Implementation of QAOA Maxcut on Amazon Braket

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QAOA Algorithm

- Max-Cut problem: Given a graph **G=(V,E)**, find a best way to separate the node into two groups with maximal cross-group edges.
- QAOA for Max-Cut:
  - Hamiltonian with ground state consisting Max-Cut solutions:

$$H = \sum_{(i,j)\in E} \mathbf{I} - \mathbf{Z}_i \otimes \mathbf{Z}_i$$

  - Anstaz circuit for ground state:

$$C[\gamma,\alpha] = \prod_{j=1}^{n_{\text{layers}}} e^{iH\gamma_j} e^{iH_0\alpha_j} |\psi_0\rangle$$

- Procedure of QAOA:
  - Decide number of layers
  - Optimize parameters α, γ which minimize the energy function

$$E(\gamma,\alpha) = |\langle\psi_0|C[\gamma,\alpha]|\psi_0\rangle|$$

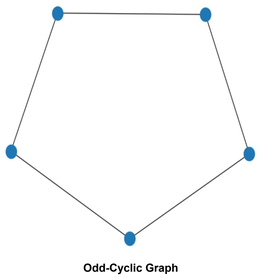
  - Evaluate optimal circuit and measure output to get potential solutions.

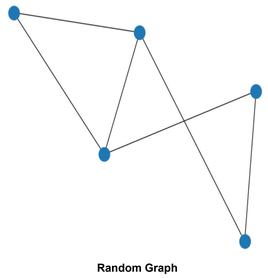
Amazon Braket

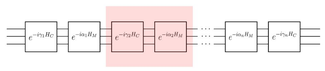
- Amazon Braket provides a full-fledged online development environment for various quantum applications.
- Crucial to our project, Bracket provides full support to various important QML packages, fine-grained noise modeling, access to efficient local/online simulators and quantum devices, and easy-to-use interface for classical-quantum hybrid tasks.

Amazon Braket

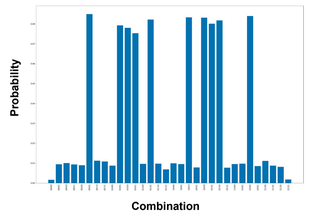
Experimental Setup





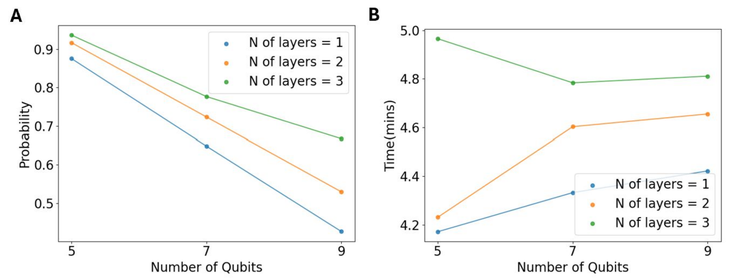


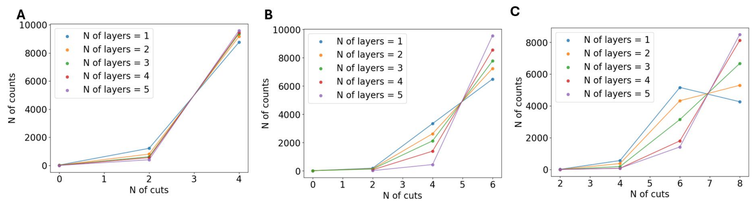
https://pennylane.ai/qml/demos/tutorial_qaoa_intro/



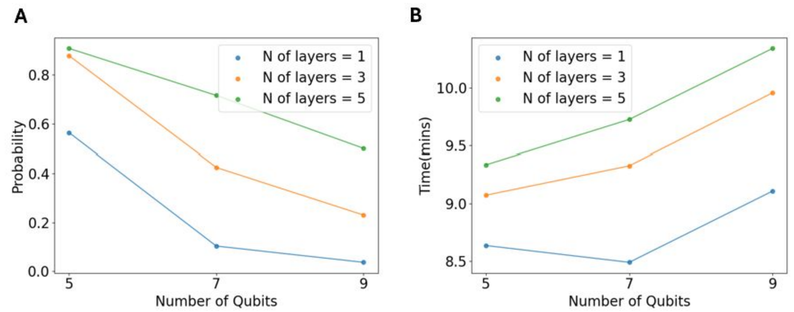
- Gate noise applies a depolarizing noise after each gate in the circuit.
- Readout noise applies a bitflip noise at the end of the circuit.

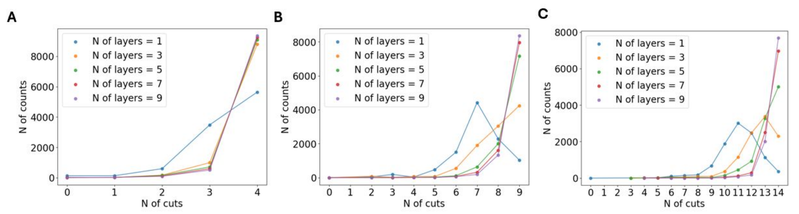
Odd-Cyclic Graphs





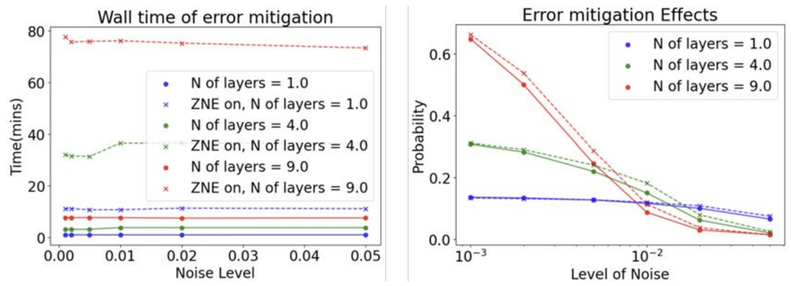
Random Graphs



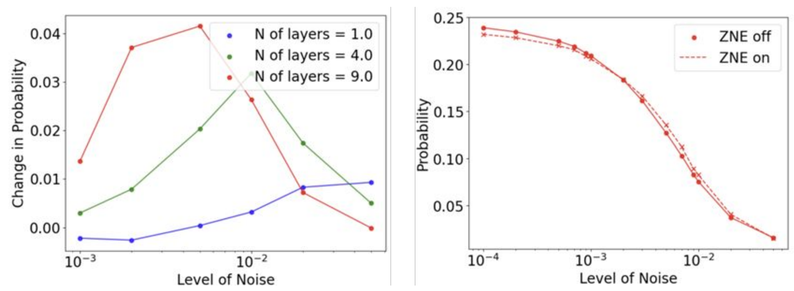


Error Mitigation

- Error mitigation is implemented using ZNE functions on the pennylane, QML.
- The Error mitigation results are ran on random graph, 7 qubits, and with corresponding number of layers.



- The ZNE functions takes about 10 times of the original wall time.
- For noise level from 0.001 to 0.05, the ZNE has has obvious improvement on probability of getting the maxcut.



- Change of the probability depends on the number of layer and level of noises.
- For lower noise level, down to 0.0001, ZNE does not always improve the probability of getting the correct maxcut.
- There is a tradeoff among number of layers, number of qubits, and wall time.

Future Work, References, and Acknowledgments

- Further improvements of the probability dependence on different number of qubits and layers, with ZNE on and off
- Test of the ZNE function on QPU, ie. IonQ
- Study the dependence with different number of cuts

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