The hardness of boson sampling under imperfections

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Boson sampling [1] offers a promising route towards a demonstration of a quantum advantage, i.e. demonstration of a computational task which can be performed faster in real time by a quantum computer than by a classical one. The task consists of sampling from the output distribution of a network of linear interferometers fed with single photons. For a sufficiently large number of photons, it is strongly believed that a quantum device implementing this problem directly will outperform a classical computer simulating the experiment.

One major limitation in the field of boson sampling has been the relatively poor understanding of how experimental imperfections compromise the computational hardness. Such imperfections may include photon distinguishability, photon loss, and noise in the interferometers and detectors. Whereas the original boson sampling is believed to remain asymptotically hard under small such imperfections [1], this does not provide a useful guide for experimentalists, since the boundary scaling of the strength of imperfections with the number of photons, required to preserve the asymptotic computational hardness, have remained unknown.

In this work, we provide upper bounds on the strength of imperfections which are permissible in a boson sampling experiment. We do this for two of the major imperfections in photonics, namely photon distinguishability and photon loss. We will do this by demonstrating classical algorithms that exploit the imperfection.

For distinguishability, we will present a recent algorithm [2] which shows that interference of low-indistinguishability photons can be broken up into interference of fewer, perfectly indistinguishable photons. This number of effective photons is only a function of the distinguishability, not of the number of photons used. This means that one cannot compensate low indistinguishability by using more photons. In boson sampling, quantity is no substitute for quality.

For photon loss, we will show two algorithms. First, we will show an algorithm [3] which is able to simulate any boson sampling experiment where the losses scale quadratically with the number of photons. This includes all photonic chip experiments, which due to the scaling of path lengths with the number of photons exhibit exponential losses. Finally, we will show numerical results on an algorithm which simulates boson sampling with linear losses, i.e. where the probability of losing a photon is independent of the number of photons.

Together, these results form a minimum set of specifications that any boson sampling experiment must clear in order to achieve computational hardness.

References

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