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Classical Approximate Algorithms for Gaussian Boson Sampling: Has quantum advantage been achieved?

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Gaussian Boson Samplers (GBS) are non-universal optical quantum computers introduced to demonstrate quantum advantage without requiring full error-correction by efficiently sampling from a classically-hard distribution. These devices are relatively simple: just squeezed states fed through a random, precise array of linear optics. Recently, the first large-scale GBS devices were created: the Jiuzhang series at China's USTC, the latest of which has reached 1152 modes, and the Borealis device made by Canada's Xanadu corporation. Both groups have claimed their GBS achieves quantum advantage.

However, verifying this is difficult. Both groups' results deviate markedly from those of an ideal implementation of their experiments. As such, multiple groups have contested the experimentalists' claims by producing results closer to the ideal ground-truth using classical sampling algorithms that replicate the output photo-count patterns. Nevertheless, while the experiments do not sample from the ideal, there is no evidence that the distribution they sample from is classically easy.

To address this concern, we use phase-space simulations to find simple, well-motivated corrections to the ground-truth to use as the basis of our comparison. In addition, we introduce two novel classical sampling algorithms for the GBS. The first approach is a relative of Google's low-order sampling method, but it samples from a physical state rather than a synthetic non-i.i.d. distribution. The second approach is based on a novel mapping of quantum-jump-method equations into phase space. Thus, we both give the experiments a fairer test and provide new challengers.

These new samplers beat the experiment on both ground-truths for the Jiuzhang 2.0, 3.0, and Borealis experiments and outperform the best current tensor-network approach. We also find evidence that previous classical sampling techniques cannot beat the experiment on the realistic ground-truth, but our novel algorithms can. Thus, we provide more rigorous evidence against demonstrable quantum advantage in current GBS experiments.

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