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Maximizing the Beneficial Effects of Testbeds: Case Studies from the Quantum Scientific Computing Open User Testbed (QSCOUT)

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1 Introduction

The benefits of the DOE quantum computing testbeds extend beyond the results of scientific computations. In this white paper, as operators of the DOE Quantum Scientific Computing Open User Testbed (QSCOUT) at Sandia National Laboratories, we detail some of the benefits beyond scientific results that emerged while running the system and offer suggestions to help maximize and extend these benefits for future generations of testbeds.

2 Building tools for future systems

While building the QSCOUT system, we developed many designs that are applicable to both trapped ion systems and other types of quantum computing systems. In particular, our programming language, Jaqal [1, 2] (and JaqalPaq, a python extension of Jaqal), is versatile and simple enough to be used with any platform and is available on Gitlab [3]. Other supporting programs like Jaqal Pulses and Waveforms (JaqalPaw) are more tailored to trapped ions, but incorporate an extensible design philosophy such that the code can be ported to other platforms in which specific or highly-customized hardware systems must be targeted. Additionally, the scalable coherent control system developed for QSCOUT, known as "Octet", is currently being used in numerous labs outside of Sandia—this is in no small part due to its wide array of features for generating arbitrarily modulated and synchronous rf waveforms needed to realize state-of-the-art quantum gate designs—for multi-qubit quantum information systems.

We also developed various custom hardware to improve the stability of our optical systems, like a 5-axis flexure mount that can attach to a vacuum chamber for stable light delivery, and a similar mount that can be used for stable light collection. These designs have been shared with groups outside Sandia for building similar structures. A central location where designs like these can be hosted, either for similar platforms or for entirely different systems, may increase their visibility to the greater scientific community. Additionally, as we continue to make enhancements to the QSCOUT system, we are documenting and publishing our design choices [4]. This allows them to serve as a blueprint for others that are interested in building a similar testbed or as a means to better understand the capabilities and limitations of ours.

Finally, while users are free to propose ideas about almost any scientific topic, several users focused on projects that have the specific intent of improving the machine itself. These involve using our low-level pulse access to simulate architectural and design changes that may improve performance of a larger system. Since these projects are designed around improving the machine's performance by artificially creating or amplifying specific conditions through gate-level control, as opposed to hardware-level modifications of the system, the tools and techniques learned from these controlled conditions can be broadly applied to other QIS systems.

3 Develop long-lasting collaborations

During the course of working with our users, we discovered many additional research directions to explore beyond the scope of the original proposals. While there wasn't time to investigate all of these questions, they gave the users ideas to submit for future proposals and led to developing collaborations between institutions beyond the QSCOUT project. Our collaborators have been an invaluable resource of fresh ideas and perspectives.

For experiments involving round one and the upcoming round two users, we have even had situations in which it was beneficial to bring in the help from our in-house theorists to further assist in the development and progression of user experiments. This has given our users opportunities to collaborate and connect with them as well to expand the impact of their project.

Even within the National Laboratories, the testbed program led to new collaborations. Engineering an entire quantum system required a variety of expertise, including, but not limited to physicists, fabrication specialists, rf electronics engineers, electrical engineers, materials scientists, mechanical engineers, optical engineers, and software developers. At a National Laboratory, these individuals may be spread across numerous departments, centers, and divisions, but can fairly easily be brought together to leverage their expertise. These relationships can lead to long-lasting collaborations beyond the scope of the current quantum testbeds.

4 Expanding the workforce

QSCOUT has already served as an educational tool on several fronts. First, QSCOUT operators consist of staff members, post-doctoral researchers, graduate students, and undergraduate student interns. Operators of the system learn the details of quantum system design and general skills related to ion-trap quantum computing. Student interns with varied backgrounds particularly benefit from this experience by learning about supporting technologies for quantum system integration and broaden their professional network. Second, several user proposals were written by post-docs and graduate students, giving them experience organizing their ideas, writing proposals, and leading teams.

To further the potential of QSCOUT as a teaching device, access to students and postdocs could be expanded, perhaps through a testbed- or QSCOUT-specific internship program that provides an easier and more direct way for undergraduate and graduate students to get involved, or granting on-site access to members of the user teams. Programs like these would allow more early career researchers to gain a holistic quantum systems skill set, which is critical for the next generation of quantum scientists and engineers.

We have also held two seminars about the Jaqal programming language, which have proven to be very useful to our new users. While previous seminars were targeted at quantum experts, the Jaqal language is simple enough that such a seminar could be tailored to people less familiar with quantum science. Similarly, a workshop discussing the use and development of the quantum testbeds might be of interest to the broader community.

5 Simplify User Agreements

One significant unanticipated challenge we encountered involved the generic DOE user facility agreements. Many of the users' legal teams took issue with and were distracted by certain aspects of the agreement which were not applicable to our purposes, and these negotiations distracted from scientific progress. For future rounds of current testbeds and future testbed developments, a quantum-computing-testbed-specific agreement may be a worthwhile addition.

6 Conclusion

Our experience developing and running QSCOUT has been very enlightening. The project has spurred on technological advances, expanded our workforce, and resulted in numerous collaborations both internal and external to Sandia. From this collective and newfound knowledge, we firmly believe that our insights for fostering more accessible, tight-knit collaborations will lead to a greater synergy between users, students and postdocs, and laboratory staff. In turn, we expect these will result in measurable improvements to current and future testbed projects, and unify research efforts more broadly for the QIS, and potentially non-QIS, community as a whole.

References

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[3] `https://gitlab.com/jaqal/jaqalpaq`.

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