Quantum Computing: Challenges and Opportunities

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ABSTRACT

CASCON x EVOKE 2019 features a two-day quantum computing track. The first day identifies challenges and opportunities in the realm of quantum computing including how to teach quantum computing in academia and industry, how to realize quantum computing applications, and how to compute with nature. Governments, investors, entrepreneurs, researchers and practitioners have realized the enormous opportunities presented by quantum technologies. But how do you get started and engaged in quantum computing? A fishbowl panel provides opportunities to share perspectives on how to enter this exciting realm. The second day is aimed at professionals across industry, academia, and government who need new skills to capitalize on quantum computing. Participants learn about IBM Q Experience on the cloud and how to program IBM's quantum computers using Qiskit—an open-source quantum computing software development framework.

CCS CONCEPTS

• **Computer systems organization → Architectures**; • **Applied computing → Emerging technologies**; **Physical sciences and engineering**; • **Software and its engineering → Software notations and tools**; • **Social and professional topics → Computing education**; **Computing industry**; **Computing profession**; **Computing and business**.

KEYWORDS

Quantum computing, computing with nature, engagement, education, training, algorithms, programming, Qiskit, IBM Q, hybrid computing, applications, chemistry, finance, cryptography, machine learning, quantum start-ups

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1 INTRODUCTION

Quantum Computing promises breakthroughs in a wide variety of problem areas [6] [17] [21]. Quantum technologies harness and exploit the laws of quantum mechanics to process information. Understanding quantum computing problem solving is one of the key challenges for researchers in this exciting realm. While solving certain problems using quantum algorithms can lead to exponential speed-ups compared to traditional algorithms, quantum algorithms cannot be programmed in the same way as classical algorithms. On a classical computer, for certain problems the solution is found by checking possibilities one at a time, which can take a long time. On a quantum computer, myriad possibilities emerge as probabilistic answers simultaneously. There is extensive literature on quantum algorithms developed over the past 20 years [1] [16].

Just like classical computing, quantum computing applies to applications in many disciplines and will have broad impact [7] [4] [20]. There are two main strands of applications where quantum computers can eventually outperform classical computers significantly [14]. On the one hand, quantum computers may exponentially speed up solutions to problems or algorithms that require massive parallel computations ,such as in optimization and simulation, cryptography and secure communications, pattern matching and big data analytics, and artificial intelligence and machine learning. On the other hand, quantum computers are expected to allow us to simulate nature more effectively and precisely than with simulators running on classical platforms, which inherently involve approximate methods in the solution of quantum problems (e.g., chemistry, materials, or subatomic particles) [8].

2 INFLECTION POINT REACHED

In 1982, Feynman, one of the first scientists to conceive the possibility of quantum computers, famously stated "Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy" [3]. Now quantum computing has reached an inflection point [14] where researchers and professionals have access to 50+ qubit universal quantum computers [9] through Quantum-as-a-Service (QaaS). Thus, we have arrived in the Noisy Intermediate-Scale Quantum (NISQ) technology era—a term coined by Preskill [18]. He argues convincingly that NISQ computers with 50–100 qubits may be able to perform tasks which surpass the capabilities of today's classical digital computers.

There are many applications for the NISQ class of quantum computers and, thus, are ideal for gaining experience with quantum algorithms and training the future workforce. One of the major findings of the 2018 Consensus Study by the US Academies of Sciences, Engineering and Medicine states: "Research and development into practical commercial applications of NISQ computers is an issue of immediate urgency. The results of this work will have profound impact on the quantum field and its commercial market" [6].

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With the rapid development of impressive quantum hardware and QaaS, it is high time to focus our attention in part on engineering quantum software and systems to reap the benefits of quantum technologies. For practical application development and economic success, it is critical to train the future quantum workforce now in recognizing quantum problems, designing quantum algorithms, hybrid quantum design, understanding quantum software architectures, programming using quantum platforms, and studying the problems and applications that benefit from quantum hardware and software. The future of quantum computing is hybrid. Hybrid programming integrates classical and quantum computing for quantum systems in the near-term and very likely in the long-term [15]. Many algorithm design, data management and software engineering challenges have to be addressed for practical hybrid programming including tool integration and debugging.

3 CHALLENGES AND OPPORTUNITIES

The first day of this CASCON x EVOKE 2019 quantum computing track discusses challenges in workforce training and opportunities for start-up companies in quantum computing applications featuring speakers from IBM, start-up companies, and academic research programs [5] [2]. One goal is sketching how to launch quantum computing training programs in computer science, software engineering, engineering, physics, chemistry and materials departments. Another goal is to highlight opportunities for start-up companies in different application areas [7], including molecular chemistry, portfolio management in finance and insurance [22], cybersecurity [19], manufacturing [13], precision health, smart cities, and intelligent cyber-physical systems.

4 SKILLS TO CAPITALIZE ON QUANTUM COMPUTING

The second day is aimed at professionals across industry and academia who are excited about acquiring new skills to capitalize on quantum computing. Participants have the opportunity to gain hands-on experiences with a quantum computing framework and selected quantum computing applications. Speakers from IBM and start-up companies review basics of quantum computing, introduce the IBM Q Experience and IBM Qiskit (Quantum Information Science Kit) [10], including Terra [12] and Aqua [11], and how to execute simple quantum circuits on either a local quantum simulator or on a real quantum computer. This day features talks and demos on chemistry and finance applications developed by IBM and start-up companies.

5 CONCLUSIONS

This two-day CASCON x EVOKE 2019 quantum computing track is a great opportunity to engage in emerging quantum ecosystems [21]. This track provides ample opportunities to network and explore partnerships, to discuss challenges and opportunities with quantum researchers, scientists, engineers, entrepreneurs, developers, students, practitioners, educators, programmers, enthusiasts, and newcomers.

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