Quantum Heuristic Solver using QAOA for the Maximum Independent Set Problem

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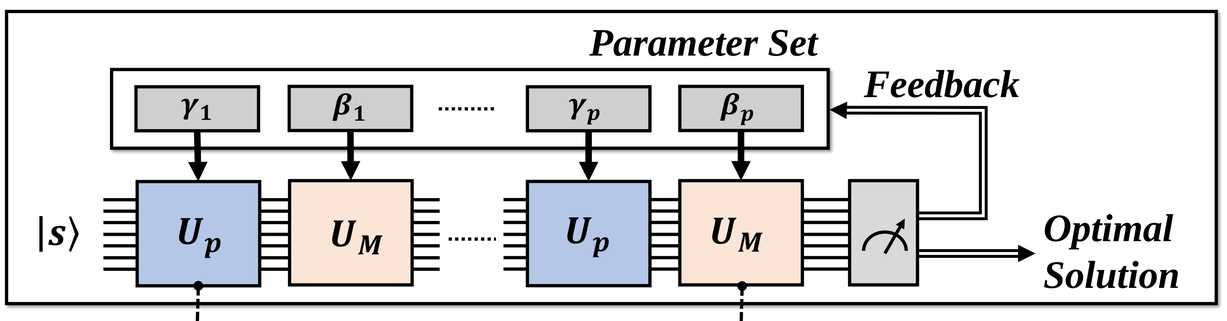
Quantum Approximate Optimization Algorithm (QAOA)

Introduction

- **Quantum Approximate Optimization Algorithm**
  - → An optimization algorithm can be used efficiently in small quantum computing environment
  - → Useful in graph-based NP-hard problems
- **Quantum Alternating Operator Ansatz**
  - → More intuitive way to solve graph problem with constraints
  - → Starts with one trial solution
  - → Explores other solutions at the same time without accessing prohibited solutions

Quantum Alternating Operator Ansatz Model



Phase Operator:
- Gives the probability shift
- Has opportunity to find optimized solution with high probability

Mixing Operator:
- Explores other solutions
- Includes the constraints of the problem

Maximum Independent Set Problem via QAOA

QAOA Mapping

Initial state ($|s\rangle$)

$|0\rangle$: **a possible solution for the problem in all case**

Phase Operator

Different objective, different phase

$Objective = The\ number\ of\ selected\ nodes$

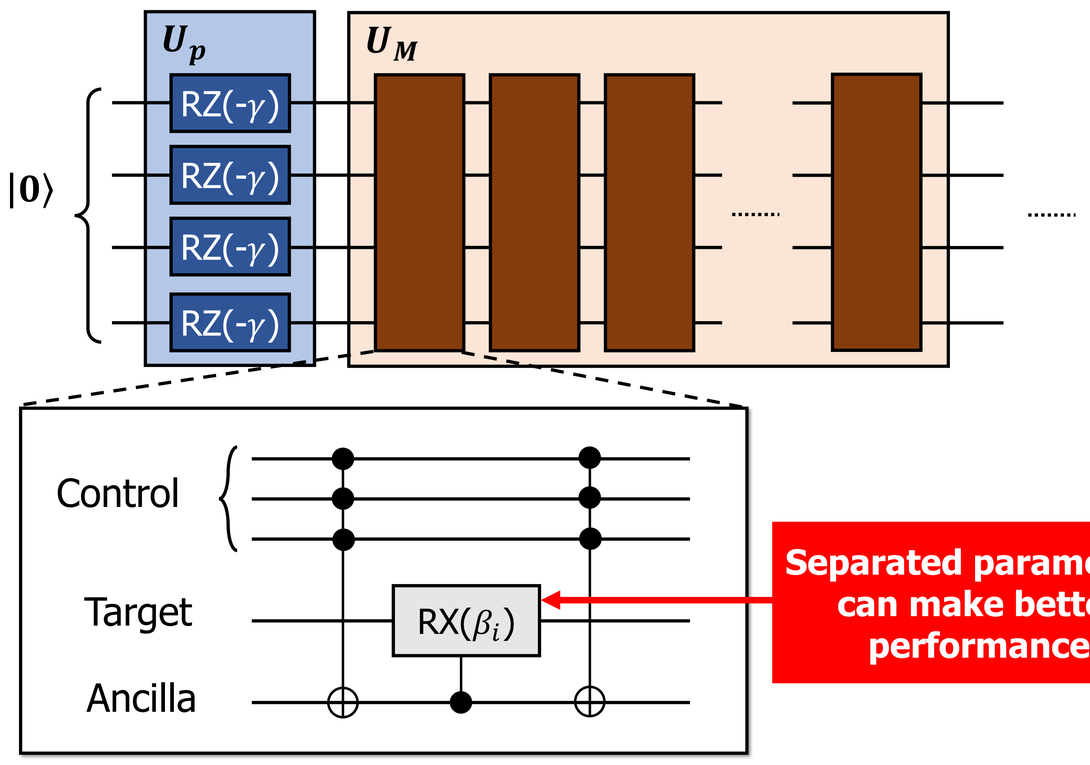
→ $U_p = \prod_i^{nodes} RZ_i$

Mixing Operator

- **If no adjacent node has flipped, apply the RX gate**
  - **Applies to all target nodes sequentially**

→ $U_M = \prod_i^{nodes} MCRX_i$

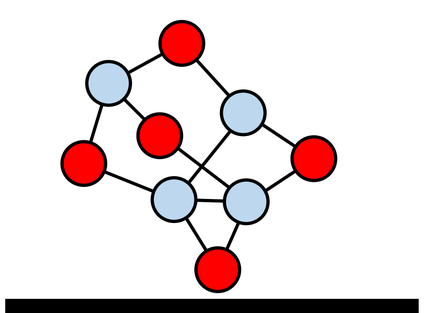
Gate Mapping to Quantum Circuit



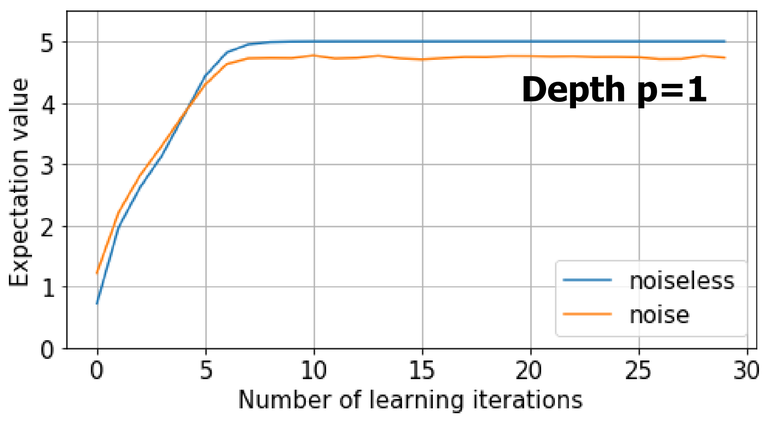
Separated parameters can make better performance

Local Environmental Simulation and Concluding Remark

Experimental Results on Local Simulation



|V|=9, |E|=12
Optimal Solution = 5



- **Noiseless Quantum Simulation**
  - → Converge to the optimal solution
- **Noise Quantum Simulation**
  - → Optimal solution observed with high probability.

Concluding Remark and Future Work

- **Concluding Remark**
  - → We have discussed QAOA and how to solve the maximum independent set problem with the corresponding algorithm.
  - → QAOA is useful for the maximum independent set problem
- **Future Work**
  - → The fault-tolerance of QAOA must be considerable for the real quantum device environment.
  - → Many of other NP-hard problems can be also solved with QAOA
- **References**

E. Farhi and A. W. Harrow, "Quantum supremacy through the quantum approximate optimization algorithm," arXiv preprint arXiv:1602.07674, 2016.
S. Hadfield, Z. Wang, B. O'Gorman, E. G. Rieffel, D. Venturelli, and R. Biswas, "From the quantum approximate optimization algorithm to a quantum alternating operator ansatz," Algorithms, vol. 12, no. 2, p. 34, 2019.

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