An IEEE Framework for Metrics and Benchmarks of Quantum Computing

Purpose

The purpose of this document is to outline a framework by which the continuing progress in quantum engineering can be monitored by the broader quantum computing community. Recent experimental demonstrations of quantum computing have passed significant milestones in the design, fabrication, and operation of small-scale quantum computing devices. These advances underscore the need to track technical progress in this field and to forecast future developments in quantum engineering research. Such insights are necessary to guide the decisions of policy makers and technology stakeholders as well to monitor the overall growth of the quantum research community.

Quantum computing is currently in an exploratory stage of engineering, and there is widespread consensus that the development of many different technologies remains necessary to meet the long-term expectation of fault-tolerant, universal quantum computers. This framework has been designed to capture the broadest definitions of quantum computing and to permit extension and refinement as new advances appear. The goal of this framework is to foster a community in quantum technology, enable communication of progress in its development, and support the migration of early devices and systems to future products. Realizing these goals will require an open partnership model, in which the developers of quantum computing technologies collaborate with the broadbase of scientist and engineers exploring potential applications in the academic, government, and commercial sectors.

History of Development

In August 2018, the IEEE held a meeting with stakeholders from across industry, academia, and government to examine the role and purpose of engineering for quantum computing. A prominent outcome from the August meeting was the recognition that the IEEE can support defining, developing, and curating metrics and benchmarks for quantum computers. Attendees proposed the following framework, which continues to be refined based on feedback from the growing quantum benchmarks community. An online planning meeting was held October 2, 2018. Attendees refined the scope and developed a schedule for publishing a draft framework. A pending release of the framework with an accompanying “Request for Comments” was scheduled for November 2018 at the International Conference on Rebooting Computing.

Framework Description

The framework proposes to identify and track metrics for quantum engineering by use cases and technology layers. This reflects the awareness of the community that the diversity of existing quantum computing devices and systems requires a similar variety of methods for tracking engineering progress. Clarifying descriptions of use cases and technology layers are included below.

Proposed Terminology

A ***metric*** is a measurable quantity that characterizes a feature or behavior in a quantum computing device or systems.

A ***benchmark*** is a method by which a quantum computing metric can be evaluated.

A ***use case*** is a category that identifies a designed purpose for a quantum computing device or system.

A ***technology layer*** is a category that identifies a level of design complexity for a quantum computing device or system.

Use Cases

A prominent feature that differentiates existing quantum computing technologies is the proposed usage for which the system or device is designed. Presently, there are a variety of potentially impactful designs for quantum computers, and the methods by which to evaluate technological progress varies with each usage. This framework recognizes these distinct designs as *use~~s~~ cases* by which to categorize the relevant metrics. An important consequence is that metrics may not be readily compared across use cases, as they can be specific to the expected design. The resulting degree of variation is itself a measure of the breadth and diversity of quantum computing.

Table 1. Quantum computational models with brief descriptions

Circuit Quantum Computing	A model of quantum computing ~~in~~ which uses a sequence of logic gates to process quantum information
Adiabatic Quantum Computing	A model of quantum computing which uses ~~the adiabatic theorem~~ to process quantum information
Analog Quantum Simulation	A model of quantum computing specialized to ~~provide insight into~~ specific physics problems

Use cases may be discriminated in part by computational model and purpose. The computational model represents the principles of operation by which a quantum computer is designed. Table 1 lists several common examples of quantum computational models.

Similarly, the expected functionality of the quantum device or system may be used to describe how progress should be quantified. Table 2 categorizes several known examples of devices based on functionality. While fault-tolerant quantum devices remain a long-term engineering goal, intermediate descriptions provide insight perspectives on the overall engineering progress.

Table 2. Families of devices discriminated by intended use case

Noisy Intermediate Scale Quantum (NISQ) Devices	A family of quantum devices with 50-100 qubits and noisy gates
Quantum Annealers	A family of quantum devices for finding the global minimum of a given objective function over a given set of candidate solutions by a process using quantum fluctuations
Quantum Simulators	A family of devices that uses continuous-time or discrete-time evolution to simulate the properties of quantum mechanical models
Fault-tolerant Quantum Error Corrected (FTQEC) Devices	A family of quantum devices capable of recovering from faults during operation

Technology Layers

Efforts to demonstrate quantum computing depend on sophisticated engineering that spans from the lowest technology level through the control systems, device integration, and system architecture and deployment. The hierarchy of these technology layers include features that are uniquely quantum mechanical as well as hybrid implementations that combine both quantum and conventional computing devices.

The technology layers for a quantum computer used in the framework are derived from models of computational engineering for existing conventional computers. They have been refined to capture the concerns of quantum computation and allow for potential development pathways.

Table 3. Examples of technology layers that categorize engineering concerns

Physical Register	Stores qubits
Physical Device	Performs quantum operations on physical register
Physical Circuit	Controls networks of physical devices
Logical Register	Stores logical qubits
Logical Device	Performs logical quantum operations on logical register
Integrated Device	Controls networks of logical or physical devices
System Architecture	Orchestrates interactions between logical and physical devices
Computer System	Executes applications with integrated device
Application	Solves problem using system
Manufacturing	Produces system
Packaging	Encloses system

Request for Comments

Recent experimental demonstrations of quantum computing have passed significant milestones in the design, fabrication, and operation of small-scale quantum computing devices. These advances underscore the need to track technical progress in this field and to forecast future developments in quantum engineering research. Such insights are necessary to guide the decisions of policy makers and technology stakeholders as well to monitor the overall growth of the quantum research community.

The IEEE Rebooting Computing Initiative is requesting comments on the document "An IEEE Framework for Metrics and Benchmarks of Quantum Computing," Version 0.2. The purpose of the document is to outline a framework by which the continuing progress in quantum engineering can be monitored by the broader quantum computing community. Comments on the proposed scope, structure, and implementation of the framework from all parts of the quantum computing community are welcome.

The published document is available at: https://rebootingcomputing.ieee.org/quantum

Brief written comments may be submitted online in PDF format using the EasyChair submission system until 31 January 2019. Submissions to the RFC may be made at: https://easychair.org/conferences/?conf=ieeemabqcv2