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

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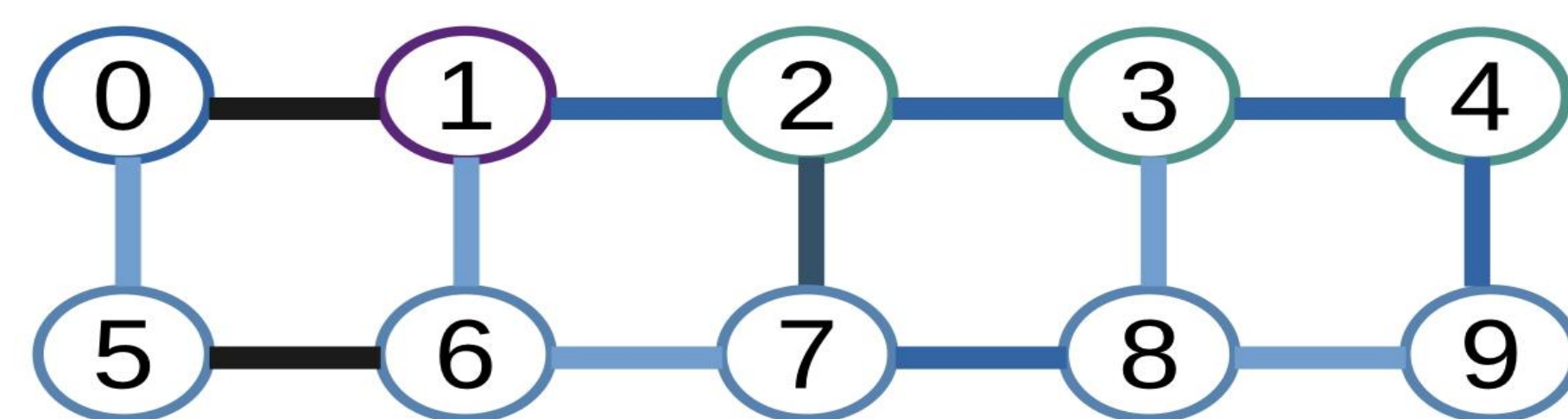
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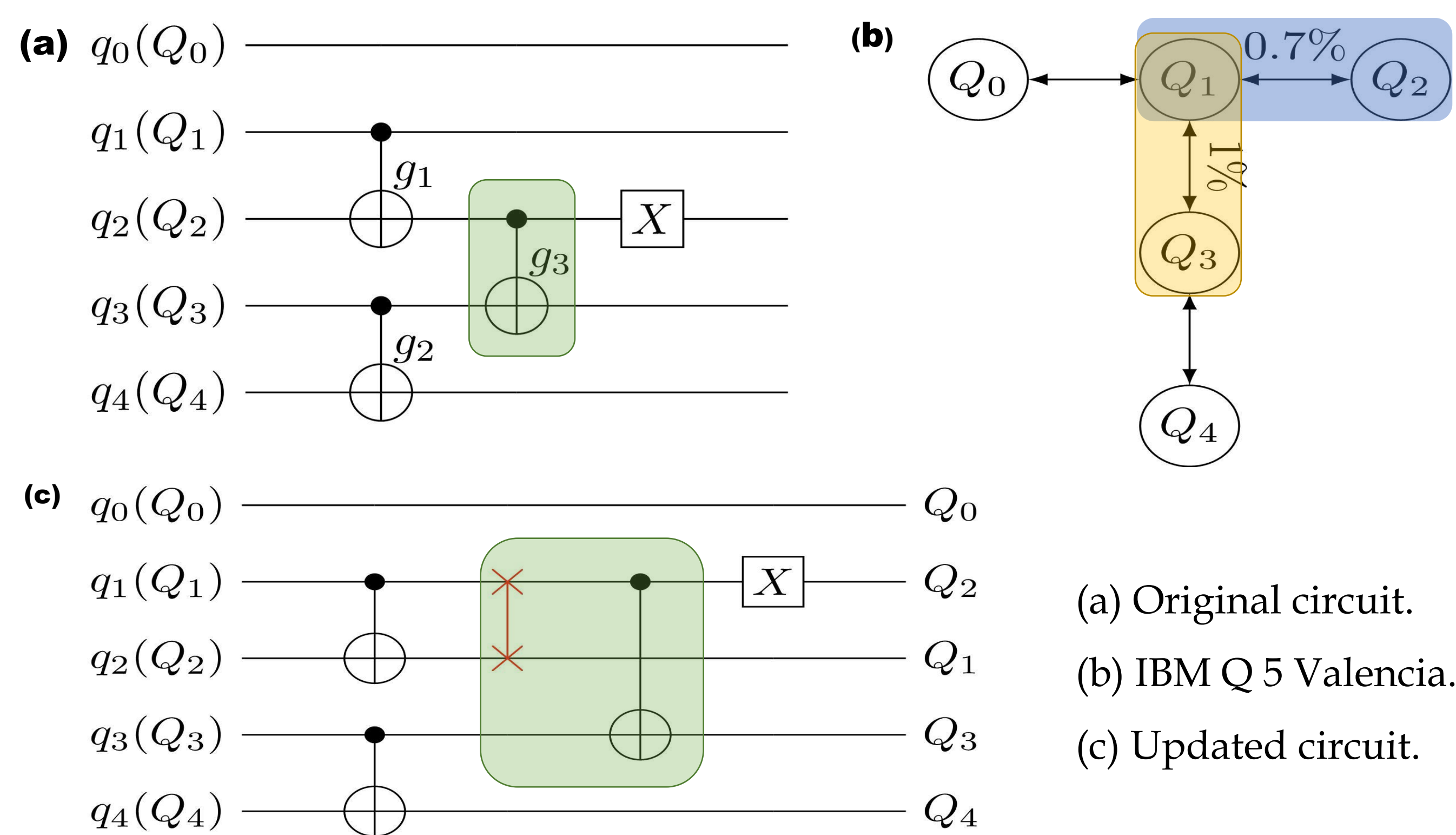
Introduction



Avg 1.256e-2
min 7.978e-3 max 1.587e-2

- 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



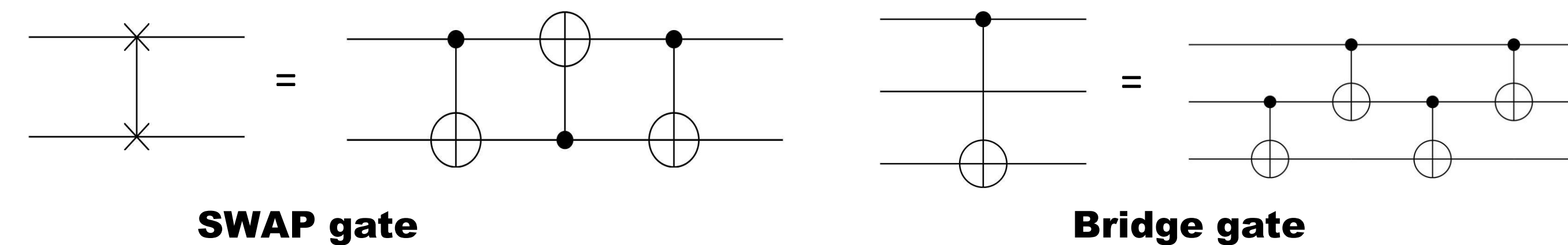
- Initial mapping
 - $\{q_0 \rightarrow Q_0, q_1 \rightarrow Q_1, q_2 \rightarrow Q_2, q_3 \rightarrow Q_3, q_4 \rightarrow Q_4\}$
- SWAP candidates:
 - $\{q_1, q_2\}$ and $\{q_1, q_3\}$
- Choose $\{q_1, q_2\}$ because of the lower error rate.
- Final mapping
 - $\{q_0 \rightarrow Q_0, q_1 \rightarrow Q_2, q_2 \rightarrow Q_1, q_3 \rightarrow Q_3, q_4 \rightarrow Q_4\}$

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

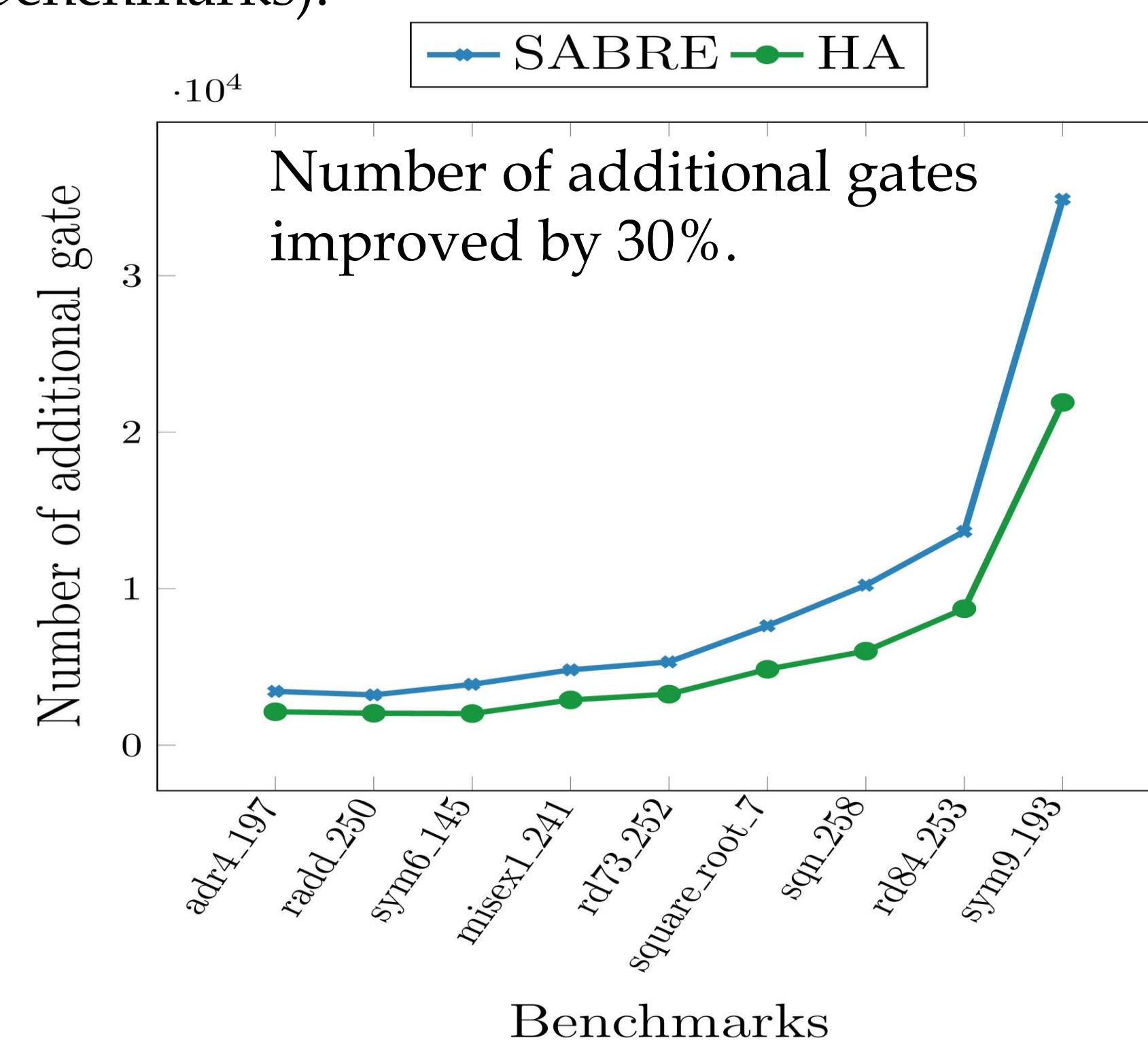
$$D = \alpha_1 \times S + \alpha_2 \times \varepsilon + \alpha_3 \times T$$
 - S : SWAP matrix, ε : SWAP error matrix, T : SWAP execution time matrix
- Selection between SWAP and Bridge gate.



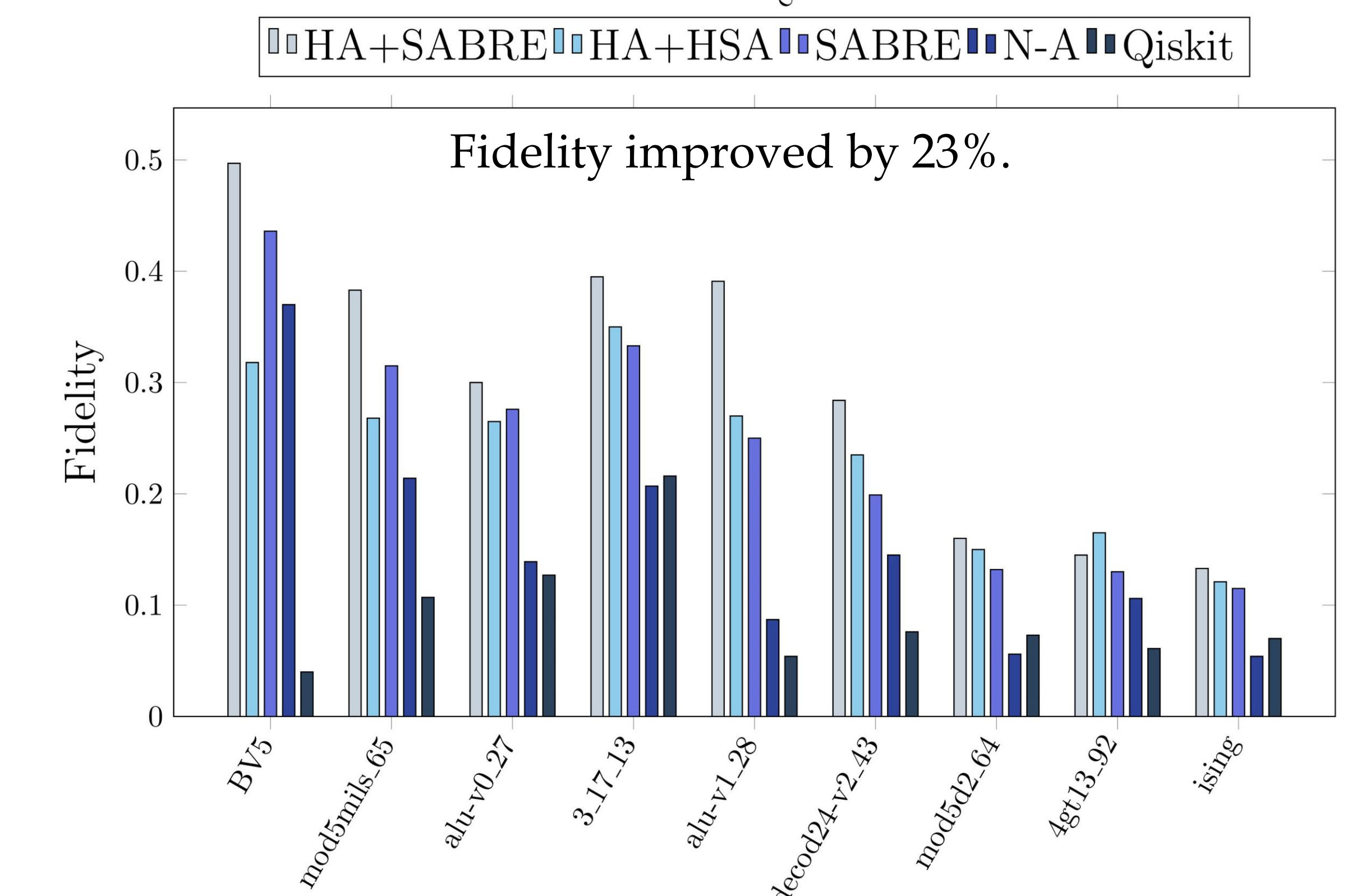
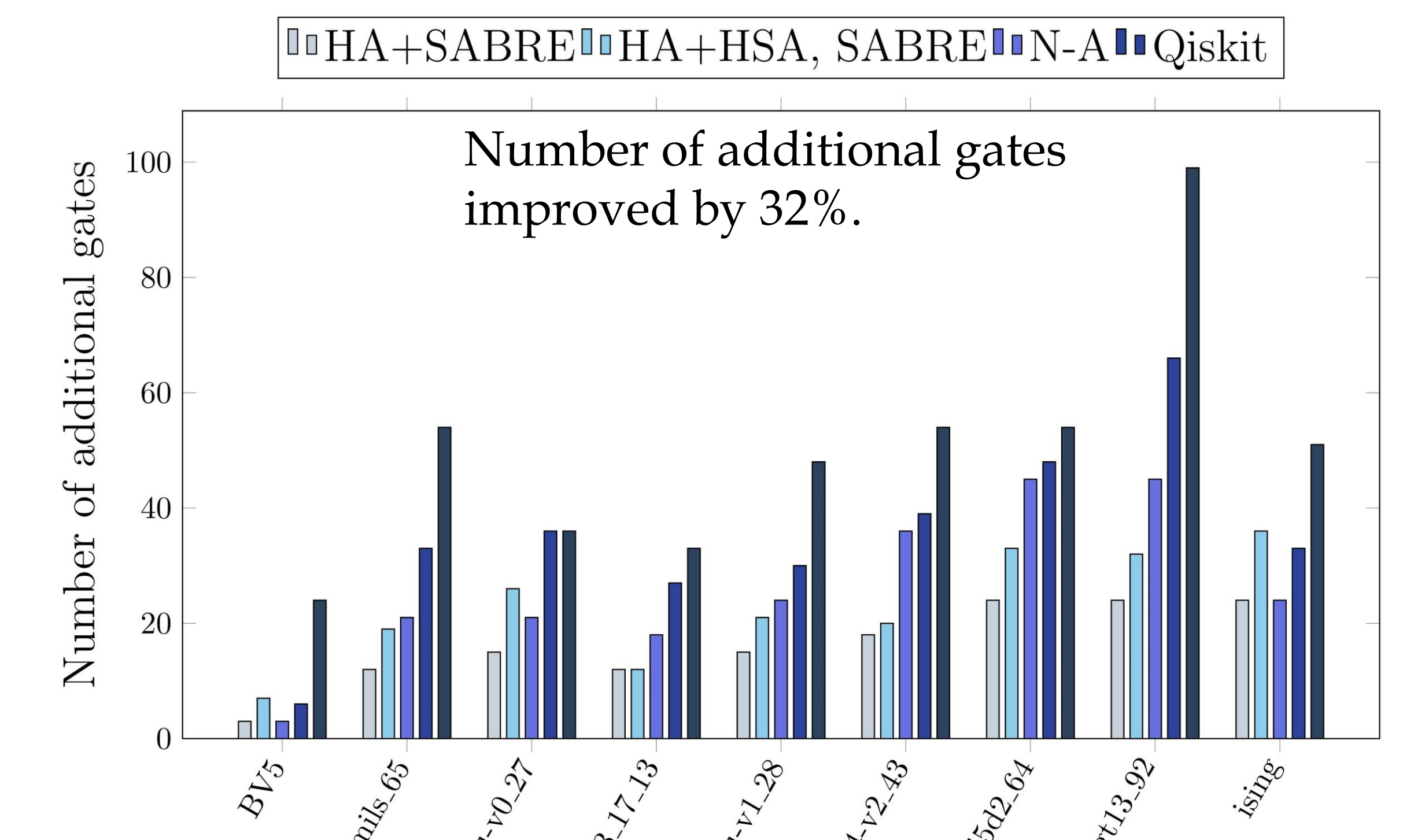
- Hardware-aware Simulated Annealing (HSA) initial mapping.
- Hardware-aware `get_neighbor` method.

Results

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



- Comparison of number of additional gates and fidelity on IBM Q 20 Almaden (small benchmarks).



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.

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