CudaqToEinsum: Scalable and Efficient Translation of Quantum Circuits into Tensor Networks for Large-Scale Quantum Computing

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Efficient translation of quantum circuits into tensor-network representations is critical for large-scale quantum simulation, yet existing approaches often suffer from scalability and compiler-integration bottlenecks. We present CudaqToEinsum, a high-performance framework that interfaces directly with CUDA Quantum and its MLIR-based Quake dialect to parse circuit IR at compile time, recover topology, qubit dependencies, and gate semantics, and emit Einstein-summation specifications with operand tensors for downstream tensor-network contraction. On block-encoded state (BPS) circuits with up to 85,000 qubits, CudaqToEinsum delivers a 30~50 times increase in translation throughput over a Qiskit + cuQuantum CircuitToEinsum workflow, sharply reducing preprocessing overhead and enabling near-interactive compilation. The resulting tensor-network descriptions are backend-agnostic and integrate seamlessly with cuQuantum, PyTorch, and other optimized contraction libraries, providing a compiler-level bridge between quantum circuit IRs and tensor-network computation for large-scale quantum computing.