This year's iQuHACK challenges require a write-up/documentation portion that is heavily considered during judging. The write-up is a chance for you to be creative in describing your approach and describing your process. It should clearly explain the problem, the approach you used, your implementation with results from simulation and hardware, and how you accessed the quantum hardware (total number of shots used, backends used, etc.).

By: Shor's Squad

Our approach: we started by understanding MIS, the King's lattice, and the system Hamiltonian of the Rydberg atom array. At first we were bogged down by trying to figure out how to use a Rabi frequency that balanced between not overpowering the final state and running in short time. Eventually, we figured out that the Rabi frequency itself was what we needed to use to determine the ground state and this helped us understand the problem a lot better. Finally, we figured out from this that the effective Rydberg blockade depends more heavily on the Rabi frequency rather than the detuning and that in order to get to an R_b = 12 microns (3a) we need to lower our Rabi by a sufficient amount that is not compatible with decrease in switching times compared to decoherence. But the r=2a would work perfectly well. Changes in hardware for minimum r, Rydberg state change, etc. could all allow an r=3a solution.

We had some interesting ideas we discussed. For instance, we talked about choosing a closer (larger overlap) starting ground state in order to minimize the errors that occur along the way. What we wanted to do is use the full NxN grid of Rydberg atoms instead of dropping atoms out of tweezers. We classically find the solution to the full NxN and excite those nodes. Then we could lower the detunings of the atoms to drop out slowly (adiabatically) to end in a ground state of the final solution while not undergoing many transitions. Our idea does not work for current Quera hardware, but is a near-term solution as multiple groups across MIT, Harvard, have developed the potential for individual addressing.

The next thing we needed to do was optimize the parameters in the classical simulator. The classical simulator has exponential time scaling, so we had to stick with a 4x4 square case. We fixed Rabi frequency as a fast excitation and varied detuning in a slow adiabatic process. We calculated a total time of 2 us was a good time to avoid decoherence issues while keeping a slow adiabatic process with sufficient switching.

To find the path in detuning we used Nelder-mead variation. Given a particular maximum value of delta, we initialized an arbitrary piecewise linear path. We then used a gradient descent optimizer to optimize the path over the following metric: weighted average number of excited atoms. Finally, we performed a grid search to look for the best hyperparameters, max values of delta and omega. Thus, we drastically improved the performance of our simulation for both the hardest and easiest 4x4 problems. Despite the solid performance, we noticed that our hyperparameters were out of the Aquila system bounds, and enforcing these bounds reduces the performance of the system.

We wanted to use ratios to scale this to higher dimensions. In the literature, the way to scale is to use variational quantum algorithms. However, we cannot do this so we must extrapolate from the 4x4 case.

Finally, we pushed to Aquila our Nelder-Mead 4x4 optimized paths. We wanted to push also to hardware our expected linear ramp from theory, but Aquila closed early. We used Bloqade to access Aquila through AWS Braket and used 100 shots; however, we only did one task on the actual hardware because of the early closure of Aquila. Furthermore, we had a plan for an 8x8 grid to push but again ran out of time. These were all planned as 100 shots and thus could not support variational algorithms.

To demonstrate the successful execution of our analysis, we tackled the MIS problem on what we determined to be the most challenging instance for a 4x4 lattice. By modeling the hardness parameter in terms of the degeneracy of the independent subsets, we discovered that a blockade radius of approximately
2.1a posed the greatest difficulty for the lattice configuration we generated using the generic tensor networks approach. In graphs with a large degeneracy density, there may exist many MIS configurations that are compatible with the local ordering in these domains.

(Figures, sources in slideshow)