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# The Hardness of Boson Sampling under Imperfections

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**Abstract**

We show that boson sampling is classically simulable in the presence of linear loss (constant per-photon transmission). We discuss the impact that this has on experimental efforts to demonstrate a quantum advantage.

In recent years, interest in quantum information processing has focused onto small-scale quantum computing machines, which could perform single tasks of scientific or technological interest faster than classical computers, and which can be constructed with current or near-future technology. An important milestone on the way to such a device is a demonstration of a quantum advantage, i.e. a problem at which a quantum machine convincingly outperforms a classical computer. Such problems could either be of practical interest (e.g. in quantum chemistry) or specifically set up for the purpose of demonstrating a quantum advantage.

One promising candidate for the demonstration of a quantum advantage is boson sampling, where the task is to provide samples of the output of a system of many bosons undergoing interference. Aaronson and Arkhipov [1] provided strong evidence that this task cannot be simulated efficiently (i.e. in polynomial time) on a classical computer. The presence of computational hardness means that as the system size increases, the classical computer is increasingly at a disadvantage. The point where a boson sampler is expected to outperform a supercomputer is around 50 bosons, an observation that has spurred a range of experimental efforts.

However, a major obstacle to demonstrating a quantum advantage is our lack of understanding of the impact of experimental imperfections. While for small imperfections, boson sampling was shown to retain its hardness, experimentalists typically have to deal with large imperfections. In that case, there is no a priori reason why claims of computational hardness could be maintained.

In our recent work [2], we simultaneously address the role of the two major imperfections in bosonic many-body interference, namely distinguishability and linear particle loss. We will demonstrate a classical simulation algorithm for many-body bosonic interference where each boson has a fixed probability $\eta$ to be transmitted through the experiment and may also have some degree of distinguishability x. This work extends our previous algorithm [3], which considered only distinguishability, to a combination of losses and distinguishability.

We find that any interference of n bosons with loss $\eta < 1$, where m bosons survive is well approximated by polynomially many ideal coherent interference processes of size $k \leq m$, supplemented with $m - k$ classical bosons. Remarkably, $k$ only depends on parameters which are independent of the number of photons undergoing interference, such $\eta$ and $x$. Therefore, boson sampling with losses $\eta$ is only as hard as computing a permanent of size k and it therefore serves no purpose to construct lossy boson samplers of size larger than k. We show that such a k exists for any level of losses or distinguishability, thereby showing that boson sampling is non-scalable for any level of imperfections.

Considering the finite-size case, we find that a transmission of $\eta > 0.88$ is necessary to simulate boson sampling with 50 bosons at an accuracy level of 10%, and that the current best boson sampling platforms technologies are restricted to interference of 21 bosons under the same criterion. This shows that achieving a demonstration of a quantum advantage through boson sampling requires more than the construction of high-rate, large-scale photonic systems, as was demonstrated previously [4]: it also requires a qualitative improvement in the equipment used.

[1] S. Aaronson and A. Arkhipov, Theory Comput. 9, 143 (2013).
[2] J.J. Renema, V. Shchesnovich, R. Gacria-Patron, arXiv 1809.01953 (2018).
[3] J. J. Renema et al., Phys. Rev. Lett. 120, 220502 (2018).
[4] A. Neville et al., Nat. Phys. 13, 1153 (2017).