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Current perspective on quantum programming: a systematic mapping study

Perspectiva actual de la programación cuántica: un estudio de mapeo sistemático

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Abstract

The objective of this study is to provide foundations and theoretical concepts that allow creating and/or cultivating lines of scientific research in application and implementation of quantum programming. The research is carried out from a systematic mapping study. This considered articles published in the current year whose search was carried out in recognized scientific databases: Google Scholar, DOAJ and SCOPUS; Similarly, the Bibliographic Manager Mendeley is used. Additionally, the snowball search strategy is also used to carry out a more exhaustive and specific search, which does not leave contributions without considering the investigation. The result achieved is the successful implementation of the methodology in the field of computer science. Said systematic mapping study yields a high number of scientific articles in the first search or inquiry. However, when applying the inclusion and exclusion criteria, the results of the significant contributions on the subject are very scarce, which allows concluding that there is a great breadth in the scientific field of research for quantum programming and its application.

Systematic, Quantum programming, Current perspective

Resumen

El presente estudio tiene como objetivo aportar fundamentos y conceptos teóricos que permitan crear y/o cultivar líneas de investigación científica en el área de aplicación e implementación en programación cuántica. La investigación se realiza a partir de un estudio de mapeo sistemático. Éste consideró artículos publicados en el presente año cuya búsqueda se realizó en las bases de datos científicas reconocidas: Google Scholar, DOAJ y SCOPUS; De igual forma, se utiliza el gestor de referencias o bibliográfico Mendeley. En adición, también se utiliza la estrategia de búsqueda bola de nieve con la finalidad de realizar una búsqueda más exhaustiva y específica, que no deje aportes relevantes sin considerar en la investigación. El resultado conseguido es la implementación exitosa de la metodología "estudio de mapeo sistemático" en el campo de las ciencias de la computación. Dicho estudio de mapeo arroja una cantidad elevada de artículos científicos en la primera búsqueda o indagatoria. Sin embargo, al aplicar los criterios de inclusión y exclusión, los resultados de los aportes significantes en el tema son muy escasos, lo que permite concluir que existe una gran amplitud en el ámbito científico de investigación para la programación cuántica y su aplicación.

Sistemático, Programación cuántica, Perspectiva actual

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Introduction

The new technologies that are being developed from quantum computing are areas in full development. Its potential will be seen in the next few years, when it evolves from the digital age to the quantum age. To achieve this, the design and implementation of quantum algorithms are currently being studied. The goal is to perform operations in less time and requiring fewer computing resources, achieving unprecedented efficiency.

Quantum computing applications move around performing operations in a different way than the current one. Under this premise, research groups around the world work on research in different areas, including computer science. In this sense, there is an opportunity to exhibit recent scientific studies that contribute to formulating foundations and theoretical knowledge to create and/or cultivate lines of scientific research that support and allow addressing the implementation of quantum programming in different case studies, context and/or applied research projects. The systematized study of scientific sources on the subject provides a clear vision of the current situation of quantum programming around the scientific field.

This is divided into three main sections:

a) Methodology to be developed, in which the steps taken to develop the research are specified.

b) Development of the study includes the detailed description of the activities carried out in each step of the methodology followed. In addition, the findings found from each step.

c) And, finally, Discussion of the results, summarizes and specifies the information obtained from the investigation.

Methodology to develop

The methodology used is the Systematic Mapping Study (SMS), which allows answering research questions through a sequential, exhaustive, systematic and auditable search of scientific literature (Pazmiño Maji, Solis Benavides, García Peñalvo, & Conde González, 2019)

Systematic mapping study like Systematic Review of the Literature (RSL) can be performed on primary or secondary studies. In both cases, well-established processes and methods are required (Tebes, Peppino, Becker, & Olsina, 2020).

The systematic mapping methodology is a useful method to build classifications and obtain information about existing knowledge on a specific topic; therefore, it allows to identify the gaps and needs in a given area, which is closer to the definition of a relevant research niche (Jácome, Ordóñez, Cerón, & Villaquirán, 2018).

The study is developed through a mapping systematic based on the need to do research in the field of computer science. Figure 1 shows the steps of the method followed to carry out the systematic mapping process.

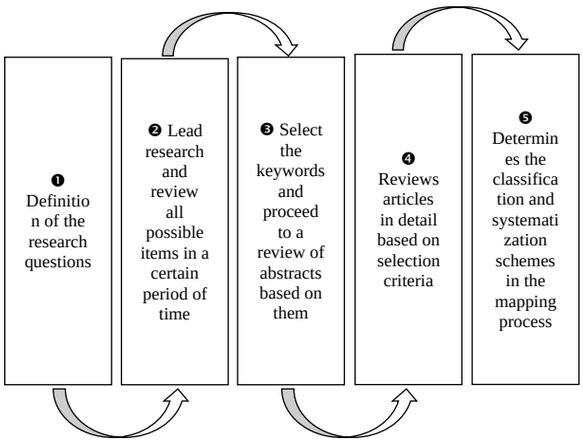

Figure 1 Systematic mapping study method applied in the study
Source: Taken from (Ramírez Montoya & Valenzuela González, 2020)

Study development

Next, the systematic mapping study is implemented to search for current scientific contributions in Quantum Programming.

Step 1: definition of research questions

In this stage of the systematic study, one or more questions are formulated focused and delimited to specific aspects of the topic to be investigated. It must be clear and precise.

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The questions defined for this study are:

- Question 1: What is quantum programming?
- Question 2: What are the fields of application of quantum programming?
- Question 3: What is the importance of quantum programming today or in the future?

Step 2: Conduct research and review as many articles as possible in a certain period of time

At this stage, the investigation is conducted by establishing the scientific sources where the search will be carried out and the period of time that the study will cover. Likewise, a critical assessment of the quality of the scientific contributions found is analyzed and specified.

In particular, the following are specified as search tools for the study:

- Scientific databases: DOAJ (Directory of Open Access Journals) and SCOPUS.
- Academic search engine: Google academic (Google Scholar).
- Reference or bibliographic manager: Mendeley.

In the context of assessing the quality of scientific contributions, the choice of scientific sources is immediately supported.

The Directory of Open Access Journals (DOAJ) is a community-curated online directory that indexes and provides access to high-quality, open access, peer-reviewed scholarly magazines (DOAJ, 2018). In other words, DOAJ is a database of open access journals, free of charge with scientific and academic rigor, of high quality (Faculty of Medical Sciences Library, 2017).

On the other hands, SCOPUS is a bibliographic database started in 2004, of abstracts and citations of articles from scientific magazines. It contains, apart from articles, more than 3,700 Gold Open Access indexed journals, more than 210,000 books, more than 8 million conference proceedings, more than 8 million Open Access documents, it also includes "Articles in Press" from more than 5,500 titles and covers 40 languages (Silva Semaan, 2018).

SCOPUS is the largest database of citations and abstracts of peer-reviewed literature: scientific journals, books, and conference proceedings. Offering a comprehensive summary of the results of world research in the fields of science, technology, medicine, social sciences, and the arts. SCOPUS includes smart tools to track, analyze and visualize the research (ELSEVIER, n.d.)

SCOPUS is the largest citation and abstract database of peer-reviewed literature and high-quality sources on the web. Although it is distributed by subscription, it is available with certain limitations for underdeveloped countries (Andalia, Labrada, & Montejo, 2010)

Academic Google (Google Scholar) is a search engine that allows you to locate academic documents, such as books, theses, articles, or specialized magazines. It is also known as Google Scholar (European Postgraduate Institute, 2018)

Academic Google is a search engine specialized in bibliography aimed at the scientific-academic community. This service allows (Gil, 2015):

- Search multiple sources from one place.
- Access full text documents.
- Search the bibliographical production of an author, of a magazine or on a subject.
- Discover new articles (papers) in your research area.
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Academic Google is a search engine that allows you to locate academic documents such as articles, theses, books, patents, documents related to congresses and summaries. It feeds on information from various sources: university publishers, professional associations, preprint repositories, universities, and other academic organizations (Autonomous University of Madrid, 2022).

Mendeley is a bibliography manager, a system for storing and organizing documents, a search engine for scientific information and an academic social network in which bibliographic citations and publications are shared. It is free and you just have to register to use it (Mendeley, 2022). More specifically, Mendeley is a social bibliographic manager that combines a web version with a desktop version. In addition, it incorporates Web 2.0 functionalities that allow bibliographic references to be shared with contacts and to browse content uploaded by other users (Huelva University Library, 2022).

In addition, Mendeley is an academic program that helps you manage your documents, read, write down and cite while you write your research papers (ULPGC Biblioteca Universitaria, 2022). It allows collaboration between groups of scientists and easily review the available contributions on any topic of scientific interest.

Step 3: select keywords and review abstracts based on them

In this step, the search terms are determined based on the questions established in Step 1, it is important to consider the similar terms to obtain more exhaustive results. Table 1 shows the search terms for the research study.

Search term	Alternative texts for search
Programming	Does not apply
Quantum	Does not apply
Future	Does not apply
Importance	Benefits and advantages
Fields	Does not apply
Applications	Use, work, management
Topicality	At present day, today, currently

Table 1 Search terms defined for the Systematic Mapping Study (SMS)
Source: Own elaboration

In addition, to target the results to the specific contributions of the search, the search strings are designated relative to the search terms. Table 2 shows the search strings for the research study.

Search term	Search string
Programming	Programming and quantum / Computer programming or quantum.
Quantum	Quantum / quantum computing / quantum features/ quantum computer.
Future	Quantum future/ future of computing.
Importance	Quantum importance / Quantum importance and programming.
Fields	Fields of the quantum programming/ fields of application of quantum programming.
Applications	Quantum programming applications.
Topicality	Topicality of quantum programming.

Table 2 Search strings established for the Systematic Mapping Study (SMS)
Source: Own elaboration

After having defined the search criteria and the scientific sources for it, the search is carried out. Table 3 shows the results of the information search. Table 4 shows the percentages of coincidences found for each scientific source.

Scientific sources	Number items
Scientific database	
DOAJ	2,586
SCOPUS	17,411
Academic search engine	
Google Scholar	511,760
Reference manager	
Mendeley	76,204
Total	607,961

Table 3 Total number of search results
Source: Own elaboration

Scientific sources	Percentage of results
Scientific database	
DOAJ	0.43%
SCOPUS	2.86%
Academic search engine	
Google Scholar	84.18%
Reference manager	
Mendeley	12.53%
Total	100%

Table 4 Search sources used in the Systematic Mapping Study (SMS)
Source: Own elaboration

Immediately, a quick review of results is carried out, with the aim of establishing more specific criteria that allow the correct delimitation of the significant contributions of the study.

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Step 4: review the articles in detail based on selectivity criteria

As can be seen in the previous section, the results of the search are very general, for this reason it is necessary to specify the inclusion and exclusion criteria of the scientific contributions to be included in the study.

The inclusion criteria are:

- Scientific articles published in quality journals.
- Scientific articles in the first quarter of the year 2022.
- Scientific articles in English and Spanish.
- Scientific articles partially or completely answer one or more of the questions defined in Step 1 of the Systematic Mapping Study (SMS).

The exclusion criteria are:

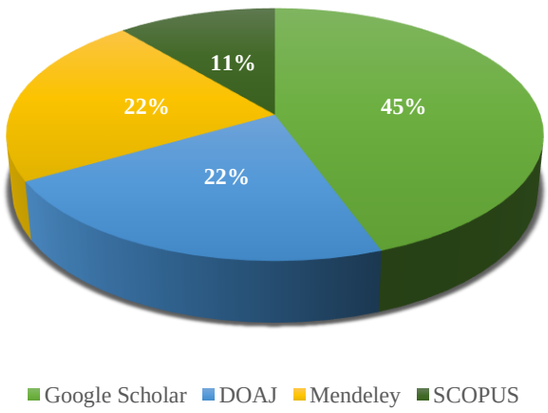
- Items that do not answer the questions defined in Step 1 of the Systematic Mapping Survey (SMS).
- Duplicate articles.
- Items that are not directly or indirectly related to the questions defined in Step 1 of the Systematic Mapping Survey (SMS).
- Articles that have not been published in the period of time established for the study.

By applying the specified inclusion and exclusion criteria, the subset of scientific contributions was considerably reduced. Table 5 shows the scientific contributions resulting after applying the inclusion and exclusion criteria for the study.

Scientific sources	Number of items
Scientific database	
DOAJ	2
SCOPUS	1
Academic search engine	
Google Scholar	4
Reference manager	
Mendeley	2
Total	9

Table 5 Total number of Search results after applying the inclusion and exclusion criteria
Source: Own elaboration

It is relevant to highlight the lack of scientific contributions related to the questions defined for this study. Graphic 1 shows the percentage corresponding to the total scientific contributions obtained by scientific source after applying the inclusion and exclusion criteria of the research.



Graphic 1 Percentage of results found in the Systematic Mapping Study (SMS) grouped by Search Source
Source: Own elaboration

Step 5: Determine the classification and systematization schemes in the mapping process

Finally, in the last step of the Systematic Mapping Study, it is determined how the results obtained are classified and synthesized. In this sense, considering the study, they are categorized according to time (month of publication). Table 6 shows the results of the study grouped by scientific source and month of publication.

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Scientific sources	Month	Number of items
Scientific database		
DOAJ	February	1
DOAJ	April	1
SCOPUS	April	1
Academic search engine		
Google Scholar	January	3
Google Scholar	February	1
Reference manager		
Mendeley	No defined	2

Table 6 Total number of search results after applying the inclusion and exclusion criteria in the Systematic Mapping Study (SMS) grouped by month of publication
Source: Own elaboration

Mainly, in this Step, the classification and systematization of the results is evidently specified based on the questions defined for the investigation. Table 7 shows the total scientific contributions classified by scientific source and research questions.

Scientific sources	Q1	Q2	Q3	Number of items
Scientific database				
DOAJ	1	0	1	2
SCOPUS	1	1		1
Academic search engine				
Google Scholar	0	2	2	4
Reference manager				
Mendeley	0	0	2	2
Total				9

Table 7 Total number of Search results after applying the inclusion and exclusion criteria
Source: Own elaboration

Discussion of the results

After the Systematic Mapping Study is finished, the group of researchers discuss, summarize, and synthesize the research findings.

Question 1 (Q1): What is quantum programming?

Quantum computing is an innovative technology in the IT field that can support global efforts to address web application and software security. (Alyami, et al., 2022)

Quantum computing is a computational architecture that uses quantum phenomena to offer a new paradigm that promises to revolutionize various scientific fields due to its superior computational power. (Costantino, Maurizio, & Paolo, 2022)

Leveraging quantum superposition to increase parallel computational power, quantum computing promises to outperform its classical counterparts and deliver exponentially greater scale. The term "quantum advantage" was proposed to mark the tipping point when people can solve a classically intractable problem by artificially controlling a quantum system on an unprecedented scale, even without error correction or known practical applications. (Gao, et al., 2022)

Question 2 (Q2): What are the fields of application of quantum programming?

Finance: Improvements in fraud detection and simulation systems. Greater optimization of investment portfolios. Biomedicine: New investigations of human DNA, too complex for conventional computers. Genetic Personalization of Medical Treatments

Cybersecurity: Quantum computing threatens current encryption systems, but it also offers a new technique to secure the sending of sensitive communications. With this technique, based on the sending of light signals, any interference with the system is automatically detected.

Mobility and transportation: Quantum computers are very useful for a more efficient design: Airbus has a quantum computer to optimize every inch of its ships by analyzing all the physical variables of navigation. In addition, qubits will give a huge qualitative leap to traffic planning and route optimization systems (Céliz Ezequiel, Leonor, Grigori, & Reymer, 2022)

As an example, the technology to detect fraud or money laundering is a very suitable area for quantum computing (Luis Alejandro, Enrique, & Sergio Ignacio, 2022)

The nature of quantum computers is more suitable for solving the Schrödinger equation in quantum chemistry than classical computers, at least from a conceptual point of view.

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Quantum computing, a new model of computing based on properties of quantum physics, has been an active area of research since the 1980s and has been greatly intensified by a) the discovery of quality control algorithms that provide exponential speedups or quadratic in computational times, and b) the advent of physical and operational quality control devices in the last decade. (Martin P, Mark N, Kurt V, Fengqi, & Seyed Soheil, 2022)

Various physical systems, encompassing much of modern physics, are being developed for quantum computing. However, it is unclear which technology, if any, will ultimately succeed. Here we describe the latest developments for each of the main approaches and explain the main challenges for the future. Id (Gao, et al., 2022)

Question 3 (Q3): What is the importance of quantum programming today or in the future?

Quantum computing will be the new industrial revolution of this incipient century, some large companies have opted for this new technology that promises to solve the bottlenecks that arise from the management and analysis of this large volume of data (Big Data). (José, Luis Héctor, Antonio, & Alberto, 2022)

Therefore, it is not expected for now that quantum computers will be home computers, like the usual ones, which are the ones that will continue colonizing our world of life (Francesc J & Vicent, 2022)

However, projections point to a fast development of quantum computing resources that will become available to academia and industry, opening up potential application areas in chemical and biomolecular design.

For a long time, chemical process design has benefited from computer-aided methods and tools to develop new processes and services that can meet the needs of society. Chemical and biomolecular design could also benefit from the use of computer-aided solution strategies and computational power to efficiently solve problems at various scales as the complexity and size of problems grow. In this context, new modes of computing, such as quantum computing, are receiving increasing attention.

Id (Martin P, Mark N, Kurt V, Fengqi, & Seyed Soheil, 2022)

Various algorithms have been developed for quantum computers that promise to pave the way for innovations in chemistry, finance, machine learning, etc. However, the practical applicability of these algorithms is limited by the limitations of current gate-based quantum computers, which are noisy and have an insufficient number of qubits (Carugno, Dacrema, & Cremonesi, 2022)

Quantum computing has made a huge leap in processing power. Through quantum effects, such as interference or entanglement, quantum computing is expected to achieve quantum advantages, such as exponential acceleration of computing performance, and effectively solve specific problems that are difficult for classical computers to solve. Additionally, the efficiency of conventional nuclear computing is not high (Huang, et al., 2022)

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Conclusions

From the scientific databases along the academic search engine and the reference manager we realized that there is not much information related to this topic for this current year, we realize that it is not a very talked about topic at the moment, but with the little data collected and with the questions solved we can give a solid answer to these: Regarding the first question we can say that quantum programming is a new technology that can help the scientific field, since it uses quantum phenomena in its architecture.

The field of quantum programming is currently used in science, as in biomedicine, in chemistry, in physics. But also, to check fraud or money laundering.

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However, quantum programming is not currently widely used, but large companies are already beginning to implement it, since it can reduce the problem they have with conventional computers, which is the bottleneck, and it is expected that in the future the conventional computers stop being manufactured and quantum ones begin to be distributed, since it offers greater benefits such as longer execution time and better waiting time in very complex operations

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