# A course in Quantum Computation
# Introduction

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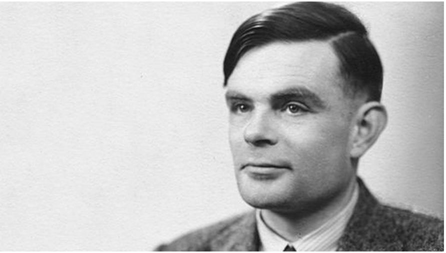
**Mestrado em Engenharia Física**

Universidade do Minho, 2025-26

# The subject

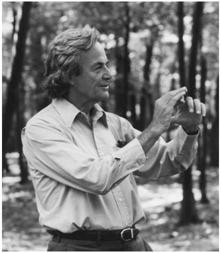
Alan Turing (1912 - 1954)



*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)

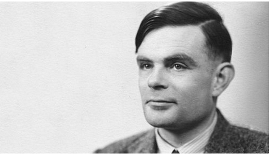
*Quantum theory, the Church-Turing principle and the universal quantum computer* (1985)
(quantum computability and computational model:
first example of a quantum algorithm that is exponentially faster than any possible deterministic classical one)

# The subject

*quantum resources*

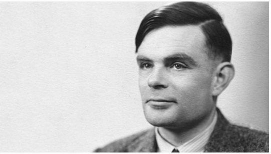
*quantum algorithms*

*computability*



# The subject

*quantum resources* *quantum algorithms* *computability*

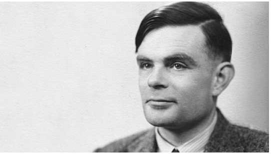


# The subject

*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?

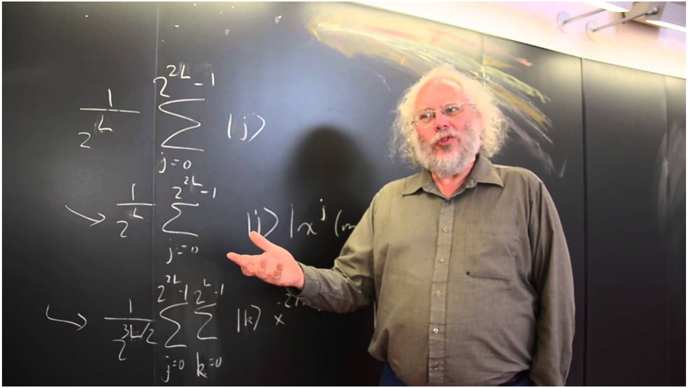
A strategic use of quantum effects potentially provides remarkable speedups to certain kinds of computational tasks

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

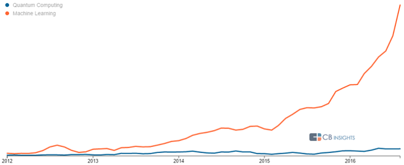
# A Concrete Example

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

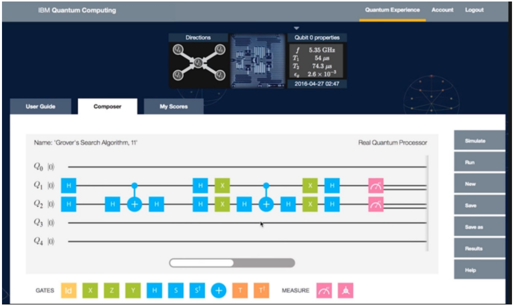

- Clearly, quantum computing will have a substantial impact on societies even if, being a so radically different technology,
- ... it is difficult to anticipate its evolution and future applications ...
- ... quantum computers are currently unreliable for performing useful computational tasks
- ... and 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, base 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.

# Course Information and Pragmatics

Refer to the course website at

`lmf.di.uminho.pt/quantum-computation-2526/`