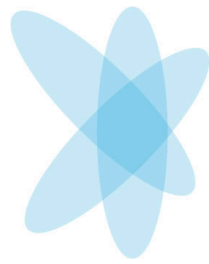


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QUANTUM+

Uncovering technology for business

QUANTUM+ Project

Newsletter #4

Quantum+ is an Erasmus+ EU funded collaborative project between industry and universities to develop a new quantum technology online training pathway. Its goal is to adapt to the growing need for trained target group and technology-industry personnel by giving them a study course in quantum fundamentals and applications, thereby improving employability and equipping them to tackle future technological problems.

Hello Quantum+ community!

A year's journey in this exciting project.

Quantum Computing

We are happy to share an update on the progress of the Quantum+ project and, in particular, on the work completed so far within the Quantum Computing learning path.

Over the past months, we have developed a coherent and self-contained sequence of lessons aimed at introducing quantum computing concepts to a broad university-level audience, including learners without a formal background in physics. The guiding idea has been to combine conceptual clarity with physical intuition, progressively linking abstract quantum principles to real technologies and algorithms.

From qubits to quantum logic

The course begins by establishing the foundations of quantum information. We introduce the qubit as a two-level quantum system and explain how its state can be visualized and controlled using the Bloch sphere. Building on this picture, we move to single-qubit quantum gates, showing how rotations on the Bloch sphere correspond to logical operations.

The framework is then extended to multi-qubit systems, where superposition and entanglement naturally emerge as key resources for quantum information processing.

Decoherence and error correction

A central part of the course is devoted to the limits imposed by real physical systems. We discuss decoherence as the loss of quantum coherence due to unavoidable interactions with the environment, emphasizing why coherence times are a critical figure of merit for any quantum technology.

This naturally motivates the introduction of quantum error correction, where learners are guided through the basic logic of protecting quantum information using multiple physical qubits to encode a single logical qubit.

Quantum hardware platforms

To connect theory with practice, several lessons focus on the main physical platforms used to build quantum computers today:

- **Trapped-ion qubits**, highlighting their long coherence times, laser-based control, and collective vibrational modes.
- **Superconducting qubits**, presented as artificial atoms engineered from superconducting circuits, with emphasis on transmon qubits and microwave control.
- **Photonic qubits**, where quantum information is encoded in single photons and manipulated using linear optical elements.

Each platform is discussed in terms of physical principles, advantages, limitations, and current industrial developments.

From quantum parallelism to powerful algorithms

The final part of the learning path is devoted to quantum algorithms. After introducing the query model and the idea of quantum parallelism, the course moves beyond purely conceptual examples to present, at a qualitative level, three cornerstone algorithms of quantum computing.

- **Deutsch–Jozsa algorithm** is presented as the first example showing an exponential separation (in the oracle model) between classical and quantum strategies. Although it has no direct practical applications, it plays a key pedagogical role by demonstrating how quantum interference can transform parallelism into a dramatic computational advantage.
- **Grover’s algorithm** addresses the problem of unstructured search and shows how a quantum computer can find a solution in a number of steps that scales as the square root of the search space size. The course emphasizes why this quadratic speed-up is significant for very large problem sizes and discusses its relevance for optimization and cryptography.
- **Shor’s algorithm** is introduced as a landmark result that fundamentally changes the computational complexity of integer factorization. At a conceptual level, learners see

how a classically intractable problem can be reduced to period finding and solved efficiently using quantum interference and the quantum Fourier transform. Its profound implications for public-key cryptography and post-quantum security are also highlighted.

Together, these algorithms illustrate different forms of quantum advantage: from quadratic speed-ups to an actual change in complexity class.



Where we are heading

Taken together, the lessons developed so far form a structured introduction to quantum computing that connects:

- quantum states and gates,
- physical implementations,
- noise and error mitigation,
- and the conceptual foundations of quantum algorithms and quantum advantage.

This material provides a solid foundation for the next stages of the **Quantum+** project.

Building on the quantum computing course, the learning path will expand into dedicated courses on **quantum simulation, quantum cryptography, quantum business, quantum foundations, and quantum sensing**.

In parallel, these theoretical modules will be complemented by **ten hands-on laboratories**, designed to translate core concepts into practical experience and applied understanding.

We look forward to your feedback and to continuing this journey together.

Best regards,
The Quantum+ Team

For more information visit our website:

Website

Thanks for reading. See you soon!

QUANTUM +



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