Exact and Efficient Simulation of Photon Quantum Interference Using Tensor Train Decomposition

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Linear-optical (LO) devices can potentially serve as a physical platform for implementing universal quantum computing [1], and it is also a natural platform for solving the boson sampling problem – sampling from the probability distribution resulting from boson interference [2]. Designing and verifying LO devices requires accurate modeling of photon interference taking place in the devices. However, simulating photon interference exactly demands an exponentially large amount of resources. This presentation suggests exploiting tensor trains (TTs) for efficient and accurate simulation of the photon quantum interference using recent research [3].

The total number of possible Fock states of N photons and M modes is given by the binomial coefficient $\binom{M-1+N}{M-1}$. To calculate the amplitude of a LO transformation from a single input Fock state to a single output Fock state, it is necessary to evaluate the permanent of an $N \times N$ matrix. The general method for evaluating permanents requires on the order of $N2^N$ operations [4]. This means that calculating transformation amplitudes naively from a single input for all possible outputs would require on the order of $N2^N\binom{M-1+N}{M-1}$ operations.

Our approach is based on TT decomposition and it only requires on the order of $N\binom{M-1+N}{M-1}$ operations – similar to the current most efficient technique [5] – resulting in an exponential speedup with respect to the number of photons N. Our method also allows for easy expansion to applications involving a restricted set of output Fock states, demonstrating improved performance in these cases. The central idea behind our approach is the use of a compact representation of the summation over the permutation group in terms of TT contraction.

The work of S. Fldzhyan and S. Straupe was supported by Rosatom in the framework of the Roadmap for Quantum computing (Contract No. 868-1.3-15/15-2021 dated October 5, 2021).

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