4th Year Projects 2019/20: Quantum Control via Shortcuts to Adiabaticity
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The preparation and control of quantum states in a quick and robust way is very important for future quantum technologies. So far, the most robust state preparation techniques were provided by adiabatic processes: the external parameters of the Hamiltonian are varied slowly and the populations of the system in the instantaneous basis remain constant. Nevertheless, in many cases this takes too long and become impractical since their slowness makes them extremely sensitive to decoherence and noise. This fact has prompted recently a lot of theoretical and experimental activity to find new schemes to speed up adiabatic processes while keeping their robustness, leading to the research field of "Shortcuts to Adiabaticity".

If you have further questions, please come to my office (**Room 216A**) or send me an email (**aruschhaupt@ucc.ie**).

Project 1:

Preliminary title: **Visualisation of Quantum Algorithms**

The main goal of quantum information processing is to use quantum mechanics to overcome the limitations of classical computers. There are in existence today quantum algorithms which are able to perform given tasks, in principle faster than any known classical algorithm.

The first task of this project is to understand a main quantum algorithm as Shor's algorithm (factorisation) or Grover's algorithm (database search). The main task is then a visualisation on a classical computer based on Mathematica or C/C++.

Project 2

Preliminary title: **Stability of Shortcuts to Adiabaticity**

This project starts with achieving an understanding of Quantum Control via Shortcuts to Adiabaticity [1]. In the next step, especially, the technique of stability optimisation using error sensitivities based on time-dependent perturbation theory will be studied [2]. In the third step and as an application, the stability of the derived shortcuts to spatial adiabatic passage [3] against different perturbations (like fluctuations of the couplings) should be studied because preserving this stability would be essential for experimental implementations.

The project will require an understanding of selective literature, analytical calculations as well as numerical simulations of a three-level system with Mathematica.

Ref: *[1] D. Guéry-Odelin, A. Ruschhaupt, A. Kiely, et al., arXiv:1904.08448*

[2] A. Ruschhaupt et. al., New J. Physics 14, 093040 (2012)

[3] A. Benseny et. al., EPJ Quantum Technology (2017) 4:3

Project 3

Preliminary title: **Non-local potentials and invisibility cloaks in quantum theory**

The scattering of quantum particles by non-Hermitian and generally non-local potentials in one dimension may result in asymmetric transmission and/or reflection from left and right incidence; such asymmetries might not be possible with "standard" local and Hermitian potentials in quantum mechanics. Six basic device types are identified in [1] when the scattering coefficients (squared moduli of scattering amplitudes) adopt zero/one values, and transmission and/or reflection are asymmetric. These devices can pictorically be described as a one-way mirror, a one-way barrier (a Maxwell pressure demon), one-way (transmission or reflection) filters (like an invisibility cloak), a mirror with unidirectional transmission, and a transparent, one-way reflector.

The project will require an understanding of [1] and analytical calculations to design additional new examples of non-local potentials and interesting devices. This can be supported by Mathematica.

Ref: *[1] A. Ruschhaupt , T. Dowdall , M. A. Simón and J. G. Muga, EPL 120, 20001 (2017)*

Project 4 (supervised together with Anthony Kiely):

Preliminary title: **Effect of Coloured Gaussian Noise on Adiabatic Processes**

In [1], a detailed derivation of the master equation describing a general time-dependent quantum system with classical Poisson white noise has been derived and its various properties have been outlined. Using this, various settings have been simulated to illustrate different effects of Poisson noise.

In this project, a similar examination should be done with coloured Gaussian noise instead of Poisson noise. The master equation should be derived and examples studied numerically with Mathematica. Therefore, this project will require analytical calculations as well as numerical calculations with Mathematica.

Ref.: *[1] A. Kiely et. al., Phys. Rev. A 95, 012115 (2017)*

Project 5:

Preliminary title: **??? (Very interesting/very difficult)**