Understanding the Quantum Computational Speed-up via De-quantisation

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Abstract

While it seems possible that quantum computers may allow for algorithms offering a computational speed-up over classical algorithms for some problems, the issue is poorly understood. We explore this computational speed-up by investigating the ability to de-quantise quantum algorithms into classical simulations of the algorithms which are efficient in both time and space, and, in some cases, as efficient as the original quantum algorithms.

The process of de-quantisation helps formulate conditions to determine if a quantum algorithm provides a real speed-up over classical algorithms. These conditions can be used to develop new quantum algorithms more effectively (by avoiding features that could allow the algorithm to be efficiently classically simulated), as well as providing the potential to create new classical algorithms (by using features which have proved valuable for quantum algorithms).

We present results on de-quantisation of many different forms. De-quantisations employing higher-dimensional classical bits, as well as those using matrix-simulations, put emphasis on entanglement in quantum algorithms, and a key result is that any algorithm in which the entanglement is bounded is de-quantisable. These methods are contrasted with the stabiliser formalism de-quantisations due to the Gottesman-Knill Theorem, as well as those which take advantage of the topology of the circuit for a quantum algorithm.

The benefits of the different methods are contrasted, and the importance of a range of techniques is emphasised. We further discuss some features of quantum algorithms which current de-quantisation methods do not cover.