An Evolutionary Algorithm for the Circuit Synthesis of Arbitrary Quantum States

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The efficient preparation of quantum states is an important step in the execution of some quantum algorithms; specifically in the noisy intermediate-scale quantum (NISQ) computing era, where quantum resources are scarce and only low-depth quantum circuits can be implemented on a physical device. We present a method – genetic algorithm for state preparation (GASP) – which generates low depth quantum circuits for initialising a quantum computer in a specified quantum state. The method uses a basis set of R_x, R_y, R_z, and C_x gates, and based on numerical experiments appears to scale polynomially in the number of gates required. Current best techniques are exact general circuit synthesis methods such as those presented by [1, 2]. In the absence of noise, these methods produce exact, but high depth and gate count circuits. In comparison the evolutionary algorithm can produce circuits of any given accuracy (99% in the results shown), with much lower depth and gate count. This variability of the required accuracy allows producing overall higher accuracy, as error accumulation as a result of noise in high depth circuits can be avoided. The results achieved outperform current best exact general circuit synthesis methods on a variety of states such as Gaussian states, and W-States. To verify, we directly compare the method to the state initialisation technique implemented in IBM's SDK Qiskit [3] based on [2], simulated with noise, and show the method reduces the number of gates required for the quantum circuits to generate these quantum states. The metrics with which the methods are compared included the number of total gates required, the number of controlled-not gates required, and the fidelity of generated state.

[1] P. Niemann, R. Datta, and R. Wille, Logic Synthesis for Quantum State Generation, in 2016 IEEE 46th International Symposium on Multiple-Valued Logic (ISMVL) (2016) pp. 247–252, iSSN: 2378-2226.

[2] V. V. Shende, S. S. Bullock, and I. L. Markov, Synthesis of Quantum Logic Circuits, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems 25, 1000 (2006), arXiv: quant-ph/0406176.

[3] ANIS, M. S. et al. Qiskit: An Open-source Framework for Quantum Computing. at https://doi.org/10.5281/zenodo.2573505 (2021).