VSB TECHNICAL UNIVERSITY OF OSTRAVA
IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTER

Atlas of Quantum Computing Use Cases

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We Support Innovations with Supercomputers and a Quantum Computer

Introduction

Quantum computing is a fascinating and powerful tool with the potential to transform computational capabilities across various scientific and industrial fields fundamentally. Unlike classical computers that operate with bits, quantum computers use quantum bits, or qubits. These qubits have a unique property – they can exist in a superposition of the states 0 and 1, meaning they can represent more than one value at the same time. This allows quantum computers to perform either impossible or extremely time-consuming computations for classical computers.

Thanks to their ability to exploit superposition and quantum phenomena such as entanglement, quantum computers can perform parallel processing of large amounts of information. This capability significantly boosts their computational power, as quantum computers can tackle complex tasks simultaneously, unlike supercomputers, which process them sequentially. This has major implications for scientific simulations, optimisation, and many other computationally intensive tasks.

As quantum technologies evolve, new opportunities arise for tackling complex problems in areas such as chemistry, materials science, optimisation, machine learning, and cryptography. Quantum computers can significantly accelerate the solution of problems that are computationally demanding or practically unsolvable for classical computers.

It is important to note that this text is relevant for the year 2025. Given the meteoric development in quantum computing, this information may become outdated quickly. New discoveries and technological advances are frequent in this dynamic area, which means the content of this document may change rapidly.

This atlas presents a representative selection of specific use cases of quantum computing across various industrial sectors. Each example includes a problem description, the approach to solving it using quantum algorithms, and details of the quantum technology used. The aim is to provide a practical overview for industry stakeholders and to illustrate where quantum computing is already being applied and where it may bring significant benefits in the future. The atlas does not aim to be an exhaustive list of all existing use cases – it offers a cross-sectional overview of selected areas. However, as quantum technologies evolve, so will their industrial use cases, with new examples and use cases emerging continuously.

The atlas also includes an up-to-date overview of the state of the art and development of quantum computers, including various approaches to their construction, such as superconducting qubits, ion traps, photonic qubits, neutral atoms, spin qubits, and quantum annealers.

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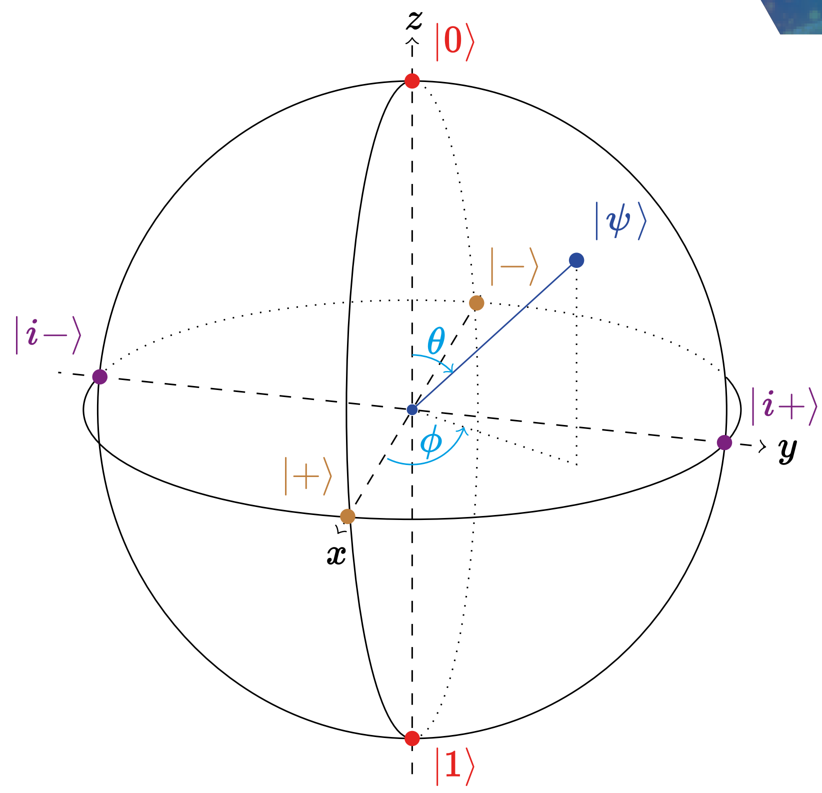
Quantum Computing at IT4Innovations

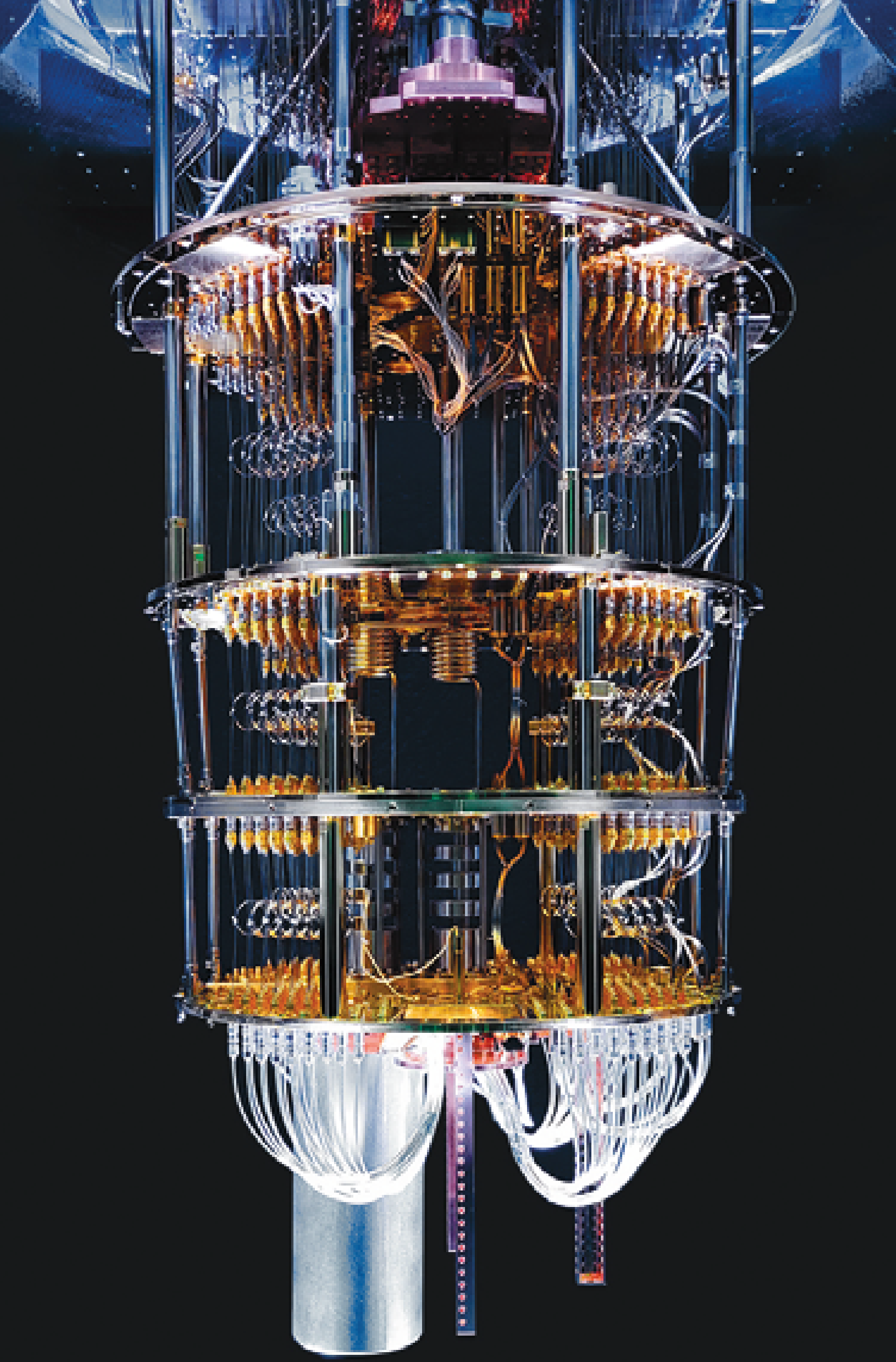
IT4Innovations National Supercomputing Center, one of the research institutes of VSB – Technical University of Ostrava, is a leading research, development, and innovation centre in the fields of High-Performance Computing (HPC), Data Analytics (HPDA), Artificial Intelligence (AI), and Quantum Computing (QC) and their applications to other scientific fields, industry, and society. It operates the most powerful supercomputing systems in the Czech Republic.

In 2025, IT4Innovations will also host VLQ, the very first Czech quantum computer, which is part of the LUMI-Q consortium, representing a major opportunity to boost research capacity and innovation in quantum technologies.

Quantum computing at IT4Innovations is led by experts from the Quantum Computing Lab, who merge innovation and collaboration to shape the future of quantum technologies. The lab is at the forefront of quantum computing research and is dedicated to deepening theoretical understanding, developing practical applications, and fostering partnerships between academia and industry. Specialised areas include optimisation problems, quantum machine learning, quantum factorisation, quantum circuit optimisation, and quantum error correction. The lab also offers educational activities for both academia and industry to ensure the sharing and development of knowledge and expertise among new generations of quantum scientists and engineers.

Visualization of a qubit using the Bloch sphere





VLQ

Consortium LUMI-Q

The LUMI-Q Consortium‘s Quantum Computer

The LUMI-Q consortium‘s quantum computer, named VLQ, will be based on superconducting qubits and will feature a unique star topology. This topology minimises the number of so-called swap operations, enabling the execution of highly complex quantum algorithms. The system will feature 24 physical qubits connected to a central resonator.

VLQ will be available to a wide range of European users, from research communities to industry and the public sector. The emerging quantum computing infrastructure will support the development of a wide range of applications with industrial, scientific, and societal relevance for Europe, and will expand the European supercomputing infrastructure by incorporating new technologies. The system will allow European end users to explore applications and algorithms tailored to the new star topology, such as the Quantum Fourier Transform (QFT), a central component of many quantum algorithms demonstrating exponential speedup compared to purely classical processing.

The LUMI-Q consortium is a truly pan-European collaborative project involving eight countries: the Czech Republic, Belgium, Denmark, Finland, Norway, the Netherlands, Poland, and Sweden. The LUMI-Q consortium will provide a pan-European quantum computing environment integrated with the EuroHPC infrastructure. It will enable the integration of the target VLQ quantum computer into the EuroHPC KAROLINA supercomputer in the Czech Republic, LUMI in Finland, and EHPCPL in Poland.

“We are excited to have a quantum computer with this unique topology. This architecture will significantly enhance the efficiency of quantum computations. The star topology offers optimal interconnection between qubits, reducing the number of hardware-imposed MOVE/SWAP operations. Thanks to this topology, we can better utilise coherence time and perform deeper quantum circuits across a wide range of applications, from artificial intelligence to complex system simulations,” said Branislav Jansik, IT4Innovations Supercomputing Services Director.

Examples of Use Cases by Industrial Sector

SECTOR

01 FINANCE

The financial sector relies on complex computations for portfolio optimisation, financial fraud detection, and risk modelling. Traditional algorithms often reach computational limits when processing large datasets and complex financial models. Quantum computing enables more efficient portfolio optimisation, faster identification of suspicious transaction patterns, and more accurate risk assessments related to market shocks. With its ability to solve complex problems in a shorter time, quantum computing can enhance efficiency, reduce risks, and provide a competitive advantage for financial institutions.

FINANCE

Portfolio Optimisation

PROBLEM DEFINITION:

PORTFOLIO OPTIMISATION INVOLVES MAKING ASSET ALLOCATION DECISIONS THAT MINIMISE RISK AND MAXIMISE RETURN. TRADITIONAL ALGORITHMS STRUGGLE WITH LARGE AMOUNTS OF ASSETS AND CONSTRAINTS.

Solution:

A quantum algorithm using *the Quantum Approximate Optimization Algorithm (QAOA)* was applied to optimise a portfolio with large amounts of assets.

Technology Used:

QASM Simulator

Technical Details:

The QAOA was implemented with 5 and 10 qubits, each representing an asset. The algorithm was tested on many instances of available assets and acceptable risks, in a simulator with varying noise levels.

Results:

The quantum algorithm found the optimal portfolio more efficiently than classical methods, even in high-noise environments.

Reference here

FINANCE

Financial Fraud Detection

PROBLEM DEFINITION:

FINANCIAL FRAUD DETECTION INVOLVES ANALYSING LARGE VOLUMES OF TRANSACTIONS TO IDENTIFY SUSPICIOUS PATTERNS, WHICH IS COMPUTATIONALLY INTENSIVE.

Solution:

A hybrid quantum machine learning algorithm for pattern classification was used to analyse transaction data and detect fraudulent activities.

Technology Used:

Quantum Support Vector Machine (QSVM), a hybrid approach using quantum simulators and classical computers.

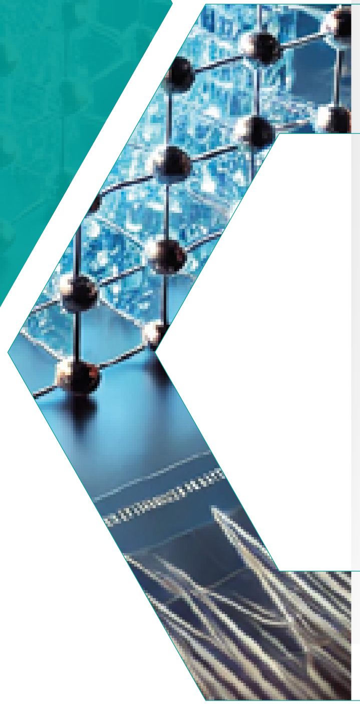
Technical Details:

The algorithm used a hybrid method combining a classical classifier trained on transaction features and a quantum circuit encoding the most impactful features for detection accuracy.

Results:

The algorithm detected fraudulent transactions with higher accuracy than traditional methods, contributing to more effective financial loss prevention.

Reference here



FINANCE

Risk Modelling

PROBLEM DEFINITION:

RISK MODELLING IS ESSENTIAL FOR ASSESSING POTENTIAL LOSSES IN FINANCIAL PORTFOLIOS DUE TO MARKET SHOCKS AND OTHER FACTORS.

Solution:

The algorithm employed *Quantum Amplitude Estimation* (QAE), which enables estimating certain quantities with quadratic speedup over classical methods.
This technique is used to simulate various financial scenarios and estimate risk metrics such as *Value-at-Risk* (VaR) and *Conditional Value-at-Risk (CVaR).*

Technology Used:

Superconducting qubits (IBM Quantum)

Technical Details:

Simulations were performed using 4 qubits to model different market variables and their interactions.

Results:

Quantum simulations demonstrated a quadratic acceleration in risk analysis compared to classical approaches, allowing financial institutions to better prepare for potential unfavourable events.

Reference here

SECTOR

02 PHARMACEUTICAL INDUSTRY

Developing new drugs requires advanced computational methods for analysing molecular structures and chemical interactions. Traditional approaches to modelling electronic structures and predicting molecular-protein binding are computationally intensive. Quantum computing introduces revolutionary capabilities, enabling faster and more accurate simulations that accelerate the identification of effective pharmaceuticals. For example, in the search for SARS-CoV-2 main protease (Mpro) inhibitors, quantum computing can help optimise the binding configurations of potential candidates, leading to more efficient antiviral development and faster market deployment.

- New Drug Design
- Prediction of Molecular and Protein Binding
- Search for Antivirals against SARS-CoV-2

PHARMACEUTICAL INDUSTRY

New Drug Design

PROBLEM DEFINITION:

TRADITIONAL DRUG DEVELOPMENT METHODS ARE COMPUTATIONALLY DEMANDING, ESPECIALLY WHEN SIMULATING ELECTRONIC STRUCTURES OF MOLECULES AND MODELLING QUANTUM CHEMICAL INTERACTIONS.

Solution:

A quantum computer was used to solve electronic structures more efficiently using the Variational Quantum Eigensolver (VQE) algorithm, improving simulation accuracy and speed.

Technology Used:

Superconducting qubits (IBM Quantum) and hybrid quantum-classical technologies

Technical Details:

Experiments were conducted on the IBM Quantum Experience using quantum circuits optimised for molecular simulations. The performance of VQE was tested against classical methods for calculating molecular energy.

Results:

Quantum computing demonstrated potential for more accurate simulations of electronic structures. However, current hardware limitations, such as decoherence and high noise levels, remain challenges for scaling to larger systems.

Reference here

PHARMACEUTICAL INDUSTRY

Prediction of Molecular and Protein Binding

PROBLEM DEFINITION:

PREDICTION OF MOLECULAR AND PROTEIN BINDING IS A METHOD FOR PREDICTING THE SPATIAL ORIENTATIONS OF MOLECULES AS THEY BIND TO LARGER PROTEINS. THIS IS CRUCIAL IN PHARMACEUTICAL DRUG DESIGN, WHERE THE BINDING CONFIGURATIONS OF NUMEROUS CANDIDATE MOLECULES MUST BE PREDICTED.

Solution:

The proposed solution uses Gaussian Boson Sampling (GBS), a photonic quantum device. GBS is employed to find the maximum weighted cliques in a graph, representing stable configurations. This approach allows for high-probability sampling of large weighted cliques, aiding in identifying binding configurations.

Technology Used:

Photonic qubits

Technical Details:

An experiment was performed on a graph with 4 nodes for the ligand and 6 nodes for the receptor, creating 24 interaction pairs. The maximum cliques had 8 nodes. The quantum circuit used photonic modes, the number of which depended on the graph size representing pharmacophore points.

Results:

Quantum simulations using GBS significantly outperformed classical random sampling in finding maximum weighted cliques. The quantum approach achieved a 70% success rate compared to less than 35% for the classical method, showing strong potential in pharmaceutical research, particularly for rapid screening of a large number of molecular configurations.

Reference here

PHARMACEUTICAL INDUSTRY

Search for Antivirals Against SARS-CoV-2

PROBLEM DEFINITION:

THE SARS-COV-2 MAIN PROTEASE (MPRO) IS A KEY ENZYME IN VIRAL REPLICATION AND A CRITICAL TARGET FOR DEVELOPING NEW ANTIVIRAL DRUGS.

Solution:

Quantum simulations of molecular interactions were used to evaluate potential inhibitors of the SARS-CoV-2 main protease.

Technology Used:

Superconducting qubits (IBM Quantum)

Reference here

Technical Details:

Researchers combined quantum computing and classical simulations to evaluate energy profiles of various ligands and their binding affinities to the main protease. Quantum simulations were conducted using 8 qubits, each representing different molecular states. Quantum circuits were optimised for high-precision interaction modelling.

Results:

Quantum simulations enabled the precise scoring of different ligands and the identification of several new potential Mpro inhibitor candidates. This approach reduced development time and provided valuable insights for further experimental validation.

SECTOR

03 ENERGY

With the growing share of renewable sources and the deployment of converter technologies, the complexity of power grid management is increasing. Traditional methods for power flow analysis and power system optimisation often reach computational limits due to the vast number of variables and the combinatorial nature of the problems. Quantum computing offers new possibilities for more efficient solutions to tasks such as unit commitment, equipment allocation, and heat exchanger network synthesis. Although optimising biogas plant operations poses challenges, developing hybrid approaches combining quantum and classical algorithms could provide innovative solutions for sustainable power systems.

- Power Distribution Optimisation
- Power System Optimisation
- Renewable Energy Output Prediction

ENERGY

Power Distribution Optimisation

PROBLEM DEFINITION:

THE GROWING SHARE OF RENEWABLE ENERGY SOURCES AND THE WIDESPREAD DEPLOYMENT OF CONVERTER TECHNOLOGIES INCREASE THE COMPLEXITY OF MANAGING POWER GRIDS. TRADITIONAL POWER FLOW ANALYSIS METHODS ARE COMPUTATIONALLY INTENSIVE AND DIFFICULT TO SCALE.

Solution:

Quantum computing was used to calculate power flows using the HHL algorithm, which solves systems of linear equations with potential exponential speedup over classical methods.

Technology Used:

Superconducting qubits (IBM Quantum)

Reference here

Technical Details:

The HHL algorithm was implemented to solve matrix equations on five different IBM Quantum computers for calculating power flows in 3-bus and 5-bus systems. The study focused on the impact of quantum noise and the scalability of the method under NISQ hardware conditions.

Results:

Quantum power flow converged to the correct solution; however, current limitations of quantum hardware, such as noise and a limited number of qubits, resulted in a higher number of iterations than classical methods. With future quantum hardware improvements, better scalability for larger systems is expected.

ENERGY

Power System Optimisation

PROBLEM DEFINITION:

OPTIMISING POWER SYSTEMS INVOLVES CHALLENGES SUCH AS EQUIPMENT ALLOCATION, UNIT COMMITMENT, AND HEAT EXCHANGER NETWORK SYNTHESIS. THESE PROBLEMS ARE COMPLEX DUE TO THE LARGE NUMBER OF VARIABLES, CONSTRAINTS, AND THEIR COMBINATORIAL NATURE, LEADING TO LONG COMPUTATION TIMES ON CLASSICAL COMPUTERS.

Solution:

The solution is to reformulate these optimisation problems into *Quadratic Unconstrained Binary Optimisation* (QUBO). Hybrid quantum optimisation algorithms such as *Quantum Approximate Optimisation Algorithm* (QAOA) and *Variational Quantum Eigensolver* (VQE) were applied.

Technology Used:

Superconducting qubits (IBM Quantum) and quantum annealer (D-Wave)

Technical Details:

The full optimisation problem involved over 2,000 binary variables optimised using up to 20 superconducting qubits or up to 2,048 annealed qubits. A comparison was also made using the classical Gurobi solver.

Results:

For smaller problem instances, the quality of results was comparable to those from the Gurobi solver. As the problem size increased, Gurobi's computation time grew exponentially, while the quantum approach remained relatively constant. This advantage is expected to become increasingly significant with further development of quantum technologies.

Reference here

ENERGY

Renewable Energy Output Prediction

PROBLEM DEFINITION:

THE OPERATION OF BIOGAS FACILITIES REQUIRES OPTIMAL BIOMASS COMPOSITION, BUT THE CONTINUOUS NATURE OF THE DECISION SPACE COMPLICATES THE USE OF QUANTUM METHODS, WHICH ARE PRIMARILY DESIGNED FOR DISCRETE PROBLEMS.

Solution:

The QuAnCO *(Quantum Annealing Continuous Optimisation)* method was developed to convert the continuous optimisation problem into a discrete QUBO *(Quadratic Unconstrained Binary Optimization)* format suitable for quantum hardware.

Technology Used:

Quantum annealer (D-Wave)

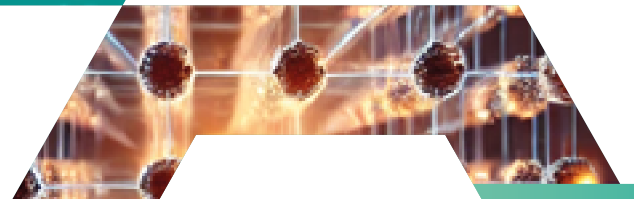
Reference here

Technical Details:

Continuous variables (e.g., biomass composition ratios) were transformed into discrete values via interval-limited integers and subsequent binary encoding. The proposed approach was applied to a real-world biomass mix optimisation case for the Nature Energy company.

Results:

The QuAnCO method produced significantly better optimisation results, reducing operating costs and increasing the biogas facilities' overall efficiency.



SECTOR

04 AUTOMOTIVE INDUSTRY

The automotive industry faces growing computational challenges, from optimising manufacturing processes to developing autonomous vehicles. Quantum computing can significantly improve vehicle painting sequence planning efficiency by minimising colour changes, thereby reducing time loss and material consumption. It can also help optimise the testing of pre-production vehicles by reducing their number while ensuring all required configurations are tested. In autonomous driving, quantum algorithms enable faster and more accurate processing of sensor data and real-time route optimisation, contributing to safer and more efficient future mobility.

- Painting Process Optimisation
- Test Vehicle Configuration Optimisation
- Route Planning for Autonomous Vehicles

AUTOMOTIVE INDUSTRY

Painting Process Optimisation

PROBLEM DEFINITION:

ONE OF THE KEY PROBLEMS IN THE AUTOMOTIVE INDUSTRY IS MINIMISING COLOUR CHANGES DURING THE VEHICLE PAINTING PROCESS. EACH COLOUR CHANGE CAUSES TIME DELAYS AND INCREASED MATERIAL CONSUMPTION, RESULTING IN HIGHER COSTS AND REDUCED PRODUCTION EFFICIENCY.

Solution:

To optimise the sequence of vehicles on a paint line, this NP-hard combinatorial problem was formulated as an Ising model solvable by quantum annealing. Calculations were performed on a D-Wave quantum annealer and compared with classical heuristic and hybrid approaches.

Technology Used:

Quantum annealer (D-Wave)

Reference here

Technical Details:

The problem was expressed as an Ising model and represented in *Quadratic Unconstrained Binary Optimisation* (QUBO) form. Experiments were conducted on the D-Wave 2000Q quantum computer using real production line data from the Volkswagen factory in Wolfsburg. The performance of the quantum solution was compared with classical heuristics and D-Wave's hybrid algorithms.

Results:

The quantum solution proved effective for smaller problem instances, while the hybrid quantum-classical algorithm achieved competitive results for medium-sized production sequences. These results indicate that quantum computing can potentially improve the efficiency of the painting process planning in the automotive industry.

AUTOMOTIVE INDUSTRY

Test Vehicle Configuration Optimisation

Solution:

A hybrid quantum-classical approach using the *Constrained Quadratic Model* (CQM) solver from D-Wave efficiently solved the feasibility problem under defined conditions.

Technology Used:

Hybrid CQM solver from D-Wave, quantum annealer (D-Wave), and classical supercomputer

Technical Details:

The problem was modelled as constrained quadratic programming using Boolean variables to represent the presence or absence of specific vehicle features. An objective function was formulated to minimise the number of test vehicles while adhering to configuration rules and test requirements. The CQM solver's results were compared to those of classical solvers like CBC and Gurobi.

Results:

The CQM solver performed comparably to classical solvers in optimising the number of test vehicles. A method was also proposed to integrate test scheduling into the model, potentially improving overall process efficiency.

PROBLEM DEFINITION:

BEFORE NEW CAR MODELS ENTER SERIAL PRODUCTION, A RANGE OF TESTS MUST BE CONDUCTED ON PRE-PRODUCTION VEHICLES WITH VARIOUS CONFIGURATIONS. THE GOAL IS TO MINIMISE THE NUMBER OF TEST VEHICLES WHILE ENSURING ALL REQUIRED TESTS ARE COVERED AND CONFIGURATION RULES ARE RESPECTED.

Reference here

AUTOMOTIVE INDUSTRY

Route Planning for Autonomous Vehicles

PROBLEM DEFINITION:

AUTONOMOUS DRIVING REQUIRES FAST AND ACCURATE REAL-TIME DECISION-MAKING BASED ON MASSIVE VOLUMES OF SENSOR DATA. TRADITIONAL ALGORITHMS (E.G. DIJKSTRA, A*, GA, ACO, PSO) SUFFER FROM SLOW CONVERGENCE, INSTABILITY, AND THE TENDENCY TO GET STUCK IN LOCAL OPTIMA.

Solution:

The Gradient Statistical Mutation Quantum Genetic Algorithm (GSM-QGA), which combines a quantum genetic algorithm with gradient descent and a statistical mutation operator, was used. The algorithm dynamically adjusts the quantum rotation gate based on the chromosome's fitness value.

Technology Used:

IBM Quantum simulator

Reference here

Technical Details:

Each point on the route is encoded using one qubit in a grid map.
The simulation was run on a 20×20 grid with a grid length of 0.05 km.

Results:

The quantum algorithm's results were compared to those of classical algorithms. Compared to the best classical method, the quantum approach reduced average route length by 5.52% and improved convergence speed by 32.48%.

SECTOR

05 TELECOMMUNICATIONS

Modern telecommunications networks are facing increasing computational demands, particularly with the development of 5G and future 6G technologies. Massive MIMO systems require efficient signal processing, while traditional optimisation methods reach computational limitations when managing numerous antennas and devices. Quantum computing can significantly accelerate calculations related to resource allocation and radio access network optimisation. Additionally, it enables secure encrypted computations, enhancing data transmission privacy. Using quantum algorithms can contribute to more efficient, secure, and high-performing future telecommunications networks.

- 5G Network Optimisation
- Encryption in Communication Networks
- Scheduling Optimisation for Mobile Operators

TELECOMMUNICATIONS

5G Network Optimisation

PROBLEM DEFINITION:

5G NETWORKS REQUIRE EFFICIENT SIGNAL PROCESSING IN MASSIVE MIMO SYSTEMS TO ENSURE HIGH CAPACITY, LOW LATENCY, AND RELIABLE TRANSMISSION. TRADITIONAL OPTIMISATION METHODS STRUGGLE WITH THE COMPUTATIONAL LOAD OF HANDLING LARGE NUMBERS OF ANTENNAS AND USER DEVICES.

Solution:

Quantum annealing was used to optimise signal detection in massive MIMO systems, improving spectrum allocation and network performance in real time.

Technology Used:

Quantum annealer (D-Wave)

Technical Details:

Experiments were conducted on the D-Wave 2000Q quantum annealer with 2031 qubits. The signal detection task was formulated as a *Quadratic Unconstrained Binary Optimisation* (QUBO) problem. The algorithm was tested across scenarios involving different numbers of users and antennas.

Results:

Simulations showed that quantum annealing delivers competitive results compared to classical signal detection methods and offers potential advantages in scaling to larger systems.

Reference here

TELECOMMUNICATIONS

Encryption in Communication Networks

PROBLEM DEFINITION:

PERFORMING COMPUTATIONS ON ENCRYPTED QUANTUM OR CLASSICAL DATA IS CRUCIAL FOR ENSURING PRIVACY AND SECURITY IN TELECOMMUNICATIONS. THE CHALLENGE IS TO ENABLE ARBITRARY QUANTUM COMPUTATIONS ON QUBITS CONTAINING ENCRYPTED INFORMATION WITHOUT REVEALING ANY DATA TO UNAUTHORISED PARTIES.

Solution:

Encryption and decryption of qubits were achieved using specific sequences of quantum operations executed on the server. These operations cannot be intercepted as in classical systems. The client decrypts the data using their own key combined with the operation sequence.

Technology Used:

Photonic qubits

Technical Details:

Protocols were implemented using specific polarisation beam splitters that performed quantum operations on the qubit. Each qubit represented a portion of the encrypted input data.

Results:

The protocol allows the server to perform arbitrary quantum operations on encrypted data without learning anything about the inputs. It requires fewer auxiliary qubits and fewer rounds of classical communication than other quantum homomorphic encryption schemes.

Reference here

TELECOMMUNICATIONS

Scheduling Optimisation for Mobile Operators

PROBLEM DEFINITION:

OPTIMISING RADIO ACCESS NETWORKS FOR MOBILE OPERATORS INCLUDES PLANNING AND MANAGING TRANSMISSION CAPACITY AND RESOURCE ALLOCATION, SUCH AS ASSIGNING THE ROOT SEQUENCE INDEX (RSI) IN LTE/NR NETWORKS.

Solution:

Quantum algorithms were used to optimise RSI assignment without conflicts within the radio access of mobile networks.

Technology Used:

Quantum annealer (D-Wave)

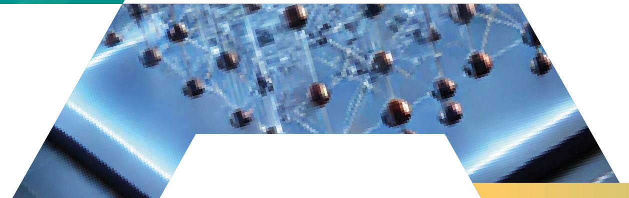
Technical Details:

Optimisation was carried out using quantum annealing on a D-Wave 2000Q to solve Quadratic Unconstrained Binary Optimisation (QUBO). It was compared with classical heuristics, with the quantum approach showing flexibility but with variable performance depending on the problem parameters.

Results:

The quantum annealer successfully assigned the RSI without conflicts, demonstrating the potential of quantum computing in mobile network automation.

Reference here



SECTOR

06 LOGISTICS

The logistics sector constantly faces challenges related to supply chain optimisation, transport planning, and inventory management. Traditional methods often reach computational limits when solving complex combinatorial problems, such as finding the most efficient routes in real time or optimal stock allocation. Quantum algorithms offer new possibilities for faster and more accurate decision-making, leading to more efficient distribution, lower costs, and better resource utilisation. With quantum computing, logistics companies can respond more flexibly to dynamic conditions and improve overall supply chain efficiency.

- Supply Chain Optimisation
- Transport Planning
- Inventory Optimisation
- Underground Watercourse Permeability Optimisation

LOGISTICS

Supply Chain Optimisation

PROBLEM DEFINITION:

SUPPLY CHAIN OPTIMISATION INVOLVES COMPLEX DECISION-MAKING REGARDING DISTRIBUTION, INVENTORY, AND TRANSPORT PLANNING.

Solution:

Quantum algorithms for route and schedule optimisation were used to optimise a global-scale supply chain.

Technology Used:

Quantum annealer (D-Wave)

Technical Details:

Optimisation was performed using 2,048 qubits. The algorithm minimised both logistics costs and delivery times.

Results:

The quantum annealer reduced logistics costs and shortened delivery times by finding optimal or near-optimal solutions, resulting in cost savings and more efficient supply chain operations.

Reference here

LOGISTICS

Transport Planning

Solution:

Quantum algorithms were used for dynamic route planning to minimise the time and cost of transportation.

Technology Used:

Superconducting qubits (IBM Quantum)

Technical Details:

The route planning algorithm was implemented using 16 qubits. Each qubit was mapped to different vehicles and their respective routes. Circuit parameters were optimised for fast real-time decision-making.

Results:

With larger datasets, the quantum algorithm improved solution accuracy by up to 15%. As a result, travel times were reduced, and vehicle usage efficiency improved, leading to cost and emissions reductions.

Reference here

PROBLEM DEFINITION:

TRANSPORT PLANNING INVOLVES OPTIMISING ROUTES FOR GOODS AND PASSENGER TRANSPORT IN REAL TIME, WHICH IS DEMANDING DUE TO DYNAMIC ROAD CONDITIONS AND VARIOUS CONSTRAINTS.

LOGISTICS

Inventory Optimisation

PROBLEM DEFINITION:

INVENTORY OPTIMISATION INVOLVES PROPER PLANNING AND ALLOCATION OF STOCK TO MINIMISE COSTS AND MAXIMISE PRODUCT AVAILABILITY.

Solution:

Quantum optimisation algorithms were used to manage and optimise inventories in real time.

Technology Used:

Quantum annealer (D-Wave)

Reference here

Technical Details:

Optimisation was performed using 2,048 qubits. Various inventory and demand parameters needed to be optimised. The algorithm minimised storage costs and losses from surplus or stockouts.

Results:

The quantum annealer processed up to 3.5 times more input data, enabling more effective solution selection. It achieved better storage cost reductions and improved demand forecasting accuracy, leading to enhanced inventory management and lower costs.

LOGISTICS

Underground Watercourse Permeability Optimisation

PROBLEM DEFINITION:

PREDICTION AND ANALYSIS OF FLOW AND TRANSPORT PROCESSES IN UNDERGROUND WATER STREAMS FOR SEWER SYSTEM DESIGN – FOR EXAMPLE, DETERMINING RESERVOIR PERMEABILITY BASED ON OBSERVED VARIABLES SUCH AS HYDRAULIC HEAD.

Solution:

Minimisation of the difference between observed and predicted variable values using quantum optimisation algorithms.

Technology Used:

Quantum annealer (D-Wave)

Reference here

Technical Details:

Optimisation was carried out using 1,095 qubits. The simulation involved optimising individual water flow parameters. The quantum annealer generated 10,000 samples in just 0.2 seconds.

Results:

The D-Wave quantum annealer outperformed the classical Gurobi solver. It consistently achieved optimal results for one parameter and for the second in 90% of cases. The quantum annealer solved complex hydrological problems significantly faster than Gurobi—in some cases, the classical solver failed to find a solution at all.

SECTOR

07 CHEMICAL INDUSTRY

The chemical industry uses advanced simulations to optimise catalytic processes, develop new materials, and model chemical reactions. Traditional computational methods often reach limits when simulating quantum properties of electrons in materials, slowing innovation. Quantum computing enables faster and more precise analysis of catalysts, more efficient design of new compounds, and optimisation of production processes. Thanks to the ability to simulate complex molecular interactions with unprecedented detail, quantum computing can accelerate the discovery of new materials and chemical technologies with higher efficiency and lower cost.

- Catalytic Process Simulations
- New Material Development
- Chemical Reaction Simulations

CHEMICAL INDUSTRY

Catalytic Process Simulations

PROBLEM DEFINITION:

CATALYTIC PROCESSES ARE VITAL IN MANY CHEMICAL PRODUCTION SYSTEMS, AND THEIR SIMULATION IS IMPORTANT FOR OPTIMISING EFFICIENCY AND SELECTING SUITABLE CATALYSTS.

Solution:

Quantum simulations of molecular interactions were used to model catalytic reactions accurately at the molecular level.

Technology Used:

Superconducting qubits (IBM Quantum) and ion traps (simulator)

Technical Details:

The authors modelled the electronic states of catalysts and reactants using 10 to 100 qubits. Quantum circuit parameters were optimised for simulating quantum chemical interactions.

Results:

Quantum simulations enabled the identification of more effective catalysts, thereby increasing the efficiency of catalytic processes depending on the simulation scale.

References here and here

CHEMICAL INDUSTRY

New Material Development

Solution:

Quantum and hybrid computations were used to simulate the electronic properties of new materials with high precision, particularly in regions involving strongly correlated electrons.

Technology Used:

Superconducting qubits (IBM Quantum)

Technical Details:

Simulations were conducted using 4 qubits to model the electronic structure of proposed materials (4 electrons in 6 spin orbitals). Quantum Fourier transform was applied, followed by optimisation of quantum circuits.

Results:

Quantum simulations enabled faster development of materials with desired properties, shortening the time needed for market introduction. Compared to classical algorithms, significantly lower energy consumption was also achieved.

PROBLEM DEFINITION:

THE DEVELOPMENT OF NEW MATERIALS, ESPECIALLY THOSE WITH UNIQUE PROPERTIES, IS A COMPUTATIONALLY DEMANDING PROCESS THAT INVOLVES SIMULATING THE QUANTUM PROPERTIES OF ELECTRONS IN MATERIALS.

Reference here

CHEMICAL INDUSTRY

Chemical Reaction Simulations

PROBLEM DEFINITION:

UNDERSTANDING AND SIMULATING CHEMICAL REACTIONS IS ESSENTIAL FOR OPTIMISING PRODUCTION PROCESSES AND DEVELOPING NEW PRODUCTS.

Solution:

Quantum simulations were used to model complex chemical reactions, leading to a deeper understanding and optimisation of processes.

Technology Used:

NMR spectroscopy (simulator) and ion traps (IonQ)

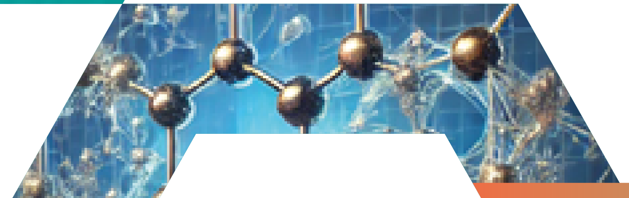
References here and here

Technical Details:

Reactions were simulated using 3 qubits, with each qubit representing interactions between reactants (e.g., molecular isomerisation). The qubits expressed individual parts of the chemical reaction. Quantum algorithms included quantum state simulations and quantum dynamics. In a similar experiment, ion trap technology was used to simulate hydrogen bond dynamics and vibrational spectra.

Results:

The optimisation results were 95.7% consistent with the theoretical optimum. Quantum simulations enabled better and faster optimisation of chemical reactions, resulting in more accurate outcomes and reduced energy consumption in processes.



SECTOR

08 MANUFACTURING INDUSTRY

The manufacturing sector faces increasingly complex challenges in schedule optimisation, production planning, and inventory management. Traditional methods often reach computational limits when searching for optimal solutions in large datasets. Quantum computing offers new opportunities in predictive maintenance by enabling more accurate data analysis and early fault detection, thus reducing unplanned downtime. It can also improve the efficiency of logistics operations by optimising supply and distribution. With faster processing of complex computations, quantum computing can significantly enhance productivity and competitiveness in manufacturing enterprises.

- Manufacturing Process Optimisation
- Predictive Maintenance
- Logistics Operations Optimisation

MANUFACTURING INDUSTRY

Manufacturing Process Optimisation

PROBLEM DEFINITION:

MANUFACTURING PROCESSES ACROSS INDUSTRIES REQUIRE OPTIMISATION OF SCHEDULES, INVENTORY MANAGEMENT, AND PRODUCTION PLANNING.

Solution:

Quantum optimisation algorithms were applied to production planning and management, leading to more efficient manufacturing.

Technology Used:

Quantum annealer (D-Wave)

Reference here

Technical Details:

Various parts of the steel manufacturing process were modelled and optimised using 2,000 qubits. The algorithm minimised delays and maximised the utilisation of production capacity.

Results:

In a specific case, the quantum annealer enabled the processing of larger instances of the steel production planning problem (60% increase).
It provided optimal sequencing and configuration of processes in a short time, resulting in improved production efficiency and reduced manufacturing costs.

MANUFACTURING INDUSTRY

Predictive Maintenance

PROBLEM DEFINITION:

PREDICTIVE MAINTENANCE OF MANUFACTURING EQUIPMENT INVOLVES DATA ANALYSIS AND FAILURE PREDICTION TO ALLOW TIMELY MAINTENANCE.

Solution:

Quantum algorithms were used to analyse sensor data and predict potential equipment failures.

Technology Used:

Superconducting qubits
(IBM Quantum)

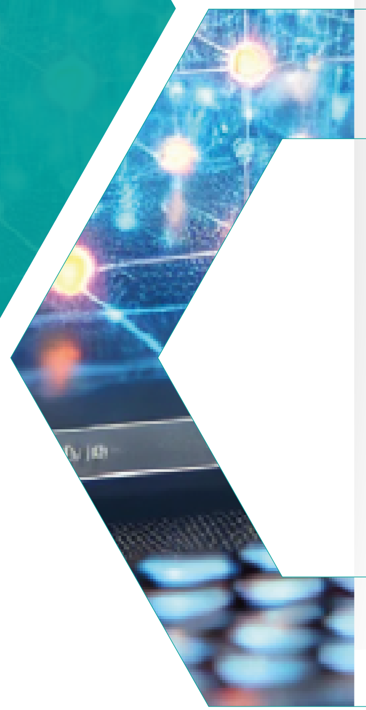
Technical Details:

Various equipment parameters were modelled and analysed using 7 and 27 qubits. Quantum operations included quantum classification and predictive models.

Results:

Quantum algorithms improved failure prediction accuracy by 67.8% and reduced maintenance costs, leading to higher equipment reliability.

Reference here



MANUFACTURING INDUSTRY

Logistics Operations Optimisation

PROBLEM DEFINITION:

LOGISTICS OPERATIONS OPTIMISATION INCLUDES PLANNING AND MANAGING SUPPLY, DISTRIBUTION, AND STOCK CONTROL.

Solution:

Quantum algorithms were used to optimise logistics operations, including route planning and inventory management.

Technology Used:

Quantum annealer (D-Wave)

Reference here

Technical Details:

The optimisation was performed using 2,000 qubits. Different logistics operations were modelled. The algorithm minimised delivery costs and times.

Results:

The quantum annealer improved the original warehouse picking system. With an optimal combination of components, transportation time was reduced, and the average distance to pick components decreased by 20%. It also suggested optimal storage locations to minimise distances to the production line, reducing average travel by 45% and increasing manufacturing efficiency.

SECTOR

09 HEALTHCARE

Healthcare generates vast amounts of data, and effective analysis of this data is crucial for diagnosis, personalised medicine, and disease research. Quantum computing can significantly accelerate the processing of medical data, enabling more accurate and faster disease diagnosis. In personalised medicine, it helps analyse genetic data and predict individual responses to treatment. For modelling neurodegenerative diseases, quantum computing allows more detailed brain process simulations, contributing to a better understanding and development of new therapies. These capabilities can lead to a revolution in medicine and improved patient care.

- Disease Diagnosis
- Personalised Medicine
- Neurodegenerative Diseases Modelling

HEALTHCARE

Disease Diagnosis

PROBLEM DEFINITION:

DISEASE DIAGNOSIS REQUIRES THE ANALYSIS OF LARGE VOLUMES OF HEALTHCARE DATA TO ACCURATELY IDENTIFY HEALTH PROBLEMS AND PROPOSE APPROPRIATE TREATMENT.

Solution:

Quantum machine learning algorithms were used to analyse medical data and improve diagnostic accuracy.

Technology Used:

Superconducting qubits (IBM Quantum) and ion traps (IonQ)

References here and here

Technical Details:

An algorithm for diagnosing heart disease was implemented using up to 5 qubits. Each qubit was mapped to different biological markers. Quantum operations included quantum classification and optimisation of diagnostic decisions.

Results:

The quantum algorithm improved diagnostic accuracy by 5% and reduced the time required for data analysis, enabling quicker and more accurate diagnosis.

HEALTHCARE

Personalised Medicine

Solution:

Quantum algorithms were used to analyse genetic data and optimise personalised treatment plans.

Technology Used:

Superconducting qubits (IBM Quantum)

Technical Details:

Analysis was performed using 8 qubits, each representing different genetic markers and treatment responses. Quantum operations included quantum simulations and optimisation of treatment strategies.

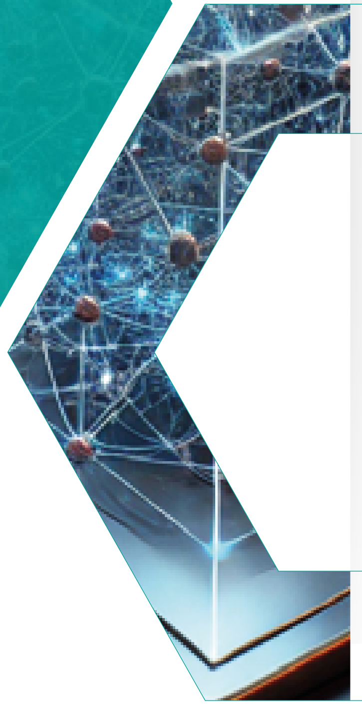
Results:

Quantum algorithms improved the accuracy of drug effect predictions in cancer patients by 15%. As a result, the rate of side effects decreased, leading to better treatment personalisation.

Reference here

PROBLEM DEFINITION:

PERSONALISED MEDICINE REQUIRES THE ANALYSIS OF GENETIC DATA AND PREDICTION OF INDIVIDUAL TREATMENT RESPONSES.



HEALTHCARE Disease Diagnosis Personalised Medicine Neurodegenerative Diseases Modelling

HEALTHCARE

Modelling Neurodegenerative Diseases

PROBLEM DEFINITION:

MODELLING NEURODEGENERATIVE DISEASES INVOLVES ANALYSING COMPLEX BRAIN INTERACTIONS AND THEIR IMPACT ON HEALTH.

Solution:

Quantum simulations were used to model and analyse neurodegenerative processes, such as Alzheimer's and Parkinson's diseases.

Technology Used:

IBM Quantum simulátor

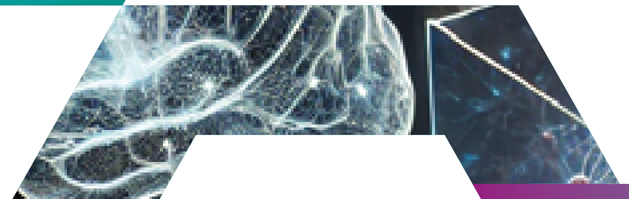
Reference here

Technical Details:

The modeling was carried out using 4 qubits, onto which various aspects of neurodegenerative processes were encoded. The quantum algorithms involved simulations of brain interactions and quantum dynamics using hybrid machine learning approaches.

Results:

Quantum simulations enabled a better understanding of neurodegenerative processes as well as their rapid diagnosis. The quantum algorithms achieved 5% higher accuracy compared to classical algorithms, leading to the identification of new therapeutic targets and improved treatment strategies.



VLQ Quantum computer

State-of-the-Art and Development of Quantum Computers

The development of quantum computers brings new possibilities in computational performance and paves the way for solving complex problems. Although quantum advantage has so far only been demonstrated for specific problems, it shows significant potential for accelerating certain computations. A major step forward is hybrid computing, which combines the power of quantum and classical systems to offer a more efficient approach to demanding computational tasks.

01 Quantum Advantage

Quantum advantage refers to the situation where a quantum computer can solve specific problems significantly faster than the best classical algorithms. This phenomenon has been experimentally demonstrated in several cases, for example, in solving specific optimisation problems or simulating quantum systems that are highly demanding for classical computers. Quantum advantage thus offers a substantial speed-up for computations currently unsolvable or extremely demanding by classical methods.

The advantages of quantum supremacy include faster and more efficient solutions to certain specific tasks that are computationally limiting for classical computers, such as in the fields of optimization and simulation. On the other hand, quantum advantage has so far been demonstrated only for a limited number of problems, and its broader application faces significant technological and practical challenges, such as the stability of quantum bits and the need for advanced algorithms to make effective use of quantum computers.

02 Hybrid Computing

Hybrid computing combines the advantages of quantum and classical computers, allowing each to handle the tasks they are best suited for. In this approach, certain parts of a problem are efficiently solved by a quantum computer, while others are processed using classical methods. This enables the utilisation of quantum advantage for specific tasks such as optimisation or simulation, while maintaining robustness and efficiency through classical computation.

Advantages:

- Ability to leverage quantum advantage for targeted problems
- Flexibility in selecting the optimal computational environment
- Classical systems offer reliability where quantum systems are not yet fully effective

Disadvantages:

- Complexity of integrating quantum and classical systems
- Need for careful optimisation in splitting tasks between quantum and classical components, which can be demanding to design and implement

03 Energy Efficiency of Quantum Computing

Quantum computers have the potential to be more energy-efficient than classical computers, especially for computationally intensive tasks. Thanks to their ability to process information in parallel, quantum computers can find efficient solutions requiring less energy than traditional methods. This feature may be key in optimising computations such as complex system simulations or searching for optimal solutions of large-scale problems.

Advantages:

- Lower energy consumption for specific tasks
- Potential reduction in energy costs for large-scale computations

Disadvantages:

- High requirements for cooling and isolation of quantum systems, which in some cases may result in higher total energy usage than classical computers

Quantum computers are still developing, and multiple approaches to building quantum processors are being explored. Each technology comes with its own advantages and disadvantages, which must be carefully considered when selecting the most suitable architecture.

04 Superconducting Qubits

Superconducting qubits are among the most widely used types of quantum bits and form the basis of many current quantum computers. They use Josephson junctions to create quantum states as superpositions of different energy levels in superconducting circuits, which can be quickly manipulated using microwave pulses.

Advantages:

- High operation speed
- Relatively mature technology with an advanced manufacturing infrastructure

Disadvantages:

- Relatively short coherence times
- High demands for cooling and isolation from the environment

05 Ion Traps

Ion traps use individual ions as qubits, held in electromagnetic fields and manipulated with laser pulses. Quantum information is encoded in their electronic or vibrational states. This method offers very long coherence times and high operation fidelity.

Advantages:

- Long coherence times
- High fidelity operations
- Easy interconnection of multiple qubits

Disadvantages:

- Slower operations compared to superconducting qubits
- Complexity and cost of laser systems

06 Photonic Qubits

Photonic quantum computers use individual particles of light – photons – as qubits. Quantum information can be encoded in various ways, including polarisation (horizontal or vertical) or the path taken by the photon.

Advantages:

- Naturally resistant to certain types of quantum noise due to minimal environmental interaction
- Photons can travel long distances over existing fibre-optic cables, enabling fast communication in future quantum networks

Disadvantages:

- Photons are prone to loss, requiring quantum error correction to ensure reliable measurement
- Although they operate at room temperature, some photonic components require large cryogenic setups

07 Neutral Atoms

A quantum computer using neutral atoms is based on so-called Rydberg atoms. This type shares many features with ion trap quantum computers. Atoms are held in magneto-optical traps, and their quantum states are encoded in the atoms' energy levels. The system is initialised and operated by laser control of the qubits.

Advantages:

- Excellent scalability compared to other platforms such as ion traps or superconducting qubits
- Systems with 100+ qubits already exist and can be scaled to several thousand using a single trap or lattice

Disadvantages:

- Quantum gate operations are slower than those of superconducting qubits
- Physical movement of qubits (qubit shuttling) is needed during the initial system setup and for entangling qubits

08 Spin Qubits

Spin qubit quantum computers use the spin of charge carriers (electrons and holes) in semiconductors to implement quantum states of qubits. Typically, microscopic wells (quantum dots) are embedded in semiconductor substrates, with gate electrodes above each well. The spins of one or more electrons in the dot are manipulated via the transistor gate voltage.

Advantages:

- Relatively long coherence times
- Cost-effectiveness due to semiconductor manufacturing technology
- Small size allows for a very high number of qubits on a single chip
- Can operate at relatively high temperatures, lowering operating costs
- High-speed quantum gates enable more operations within coherence times

Disadvantages:

- Photons are prone to loss, requiring quantum error correction to ensure reliable measurement
- Although they operate at room temperature, some photonic components require large cryogenic setups

09 Quantum Annealers

Quantum annealers, such as D-Wave, are a specialised type of quantum computer designed to solve optimisation problems. Unlike universal quantum computers, annealers are limited to specific types of tasks but can be highly effective at solving them.

Advantages:

- Can solve large-scale optimisation problems
- Relatively low requirements for coherence times

Disadvantages:

- Limited versatility
- Performance depends heavily on the quality of qubit interconnects

10 Future Development

Future advances are expected across all these areas, with research focused on extending coherence times, increasing the number of qubits, and enhancing the reliability of quantum operations. Hybrid systems that combine different quantum technologies are also anticipated, aiming to deliver better results across a broad range of applications.

In the coming years, we expect a transition into the „Quantum Utility“ era (as forecast by IQM for 2026–2028), followed by the final phase of the „Quantum Advantage“ era (post-2030). For future development, it is crucial to monitor not only the number of logical and physical qubits but also the precision and error-free operation time of quantum computers. These factors are essential to the practical usability of quantum technologies.

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