower-level specifications
    - Optimization of circuit layouts
    - Pulse optimization

In all cases we rely heavily on our quantum circuit simulators, AI tools, and supercomputers

Argonne's Quantum Circuit HPC Simulators

- Tensor network quantum circuit simulators:
  - QTensor for QAOA simulations (200+ qubit simulations)
  - QTensor approximate simulation using lossy compression (300+ qubit simulations)
  - Stochastic Noise QTensor simulator (100+ qubit simulations)
  - QTensorAI for quantum machine learning (analytical backpropagation is implemented)
  - Boson sampling simulator
  - Approximate Matrix Product State simulator (goal 1,000+ qubit simulations)
  - Surface code decoding simulator in planning
- State vector quantum circuit simulators:
  - Lossy compression of state-vector (Intel-QS simulator)

Operator Backpropagation (OBP) method

- Developed HPC-assisted quantum computing using the novel method called Operator Backpropagation (OBP) method
- OBP works for any expectation value quantum circuit simulation
- OBP allows to increase the depth of quantum circuits using fast quantum circuit simulators by 5-10 Trotter steps in the quantum time dynamics simulations
- Combine with lightcones, tensor slicing, tensor circuit compression, circuit knitting, and approximate quantum simulators (MPS) to improve performance
- Complements circuit cutting/knitting method

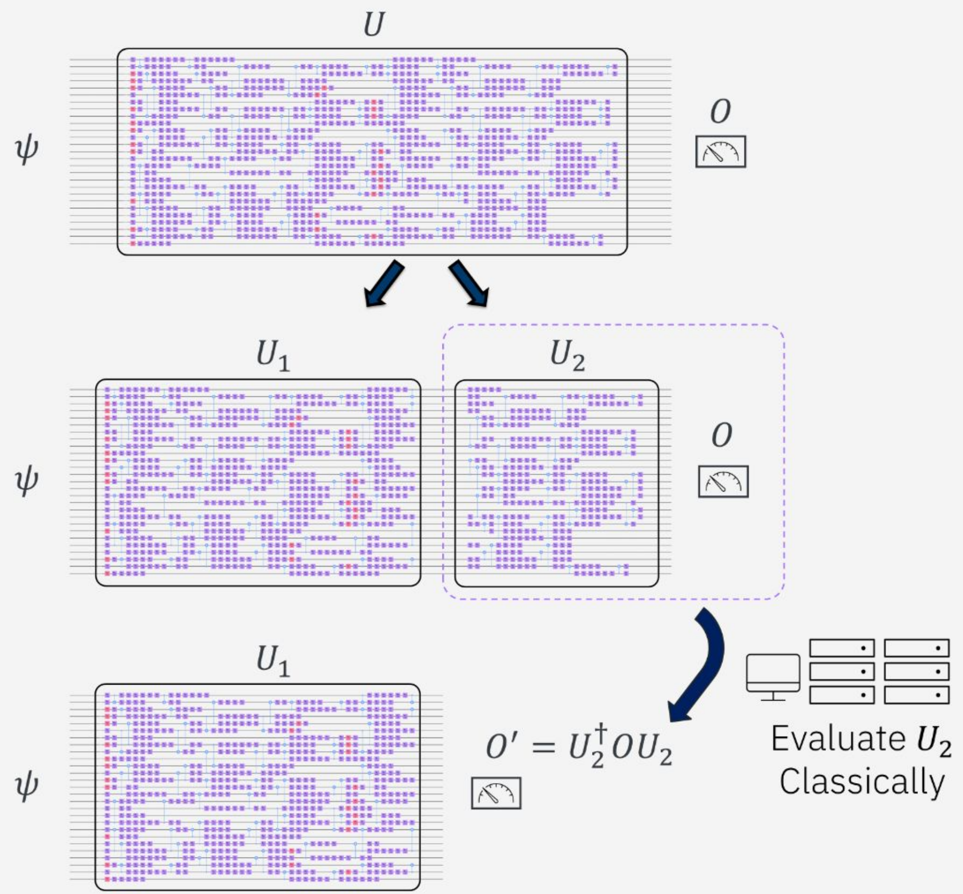
Theory

Operator Backpropagation Method (OBP):

Divide a circuit into two parts $U = U_2 U_1$.

Propagate O under U_2 to figure out an equivalent observable O'.
Classically expensive!

Apply U_1 to the quantum state and measure O'. Which can be more complicated to measure.



AI-assisted Quantum Computing

- Optimal ansatz design using generative models and reinforced learning
- Error decoding and mitigation using both neural networks and generative models; in particular, use diffusion models
- Find and predict optimal circuit parameters using knowledge transfer methods
- Finding optimal unitary operator tensor decomposition scheme in terms of native gates
- Create parameterized quantum circuit vector database to be used in AI projects