Contribution ID : **3** Type : **Abstract**

The design and implementation of a benchmark based on an iterated post-selective protocol

Content

The advent of cloud-based quantum computing opened the possibility for easy access to the new quantum revolution. The road-maps of companies like IBM, Microsoft or IonQ promise to achieve a competitive quantum computer in the following years. Yet, one of the physical restrictions that hinders such scalability has to do with the high degrees of decoherence that current quantum computers suffer. We are in the aptly named Noise Intermediate-Scale Quantum era (NISQ) where quantum computation is possible, modulo the inherent noise always present in these devices. The presence of such problems are interesting to address because one will understand the technology better in order to scale it and improve it. Albeit different physical qubits can present particular errors, it is useful to address the capabilities of current NISQ devices with the use of metrics and benchmarks that give a meaningful description of the performance of a current device. These types of early benchmarks can help to decide matters like which technology is most promising or which one is suitable for a specific task or application.

In this paper, we address the design and implementation of a benchmark based on a meaningful quantum information task, dubbed the quantum state matching protocol [Phys. Rev. A 97, 032125 (2018)]. Among the different physical implementations of qubits, we have chosen to work with superconducting ones provided by IBM. Superconducting qubits are one of the most promising and with a considerable technological development [see for instance Rev. Mod. Phys. 73, 357 (2001), Nat.453, 1031 (2008), Rep. Prog. Phys. 80, 106001 (2017), Appl. Phys. Rev. 6, 021318 (2019), Proc. of the IEEE 108, 1338 (2020), Rev. Mod. Phys. 93, 025005 (2021) and references therein]. It must be noted that our approach is indeed agnostic and not dependent on this particular implementation. The benchmark that we shall present can be as well applied to any commercially available quantum computer.

The aim of the paper is to show explicitly how to construct such benchmark from the ground up, as well as point out possible pitfalls in the implementation and to present it in a pedagogical vein. We divide our paper in three parts; in what follows we describe the contents in a more detailed way. We start by describing in detail how to program efficiently in a quantum circuit an entangling two-qubit gate. The decomposition was first given by Khaneja and Glaser [arXivquant-ph/0010100 (2000), Phys. Rev. A 63, 032308 (2001)] and it decomposes a SU(4) entangling unitary into a canonical form. After this, we employ a further decomposition by Vidal and Dawson [Phys. Rev. A 69, 010301 (2004)] that transforms the canonical form into a decomposition of one-qubit and CNOT gates, i.e. in a set of programmable quantum gates. Furthermore, such decomposition is optimal because it minimizes up to three CNOT gates, thus reducing the circuit error due to unnecessary crosstalks. The implementation of the quantum state matching protocol requires only a subcase of the general case presented by Khaneja and Glaser and Vidal and Dawson. Yet, we present the decomposition in general and discuss in some detail the caveats of actually implementing such decomposition in a Python code (not just the mathematical decomposition, which is presented in some detail by Tucci [arXiv:quant-ph/0507171 (2005)]). After discussing the decomposition we present the state matching protocol, the associated entangling unitary, and its optimal implementation in a quantum circuit. We also present the first test we developed in two real quantum computers that was published in [Phys. Scr. 98, 024006]. In these results, we stress the importance of how the way to test a quantum computer influences the results of a potential metric. Because of our particular protocol, different tests can be taken using two different ways to choose the initial preparation of qubits. Hence it is easy to track where the differences come from in comparison e.g. with the old IBM metric of the Quantum Volume (QV). In the final part of our paper we describe how to build two statistical metrics that, coupled with the methodology of the state matching protocol, give a benchmark that can help us test different quantum computers. The results are presented in [arXiv:2410.07056 (2024)] and are being held in the referee process at the time of writing and will be published elsewhere. We apply this benchmark to 6 different quantum computers and discuss the differences among the devices, specially in those where the QV is the same. As a salient feature, our experimental results show a trend that can be described with a very good approximation by using a reduced channel-error model. This error model can be later fed with the error data of the real quantum devices as fitting parameters, thus completing the description of the trend in the experimental data.

Although our results are already (or in the process of being) published, we believe it would be valuable to the community to present them in an integrated manner. In this way, the community can benefit from the present research and avoid important pitfalls or dead-ends in the design of quantum benchmarks.

Summary

We present a review on the design an implementation of a benchmark based on the quantum state matching protocol for quantum computers. The work is divided in three parts. In the first one, we present a decomposition of an entangling SU(4) gate given by Khaneja and Glaser coupled with a further gate-based reduction due to Vidal and Dawson. The decomposition is optimal, in the sense that it minimizes to up to three CNOT gates and one-qubit gates. We pay special attention to the numerical implementation of the decomposition, and mention a couple of details that, up to our knowledge, they are first presented here in an integrated manner. In the second part, we describe the protocol of the state matching protocol and give its optimal decomposition as specified on part one. We test the protocol in two IBM quantum computers (qcs) with different quantum volumes and analize the effect of the initial state on the performance of the qcs. When the initial conditions are chosen at random, the qcs behave more or less similar and when it is non-random one can clearly see different performance. In the third part we present an statistical benchmark and analize 6 different quantum computers and also with different quantum volumes. We also show how to describe the average behaviour of the experimental results by using a reduced error model. As already mentioned, we focus on the experiments obtained from superconducting qubits from IBM, but our results can be easily generalized to other gate-based quantum computers. Our aim is to present the benchmark in an integrated and pedagogical manner, so that the community can benefit from it and avoid potential pitfalls and dead-ends in the design of such benchmarks.

Primary author(s) : Ms. ALONSO, Yahaira E. (Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara); Dr. ORTEGA, Adrian (Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara)

Co-author(s) : Dr. KÁLMÁN, Orsolya (HUN-REN Wigner Research Centre for Physics); Dr. KISS, Tamás (HUN-REN Wigner Research Centre for Physics)

Presenter(s) : Dr. ORTEGA, Adrian (Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara)