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Towards Benchmarking the VLQ Quantum Computer

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INTRODUCTION

Hybrid computing systems integrating classical supercomputers with quantum processors (HPC-QC) are emerging as a promising approach for solving computationally challenging problems, particularly in quantum simulation and optimization.
Unlike classical HPC systems, performance evaluation of hybrid architectures remains an open problem [1]. Standard benchmarking methods do not capture key aspects such as quantum noise, limited qubit connectivity, or the overhead introduced by hybrid workflows.
In this work, we focus on the Quantum Volume (QV) benchmark [1,2] as a standard approach for evaluating quantum devices and extend it towards hybrid scenarios. Instead of introducing new performance metrics at this stage, we concentrate on understanding circuit construction, execution, and decomposition techniques, which are essential for future benchmarking of hybrid systems.

METHODOLOGY

Our approach is based on the Quantum Volume benchmark, which evaluates the capability of a quantum device to execute random circuits of increasing size and depth. The circuit consists of N qubits, random permutations of qubits, and random two-qubit gates sampled from the Haar distribution.
The key quantity is the heavy output probability [3], defined as the probability of measuring bitstrings whose ideal probabilities exceed the median of the output distribution. A device successfully passes the QV test if the average heavy output probability exceeds the threshold 2/3 [4], and the Quantum Volume is defined as $V_Q=2^N$ for the largest successful circuit size.

TOPOLOGY

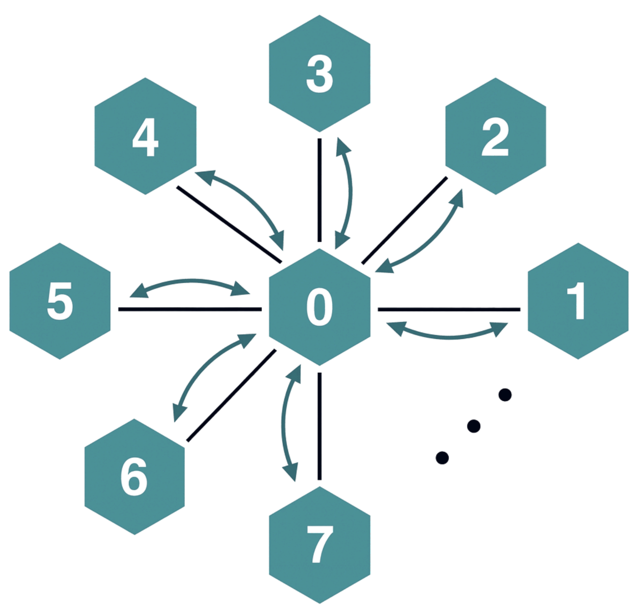
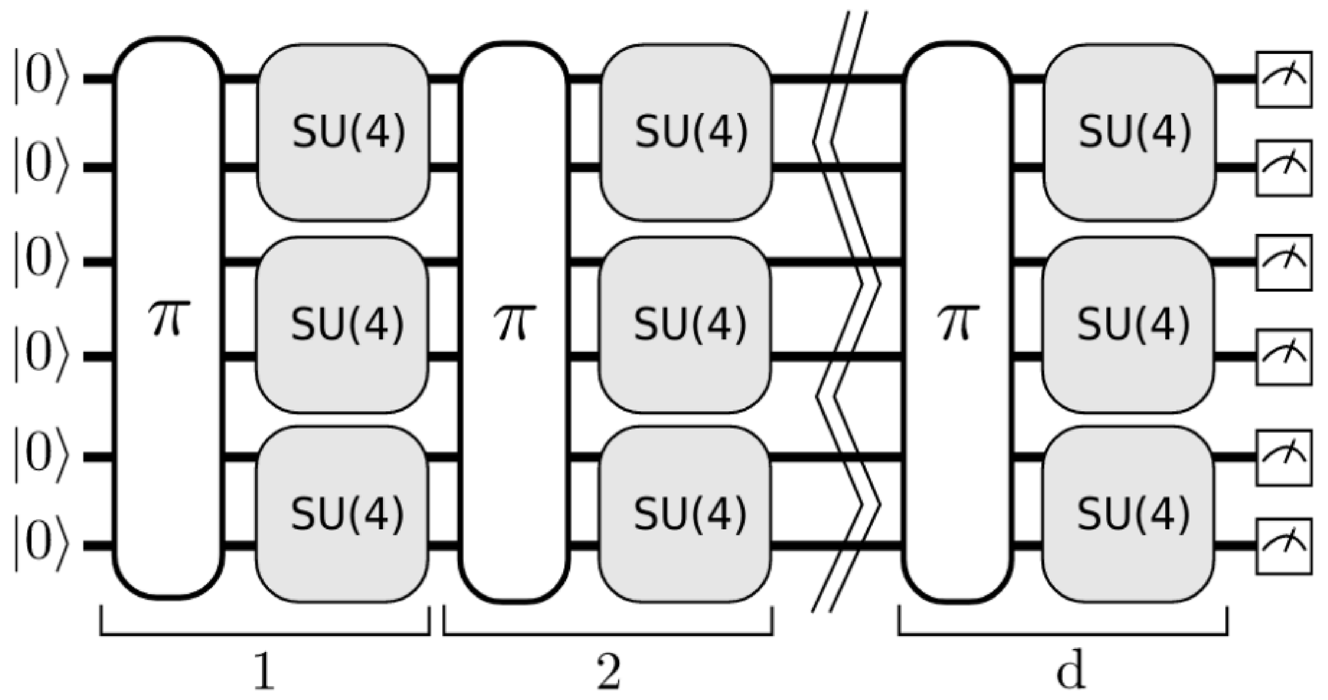


Figure 1: Star-topology of 25-qubit VLQ quantum processor [5].

QUANTUM APPROACH



Workflow:

- Generate random quantum circuits
- Simulate ideal output distribution
- Identify heavy output set
- Execute circuits on quantum hardware
- Estimate heavy output probability

Figure 2: Structure of a Quantum Volume circuit; layers of random SU(4) two-qubit gates alternating with random qubit permutations (π) [6].

HYBRID APPROACH

To enable hybrid execution, we apply quantum circuit cutting, which decomposes a large quantum circuit into smaller subcircuits that can be executed separately:

- circuits are partitioned into fragments,
- each fragment is executed independently (quantum + classical),
- results are reconstructed via classical post-processing,
- automatic cut placement can be used.

This approach reduces quantum resource requirements while introducing classical overhead.

TARGET PLATFORM

The framework will be tested at IT4Innovations on:

- Karolina supercomputer (HPC)
- VLQ quantum processor (IQM)

The VLQ architecture modifies standard QV circuits by adapting gate operations and connectivity constraints.

CONCLUSION

We presented an ongoing effort towards benchmarking hybrid HPC-QC systems with a focus on the Quantum Volume framework.
Instead of introducing complex performance metrics, we concentrate on understanding Quantum Volume circuit construction, adapting QV for real hardware constraints, and extending QV via circuit cutting for hybrid execution. This work establishes a foundation for future benchmarking of hybrid systems, where performance metrics such as computational time, accuracy, and energy consumption can be systematically evaluated.
Future work will focus on:

- Experimental validation on real hardware
- Optimization of circuit cutting strategies
- Integration with hybrid HPC workflows

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