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# INNOVATION AS AN INITIATOR OF THE DEVELOPMENT

## ИНОВАЦИЈЕ КАО ПОКРЕТАЧ РАЗВОЈА

INTERNATIONAL CONFERENCE PROCEEDINGS
ЗБОРНИК РАДОВА СА МЕЂУНАРОДНОГ СКУПА

INNOVATIONS

December 5th
Belgrade, 2024

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University Business Academy in Novi Sad

Факултет за примењени менаџмент, економију и финансије, Београд
Faculty of Applied Management, Economics and Finance, Belgrade

## MEFkon 2024 / МЕФкон 2024

International Scientific & Professional Conference
Међународна научно-стручна конференција

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# ПРЕДГОВОР

Поштовани аутори, читаоци, колеге, студенти и ентузијасти жељни знања,

Пред вама се налази зборник радова десете јубиларне Међународне научно-стручне конференције „Иновације као покретач развоја“ коју организује Факултет за примењени менаџмент, економију и финансије, Београд. Већ десет година заредом заједно истражујемо границе и могућности реализације иновативних активности, а стечена сазнања презентујемо у виду чланака обједињених у зборнику радова. На том десетогодишњем путу учили смо, расли и развијали се заједно, а све са циљем креирања базе знања која ће допринети будућем економском развоју и просперитету. Значај конференције препознало је Министарство науке, технолошког развоја и иновација Републике Србије које је пружило финансијску подршку у њеној организацији. До сада смо се дотакли многих тема које прожимају различите научне области и сагледали их кроз призму иновативности. Неки научни одговори су понуђени, неки чак и усвојени, а за неким одговорима и решењима још увек трагамо. Захваљујемо вам што сте десет година уз нас и изражавамо наду да ћете и надаље учествовати у потрази за иновативним решењима и одговорима који ће овај свет учинити бољим него што је сада.

У Београду, децембра 2024.

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# FOREWORD

Dear authors, readers, colleagues, students, and enthusiasts seeking for knowledge,

In front of you are the proceedings of the tenth Jubilar International Scientific & Professional Conference, "Innovations as an initiator of the Development," which is organized by the Faculty of Applied Management, Economics and Finance, Belgrade. Ten years in a row, we explored the borders and possibilities for realizing innovative activities and gained knowledge presented in the form of articles united in the conference proceedings. In that ten-year road, we have learned, grown, and developed together, all with the goal of creating the knowledge base that will contribute to future economic development and prosperity. Conference significance is recognized by the Ministry of Science, Technological Progress and Innovation of the Republic of Serbia, which financially supports it. We have touched on many subjects that pervade different scientific fields and perceive them through the prism of innovativeness. Some scientific answers are offered, some are even accepted, and for some of them, we are still looking. Thank you for being these ten years by us, and we hope you will still be a part of the quest for innovative solutions and answers that will make this world better than it is now.

In Belgrade, December, 2024

Editors

Darjan Karabašević, PhD

Svetlana Vukotić, PhD

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# САДРЖАЈ / CONTENT

## РАДОВИ ПО ПОЗИВУ

## INVITED PAPERS

## РАДОВИ СА КОНФЕРЕНЦИЈЕ

## CONFERENCE PAPERS

# РАДОВИ ПО ПОЗИВУ

# INVITED PAPERS

# Quantum computing – the next frontier in technology

# Квантно рачунарство – наредни искорак у технологији

**Dušan Rajčević[1], Ivona Brajević[2], Francine Niedo[3]**

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**Abstract:** *Quantum computing is a groundbreaking innovation in the field of computer science. It adapts the unique characteristics of quantum mechanics to process information in ways that classical computers cannot. This article explores the fundamental principles of quantum computing, which consist of superposition and entanglement and their effects on computing performance. The article dives into how quantum computing can be used in the different industries like manufacturing, finance, and chemistry along with the emphasis on the fact that there's still a great deal of work required in this field before the broad adoption of practical quantum computers. The main goal of this article is to present the potential of quantum computing that will not only bring about the digital transition period but also the direction forward of quantum computing, by evaluating the impact of the global contributions and collaborations in quantum research.*

**Keywords:** *Computing, Quantum mechanics, Qbit, supercomputers.*

**Апстракт:** *Квантно рачунарство представља револуционарни напредак у области рачунарских наука. Користи уникатна својства квантне механике за обраду информација на начине које класични рачунари то не могу. Овај рад истражује основне принципе квантног рачунарства, који укључују суперпозицију и квантно спрезање, и њихов утицај на рачунарске перформансе. Рад такође обрађује како се квантно рачунарство може употребити у различитим индустријама као што су производња, финансије, хемија заједно са акцентом на чињеницу да је и даље потребно обавити пуно посла пре практичног увођења квантних рачунара. Главни циљ овог рада је да представи потенцијал квантног рачунарства који ће не само донети период дигиталне транзиције, већ ће такође погурати напред квантно рачунарство, узимајући у обзир утицај глобалног доприноса и сарадње у квантном истраживању.*

**Кључне речи:** *рачунарство, квантна механика, qbit, суперкомпјутери.*

## Introduction

Aim of this article is to introduce the field of quantum computers to the wider audience by emphasizing its huge potential on different fields and industries and what implications all of this brings to our understanding of the world and the universe itself.

In the first section, we will examine some of the distinctions between classical and quantum systems, and we will also explore how quantum computers can use entanglement and superposition to carry out calculations that are significantly more complex than those that can be completed by classical computers.

Following that, we will take a look at various industries where quantum computing is being used as well as the obstacles that the technology is now facing in its broader use.

After that, we will tackle the significant challenges that need to be addressed to fully unleash the power of quantum computing.

Lastly, we will focus on the global competition to advance quantum computing technologies, the investments and initiatives taken by various countries and companies to boost quantum research and development efforts.

By shedding light on collaborative efforts and the competitive landscape, readers will have an insight into the future trajectory of quantum computing and its potential to reshape our world.

## 1. Fundamental differences between classical and quantum systems

Classical and quantum systems differ in many different aspects, particularly in their core characteristics. In this chapter, we will explore some of these fundamental distinctions, which gave rise to various practical applications and theoretical implications in fields such as cryptography, optimization, and materials science, etc. Let's take a look at some of the differences between these two types of systems.

### 1.1. State representation

Classical systems are described using definite states, where properties such as position and momentum can be precisely measured. For example, a classical particle can be in a specific location at any given time. Quantum systems, on the other hand, are described by a wave function, which encapsulates the probabilities of finding a particle in various states. Instead of being in a single state, a quantum system can exist in a superposition of multiple states simultaneously (Nielsen & Chuang, 2010).

### 1.2. Superposition

A classical system cannot be in several different states at the same time – it has only one state at one moment of time. Quantum mechanics enables particles to exist in superpositions, i.e. quantum bits (qubit), which can be in a state that is both 0 and 1 at the same time, as opposed to classical bits that are either 0 or 1 at a given moment (Nielsen & Chuang, 2010).

### 1.3. Entanglement

In classical physics, systems can be correlated, but this correlation in the general case can be explained without going into the intrinsic properties of the system to which they refer. Quantum entanglement occurs when two or more particles become interconnected in such a way that the state of one particle instantly influences the state of another particle, regardless of their mutual distance. This interconnection has no classical counterpart (Nielsen & Chuang, 2010).

### 1.4. Measurement

Measurements of a classical system produce a unique deterministic outcome that reflects the state of the system, while measurements in a quantum system affect the state of the system being measured. When a measurement of a quantum system is performed, the system “collapses” from a superposition of states into a particular state, introducing inherent uncertainty and a statistical result (Nielsen & Chuang, 2010).

### 1.5. Determinism vs. Probabilism

Classical physics is generally deterministic. Taking into account the initial conditions, the future state can be predicted with certainty. On the other hand, quantum mechanics is fundamentally probabilistic. Measurement outcomes can only be predicted in the context of probability, but not certainty (Zettili, 2001).

### 1.6. Energy levels and quantization

Energy levels are continuous in classical systems, allowing for an infinite range of values. In quantum systems, energy levels are quantized, meaning that particles can only occupy certain discrete energy levels. This is fundamental to the behavior of atoms and molecules (Nielsen & Chuang, 2010).

### 1.7. Interference

Interference effects are typically associated with waves, but in classical mechanics, they do not occur universally in the same way quantum effects do. Quantum systems exhibit wave-like behavior and interference patterns due to the probability amplitude associated with their wave functions, leading to phenomena such as the famous double-slit experiment (Nielsen & Chuang, 2010).

### 1.8. Information processing

Classical computers use bits as the basic unit of information, which can represent either 0 or 1.: Quantum computers, on the other hand, use qbits, which can represent 0, 1, or both at the same time due to superposition. This allows for potentially exponential increases in processing power for certain types of problems (Arute et al., 2019).

## 2. Quantum entanglement

As we discussed previously, quantum entanglement is a phenomenon that occurs when two or more quantum systems become linked in such a way that the state of one system is directly related to the state of another, regardless of the distance separating them. When particles are entangled, knowing the state of one particle gives instantaneous information about the state of the other, even if they are light-years apart.

### 2.1. Key aspects of quantum entanglement

#### 2.1.1. Formation of entangled states

Entanglement typically arises during interactions between particles. For example, when two particles collide, their properties can become correlated, resulting in an entangled state.

Mathematically, if two particles A and B are entangled, their joint state cannot be factored into individual states. If particle A is in state $|A\rangle$ and particle B is in state $|B\rangle$ then the entangled state might be represented as Hilbert space for two qbits shown on Figure 1:

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\big(|0\rangle_A \otimes |0\rangle_B + |1\rangle_A \otimes |1\rangle_B\big) \tag{1}$$

$$|\Phi^-\rangle = \frac{1}{\sqrt{2}}\big(|0\rangle_A \otimes |0\rangle_B - |1\rangle_A \otimes |1\rangle_B\big) \tag{2}$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}\big(|0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B\big) \tag{3}$$

$$|\Psi^-\rangle = \frac{1}{\sqrt{2}}\big(|0\rangle_A \otimes |1\rangle_B - |1\rangle_A \otimes |0\rangle_B\big) \tag{4}$$

**Figure 1.** Hilbert space for two qbits
Source: Nielsen & Chuang, 2010

This expresses a situation where if quantum system A is observed in state $|0\rangle$, quantum system B will instantly be in state $|1\rangle$ and vice versa.

### 2.1.2. Non-locality

One of the most striking features of entanglement is its non-local nature. Changes or measurements made on one particle affect the other instantaneously, irrespective of the distance separating them. This phenomenon seems to defy Einstein's theory of relativity, which states that information cannot travel faster than the speed of light.

Einstein famously referred to this as "spooky action at a distance," expressing his discomfort with the implications of entanglement (Bell, 1964).

### 2.1.3. Bell's Theorem

In the 1960s, physicist John Bell formulated a theorem that showed that no local hidden variable theories could reproduce all the predictions of quantum mechanics, particularly regarding entangled states.

Experimental tests of Bell's inequalities (inequalities that must be satisfied by any local hidden variable theory) have consistently supported quantum mechanics, demonstrating the non-classical correlations predicted by entanglement (Bell, 1964).

### 2.1.4. Quantum measurement

When measuring one of the entangled particles, the entire system collapses into a definite state. For example, if a measurement is made on particle A and found to be in state $|0\rangle$, particle B will be found in state $|1\rangle$ when measured, reflecting perfect correlation.

This process is probabilistic, and while the outcomes are correlated, they remain random when considered individually (Nielsen & Chuang, 2010).

### 2.1.5. Types of entangled states

There are two types of entangled states: Maximally entangled states and partially entangled states. Maximally entangled states are the states where measuring one particle fully determines the state of the other (e.g., Bell states). They have the highest degree of entanglement.

Partially entangled states are the states particles are correlated but not in a way that provides complete information about the other upon measurement (Nielsen & Chuang, 2010).

### 2.1.6. Applications of quantum entanglement

Quantum entanglement has numerous applications across various fields, some of which include quantum computing. Entanglement is a key resource in quantum computing, allowing qubits to perform complex calculations in parallel due to their correlated states.

Quantum algorithms, like Shor's algorithm for factoring large numbers or Grover's algorithm for searching databases, leverage entangled states to achieve significant speedups over classical algorithms (Shor, 1994).

### 2.1.7. Quantum cryptography

In protocols like Quantum Key Distribution (QKD), entangled particles can be used to securely share cryptographic keys. Eavesdropping can be detected due to the disturbance of the entangled states.

The most well-known protocol is BB84, which employs the principles of quantum mechanics to ensure secure communication (Ekert, 1991).

### 2.1.8. Quantum teleportation

Quantum teleportation involves the transfer of quantum information from one location to another utilizing entangled particles as a resource. Importantly, this does not entail the physical transfer of matter but instead transmits the state of a quantum system.

The process requires an entangled pair shared between the sender and receiver, along with classical communication to complete the teleportation (Fan et al., 2024).

#### 2.1.9. Quantum sensors and metrology

Entangled states can improve the precision of measurements beyond classical limits. Techniques utilizing entangled photons enhance the sensitivity of sensors, which is valuable in fields like gravitational wave detection and medical imaging (Degen et al., 2017).

#### 2.1.10. Foundational studies in quantum mechanics

Entanglement continues to be a central topic in the philosophical examination of the foundations of quantum mechanics. It raises questions about the nature of reality, the understanding of quantum states, and the measurement problem.

## 3. Potential applications of quantum computing

Quantum computing is an emerging field that is based on the principles of quantum mechanics to perform calculations and solve problems in ways that are fundamentally different from classical computing. Some of the most promising potential applications of quantum computing across various fields include:

### 3.1. Cryptography

Quantum Key Distribution (QKD) uses the principles of quantum mechanics to create secure communication channels. Protocols like BB84 ensure that any eavesdropping attempt can be detected because it alters the quantum states being transmitted (Quantum Key Distribution (QKD) and Quantum Cryptography (QC), 2024).

Quantum computers have the potential to break widely used cryptographic systems, such as RSA and ECC (Elliptic Curve Cryptography). Research is ongoing to develop new cryptographic methods resistant to quantum attacks, known as post-quantum cryptography (The Case for Elliptic Curve Cryptography, 2024).

### 3.2. Optimization problems

Quantum computers can tackle complex optimization problems more efficiently than classical computers. For instance, quantum annealers and algorithms like the Quantum Approximate Optimization Algorithm (QAOA) are being explored for problems in logistics, scheduling, and resource allocation.

Quantum algorithms can optimize numerous factors in supply chains, including routes, inventory levels, and costs, leading to improved efficiency and reduced operational costs (Zhou et al., 2020).

### 3.3. Drug discovery and chemistry

Quantum computers can simulate quantum systems more naturally and efficiently than classical computers. This capability is vital in drug discovery, where understanding the interactions of complex molecules can lead to the development of new pharmaceuticals.

Understanding the properties of materials at the quantum level can lead to the design of new materials with superior characteristics, such as superconductors or carbon-based nanomaterials, with potential applications in electronics and energy storage (Thompson & Xiaodi, 2024).

### 3.4. Machine learning and artificial intelligence

Quantum Machine Learning (QML): Quantum computing has the potential to enhance machine learning algorithms by efficiently processing high-dimensional data. Algorithms like the Quantum Support Vector Machine present novel strategies for classification and clustering tasks.

Pattern Recognition: Quantum computers have the capacity to advance pattern recognition in various fields including image processing, natural language processing, and bioinformatics. This advancement could result in quicker and more precise model development (Suzuki et al., 2024). (Suzuki, Hasebe, & Miyazaki, 2024)

### 3.5. Financial services

Quantum computing can facilitate complex financial modeling and risk assessment, enabling firms to analyze vast datasets and assess portfolio risks more accurately than classical methods. Quantum algorithms, such as Quantum Monte Carlo simulations, can offer more efficient methods for pricing various financial derivatives, improving real-time trading strategies and risk management (Wang, 2011).

### 3.6. Climate modeling and weather forecasting

Quantum computers can model complex system simulation. For example, they are capable of simulating the intricate interactions within climate systems more effectively, providing better predictions for climate change scenarios and improving our understanding of weather patterns.

They can also perform optimization of energy systems. By utilizing quantum algorithms, we can help optimize power grids, energy usage, and renewable energy resource allocation to enhance sustainability and reduce costs (Tennie & Palmer, 2023).

### 3.7. Telecommunications

Quantum computing can enable optimal planning and usage of resources in communication networks, leading to improved bandwidth utilization and reduced latency. Also, quantum error correction techniques can vastly enhance the reliability and efficiency of data transmission on quantum networks (Quantum error correction, 2024).

### 3.8. Quantum simulation

Quantum computers are ideally suited for simulating other quantum systems, which is impossible with classical computers at a practical scale. This can provide new insights in physics and improve our understanding of fundamental particles and forces (Widdows et al., 2024).

### 3.9. Logistics and transportation

Routing Problems: Algorithms based on quantum principles could optimize routing for delivery vehicles, reducing transportation costs and improving timing efficiency in logistics.

Traffic Flow Optimization: Quantum computing can enhance traffic modeling and simulation, leading to smarter urban planning and more efficient public transport systems (Sales & Araos, 2023).

### 3.10. Artificial intelligence and natural language processing

Enhanced NLP Models: Quantum computing could lead to more efficient algorithms in natural language processing and understanding, which are crucial for applications like translation, chatbots, and text analysis (Widdows et al., 2024).

## 4. Challenges in quantum computing

While the potential applications of quantum computing are vast and exciting, there are significant challenges that need to be addressed (Sood & Chauhan, 2024):

- Error Rates and Decoherence: Quantum bits (qubits) are highly susceptible to errors due to decoherence and noise. Robust error correction methods and more stable qubit designs are critical for practical applications.
- Scalability: Building scalable quantum systems that can handle a sufficiently large number of qubits to tackle complex problems remains a significant engineering challenge.
- Resource Requirements: Quantum algorithms may require significant resources in terms of time and implementation complexity, making it essential to determine where they can provide real advantages over classical counterparts.

## 5. Global Efforts in Quantum Computing

The global landscape of quantum computing research and development is rich and dynamic, characterized by significant investments from governments, academia, and the private sector.

### 5.1. Government initiatives and funding

Governments across the globe recognize the immense potential of quantum computing and are investing heavily in research programs and initiatives.

The U.S. government has increased its investments in quantum technology significantly through initiatives such as the National Quantum Initiative Act, established in 2018, which allocates substantial funding for quantum technologies to foster research and development (An act to provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States, n.d.).

Agencies like the National Science Foundation (NSF), the Department of Energy (DOE), and the National Institute of Standards and Technology (NIST) play essential roles in supporting quantum research, providing grants, and fostering public-private partnerships (Quantum Information Science, 2024).

The Quantum Flagship, an initiative launched in 2018, is a 1 billion Euros program aimed at developing quantum technology over the next decade. It supports research across various domains, including quantum computing, quantum communication, and sensing (Introduction to the Quantum Flagship, 2024).

Countries such as Germany, France, and the Netherlands have also established national strategies for quantum technology, facilitating collaboration among research institutions and industry (Germany's Action Plan on Quantum Technologies, 2023).

China has become a leader in quantum research, investing heavily in both fundamental research and practical applications. The Chinese government announced the National Laboratory for Quantum Information Sciences in 2020, focusing on developing quantum computing and communication technologies.

Chinese researchers have made significant advances in quantum communication, including the successful launch of the Micius satellite, which established a secure quantum communication link between Beijing and Vienna (China is opening a new quantum research supercenter, 2021).

The UK has launched the UK National Quantum Technologies Programme, which aims to support research and innovation in quantum technologies and foster collaboration between academia and industry.

Universities such as the University of Oxford and the University of Cambridge are at the forefront of quantum research and technology development in the UK (UK National Quantum Technologies Programme, 2024).

### 5.2. Industry investment and collaborations

The private sector is equally active in quantum computing, with tech giants, startups, and established companies investing in research and development:

IBM has developed the IBM Quantum Experience, an online platform that gives researchers and developers access to quantum computers. The company has set ambitious goals for building more powerful quantum systems and has been at the forefront of developing quantum algorithms and applications (IBM Quantum Platform, 2024).

Google made headlines in 2019 with its claim of demonstrating quantum supremacy as it successfully performed a calculation that would have been infeasible for classical supercomputers. The Google Quantum AI team continues to work on a scalable quantum computing architecture (Google Quantum AI, 2024).

With its Azure Quantum platform, Microsoft is actively promoting quantum applications in cloud computing and is developing topological qubits that aim to be more stable than conventional qubits (Azure Quantum, 2024).

A pioneer in quantum annealing, D-Wave has focused on commercializing quantum computing solutions and offers access to its quantum hardware through the cloud (D-Wave Systems, 2024).

### 5.3. International collaboration

The nature of quantum computing research encourages collaboration across borders. Several initiatives aim to foster international cooperation:

- Q-Exchange: This international collaboration focuses on the exchange of ideas and expertise in quantum technologies across the UK and the rest of the world (Global initiatives in quantum computing: The role of international collaboration, 2023).
- European Quantum Communication Infrastructure (EuroQCI): This project aims to create a secure quantum communication network across Europe, enhancing cybersecurity at national levels through quantum communication technologies (The European Quantum Communication Infrastructure (EuroQCI) Initiative, 2024).
- Global Efforts in Education: Many countries are collaborating to develop educational programs and resources to train a new generation of quantum scientists and engineers. Initiatives are being formed globally to create curricula and workshops that address quantum technology (Kaur & Venegas-Gomez, 2022).

### 5.4. Educational programs and outreach

As quantum computing grows, educational institutions are expanding programs to prepare the workforce of the future:

Degree Programs: Universities are increasingly offering undergraduate and postgraduate degrees in quantum computing and quantum information science. These programs cover topics such as quantum algorithms, quantum cryptography, and quantum hardware (12 Top Quantum Computing Universities in 2024, 2024).

Online Courses and Workshops: Many organizations, including edX (edX Quantum Computing, 2024) and Coursera (Coursera Quantum Computing, 2024), offer online courses on quantum computing to help professionals and students understand foundational concepts and applications. Public

Engagement: Various outreach initiatives aim to demystify quantum mechanics and computing for the general public, promoting understanding and interest in this field.

## Conclusion

The global efforts in quantum computing are multidimensional, involving investments, research, collaborations, and educational initiatives across governments, academic institutions, and the private sector. As advancements continue to unfold, the combined knowledge and innovation emerging from these efforts promise to unlock the full potential of quantum computing, shaping the future of technology and science. The coordinated approach taken across different countries and sectors is essential in overcoming challenges and realizing the transformative applications of quantum technology.

Quantum computing holds the promise of revolutionizing numerous fields by enabling solutions to problems that are currently impossible for classical computers. As research and development in this area continue to progress, the ability to harness its potential will deepen our understanding and facilitate breakthroughs across various disciplines. As quantum technologies mature, we can expect more tangible applications to emerge in the coming years.

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