Quantum approximate optimization algorithm thermal-like states

Pablo Díez Valle
Diego Porras, Juan José García-Ripoll

Instituto de Física Fundamental IFF-CSIC, Calle Serrano 113b, Madrid, Spain

pablo.diez@csic.es

In this talk we present the main results of [1], where we provide analytical and numerical evidence that the single-layer Quantum Approximate Optimization Algorithm (QAOA) on universal Ising spin models creates pure, but thermal-like states with Gaussian perturbations (see Fig.1). These states resemble Boltzmann distributions that cannot be efficiently simulated on classical computers according to state-of-art techniques, and we relate these distributions to the optimization potential of QAOA.

QAOA was originally proposed as a hybrid variational algorithm suitable for solving combinatorial optimization problems on NISQ devices [2]. It has been shown that the shallowest version of the algorithm already engineers a quantum probability distribution that is classically hard to sample [3]. Our work illustrates that the sampling advantage manifests itself in pseudo-Boltzmann states with a temperature lower than can be simulated classically using state-of-art Markov Chain Monte Carlo algorithms (see Fig.2). Moreover, we connect the sampling advantage and the optimization properties, presenting that this low temperature also implies an advantage with respect to optimization. In specific, there is an algebraic (Grover-like) enhancement of the ground state probability.

References

[1] P. Díez-Valle, D. Porras, J.J. García-Ripoll, arxiv: 2201.03358 (2022)

[2] E. Farhi, J. Goldstone, S. Gutmann, arxiv:1411.4028 (2014)

[3] E. Farhi, A. W. Harrow, arxiv:1602:07674 (2019)

Figures

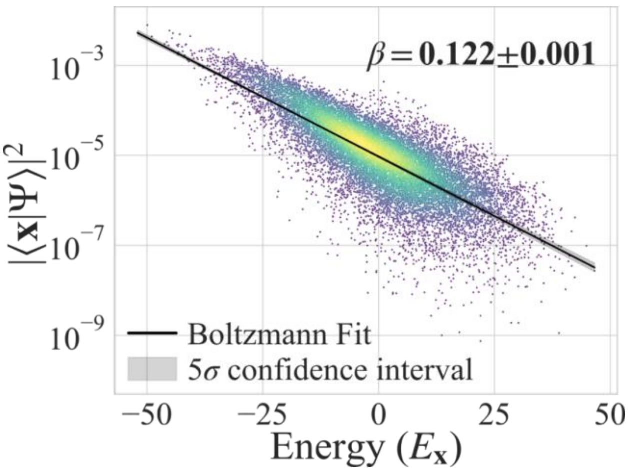

Figure 1: Eigenstate probabilities (dots) and fitted Boltzmann distribution (line) for single-layer QAOA ansatz with optimal angles.

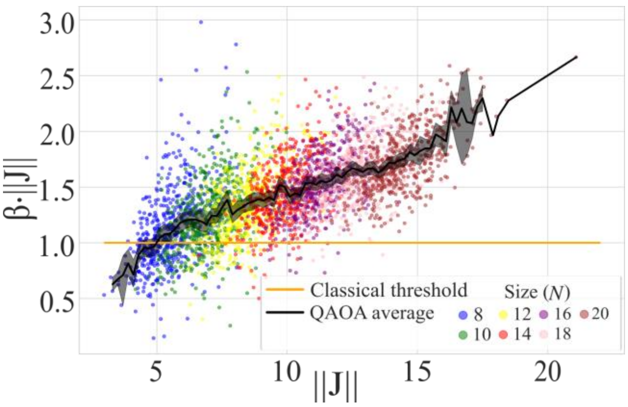

Figure 2: Effective temperatures β after single-layer QAOA with optimal angles, as a function of the interaction matrix J norm for QUBO problems. The dots display the results for 500 instances for each problem size, which grows with the J norm. We show the average of these results (black line) and the threshold given by Monte Carlo methods (orange line) which demonstrates that the distributions obtained with one-layer QAOA are hard to sample classically