Understanding how Quantum Weirdness Could Solve Hard Problems

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Research project
Quantum computing is an exciting area which brings together both very abstract quantum theory and the potential for new routes to tackle some of the hardest computational problems. Within this project we will use some of the tools for understanding how strange and counter-intuitive behaviours may play a role in near term algorithms for solving NP-Hard (travelling salesperson type) problems. Specifically, we will be looking at algorithms related to quantum annealing (including quantum walks and some gate-model algorithms), the quantum analogue of simulated annealing for which real large hardware has been built [1]. The relevant regime for real devices is a rapid quench regime where very little is understood [2], the goal of this project.

We will be analysing this near-term algorithm using the Kirkwood-Dirac distribution [3] – an attempt to extend probability to quantum scenarios: when everything is classical, this behaves like a normal probability, but it has been shown to take on puzzling properties (like negativity) in scenarios which may provide quantum advantage [4]. By analysing the behaviour between time-steps in the rapid quench regime using the Kirkwood-Dirac distribution, this research project will be one of the first to use this novel foundational tool to assess properties of near-term algorithms which could be deployed on Noisy Intermediate-Scale Quantum (NISQ) devices. This should both give us a useful tool for quantifying some measure of the potential advantage in these algorithms, and give us a useful test-bed for investigating the origin of this negativity in these inherently quantum systems.

Applicant skills/background
The main requirement for this project is willingness to learn the relevant material. Since the systems we wish to study are not easy to describe analytically the study will mostly be carried out numerically, so the student will be expected to perform some coding in Python.

References
[1] https://www.dwavesys.com/
[2] https://journals.aps.org/prxquantum/abstract/10.1103/PRXQuantum.2.010338
[3] https://arxiv.org/abs/2403.18899
[4] https://iopscience.iop.org/article/10.1088/2058-9565/ad124c