Synthesis of Approximate Parametric Circuits for Variational Quantum Algorithms

Blake Burgstahler

Dr. Frank Mueller (NCSU)
Dr. Scott Pakin (LANL)

NC STATE UNIVERSITY
Los Alamos NATIONAL LABORATORY

Motivation

- Variational Quantum Algorithms (VQA) are promising in many applications on NISQ devices
  - Quantum Chemistry and Optimization
- Prioritize use of shallow circuits to avoid decoherence
  - This limits the tractable size of executable circuits

Problem

- Basic VQA scheme outlined in Figure 2
  - Superposition state
  - (Repeat) Problem and Mixing Hamiltonians
  - Measure
- QAOA specializes the scheme,
  - 2-parameter subcircuits repeated *p* times
  - Parameters optimized classically at each iteration
- Two major issues arise on NISQ hardware
  - Repetitions of the subcircuits linearly increase depth.
  - Hardware only supports small gate set (may complicate ansatz)

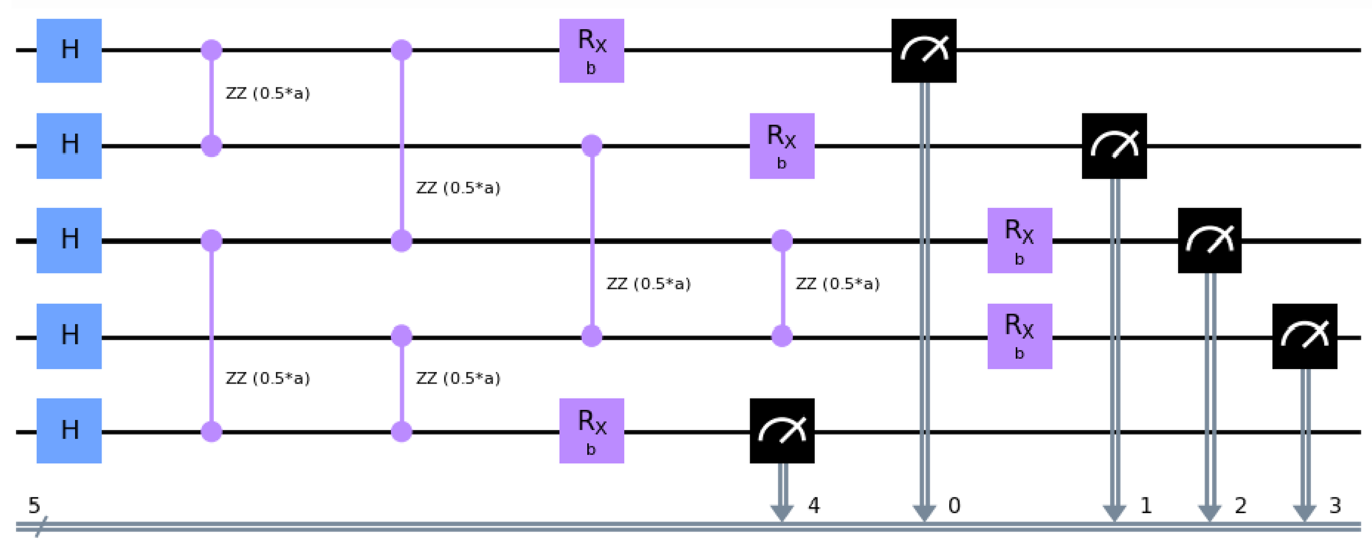

Figure 1: A sample of a QAOA circuit formulated for a max-cut problem

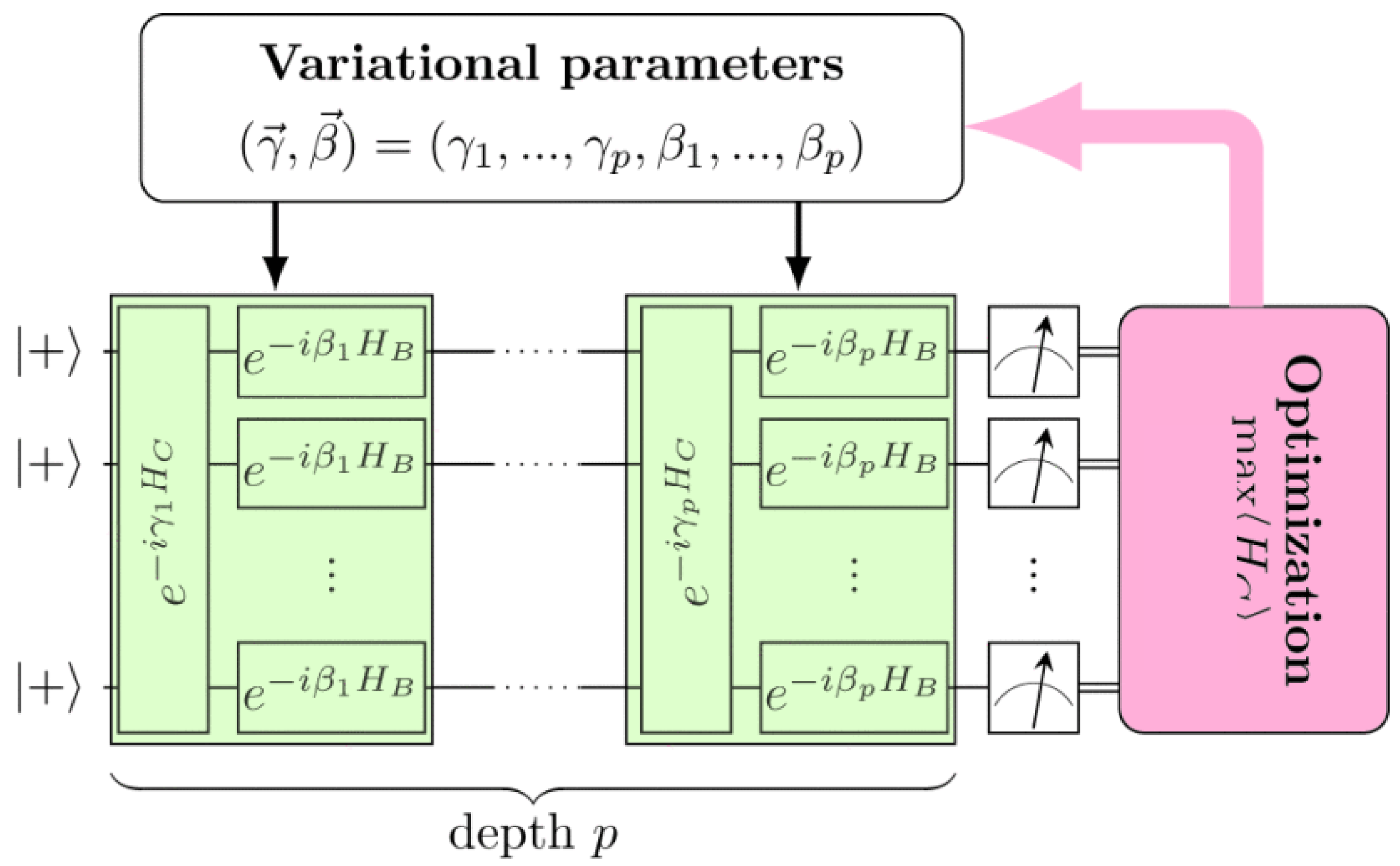

Figure 2: The basic Quantum Approximate Optimization Algorithm (QAOA) routine.
https://doi.org/10.1109/QCE52317.2021.00016

Approach

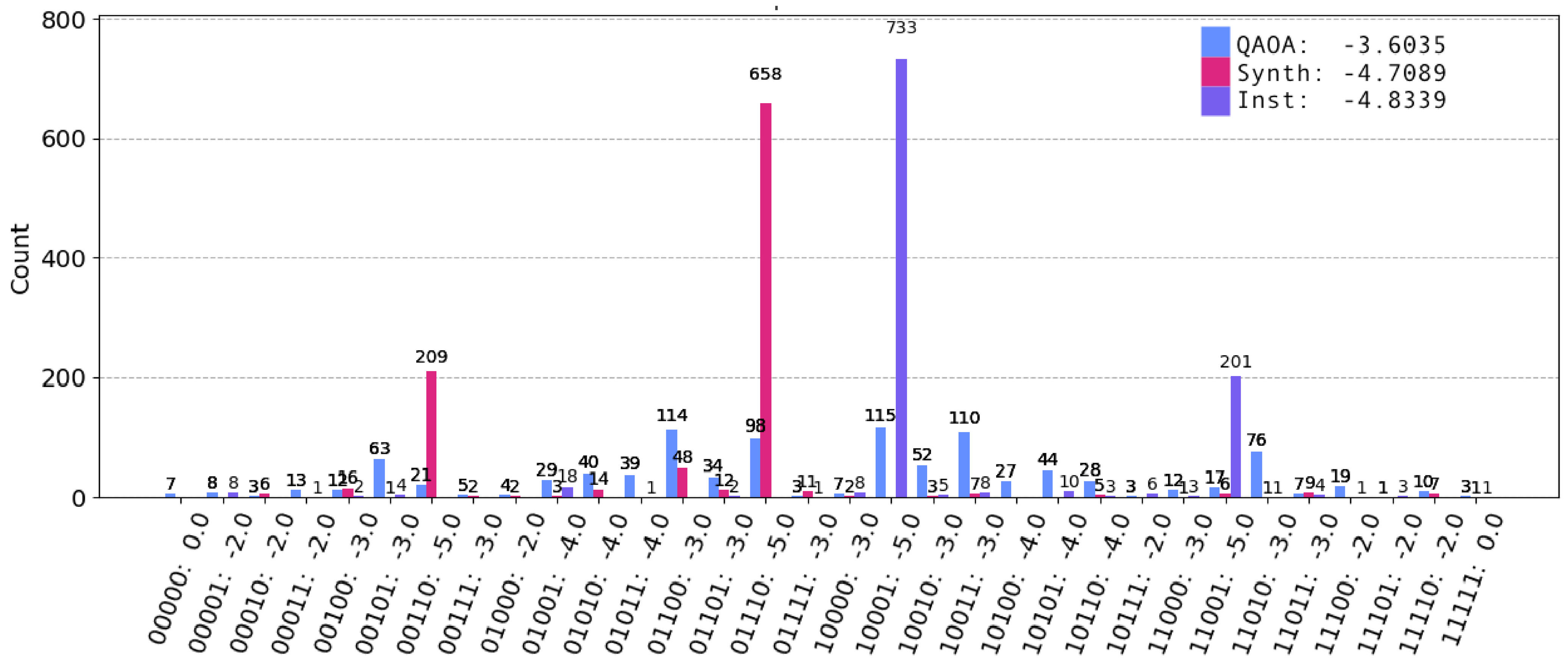

Figure 3: Solutions generated by typical QAOA, Synthesis based QAOA, and Instantiation accelerated synthesis

- Formulate circuits using NchooseK.
  - Logic formulates constraints as '*n* of the *k* items in this set should/must be true'
    - Each edge in Figure 4 correspond to one of these such constraints
    - ie, Choose 1 from {A,B}
- Employ synthesis using the interface of Berkeley Quantum Synthesis Toolkit (BQSKit)
  - Create candidate templates using device native gates (CNOT and U3).
  - Two approaches:
    - Synthesis only: synthesize new circuits at each iteration of the optimization
    - Instantiation: Attempt to optimize the parameters of an existing template
- Select a representative of minimal CNOT count (favor shallow circuits as necessary)
- Optimize the parameters of the representative of using a typical QAOA-like approach.

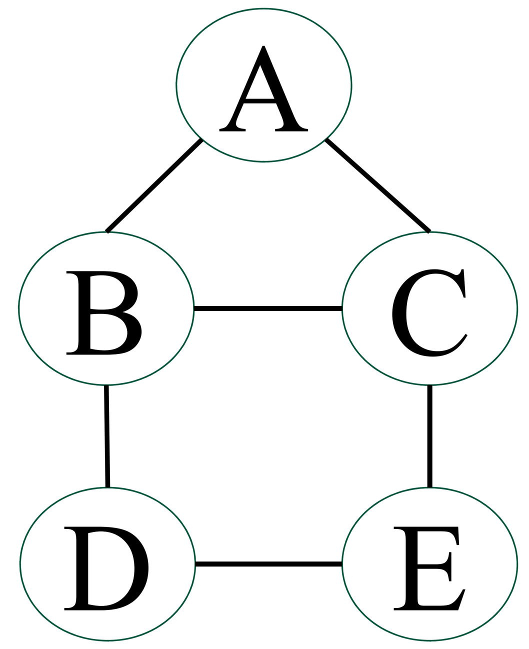

Figure 4: Graph for Max-Cut problem

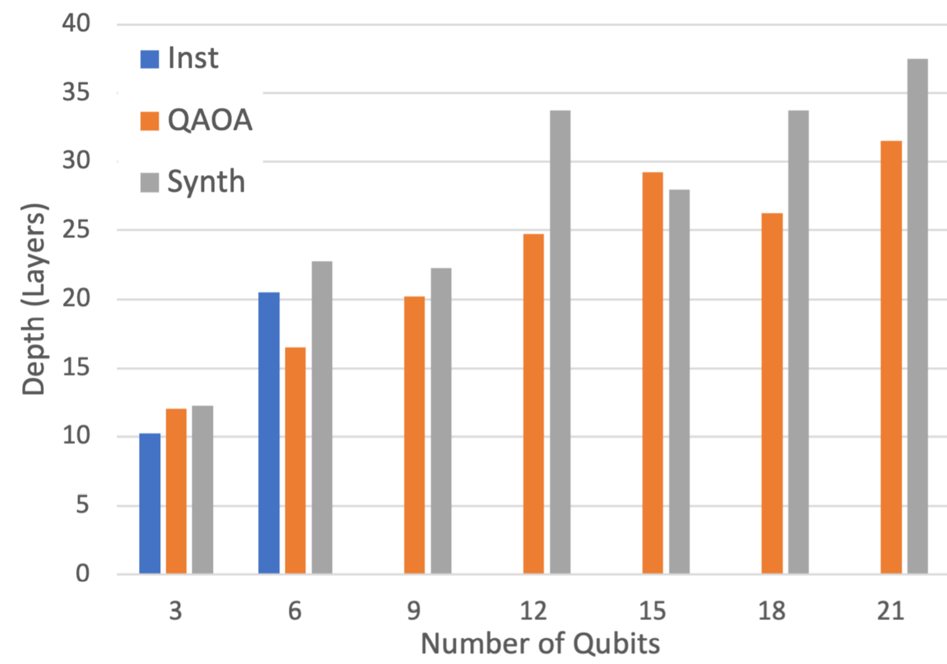

Figure 5: Average depth of resulting circuits

Results

Figure 6: Average number of 'Top 5' correct

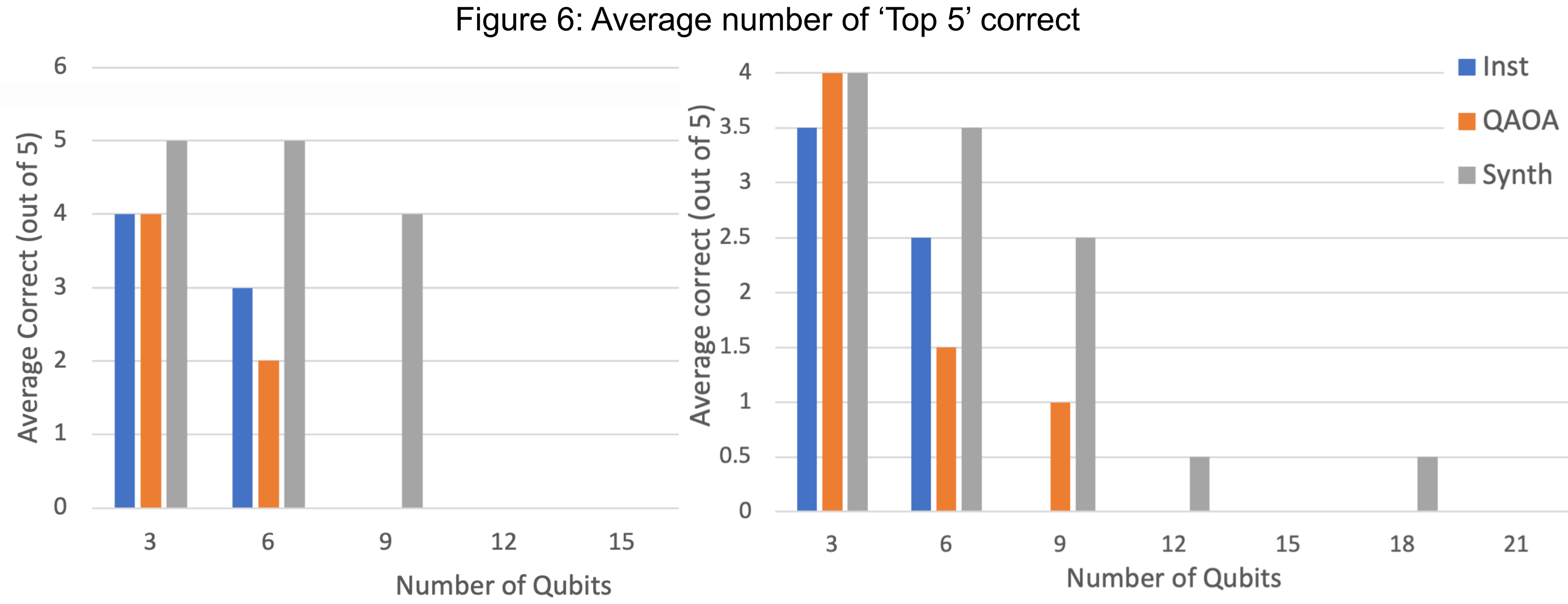

Figure 6a: Noise-free Simulation

Figure 6b: Noisy Simulation

- Use existing test circuit suite from NchooseK (maxcut, set cover, map coloring, etc.)
- All result circuits submitted to IBM's 27 qubit Hanoi machine
- Note: Native Instantiation methods were terminated prior to completion
  - Unusably slow to instantiate huge number of parameters

Conclusions

- Advantages of new synthesis-based approaches:
  - Comparable depth
  - Greatly improves isolation of correct results
  - Trends continue into Noisy simulation
- Disadvantages (at scale):
  - Synthesis time consuming
  - Instantiation presently even slower

References

- NchooseK (github.com/lanl/nchoosek):
  - E. Wilson, F. Mueller, and S. Pakin, "Combining Hard and Soft Constraints in Quantum Constraint-Satisfaction Systems," in Proceedings of the International Conference on High Performance Computing, Networking, Storage and Analysis, SC '22 https://dl.acm.org/doi/abs/10.5555/3571885.3571902

Acknowledgements

Research presented on this poster was supported by the Laboratory Directed Research and Development program of Los Alamos National Laboratory under project number 20210397ER and is released under LA-UR-23-27212. Los Alamos National Laboratory is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy (contract no.~89233218CNA000001). This work was also supported in part by LANL subcontract 725530 and by NSF awards DMR-1747426, PHY-1818914, CCF-2217020, and MPS-2120757.