



# Exploring Multi-programming Applications in the NISQ Era

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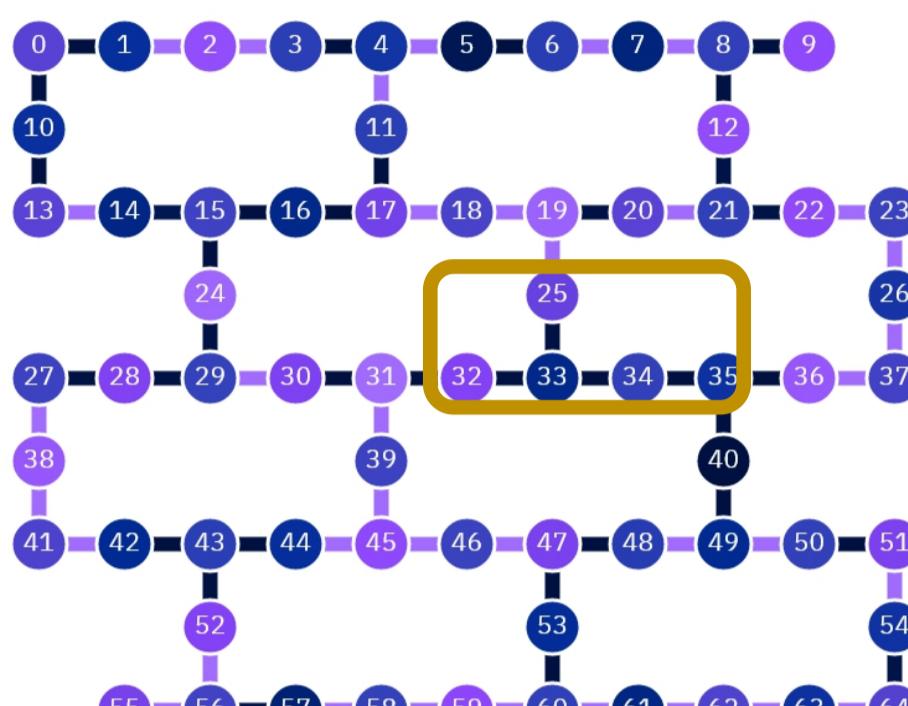
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# Exploring Multi-programming Applications in the NISQ Era



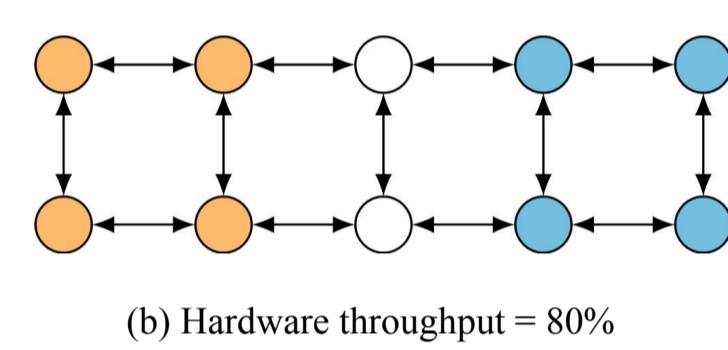
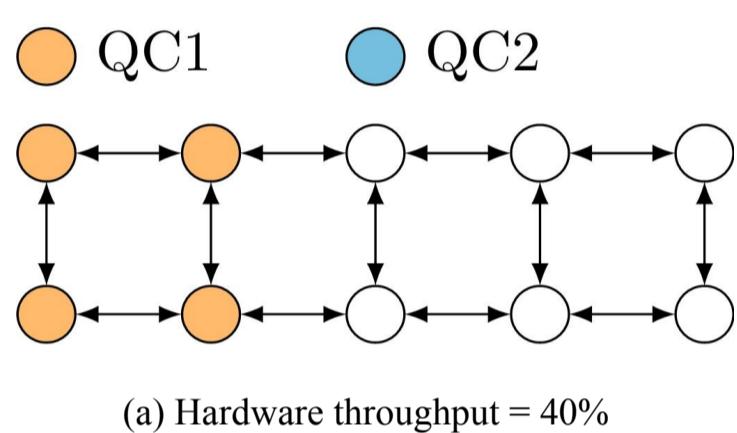
BQIT:22

## Introduction



- Limited hardware connectivity
- Unavoidable error rates
- Only small circuits can obtain reliable results
- Long waiting time
- Hardware throughput: 8%
- Total pending jobs: 1038

## Motivation



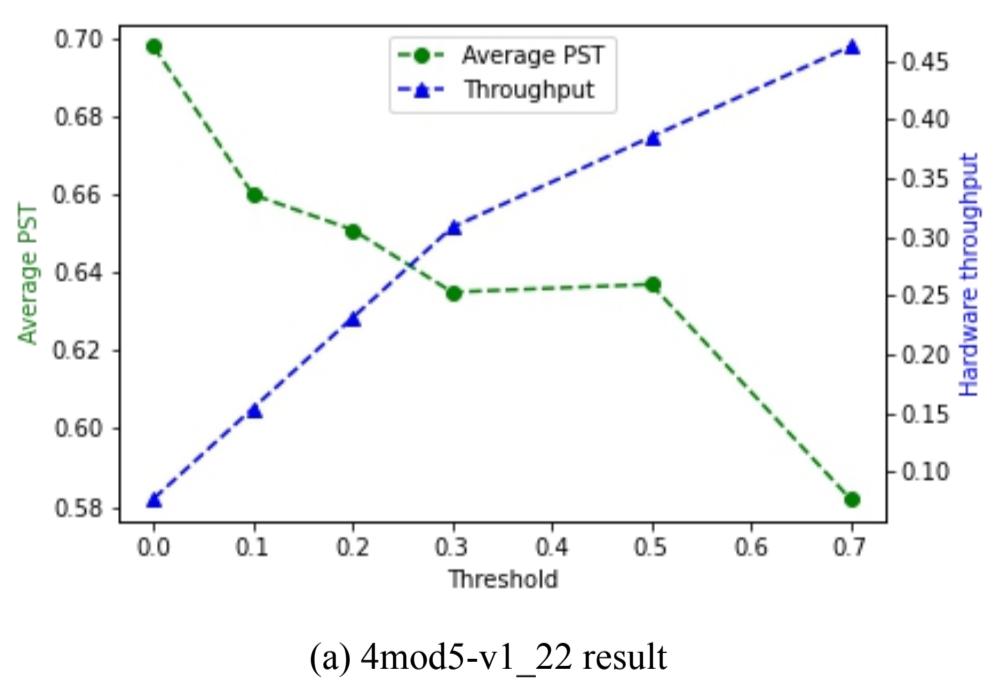
Key ideal: execute multiple circuits simultaneously to increase the hardware throughput and total runtime.

## The multi-programming mechanism

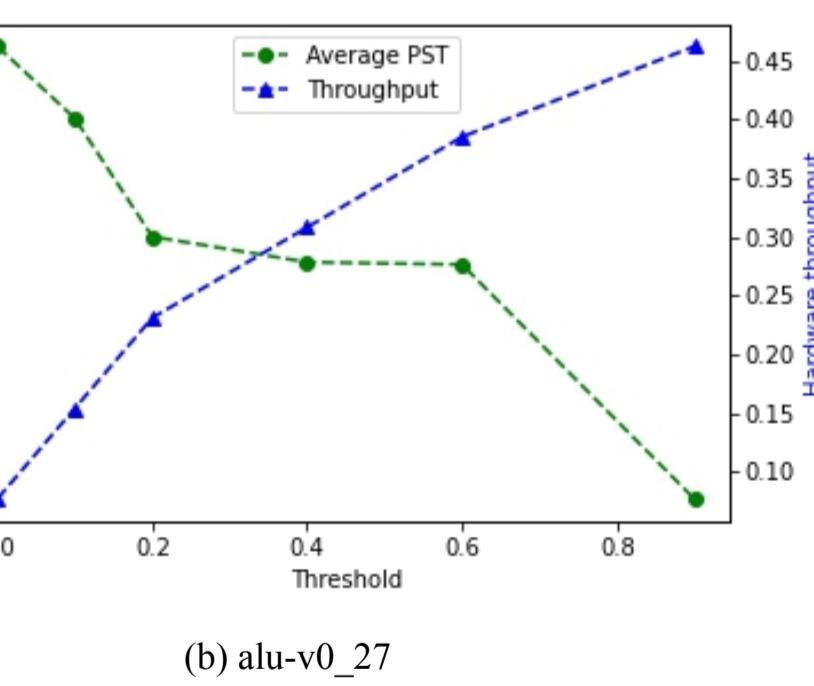
Which factors should we consider to build a multi-programming technique?

- Crosstalk
- Partition qubits to reliable regions
- Qubit mapping (routing)
- Task scheduling
- Number of simultaneous circuits

## Hardware throughput vs Circuit fidelity



(a) 4mod5-v1\_22 result

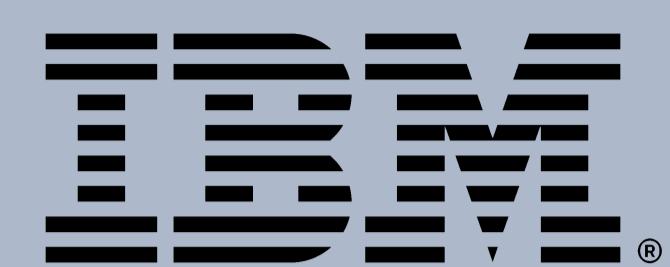


(b) alu-v0\_27 result

- Experiment setup
  - Execute different number of the same circuit on IBM Q 65 Manhattan.
  - Report the relation between hardware throughput and circuit fidelity.
- Results
  - # parallel circuit executions: one to six
  - Hardware throughput: 7.7% to 46.2%
  - Significant fidelity loss when hardware throughput is over 38%.

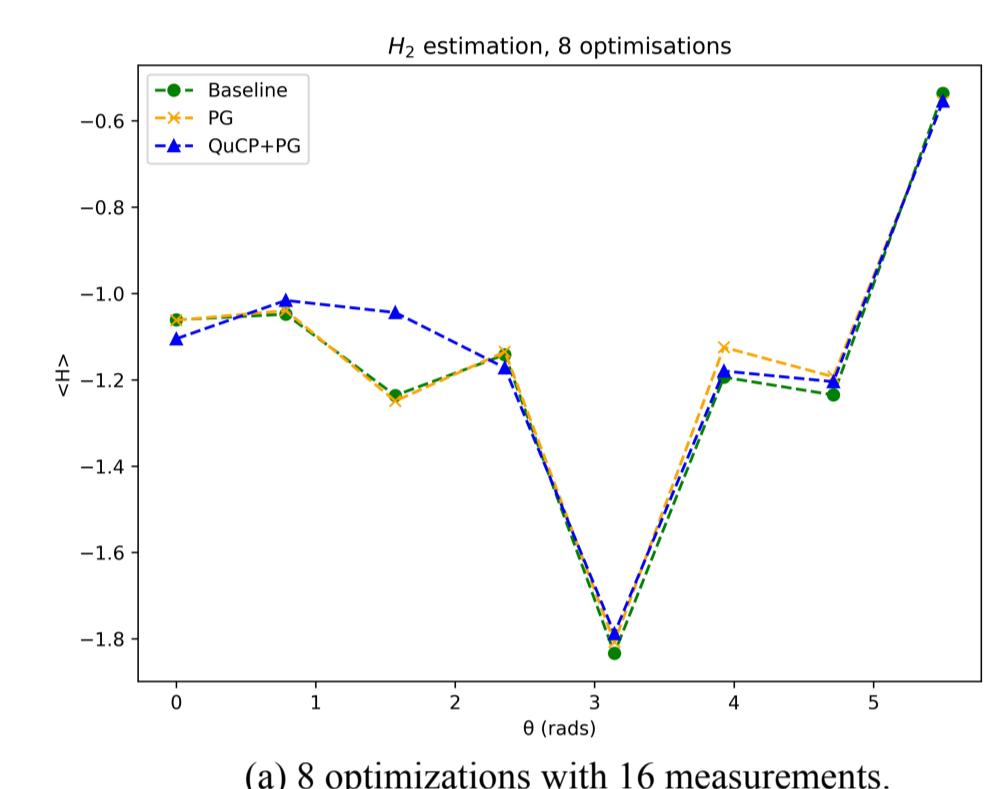
## Acknowledgment

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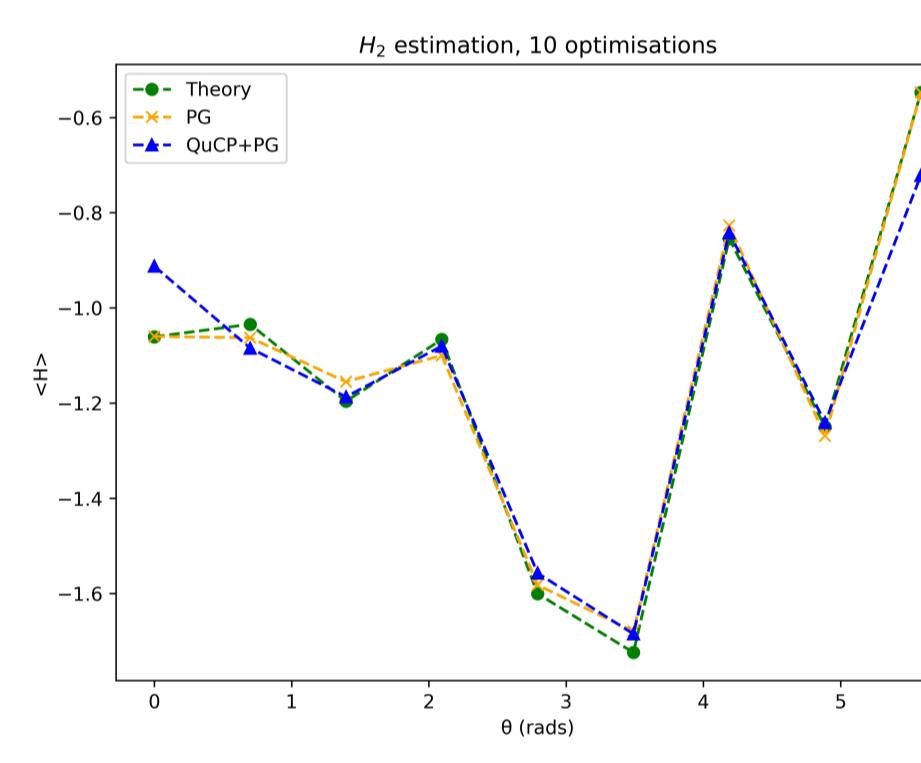


## Multiprogramming and VQE

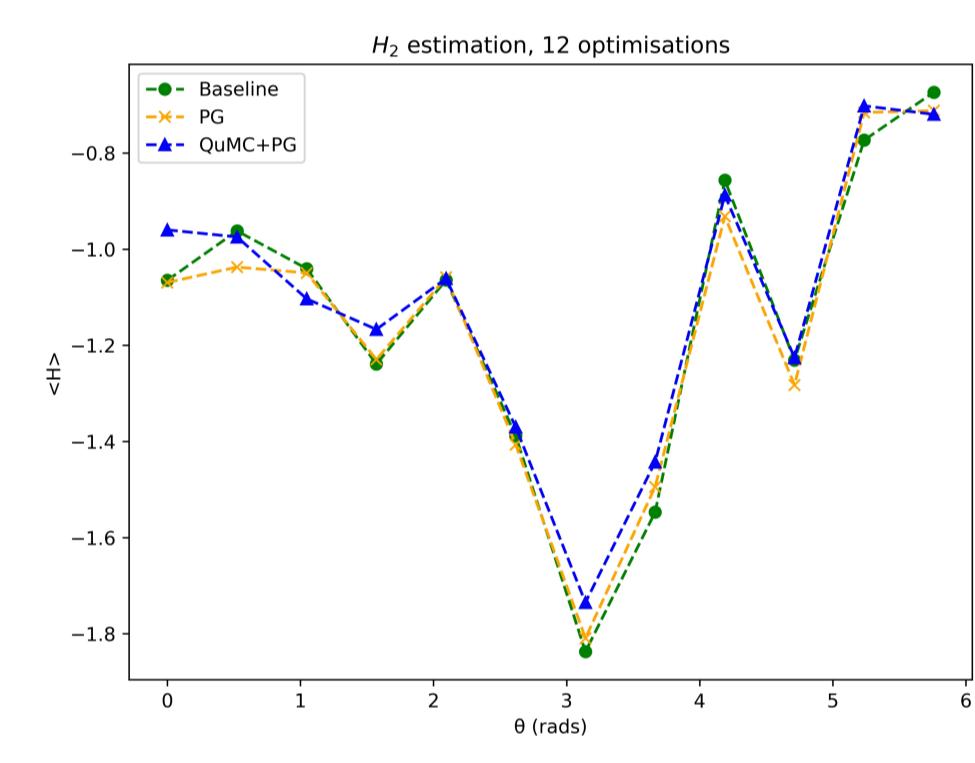
- VQE limitation
  - Split the computation into  $O(N^4)$  sub-problems, introducing a large overhead of measurement circuits.
- Pauli grouping
  - Grouping commuting Pauli terms and measure them simultaneously.
- Idea
  - Apply multiprogramming to Pauli grouping
- Experiment setup
  - Estimate ground state energy of  $H_2$ 
    - Hamiltonian:  $\{II, IZ, ZI, ZZ, XX\}$
    - Heuristic ansatz state
    - Two repetitions
    - $RyRz$  on each qubit



(a) 8 optimizations with 16 measurements.



(b) 10 optimizations with 20 measurements.



(c) 12 optimizations with 24 measurements.

- Results
  - Hardware throughput can be up to 73.8% with an error rate of less than 10%.

## Multiprogramming and ZNE

- Zero noise extrapolation (ZNE) error mitigation.
  - Noise-scaling
  - Extrapolation
  - Extra circuit overhead
- Bar chart showing Absolute error for various benchmarks (adder, Atmod, fred, ali, lin, qc, var, bell) comparing Baseline (light blue), QuCP+ZNE (medium blue), and ZNE (dark blue). ZNE consistently shows the lowest error across all benchmarks.
- Results
  - The error rate is reduced by 2x without any circuit overhead.

## References

- [1] S.Niu et al. arxiv.2112.00387, 2021.
- [2] S.Niu et al. arxiv.2102.05321, 2021.
- [3] P.Gokhale et al. QCE 2020.
- [4] Y.Li et al. PRX 2017.

