Proposed subtopic for GC7: "Journeys in Non-Classical Computing"

Quantum Computational Models

Samuel L. Braunstein and Susan Stepney
Department of Computer Science, University of York

There are very many models of classical computation, including Turing machines, functional combinators, logic circuits, fixed point approaches, and so on. Within the context of classical computation these are essentially equivalent, yielding identical results but from vastly differing underlying formalisms.

Within the quantum computational world this unity is less clear. For example, a fixed-point algorithm on a quantum computer could include a superposition of all fixed points, not just the stable one obtained by repeated substitution. This suggests that the manifold classical formalisms may generalise to the quantum realm in different ways. Currently, the most extensively studied quantum computational model is the circuit model. This gate-level model is not good for designing high-level algorithms, for reasoning about complexity, or other such important tasks. These problems are very hard in this formalism. More importantly, it may be this model is just not the most appropriate quantum generalisation.

It may well be that the underlying structure of Quantum Information is so radically different from anything that we currently understand that we need a whole new approach. Quantum mechanical versions of classical models simply might be insufficiently powerful to encompass the new properties offered by the quantum domain. However, before we attempt to resolve such a daunting issue, there is much to be gained from examining the various classical models, to see if, and how, and how far, they might provide us with new insights into computation within the quantum domain.

We propose a long-term research programme to thoroughly investigate the multitude of classical computational models in terms of their generalisability to cover quantum properties. Such work will either provide powerful new generalised quantum computational models, or potentially demonstrate that a truly novel, fundamentally quantum, paradigm is indeed required. Additionally, this work will feed back into classical computation (one example of this interrelationship between the necessity of quantum reversibility and the possibility of designing efficient classical "reversible compilers").