Getting topologically protected qubits to work

Supervisors: Daniel Burgarth (Aberystwyth University) & Florian Mintert

Background Some concepts in quantum information only require a few qubits, but, perhaps the most important theoretical concept - a full quantum computer - is still out of reach, because it requires thousands of controllable qubits. One promising route toward quantum computing is the use of topological stability [1]. Here, quantum operations are protected by global topological properties of the system which remain invariant under local noise. Combined with quantum error correction [2] these provide the leading theoretical framework for fault-tolerant quantum computing.

On the more practical side though it is not clear how the exotic interactions used in topological systems can be engineered with real-world systems, and how states can be written into such memories, let alone how universality may be achieved. This project looks into using control theory [3] - a method to steer dynamics - to achieve topological order and fault-tolerance in experimentally realistic situations. The big question is, if control will turn local errors into global ones, which would then destroy topological order, or, if it is actually feasible to induce desired dynamics in topological qubits.

I. SIX MONTH PROJECT

You will start by learning about the general methods of topological order, error correction and quantum control. You will then study Kitaev’s honeycomb model [1] for topological memories. This model can be solved analytically, but things get more complicated if additional (time-dependent) control Hamiltonians are present. The complete system dynamics needs to be described in an approximate fashion in terms of the Magnus expansion

$$U(t) \simeq \exp \left(-i \left( \int_0^t dt_1 \mathcal{H}(t_1) + i \frac{1}{2} \int_0^t dt_1 \int_0^{t_1} dt_2 [\mathcal{H}(t_1), \mathcal{H}(t_2)] + \ldots \right) \right).$$

This description will allow you find analytic relations between the time-dependent Hamiltonian $\mathcal{H}(t)$ and the system dynamics $U(t)$. In this fashion, you can describe controllable interactions and study how local errors propagate under time-dependent fields. Finally you will find the best possible controls under the constraint of maintaining topological order by numerical optimisation.

II. PHD PROJECT

There are various possible paths to widen up the research from the MRes project, depending, in particular, on your findings and your interests and skills. On the mathematical side, the main goal could be to enforce topological order through design of interactions and noise terms (Lindbladians) with desirable properties. On the physics side, you could look into models of specific experiments and noise models to suggest implementations of topological error correction. On the foundational side it would also be exiting to investigate the role of measurements and feedback in control theory (measurement based quantum computing shows that these can make a huge difference to the achievable operations, but how can this be described in general?).

Aberystwyth is a lovely seaside town in Wales, with a friendly university and a small but active group working on mathematical structures of Quantum Mechanics and Control Theory. It is full of beautiful nature and spending some time there could perfectly complement your busy London life. Our supervision model provides flexibility for working mainly in London, mainly in Aberystwyth or any share of time in the two places.

Questions Please get in touch; you find Florian in EEE and you can contact Daniel via burgarth@gmail.com.