Quantum Services Engineering: development, quality, testing, and security (Q-SERV Project)

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Abstract. *The new and revolutionary quantum computation aims to advance in important fields such as AI, cybersecurity, and medicine. The development of this technology has encouraged several research centers and companies such as Amazon, IBM, Google or Microsoft to devote considerable efforts to the development of new technologies that bring quantum computing to the market. Currently, access to this technology is provided through the Infrastructure as a Service paradigm and with hybrid systems that combine classical and quantum computing. In order to create these systems, significant advances in service-oriented quantum computing are required to enable developers to create and operate quantum services with the same level of quality and security as their classical counterparts. Therefore, the project presented in this paper is primarily aimed at providing techniques and methodologies for quantum software development by applying the lessons learned from classical software engineering.*

1. Introduction

Quantum computing is rapidly gaining interest in many research areas, from mathematics or physics focused on building more powerful quantum computers or more stable qbits, to economics or healthcare focused on creating new quantum algorithms for specific problems. However, not much research effort is yet devoted to the development of technologies to build future quantum software [Mario Piattini et al. 2020].

Today's information systems are, in general, complex structures composed of simpler parts globally distributed and connected by complex communication infrastructures and protocols. The simpler parts are usually encapsulated as services with clear responsibilities. All this is made possible by different technologies such as service-oriented computing, cloud computing, etc. Building software systems in this way provides advantages such as paying only for the infrastructure used or obtaining high-quality attributes such as increased interoperability, independence, high decoupling, reusability, maintainability, reliability, scalability, security, etc.

The main objective of the project presented in this article (Q-SERV project) is to provide techniques and methodologies for quantum software development by applying the lessons learned from classical software engineering.

2. Q-SERV Project

The Q-SERV project is a coordinated project of the Call 2021 "Knowledge Generation Projects", and its aim is to solve the aforementioned problems by addressing three of the main limitations of current quantum services. Firstly, the subproject led by the University of Extremadura (UEx) focuses on the **development and operation of quantum services**; secondly, the subproject led by the University of Castilla-La Mancha (UCLM) focuses on the **quality and testing of quantum services**; and thirdly, the subproject led by the University of Deusto (UD) focuses on the **security aspects of quantum services**.

2.1. Development and Operation of Quantum Services

In its current form, most of the existing quantum computers can be accessed through the cloud in a model called Quantum Computing as a Service (QCaaS). QCaaS allows developers to access some of the existing quantum computers in the world, however, this access is highly dependent on specific hardware and developers must be highly proficient in quantum computing to benefit from its advantages.

To increase the level of abstraction of QCaaS, there are multiple research efforts underway. However, very few works focus on service engineering for quantum software.

The team at the UEx focuses on the development and exploitation of quantum microservices. More specifically, it focuses on aspects related to the servitization of quantum algorithms and their life cycle (deployment, execution, orchestration, etc).

2.2. Quantum Software Quality and Testing

There are several factors that influence the quality of quantum information systems: the quantum hardware, the quantum software platform, and the quantum software. There are different types of simulators and quantum computers. However, to date, most of them are still buggy, hence the name "*NISQ-Noisy Intermediate-Scale Quantum*". In addition, the underlying technology has a decisive influence on the maturity level of quantum computers. These different technologies exhibit different coherence times, gate latencies, etc.

Additionally, and despite the vast knowledge of software testing, "classical software testing techniques" are not directly applicable to quantum software test cases. Moreover, qubits cannot be "observed" or "measured" during the execution of a program. For these reasons, among others, approaches to software testing as conceived from the classical software point of view are very limited, but some proposals are already appearing on the research horizon [García de la Barrera et al. 2023].

The UCLM team is focused on the development of techniques [Díaz et al. 2024] and tools that guarantee the development of quality quantum software. Quantum Software Engineering needs to establish itself as a body of knowledge, therefore, research in those areas of Quantum Software Engineering that allow activities such as measurement and testing of such software, with the aim of evaluating and improving its quality, is considered crucial.

2.3. Quantum Services Security

Quantum code security must be addressed by design. This is important learning that the fields of Computer Science and Software Engineering have gained and matured after more than two decades of incidents, challenges, and advances in security [Arias et al. 2022].

The current limitations of quantum hardware lead to qubits being more unstable and error-prone than classical bits. These errors are extremely attractive to attackers. Therefore, a security analysis must be performed to ensure the intended operation of the program.

Based on its solid, broad, and deep experience in terms of cybersecurity-oriented software analysis, the UD team focuses on the design and development of new methods and tools to secure current quantum computing paradigms.

3. Results obtained

This project is at the halfway point of its execution and has made significant progress. Firstly, the subproject led by UEx has developed technologies to facilitate developers' access to different quantum service providers [Alvarado-Valiente et al. 2023d]. It has also worked on tools for the development and deployment of quantum services [Romero-Álvarez et al. 2023]; on the orchestration and management of quantum services using DevOps techniques [Alvarado-Valiente et al. 2023c]; on the generation of quantum services using OpenAPI and AsyncAPI; among others.

In addition, the subproject led by the UCLM has achieved the evaluation of the quality of quantum services, focusing for now on the analyzability of these services. During future work, research will be carried out to extend this evaluation to the rest of the characteristics that make up the quality of the software product following ISO 25010.

And finally, the subproject led by the UD has analyzed the security of current quantum software engineering [Arias et al. 2022]. It has also worked on avoiding the potential risks produced by noise on NISQ computers, creating error estimation techniques, and analyzing the effects of noise in data encoding circuits [Terres Escudero et al. 2023]. Additionally, the UD has developed a piece of software to detect bug patterns on quantum circuits in order to avoid known vulnerabilities.

There have also been collaborations between the different promoters as in the work [Alvarado-Valiente et al. 2023b] in which UEx and UCLM propose a process for the generation and deployment of quantum services focused on the quality of services; the work [Alvarado-Valiente et al. 2023a] in which UEx and UD propose a process for error and noise control for the generation of quantum services; the work [Arias et al. 2023] in which UD and UCLM analyze the concerns in the process of achieving secure quantum software engineering.

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