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DOE Final Technical Report
John Preskill
California Institute of Technology

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Executive Summary

Quantum computing is unique among Beyond Moore's Law computing contenders in that it leverages quantum mechanics to offer potentially exponential resource advantages over technologies relying only on classical physics. A few beacons, such as Shor's famous quantum algorithm for integer factorization, suggest applications where quantum computing may offer a tremendous advantage. However, the scope of such applications is currently limited, and in many cases achieving a quantum advantage requires restrictive assumptions. We will build on our previous and ongoing work as part of the ASCR QAT/QCAT programs to: (i) develop novel quantum, classical, and hybrid quantum-classical algorithms to advance basic capabilities in quantum simulation, optimization, and machine learning, and (ii) provide rigorous resource scaling estimates for fundamental quantum algorithmic primitives.

Anticipation of the noisy intermediate-scale quantum (NISQ) era has sparked unprecedented interest in quantum computing. Executing quantum algorithms on NISQ hardware is essential to fulfilling the promise of quantum computing. Yet, there is no guarantee that encouraging results gleaned from empirical assessments of NISQ devices imply sustained performance advantages over classical computing as quantum processing matures and scales. Rigorous asymptotic analysis of quantum algorithms presents a means of mitigating this risk. Our proposed effort will deliver quantum algorithms that offer provable asymptotic advantages over the best-known or best-possible classical counterparts. Our high-level algorithms will serve as a template for implementations on emerging and future quantum architectures. We will also produce hybrid quantum-classical algorithms that may deliver speedups by combining NISQ hardware with ubiquitous and robust classical computing resources, as well as quantum-inspired classical algorithms, which will help us better understand the types of advantages that quantum algorithms can ultimately realize. Additionally, we will engage in complementary coordination with other

ARQC teams that are focused on more practical aspects of quantum algorithm implementation, to adapt and optimize our high-level algorithms for NISQ devices.

Our ARQC team assembles physicists, applied mathematicians, quantum information scientists, and computer scientists to design and analyze the performance and scaling of fundamental quantum and classical algorithms, with the goal of advancing DOE capabilities in simulation, optimization, and machine learning. We are accustomed to working in multidisciplinary teams of theoreticians and practitioners on both far-reaching basic science problems as well as mission-critical applications with immediate impact. The majority of our team is drawn from the current ASCR QAT/QCAT projects, and we are exceptionally well-positioned to leverage the outputs of these existing efforts to advance our research goals. By bringing together a wide-ranging interdisciplinary expertise that spans academia, industry, and the national labs, we will ultimately work to better understand and realize the broad impact promised by quantum computation.

Major goals and objectives of this project

Anticipation of the noisy intermediate-scale quantum (NISQ) era has sparked unprecedented interest in quantum computing, yet we still lack a clear understanding of how NISQ-era applications will perform relative to the best classical algorithms solving the same problems. The goals of this project include: (1) Developing better tools for characterizing the performance of NISQ devices and for assessing whether such devices can achieve a quantum advantage. (2) Conceiving and analyzing potential applications of quantum computing technology in the NISQ era and beyond.

What was accomplished under these goals?

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