Gaussian Boson Sampling experiments with displacements and time-bin encoding

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Gaussian boson sampling (GBS) is a quantum sampling task in which samples are drawn from the photon-number distribution of a high-dimensional nonclassical squeezed state of light. GBS has garnered much attention, since its proposal, for its ability to perform a task which is intractable with a classical machine, whilst alleviating some of the experimental limitations associated with standard Boson Sampling. Here we consider two GBS experiments each realised with a different type of encoding [1,2].

Experiments building GBS machines have mainly focused on increasing the dimensionality and squeezing strength of the nonclassical light to make the task intractable on even the fastest supercomputers. However, no experiment has yet demonstrated the ability to displace the squeezed state in phase space, which is a key operation that opens new avenues for the utility of GBS. Here, we built a GBS machine that achieves the displacement by injecting a laser beam alongside a two-mode squeezed vacuum state into a 15-mode interferometer realised in silicon integrated photonics. Doing so enabled two new capabilities. Firstly, we use displacements to reconstruct the multimode Gaussian state at the output of the interferometer. Our reconstruction technique is in-situ and requires only three measurement settings regardless of the state dimension. Secondly, we study how the addition of classical laser light in our GBS machine affects the complexity of sampling its output photon statistics. We introduce and validate approximate semiclassical models that reduce the computational cost when a significant fraction of the detected light is classical.

Additionally, we use a time-bin encoded fibre-loop interferometer to implement GBS experimentally. Such an apparatus is highly scalable using a fixed number of physical resources. To demonstrate the applicability of this architecture we perform GBS experiments to produce samples to enhance the search for dense subgraphs in a graph. Our results indicate an improvement over classical methods for subgraphs of sizes three and four in a graph containing ten nodes. Finally, we numerically explore the role of imperfections in the optical circuit and on the performance of the algorithm.

[1] G. S. Thekkadath, S. Sempere-Llagostera, B. A. Bell, R. B. Patel, M. S. Kim, and I. A. Walmsley, PRX Quantum, 3(2), 020336 (2022)

[2] S. Sempere-Llagostera, R. B. Patel, I. A. Walmsley, and W. S. Kolthammer, arXiv preprint arXiv:2204.05254 (2022).