

# A course in Quantum Computation Introduction

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# The subject

Alan Turing (1912 - 1934)



*On Computable Numbers, with an Application to the Entscheidungsproblem* (1936)  
(computability and the birth of computer science)

# The subject

Richard Feynman (1918 - 1988)



*Simulating Physics with Computers* (1982)  
(quantum reality as a computational resource)

# The subject

Davis Deutsch (1953)



*Quantum theory, the Church-Turing principle and the universal quantum computer (1985)*

(quantum computability and computational model:  
first example of a quantum algorithm that is exponentially faster than  
any possible deterministic classical one)

# The subject

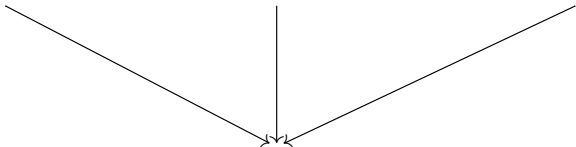
*quantum resources*



*quantum algorithms*



*computability*



# The subject

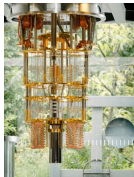
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# The subject

*quantum resources*



*quantum algorithms*



*computability*



## Quantum is trendy ...

Quantum Computing is coming of age

... moving from a potential far-future technology to a stage where prototypes become available and **major investments** arise

- The **race for quantum** rising between major IT players (IBM, Google, Microsoft, and Intel)
- Public investment (UK, Sweden, Canada, Australia, Portugal)
- EU Flagship initiative with a 10 year timespan and an estimated budget of over one billion euros

For the first time the viability of quantum computing may be **demonstrated in a number of real problems** extremely difficult to handle, if possible at all, classically, and **its utility discussed across industries**.

cf, Sycamore, 2019 and Zuchongzhi, 2021



# Why this growing interest?

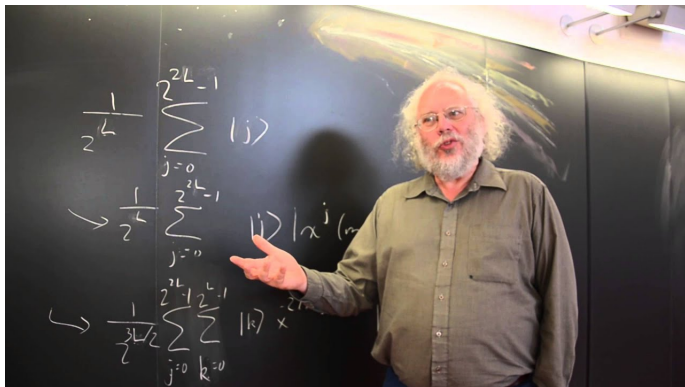
A strategic use of quantum effects potentially provides remarkable speedups to certain kinds of **computational tasks**

- Cryptography
- Molecular simulation and weather prediction
- Processing of large data

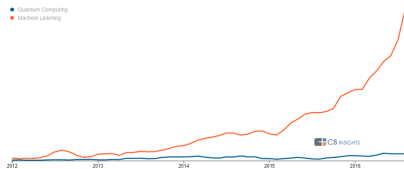
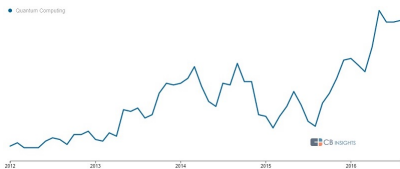
## A Concrete Example

Cryptographic schemes often assume that factoring large integers is computationally intractable

In 1994 Peter Shor presented a quantum **algorithm** for factoring integers that runs in **polynomial time**



## ... but the race is just starting



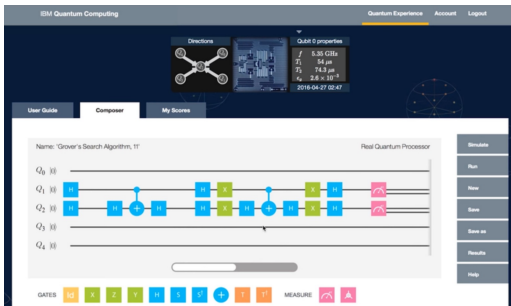
- Clearly, quantum computing will have a **substantial impact on societies** even if, being a so **radically different technology**,
- ... it is difficult to **anticipate its evolution** and future applications ...
- ... quantum computers are currently **unreliable** for performing useful computational tasks
- ... and its **commercial potential** in the near term (5 to 10 yrs) is still debatable

# Where exactly do we stand?

## Short term

Quantum advantage with **Noisy Intermediate-Scale Quantum (NISQ)** **Hybrid** computational models:

- the quantum device as a coprocessor
- typically accessed as a service over the cloud



# Where exactly do we stand?

## Longer term

**Fault tolerant** quantum computing, based on error correction codes (using millions of physical qubits to implement a logic one)

## From now to then there is a need for

- basic research (in several fronts), but also
- use cases
- capacity building
- process re-engineering
- anticipating social impacts and challenges

# Learning Outcomes

On successful completion of the course students should be able

- To understand basic concepts of computability, computational complexity, and underlying mathematical structures;
- To master the quantum computational model;
- To design and analyse quantum algorithms;
- To implement and run quantum algorithms Qiskit open-source development kit for IBM Q quantum processors.

# Course Information and Pragmatics

Refer to the course website at

`lmf.di.uminho.pt/quantum-computation-2425/`