Quantum simulation of partially distinguishable boson sampling

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Abstract

Boson Sampling is the problem of sampling from the same probability distribution as that output by indistinguishable single photons travelling through a linear interferometer. There are a number of challenges faced by Boson Sampling experiments, including the generation of indistinguishable single photons. We show how distinguishabililty leads to decoherence in the standard quantum circuit model.

Boson Sampling is proposed as a quantum experiment that is easy to implement but hard to classically simulate. It was famously shown that classically sampling from n indistinguishable photons output from an m-mode linear optical interferometer is hard, modulo several conjectures [1]. This has led to significant interest and experimental demonstrations. However, outperforming classical simulation is difficult [2], and any advantage will also need to consider experimental challenges such as photon distinguishability.

Here we consider Boson Sampling with partially distinguishable photons via first quantisation. When photons are indistinguishable, this is akin to constructing a symmetric state over $(\mathbb{C}^m)^{\otimes n}$, which can be done efficiently via the Schur transform [3], followed by applying $U^{\otimes n}$ where $U \in \mathrm{U}(m)$ describes the interferometer. This in shown in Figure 1 with the second quantisation equivalent, which is the standard picture for linear optics. With distinguishability, the state is symmetric on the space of $(\mathbb{C}^{m\times n})^{\otimes n}$, with the extra dimensions accommodating the relative distinguishability of the photons. We can decompose this into two registers $(\mathbb{C}^m)^{\otimes n} \otimes (\mathbb{C}^n)^{\otimes n}$, trace out the distinguishability register $(\mathbb{C}^n)^{\otimes n}$, and then apply the interferometer transformation.

This shows how distinguishability and can be modelled as decoherence in a quantum circuit, arising from entanglement between registers. This paves the way for applying research in decoherence and quantum error correction to Boson Sampling, which will allow us to elicit how much distinguishability we can tolerate in linear optics, as well as how such distinguishability can be mitigated through, for example, postselection.

[1] Scott Aaronson and Alex Arkhipov, *The computational complexity of linear optics*, In Proceedings of the Forty-third Annual ACM Symposium on Theory of Computing, **STOC '11**, pages 333–342 (2011).

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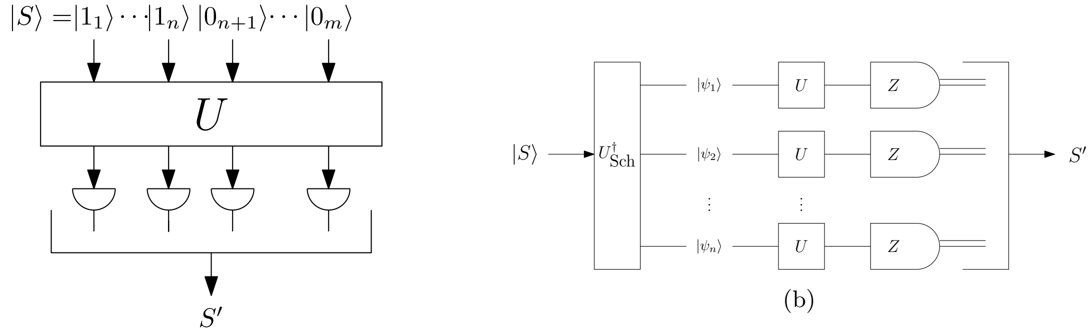
[3] Dave Bacon, Isaac L. Chuang, and Aram W. Harrow, *The quantum Schur and Clebsch-Gordan transforms: I. efficient qudit circuits*, In Proceedings of the Eighteenth Annual ACM-SIAM Symposium on Discrete Algorithms, **SODA '07**, 1235–1244 (2007).



(a) (b)

Figure 1: Boson Sampling as described in (1a) second and (1b) first quantisation. U_{Sch} represents the Schur transform, Z is a measurement in the qudit basis, and S & S' are the input and sampled output occupation numbers, respectively.