# Hybrid Quantum Circuit Simulation: Balancing Efficiency through Dynamic Method Selection and Database Integration

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Simulating quantum systems is critical for advancing quantum computing, particularly as circuit complexity and entanglement grow. Current simulation methods – such as tensor networks, decision diagrams, and state vector approaches – each excel under specific conditions to simulate the operations applied to a quantum state in a given quantum circuit [1]. Tensor network methods like Matrix Product State (MPS) perform well for low-entanglement states, while graph-based methods are efficient for high-entanglement states. However, on the one hand solutions like cuQuantum [2] for state-vector and tensor network simulations lack scalability; on the other hand, approaches like GraFeyn [3], as a hybrid approach, fail to optimise resource usage for varied circuit structures. This gap highlights the need for a comprehensive, adaptive simulation system that leverages the strengths of different methods based on circuit characteristics.

We propose a novel hybrid quantum circuit simulation framework that dynamically selects the most efficient simulation method based on key metrics such as Schmidt rank [4] and tensor sparsity. Our system partitions quantum circuits into subcircuits, applying MPS for low-entanglement subcircuits and decision diagrams or Feynman-based methods for highly entangled subcircuits, improving scalability and performance.

The first key contribution is the innovative use of relational databases to manage tensor network contractions, treating tensors as relations and contractions as table joins [5]. This approach enhances scalability by addressing memory bottlenecks. The second contribution is dynamic circuit segmentation, which reorders and optimises gate operations to improve computational efficiency and resource utilisation. This system not only optimises method selection but also leverages database and graph-based techniques, offering a scalable tool for simulating larger quantum circuits and addressing the aforementioned limitations of existing solutions.

## References

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