Quality concerns when integrating quantum and classical computing: a systematic mapping study

Cristian Marquez[1], Johana Ojeda[1] and Kelly Garcés [1]

[1]Department of Systems and Computing Engineering – Universidad de los Andes
Bogotá – Colombia
(e-mail: c.marquezb, j.ojedaa, kj.garces971@uniandes.edu.co)

Abstract. *This article presents a systematic mapping review to categorize software quality research for hybrid computing systems; meaning the combination of classical software and quantum technologies to solve a problem. This work attempts to categorize primary studies with respect to quality attributes and metrics in hybrid systems reported in state of the art literature. Moreover, it identifies potential research areas and surveys the challenges of the practical integration of quantum software into classical infrastructures.*

1. Introduction

Hybrid computing systems present several challenges, including heterogeneity of quantum hardware due to multiple quantum phenomena [Elsharkawy et al. 2023, Sodhi and Kapur 2021], multiple ways to represent data in Qubits [Moguel et al. 2022], lack of software standardization [Elsharkawy et al. 2023, Cerezo et al. 2022, Sodhi and Kapur 2021], limited monitoring tools [Moguel et al. 2022, Alvarado-Valiente et al. 2023], error-prone algorithm development [Sodhi and Kapur 2021], shortage of quantum experts [Sodhi and Kapur 2021], and limited visibility between quantum and classical computing boundaries [Vietz et al. 2021]. While current literature focuses on specific topics such as quantum verification [Gheorghiu et al. 2019], compilation [Heyfron and Campbell 2018], simulation [Dong et al. 2022], and development [Cruz-Lemus et al. 2021], these studies typically adopt a theoretical perspective without addressing practical strategies for software quality attributes. These challenges and advancements motivate our systematic mapping study to examine progress in software quality for hybrid quantum-classical systems.

2. Systematic mapping review process

We conducted a systematic mapping review using *Web of Science* and *Scopus* databases. The search focused on studies addressing quality attributes and metrics in hybrid quantum-classical systems. A total of 559 papers were identified; out of which, 484 articles matched the search criteria from *Web of Science*, while *Scopus* yielded 75 results. Following a two-phase screening process, we selected 16 articles for detailed analysis. Our analysis revealed that while 87% of studies focus on quality metrics and attributes, only 43% address integration challenges, highlighting a significant research gap in hybrid systems.

The study primarily addresses two main research questions: (1) *What are the challenges of integrating quantum computing systems with an existing classical computing infrastructure?* and (2) *What attributes and/or metrics of classical software qual-*

ity are relevant to the quantum realm, and which are unique in the context of quantum computing?. Additional analyses are available in our supplementary material at `https://zenodo.org/records/7942307`.

3. Mapping Results

3.1. Integration Challenges

Hybrid quantum/classical systems present challenges in four main areas. First, scalability and performance issues arise from supporting diverse quantum technologies [Elsharkawy et al. 2023], managing high latency, and addressing lack of standardization [Cerezo et al. 2022]. Second, data and encoding challenges include difficulty in defining boundaries between quantum and classical systems [Vietz et al. 2021], and scarcity of standardized datasets [Cerezo et al. 2022]. Third, algorithmic development faces the need for unique algorithms per problem, limited component reuse [Moguel et al. 2022], and lack of standardization [Alvarado-Valiente et al. 2023]. Finally, developer expertise requirements encompass both quantum and traditional computing knowledge, including software integration and cloud computing [Vietz et al. 2021, Sodhi and Kapur 2021].

3.2. Quality Attributes and Metrics

Our review identified that hybrid systems currently use classical software quality attributes [Silva et al. 2023] found in the literature. The only software-related metrics reported include quantum volume (now known as layer fidelity), and total quantum factor [Verduro et al. 2021]. While other metrics such as T1 (Energy relaxation) and T2 (Dephasing) are relevant for quantum systems [Youssef 2020].

4. Conclusions

The systematic mapping review reveals that quantum computing technologies remain in their early developmental stages, evidenced by the limited literature addressing quality assurance in quantum computing. Current studies focus on establishing theoretical quality attributes derived from classical software standards, with minimal exploration of quantum or hybrid specific metrics. Moreover, documented quality attributes require validation in operational environments to assess their practical utility.

The analysis of hybrid systems shows that cloud services represent the most viable solution for accessing quantum hardware, given the challenges of maintaining stable qubits and meeting specialized requirements. However, this approach inherits traditional cloud computing challenges while confronting quantum-specific issues such as system availability and exponential error propagation.

Finally, we found that the field requires quantum-specific standards and empirical validation of quality metrics. The development of observability tools and testing frameworks for hybrid quantum-classical systems represents a clear research opportunity. Future work should focus on establishing robust quality assurance practices that can be validated in operational environments.

5. References

Due to space limitations, all references cited in this paper can be consulted in our supplementary material available at `https://zenodo.org/records/7942307`.

References

Alvarado-Valiente, J., Romero-Álvarez, J., Díaz, A., Rodríguez, M., García-Rodríguez, I., Moguel, E., Garcia-Alonso, J., and Murillo, J. M. (2023). Quantum services generation and deployment process: A quality-oriented approach. *Communications in Computer and Information Science*, 1871 CCIS:200–214.

Cerezo, M., Verdon, G., Huang, H. Y., Cincio, L., and Coles, P. J. (2022). Challenges and opportunities in quantum machine learning. *Nature Computational Science 2022 2:9*, 2:567–576.

Cruz-Lemus, J. A., Marcelo, L. A., and Piattini, M. (2021). Towards a set of metrics for quantum circuits understandability. *Communications in Computer and Information Science*, 1439 CCIS:239–249.

Dong, Y., Whaley, K. B., and Lin, L. (2022). A quantum hamiltonian simulation benchmark. *npj Quantum Information*, 8(1):1–8.

Elsharkawy, A., To, X.-T. M., Seitz, P., Chen, Y., Stade, Y., Geiger, M., Huang, Q., Guo, X., Ansari, M. A., Ruefenacht, M., Schulz, L., Karlsson, S., Mendl, C. B., Kranzlmüller, D., and Schulz, M. (2023). Challenges in hpcqc integration. In *2023 IEEE International Conference on Quantum Computing and Engineering (QCE)*, volume 02, page 405–406.

Gheorghiu, A., Kapourniotis, T., and Kashefi, E. (2019). Verification of quantum computation: An overview of existing approaches. *Theory of Computing Systems*, 63(4):715–808.

Heyfron, L. E. and Campbell, E. T. (2018). An efficient quantum compiler that reduces t count. *Quantum Science and Technology*, 4(1):015004.

Moguel, E., Rojo, J., Valencia, D., Berrocal, J., Garcia-Alonso, J., and Murillo, J. M. (2022). Quantum service-oriented computing: current landscape and challenges. *Software Quality Journal*, 30:983–1002.

Silva, S., Tuyishime, A., Santilli, T., Pelliccione, P., and Iovino, L. (2023). Quality metrics in software architecture. In *2023 IEEE 20th International Conference on Software Architecture (ICSA)*, page 58–69. Institute of Electrical and Electronics Engineers Inc.

Sodhi, B. and Kapur, R. (2021). Quantum computing platforms: Assessing the impact on quality attributes and sdlc activities. *Proceedings - IEEE 18th International Conference on Software Architecture, ICSA 2021*, pages 80–91.

Verduro, J., Rodríguez, M., and Piattini, M. (2021). Software quality issues in quantum information systems. *Q-SET@QCE*.

Vietz, D., Barzen, J., Leymann, F., Weder, B., and Yussupov, V. (2021). An exploratory study on the challenges of engineering quantum applications in the cloud. *Q-SET@QCE*.

Youssef, R. (2020). Measuring and Simulating T1 and T2 for Qubits. In *Measuring and Simulating T1 and T2 for Qubits*. US DOE.