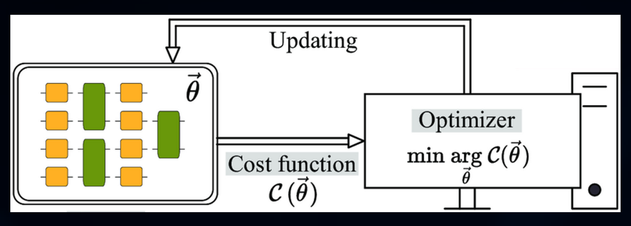
Enhancing Variational Quantum Algorithms by Balancing Classical and Quantum Hardware

Check out our full paper here!

Background

Variational Quantum Algorithm (VQA) :

Quantum circuit with trainable parameters + Parameters updated iteratively until a cost function is optimized



Various applications like Drug Discovery, Material Exploration, Quantum Chemistry and ML/AI

Challenges & Our Proposal

VQA has several bottlenecks in training:

- **High Quantum Hardware** usage for obtaining gradients of cost function
- **Vanishing gradient issue** or Barren Plateau phenomenon

To address these challenges, we propose:

- Hardware Efficient and dynamical Lie algebra Supported Ansatz **(HELIA)**
- New training methods: **Alternate, Simultaneous and Alt+Sim**

Results

For the application of ground-state estimation, our method compared to PSR shows:

- Lower estimation error: Up to an order of magnitude
- Reduced Quantum Processing Unit Calls : Up to 60%
- Barren Plateau Mitigation

New ansatz & tailored training schemes

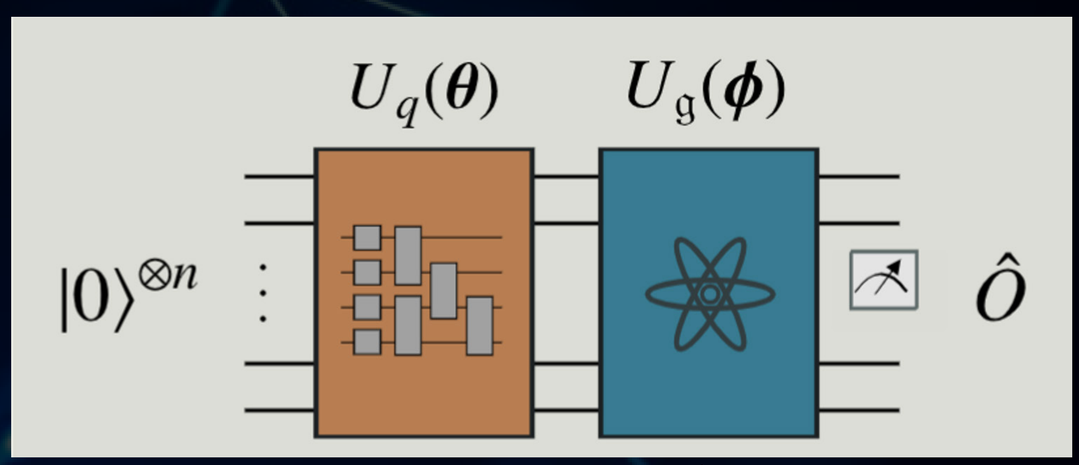
Hardware Efficient and dynamical Lie algebra Supported Ansatz (HELIA):

- Hardware-Efficient Ansatz (HEA) block $U_q(\theta)$ followed by block $U_g(\phi)$ of gates from problem-specific dynamical Lie Algebra (DLA)
- Measurement operator also belongs to the problem-specific DLA

Three training schemes:

- Alternate: Update $U_q(\theta)$ and $U_g(\phi)$ in alternate iterations
- Simultaneous: Update $U_q(\theta)$ and $U_g(\phi)$ in same iteration
- Alt+Sim: Alternate protocol for a fixed number of iterations followed by Simultaneous protocol

HELIA



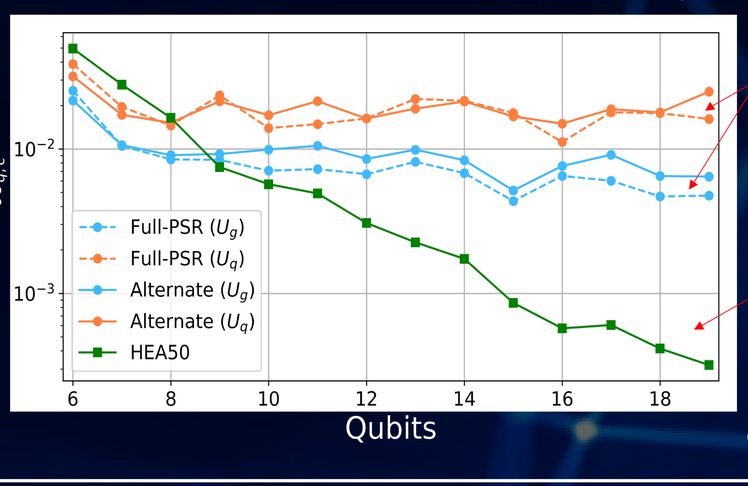
PSR (Run on quantum hardware)

g-sim (Run on quantum hardware)

Application: Ground-State Energy Estimation for the quantum XY model: $H_{XY} = \sum_i^{N-1} \alpha_i \hat{X}_i \hat{X}_{i+1} + \sum_j^{N-1} \beta_j \hat{Y}_j \hat{Y}_{j+1}$

Barren Plateau Mitigation: HELIA vs Deep HEA (50 layers)

HELIA: 1 Hamiltonian DLA block and 9 YZ Linear layers



Higher Gradients for HELIA

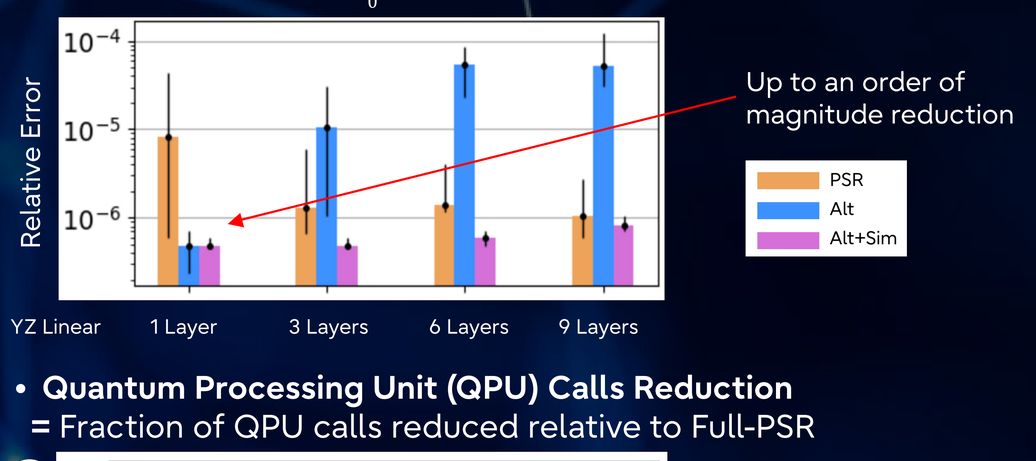
BP in Deep HEA

Qubits 6-19

Barren Plateau Mitigation: HELIA vs Deep HEA (50 layers)

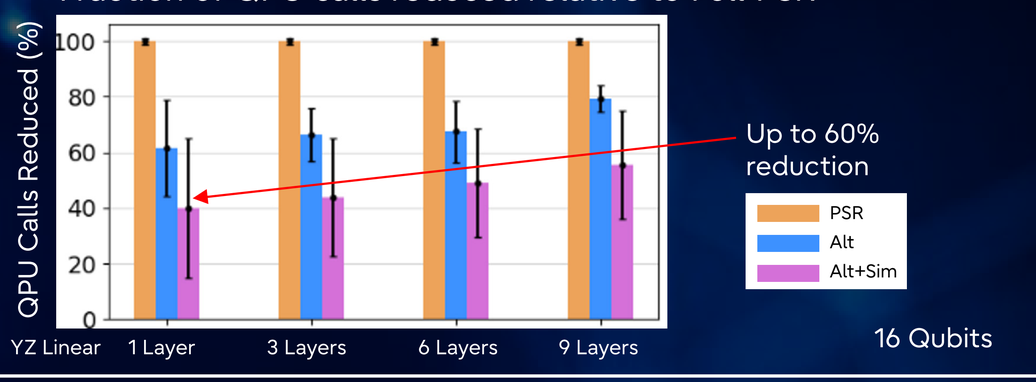
- Our proposal gives more accurate solution than Parameter-shift Rule while using much less quantum resources, and also mitigates Barren Plateaus.
- Improves VQE, Quantum Machine Learning and Optimization algorithms

- **Relative Error =** $\frac{(E_g^t - E_0)}{E_0}$ E_g^t = Estimated ground-state energy, E_0 = True ground-state energy



Up to an order of magnitude reduction

- **Quantum Processing Unit (QPU) Calls Reduction**
  = Fraction of QPU calls reduced relative to Full-PSR



Up to 60% reduction

16 Qubits

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