Hamiltonian Quantum Computing

External supervisor: Viv Kendon (Durham University), Imperial supervisor: Florian Mintert
Collaborators: Sougato Bose (UCL), Nick Chancellor (Durham), Andrew Daley (Strathclyde).

Background: Hamiltonian quantum computing encodes the problem into qubits, then, instead of applying quantum gates, uses a Hamiltonian-based, continuous time evolution to produce the final state of the qubits, which encode the answer. The time evolution can include coupling to a thermal bath, or other non-unitary dynamics. This model of computation includes as special cases: adiabatic quantum computation, computation by (continuous-time) quantum walk, quantum annealing, and many types of special purpose quantum simulation. A hybrid strategy that takes advantage of features from all of these, tailored to suit the problem, will provide a quantum advantage for practical computation. A very wide range of important optimisation and sampling problems, in finance, microbiology, aerospace, big data, neural networks and many other areas, are well-suited to this approach. Furthermore, hardware being designed and built for one of these types of computation should be suitable for a wider range of problems than originally envisaged. The D-Wave architecture is an example, but it is very noisy and can access only a rather limited range of this computational space. These unifying ideas are very new: you would be essentially the first PhD student working on the topic, putting you in a position to make a seminal contribution to the development of practical quantum computation through this method.

First year project: We have been developing these ideas since 2012, and we now have strong evidence for the usefulness of hybrid strategies. We have been studying the search problem (Grover’s search) in adiabatic and quantum walk settings, interpolating between the two, and adding (high temperature, unwanted) noise to test robustness to errors. You can find a paper here* that describes some of this work. Further work was done by James Morley at UCL for his 2016 MRes project (report available on request). Quantum searching only gains a quadratic speed up over classical algorithms, and it is time to investigate harder-to-solve problems. For the first year project, you will do a similar study but based on real-world optimisation problems. It will be largely numerical, with some possibilities to apply analytical methods (e.g., arXiv:1508.01327 for their use of random matrix analysis). We expect to find distinctly different optimal strategies, due to the different nature of this type of problem.

PhD project: There are many possible directions to pursue after the first year project, and you will by then know enough to choose your topics based on your interests. The theoretical underpinning of Hamiltonian quantum computing needs to be established in more detail, with known properties of one type of computation extrapolated across the whole range. For example, there are requirements for the connectivity of the graphs on which quantum walk computation takes place that have implications for the hardware connectivity in any new designs. The various quantum simulators being developed need to be analysed for what else they will be capable of computing, and new, more optimal hardware designs produced. And we have only studied time evolutions that are similar to adiabatic or quantum annealing schedules; there are many more possibilities that may yield exciting new computational methods, especially when combined with open quantum systems effects (low temperature bath coupling is essential for quantum annealing). For some examples of algorithmic innovations, see arXiv:1606.06833 and arXiv:1609.05875.

Given the locations of collaborators, you can choose to be based in London (with visits to Durham +Glasgow), or to move to Durham, or even Glasgow, for the main PhD project.