Solving Maximum Independent Set using Analog Quantum Computing

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1 Introduction

The manipulation of neutral atoms by light is at the heart of countless scientific discoveries in the field of quantum physics in the last three decades. The level of control that has been achieved at the single particle level within arrays of optical traps, while preserving the fundamental properties of quantum matter, makes these technologies prime candidates to implement new computation paradigms. One of these new models is analog computing with neutral atom [1], which allows Maximum Independent sets to be encoded quite naturally on Unit Disk Graphs. Solving the maximum independent set problem holds significant importance across various domains, including algorithmics, theoretical computer science, and complex networks.

2 Methodology

Considering an undirected graph composed of a set of vertices connected by unweighted edges, an independent set of this graph is a subset of vertices where no pair is connected by an edge. The objective of the MIS problem is to find the largest of such subsets. As presented in [**?**], the MIS problem on unit disks graphs can be tackled by using an ensemble of interacting cold neutral atoms as a quantum resource, where each atom represents a vertex of the graph under study. As with any quantum system, the dynamics of the atoms are governed by the Schrödinger equation, involving a Hamiltonian (energy functional) depending on the atomic positions, the electronic energy levels and their interactions. Interestingly, the physical interactions encoded in the Hamiltonian constrain the dynamics to only explore independent sets of the graph under study, then leading to an efficient search in the set of possible solutions.

During this presentation, we propose to explain the functioning of the machine in an accessible manner by providing a simple explanation of its internal mechanisms. We will highlight its current promising capabilities in addressing the Maximum Independent Set (MIS) problem. In essence, this presentation aims to offer a balanced perspective, showcasing current successes while acknowledging the challenges, both practical and theoretical, in the development and optimal utilization of this innovative machine to solve combinatorial problems.

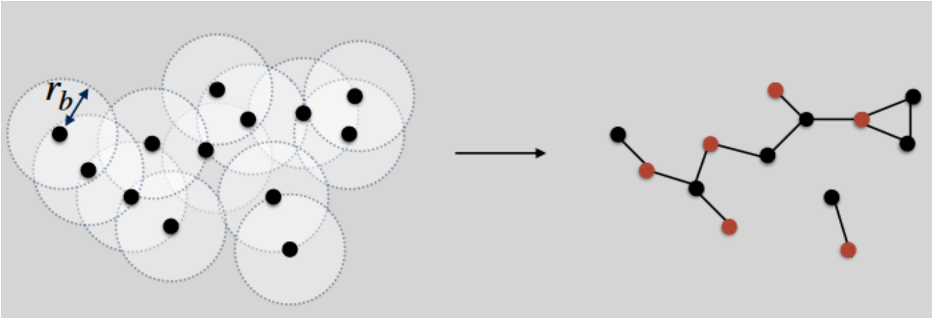

FIG. 1: The positions of the atoms, that have two internal energy levels, are chosen to match directly the graph under consideration. The levels of two Rydberg atoms strongly interact if the distance between the atoms is smaller than a typical distance (rb, see left part), resulting in the impossibility for the two atoms to be both in the same state at the same time (phenomenon of Rydberg blockade). This naturally corresponds to the independent set constraint in the graph defined by the atoms, with edges linking atoms that sit at a distance closer than rb. We show on the right the corresponding graph, with the red vertices forming one independent set.

3 Conclusion and perspective

In the near future, advancements in solving the Weighted Maximum Independent Set (MIS) problem hold great promise. The evolution of algorithms could enable the efficient resolution of weighted MIS, where node weights influence the composition of the maximum independent set. This extension of MIS paves the way for more diverse applications.

Additionally, the potential use of Quantum Processing Units (QPUs) as MIS solvers is getting increased interest. This approach could also extend the reach of QPUs beyond direct MIS resolution, positioning them as versatile tools for encoding and solving a variety of graph-related problems.

References

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