Quantum Computing

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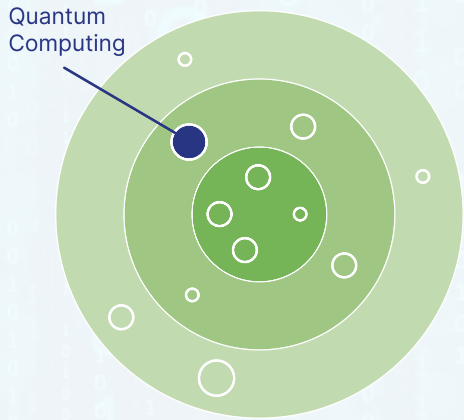
	low	medium	high
Impact		■	
Complexity			●



1 INTRODUCTION

Purpose

Quantum computing harnesses the principles of quantum mechanics to solve problems that are infeasible for classical computers. By utilising qubits and phenomena like superposition and entanglement, quantum computers can potentially revolutionise fields such as cryptography, automation/optimisation, material science and complex simulations.

Key benefits

Quantum computers offer the potential for exponential speedups in certain calculations, enabling breakthroughs in optimisation, cryptography and simulation of quantum systems, which could lead to significant advancements in technology and science.

2 KEY CONCEPTS

Fundamental principles

Qubits, or quantum bits, are fundamental units in quantum computing that can represent multiple states simultaneously due to a property called superposition. In a state of superposition, a qubit can exist in a combination of both 0 and 1 states at the same time, enabling parallel processing of information. In Entanglement, qubits become interconnected, yet the state of one qubit can instantaneously influence the state of another, regardless of the distance between them. Quantum gates, which operate on qubits, utilise the unique properties of quantum mechanics to manipulate quantum states and perform complex computations.

Terminology

- Quantum Algorithm: an algorithm designed to run on a quantum computer, aiming to exploit quantum mechanical principles for solving specific problems.
- Quantum Decoherence: the loss of quantum coherence when a quantum system interacts with its environment, causing it to behave classically.

Comparison

- **IBM Quantum Experience vs Microsoft Quantum Development Kit:** IBM's platform focuses on providing real quantum hardware access via the cloud, whereas Microsoft's kit offers robust development tools and simulations.
- **Google Cirq vs Qiskit**: Cirq is oriented towards building quantum circuits for Google's hardware, while Qiskit, developed by IBM, includes comprehensive libraries for quantum algorithms and circuit design.

3 POPULAR TOOLS AND FRAMEWORKS

Primary tools

- IBM Quantum Experience: provides access to IBM's quantum processors and development tools for designing and running quantum algorithms.
- Microsoft Quantum Development Kit: offers a suite of tools, including the Q# programming language and quantum simulators.
- Google Cirq: an open-source framework for creating, simulating and executing quantum circuits on Google's quantum hardware.

4 APPLICATIONS

Industry use cases

- **Cryptography:** quantum computing could break classical cryptographic systems by efficiently solving problems like integer factorisation.
  > **Best Practice:** Shor's Algorithm.
- **Optimisation:** quantum algorithms can solve complex optimisation problems more efficiently, such as route planning and resource allocation.
  > **Best Practice:** D-Wave Systems.
- **Complex simulations:** quantum computers can simulate quantum systems, aiding in research and development.
  > **Best Practice:** Quantum Supremacy Experiment.

Practical examples

- IBM Quantum Hummingbird: a quantum processor designed to improve performance and scalability.
- Google Sycamore: Google's quantum processor that achieved quantum supremacy in a specific computation.
- Rigetti: enhances predictive weather modelling with Quantum Machine Learning.

5 IMPLEMENTATION INSIGHTS

Best practices and tips

- **Error correction:** implement quantum error correction techniques to address qubit errors and decoherence.
- **Hybrid approaches:** use hybrid quantum-classical algorithms to combine the strengths of both types of computing.
- **Collaborate with experts:** work with researchers and institutions specialising in quantum computing.

Common challenges

- **Quantum decoherence:** managing the effects of decoherence to maintain qubit stability and accuracy.
- **Scalability:** developing scalable quantum systems that can handle a large number of qubits while maintaining coherence.
- **Error rates:** high error rates and difficulties in maintaining quantum coherence.

6 KEY TRENDS AND PREDICTIONS

Top milestones in Quantum Computing

- **1981:** Richard Feynman proposed the concept of a quantum computer in his Feynman Lecture.
- **1994:** Peter Shor developed Shor's Algorithm, demonstrating the potential of quantum computing for cryptography.
- **2019:** Google claimed quantum supremacy with its Sycamore Processor, performing a computation beyond classical capabilities.

Current trends

- Quantum Supremacy: achieving and proving quantum supremacy, where quantum computers outperform classical ones in specific tasks.
- Quantum Networking: developing quantum networks and communication systems for secure information transfer.
- Quantum Algorithms: development of new algorithms to solve complex problems more efficiently.

Future predictions

- Universal Quantum Computers: building scalable quantum computers that can solve a wide range of problems.
- Quantum Internet: establishing a quantum internet for secure communication and distributed quantum computing.
- Quantum-resistant cryptography: quantum computers could break current cryptographic systems like RSA and ECC encryption by solving complex mathematical problems in seconds that would take classical computers millennia.

7 KEY RESOURCES AND MOST HELPFUL LINKS

Websites and blogs

- Quantum Computing Report: a news and analysis website that covers the latest developments in quantum computing.
- Quanta Magazine: in-depth articles and news on quantum physics and computing.
- IBM Quantum Software: updates and insights from IBM on quantum computing developments.

Online courses

- Introduction to Quantum Computing using Qiskit: offered by Udemy.
- Quantum Computation: by MIT Open Learning.
- Discovering Quantum Computing with Matthew Versaggi: by Udacity.

Communities and forums

- Quantum Open Source Foundation: supporting the development and standardisation of open tools for quantum computing.
- ResearchGate Quantum: a forum on ResearchGate for scientists and researchers to discuss quantum computing-related research and collaborate on quantum studies.
- Quantum Computing Stack Exchange: Q&A forum for quantum computing topics.

8 GLOSSARY

Common terms and definitions

- Quantum Algorithm: a step-by-step procedure used to solve problems using quantum computation, with notable examples like Shor's and Grover's algorithms.
- Quantum Circuit: a sequence of quantum gates applied to qubits, representing a quantum algorithm.
- Quantum Error Correction: techniques used to protect quantum information from errors due to decoherence and noise in quantum systems.
- Quantum Supremacy: the point at which a quantum computer can solve problems faster than classical computers.

Authors

Dr Torsten Wingenter
Torsten established Digital Innovations at Lufthansa, founded the FlyingLab, and was responsible for the digital strategies of Austrian, Lufthansa and Swiss airlines. Today, as the "Inno Doc", he is digital advisor, coach and catalyst, interim manager and fire fighter for many organisations in their pursuit for digital innovations.
www.inno-doc.com

Prof Marc K Peter
Marc was an executive at eBay, E*TRADE (ANZ) and LexisNexis. Today, he is the "Digital Prof" at Rochester-Bern Executive Programs, the University of Rochester, at FHNW and at CSU in Australia. His research and teaching covers digital transformation, digital technology, digital leadership, cybersecurity and digital marketing.
www.digitalprof.com