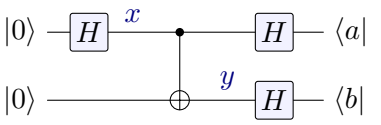
Functional Aggregate Queries for Strong Simulation of Quantum Circuits

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This talk presents joint work with Rihan Hai, Matthias Lanzinger, Reinhard Pichler, Emanuel Sallinger, and Daniel Unterberger [4] on computing exact quantum circuit amplitudes using functional aggregate queries (FAQs) [1]. Each gate is a weighted relation. For a specified computational-basis input and output, we join the gate relations on shared wire variables, multiply their weights, and sum over internal assignments. InsideOut eliminates each internal variable by joining the factors that contain it and summing out its values. The semiring specifies the operations on weights. The elimination plan and the representation of intermediate factors govern the cost of those operations.



$$A(a,b) = \sum_{x,y\in\{0,1\}} H_{x,0}\,\mathbf{1}_{y=x}\,H_{a,x}\,H_{b,y}$$

CNOT enforces $y = x$, and the sum eliminates the internal bits.

Over the complex numbers, explicit tables recover the line-graph treewidth bound for tensor-network contraction [5], and fractional edge covers give bounds that exploit sparsity. Over a formal phase semiring, compressed factors recover phase-graph rank-width bounds for compatible quadratic phases [2]. For Clifford circuits, affine–quadratic factors [3] remain compact under multiplication and aggregation, giving polynomial-time evaluation regardless of treewidth or rank-width.

We use the query plan to define *tensor layout symmetry width*. Local cut-rank controls factor construction, while exchangeability among separator variables keeps intermediate messages compact as exact tree tensors. For compatible quadratic phases, a supplied plan of bounded width yields polynomial-time evaluation. We construct such plans for a family whose phase graphs are chains of cliques and whose phase-graph rank-width and circuit line-graph treewidth are both unbounded.

References

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