A Hardware-aware Heuristic for the Qubit Mapping Problem in the NISQ Era

Siyuan Niu, Adrien Suau, Gabriel Staffelbach, Aida Todri-Sanial

HAL Id: lirmm-03197069
https://hal-lirmm.ccsd.cnrs.fr/lirmm-03197069v1

Submitted on 13 Apr 2021

A Hardware-aware Heuristic for the Qubit Mapping Problem in the NISQ Era

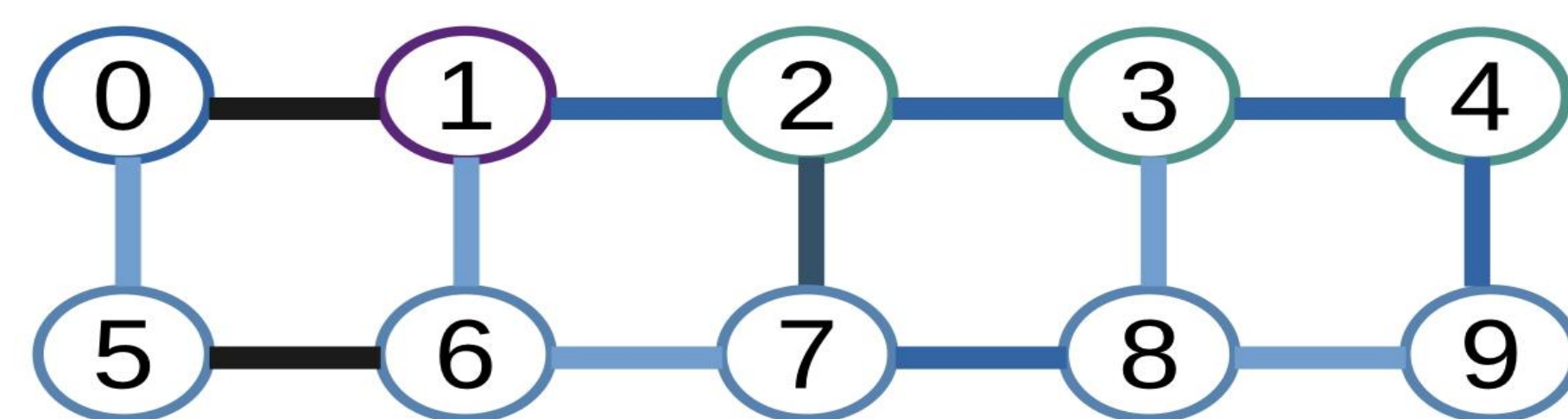**Siyuan Niu**[1], Adrien Suau[1,2], Gabriel Staffelbach[2], and Aida Todri-Sanial[1]

[1]LIRMM, University of Montpellier, 34090, Montpellier, France
[2]CERFACS, 42 Avenue G.Coriolis, 31057, Toulouse, France
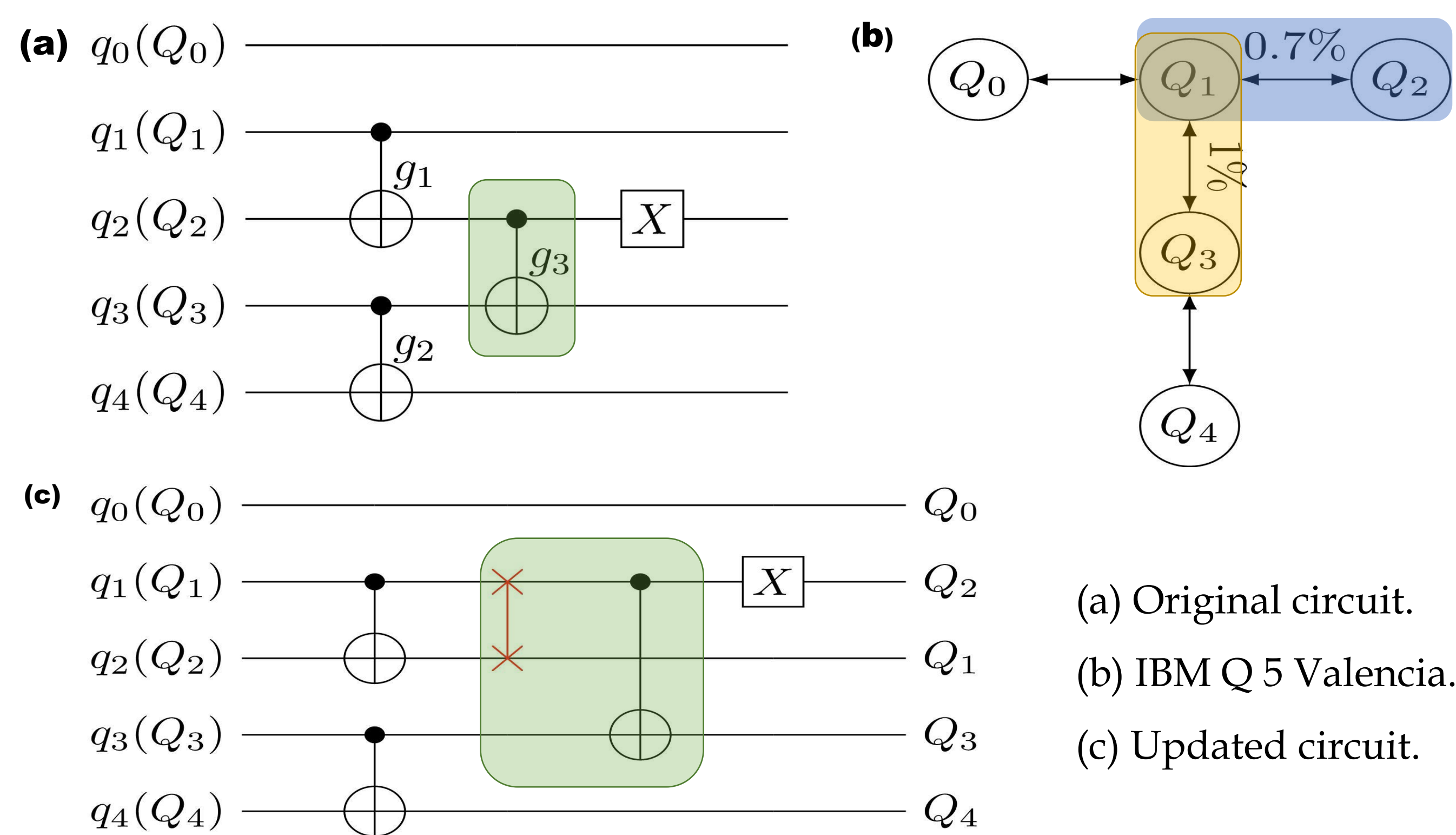Contact e-mail: siyuan.niu@lirmm.fr

Introduction

- NISQ devices.
- Connectivity constraint: Nearest-neighbor connections.
- Different physical qubits: various calibration data.
- Qubit mapping problem: Adapting a quantum program to given hardware connectivity.

Motivation

(a) Original circuit.
(b) IBM Q 5 Valencia.
(c) Updated circuit.

- Initial mapping
  - $\{q_0 \to Q_0, q_1 \to Q_1, q_2 \to Q_2, q_3 \to Q_3, q_4 \to Q_4\}$
- SWAP candidates:
  - $\{q_1, q_2\}$ and $\{q_1, q_3\}$

- Choose $\{q_1, q_2\}$ because of the lower error rate.
- Final mapping
  - $\{q_0 \to Q_0, q_1 \to Q_2, q_2 \to Q_1, q_3 \to Q_3, q_4 \to Q_4\}$

Methods

- Hardware-Aware (HA) mapping transition algorithm.
  - Cost function

$$H = \frac{1}{|F|}\sum_{g \in F} D[\pi(g.q_1)][\pi(g.q_2)] + W \times \frac{1}{|E|}\sum_{g \in E} D[\pi(g.q_1)][\pi(g.q_2)]$$

  - Distance matrix

$$D = \alpha_1 \times S + \alpha_2 \times \varepsilon + \alpha_3 \times T$$

  - S: SWAP matrix, ε: SWAP error matrix, T: SWAP execution time matrix
- Selection between SWAP and Bridge gate.


SWAP gate **Bridge gate**
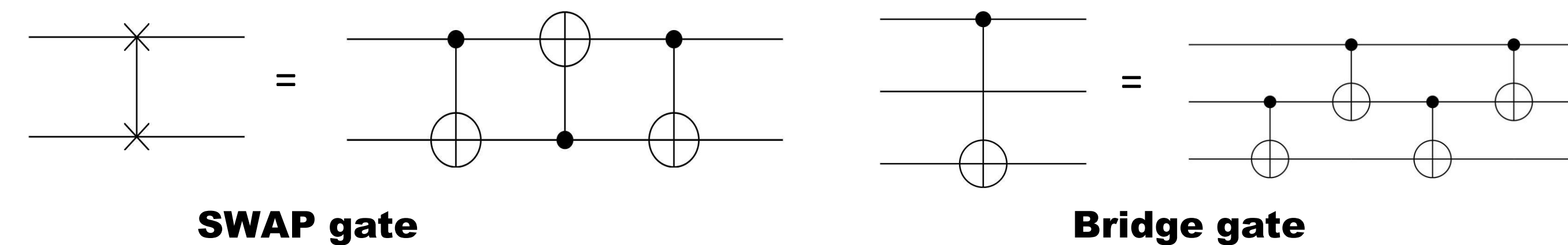
- Hardware-aware Simulated Annealing (HSA) initial mapping.
  - Hardware-aware **get_neighbor** method.

Results

- Comparison of number of additional gates on IBM Q 20 Almaden (large benchmarks).

Number of additional gates improved by 30%.
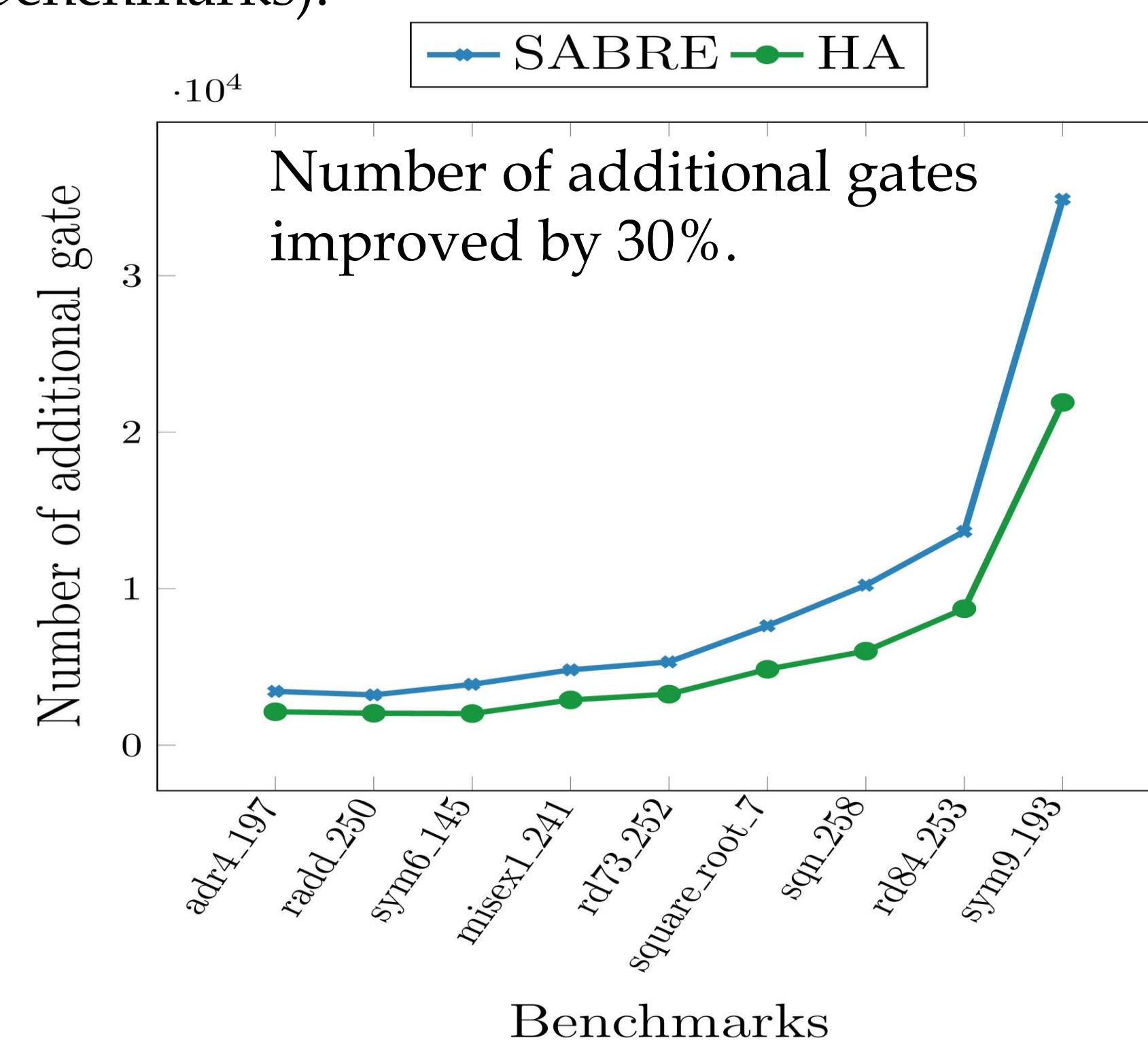
- Comparison of number of additional gates and fidelity on IBM Q 20 Almaden (small benchmarks).

Number of additional gates improved by 32%.

Fidelity improved by 23%.
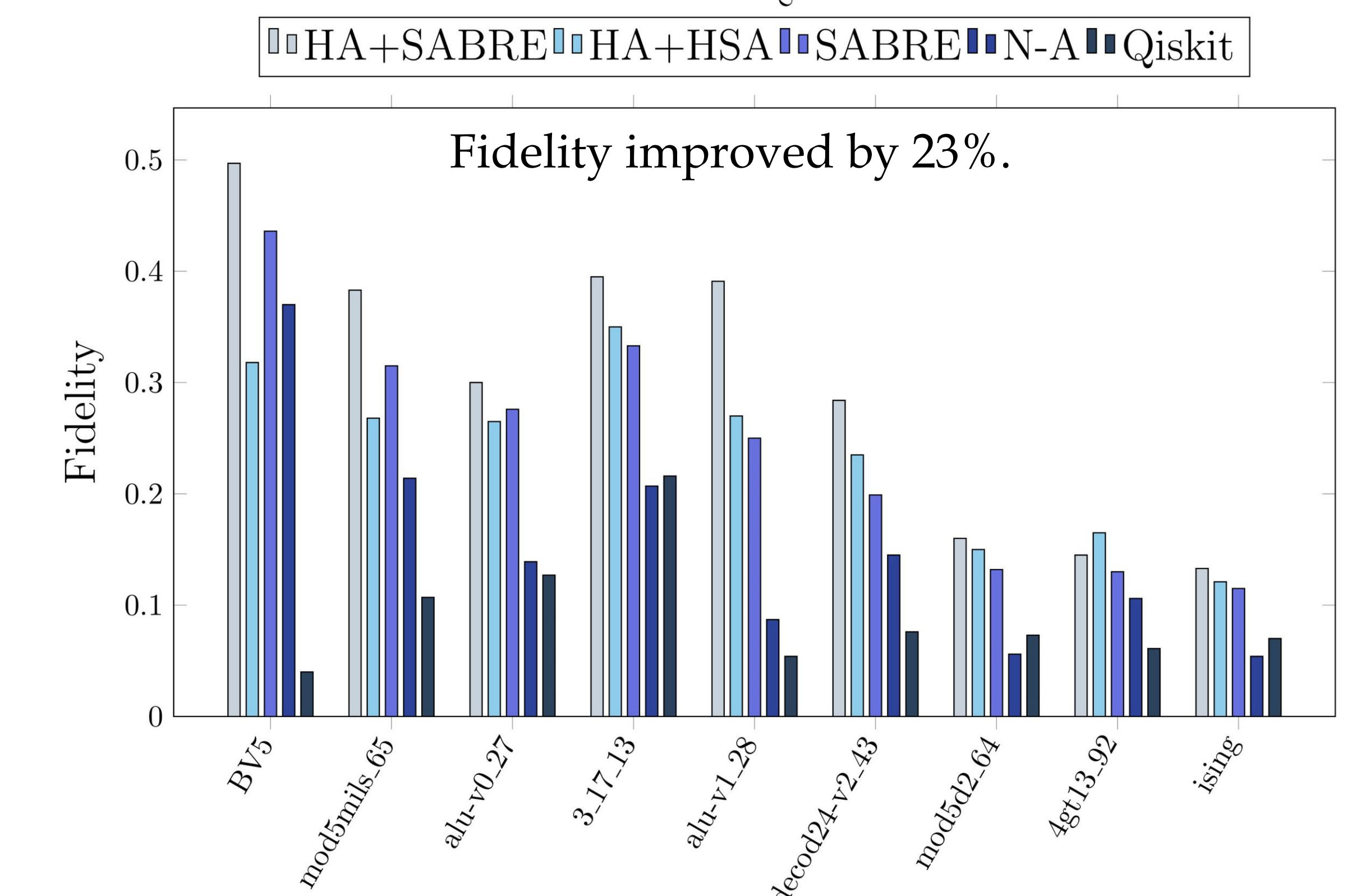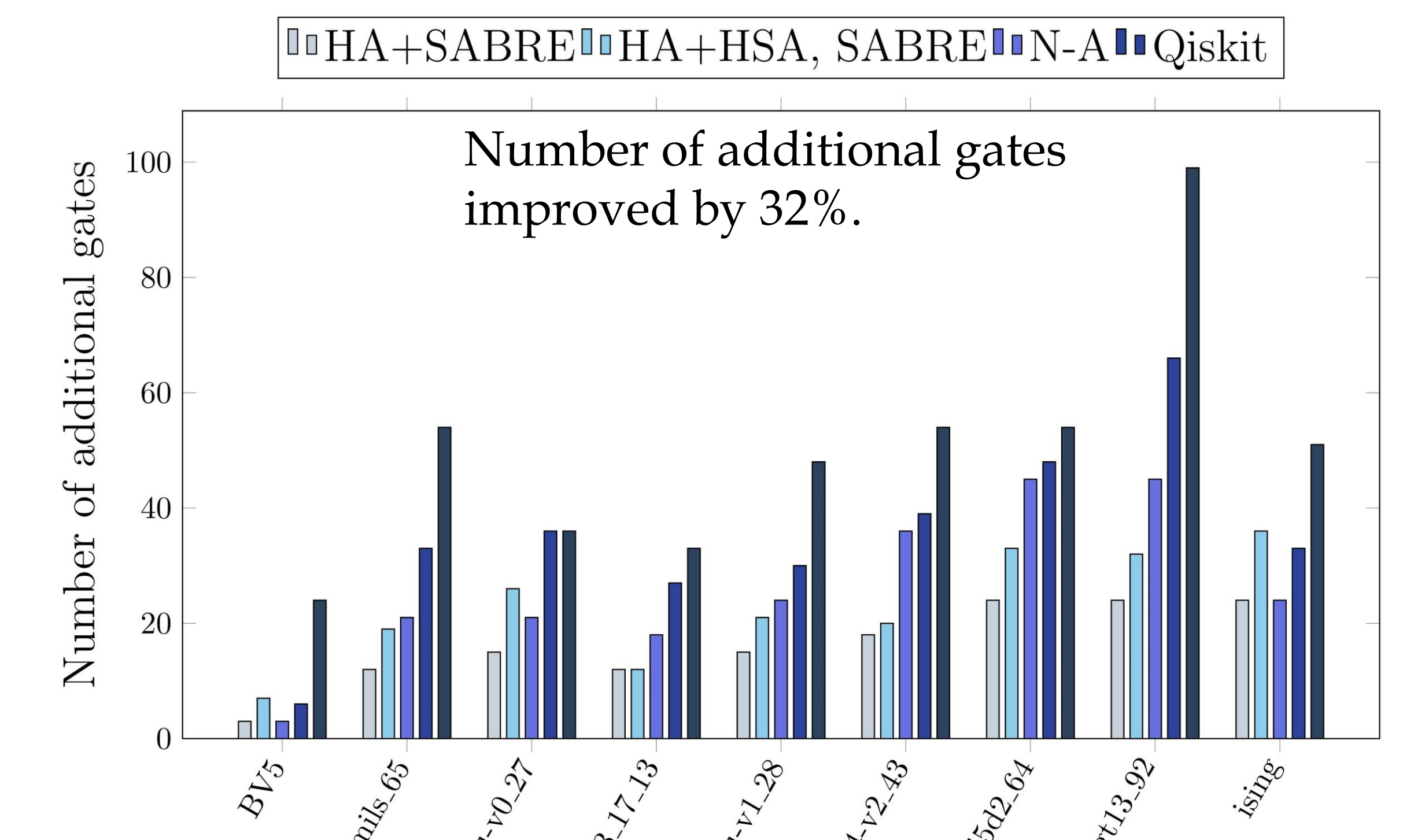
Conclusion

- Map the most used qubit of the mapped circuit to the most connected physical qubit.
- Apply CNOT gates on qubits that are directly connected and with reliable interconnects.
- If a CNOT cannot be applied on two neighbor qubits, apply on two qubits whose distance is two.