Quantum Control and Computation

P. G. Morrison, BSc. (UNSW)

Centre of Excellence for Quantum Computer Technology, Macquarie University, Australia.

What's the difference with the quantum world?

Consider a game of pool, with fixed positions for the hole and cue ball. In a classical game, looking at the position of the target ball will not change the outcome of the experiment. However, quantum systems differ in that the observation of the target will alter its position to a significant degree, and this observation will change the way we have to play the game. If we don't know where it **is**, we have to assume that it is anyplace where it **could** possibly be.

In short, we have to start considering questions such as "What is the probability that the pool ball is at such and such a position and time?" in order to develop a strategy for maximizing the chance of sinking it. This is different from the naïve classical theory which assumes a definite position for the pool ball at all times.

Classical digital computational systems are based almost exclusively on binary systems; a variable can only take the values **1** or **0**. Quantum computational systems are more general than this in that the variables can be a little of each. This can be imagined as instead of a true/false answer to a question, the answer is "true in context A" and "false in context B" at the same time.

For the technically inclined, the state of the simplest quantum system may be written as $|\psi\rangle = a|0\rangle + b|1\rangle$. This means that if we can construct quantum states which are robust to decoherence we can do the calculation for the input values **0** and **1** in a single step!

If we can't predict it, how can we control it?

This project is examining the different possible techniques we can use to control quantum systems. For the simplest problem, the "state space" can be imagined as the surface of a sphere. The optimal trajectory between two points is then given by the great circle whose arc joins both points. However, for multi-qubit systems there is no simple geometric picture available, and this difficulty requires us to begin applying mathematics to the problem. As part of the CQCT program, we aim to supply experimentalists with concise algorithmic methodologies which are useful in the lab!

What is quantum control and computation?

Classical control theory assumes that the interaction from the experimental apparatus can be made so weak that we can neglect them. Quantum mechanics tells us that it can't be so, that any interaction with the system causes change that is unpredictable! Unpredictable doesn't necessarily mean uncontrollable…. however the key point to note is that when we observe the system, we change it. Developing new control strategies to adapt to this reality presents a significant challenge to modern science.

Why is quantum control and computation important?

Nanotechnology is fast becoming a crucial field of modern science, as computer size and weight continues to contract. This has been achieved by shrinking the components to mesoscopic dimensions (and below) and fitting many more onto chipsets. As the components become tiny, the wires in the circuit no longer operate independently of one another. This causes problems in classical computers, as the scrambling of data from one line to another would present itself as a possible error.

How is quantum control applicable?

The dynamics and operation of the quantum computer will be quite different from the classical case. We are going to have to develop new methods to:

- transfer data (quantum data bus)
- hold and store data (quantum memory)
- co-ordinate programs in the operating system

The control of quantum systems will be crucial to the development of workable computers based on these new technologies and ideas. Quantum control must be the glue that holds the computer together!

Where is quantum control going in the future?

At present the science of quantum control is undergoing a rapid diversification in both ideas and applications. At present it is possible to test these ideas of quantum control in the laboratory. The experimental analysis will allow us to determine the most effective and efficient methods for specific use in quantum computation. This natural process of scientific evolution will in turn allow us further insight into the behaviour and dynamics of real physical systems.

Contact details: If you would like further information, feel free to contact me at pmorriso@ics.mq.edu.au . Technical information and equations available on request! For other quantum information check http://www.ics.mq.edu.au/qis/.

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