A Faster Algorithm for Solving Constant and Variable Delay Differential Equations via Quantum Block Encoding

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Delay Differential Equations (DDEs) are a more realistic and powerful version of regular Differential Equations, and are extremely common in anatomy, chemistry, ecology, and climate research. However, due to their complexity, classical solving algorithms slow heavily for detailed simulations with large dimensions and step counts. This research is the first to introduce quantum computing to delay equations, and constructs a method for solving linear DDEs significantly faster than any technique previously available. (O(log^2(N)+g^2) versus O(N*g^2) for g-dimensional DDEs and N steps) First, an efficient method of discretizing a DDE into a matrix equation through the Backward Euler method was created, allowing quantum circuits to solve for all time values at once. Another key advancement was the construction of the first quantum encoding circuits and equations for Block-Toeplitz matrices, allowing the DDE to be embedded within a quantum circuit. Such equations were also developed for advanced DDEs where the delay is not constant, but a smooth function, by utilizing polynomial approximations of the delay function and Horner's Rule. The pre-processing steps were verified on blood flow and drug reabsorption DDEs from literature, and the block-encoding equations were also verified. 18,432 shots of the proposed circuits were physically run on both a current quantum computer (IBM Fez) and a noise simulator. The circuits differed only (5.94 +/- 0.67)% and (2.63 +/- 0.41)% from the theoretical maximum success rates on the quantum computer and the simulator, respectively, confirming the high viability of this algorithm for accelerating complex scientific computation in the near-term.

Awards Won:

Third Award of $1,200

Association for Computing Machinery: First Award of $4,000